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SUSTAINABLE BIOENERGY POTENTIAL IN ZAMBIA

An integrated bioenergy and food security assessment

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FOREWORD

Zambia is richly endowed with a wide range of biomass sources including woodlands, forests, agricultural residues and livestock waste. Biomass based energy contributes significantly to the country's total energy consumption supplying over 70 percent of the country's energy needs. Woodfuel provides reliable and readily available energy and is also an important source of livelihood employing approximately 500 000 people along various stages of the charcoal value chain.

Due to the current extraction and consumption methods, the use of biomass energy has been linked with detrimental environmental effects such as deforestation and forest degradation as well as climate change, due to the loss of carbon sinks. Inefficient utilisation of biomass contributes significantly to deforestation which is estimated at between 79 000–150 000 ha per year, and negatively affects the health and income of rural households that depend on forest products for their livelihoods.

The situation is exacerbated by the fact that only 31 percent of the population has access to electricity. In addition, Zambia, like many countries in sub Saharan Africa, has experienced increasingly unreliable rainfall patterns and more frequent and prolonged droughts over the past two decades, with climate change impacts increasing. For a country heavily reliant on hydropower, this has reduced the country's capacity to generate power.

Unsustainable woodfuel production coupled with limited access to electricity has added increasing pressure on biomass resources in Zambia. There are also growing concerns over food versus energy conflicts as a result of utilizing energy crops for bioenergy. It has therefore been imperative that a balance between national development and matters concerning environmental protection and food security is defined.

The Ministry of Energy (MOE) in collaboration with the Food and Agriculture Organization of the United Nations (FAO), undertook the Bioenergy and Food Security (BEFS) Assessment Technical Cooperation Project (TCP) in 2018 to assess the extent to which sustainable bioenergy can contribute to the National Energy Mix and to the share of renewable energy. The project assessed the potential to use bioenergy for (i) electricity generation in rural areas using off-grid solutions; (ii) cooking and heating in rural and urban areas; and (iii) the production of liquid biofuels for the transport sector.

This report outlines the viable feedstock options and sustainable bioenergy supply chains that can contribute to the sustainable use of biomass-based energy resources to diversify the energy mix and attain the Government's long-term sector-wide targets. The report provides a basis for planning and developing sustainable bioenergy projects. This will ultimately contribute to the attainment of the country's 2030 vision of becoming a prosperous middle-income nation, through increased access to reliable energy services, and improved health and livelihoods.

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ABBREVIATIONS AND ACRONYMS

2NAP	Second National Agricultural Policy
7NDP	Seventh National Development Plan
AAC	Annual allowable cut
ADB	African Development Bank
B5	Biodiesel and diesel blend at 5% v/v
BEFS	Bioenergy and Food Security
CFS	Crop Forecast Survey
CHP	Combined heat and power
CSO	Central Statistical Office of Zambia
DDS	Dried distillers grains with solubles
E10	Ethanol and gasoline blend at 10% v/v
E4A	Energy for Agriculture project
EA	Enumeration area
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gases
hh	Households
IAPRI	Indaba Agricultural Policy Research Institute
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
ILUA	Integrated land-use assessment
NDC	Nationally Determined Contribution
ktoe	Kilotonne of oil equivalent
LCOE	Levelized cost of energy
LHV	Low heating value
ML	Million litres
MLNR	Ministry of Lands and Natural Resources of Zambia
MNDP	Ministry of National Development Planning of Zambia
MoA	Ministry of Agriculture of Zambia
MACO	Ministry of Agriculture and Co-operatives

MOE	Ministry of Energy of Zambia
MoFL	Ministry of Fisheries and Livestock of Zambia
MTF	Multi-Tier Framework
NAP	National Agricultural Policy
NEP	National Energy Policy
NFP	The National Forestry Policy
NPCC	National Policy on Climate Change
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Develop
PV	Photovoltaic
PZM	Profitability Zone Map
RALS	Rural Agricultural Livelihood Survey
REA	The Rural Electrification Authority
REDD+	National Strategy to Reduce Deforestation and Forest Degr
REMP	Rural Electrification Master Plan
RMP	Realistic methane potential
SDG	Sustainable Development Goals
SHS	Solar home systems
UNFCCC	United Nations Framework Convention on Climate Change
WB	The World Bank
WFP	World Food Programme
WISDOM	Wood-fuel Integrated Supply and Demand Overview Mapping
ZAFFICO	Zambia Forest and Forest Industries Corporation
ZFAP	Zambia Forestry Action Programme

EXECUTIVE SUMMARY

This report outlines viable feedstock and sustainable bioenergy supply chains that can contribute to the sustainable use of biomass energy sources to diversify the energy mix and attain the Government's long-term sector-wide targets. It contains an assessment of the potential to use bioenergy for (i) electricity generation in rural areas using off-grid solutions; (ii) cooking and heating in rural and urban areas; and (iii) the production of liquid biofuels for the transport sector.

The assessment was composed of three main blocks:

1. **Country context:** The country context defines the baseline of the analysis by outlining the current agricultural, forestry, economic and energy context.
2. **Biomass assessment:** The biomass assessment analyses the availability of crop, livestock and forest harvesting residues for energy production (electricity, cooking fuels and transport). The assessment prioritises food security, agricultural needs and the sustainable use of natural resources. The results of the biomass assessment, namely the potential availability of feedstock in terms of quantity and spatial distribution, were used as input for the bioenergy technology assessment.
3. **Bioenergy technology assessment:** The bioenergy technology assessment is based on a techno-economic assessment of bioenergy technologies that can be used to generate electricity, produce cooking fuels and liquid biofuels. The technologies assessed included briquettes, biogas, charcoal briquettes, gasification, combustion, ethanol and biodiesel fuels. The assessment further evaluated improved technologies for charcoal, which can represent an option to reduce the amount of wood consumed in charcoal production.

KEY RESULTS/FINDINGS

The analysis of selected bioenergy supply chains illustrates which supply chains can be viable, based on a combination of feedstock options and technologies. A selection of options was identified for cooking fuels, electricity generation and the transport sector.

Briquettes and biogas were identified as viable cooking options for Zambia. This combination could meet up to 14 percent of the country's clean cooking fuel target. By combining gasification and combustion technologies, a total electricity generation capacity of 1 192 MW_{el} could be supplied. The feedstock options available could be used for both cooking fuels and electricity, so if a certain amount of feedstock is used to produce electricity, less would be available to produce cooking fuel and vice versa.

The ethanol blending target E10 (72 million litres per year) could be met with cassava and molasses. However, biodiesel blending targets would not be viable given the nascent local market. In the best case scenario, it might be possible to establish three production hubs with a maximum production capacity of 5.8 million litres per year (equivalent to a B2 blending target), but collection distances could reach 200 km, which is not advisable as a procurement area for biofuel industries.

CONCLUSION AND RECOMMENDATIONS OF REPORT

All energy subsectors would require considerable investment to ensure the identified bioenergy supply chains are established and function effectively. Investments would be required to support the feedstock supply chain and ensure that a steady supply reaches the bioenergy plants. Weighing up investment requirements against the creation of new jobs and improved livelihoods may also be a deciding factor in the development of the liquid biofuel industry.

CHAPTER

1

INTRODUCTION

Access to modern, stable and sustainable energy is essential to achieving food security, agriculture growth and poverty reduction. Furthermore, modern, affordable and reliable energy is fundamental to underpinning economic growth that can then drive development, poverty reduction and food security. There are several ways in which the lack of access to energy negatively affects a country's food security. The lack of access to sufficient fuel for cooking can negatively affect cooking habits by forcing people to skip meals, to switch to less nutritious foods requiring less cooking time or to undercook food in order to save fuel. Moreover, the unsustainable use of wood fuel can cause deforestation and negatively affect the income of rural households that depend on forest products for their livelihoods. On the other hand, access to modern energy can serve as a vehicle for achieving food security and reducing poverty by promoting the creation of rural enterprises, as well as productive uses of energy. In the same way, bioenergy can help farmers improve their income by increasing their agricultural production and diversifying potential markets for by-products, such as crop residues.

Alternative sustainable energy sources can be used to both increase access to energy and allow energy use to be more sustainable. Bioenergy is one of the possible renewable energy types that can be utilized as an alternative energy source; it is generated from a number of biomass options including crop residues, livestock residues and sustainably managed forest resources and residues. A key part of Bioenergy and Food Security (BEFS) assessment is to identify the amounts of biomass that can be sustainably sourced and that can support development and poverty reduction. In effect, when bioenergy is managed sustainably it can provide multiple benefits including energy provision, employment and rural development. Nonetheless, sustainable bioenergy development remains a complex topic due to the vast breadth

of options ranging over all agriculture sectors, and the variety of technologies as well as economic and financial viability. In fact, many African countries still rely considerably on biomass for energy, however, often this biomass is not sustainably sourced.

Zambia still has limited access to modern energy, especially in rural areas, and it is striving to increase its access to energy and to make energy supply and use more sustainable. To date, the country mainly relies on the use of traditional biomass, which accounts for 77 percent of the primary energy use. Access to electricity is low; as of 2019, 67.3 percent of all Zambian urban households and 4.4 percent of rural households had access to electricity (MOE, 2019).

Energy is consumed primarily by households (60 percent) followed by industry (32 percent) and the transport sector (5 percent). The energy consumption of households consists almost exclusively of traditional biomass (94 percent), mainly in the form of firewood and charcoal for heating and cooking. Current levels of wood fuel consumption contribute to the country's high rate of deforestation, with a reported deforestation rate ranging from 166 000 hectares to 300 000 hectares per year. Moreover, wood fuel is expected to continue to be the main source of energy in the near future, and the demand for fuelwood and charcoal is expected to increase as the population of the country grows (REMP 2008–2030). In terms of food security, one in two people in Zambia are undernourished and 60 percent of the population is poor (classified as living below the national poverty line).

Access to a sustainable supply of energy was recognised as a key element by the Government of Zambia during the 7th National Development Plan 2017-2021 (MNDP, 2017) for achieving the 2030 vision to become a "prosperous middle-income country by 2030". In this respect, a transition from using traditional biomass for cooking and heating to using sustainably-sourced modern biofuels is one of the main priorities. The Ministry of Energy (MOE) has also been analysing options for the promotion of ethanol and biodiesel production for use in the transport sector. The objective is to produce the biofuels locally, thus reducing the import bill and dependence on imported petrol and diesel.

In this context, this report contains an assessment of the potential to use bioenergy for (i) electricity generated with off-grid solutions in rural areas; (ii) cooking and heating in rural and urban areas; (iii) the production of liquid biofuels for the transport sector. The assessment was carried out using the Bioenergy and Food Security (BEFS) Approach of FAO and assists Zambia in understanding which bioenergy options could be viable in the country, based on specific feedstock and bioenergy supply chains.

As a result, the BEFS Assessment for Zambia contains a comprehensive analysis of the potentially viable bioenergy supply chains. It is composed of three main blocks:

1. Country context,
2. Natural resources assessment,
3. Bioenergy technologies assessment.

The key elements of the analysed bioenergy supply chains are shown in **Figure 1**.

The country context sets the baseline of the analysis by outlining the current agriculture, economic and energy context. This includes an outline of the current agriculture production,

an outline of the current energy supply and consumption of the country, and the key indicators such as food security, poverty, economic levels and growth, and energy consumptions and access. Feedstock possibilities are defined in the context of what is produced in the country. Next, key food stuffs for food security are flagged and generally excluded for direct use. Finally, energy targets are identified based on current energy consumption levels and energy access levels.

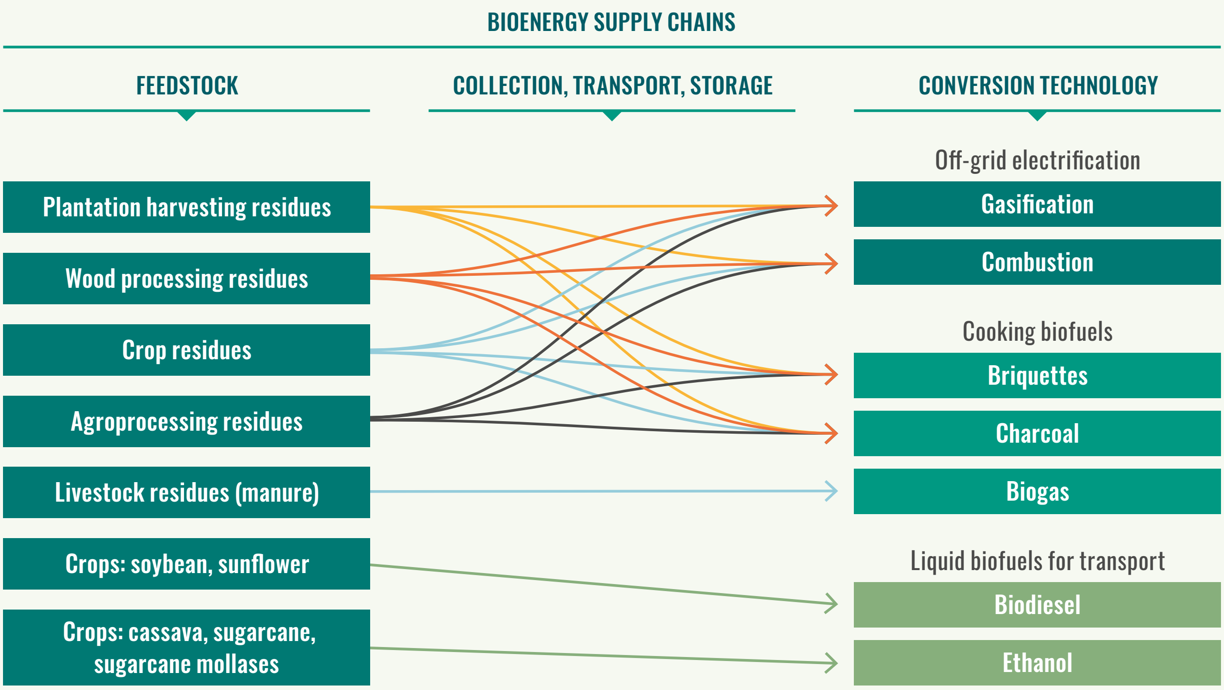
The biomass assessment components assess feedstock options in detail. This covers crops for biofuels for transport, crop residues for electricity production or cooking fuel production, and livestock residues for biogas and woody residues for electricity production or cooking fuel production. The assessment is carried out in a specific way that sets food security needs, agriculture needs and sustainable forestry requirements as a priority.

The bioenergy technology assessment is a technoeconomic assessment of the bioenergy technologies suitable for the generation of electricity, as well as production of cooking fuels and biofuels. Therefore, this includes briquettes, biogas, charcoal briquettes, combustion, gasification and ethanol and biodiesel fuels. Moreover, the assessment includes improved technologies for charcoal, aiming to reduce the wood quantities consumed for charcoal production. The output of the biomass assessment is an input to the bioenergy technology assessment component, whereby one of the key elements of the viability analysis is the availability of feedstock in terms of quantity.

All elements of the analysis are explained in more detail in the following sections. The report is subdivided according to the three blocks identified above. The last and final section of the report presents the conclusions, followed by annexes supporting the calculations and steps of the assessment.

FIGURE 1.

SCOPE OF THE BEFS ASSESSMENT FOR ZAMBIA – BIOENERGY SUPPLY CHAINS INCLUDED IN THE ASSESSMENT



Source: Authors

CHAPTER

2

COUNTRY CONTEXT

2.1 OVERALL COUNTRY CONTEXT AND PERFORMANCE OF THE ECONOMY

With large reserves of copper and a well-developed mining industry, Zambia is the second largest producer of copper in Africa (CSO, 2018). Over the past two decades Zambia's GDP has been growing with an average annual rate of 6.1 percent, but growth slowed down in the second decade (WB, 2019). In the first decade the annual growth rate continuously increased reaching 10.3 percent by 2010. This trend then weakened and the growth rate reduced to 2.9 percent in 2015, increasing back to 4 percent in 2018 (ADB, 2019).

In 2011, Zambia was classified as a middle income country following growth by the country between 2004 and 2010. Nevertheless, the growth has benefitted a small segment of the urban population and has not had significant impacts on poverty reduction. Zambia is ranked as one of the countries with the highest rates of inequality in the world. In fact 6 out of 10 people remain poor in the country, with levels of extreme poverty in rural areas (WB, 2020; IFAD, 2020).

According to the Zambian Central Statistical Office (CSO), the contribution of the tertiary sector to the GDP was 54 percent in 2016, while that of the secondary and primary sectors was 21.7 and 19.4 percent, respectively. Within the primary sectors, the gross added value from agriculture, forestry and fishing was 6.2 percent, while from mining and quarrying it was 13.2 percent (CSO, 2018). This remained more or less the same, with a somewhat smaller contribution from agriculture, in 2018 (WB, 2019).

The agriculture sector is still recognized as one of the key sectors of the country's economy, given the fact that it provides employment for the majority of the labour force and provides a livelihood for more than 70 percent of the population (CSO, 2016).

In fact, given the country's abundant fertile land and good rainfall, agriculture has the potential to be a major source of economic growth. Nevertheless, agricultural productivity remains extremely low compared to global standards. In sum, increased growth in the agriculture sector is critical to reducing poverty, especially in rural areas (CSO, 2016; IFAD, 2020; WB, 2020).

High capital investment, high debt servicing cost, and a large wage bill have contributed to fiscal deficits in the mid-2000s. However, in 2018 domestic debt was still estimated at 20 percent of the GDP and the external debt including government guarantees was 39.2 percent of the GDP. The inflation rate in 2018 was around 7.6 percent, while the average lending rate and the lending base rate (prescribed by the Central Bank of Zambia) were 23.7 and 9.75 percent, respectively (ADB, 2019).

Despite the positive economic growth, poverty is still widespread in the country. In 2015, as much as 54.4 percent of the population, and 76.6 percent of people living in rural areas, was living below the national poverty line. Furthermore, it is important to note that 75 percent of the poor were categorized as extremely poor. Apart from the difference between rural and urban populations, poverty rates differ across the country. The Lusaka and Copperbelt provinces have the lowest prevalence of poverty (20 and 30 percent), while the "poorest" provinces are Luapula and the Western Province, where the poverty rate is more than 80 percent. Zambia is not only facing poverty issues but it is also dealing with food security. The rate of the undernourished population in 2016 was 44.5 percent (World Bank, 2019) and 35 percent of the children between 6 and 59 months were suffering from stunted growth (WFP, 2019). Due to prolonged droughts, which affected agricultural production and resulted in significant crop losses and poor harvests, the food security problem escalated in 2019 (WFP, 2019).

The employment level is also a significant problem for the country. In 2017, 12.6 percent of the total labour force was reported as unemployed, of which 60 percent were living in urban areas. In particular, the magnitude of the problem is even more evident when labour underutilisation is taken into consideration. Namely, in addition to the 427 125 unemployed there were 1.58 million people within the "potential labour force" category. This category is defined as persons of working age who were neither employed or unemployed (CSO, 2018). Among the active labour force, more than 50 percent is employed in agriculture, forestry and fishing (WB, 2019).

2.2 AGRICULTURE

Zambia is divided into three major agro-ecological regions: Region I, II and III (see **Figure 2**). Region I, *the Luanwga-Zambezi river zone*, receives less than 800 mm of rainfall annually and covers 12 percent of the total land area. It consists of loamy to clayey soils on the valley floor and course to fine loamy shallow soils on the escarpment in the Southern, Eastern and Western provinces. Region II receives between 800 and 1 000 mm of rainfall annually and covers 42 percent of the country, and is divided into Region IIa: *Central, Southern and Eastern Plateau*, and Region IIb: *Western semi-arid plains*. Region IIa generally has inherent fertile soils and covers the Central, Lusaka and parts of Southern and Eastern provinces. Region IIb consists of sandy soils and covers parts of the Western Province. Finally, Region III: *Northern, Copperbelt and North-western high rainfall* receives between 1 000 and 1 500 mm of rainfall annually and constitutes 46 percent of the country area. It encompasses Copperbelt, Luapula, northern Muchinga and the North-Western provinces. This region is characterized by highly leached, acidic soils, except in the Copperbelt Province.

Even with favourable agro-ecological conditions the potential for agricultural production is still underutilised. Currently only 14 percent of the 42 million hectares of agricultural land is being utilised, although

FIGURE 2.

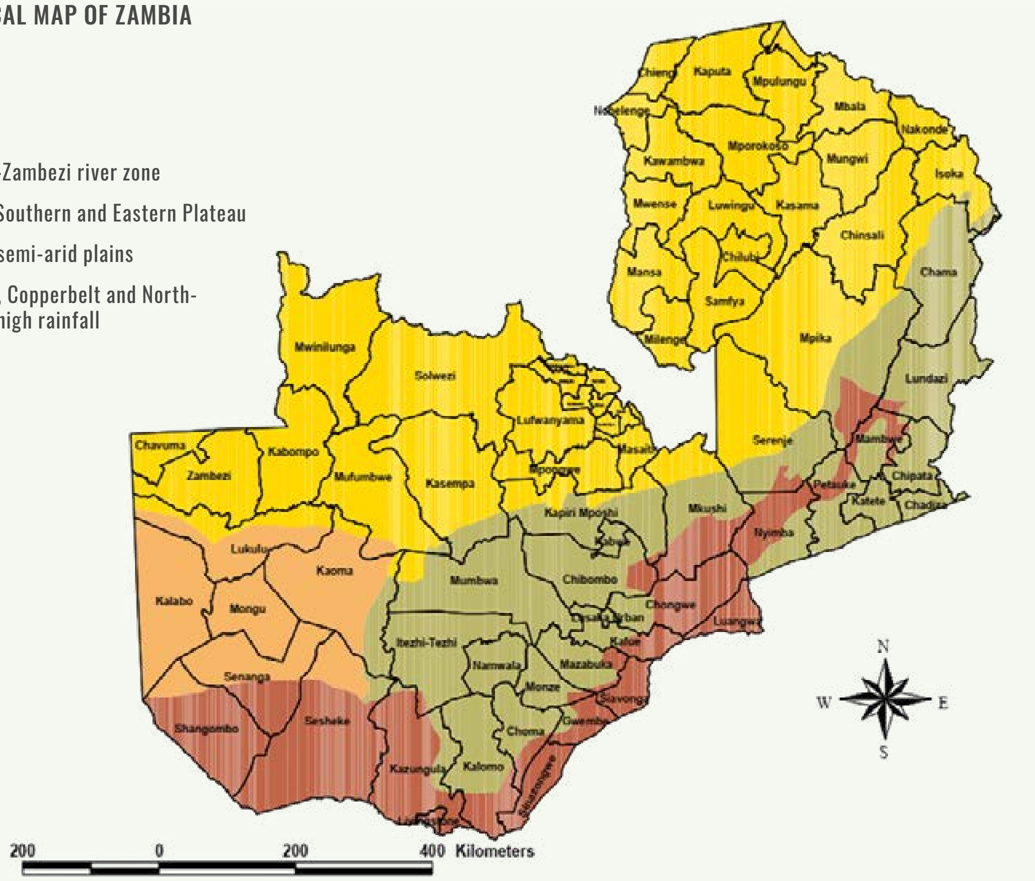
AGRO-ECOLOGICAL MAP OF ZAMBIA

Regions

- I Luanwga-Zambezi river zone
- IIa Central, Southern and Eastern Plateau
- IIb Western semi-arid plains
- III Northern, Copperbelt and North-western high rainfall

Key

— District boundary



Source: Second National Agricultural Policy, MoA&MoLF 2016

58 percent has medium to high potential for agriculture production (MoA and MoLF, 2016). The agriculture production is dominated by small-scale farmers (95 percent of the 2 million rural agricultural households[1]) (MoFL and CSO, 2019), whose production relies on family labour, manual and animal traction, low usage of fertilizers and rainfed production systems. The small-scale farmers obtain only 25–50 percent of the yields produced by large-scale farms. The causes of low productivity include low access to inputs, inappropriate farming practices that lead to soil degradation, rainfall variations, and the failure to fully develop the irrigation potential (MoA, 2011).

2.2.1 Crop production

In terms of quantities and production area, crop production is dominated by maize, cassava and sugarcane. According to the Crop Forecast Surveys (CFS) conducted by the Central Statistical Office of Zambia, maize is grown by 80 percent of the farming households, while cassava is the main staple food in the northern provinces of the country. Other important crops are soybeans, wheat, sweet potatoes and groundnuts, as presented in the **Table 1**.

Regarding the main staple foods in Zambia, maize dominates food consumption by providing 33 percent of the total calories consumed per capita per day. Cassava is the second most important staple crop nationally with 22.5 percent of total calories, and in some regions it is the preferred staple. Both wheat and sugar are next in importance with 9.2 and 7.8 percent, respectively (MoA, 2019), as presented in **Table 2**.

[1] This value was estimated as 2 027 591 households. It was calculated from the number of agriculture households (2.3 million households) reported in the 2017/2018 Livestock, and Aquaculture Census (MoFL and CSO, 2019) and the share of rural households carrying out agricultural activities (89.5%) reported in the 2015 Living Conditions Monitoring Survey Report (CSO, 2016).

TABLE 1.

AVERAGE ANNUAL PRODUCTION OF CROPS IN ZAMBIA FOR THE PERIOD 2008–2018

RANK	CROP	PRODUCTION (tonnes)	AREA HARVESTED (ha)	YIELD (tonnes/ha)
1	SUGARCANE	3 295 910	33 501	98.38
2	MAIZE	2 728 868	1 097 809	2.49
3	CASSAVA	1 580 794	135 283	11.69
4	WHEAT	214 461	33 568	6.39
5	SOYBEAN	200 231	118 632	1.69
6	SWEET POTATOES	160 750	46 671	3.44
7	GROUNDNUTS	127 141	206 415	0.62
8	COTTON	120 640	139 349	0.87
9	CASHEW NUTS	85 609	1 449	59.07
10	TOBACCO	48 624	49 845	0.98
11	RICE	44 534	33 524	1.33
12	IRISH POTATOES	41 864	17 709	2.36
13	MILLET	39 067	40 414	0.97
14	SUNFLOWER	33 508	62 958	0.53
15	SORGHUM	16 727	20 902	0.8
16	BARLEY	10 775	1 459	7.39

Source: Crop forecast surveys 2008–2019 (Central Statistics Office of Zambia, 2019)

TABLE 2.

FOOD BALANCE SHEET 2019

RANK	FOOD COMMODITY	FOOD SUPPLY (kcal/capita/day)	SHARE IN TOTAL FOOD SUPPLY (%)
1	MAIZE FLOUR	737.8	33.0%
2	CASSAVA FLOUR	503.5	22.5%
3	WHEAT FLOUR	205.6	9.2%
4	SUGAR, REFINED	174.4	7.8%
5	SOYA BEANS	168.2	7.5%
6	GROUNDNUTS	152.6	6.8%
7	RICE, MILLED	55.6	2.5%
8	BEEF MEAT	45.7	2.0%
9	MIXED BEANS	34.9	1.6%
10	PIG MEAT	29.8	1.3%
11	POULTRY	27.9	1.2%
12	OTHER	100.1	4.5%
TOTAL		**2 236.0**	**100%**

Source: Crop Forecast Survey 2018/19 (Central Statistics Office of Zambia, 2019)

Maize, sugar and tobacco are the most important cash crops in terms of export values. While tobacco is produced mostly for the export market, both maize and sugarcane are exported depending on the production levels and prices in internal and international markets. **Table 3** shows the main agricultural commodities exported in 2017 (FAO, 2019).

TABLE 3.

MAIN AGRICULTURAL EXPORT COMMODITIES IN 2017

RANK	AGRICULTURE COMMODITY	EXPORT QUANTITY (tonnes)	EXPORT VALUE (thousand USD)	SHARE IN TOTAL AG. EXPORTS (%)
1	MAIZE	326 998	97 702	15%
2	SUGAR RAW CENTRIFUGAL	165 441	96 875	15%
3	TOBACCO, UNMANUFACTURED	26 829	87 740	14%
4	BEVERAGES, NON-ALCOHOLIC	72 677	45 715	7%
5	SOYBEANS	83 748	44 748	7%
6	CAKE, SOYBEANS	129 045	42 513	7%
7	COTTON LINT	26 351	38 130	6%
8	PASTRY	7 130	10 618	2%
9	FLOUR, MAIZE	21 556	10 112	2%
10	BRAN, MAIZE	81 059	6 789	1%
TOTAL			**643 570**	**100%**

Source: FAOSTAT – Trade (FAO, 2019)

2.2.2 Livestock production

The livestock production is dominated by traditional, smallholder production, whereas only 20 percent of all animals are raised in commercial systems. The commercial livestock sector in Zambia is comprised of medium and large-scale animal farms that link to export markets and an expanding network of supermarkets and commercial retailers. Smallholder livestock farmers rely on traditional systems, where the animals often perform multiple functions such as provision of food for the household and sale, draught animal power for land preparation, uses in cultural practices, and other social functions (Lubungu and Mofya-Mukuka, 2012).

The Zambian livestock sector contributes more than 42 percent to the agricultural GDP and makes an important contribution to poverty reduction, household food security and nutrition. According to the Indaba Agricultural Policy Research Institute (IAPRI), in 2012 livestock contributed about 45 percent to the income of the poorest smallholders. The latest Livestock and Aquaculture Census for 2017/2018 (MoFL and CSO, 2019) shows that about 72.2 percent of agricultural households were involved in animal raising in 2018. The average size of herd or flock per household was 8 for cattle, 7.4 for goats and 5.8 for pigs. In the case of commercial production, the average size of herds per farm was 223 cattle, 42 goats and 181 pigs. It is important to note that there are considerable differences between the average herd sizes between the provinces, in both smallholder and commercial production systems (**Table 4**).

TABLE 4.

MAIN LIVESTOCK TYPES PRODUCED IN ZAMBIA IN 2018 AND NUMBER OF ANIMALS PER PROVINCE

PROVINCE	CATTLE		PIGS		GOATS	
	HOUSEHOLDS	COMMERCIAL	HOUSEHOLDS	COMMERCIAL	HOUSEHOLDS	COMMERCIAL
CENTRAL	743 595	92 025	93 225	9 105	578 825	9 873
COPPERBELT	74 628	18 801	106 545	5 783	163 903	2 600
EASTERN	597 147	4 772	305 955	571	357 761	1 486
LUAPULA	10 789	1 597	20 861	269	165 292	383
LUSAKA	147 574	25 186	67 664	25 183	334 759	2 918
MUCHINGA	81 829	3 333	66 807	550	159 187	511
NORTHERN	47 841	689	52 929	328	215 317	203
NORTH WESTERN	95 484	3 188	52 420	177	230 185	575
SOUTHERN	1 225 090	90 148	176 021	5 762	1 284 510	6 346
WESTERN	450 116	833	92 630	5	68 875	187
ZAMBIA	**3 474 093**	**240 572**	**1 035 057**	**47 733**	**3 558 614**	**25 082**

Source: The 2017/18 Livestock and Aquaculture Census Report, 2018

In the case of chickens, most are village chickens held by households; commercial producers produce broiler and layer chickens. The major part of chicken production is concentrated in the Lusaka, Copperbelt and Central provinces (**Table 5**).

TABLE 5.

MAIN CHICKEN TYPES PRODUCED IN ZAMBIA IN 2018 AND NUMBER OF ANIMALS PER PROVINCE

PROVINCE	VILLAGE CHICKENS		BROILER CHICKENS		LAYER CHICKENS	
	HOUSEHOLDS	COMMERCIAL	HOUSEHOLDS	COMMERCIAL	HOUSEHOLDS	COMMERCIAL
CENTRAL	2 618 909	11 332	409 017	220 849	56 670	315 550
COPPERBELT	1 377 544	43 336	1 795 154	84 859	48 284	211 527
EASTERN	2 011 608	1 913	322 271	44 069	9 237	12 007
LUAPULA	796 075	906	160 328	9 778	1 237	4 335
LUSAKA	1 254 527	7 731	2 282 752	272 000	557 679	316 491
MUCHINGA	1 148 255	3 427	172 853	5 701	16 140	6 081
NORTHERN	1 299 368	848	141 943	1 610	8 196	-
NORTH WESTERN	755 366	601	354 068	2 955	10 433	27 040
SOUTHERN	3 150 184	7 248	409 691	49 407	17 538	36 942
WESTERN	901 944	28	30 615	-	17 566	-
ZAMBIA	**15 313 780**	**77 370**	**6 078 693**	**691 228**	**742 981**	**929 973**

Source: The 2017/18 Livestock and Aquaculture Census Report, 2018

2.2.3 Agriculture performance and policy

The leading documents in the agriculture sector development in Zambia are the National Agricultural Policy (NAP) 2004-2015 (MACO, 2011) and the Second National Agricultural Policy (2NAP) 2016–2020 (MoA and MoLF, 2016). These documents build upon the Seventh National Development Plan (7NDP) 2017-2021 (MNDP, 2017). The 7NDP 2017 – 2021 aims to create a diversified and resilient economy for sustained growth and socio-economic transformation driven by agriculture, mining and tourism.

The NAP 2004-2015 (MACO, 2011) seeks to facilitate the development of a competitive, diversified, equitable and sustainable agriculture sector by promoting a sustainable increase in the agricultural productivity of major crops, increase in agricultural exports and improved access to inputs and services for small-scale farmers. The 2NAP revised NAP 2016-2020 in order to address new developments and trends, as well as the challenges observed until 2015.

In line with the objectives of the 7NDP, the 2NAP identifies 10 policy objectives and defines a number of implementation measures for each of them. The policy objectives are:

- Objective 1: to increase agriculture production and productivity;
- Objective 2: to increase effectiveness and efficiency of agriculture research and development (R&D);
- Objective 3: to strengthen the capacities of agricultural training institutions;
- Objective 4: to improve the efficiency of agricultural markets for inputs and outputs;
- Objective 5: to promote availability of and accessibility to agricultural finance, credit facilities and insurance;
- Objective 6: to increase private sector participation in agricultural development;
- Objective 7: to improve food and nutrition security;
- Objective 8: to promote the sustainable management and use of natural resources;
- Objective 9: to mainstream environment and climate change in the agriculture sector;
- Objective 10: to promote the mainstreaming of gender, HIV and AIDS, and governance issues in agriculture.

It is important to add that the measures under Objective 8 include the promotion of renewable energy use and energy efficiency in agriculture production and processing.

The Ministry of Agriculture and the Ministry of Fisheries and Livestock are responsible for the implementation of the 2NAP in cooperation with other institutions as well as all relevant stakeholders, including farming communities, agro-industry, financial institutions, etc.

2.3 FORESTRY SECTOR

2.3.1 Forest resources and trends

Forests are one of the most important natural resources of Zambia, covering 66 percent of the total land area of the country. About 9.6 percent are under protected forest reserves. Forests play vital role in people’s livelihoods as major sources of timber, traditional medicine, wood fuel, food and building materials. Furthermore, forests play major roles in both carbon and hydrological cycles. They are key factors in watershed and soil conservation, and are important for other landscape factors (e.g. soil erosion).

Based on forest vegetation, Zambian forests can be classified into four categories (Ng’andwe *et al.*, 2015). The first category is comprised of closed forests consisting of the evergreen forests, dry deciduous forests, montane forests, swamp forests and riparian forests. These forest types constitute different vegetation types within the Miombo woodlands; these woodlands account for a majority of the commercial growing stock. They are economically important for the supply of timber, poles, firewood and charcoal, and they are also the source of many non-wood forest products. The second category is the open forests, commonly known as the savannah woodlands: the most dominant in this category is the Kalahari woodland vegetation found on

the Kalahari sands in western Zambia. The third and fourth woodlands are the Mopane and Munga woodlands characterized by vegetation of the *Colophospermum mopane* and *Acacia* species. Finally, the areas located around ephemeral rivers are covered with grassland vegetation, which includes wetlands (flood plains or swamps) and dambos; these grasslands range from pure grasslands to grasslands with scattered trees. According to the Forest Act 2015, Zambian natural forests are legally divided into national forests, local forests, botanical reserves, private forests, community forests and forests in an open area.

Long-term observations show that forest cover in Zambia is decreasing. The Forest Resource Assessment Report (FAO, 2015) indicates that the total forest area decreased by 2 499 000 ha from 2000 to 2015. This is equivalent to a reduction of 166 000 ha of forest cover per year. Other sources indicate an even higher deforestation rate, e.g. according to CIFOR (2014) the annual rate of deforestation ranges from 250 000 to 300 000 ha. The main drivers of deforestation identified through Integrated Land Use Assessments (ILUA I and II) include the expansion of agriculture and conversion of land into "other-land", which was mainly attributed to the opening up of new mines and related infrastructure (Forestry Department, 2016). Unsustainable logging for timber, firewood and charcoal production also contribute to forest degradation and deforestation (MLNR and MNDP, 2019).

According to the Natural Capital Accounts for Forests Version 2.0 (MLNR, 2019), in 2015 the total forest land covered 45 944 415 hectares, out of which 10 503 819 hectares were primary forests, 27 107 187 naturally regenerated forests and the remaining area was covered with planted forests (plantations) and other wooded land.

Apart from natural forests, forest plantations are also an important part of the Zambian forestry sector. In total, there are around 53 000 hectares of plantations located in the Copperbelt Province, in Ndola, Mufulira, Kitwe, Kalulushi, Lufwanyama and Chingola districts. The plantations are divided into four administrative plantation groups namely Ndola (20 531 ha), Chati (16 000 ha), Ichimpe (11 936 ha) and Lamba (5 987 ha). Other plantation stations include Kawambwa and Shiwang'ndu in Luapula and Muchinga provinces, respectively. These comprise of young stands of recently planted forest plantations. The main species in all of these plantations are exotic species comprising mainly *Pinus sp.*, *Eucalyptus sp.* and *Gmelina aborea*. The total standing stock in the plantations is around 4 768 036 m^3 and the average annual allowable cut (AAC) is around 150 000 m^3. The national company Zambia Forest and Forest Industries Corporation (ZAFFICO) has the right of ownership and management of plantations, in collaboration with the Forestry Department of the Ministry under Lands and Natural Resources (MLNR). The Forestry Department administrates the plantations, while the plantation harvesting and exploitation of timber is regulated through permits issued by ZAFFICO. However, harvesting and exploitation of indigenous forests or timber is regulated by the Department of Forestry through the Forests Act No. 4 of 2015. In addition, Forestry Department manages local and Regional Supply Forest Plantations of exotic species in various provinces including Northern, Southern, Luapula and Eastern. According to the information provided by the Forestry Department, in 2019 there were 151 active forest concession licences: 101 were issued to small-scale companies, 42 to medium-size companies and 8 to large-scale companies.

2.3.2 Roundwood production and use

The official data on roundwood production in Zambia has not been recorded or published in a systematic manner. The latest available information on estimates of roundwood production can be found in the report entitled Natural Capital Accounts for Forests Version 2.0 (MLNR, 2019) and the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) analysis published in 2016 (Drigo, 2016). The estimated average annual roundwood production from 2010 to 2015, according to the Natural Capital Accounts for Forests report, amounted to 83.3 million m^3. Similar estimates are presented in the WISDOM report.

As much as 90 percent of roundwood produced is woodfuel, which is used as firewood and for charcoal production. Charcoal and fuelwood

were mainly consumed by the residential sector (82 percent), followed by industry (6.41 percent). Woodfuel was also consumed in commercial and public sectors (6.38 percent), for fish drying (2.7 percent) and tobacco curing (2.5 percent) (MoE, 2017).

The industrial roundwood is processed domestically. In 2012 there were more than 1 000 sawmills operating in the country (Ng'andwea *et al.*, 2015). Among these sawmills, more than 900 were small-scale sawmills processing plantation roundwood and more than one hundred operators processing hardwood timber. After primary processing, the sawmills trade their products downstream for further processing and production of furniture, panels, crates, pallets, mine lug boxes, cable drums, and other products. A major part of the processed wood is used in Zambia and only a portion is exported.

2.3.3 Forestry policy

The National Forestry Policy (NFP) of 2014 and the Forests Act of 2015 are the major policy documents governing the sector. Apart from these documents, the key national documents used by forest management as a guide are: the 7NDP, Vision 2030, the Sustainable Development Goals (SDG), the National Strategy to Reduce Deforestation and Forest Degradation (REDD+), the Investment plan to reduce deforestation and forest degradation, and the Zambia Forestry Action Programme (ZFAP).

The NFP of 2014 and the Forest Act of 2015 provide a foundation for the establishment of the sustainable management of forest resources including: planning, providing licences, monitoring and control as well as cooperation with stakeholders and involvement of local communities. The sustainable forest management activities described in the Nationally Determined Contribution (NDC) to UNFCCC for Zambia include forest enhancement, which encompasses: natural regeneration and afforestation/reforestation, sustainable charcoal production with improved kilns, promoting alternative cooking fuels to reduce demand for charcoal and fuelwood. While the policy documents clearly define measures for ensuring sustainable management of forests, the report in 2017 of the Auditor General on Sustainable Forest Management (CALNR, 2017) shows that the implementation of the measures is staggering due to insufficient financial and human resources for their implementation.

The Forestry Department under the MNLR is responsible for policy formulation, coordination and forest resource management. The Department is also responsible for ensuring a sustained flow of wood and other

non-wood forest products through the issuance of licences and various permits including production and conveyance permits for fuelwood. The Ministry of Energy is responsible for formulating national energy policies and coordinating the activities and operations of energy sector agencies, as well as ensuring the proper management and development of the energy resources in accordance with the guiding principles contained in the National Energy Policy. Other stakeholders may include governmental and non-governmental actors, as well as representatives from each of the ten provinces of the country, for example: forest officers, agricultural extension workers and non-governmental development practitioners, international experts, donor representatives, indigenous peoples and local community representatives.

2.4 ENERGY SECTOR

2.4.1 Energy demand and supply

The total primary energy supply in Zambia in 2015 was 10 284 ktoe, of which almost 80 percent was sourced from biofuels and waste. Woodfuels (firewood and charcoal) are mainly domestically sourced and electricity is produced domestically in five hydropower plants and one coal powered power station. The imported crude oil, which in 2015 amounted to 656 000 tonnes, is refined in the Zambia's only refinery, INDENI. In addition to the supply from the INDENI refinery, part of the demand for oil products is supplied by imports. **Table 6** provides information on the simplified energy balance for Zambia for 2017, sourced from International Energy Agency.

Consumption in the residential sector makes up the major part of the final energy consumed, that is around 60 percent, followed by industry (27 percent) and transport (5 percent). In the residential sector, biomass is the primary fuel used for cooking and heating (**Figure 3**), mostly in the form of charcoal in urban areas and firewood and animal dung for cooking in both rural and urban areas. Electricity is the second most important source of energy used in households, however its supply is far below the actual demand since only 31 percent of households have access to electricity.

2.4.1.1 Energy demand for cooking by households

As described in **Figure 3**, the consumption of biomass and waste within the residential sector is the most prevalent use of energy within the country, the biomass mainly being used as fuel for cooking in the form of wood and charcoal. A more detailed description of fuel consumption at household level will be presented in the section 4.5 Fuels for cooking. There, it will be explained how the fuel most used in the rural area for cooking is fuelwood, when analysing the amounts in terms of useful energy actually provided by the cooking fuel, both sources are used equally. In the case of urban households, charcoal is the fuel the most commonly used for cooking while other important sources include LPG, electricity and briquettes.

2.4.1.2 Electricity demand by urban and rural households

In the case of the electricity demand from urban and rural households, the information collected in the country was compared using the World Bank's multi-tier framework approach (MTF). This approach defines the access according to a spectrum ranging from Tier 0 (no access) to Tier 5 (full access) through seven attributes: capacity, availability, reliability, quality, affordability, formality, and health and safety. The final aggregate tier for a given household is based on the lowest tier reached by households among all the attributes (Bhatia and Angelou, 2014; Luzi *et al.*, 2019).

2.4.2 Electricity generation

In 2015, the total installed electricity generation capacity in Zambia's national grid was 2 800 MW, with 85 percent hydropower (2 380 MW) while coal, heavy fuel oil and other primary energy sources contributed the remaining 15 percent. The largest consumers of electricity were the mining and residential sectors, which accounted

TABLE 6.

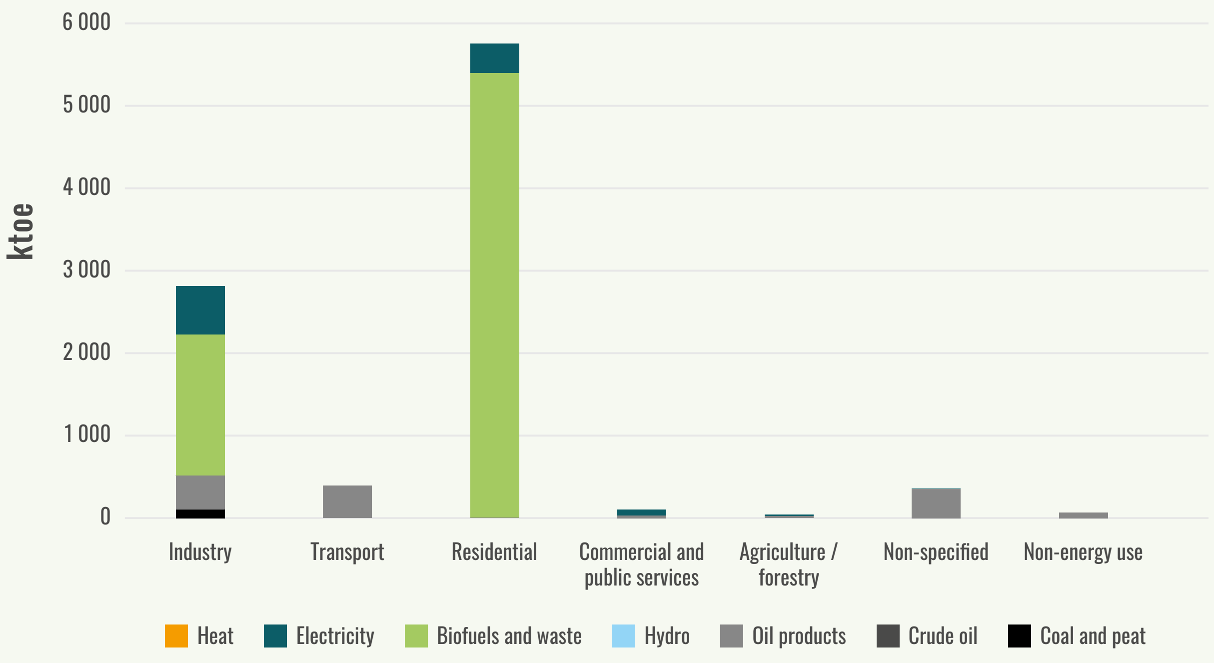
SIMPLIFIED ENERGY BALANCE FOR ZAMBIA 2017

SIMPLIFIED AGGREGATED ENERGY BALANCE							
UNIT: ktoe	COAL & PEAT	CRUDE OIL	OIL PRODUCTS	HYDRO	BIOFUELS & WASTE	ELECTRICITY	TOTAL
TOTAL PRIMARY ENERGY SUPPLY	**470**	**531**	**962**	**1 049**	**9 106**	**- 26**	**12 092**
PRODUCTION	470			1 049	9 106		10 625
IMPORT		531	976			65	1 572
EXPORT			14			91	105
FINAL CONSUMPTION	**104**	**0**	**1 281**	**0**	**7 102**	**1 047**	**9 534**
INDUSTRY	104		412		1 710	588	2 814
TRANSPORT			391			3	394
RESIDENTIAL			4		5 392	356	5 752
COMMERCIAL AND PUBLIC SERVICES			32			71	103
AGRICULTURE / FORESTRY			23			22	45
FISHING							0
NON-SPECIFIED			352			7	359
NON-ENERGY USE			67				67

Source: IEA, Energy Balance for Zambia 2017

FIGURE 3.

ENERGY CONSUMPTION PER SECTOR BASED ON THE ENERGY BALANCE FOR ZAMBIA 2017



Source: IEA, Energy Balance for Zambia 2017

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for 54.8 percent and 30.3 percent of total consumption in 2014, respectively. The other sectors collectively consumed the remaining 14.9 percent. In Zambia, access to electricity nationwide is 31 percent, however, in rural areas only 4.4 percent of the population has access to electricity. The challenges for rural electrification include insufficient funding for electrification, isolation of rural communities and high initial investments for mini-grids. Poverty, moreover, conditions the limited willingness (and ability) of rural households to pay for electricity and hinders the participation of the private sector in electrification projects.

In line with the policy goals to provide electricity access for 66 percent of the total population and 50.6 percent of the rural population by 2030, there are a number of rural electrification projects being implemented. The technologies being promoted include grid extension, mini-hydro systems (from 200kW to 10MW), solar mini-grids, solar home system installations, biomass and biogas and wind.

2.4.3 Crude oil and oil products

The country imports crude oil via the TAZAMA pipelines, which are owned by the Governments of Zambia (67 percent) and Tanzania (33 percent). The crude oil is then refined at the INDENI Oil Refinery to produce diesel, petrol and other fuels. In addition, the country imports diesel and petrol to cover the demand that is higher than the refining capacity installed in the country. The main consumer sector of petroleum products in the country is the transport sector. Moreover, the most important sectors are the mining and non-mining sector that includes industries and commercial sectors, and the retail sector that refers to the transport sector. It is evident that almost all of the demand for petrol corresponds to the retail sector. In the case of diesel, the retail sector consumes between 37.5 and 39 percent of the country's demand for diesel. A more detailed description, demand projections and target liquid biofuel production will be presented in the section Liquid biofuels for transport.

2.4.4 Energy policy

In order to improve access to modern energy, the Zambian Government has put a series of policies into place. The most relevant are the National Energy Policy (NEP) 2008 and 2019 NEP (revised 2008 NEP), the Nationally Determined Contributions (NDC, 2016), the 7NDP (2017–2021) and the Rural Electrification Master Plan (REMP) 2008–2030. The policies have established a series of targets that aim at reducing the use of fuelwood, producing sustainable renewable energy, increasing access to energy in rural areas and reducing the fossil fuel import bill.

The 7NDP has proposed a strategy to promote the use of renewable energy to diversify the energy matrix and improve supply. The REMP 2008–2030 defines electricity access rate targets to reach 66 percent of the total population and 50.6 percent of the rural population by 2030. The electrification methods currently being considered by the plan include, in order of priority, (i) the extension of existing grids; (ii) isolated mini-grids with renewable energy; (iii) solar home systems (SHS) and (iv) mini-grid with diesel power generation, if none of the previous options are available.

The Rural Electrification Authority (REA) has been mandated to coordinate and lead the implementation of REMP. At the moment, the electrification method for installation of mini-grids with renewable energy includes only micro and mini- hydro power generation, solar and wind energy. According to the REA, more information is needed about the feasibility of biomass based off-grid electricity technologies, so that they may be included in rural electrification plans.

2.5 CLIMATE POLICY

Zambia has currently put into place the National Policy on Climate Change (NPCC), which recognises the threats of climate change within different sectors. Due to the changes in weather patterns there is a risk of droughts and flooding, which can result in crop failure, reduced livestock production and consequentially, food insecurity. In addition, these changes can create further difficulties for the control and management of pests and diseases.

Indeed, the effects of climate change can have significant impacts on the energy sector, such as droughts and rising temperatures leading to the gradual drying up of biomass, thus resulting in a reduction in the availability of fuel wood. Furthermore, the country depends on hydropower generation; droughts and alterations in the hydrology of the country could cause power cuts and wasted investments in dams. As a result, the dams would not have an adequate water supply to generate electricity.

The NDC for the 2015 Agreement on Climate Change, submitted to the UNFCCC, established a national goal to reduce the total GHG emissions by 38 000 Gg CO_2eq; this translates into 47 percent (internationally supported efforts) against 2010 as a base year. The objective is to achieve the goals set to define climate change mitigation measures, as well as a set of adaptation measures. The programmes through which the mitigation measures are implemented are the Sustainable Forest Management, Sustainable Agriculture and Renewable Energy and Energy Efficiency. The most important measures included in the programmes address the sustainable production and use of charcoal, as well as the appropriate alternatives to reduce the consumption of woodfuel. Moreover, these measures include improved technologies for the sustainable production of charcoal and the promotion of the use of improved cooking devices and alternative fuels to woodfuel. These policies seek to reduce dependence on woodfuel and ensure a sustainable provision of affordable, reliable modern energy as a means for raising productivity, as well as the standards of living both in urban and rural areas. The measures taken for a decrease in the emissions from fossil fuel combustion aim to create by 2030, a blend of ethanol, gasoline and biodiesel with diesel, shared between 10 and 5 percent, respectively. Rural electrification based on sustainable renewable energy sources is also included as one of the mitigation measures. The successful outcome of the ambitious goals for GHG emission reduction by 2030 will depend on the availability of funds and international support in the form of finance, technology and capacity building.

CHAPTER

3

BEFS ASSESSMENT: NATURAL RESOURCES

3.1 THE AIM AND SCOPE OF THE ASSESSMENT

The aim of the natural resources assessment is to determine the types of biomass that can serve as bioenergy feedstock, estimate their potential availability for energy generation and map their spatial distribution. In order to ensure that bioenergy production is sustainable, the biomass currently used for other purposes is not deemed potentially available for bioenergy production. The BEFS methodology also takes into account the sustainability of agricultural and forest ecosystems. It assumes that after harvesting a certain volume of residues is left on the ground, in order to maintain soil fertility, stability and biodiversity. This amount of residues is therefore, not considered available for bioenergy.

In line with the scope of the BEFS Analysis for Zambia, the natural resources assessment was applied to two bioenergy feedstock groups:

1. Agriculture and forestry residues that can be used as bioenergy feedstock for electricity generation and cooking fuels production:
   a. Crop residues,
   b. Agro-processing residues,
   c. Livestock residues – manure,
   d. Forest plantation residues,
   e. Wood processing residues.
2. Crops that can serve as feedstock for liquid biofuels production:
   a. Cassava,
   b. Sugarcane,
   c. Soybean,
   d. Sunflower.

The BEFS assessment was implemented through a participatory process that included bilateral and multi-disciplinary technical consultations and snap field surveys through

the support of the Bioenergy Work Group and the other relevant bioenergy stakeholders. The Bioenergy Work Group is composed of representatives from the Ministry of Energy, Ministry of Agriculture, Ministry of Fisheries and Livestock, and the Department of Forestry under the Ministry of Lands and Natural Resources. The other stakeholders involved in the process were the Zambia Statistics Agency (earlier named Central Statistical Office of Zambia), University of Zambia, Zambia Environmental Management Agency, ZAFFICO and representatives of livestock, poultry and sugar producers. In the following sections the BEFS assessment for each bioenergy feedstock type will be described. The sections are divided into three subsections: scope, assessment methodology and data collection, and results.

3.2 LIVESTOCK RESIDUES

3.2.1 Scope

The scope of the livestock residues analysis has been defined in agreement with the Bioenergy Work Group and according to the information provided by experts and stakeholders involved in animal husbandry. The aim of the assessment was to evaluate the amount of livestock manure that can be collected and subsequently used for biogas production.

When defining the scope of the assessment, various factors were taken into account: the livestock production levels and production systems, the practicality of manure collection, the feasibility of using the manure for biogas production considering the characteristics of manure and other aspects such as composition, moisture content and the impurities that could affect the process. Taking into account these factors the overall scope of the assessment was defined as presented in **Table 7**.

TABLE 7.

SCOPE OF THE LIVESTOCK RESIDUES ANALYSIS

TYPE OF LIVESTOCK	PRODUCTION LEVELS	ADDITIONAL CONSIDERATIONS
CATTLE	HOUSEHOLD AND COMMERCIAL	Feeding systems prevailing in the country. The four types of feeding systems typically used in Zambia include: (i) year-round grazing on pastures (ii) seasonal grazing on pastures, (iii) mixed system of stable and grazing; and (iv) stable only. The amount of manure produced and the percentage that can be collected was determined based on the number of animals in each production system. It was assumed that manure generated in open areas (on pastures) is not collected. The number of animals raised by households and in commercial production is based on the 2017/18 Livestock and Aquaculture Census. The estimated percentage of manure that can be collected is different for household level production and commercial production.
PIGS	HOUSEHOLD AND COMMERCIAL	The number of animals raised by households and in commercial production is based on the 2017/18 Livestock and Aquaculture Census. The estimated percentage of manure that can be collected is different for household level production and commercial production. The amount of manure produced and the percentage that can be collected was determined based on the number of animals in each production system. It was assumed that manure generated under free-range pig production systems is not collected.
GOATS	COMMERCIAL	The analysis has been limited to the commercial production of goats, where goats are housed in night shelters. The assumption is that considerable number of goats are kept together, and thus a large amount of manure is generated in one place, which can be collected.
CHICKEN – LAYER	COMMERCIAL	Commercial layer chicken production in Zambia allows the recovery of manure free of impurities. In the case of broiler chickens, village chickens and layers produced at a household level, the manure that can be recovered is usually mixed with bedding or litter material. Where the birds are kept in free-range system or semi-intensive rearing system, there is very limited amount of manure that can be collected or it is not possible at all.

Source: Elaboration based on BEFS Assessment Results

3.2.2 Assessment methodology and data sources

The amount of manure available for biogas production corresponds to the amount produced by animals raised in the assessment area that can be collected at a reasonable cost. It is noteworthy that the scope and detail of the field study of manure produced by livestock could not permit taking specific measurements of quantities produced under each management or production system. This is an area for future in-depth study, as it requires specific tools and detailed recording of necessary parameters. The BEFS assessment therefore relies on the respective estimates gathered through technical consultation and information from the literature sources.

Firstly, the total manure production is calculated and secondly, the percentage that can be collected for biogas production based on the analysed production system and common practices is determined.

3.2.2.1 Total manure production

The calculation for the total production of manure per year is based on the number of animal species considered within the assessment area and the average daily manure production per head:

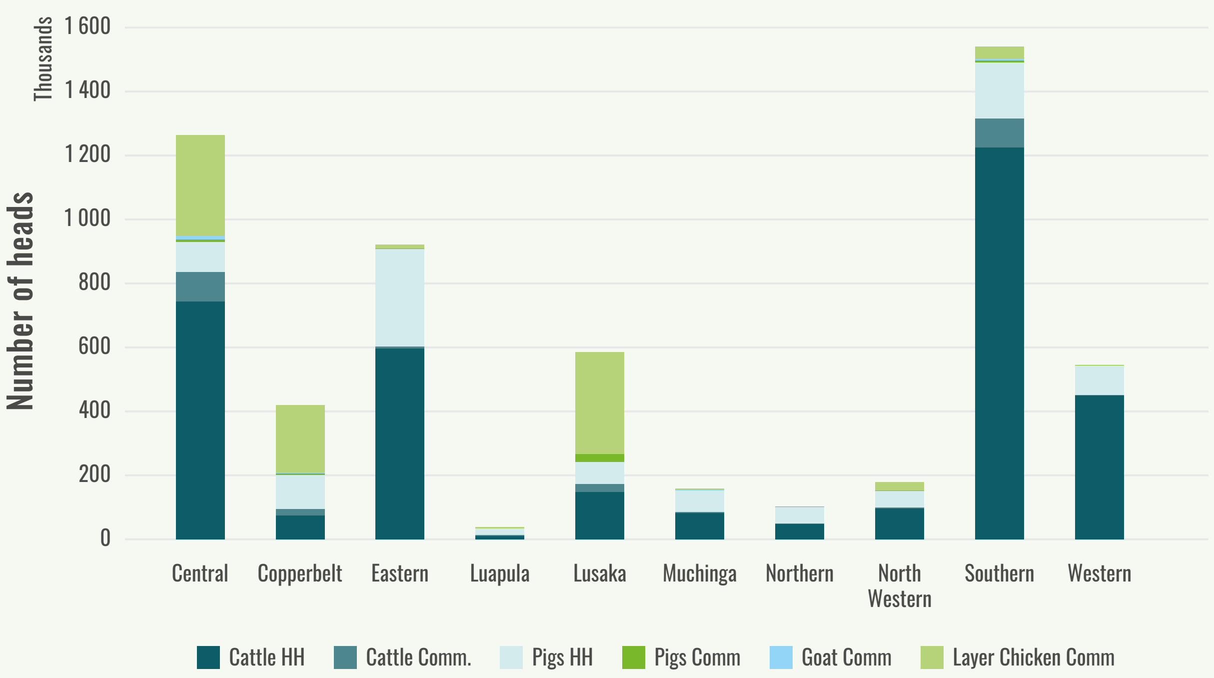
$$M_{tot\ (i)} = LVS_{head\ (i)} \times M_{head\ (i)}$$

Where:

- $M_{tot\ (i)}$ [tonnes/year] = Total amount of manure produced per year within the assessment area;
- $LVS_{head\ (i)}$ [head/year] = Average number of animals raised per year within the assessment area;
- $M_{head\ (i)}$ [tonnes/head] = Amount of manure produced per head per year;
- (i) = Analysed livestock type – production level category: cattle-commercial production, cattle – household production, pigs – commercial production, pigs – household production, chicken (layers) – commercial production and goats – commercial production.

FIGURE 4.

NUMBER OF ANIMALS PER PRODUCTION LEVEL PER PROVINCE IN 2017/2018



Source: Livestock and Aquaculture Census Report 2017/18 (CSO, 2018)

This equation is applied separately for each livestock type – production level category analysed, i.e. for the commercial and household level production of cattle and pigs and the commercial production of chicken (layers) and goats. In the case of cattle further disaggregation was carried out to reflect the amount of manure produced according to each type of feeding system: seasonal grazing in pastures, a mixed system of stable and grazing and stable only.

The assessment area was done by district, in other words, the total manure production by the assessed livestock types in each district was calculated. The number of animals per district was based on the 2017/18 Livestock and Aquaculture Census and RALS 2012 Report.

The average daily amount of manure produced per head by the analysed livestock types in Zambia is presented in **Table 8**.

The shares of cattle according to the prevalent feeding system is presented in **Table 9**. The animals that are in pasture year-round were not considered, since manure collection produced by these animals would not be economically reasonable. In the case of animals that are in pastures for seasonal grazing, manure production is calculated only for the months when animals are not in pasture. The mixed stable/grazing feeding system makes the assumption that animals spend half a day in the stables or enclosed areas where manure can be collected. Therefore, it can be assumed that 50 percent of the daily manure production could be collected for biogas production.

TABLE 8.

AVERAGE DAILY MANURE PRODUCTION PER HEAD FOR THE ANALYSED LIVESTOCK TYPES

LIVESTOCK TYPE	TOTAL SOLIDS IN FRESH MANURE [%]	DRY MATTER (DM) MANURE [kg/head/day]	FRESH MANURE [kg/head/day]
CATTLE	30%	1.8	6.00
PIGS	93%	0.8	0.86
GOATS	27%	0.4	1.49
LAYER CHICKEN	25%	0.02835	0.1134

Source: Elaboration based on BEFS Assessment Results

TABLE 9.

DISTRIBUTION OF CATTLE NUMBER IN DIFFERENT FEEDING SYSTEMS

FEEDING SYSTEM	CATTLE COMMERCIAL PRODUCTION [%]	CATTLE HOUSEHOLD PRODUCTION [%]
STABLE ONLY	5%	0.1%
MIXED – STABLE/GRAZING	25%	2%
SEASONAL GRAZING	55%	6 %
YEAR-ROUND GRAZING	15%	36.5%

Source: Elaboration based on BEFS Assessment Results

3.2.2.2 Collectible manure

After estimating the total manure production, the next step was to estimate the amount that can be collected and thus made available for bioenergy production.

The calculation of the collectible manure for biogas follows the equation below:

$$M_{bioenergy\,(i)} = M_{tot\,(i)} \times c_{(i)}$$

Where:

- $M_{bioenergy\,(i)}$ [tonnes/year] = Amount of manure available for biogas produced by the analysed livestock type per year within the assessment area
- $c_{(i)}$ = Share of collectible manure for each analysed category

The estimated share of collectible manure for each species and production system is given in **Table 10**.

Within this study the current uses of manure were investigated through a nation-wide survey on manure use. The survey was implemented as part of the 2019 Crop Forecast Survey conducted by the Central Statistics Office of Zambia (CSO). Some of the uses of manure in Zambia that have been reported include fertilizer, compost and energy production. The production of biogas from manure produces bio-slurry as a by-product. Since bio-slurry can be used as fertiliser its utilisation for biogas production should not undermine the current uses of manure, instead it could potentially bring additional benefits to farmers. Therefore, during the assessment the total amount of collectible manure was considered as potential feedstock for biogas production.

TABLE 10.

SHARE OF COLLECTIBLE MANURE FOR THE ANALYSED LIVESTOCK TYPES AND PRODUCTION LEVELS

SPECIES	LEVEL OF PRODUCTION	
	HOUSEHOLDS	COMMERCIAL
CATTLE (WHEN IN STABLE)	80%	90%
PIGS	60%	90%
CHICKEN – LAYERS		90%
GOATS		50%

Source: Elaboration based on BEFS Assessment Results

3.2.2.3 Data sources

The manure available for biogas production in Zambia was calculated using the statistical data and technical coefficients applicable for Zambian livestock production, which were provided and verified by Zambian experts through the BEFS Technical Consultation. **Table 11** shows data sources for each group of data used in the assessment.

TABLE 11.

DATA SOURCES FOR TECHNICAL COEFFICIENTS USED IN BIOGAS FEEDSTOCK ASSESSMENT

DATA TYPE	LIVESTOCK TYPE	DATA SOURCE
Number of heads per province and per level of production > Distribution of heads per district was done based on the RALS 2012 survey	Cattle, pigs, chicken, goats	2017/18 Livestock and Aquaculture Census
Types of feeding systems and share of total number of cattle heads per system	Cattle	Ministry of Fisheries and Livestock – Livestock Department
Average manure production per head per day/year ($M_{head(i)}$)	Cattle, pigs, chicken, goats	Technical consultation – Zambian technical experts: University of Zambia; Zambian Poultry Association; Zambian Dairy Association
Share of manure collectible for bioenergy for each animal category ($c_{(i)}$)	Cattle, pigs, chicken, goats	Technical consultation – Zambian technical experts

Source: Elaboration based on BEFS Assessment Results

3.2.3 Results

3.2.3.1 Cattle

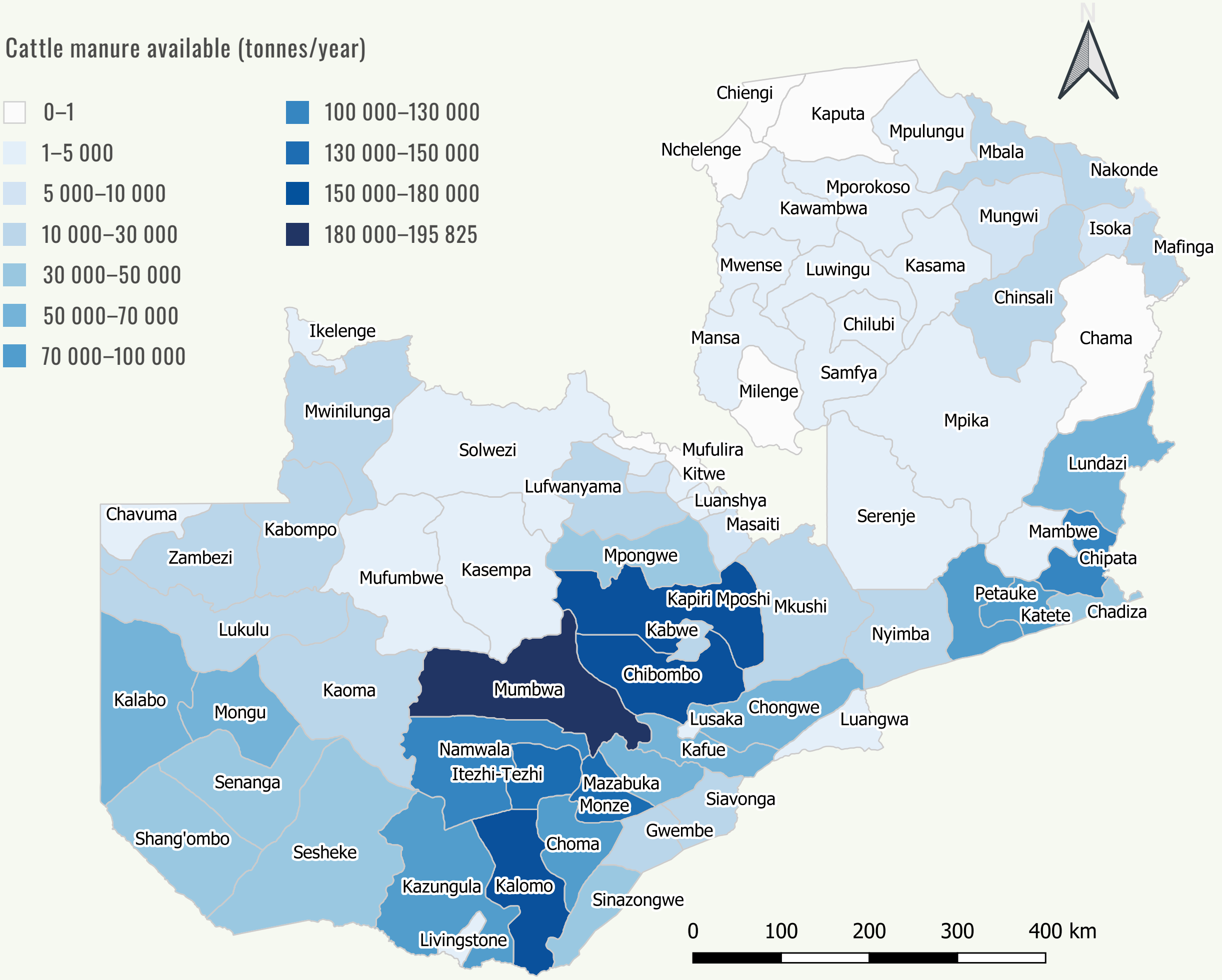
Figure 5 shows the geographical distribution of cattle manure available for biogas production at a district level in Zambia. The darker areas represent higher manure availability, while the lighter shades represent a lower availability rate.

Total production of cattle manure at the national level was estimated at approximately 2.5 million tonnes/year. Three districts show the highest production levels: Mumbwa, Chibombo and Kalomo. The shares are 7.8 percent, 7 percent, and 6.9 percent, respectively. These three districts account for about a quarter of the entire national potential. These are also the top three districts in terms of the number of cattle, therefore the link between manure production and quantity of livestock is quite clear.

At the provincial level, the Southern Province has the highest production of cattle manure, and accounts for about 35.5 percent (0.8 million tonnes/year). It is followed by the Central Province and Eastern Province, whose contribution is 23 percent and 15.8 percent, respectively. These three provinces exclusively concentrate almost 75 percent of all manure

FIGURE 5.

SPATIAL DISTRIBUTION OF CATTLE MANURE AVAILABLE FOR BIOENERGY

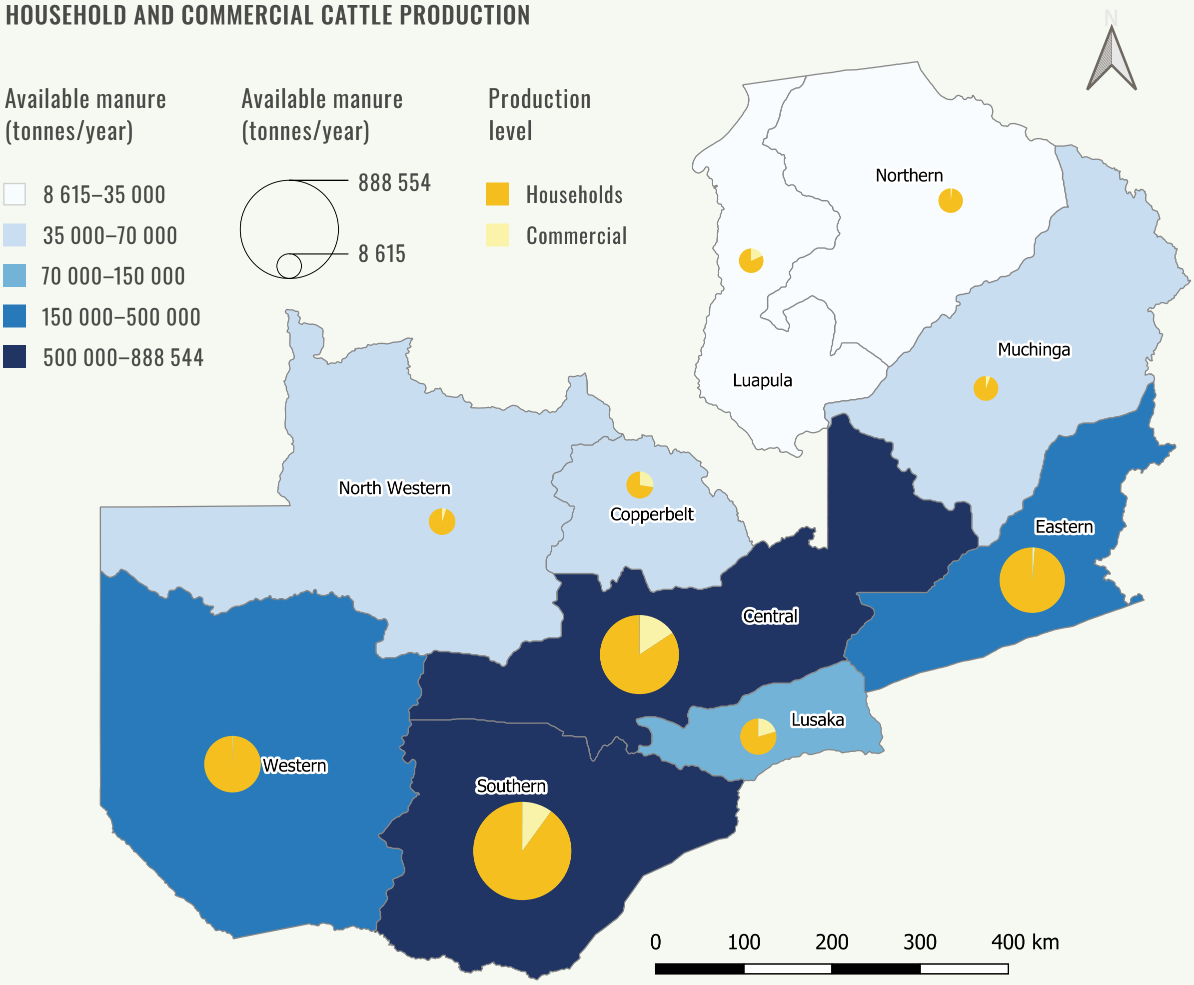


Source: Elaboration based on BEFS Assessment Results

produced in the country. **Figure 6** shows the share of manure produced according to the production level varying between household and commercial level of production (presented with pie charts).

FIGURE 6.

SPATIAL DISTRIBUTION OF CATTLE MANURE AVAILABLE FOR BIOENERGY BY PROVINCE WITH INDICATION OF SHARES BY HOUSEHOLD AND COMMERCIAL CATTLE PRODUCTION



Source: Elaboration based on BEFS Assessment Results

In provinces with the highest production levels, the Central Province and Southern Province, more than 80 percent of the manure is produced at a household level farms. Manure produced by commercial farms is concentrated in the districts of the Copperbelt Province with shares that range from 20 to 30 percent of the total manure produced in the province. In the Western Province, cattle is produces almost exclusively by households.

A detailed presentation of the results per district and province is given in Table A.1 in **Annex 1**.

3.2.3.2 Pigs

Figure 7 shows a map of the geographical distribution of the available pig manure for biogas production at a district level in Zambia. The darker areas represent higher manure availability, while the lighter shades represent a lower availability rate.

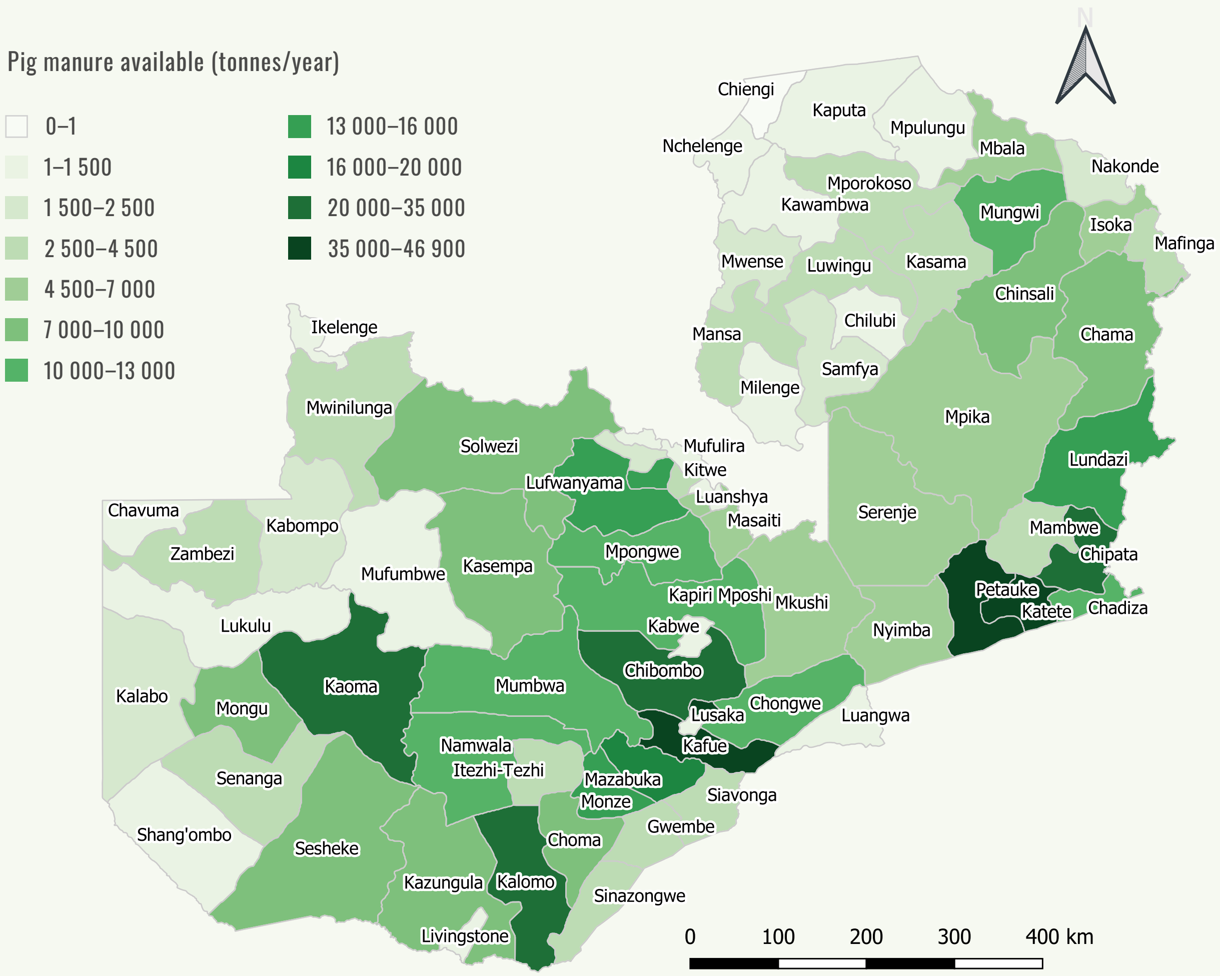
Total production of pig manure at the national level was estimated at approximately 572 thousand tonnes/year. Three districts show the highest production levels: Petauke, Katete and Kafue. The shares are 8.2 percent, 7.8 percent and 7.5 percent, respectively, which account for approximately one-fourth of the entire national potential. These are also the top three districts in terms of pig numbers.

At the provincial level, the Eastern Province shows the highest pig manure availability, accounting for about 27.7 percent (159 thousand tonnes/year). This is followed by the Southern Province, Copperbelt Province and Central Province, whose contributions are 16.7 percent, 10.4 percent and 9.7 percent, respectively. These four provinces represent almost 65 percent of all manure produced in the country.

Figure 8 also shows the share of manure produced according to production level in the form of pie charts, varying household or commercial level of production.

FIGURE 7.

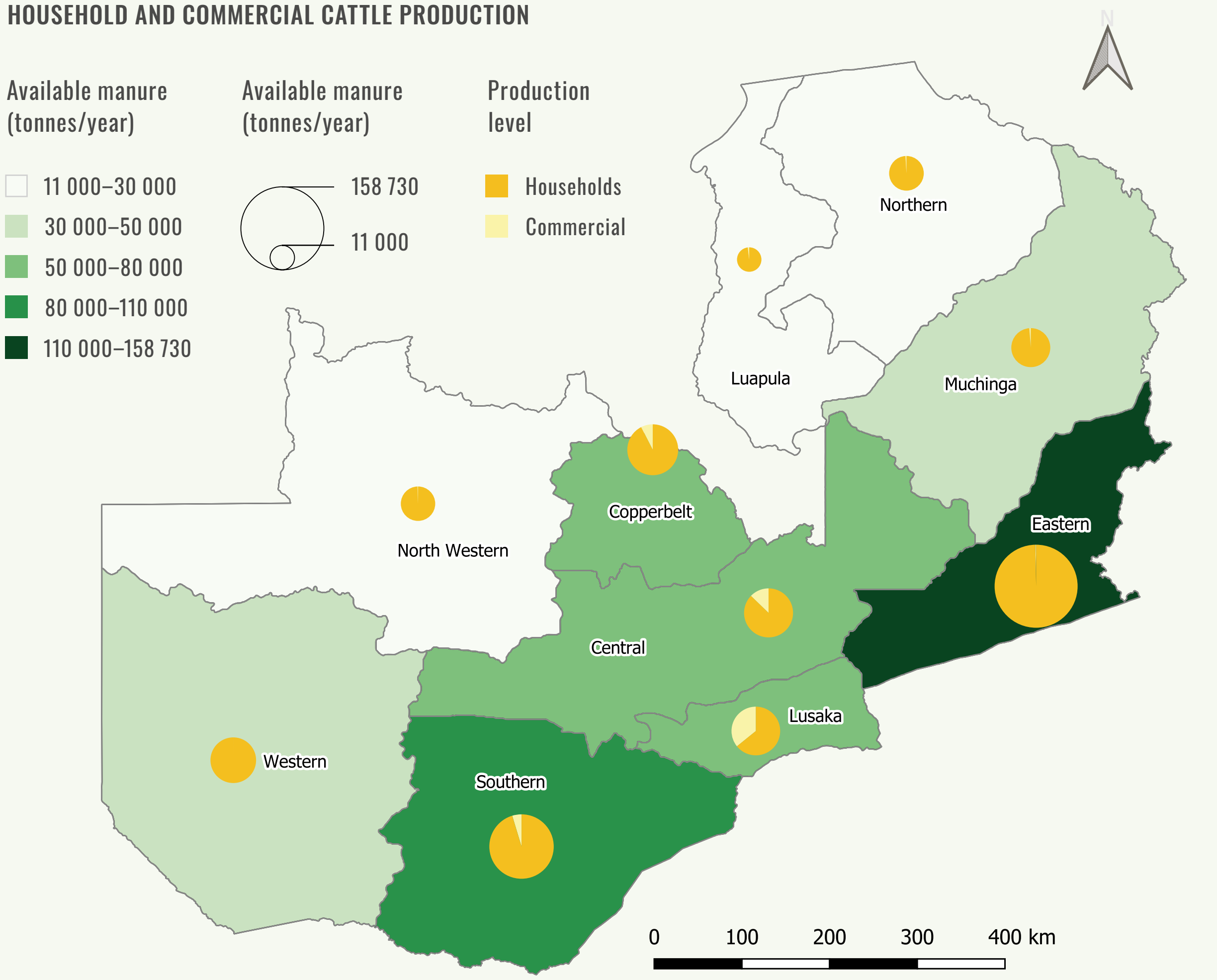
SPATIAL DISTRIBUTION OF PIG MANURE AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

FIGURE 8.

SPATIAL DISTRIBUTION OF PIG MANURE AVAILABLE FOR BIOENERGY BY PROVINCE WITH INDICATION OF SHARES BY HOUSEHOLD AND COMMERCIAL CATTLE PRODUCTION



Source: Elaboration based on BEFS Assessment Results

Manure produced by commercial farms is concentrated in districts of the Lusaka Province with shares that range from 30 to 40 percent of total manure produced in the district. In the case of Eastern Province almost 100 percent of manure is produced at a household level.

A detailed presentation of the results per district and province is given in Table A.1 in **Annex 1**.

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3.2.3.3 Chicken

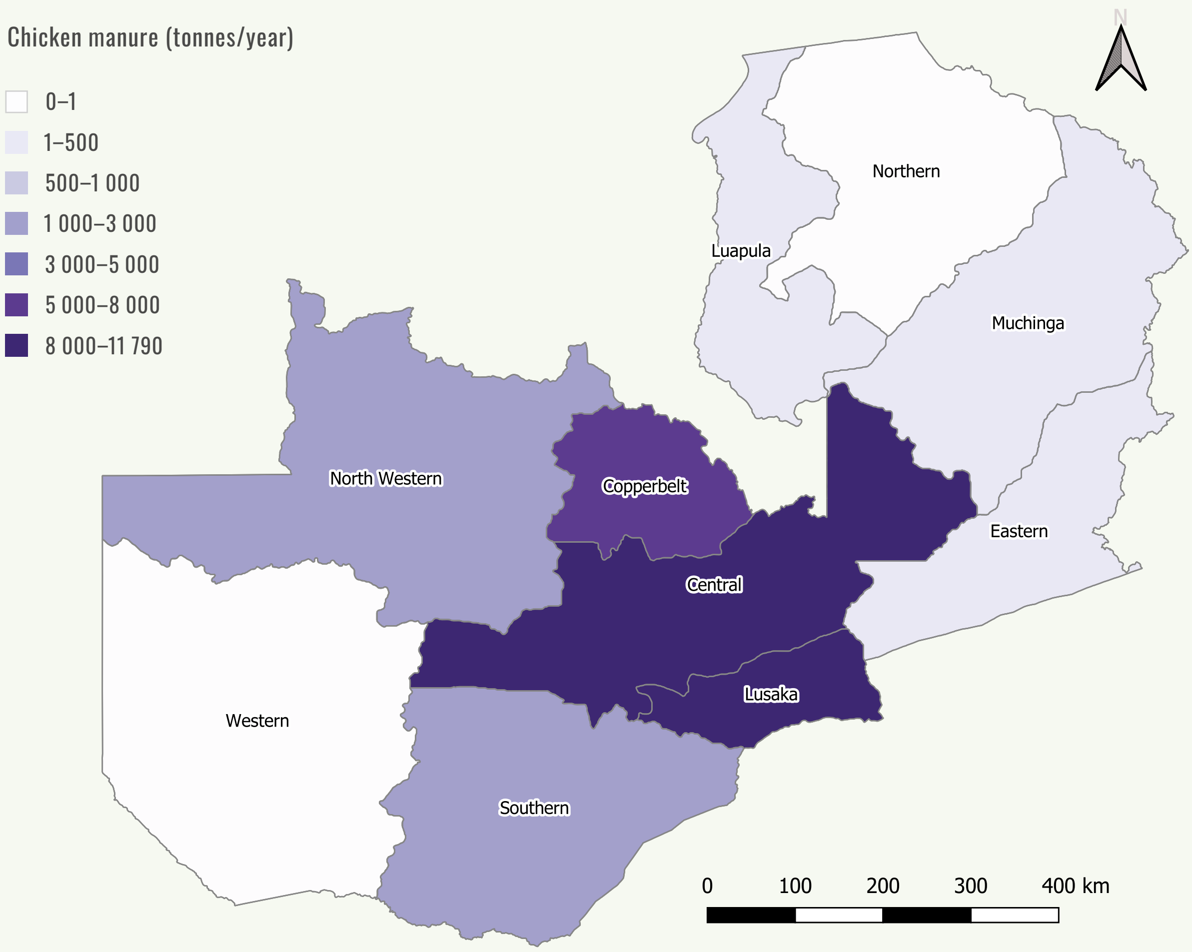
Figure 9 shows a map of the geographical distribution of layer chicken manure production at the provincial level in Zambia.

Total production of layer chicken manure at the national level was estimated at approximately 35 000 tonnes/year and three provinces show the highest production levels: Central, Lusaka and Copperbelt. The shares are 34 percent (13.1 thousand tonnes/year), 34 percent (13.1 thousand tonnes/year) and 23 percent (7.9 thousand tonnes/year), respectively. In sum, these three provinces account for about 91 percent of the entire national potential.

A detailed presentation of the results per district and province is given in Table A2 in **Annex 2**.

FIGURE 9.

SPATIAL DISTRIBUTION OF LAYER CHICKEN MANURE AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

3.2.3.4 Goats

Figure 10 shows a map of the geographical distribution of commercial goat manure availability at a district level in Zambia.

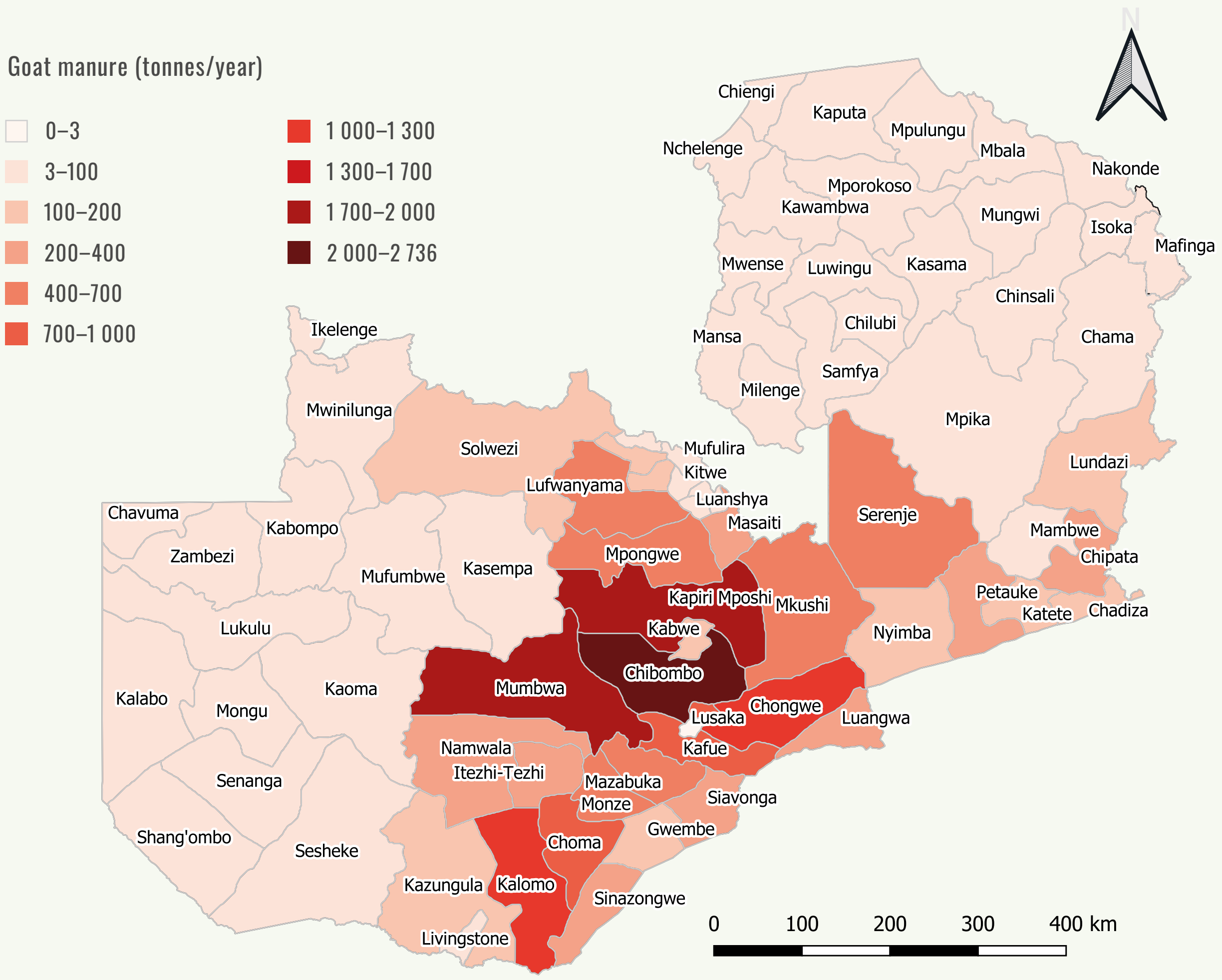
The total production of goat manure at the national level was estimated at approximately 19 000 tonnes/year. The district with the highest production level is Chibombo, which has a share of 14.6 percent of the entire national potential. Other districts with a significant amount of goat manure are Mumbwa and Kapiri Mposhi with 9.5 percent and 9.1 percent, respectively. These three districts account for about one-third of the entire national potential.

At the provincial level, the Central Province shows the highest level of goat manure availability, accounting for almost 40 percent (7.4 thousand tonnes/year). This is followed by the Southern Province and the Copperbelt Province, whose contributions are 25.3 percent and 11.6 percent, respectively. These three provinces represent about 76 percent of all manure available in the country.

A detailed presentation of the results per district and province is given in **Table A.1** in **Annex 1**.

FIGURE 10.

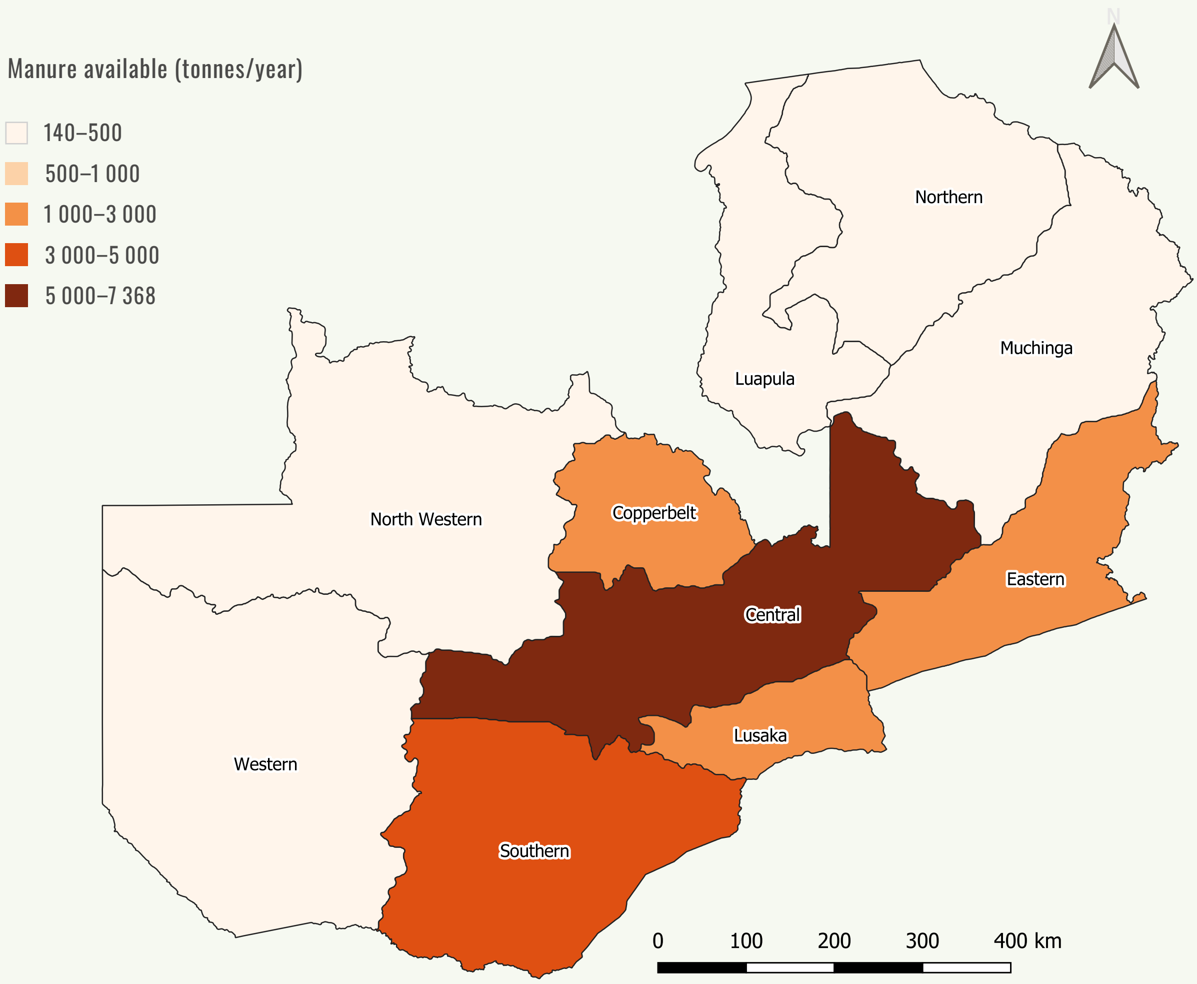
SPATIAL DISTRIBUTION OF GOAT MANURE AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

FIGURE 11.

SPATIAL DISTRIBUTION OF GOAT MANURE AVAILABLE FOR BIOENERGY BY PROVINCE



Source: Elaboration based on BEFS Assessment Results

3.2.4 Summary of results

The assessment of livestock residues availability for biogas production shows that the highest amount of available manure comes from cattle, followed by pig manure, chicken manure and goat manure. On the country level a total of 2 504 901 tonnes of cattle manure is potentially available for biogas production. Three districts show the highest production levels: Mumbwa and Chimbombo in the Central Province and Kalomo in the Southern Province; these three districts have 24 percent of the total available cattle manure at the national level.

Out of the total amount of manure potentially available in these districts, 75 580 tonnes/year originates from commercial cattle production. The potentially available pig manure at the national level amounts to 572 532 tonnes/year, out of which 37 042 tonnes originate from commercial production. Three districts show the highest production levels: Petauke, Katete and Kafue, which account for a quarter of the entire national potential. The highest potential from the commercially produced pigs is found in the Petauke, Katete and Chipata districts (Eastern Province), with a potential availability of 46 769 tonnes, 44 356 tonnes and 32 110 tonnes

of manure per year, respectively. In the case of chicken manure, the results show that commercial layer producers could annually supply 34 643 tonnes of manure for biogas production at the national level, and the highest potential is found in the Lusaka, Central and Copperbelt provinces. Finally, goat manure also has a certain amount of potential with 18 718 tonnes of manure from commercial goat farms, which could be available for biogas production at the national level. The districts with the highest potential availability are Chibombo, Mumbwa and Kapiri Mposhi in the Central Province, which account for about a third of the entire national potential.

3.3 CROP RESIDUES

Crop residues are the organic material produced as by-products from harvesting and processing of agricultural crops. They can be categorized further as primary and secondary residues (**Figure 12**).

- Primary residues are those generated in the field at the time of harvest. They can then be collected in the field, such as cereal straw (when baled) or can be spread in the field, as is the case of sugarcane tops, cassava and maize stalks.
- Secondary residues are those that are co-produced during processing. These include rice husk, sugarcane bagasse, cashew nut shells, and other. The secondary residues are collected at a processing facility.

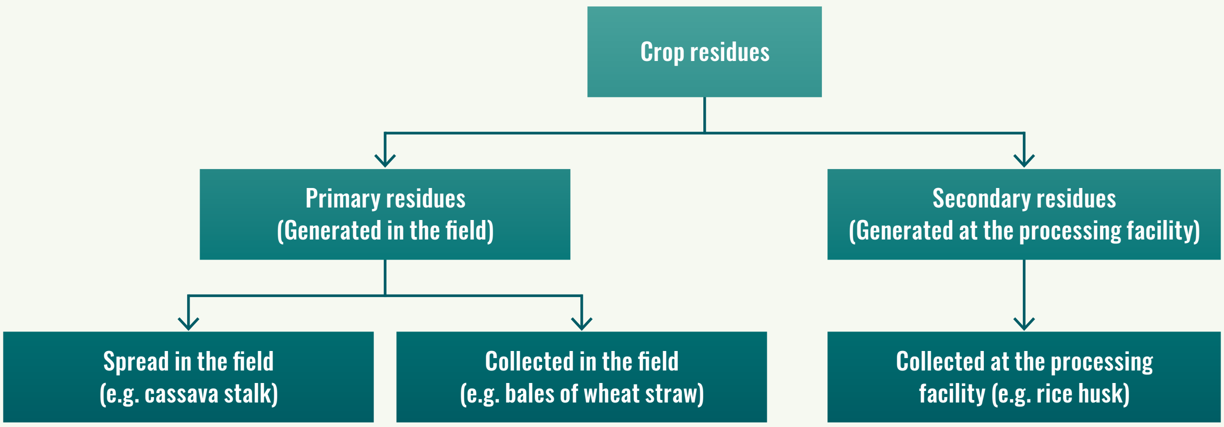
3.3.1 Scope

The aim of the crop residues assessment is to determine the quantity of primary and secondary residues, suitable for bioenergy production in view of their physical and chemical characteristics. The initial selection of crop residues was based on long-term statistics on agricultural production in Zambia. The preference is given to the most produced crops also being produced continuously. Based on these criteria, a total of 15 crops produced in the country and the respective 19 residue types were identified and selected for the BEFS assessment (**Table 12**).

The assessment was carried out at the district level, the lowest spatial level for which statistical data on crop production was available. The spatial analysis and presentation of the assessment

FIGURE 12.

TYPES OF CROP RESIDUES ACCORDING TO THE LOCATION IN WHICH THEY ARE GENERATED



Source: BEFS Crop residues user manual

TABLE 12.

MAIN CROPS PRODUCED IN ZAMBIA AND INCLUDED IN THE CROPS RESIDUE ASSESSMENT

CROP	RESIDUE TYPE	CROP	RESIDUE TYPE
CEREALS		**TUBERS & ROOTS**	
MAIZE	STOVER	SWEET POTATOES	LEAVES
	COB		PEELS
RICE	STRAW	CASSAVA	STALK
	HUSK	IRISH POTATOES	LEAVES
MILLET	STRAW/STALK		PEELS
WHEAT	STRAW		
SORGHUM	STALK	**CASH CROPS**	
BARLEY	STRAW	TOBACCO	STALK
OILSEEDS		COTTON	STALK
SOYBEANS	STRAW	**SUGAR CROPS**	
GROUNDNUTS	HUSK	SUGARCANE	BAGASSE
SUNFLOWER	STALK		

results relies on the agricultural statistics published by the CSO[2]. The CFS that have been published include long-term data on the crop production and harvested area for 74 districts (in line with the administrative division of Zambia in 2016); the results were subsequently consolidated and presented at the provincial and country level. Moreover, the assessment took into consideration the level of agricultural production, i.e. if the residues were generated by small and medium-scale farms or large-scale commercial farms.

In the case of residues generated at processing facilities (secondary residues) a field survey among the selected crop processing industries was conducted. The aim of the survey was to identify the type and the amount of residues generated, the methods of management and the amount of unused residues, i.e. disposed of, that could be used for bioenergy generation. Since the data about the residues generated is not systematically recorded, the survey resulted in limited and incoherent information for most of the surveyed facilities. Nevertheless, upon analysis of the survey results, the results for rice mills was verified and used for the assessment of rice husk availability.

Other processing facilities that were initially selected for the assessment were cassava flour mills, cotton ginneries, cashew nuts and groundnuts de-shelling plants. However, due to insufficient information about their residue generation and use, they were later excluded from the analysis. These processing facilities may be generating significant amounts of residues that could be used to produce bioenergy. Residues include shells in the case of cashew nuts and groundnuts, husks in the case of cotton and peels in the case of cassava. A census of these industries where basic information is collected about their location, yearly production volumes, as well as the volume of residues generated and their current uses, would allow for an assessment of the viability of the energy use of such residues.

3.3.2 The assessment methodology and data sources

3.3.2.1 Production of crop residues

The total production of crop residues represents the theoretical bioenergy potential, that is, it represents the amount of a type of residue produced in the fields or within the processing

[2] As of 2020 Zambian Statistical Office (https://www.zamstats.gov.zm/)

facility that potentially could be collected. This amount does not take into account whether the type of residue is collectible or how much and for what purpose it is already being utilised.

The equation for the calculation of the total production of crop residue is as follows:

$$CR_{Tot(i-j)} = C_{prod\ (i)} * RCR_{(i-j)}$$

Where:

- ▶ $CR_{Tot(i-i)}$[tonnes/year] = total amount of residues produced from crop *(i)* and type of residue *(j)* per year;
- ▶ $C_{prod\ (i)}$ [tonnes/year] = average production of crop *(i)* per year;
- ▶ $RCR_{(i-j)}$ = residue to crop ratio of the specific crop *(i)* and type of residue *(j)*.

This equation is applied separately for each type of crop and residue. Some crops produce more than one type of residue that could potentially be used for bioenergy. Each of these types of residue has a different residue-to-crop ratio for estimating the residues produced $CR_{Tot(i-j)}$.

3.3.2.2 Data sources for assessment of crop residues production

The data collected on the crop production used in the assessment ($C_{prod(i)}$) is based on the agricultural statistics data. The Zambia Statistics Agency (ZamStats)[3] conducts the CFS before the harvesting season on an annual basis. The CFS collects data from farmers on area planted to various crops, expected production, expected sales, and the quantity of fertilizer used among many other variables.

The CFS results provided data on the production of the 15 main crops produced in the country (see **Table 14**). Furthermore, other important data provided by CFS included the

TABLE 13.

RESIDUE-TO-CROP RATIO (RCR) APPLIED FOR THE ASSESSMENT

CROP	TYPE OF RESIDUE	RCR
MAIZE, POPCORN, MAIZE FOR SEED	STOVER	2.03
	COB	0.41
SORGHUM	STALK	2.44
RICE	STRAW	1.33
	HUSK	0.25
MILLET	STAW/STALK	2.54
SUNFLOWER	STALK	3.00
GROUNDNUTS	HUSK	0.50
SOYABEANS	STRAW	1.53
	PODS	1.09
COTTON	STALK	3.40
	HUSK	0.26
IRISH POTATOES	LEAVES AND PEELS	0.76
TOBACCO (VIRGINIA, BURLEY)	STALK	1.00
SWEET POTATOES	LEAVES AND PEELS	0.40
WHEAT	STRAW	1.00
BARLEY	STRAW	1.35
CASSAVA	STALK	0.40

Source: Elaboration based on BEFS Assessment Results

[3] Until 2020, officially named Central Statistical Office of Zambia (CSO).

corresponding harvest area per district and the obtained yields. The average value for seasons 2008–2019 was used as a basis for the analysis to reduce uncertainty due to annual changes in production.

The residue-to-crop ratio (RCR) is the ratio of the residue amount generated in relation to the amount of the main product of the crop. The RCR values used for the analysed crops were collected by way of a literature review and validated or corrected during technical consultation with relevant national experts in Zambia. The values are shown in **Table 13**.

3.3.2.3 Available crop residues

The $CR_{Tot(i-j)}$ quantifies the total amount of crop residues produced in a given area, however, not all residues produced are available for bioenergy production. Agricultural residues are used for various purposes including soil amendment, animal feed, animal bedding, fuel, construction materials, and other. Therefore, the availability of residues for energy application can vary significantly across provinces and even some districts depending on the existing uses. The reasons for discounting the current uses of residues is to avoid affecting other sectors where these residues could play an important role.

The residues available for bioenergy are calculated by using the following formula:

$$CR_{available\ (i-j)} = CR_{Tot(i-j)} - CR_{soil\ (i-j)} - CR_{used\ (i-j)}$$

Where,

- $CR_{available\ (i-j)}$ [tonnes/year] = crop residues available for bioenergy production from crop *(i)* and type of residue *(j)* per year;
- $CR_{Tot(i-j)}$ [tonnes/year] = total residues produced from crop *(i)* and type of residue *(j)* per year;
- $CR_{soil\ (i-j)}$ [tonnes/year] = amount of residues that should be left in the field from crop *(i)* and type of residue *(j)* per year;
- $CR_{used\ (i-j)}$ [tonnes/year] = amount of crop residues already used from crop *(i)* and type of residue *(j)* per year.

The amount of residues that should be left in the field ($CR_{soil(i-j)}$) depends on many factors such as, the soil type and structure (content of soil organic carbon, nutrients, rock weathering), level of inputs (chemical, organic fertilizers), agricultural practice (crop rotation, tillage, conservation agriculture) and the crop cultivated (nutrient uptake, content of nutrients in the residues and root system). Conservation agriculture in Zambia is being promoted and in some parts of the country practiced. The principles of conservation agriculture call for the maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. Keeping this in mind, as part of the BEFS assessment special attention was given to evaluating the amount of residues that should be left in the field after crop harvesting. In consultation with technical experts from the Ministry of Agriculture, each of the assessed crop residue types were examined and how much should be left in the field was estimated. The amount that should remain in the field depends on the harvesting practices and methods of soil preparation for the following season. Based on the above-mentioned consultations, during the BEFS assessment it was determined that at least 30 percent of the total crop residues generated during the harvest should be left in the field This was taken into consideration in the BEFS assessment. On the other hand, as it is unlikely that residues produced at processing facilities would be transported back to the fields, their use for soil fertility was not taken into consideration.

Agricultural residues are used for various purposes such as animal feed, animal bedding, fuel, construction materials, and other. The residues currently used for other purposes are not deemed potentially available for bioenergy production, in order to not affect other sectors where these residues could play an important role.

In order to determine the current uses of crop residues in Zambia a new section was included in the CFS survey for the 2018/19 growing season. This new section collected information from farmers on the types and volume of residues generated in the fields during harvesting, as well as the different uses currently given to residues. The current uses of selected crop residues being considered are as follows:

- Left in the fields/mulching (for soil regeneration),
- Animal feed and bedding,
- Fuel for cooking/heating,

- Other uses such as building material, food, planting material for next season and other,
- Burnt in the fields, disposed of or not used.

The CFS survey where the sample was representative for all districts (74 districts) was nationwide. The survey results showed that the current use of crop residues depends on local practices, availability of other resources, activities, and the socio-economic conditions of the population in the area. The survey results on the total percentage of residues left in the field as well as the percentage of residues used for other purposes were respectively applied for each district in the BEFS assessment.

3.3.3 Results

3.3.3.1 Crop residues in the fields

The results on total crop residues in the fields highlight that a total of 8.76 million tonnes are generated per year, mostly deriving from cereals (81 percent), tubers (8.3 percent) and cash crops (5.6 percent). The crop residue production data confirms that the top three crops produced in the country generate almost 88 percent of the total amount of residues produced in the fields in Zambia; these crops are maize, sugarcane and cassava. The details of the types and volume of residues generated is shown in **Table 14**.

TABLE 14.

RESIDUE PRODUCTION AND AVAILABILITY FROM MAIN CROPS PRODUCED IN ZAMBIA

CROP	TYPE OF RESIDUE	AVERAGE CROP PRODUCTION [tonnes/year]	RCR	AMOUNT OF RESIDUES PRODUCED [tonnes/year]	AMOUNT OF RESIDUES LEFT IN THE FIELD AND USED FOR OTHER USES [tonnes/year]	SHARE OF RESIDUES USED FOR SOIL FERTILITY AND OTHER USES %	AMOUNT OF RESIDUES AVAILABLE FOR BIOENERGY [tonnes/year]	SHARE OF RESIDUES AVAILABLE FOR BIOENERGY %
MAIZE, POPCORN, MAIZE FOR SEED	STOVER	2 728 868	2.03	5 536 895	2 765 182	49.9%	2 771 713	50.1%
	COB		0.41	1 107 379	554 784	50.1%	552 595	49.9%
SORGHUM	STALK	16 727	2.44	40 813	23 544	57.7%	17 270	42.3%
RICE	STRAW	44 534	1.33	59 230	24 396	41.2%	34 834	58.8%
	HUSK		0.25	11 133	1 742	15.6%	9 392	84.4%
MILLET	STALK	39 067	2.54	99 230	36 835	37.1%	62 396	62.9%
SUNFLOWER	STALK	33 508	3.00	100 524	45 185	44.9%	55 339	55.1%
GROUNDNUTS	HUSK	127 141	0.50	63 570	29 857	47.0%	33 713	53.0%
SOYA BEANS	STRAW	200 231	1.53	306 353	143 588	46.9%	162 765	53.1%
	PODS		1.09	218 251	82 076	37.6%	136 175	62.4%
COTTON	STALK	120 640	3.40	410 177	132 451	32.3%	277 726	67.7%
	HUSK		0.26	31 366	1 148	3.7%	30 218	96.3%
IRISH POTATOES	LEAVES AND PEELS	41 864	0.76	31 817	10 868	34.2%	20 949	65.8%
TOBACCO (VIRGINIA, BURLEY)	STALK	48 624	1.00	48 624	14 659	30.1%	33 964	69.9%
SWEET POTATOES	LEAVES AND PEELS	160 750	0.40	64 300	27 132	42.2%	37 168	57.8%
WHEAT	STRAW	214 461	1.00	214 461	107 367	50.1%	107 094	49.9%
BARLEY	STRAW	10 775	1.35	14 546	7 275	50.0%	7 272	50.0%
CASSAVA	STALK	1 580 794	0.40	632 318	315 712	49.9%	316 605	50.1%

Source: Elaboration based on BEFS Assessment Results

3.3.3.2 Crop residues at processing facilities

In the case of residues generated at processing facilities, results show that 11 thousand tonnes of rice husks are generated each year.

3.3.3.3 Crop residue availability

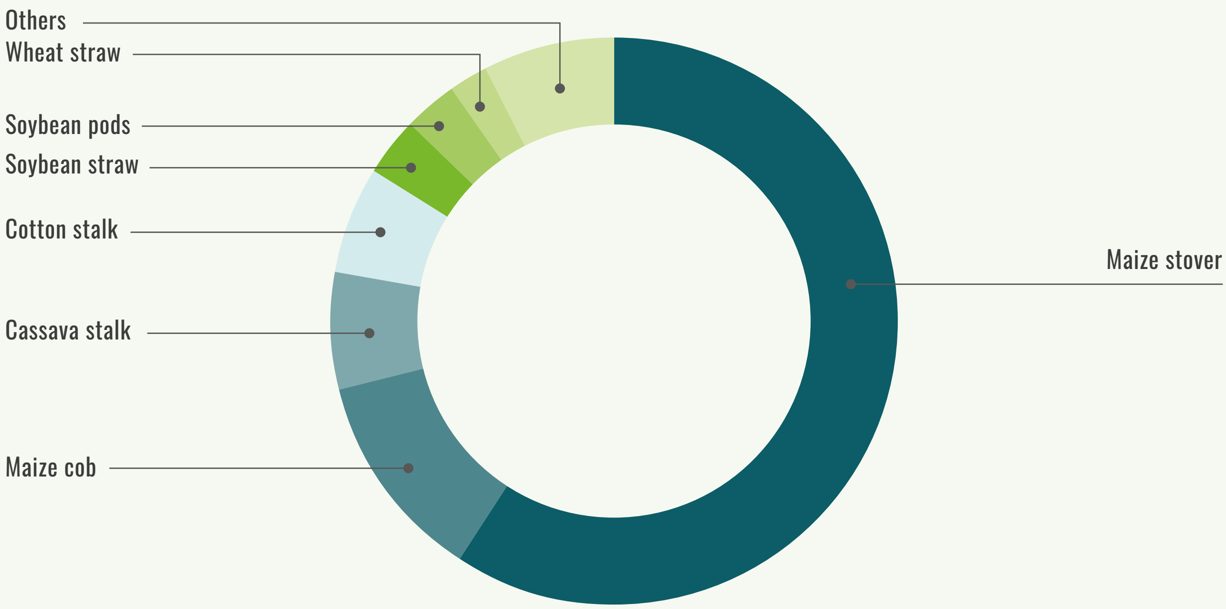
Both **Table 14** and **Figure 13** show the amount of crop residues available for bioenergy at the national level, after having discounted the amount of residues that should be left in the field and the amounts currently used. Results show that on average around 4.67 million tonnes of crop residues are potentially available for bioenergy production every year. For example, maize stover is a crop residue demonstrating the highest availability with 59.4 percent by weight of the total amount of residues available. Moreover, high-ranking types of residues such as maize cobs and cassava stalk with 11.8 percent and 6.8 percent of the total amount of residues are potentially available, respectively. Other important types of residues are cotton stalks (6 percent), soybean straw (3.5 percent), soybean pods (2.9 percent) and wheat straw (2.3 percent). The category "others" in **Table 14** and **Figure 13** includes consolidated data for the remaining 11 types of crop residues assessed and represents 7.3 percent of the total amount of residues available.

It is worth noting that residues from maize production, that is, maize stover and cobs together, represent more than 71.2 percent by weight of the total amount of crop residues available in the country. This amounts to around 3.32 million tonnes of residues per year that could be used for bioenergy production.

Figure 14 Volume of residues available for bioenergy by province shows the distribution of residues available for bioenergy by province. The results show that 0.94 and 0.93 million tonnes of crop residues are concentrated in the Eastern and Central provinces, respectively. These values represent around 40 percent of the total residues potentially available for bioenergy in the country. The Muchinga, the Southern and Northern provinces could make available between 400

FIGURE 13.

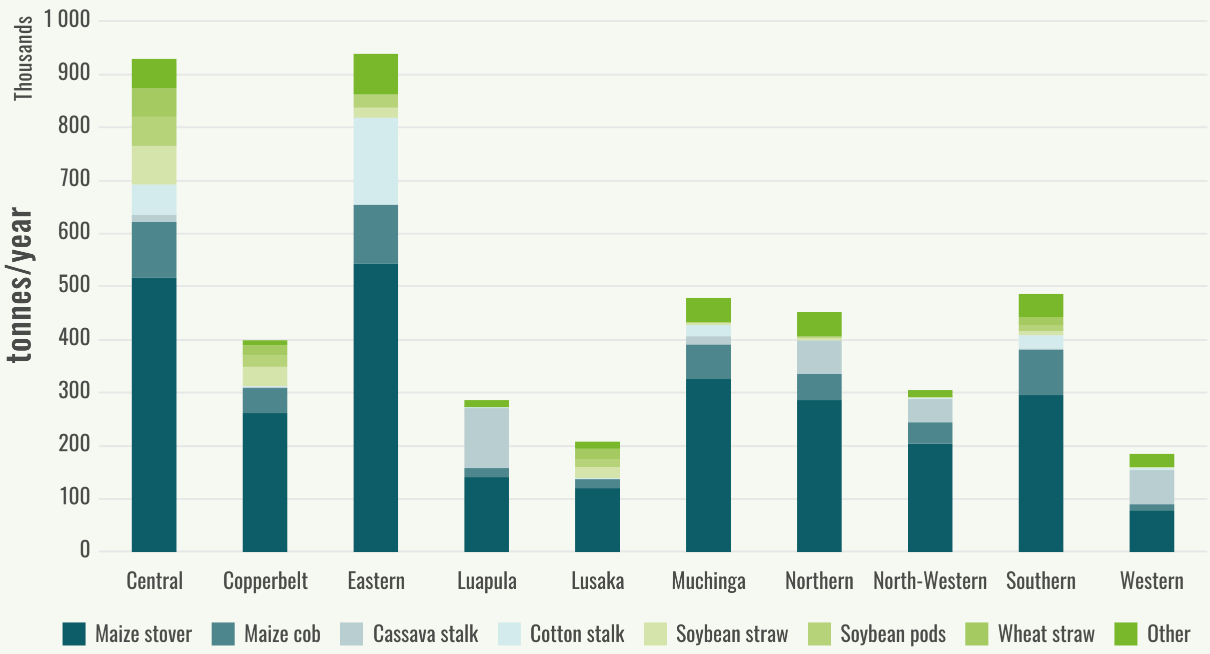
VOLUME OF RESIDUES AVAILABLE FOR BIOENERGY AT A NATIONAL LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 14.

VOLUME OF RESIDUES AVAILABLE FOR BIOENERGY BY PROVINCE



Source: Elaboration based on BEFS Assessment Results

and 500 thousand tonnes of crop residues for bioenergy production annually. Together the three provinces represent a concentration of 30.4 percent of total crop residues available for bioenergy in the country.

Finally, in the remaining regions of Copperbelt, Luapula, Lusaka, North-Western Province and Western Province, between 180 and 400 thousand tonnes of crop residues could be available, in other words, the remaining 29.6 percent of the country level potential.

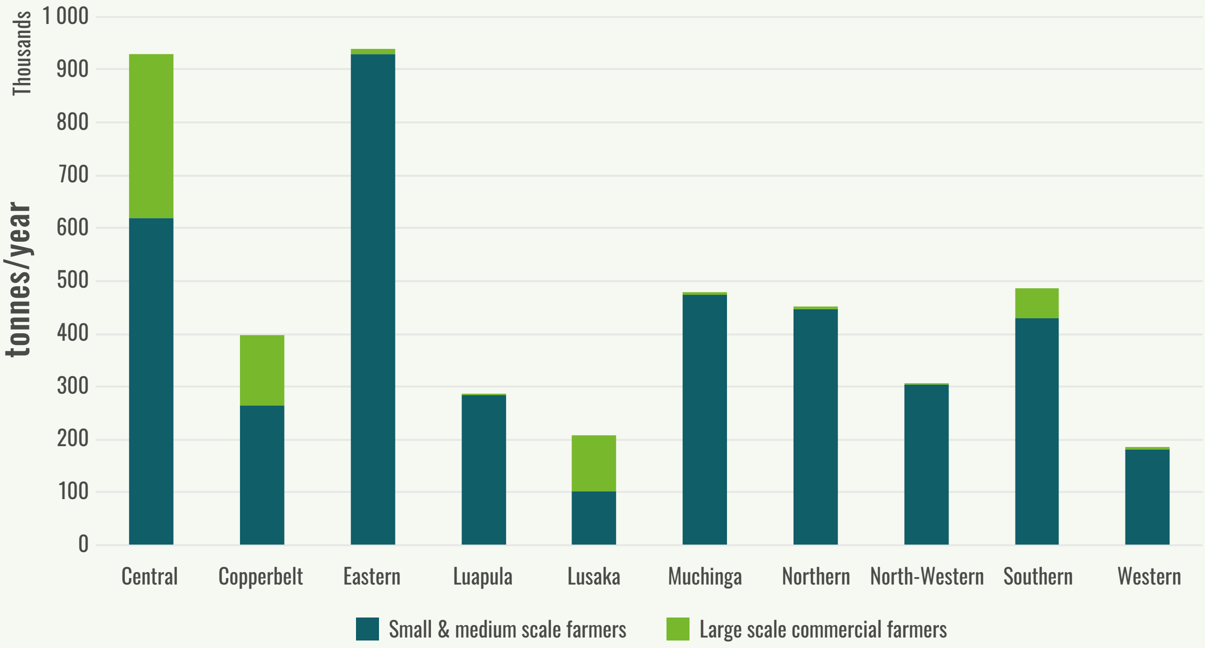
Figure 15 and **Figure 16** show the results of the availability of crop residues by province generated by small and medium-scale farms and large-scale commercial farms. It is evident that a large majority of available crop residues is generated by small and medium-scale farms and also that the production of large-scale commercial farms is mainly located in Central Province, Copperbelt, Lusaka and the Southern Province. The crops produced by commercial farms are mostly maize, wheat and soybeans.

In the case of the Central Province, each year more than 310 thousand tonnes of crop residues potentially available for bioenergy are produced by large-scale commercial farms. This represents almost 33.4 percent of the total amount of residues available in the province. In the case of the Copperbelt and Lusaka provinces, the volumes of crop residues available from large-scale commercial farms reaches up to 133 and 104 thousand tonnes per year, respectively.

Figure 17 shows the available crop residues with the indication of the share of crop residue types and residue density per province. The darker areas in the map represent higher amount of residues is available. The residue density is presented with the size of pie charts, which also show the shares of residue types. The highest residue density, between 3 and 3.5 tonnes/ha, is found in the Muchinga, Lusaka and Copperbelt provinces, while the lowest residue density is between 1 and 1.5 tonnes/ha and found in the Western Province.

FIGURE 15.

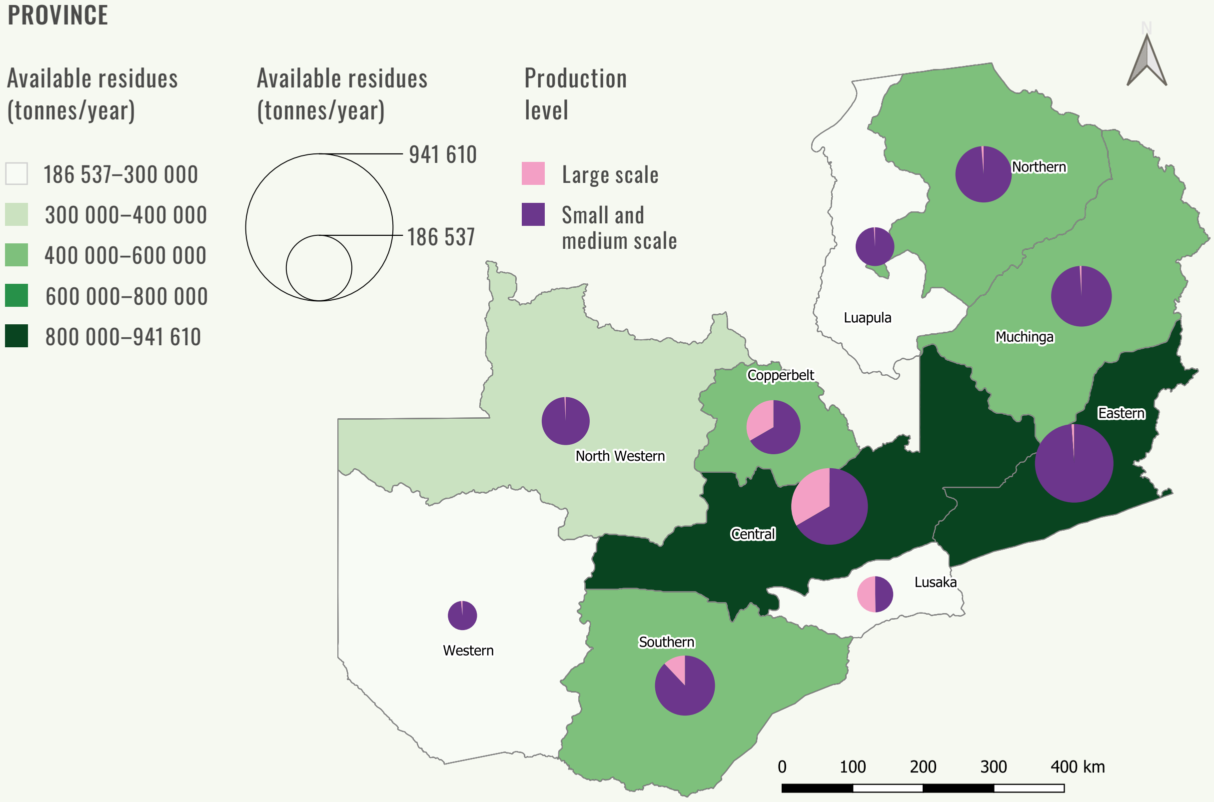
VOLUME OF RESIDUES AVAILABLE FOR BIOENERGY BY PROVINCE ACCORDING TO FARM PRODUCTION LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 16.

CROP RESIDUES AVAILABLE FOR BIOENERGY: AMOUNT OF CROP RESIDUES AND SHARE OF PRODUCTION LEVEL PER PROVINCE



Source: Elaboration based on BEFS Assessment Results

FIGURE 17.

CROP RESIDUES AVAILABLE FOR BIOENERGY: DENSITY OF CROP RESIDUES AND SHARE OF CROP RESIDUE TYPES PER PROVINCE

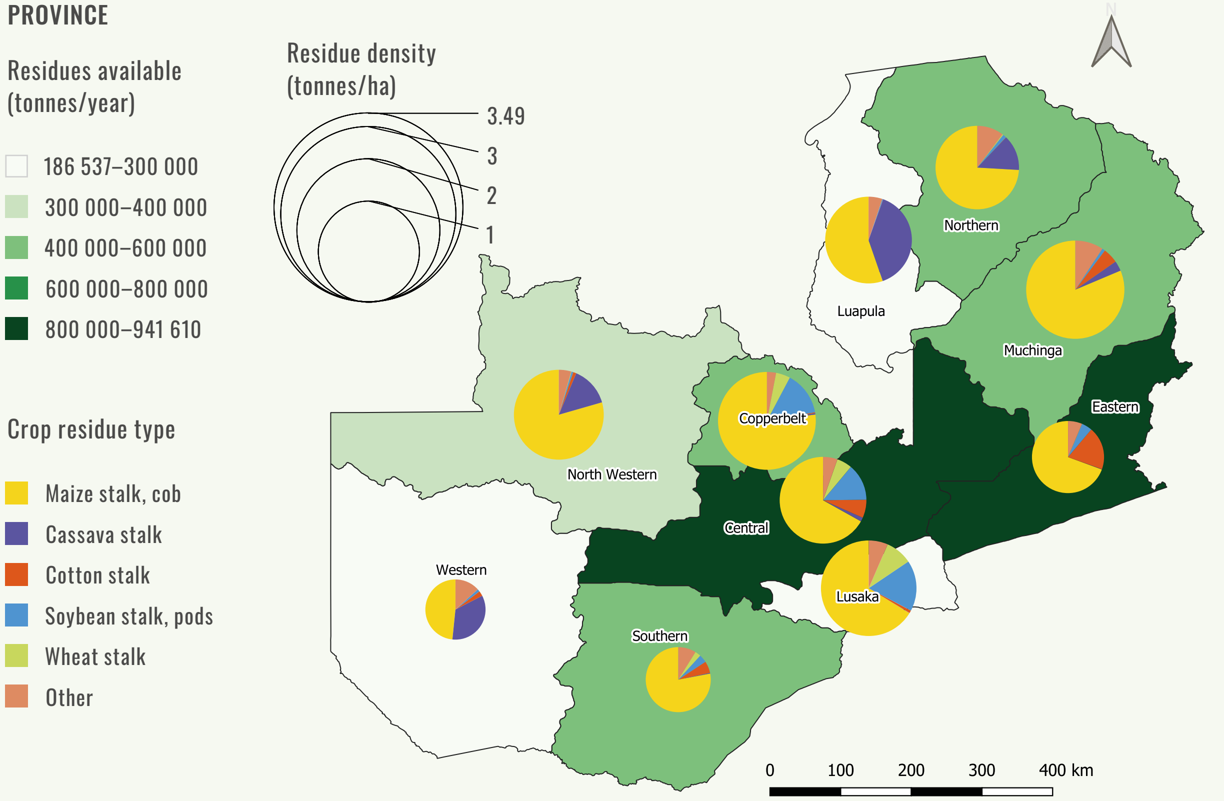
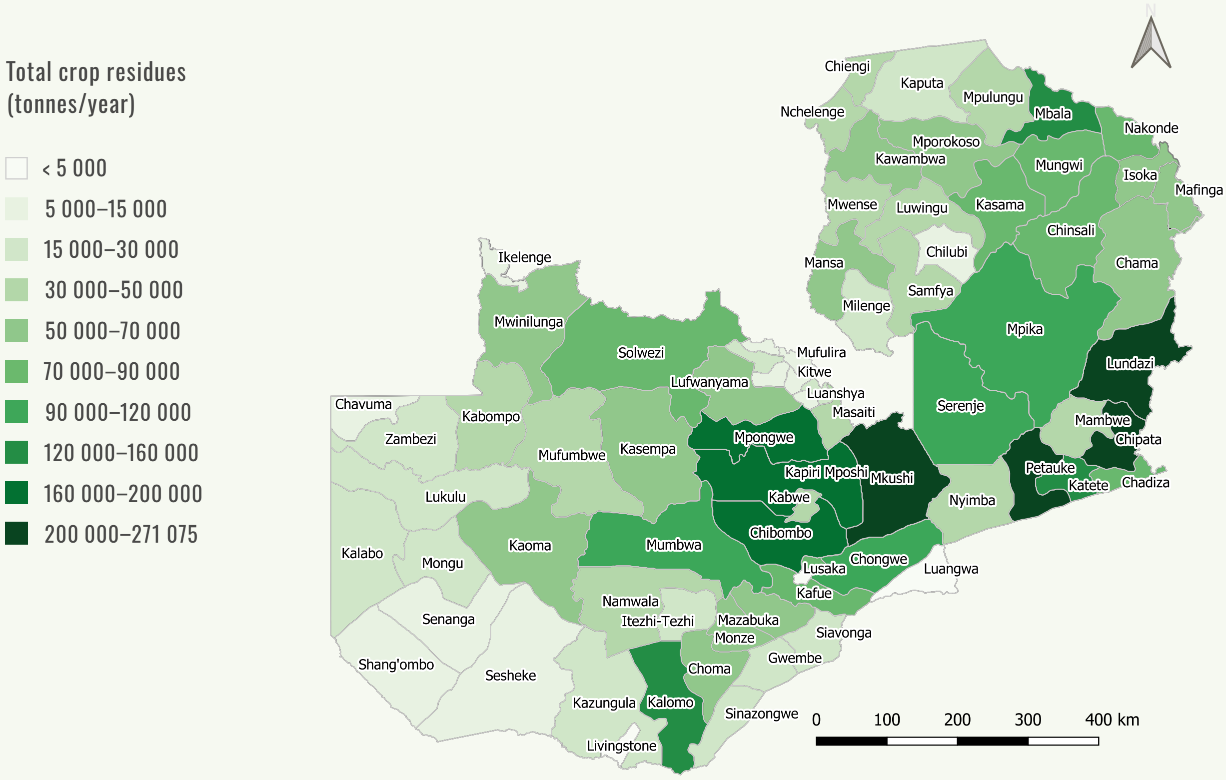


FIGURE 18.

SPATIAL DISTRIBUTION OF AVAILABLE CROP RESIDUES AT A DISTRICT LEVEL IN ZAMBIA

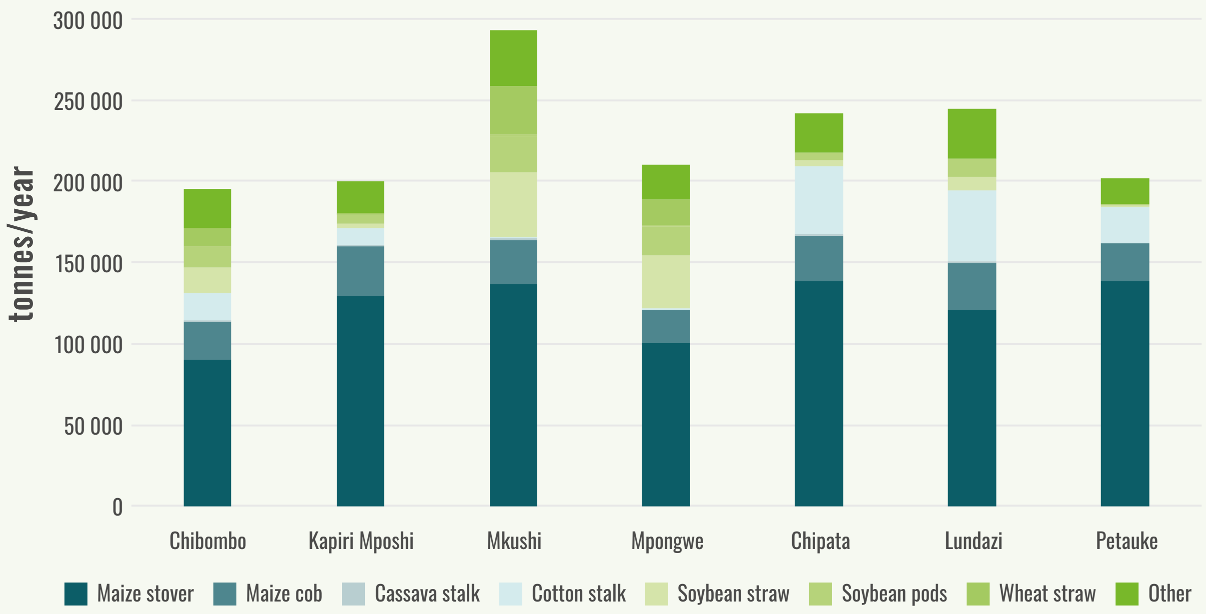


Source: Elaboration based on BEFS Assessment Results

Figure 18 and **19** show the details of the available crop residues across districts. It is clearly indicated that in all districts both maize stover and maize cobs represent the largest share of all available residues.

FIGURE 19.

DISTRICTS WITH THE HIGHEST CONCENTRATION OF CROP RESIDUES AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

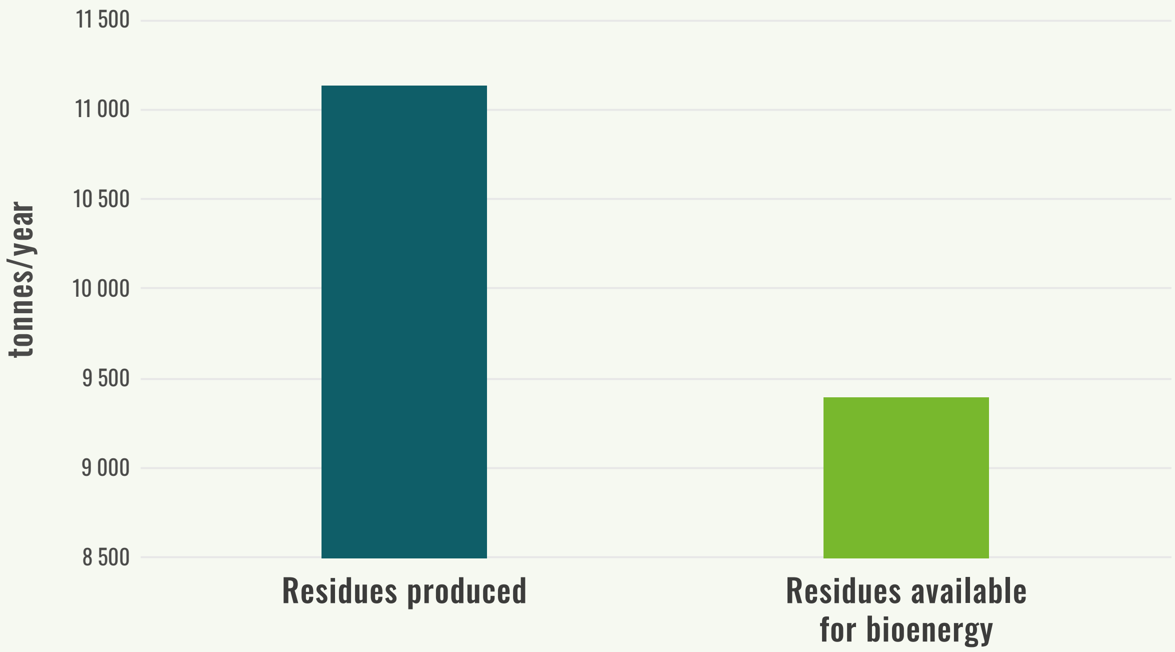
3.3.3.4 Availability of residues produced at processing facilities

Figure 20 shows the available rice husk generated at processing facilities. It is evident that more than 11 thousand tonnes of rice husks are generated each year and out of these 9.4 thousand tonnes are available each year for bioenergy.

Figure 21 shows that rice husk available at processing plants are concentrated mostly in the Western, Northern and Muchinga provinces. Between 2.3 and 2.7 thousand tonnes are available per year in each of these provinces.

FIGURE 20.

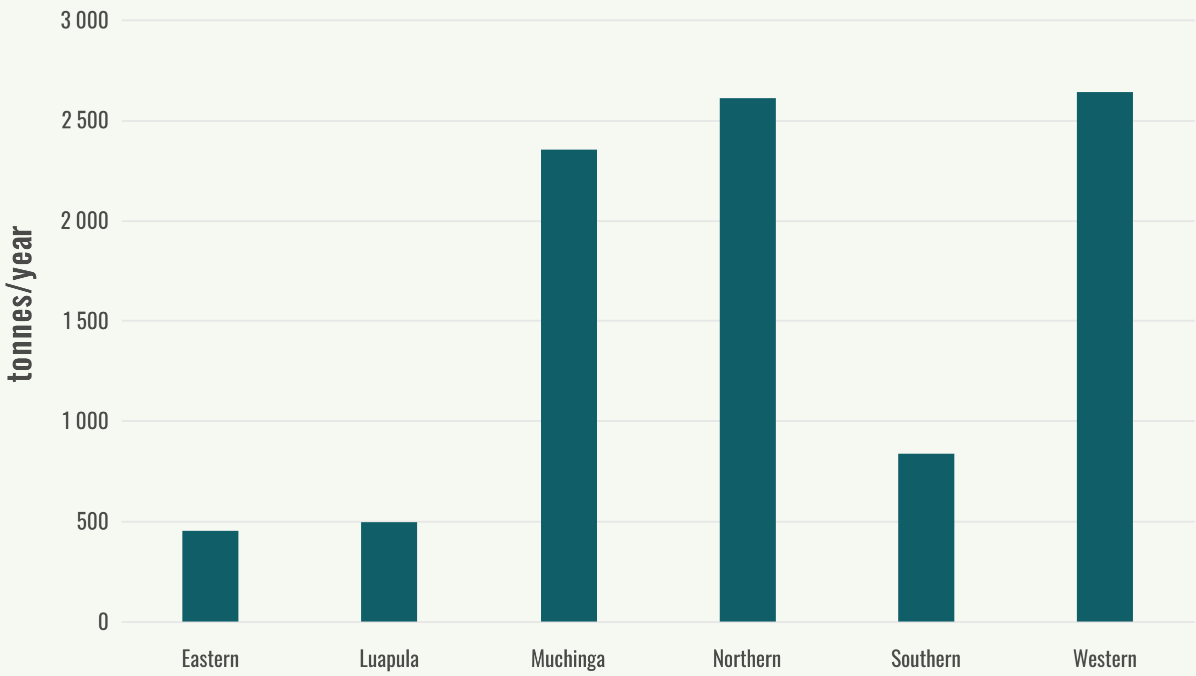
RICE HUSK PRODUCED AND AVAILABLE FOR BIOENERGY AT PROCESSING PLANTS



Source: Elaboration based on BEFS Assessment Results

FIGURE 21.

RICE HUSK AVAILABLE FOR BIOENERGY AT A PROVINCE LEVEL



Source: Elaboration based on BEFS Assessment Results

3.3.4 Summary of results

The results on total crop residues in the fields highlight that a total of 8.76 million tonnes are generated per year. Most of the residues derive from cereals (81 percent), tubers (8.3 percent), and cash crops (5.6 percent). Maize stover, maize cobs (jointly 71.2 percent) and cassava stalk are the residue types with the highest potential, although these crops are predominantly produced on a small and medium scale. Some of the other important types of residues also generated by large-scale farmers are cotton stalks, soybean straw, soybean pods and wheat straw.

The seven districts showing the greatest potential for crop residue availability are: Mkushi, Kapiri-Mposhi and Chibombo in the Central Province, Chipata, Lundazi and Petauke in the Eastern Province, and Mpongwe in the Copperbelt Province. Each of these districts has more than 160 thousand tonnes of crop residues potentially available for bioenergy per year. In the districts in the Eastern Provinces the available residues are produced almost exclusively by small-scale farmers, while in the Central and Copperbelt provinces residues are produced by both large commercial and small-scale farmers, in different shares according to district.

The production of large-scale commercial farms is mainly located in the Central, Copperbelt, Lusaka and Southern provinces. In the case of the Central Province, each year more than 310 thousand tonnes of crop residues potentially available for bioenergy are produced by large-scale commercial farms. This represents almost 33.4 percent of the total amount of residues available in the province. In the case of the Copperbelt and Lusaka provinces, the volumes of crop residues available from large-scale commercial farms reaches 133 and 104 thousand tonnes per year, respectively.

The highest residue density, between 3 and 3.5 tonnes/ha of cultivated land, is located in the Muchinga, Lusaka and Copperbelt provinces, while the lowest is found in the Western Province and is between 1 and 1.5 tonnes/ha.

In the case of residues generated at processing facilities, results show that 11 thousand tonnes of rice husks are generated each year.

3.4 CROPS

The Zambian policy has set a 2030 blending target for ethanol and biodiesel. In order to achieve this target, ethanol would be blended with gasoline at 5 percent and biodiesel with diesel at 10 percent. An assessment was made of the potential for domestic production of liquid biofuels, keeping in line with Zambia's policy on liquid biofuels for transport. Furthermore, the crops assessment has estimated the potential for sustainable intensification and additional production of crops that could be used as bioenergy feedstock for ethanol and biodiesel. Ethanol can be produced from sugar and starch crops such as sugarcane, maize and cassava, while biodiesel is produced from oilseed crops such as sunflower and soybean.

3.4.1 Scope

3.4.1.1 Intensification and potential additional production

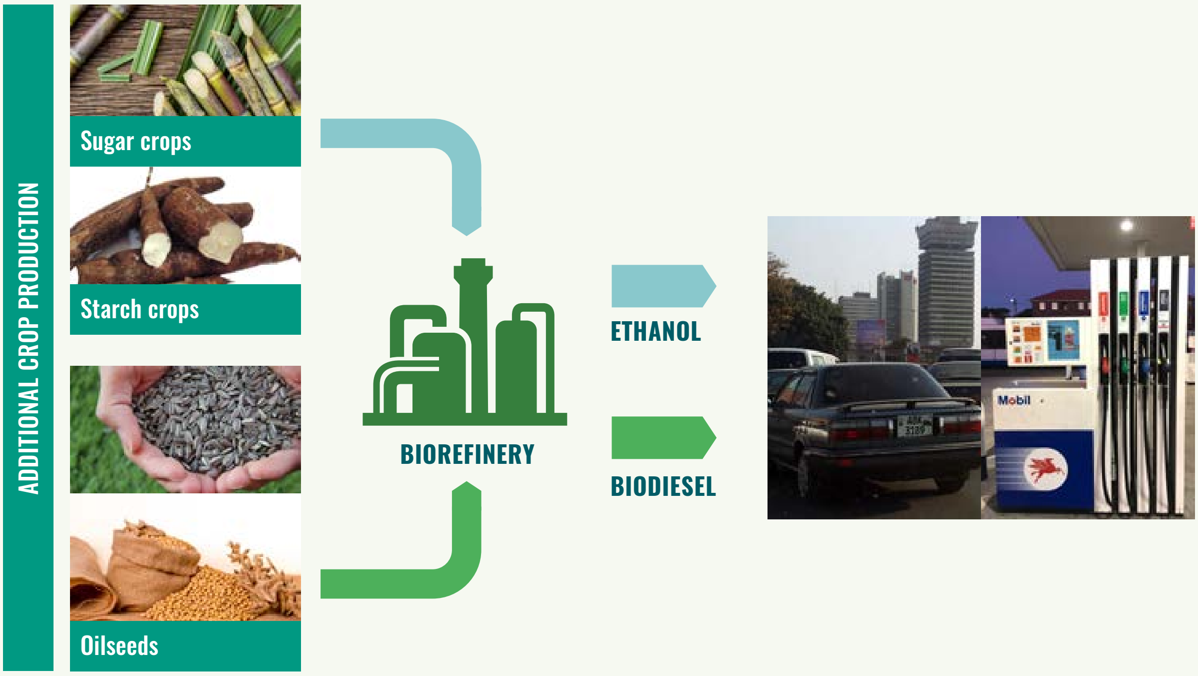
Considering the current production volumes, key staple crops and the potential for sustainable intensification, four main crops were identified as suitable for the production of liquid biofuels in Zambia: sugarcane and cassava for ethanol and sunflower and soybeans for biodiesel production.

In the case of sunflower, soybeans and cassava, the assessment made an estimate of the potential additional production level of small and medium-scale farms and large-scale commercial farms. The assessment was carried out at the district level and the results were subsequently consolidated and presented at the provincial and country level.

In the case of sugarcane, the assessment focused on the three sugar mills that process almost all of the country's sugarcane production. These sugar mills source their sugarcane from their own plantations and from out-grower schemes that include large-scale commercial farms and cooperatives of small producers. The assessment estimated the potential additional production that these providers could make available.

FIGURE 22.

LIQUID BIOFUELS SUPPLY CHAIN



Source: Elaboration based on BEFS Assessment Results

The basic reasons for selecting sugarcane, cassava, sunflower and soybean as potential feedstock for liquid biofuels production are described below:

SUGARCANE

Sugarcane is currently the crop with the highest production volume in Zambia with an average annual production of 3 million tonnes. However, in terms of area coverage, the amount of hectares devoted to sugarcane is relatively small compared to other crops with similar production volumes. Sugar cane yields are amongst the highest in the world and Zambia's sugar is traded internationally.

Ethanol can be produced from the sugarcane juice, as well as from molasses, a by-product of sugar production. In terms of current use of the molasses, this was discussed with Zambia Sugar Plc., Zambia's largest sugar producer. It appears that currently, on average, 36 percent of the molasses are sold at the local market and just over 43 percent is exported to neighbouring countries. The remaining share is either used to coat dusty roads or is disposed of.

CASSAVA

Cassava is the second most important staple crop in Zambia after maize, and the third most produced crop with around 1.6 million tonnes generated every year. Cassava is considered to be a food security crop given that it can be cultivated with low inputs and remain underground for long periods of time, to be harvested when needed by the household.

Cassava shows high variability in the yields across the country. This is partly due to the fact that in many regions, cassava is harvested irregularly and uniquely to ensure food for households during the dry season or during droughts. Considering the aforementioned factors and other patterns in cassava production and consumption, ZamStats and the Ministry of Agriculture have estimated an average yield of 11.7 tonnes/ha across the country. This indicates a great potential for improvement since yields of up to 20 tonnes/ha have been obtained for traditional cassava varieties, in addition to up to 40 tonnes/ha for improved varieties (Barrat, 2006).

Another important factor in cassava production is that it is carried out almost exclusively by small-scale farmers. The possible inclusion of smallholders as a source of cassava feedstock for ethanol production could represent a secure and steady income for smallholders. This could be accomplished by way of out-grower schemes and improved varieties and cultivation practices that could be promoted among smallholders, which would consequently, improve yield production.

Indeed, cassava could be used as an ethanol feedstock. Due to its importance as a staple crop as well as for the population's food security, special attention should be placed on the exclusive use of the additional production of cassava after fulfilling existing or foreseen needs for food, feed and other non-bioenergy uses.

SOYBEANS

Soybean production in Zambia is predominantly found in large-scale commercial farms, whereby small and medium-scale farms produce only about 20 percent of the total national production. During the last decade, average yields obtained at the country level reached 1.69 tonnes/ha. Furthermore, the yields among large-scale farmers ranged between 1.6 and 2.6 tonnes/ha in different provinces, whereas in most provinces the average yields among smallholders were below 1 tonne/ha.

Indeed, soybean production has demonstrated a steady trend in growth during the last ten years and according to government development plans, its production is expected to increase. This growth accompanied by improvement in the yields has strong potential for further production of this crop. Moreover, the beneficial agro-ecological conditions for soybeans in Zambia provide a great opportunity for the improvement of yields to increase production. The GAEZ (FAO and IIASA, 2012) stated that under a high-level input production, yields of up to 4 tonnes/ha are feasible in the central and eastern part of the country, and up to 3 tonnes/ha in the other regions.

SUNFLOWER

Sunflower production is carried out almost exclusively by small and medium-scale producers. The production yield is relatively low, reaching a country average of 0.53 tonnes/ha in recent years. The yields among the large-scale farmers are between 1 and 1.5 tonnes/ha, however since their production contributes only 8 percent to the total national production, the country average yields are rather low. According to the Global Agroecological Zones (GAEZ) (FAO and IIASA, 2012), the potential yields of 2.3 tonnes/ha could be attained for rainfed production across the country at intermediate input levels. Therefore, through increased inputs and improved practices sunflower production could be intensified, while as in the case of other crops, the establishment of out-grower schemes and provision of extension services could support such an intensification.

3.4.1.2 Gross margin analysis of current and intensified production

The gross margin (GM) analysis is one of the tools to assess the relative performance of different improvement options. It helps farmers to understand whether a potential improvement is worth implementing, or whether one option is better than another option. In this context the comparison can provide, on the one hand, an indication of whether a farmer would see intensification as an opportunity for increasing their incomes; on the other hand, it could indicate how much the intensification would cost.

The characteristics of the BEFS GM analysis are:

- a GM analysis was conducted for three types of farms typical for Zambia (small-scale, medium-scale and large-scale), and potential for intensified large-scale production;
- a GM analysis was conducted for each analysed crop (cassava, sugarcane, sunflower and soybean) on a per hectare basis. This means that the calculation of the GM is based on the average amount of inputs used per hectare, and the corresponding yields for each of the analysed production systems in Zambia (small, medium and large-scale).

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The assumptions of BEFS GM analysis are:

- that increase in yields can be achieved by an increased use of inputs (fertilisers and agrochemicals, manual and mechanised labour, and water in case there is an irrigation system in place), while disregarding the implications related to the fixed costs of production;
- that the small and medium-scale farmers would intensify their yields to the level, currently achieved by large-scale producers in their province, while the large-scale producers would further increase their yields to the levels that are attainable according to the Global Agro-ecological zoning (GAEZ).

With a reference to the GAEZ characterisation of low, intermediate and high input level production systems, Zambian farms were defined as follows:

- current small-scale farms in Zambia → low input level production according to GAEZ;
- current medium-scale farms in Zambia → low to medium input level production according to GAEZ;
- current large-scale farms in Zambia → medium input level production according to GAEZ;
- intensified large-scale farms → medium input level production according to GAEZ.

3.4.2 Methodology and data sources

3.4.2.1 Intensification and potential additional production

The crops assessment examines the comparison of current and potential intensified yields to determine the additional crop production that can be achieved without increasing the current production area. By comparing the total production under intensified yields and the production under current yields, the additional production of the analysed crop is determined and the amount of analysed crop that can be used as bioenergy feedstock estimated.

The calculation for the additional crop production follows the equation below:

$$AP_i = IP_i - ND_i$$

Where:

- AP_i [tonnes/year] = total amount of additional production of crop ***i*** that can be produced after intensifying yields and discounting all non-bioenergy uses for the crop;
- IP_i [tonnes/year] = intensified production of crop ***i*** that can be produced on the current production area after intensifying yields;
- ND_i [tonnes/year] = estimated non-bioenergy demand for crop ***i*** within the period of the assessment for non-bioenergy uses including food, feed and other uses.

If significant changes in demand are not foreseen then the current production can be used (current yield), and an estimate of the crops potentially available for liquid biofuels production, calculated using the following formula:

$$AP_i = I_{yi} \times A_i - C_{yi} \times A_i$$

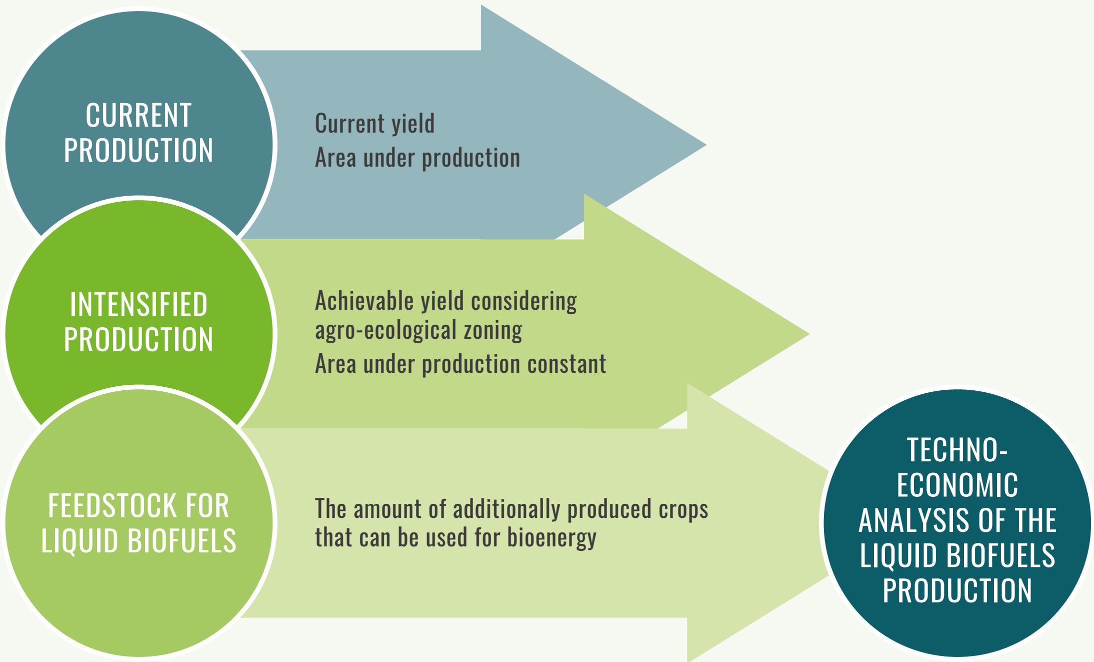
Where:

- I_{yi} [tonnes/ha] = Intensified yield of crop ***i***
- A_i [ha] = Current production area of crop ***i***
- C_{yi} [tonnes/ha] = Current yield of crop ***i***

The methodology applied for crops analysis in Zambia is presented in **Figure 23**.

FIGURE 23.

METHODOLOGY TO DETERMINE THE ADDITIONAL CROP PRODUCTION AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

3.4.2.2 Estimating the attainable intensified yields

The factors that affect crop yields include, on the one hand, prevailing climatic and agro-ecological conditions (soil characteristics and landform, water sources, surrounding vegetation) in the observed area, and on the other hand, agricultural practices and the level of inputs (fertilizer, agrochemicals, water/irrigation) used in the crop cultivation. The optimal conditions and consequently the maximal potential yields, may also vary between different varieties of the analysed crop. Based on these factors the Agro-Ecological Zoning Methodology (FAO, 1996) is used for mapping of land suitability and estimating attainable yields for crops under different production levels.

The Global Agro-Ecological Zones – GAEZ ver. 3.0 (FAO and IIASA, 2012) is a global spatial database with a raster resolution of 5 minutes (10x10 km). The database includes land suitability maps for more than 200 crops (including sugarcane, cassava, sunflower and soybean) and the estimation of maximum attainable yields. This information is presented for three different levels of production: low, intermediate and high, and for two water source conditions – rainfed and irrigated production. The three levels of production are defined as:

- low level – subsistence farming, with no or very limited use of fertilisers and other agrochemicals and the production activities are performed predominantly through manual labour and animal traction;
- intermediate level – partly market-oriented farming (farmers sell part of their production, while the other part is used by the farmer), some organic and chemical fertilisers and other agrochemicals are used, and the production is semi-mechanised;
- high level – production is fully market-oriented, the use of organic and chemical fertilisers and other agrochemicals is optimal, and the production is fully mechanised.

3.4.2.3 Assessment of intensified production of sugarcane, cassava, soybean and sunflower in Zambia

The increase in yields can be achieved through an increase in the use of inputs such as fertilizers and agrochemicals (e.g. herbicides, pesticides), water (irrigation) and/or by improving agricultural practices (e.g. optimal timing, selection and amounts of inputs applicated, use of improved varieties, organisation of work, machinery).

The assessment of the potential intensification of sugarcane, cassava, soybean and sunflower in Zambia relies on the information about the current crop production, published by the ZamStats, and the GAEZ data on attainable yields on three production levels in Zambia. The analysis showed that:

1. SUGARCANE

- The yields achieved by large-scale farmers are at very high levels, equivalent to the maximal attainable yields considering the agro-ecological conditions in the production area.
- Small and medium-scale farmers (those included in the out-grower schemes) could increase their yields through intensification, and thus come closer to the yields achieved by large scale farmers (**Table 17**).

2. CASSAVA

- The average yields of 11.7 tonnes/ha on the national level are considerably lower that the attainable yields at intermediate input level production. The existing yields achieved by commercial producers show that even at intermediate input level the yields of 30-35 tonnes/ha can be achieved.
- Small and medium-scale farmers could increase their yields through intensification and come closer to those of commercial farmers and thus the national average yields could increase (**Table 17**).

3. SUNFLOWER

- The yields achieved by large-scale farmers are equivalent to the attainable yields on moderately suitable land, at low input level production under rainfed conditions. In the case of small and medium-scale farmers, their yields are even lower than the attainable yields on average soils at a low input level production under rainfed conditions (**Table 15**).
- By stepping up to the intermediate input level farming through intensification, large-scale farmers could increase their yields up to the attainable yields on suitable land under rainfed condition, or even slightly higher when irrigation is in place (**Table 17**).
- Small and medium-scale farmers could increase their yields through intensification to the current yield level of large-scale farmers in their province (**Table 17**).

TABLE 15.

POTENTIALLY ATTAINABLE YIELDS FOR SUNFLOWER IN ZAMBIA CONSIDERING SOIL SUITABILITY, WATER SUPPLY AND INPUT LEVEL

POTENTIAL YIELDS BASED ON GLOBAL AGRO-ECOLOGICAL ZONING					
CROP		**SUNFLOWER**	**SUNFLOWER**	**SUNFLOWER**	**SUNFLOWER**
WATER SUPPLY		**RAINFED**	**RAINFED**	**IRRIGATION**	**IRRIGATION**
INPUT LEVEL		**INTERMEDIATE**	**LOW**	**INTERMEDIATE**	**HIGH**
SOIL SUITABILITY CLASS:					
COUNTRY AVERAGE	tonnes/ha	1.62	0.85	2.64	4.07
SUITABLE/VERY SUITABLE	tonnes/ha	2.30	1.34	2.79	4.07
MODERATELY SUITABLE	tonnes/ha	1.55	0.85	1.88	

Source: BEFS Crops tool / GAEZ

TABLE 16.

POTENTIALLY ATTAINABLE YIELDS FOR SOYBEAN IN ZAMBIA CONSIDERING SOIL SUITABILITY, WATER SUPPLY AND INPUT LEVEL FOR

POTENTIAL YIELDS BASED ON GLOBAL AGRO-ECOLOGICAL ZONING					
CROP		SOYBEAN	SOYBEAN	SOYBEAN	SOYBEAN
WATER SUPPLY		RAINFED	RAINFED	IRRIGATION	IRRIGATION
INPUT LEVEL		INTERMEDIATE	LOW	INTERMEDIATE	HIGH
SOIL SUITABILITY CLASS:					
COUNTRY AVERAGE	tonnes/ha	1.85	0.73	3.07	5.07
SUITABLE/VERY SUITABLE	tonnes/ha	2.88	1.22	3.28	5.07
MODERATELY SUITABLE	tonnes/ha	1.70	0.69	2.01	

Source: BEFS Crops tool / GAEZ

4. SOYBEAN

- The yields achieved by large-scale farmers are between the attainable yields on moderately suitable land and suitable/very suitable land for soybean, at an intermediate input level production under rainfed conditions. The yield achieved by small and medium-scale farmers is equivalent to the attainable yields on country average soils, at low input level production under rainfed conditions (**Table 16**).
- Under irrigation conditions and somewhat increased inputs, the large-scale farmers could achieve yields that are attainable on average soil suitability (across the country), or even higher in the areas with suitable and very suitable soils (**Table 17**).
- Small and medium-scale farmers could increase their yields through intensification to the current yield level of large-scale farmers in their province (**Table 17**).

The summary of the current yields and estimated intensified yields for large-scale farmers, and small and medium- scale farmers is provided in **Table 17**.

TABLE 17.

POTENTIAL ATTAINABLE YIELDS FOR SELECTED CROPS ACCORDING TO GAEZ METHODOLOGY

		CURRENT YIELD tonnes/ha	INTENSIFIED YIELD tonnes/ha
SUGARCANE	COMMERCIAL OUTGROWERS	89–143.77	137
	SMALL SCALE OUTGROWERS	94–105	120
CASSAVA	SMALL & MEDIUM SCALE FARMS	11.7	20
	LARGE SCALE FARMS	11.7	20
SUNFLOWER	SMALL & MEDIUM SCALE FARMS	0.50	1.40
	LARGE SCALE FARMS	1.40	2.3–2.8
SOYBEANS	SMALL & MEDIUM SCALE FARMS	0.80	2.17
	LARGE SCALE FARMS	2.17	3–4

Source: Elaboration based on BEFS Assessment Results

The following two tables include provincial level data on the current yields and the estimated intensified yields for small and medium-scale, and large-scale producers. In the case of small and medium-scale farmers, only the districts where the average production area per household was higher than 0.4 hectares have been included. It should also be noted that an analysis on the current and potential intensified production was conducted at the district level, therefore the provincial level data presented in Table 18 are aggregates of the respective districts. However, the intensified yields were estimated for each province and then applied for the respective districts.

TABLE 18.

SOYBEAN: AVERAGE ANNUAL PRODUCTION AREA AND YIELDS FOR THE PERIOD 2009–2018 AND POTENTIALLY ATTAINABLE YIELDS THROUGH INTENSIFICATION

PROVINCE	SMALL AND MEDIUM SCALE FARMERS				LARGE SCALE FARMERS		
	NUMBER OF HH PRODUCING ON MORE THAN 0.4 ha	PRODUCTION AREA (ha)	YIELD (tonnes/ha)	INTENSIFIED YIELD (tonnes/ha)	PRODUCTION AREA (ha)	YIELD (tonnes/ha)	INTENSIFIED YIELD (tonnes/ha)
CENTRAL	25 451	18 885	0.79	2.57	25 714	2.57	4
COPPERBELT	1 942	1 352	0.85	2.52	12 383	2.52	4
EASTERN	48 715	26 032	0.57	2.72	330	2.72	4
LUAPULA	0				12	2.82	4
LUSAKA	1 030	587	1.32	2.55	11 153	2.55	4
MUCHINGA	0				31	2.12	4
NORTHERN	0				327	1.56	3
NORTH-WESTERN	0				64	1.61	3
SOUTHERN	2 788	1 553	1.06	1.55	7 997	1.55	3
WESTERN	6 116	3 300	0.23	1.64	48	1.64	3
TOTAL/AVERAGE	**25 451**	**51 708**	**0.8**	**2.26**	**58 058**	**2.17**	**3.60**

Source: Elaboration based on BEFS Assessment Results

TABLE 19.

SUNFLOWER: AVERAGE ANNUAL PRODUCTION AREA AND YIELDS FOR THE PERIOD 2009–2018 AND POTENTIALLY ATTAINABLE YIELDS THROUGH INTENSIFICATION

PROVINCE	SMALL AND MEDIUM SCALE FARMERS				LARGE SCALE FARMERS		
	NUMBER OF HOUSEHOLDS PRODUCING ON MORE THAN 0.4 ha	PRODUCTION AREA (ha)	YIELD (tonnes/ha)	INTENSIFIED YIELD (tonnes/ha)	PRODUCTION AREA (ha)	YIELD (tonnes/ha)	INTENSIFIED YIELD (tonnes/ha)
CENTRAL	5 165	3 079	0.57	1.48	508	1.48	2.80
COPPERBELT	119	63	0.75	1.17	34	1.17	2.30
EASTERN	68 750	32 068	0.5	0.91	141	0.91	2.30
LUAPULA	0	0		1.02	3	1.02	2.30
LUSAKA	240	117	0.45	1.69	203	1.69	2.80
MUCHINGA	0	0		0.98	16	0.98	2.30
NORTHERN	0	0		3.69	155	3.69	2.30
NORTH-WESTERN	0	0		1.48	15	1.48	2.30
SOUTHERN	17 979	8 179	0.49	1.16	271	1.16	2.30
WESTERN	3 218	1 899	0.25	0.46	3	0.46	2.30
TOTAL/AVERAGE	**95 471**	**45 405**	**0.5**	**1.13**	**1 349**	**1.4**	**2.40**

Source: Elaboration based on BEFS Assessment Results

3.4.2.4 Gross margin analysis of the current and intensified production

GROSS MARGIN ANALYSIS OF THE CURRENT AND INTENSIFIED PRODUCTION

Gross margin per hectare represents the income derived from selling the produce less the variable costs incurred during production of the respective produce:

$$GM\ [USD/ha] = R_i - VC_i$$

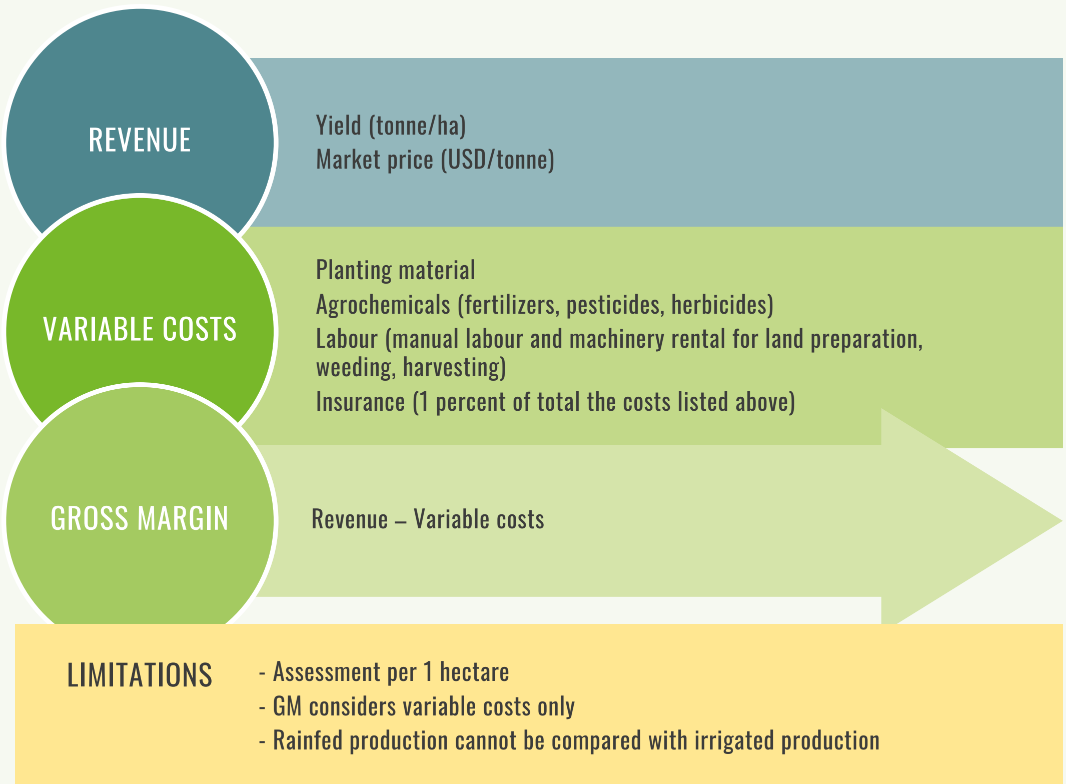
Where:

- R_i [USD] = revenue from sale of crop ***i*** calculated as
- PR_i [tonnes] = production of crop ***i*** on one hectare of land;
- P_i [USD/tonne] = market price of crop ***i*** as quoted in 2018;
- VC_i [USD] = variable costs of crop ***i*** production, which include input costs (fertilisers, agrochemicals, seed), labour costs (renting of machinery, manual labour), insurance (1 percent of total revenue) and post harvesting costs (packaging, transport). The costs of machinery renting include the machine, fuel and operator of the machine. All prices for the inputs are adjusted for inflation and presented at 2018 level.

The approach applied for the gross margin analysis of current and intensified production of sugarcane, cassava, soybean and sunflower is described in **Figure 24**.

FIGURE 24.

STRUCTURE OF THE GROSS MARGIN ANALYSIS



Source: Elaboration based on BEFS Assessment Results

The limitations of the BEFS GM analysis include:

- the assessment on a per hectare level means that the results do not fully reflect the reality of a farm budget (which would take into consideration the specifics of a particular farm);
- the GM does not consider the costs related to the improvement of farmers' knowledge of how to apply improved agricultural practices;
- GM considers only variable costs related to agro-technical inputs of production;
- due to the former limitation, the GMs of rainfed production and irrigated production are not comparable i.e. this analysis does not reflect the costs of intensification which includes a shift from rainfed to irrigated agriculture production systems (since such a shift would require additional investment and thus an increase in fixed costs of production).

The gross margins per hectare were calculated for sales at farm-gate. The structure of the GM, data on the amount of inputs used were obtained from the gross margins developed by the Zambian Ministry of Agriculture in 2016. The 2018 prices were obtained from the crop-market databases, and/or provided by the Ministry. Furthermore, scientific literature and BEFS Crop budget tool were consulted for agro-technical coefficients.

3.4.3 Results

3.4.3.1 Intensification and potential additional production

SUGARCANE

The analysis for sugarcane included the intensification of the production from large commercial out-grower farms and smallholder out-grower cooperatives that supply the sugar mills. Results show that as a result of intensification an additional production of 1.13 thousand tonnes of sugarcane on the national level could be achieved each year. The additional production is small compared to the total current production, since the current yields achieved by large scale farmers are already very high, while the share of sugarcane supplied by small-scale farmers who have higher potential for intensification is relatively low.

It is evident that 34 percent of the total achievable additional production is produced by smallholder out-growers while the remaining 76 percent is produced by large commercial out-grower farms as seen in **Table 20**.

CASSAVA

The results for cassava show that as a result of intensification an additional production of 1.12 million tonnes of cassava on the national level could be achieved each year. Most of this additional production would be concentrated in the Luapula, Northern, Western and North-Western provinces. These four provinces represent more than 87 percent of the total achievable additional production. The potential additional production per province is shown in **Table 21**. In all of the aforementioned provinces the entire volume of cassava is produced by small and medium-scale farms, see **Figure 25**.

TABLE 20.

POTENTIAL ADDITIONAL PRODUCTION OF SUGARCANE AFTER INTENSIFICATION

OUTGROWER	INTENSIFIED PRODUCTION (tonnes/year)	IN ADDITION TO CURRENT PRODUCTION (tonnes/year)
LARGE SCALE FARMERS	1 189 564	74 735
SMALLHOLDERS	296 076	38 677
TOTAL	**1 485 640**	**113 412**

Source: Elaboration based on BEFS Assessment Results

TABLE 21.

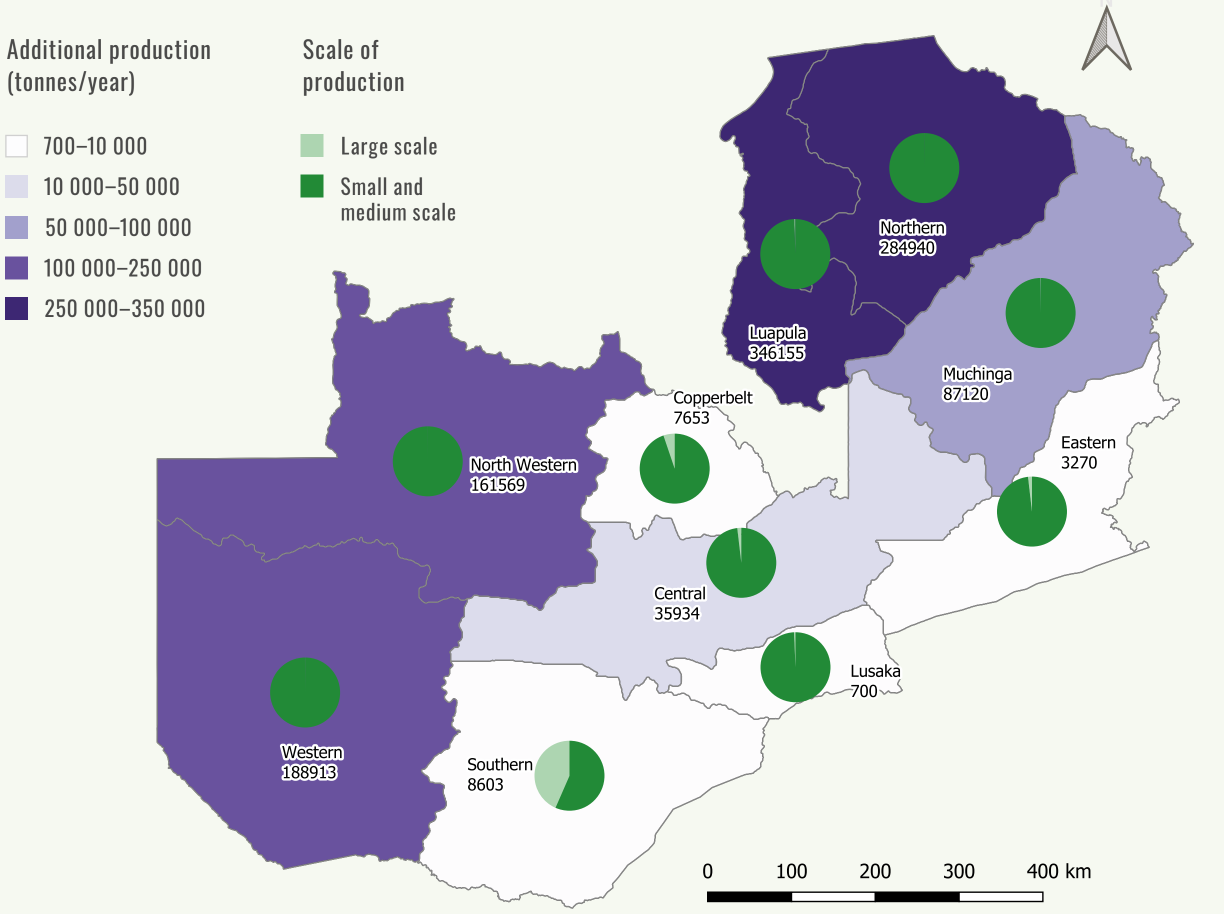
POTENTIAL ADDITIONAL PRODUCTION OF CASSAVA AFTER INTENSIFICATION

PROVINCE	INTENSIFIED PRODUCTION (tonnes/year)	IN ADDITION TO CURRENT PRODUCTION (tonnes/year)	SHARE OF S&M FARMERS (%)
CENTRAL	86 493	35 935	98%
COPPERBELT	18 442	7 653	95%
EASTERN	7 696	3 270	98%
LUAPULA	834 109	346 155	100%
LUSAKA	1 687	700	99%
MUCHINGA	209 928	87 120	100%
NORTHERN	686 602	284 940	100%
NORTH-WESTERN	389 323	161 569	100%
SOUTHERN	16 160	8 603	57%
WESTERN	455 212	188 913	100%
TOTAL	**2 705 653**	**1 124 859**	**99%**

Source: Elaboration based on BEFS Assessment Results

FIGURE 25.

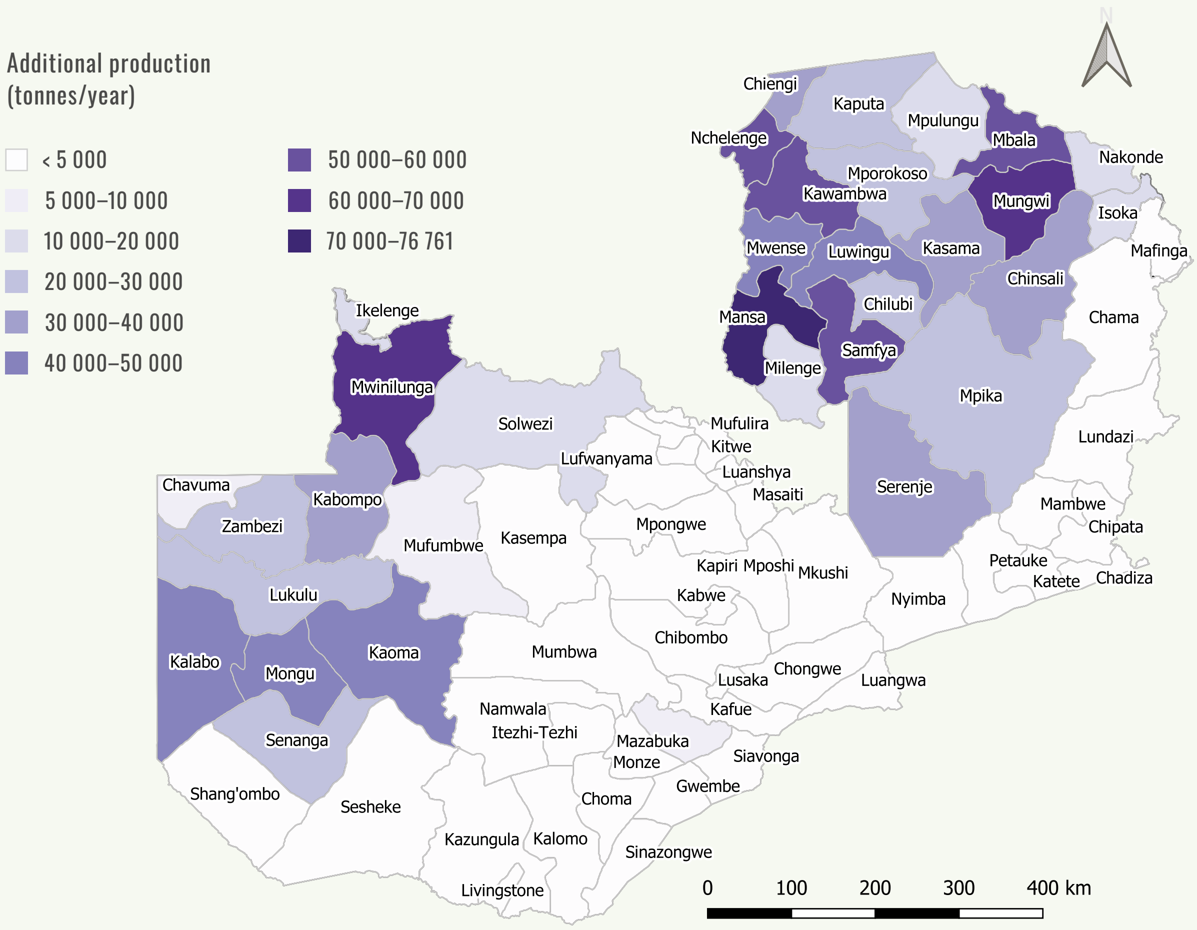
POTENTIAL ADDITIONAL PRODUCTION OF CASSAVA BY PROVINCE WITH INDICATION OF SHARES BY PRODUCTION LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 26.

POTENTIAL ADDITIONAL PRODUCTION OF CASSAVA BY DISTRICT



Source: Elaboration based on BEFS Assessment Results

On the district level, the results in **Figure 26** show that the districts with the highest potential for additional production are: Samfya, Kawambwa and Nchelenge and Mansa in the Luapula Province; Mungwi in the Northern Province; and Mwinilunga in the North-Western Province. Each of these districts could reach an additional production of over 60 000 tonnes per year. Approximately 30 percent of the total additional production of the country is concentrated in the six districts, demonstrating that the additional production of cassava is more prevalent across the country as compared to sunflower and soybeans.

SUNFLOWER

The results for sunflower shows that as a result of intensification, an additional production of 23.7 thousand tonnes of sunflower could be achieved each year at the national level. Most of the additional production would be concentrated in the Eastern, Southern and Central provinces. These three provinces encompass more than 95 percent of the total achievable additional production. Details of the additional production per province is shown in **Table 22**.

It is worth noting that both in the Eastern and Southern provinces, additional production is carried out almost exclusively by small and medium-scale farms. The Central Province shows a larger participation in the additional production of large-scale farms, however 85 percent of sunflowers is still produced by small and medium-scale farms (**Figure 27**).

TABLE 22.

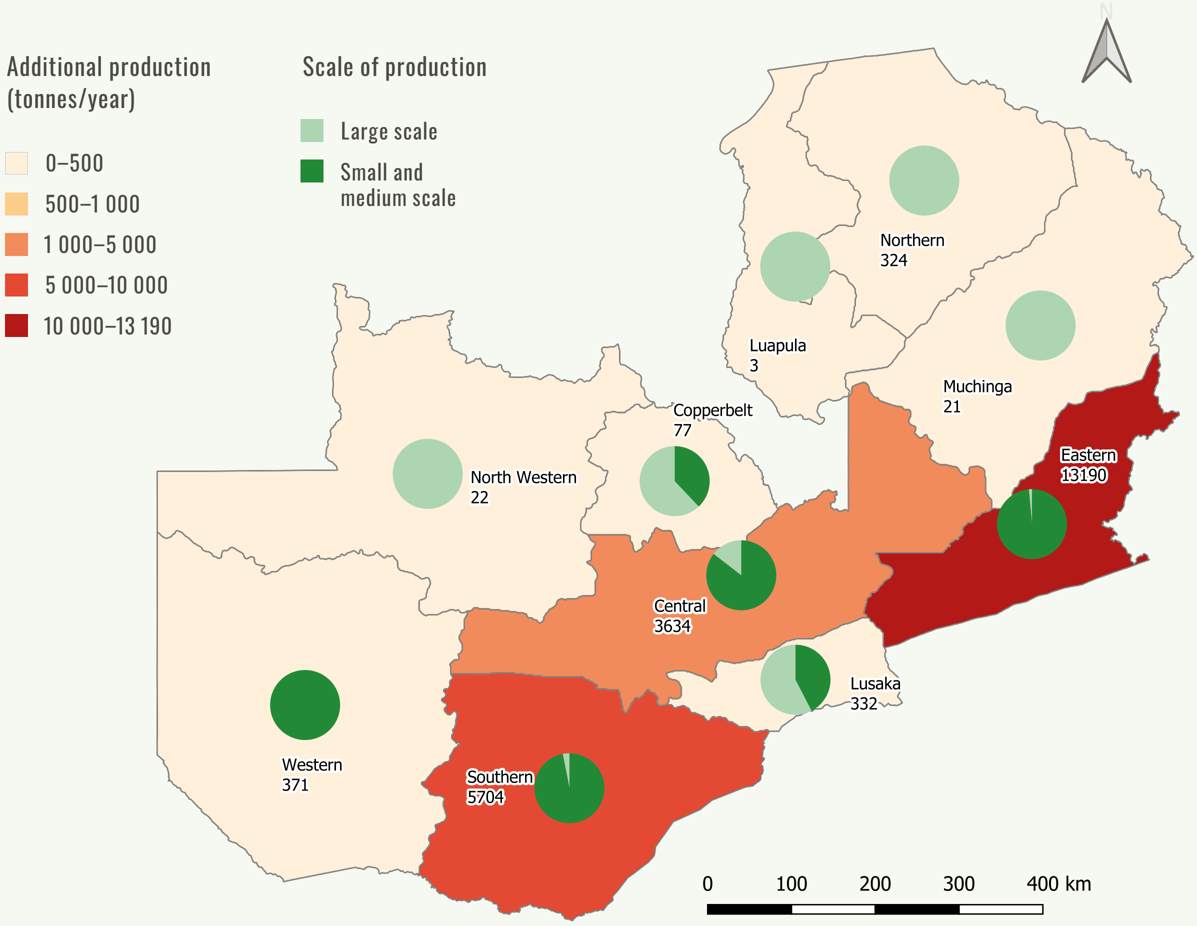
POTENTIAL ADDITIONAL PRODUCTION OF SUNFLOWER SEEDS AFTER INTENSIFICATION

PROVINCE	INTENSIFIED PRODUCTION (tonnes/year)	IN ADDITION TO CURRENT PRODUCTION (tonnes/year)	SHARE OF S&M FARMERS (%)
CENTRAL	5 989	3 634	85%
COPPERBELT	153	76	38%
EASTERN	29 506	13 190	99%
LUAPULA	6	3	>1%
LUSAKA	764	332	42%
MUCHINGA	37	21	>1%
NORTHERN	357	324	>1%
NORTH-WESTERN	35	22	>1%
SOUTHERN	10 132	5 704	97%
WESTERN	880	370	100%
TOTAL	**47 859**	**23 676**	**94%**

Source: Elaboration based on BEFS Assessment Results

FIGURE 27.

POTENTIAL ADDITIONAL PRODUCTION OF SUNFLOWER BY PROVINCE WITH INDICATION OF SHARES BY PRODUCTION LEVEL

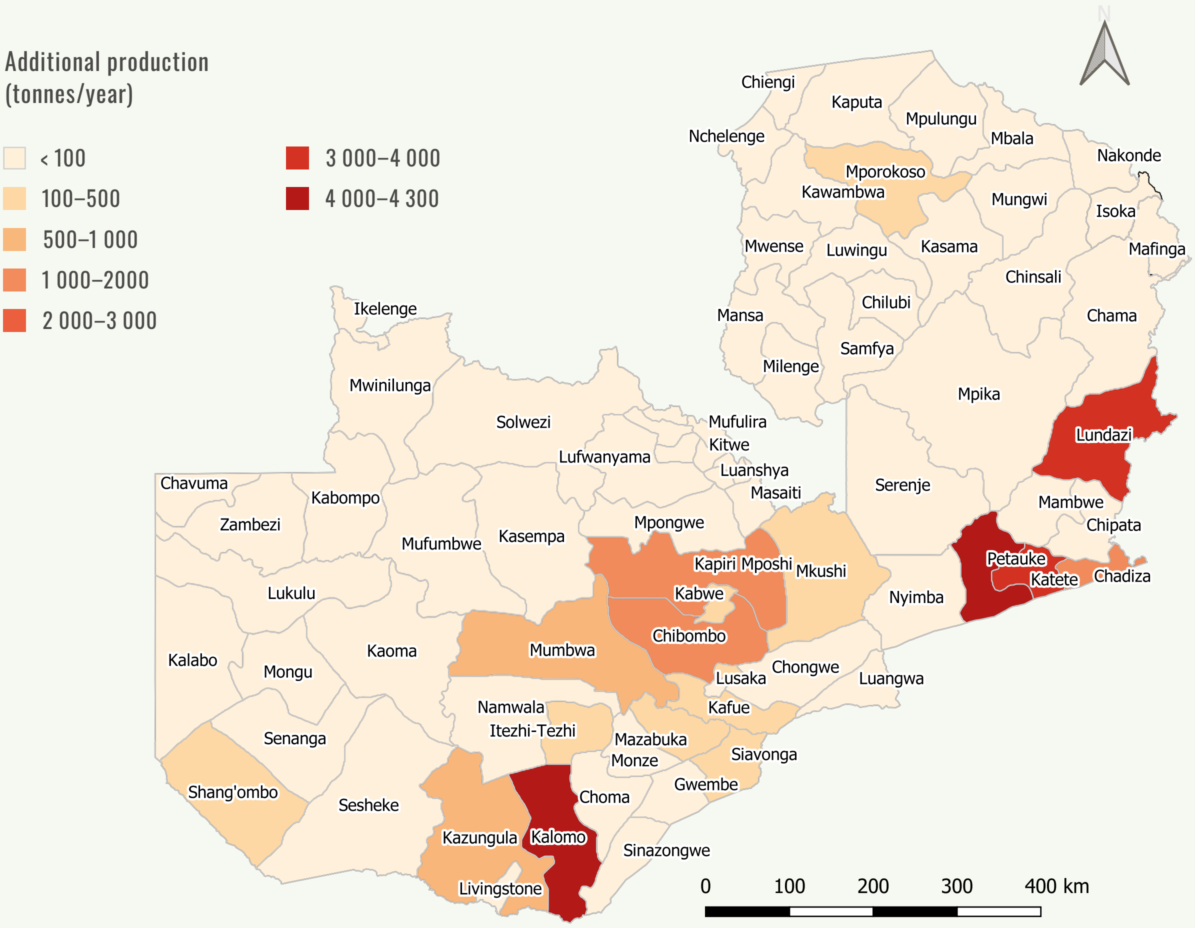


Source: Elaboration based on BEFS Assessment Results

Figure 28 shows the potential additional production per district. As it can be seen, the districts with the highest potential for additional production are Lundazi, Petauke and Katete in the Eastern Province and Kalomo in the Southern Province. Each of these districts could reach an additional production above 3 000 tonnes per year. The four provinces encompass almost 65 percent of total additional production in the country.

FIGURE 28.

POTENTIAL ADDITIONAL PRODUCTION OF SUNFLOWER BY DISTRICT



Source: Elaboration based on BEFS Assessment Results

SOYBEANS

The results for soybeans show that due to intensification, an additional production of 172 thousand tonnes of soybeans on the national level could be achieved each year. Most of this additional production would be concentrated in the Central, Eastern, Lusaka and Copperbelt provinces. These four provinces encompass almost 93 percent of the total achievable additional production; details of the additional production per province is shown in **Table 23**.

The regions with the highest additional production are found in the Central Province where the production is almost equal between large-scale farms (51 percent) and small and medium-scale farms (49 percent). On the other hand, in the Eastern Province almost all additional production is carried out by small and medium-scale farms (98 percent), see **Figure 29**.

TABLE 23.

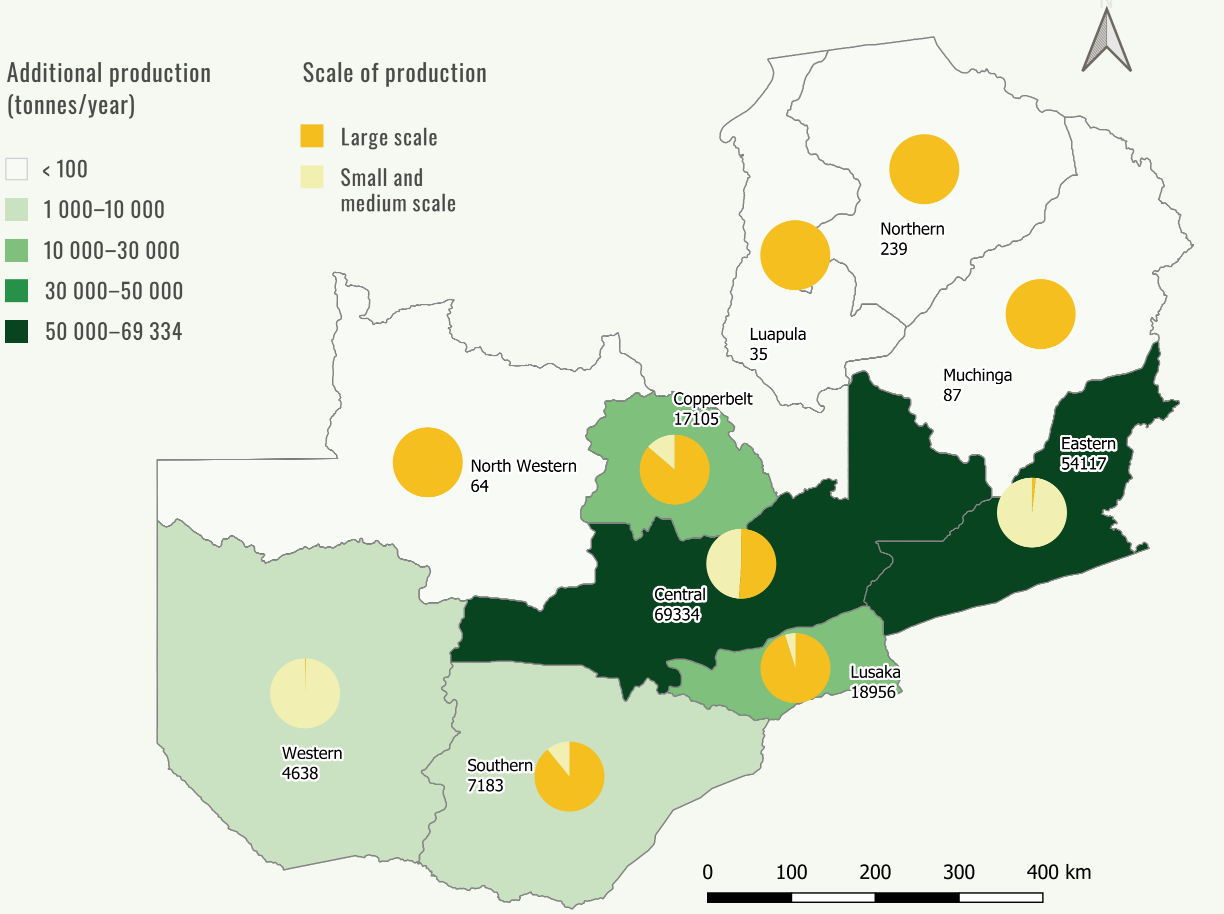
POTENTIAL ADDITIONAL PRODUCTION OF SOYBEANS AFTER INTENSIFICATION

PROVINCE	INTENSIFIED PRODUCTION (tonnes/year)	IN ADDITION TO CURRENT PRODUCTION (tonnes/year)	SHARE OF S&M FARMERS (percent)
CENTRAL	151 438	69 334	49%
COPPERBELT	52 930	17 105	14%
EASTERN	72 240	54 117	98%
LUAPULA	47	35	>1%
LUSAKA	46 106	18 956	5%
MUCHINGA	122	87	>1%
NORTHERN	982	239	>1%
NORTH-WESTERN	192	64	>1%
SOUTHERN	26 405	7 183	11%
WESTERN	5 557	4 638	100%
TOTAL	**356 018**	**171 759**	**56%**

Source: Elaboration based on BEFS Assessment Results

FIGURE 29.

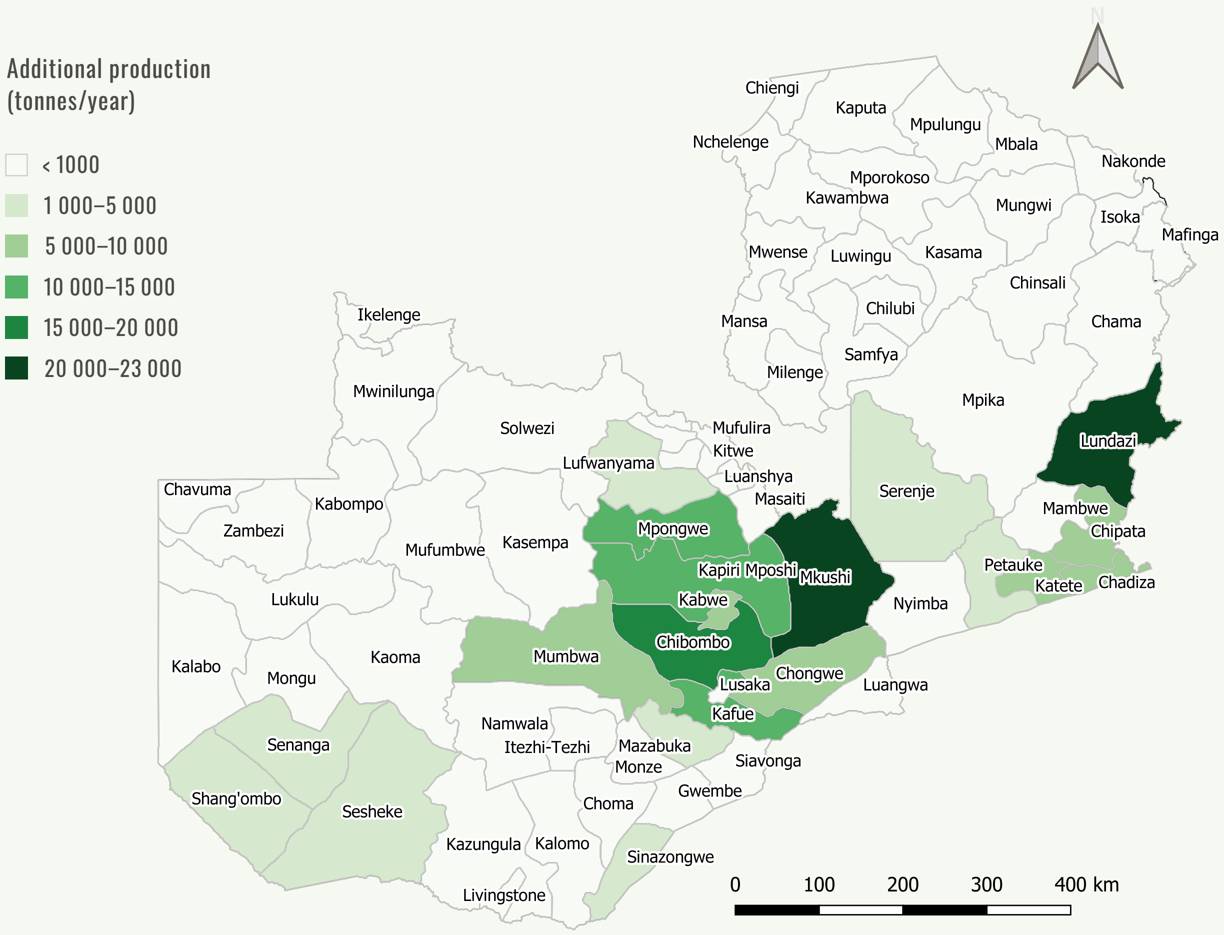
POTENTIAL ADDITIONAL PRODUCTION OF SOYBEAN BY PROVINCE WITH INDICATION OF SHARES BY PRODUCTION LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 30.

POTENTIAL ADDITIONAL PRODUCTION OF SOYBEAN BY DISTRICT



Source: Elaboration based on BEFS Assessment Results

At the district level, the results presented in **Figure 30** show that the areas with the highest potential for additional production are Mkushi and Chibombo in the Central Province, and Lundazi in the Eastern Province. Each of these districts could reach an additional production of over 15 thousand tonnes per year. The four districts encompass almost 64 percent of the total additional production of the country.

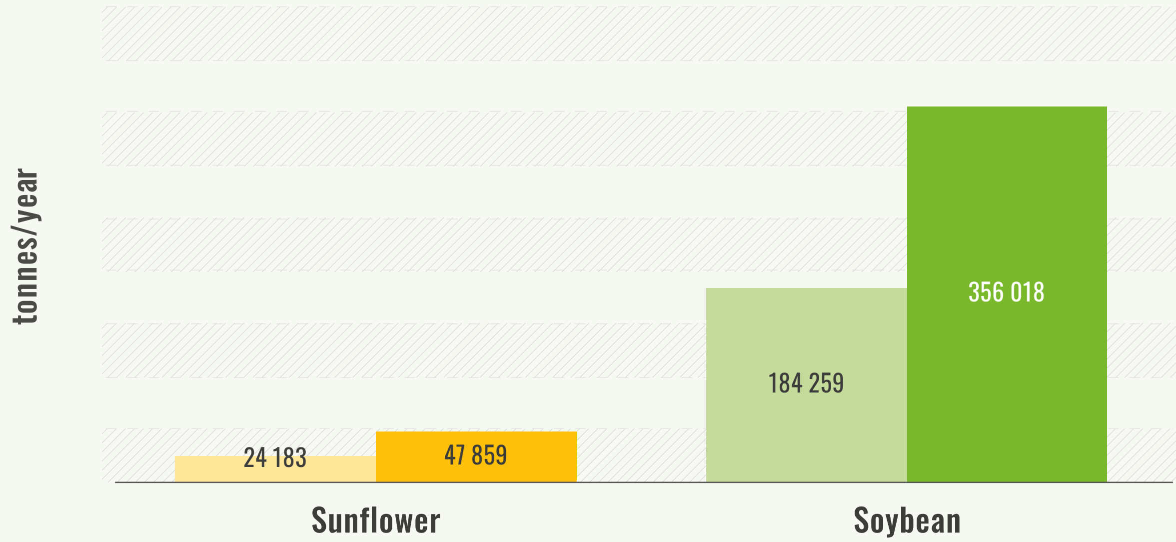
3.4.3.2 Potential total additional production

Figure 31 and **Figure 32** summarize the results of the current production, potential intensified production and additional production for the four assessed crops.

In the case of biodiesel feedstock, soybean shows a considerably higher potential for additional production, since the current production area is larger than the sunflower area. In the case of ethanol feedstock, cassava shows very promising results, since the yield gap is quite large as opposed to the yields of sugarcane, which are already at a very high level leaving little room for intensification.

FIGURE 31.

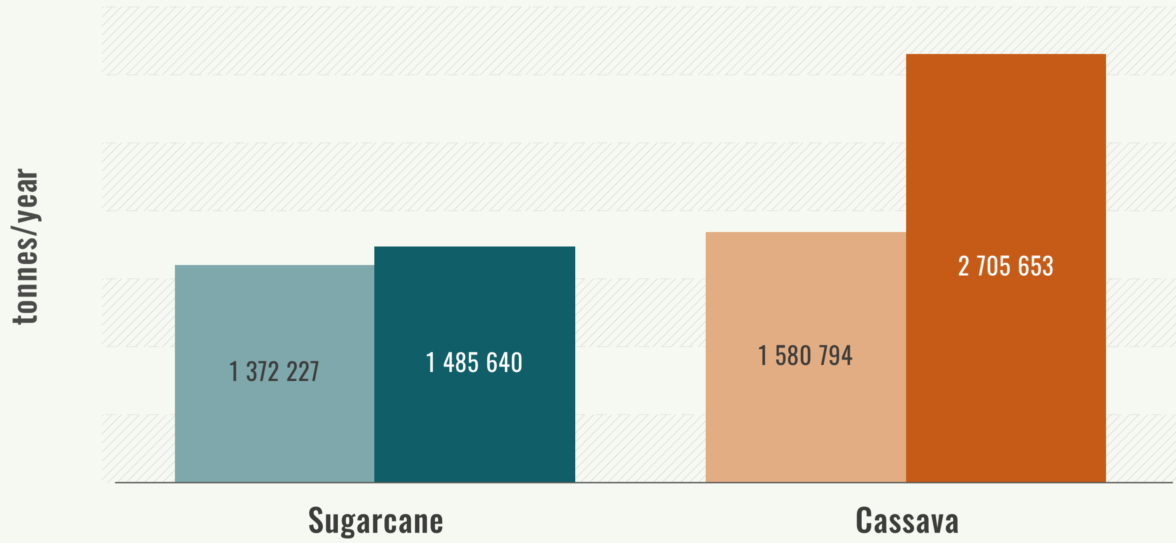
SUMMARY – ADDITIONAL PRODUCTION OF SUNFLOWER AND SOYBEAN FOR BIODIESEL PRODUCTION AT NATIONAL LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 32.

SUMMARY – ADDITIONAL PRODUCTION OF SUGARCANE AND CASSAVA FOR ETHANOL PRODUCTION AT NATIONAL LEVEL



Source: Elaboration based on BEFS Assessment Results

3.4.3.3 Gross margin analysis of the current and intensified production

The analysis of gross margin per hectare for sugarcane, cassava, sunflower and soybean is presented according to the following criteria:

1 Crop yields

- A current yields achieved by small-scale farmers in Zambia;
- B current yields achieved by medium or large-scale farmers, to which the small and medium-scale farmers could intensify, respectively;
- C yields that could be achieved by large-scale farmers through intensification.

2 Sensitivity analysis for different market prices

- A average 2018 market price;
- B the lowest market price in the last 5–10 years;
- C a price above the 2018 price, but lower than the highest market price in the last 5–10 years;
- D the highest market price in the last 5–10 years.

ETHANOL FEEDSTOCK: SUGARCANE AND CASSAVA

Sugarcane. **Table 24** shows a summary of the gross margin calculation for sugarcane yields of 25 tonnes/ha, 122 tonnes/ha and 140 tonnes/ha, and the market price of 30.91 USD/tonne. As described in the table, at the yield of 25 tonnes/ha the gross margin is negative, meaning that the variable costs outweigh the revenues. On the other hand, for the yields of 122 tonnes/ha and 140 tonnes/ha, the gross margins are positive.

The comparison of variable costs of medium-to-large scale (MS-LS) and large-scale (LS) production systems demonstrates that using additional agro-technical inputs valued at 7 USD could help increase the gross margin of 550 USD. If a farmer uses a loan to finance variable costs of production, the interest expenses incurred for the loan should also be considered. These expenses will depend on the loan interest rate. **Table 24** details the expenses for two levels of interest rates: the 2018 average interest rate for commercial loans in Zambia (23.93 percent) and the 2018 base lending rate in Zambia (9.79 percent).

The results of a sensitivity analysis regarding market prices for sugarcane are shown in **Figure 33**. The gross margin was calculated for the yields of 25 tonnes/ha, 122 tonnes/ha and 140 tonnes/ha, and the market prices of 25 USD/tonne, 31 USD/tonne, 33 USD/tonne and 37 USD/tonne. For the yield of 25 tonnes/ha the gross margin is negative for all of the price rates examined, meaning that the variable costs outweigh the revenues. In the case of yield levels 122 tonnes/ha and 144 tonnes/ha, the gross margins are positive for all of the prices analysed.

TABLE 24.

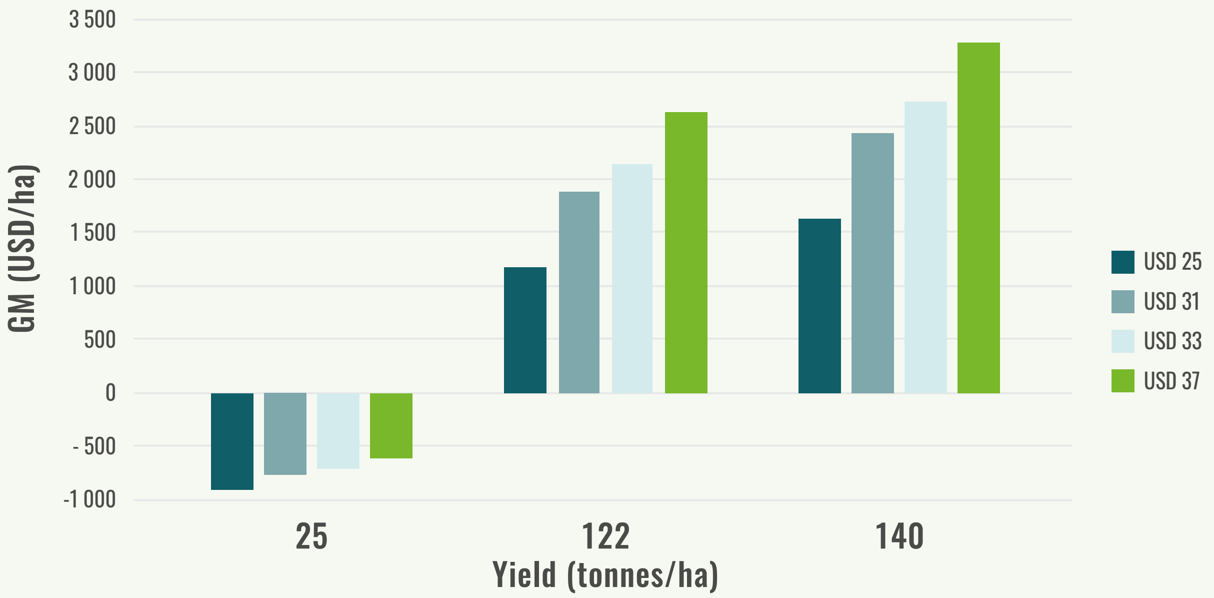
SUMMARY OF GROSS MARGIN ANALYSIS FOR SUGARCANE

MARKET PRICE (USD/tonne)	30.91		
PRODUCTION SYSTEM TYPE/WATER SUPPORT	SS / RAINFED	MS-LS / IRRIGATED	LS / IRRIGATED
YIELD (tonnes/ha)	25	122	140
REVENUE (USD/ha)	773	3 770	4 327
TOTAL VARIABLE COSTS (USD/ha)	1 536	1 872	1 879
GROSS MARGIN (USD/ha)	**-763**	**1 898**	**2 448**
EXPENSES FOR LOAN INTEREST @23.93PERCENT (USD/ha)	368	448	500
EXPENSES FOR LOAN INTEREST @9.79PERCENT (USD/ha)	150	183	184

Source: Elaboration based on BEFS Assessment Results

FIGURE 33.

SENSITIVITY ANALYSIS FOR SUGARCANE



Source: Elaboration based on BEFS Assessment Results

Cassava. Table 25 shows a summary of the gross margin calculation for sugarcane yields of 8 tonnes/ha, 28.5 tonnes/ha and 30.2 tonnes/ha and the market price of 95.48 USD/tonne. At this market price, the gross margin of cassava production is positive for all the examined yields.

At the yield of 28.5 tonnes/ha the gross margin is over eight times higher than the gross margin for the yield of 8 tonnes/ha. The variable production costs at this level of production are almost double the variable costs of producing 8 tonnes/ha. Under the assumptions of the analysis, the results indicate that the farmer would benefit from the intensification, or in other words, the intensification would "pay-off".

The GM for the yields of 30.2 tonnes/ha is only 23 USD higher than the GM for the yield 28.5 tonnes/ha. Which indicates that it would pay-off for to intensify the production in case he does not need to take a loan to finance the variable costs. In case the expenses of the loan interest need to be considered, i.e. if the farmer uses a loan to cover the variable costs of production, the potential increase of GM diminishes as it can be seen in Table 25. Namely, with the loan interest rate of 23.93 percent the GM at the yield of 30.2 tonnes/ha is 14 USD smaller than the GM at the yield of 28.5. On the other hand, with the loan interest rate of 9.79 percent, GM for the yields of 30.2 tonnes/ha is only 8 USD higher than the GM for the yield 28.5 tonnes/ha.

The results of a sensitivity analysis regarding market prices for cassava are shown in Figure 34. The gross margin was calculated for the yields of 8 tonnes/ha, 28.5 tonnes/ha and 30.2 tonnes/ha, and the market prices of 95 USD/tonne, 85 USD/tonne, 105 USD/tonne and 115 USD/tonne. Gross margins have proven to be positive for all yield levels, however it is very low for the yield of 8 tonnes/ha.

TABLE 25.

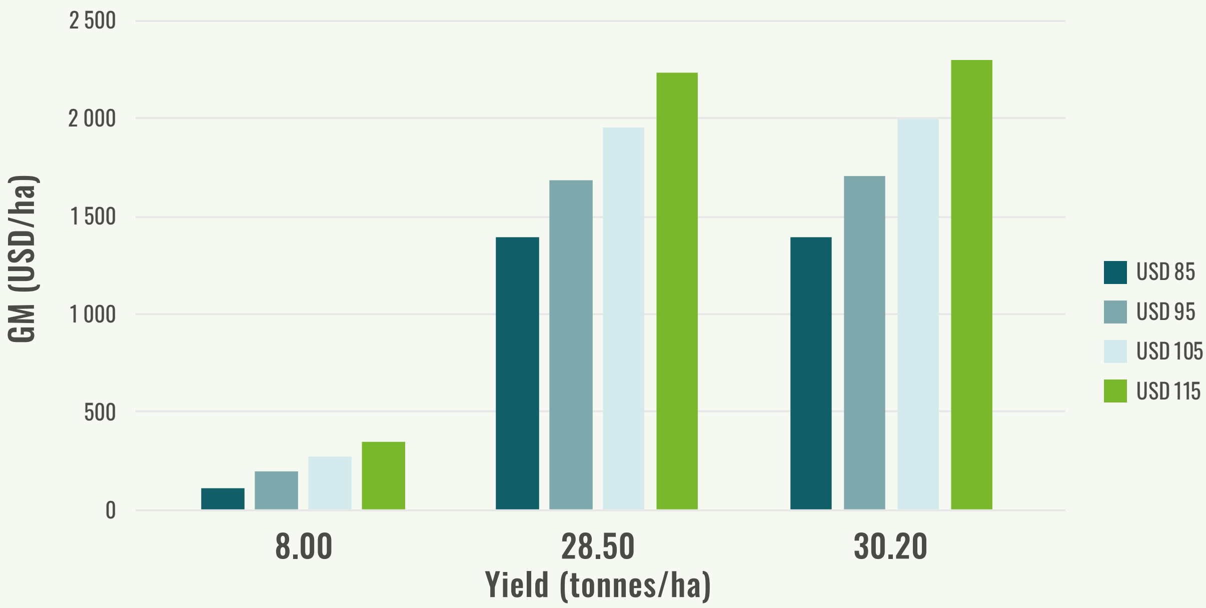
SUMMARY OF GROSS MARGIN ANALYSIS FOR CASSAVA

MARKET PRICE (USD/tonne)	95.48		
PRODUCTION SYSTEM TYPE/WATER SUPPORT	SS / RAINFED	MS-LS /RAINFED	LS /RAINFED
YIELD (tonnes/ha)	8	28.5	30.2
REVENUE (USD/ha)	764	2 721	2 883
TOTAL VARIABLE COSTS (USD/ha)	569	1 036	1 176
GROSS MARGIN (USD/ha)	**195**	**1 685**	**1 708**
EXPENSES FOR LOAN INTEREST @23.93PERCENT (USD/ha)	136	245	281
EXPENSES FOR LOAN INTEREST @9.79PERCENT (USD/ha)	56	101	115

Source: Elaboration based on BEFS Assessment Results

FIGURE 34.

SENSITIVITY ANALYSIS FOR CASSAVA



Source: Elaboration based on BEFS Assessment Results

BIODIESEL FEEDSTOCK: SUNFLOWER AND SOYBEAN

Sunflower. Table 26 shows a summary of the gross margin calculation for sunflower yields of 1 tonne/ha, 2 tonnes/ha and 3 tonnes/ha, and the market price of 229.14 USD/tonne. With a yield of 1 tonne/ha the GM is negative, therefore the variable costs outweigh the revenues; on the other hand, for the yields of 2 tonnes/ha and 3 tonnes/ha, the GMs are positive.

With a yield of 2 tonnes/ha the GM is 119 USD/ha, as compared to the loss of 67 USD/ha for the yield of 1 tonne/ha. The fact that the difference in the variable costs is only 43 USD/ha implies that the intensification could be achieved through relatively small increase in inputs you along with the better management practices. Nevertheless, the intensification from 2 tonnes/ha to 3 tonnes/ha would be more costly.

If the farmers finance their variable costs

through a loan the interest expenses also be taken into account. **Table 26** indicates the costs for two levels of interest rates: the 2018 average interest rate for commercial loans in Zambia (23.93 percent) and the 2018 base lending rate in Zambia (9.79 percent).

The results of the sensitivity analysis regarding market prices for sunflower are shown in **Figure 35**. The gross margin was calculated for the yields of 1 tonne/ha, 2 tonnes/ha and 3 tonnes/ha and the market prices of 180 USD/tonne, 229 USD/tonne, 350 USD/tonne and 410 USD/tonne.

At the price level of 180 USD/tonne, the gross margin is positive but only slightly, for the yield of 3 tonnes/ha. The gross margin is also negative for the yield of 1 tonne/ha when the price is 229 USD/tonne. For the market prices of 350 USD/tonne and 410 USD/tonne, the gross margins are positive for all production levels (yields). As can be expected, the higher the yield, the higher the gross margin.

TABLE 26.

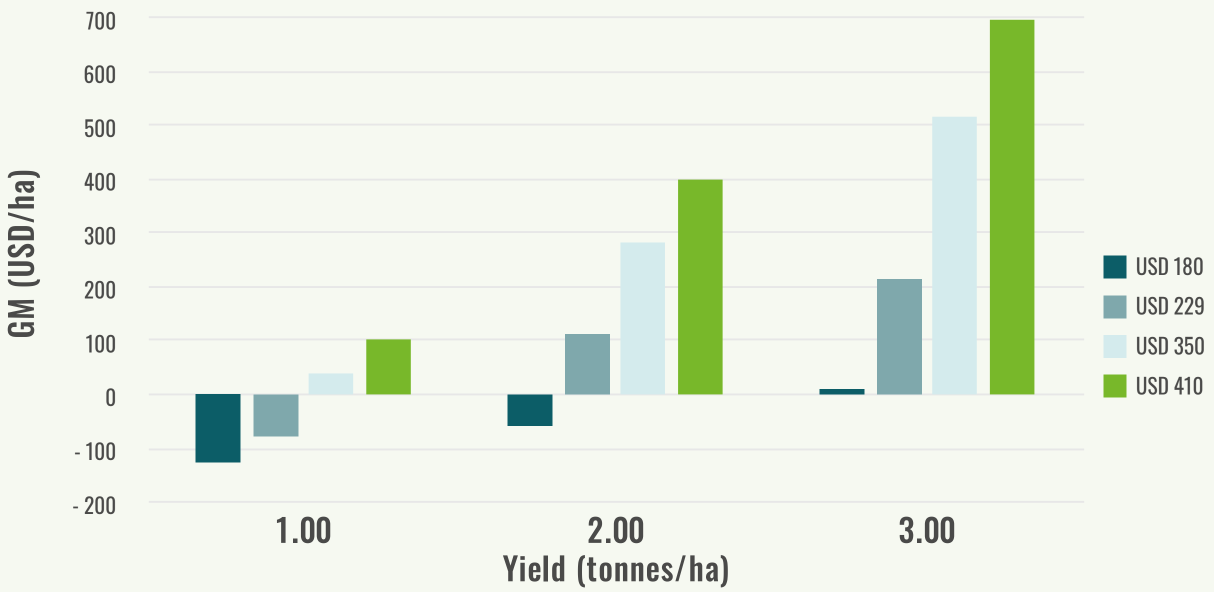
SUMMARY OF GROSS MARGIN ANALYSIS FOR SUNFLOWER

MARKET PRICE (USD/tonne)	229.14		
PRODUCTION SYSTEM TYPE/WATER SUPPORT	SS / RAINFED	MS-LS /RAINFED	LS /RAINFED
YIELD (tonnes/ha)	**1**	**2**	**3**
REVENUE (USD/ha)	229	458	687
TOTAL VARIABLE COSTS (USD/ha)	296	339	456
GROSS MARGIN (USD/ha)	**-67**	**119**	**231**
EXPENSES FOR LOAN INTEREST @23.93PERCENT (USD/ha)	73	83	112
EXPENSES FOR LOAN INTEREST @9.79PERCENT (USD/ha)	30	34	46

Source: Elaboration based on BEFS Assessment Results

FIGURE 35.

SENSITIVITY ANALYSIS FOR SUNFLOWER



Source: Elaboration based on BEFS Assessment Results

Soybean. **Table 27** shows a summary of the gross margin calculation for soybean yields of 1 tonne/ha and 1.75 tonnes/ha under rainfed production and 3 tonnes/ha and 4 tonnes/ha under irrigated production. The market price used for the analysis is 320 USD/tonne.

With the yields of 1 tonne/ha and 1.75 tonnes/ha the GMs are negative, meaning that the variable costs outweigh the revenues. On the other hand, for the yields of 3 tonnes/ha and 4 tonnes/ha the GMs are positive.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Currently soybean in Zambia is mainly produced by large-scale farmers who use irrigation. Since the production under rainfed conditions seems to be less profitable, it would be reasonable to look into possibilities to intensify the production in the areas where irrigation infrastructure is in place.

Given that the absolute value of the negative GM for 1 tonne/ha is higher than the GM for 1.75 tonnes/ha, under the assumptions of the analysis, if the farmer would intensify from 1 tonne/ha to 1.75 tonnes/ha, he would lose less, i.e. the intensification would "pay-off" for the farmer.

The difference in the revenues gained for 4 tonnes/ha and 3 tonnes/ha (320 USD/ha) considerably offsets the difference in the respective variable costs (95 USD/ha). If the farmers finance their variable costs through a loan the related interest expenses should also be taken into account. **Table 27** indicates these costs for two levels of interest rates: the 2018 average interest rate for commercial loans in Zambia (23.93 percent) and the 2018 base lending rate in Zambia (9.79 percent).

The results of the sensitivity analysis regarding market prices for soybean are shown in **Figure 36**. The gross margin was calculated for the yields of 1 tonne/ha, 1.75 tonnes/ha, 3 tonnes/ha and 4 tonnes/ha. The former two cases considered rainfed production systems, while the latter two irrigated production. The gross margins were calculated for the market prices at 270 USD/tonne, 320 USD/tonne, 345 USD/tonne and 420 USD/tonne.

With the yields of 1 tonne/ha for all of the examined price rates, the gross margin is negative meaning that the variable costs outweigh the revenues. For the yields of 1.75 tonnes/ha the gross margin is positive only for the two largest market prices under scrutiny – 345 USD/tonne and 420 USD/tonne. Instead, for the yields of 3 tonnes/ha and 4 tonnes/ha the gross margins are positive for all considered market prices.

TABLE 27.

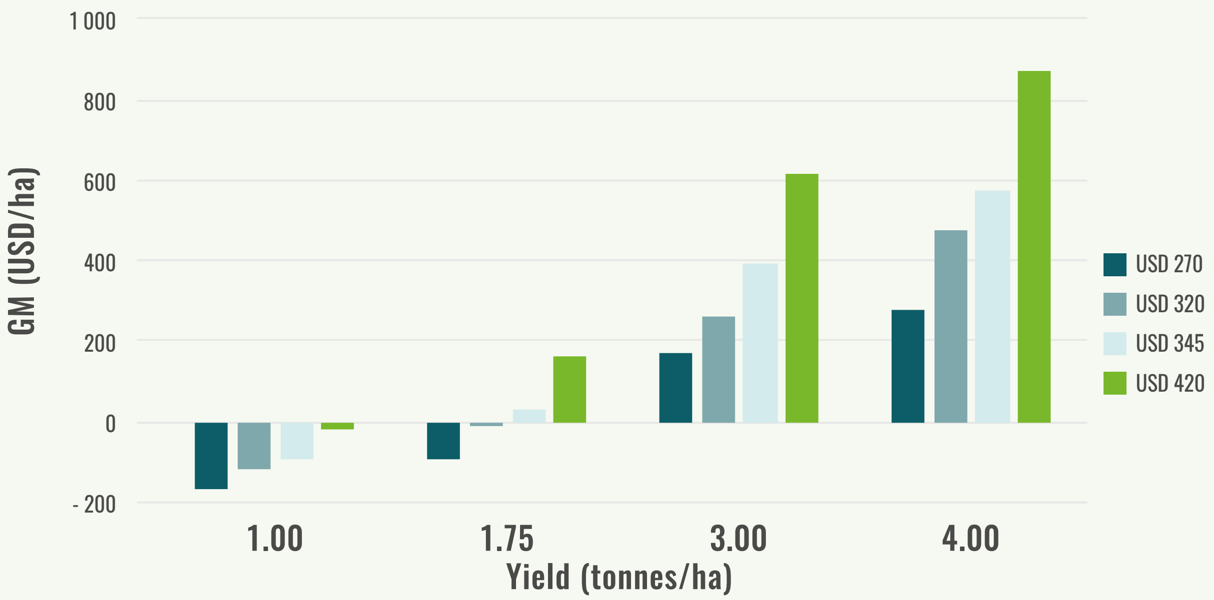
SUMMARY OF GROSS MARGIN ANALYSIS FOR SOYBEAN

MARKET PRICE (USD/tonne)	320.00			
PRODUCTION SYSTEM TYPE/WATER SUPPORT	SS /RAINFED	MS/RAINFED	LS/IRRIGATED	INTENSIFIED LS/ IRRIGATED
YIELD (tonnes/ha)	1	1.75	3	4
REVENUE (USD/ha)	320	560	960	1 280
TOTAL VARIABLE COSTS (USD/ha)	437	566	693	788
GROSS MARGIN (USD/ha)	**-117**	**-6**	**267**	**492**
EXPENSES FOR LOAN INTEREST @23.93PERCENT (USD/ha)	108	141	177	204
EXPENSES FOR LOAN INTEREST @9.79PERCENT (USD/ha)	33	55	68	78

Source: Elaboration based on BEFS Assessment Results

FIGURE 36.

SENSITIVITY ANALYSIS FOR SOYBEAN



Source: Elaboration based on BEFS Assessment Results

3.4.4 Summary of results

The analysis for sugarcane included the intensification of the production from large commercial out-grower farms and smallholder out-grower cooperatives that supply the sugar mills. Results show that as a result of intensification an additional production of 1.13 thousand tonnes of sugarcane on the national level could be achieved each year. The additional production is small compared to the total current production, since the current yields achieved by large-scale farmers are already very high, while the share of sugarcane supplied by small-scale farmers, who have higher potential for intensification, is relatively low.

Results for cassava show that as a result of intensification an additional production of 1.12 million tonnes of cassava on the national level could be achieved each year. On the district level the highest potential for additional production have Samfya, Kawambwa and Nchelenge and Mansa districts in the Luapula province; Mungwi in the Northern Province; and Mwinilunga in the North-Western Province. Each of these districts could reach an additional production above 60 000 tonnes per year.

The results for sunflower shows that due to intensification, an additional production of 23.7 thousand tonnes of sunflower on the national level could be achieved each year. The districts with the highest potential for additional production are Lundazi, Petauke and Katete in the Eastern Province, and Kalomo in the Southern Province. Each of these districts could reach an additional production of over 3 000 tonnes per year. It is worth noting that both in the Eastern and Southern Provinces additional production is carried out almost exclusively by small and medium-scale farms. The Central Province shows greater participation of the large-scale farms in additional production, however 85 percent of sunflower is still produced by small and medium-scale farms.

The results for soybeans show that due to intensification, an additional production of 172 thousand tonnes of soybeans on the national level could be achieved each year. The districts

with the highest potential for additional production are Mkushi and Chibombo in the Central Province, and Lundazi in the Eastern Province. Each of these districts could reach an additional production of over 15 000 tonnes per year. In the Central Province the production is almost equally divided by large-scale farms and small and medium-scale farms, while in the Eastern Province almost all the potential for additional production lies with small and medium-scale farms.

3.5 WOODY RESIDUES

The land cover trend analysis and information about the current consumption of wood resources in the country indicate that the level of annually harvested wood from natural forests is above the mean annual increment, thus resulting in deforestation. The major drivers of forest cover loss are mainly attributed to agriculture and settlement expansion. However, one option to reduce the pressure on forests is to replace the use of woodfuel with woody residues originating from forest plantation harvesting and wood processing industries. These woody residues have the same properties as fuelwood (firewood) and can therefore be used directly for cooking and heating purposes, or as feedstock for production of charcoal and modern solid biofuels (such as briquettes, charcoal briquettes and pellets).

3.5.1 Scope

The aim of the BEFS analysis was to evaluate to what extent woody residues originating from forest plantation harvesting and wood processing industry could replace woodfuel use. Thus, the scope of the analysis included:

TABLE 28.

NUMBER OF WOOD PROCESSING COMPANIES PER DISTRICT ENCOMPASSED BY THE QUESTIONNAIRE SURVEY ON RESIDUE GENERATION AND USE

PROVINCE	DISTRICT	NO. OF COMPANIES VISITED	NO. OF COMPANIES INITIALLY IDENTIFIED
COPPERBELT	KITWE	7	10
	KALULUSHI	0	5
	NDOLA	14	19
	MUFULIRA	8	10
EASTERN	NYIMBA	3	4
LUSAKA	LUSAKA	3	12
NORTH-WESTERN	SOLWEZI	4	4
	KABOMPO	2	4
	MANYINGA	1	5
WESTERN	KAOMA	4	2
	MONGU	3	3
	SENANGA	1	2
	SIOMA	3	4
	SESHEKE	4	4
TOTAL	**13**	**57**	**89**

Source: Elaboration based on BEFS Assessment Results

- the assessment of potential availability of harvesting residues from plantations managed by ZAFFICO, and
- the assessment of potential availability of wood processing residues on the national level, generated primarily by sawmills.

The forest plantations managed by ZAFFICO are located in the Copperbelt Province, and in the Ndola, Mufulira, Kitwe, Kalulushi, Lufwanyama and Chingola districts. The assessment was conducted for Ndola, Chati, Ichimpe and Lamba plantations. The species grown in these plantations are *Pinus kesiya, Pinus oocarpa, Pinus michocana, Pinus merkusii, Gmelia arborea, Eucalyptus cloeziana, Eucalyptus grandis*. The baseline year for the assessment and analysis of wood residues was 2018.

In the case of wood processing residues, the questionnaire survey encompassed 57 wood processing facilities located in 14 districts across five different provinces. The field survey was implemented during the period from 20 May 2019 to 18 June 2019. In the survey planning phase 89 companies were identified as candidates for the survey, however, during the survey some of the companies were not operating or were not ready to participate in the survey.

The survey results were used to obtain the information about the efficiency of sawnwood production, as well as residues generation and current uses of wood processing residues. The survey results were further used to estimate the potentially available sawmill residues at the national level; the potentially available residues generated by the surveyed sawmills have been presented.

3.5.2 Methodology and data sources

3.5.2.1 Harvesting residues from forest plantations

The potential availability of plantation harvesting residues for bioenergy depends on the volume of residues generated and the amount that is already used. The volume of residues generated will depend on the type of tree species harvested, the volume of felled trees and the felling removal rate. The felling removal rate represents the ratio between the volume of the felled tree (timber) removed from the forest after felling and the total volume of the tree, which can be expressed as:

$$\textit{Rate of felling removal} = \frac{\textit{Volume of timber removed after felling } [m^3]}{\textit{Total volume of felled trees } [m^3]}$$

In other words, if 65 m^3 of timber were removed the total volume of the felled tree would be 100 m^3; therefore, the remaining 35 m^3 (35 percent of total tree volume) are branches and leaves, which are left in the forest, i.e. harvesting residues. Part of these residues can be used as firewood and part of it should be left for soil fertility.

In the case of plantations managed by ZAFFICO, based on the composition of plantation stands (*Pinus sp., Gmelia arborea, Eucaliptus sp.)* and the form of the trees, the following assumptions were made for estimating the available residues:

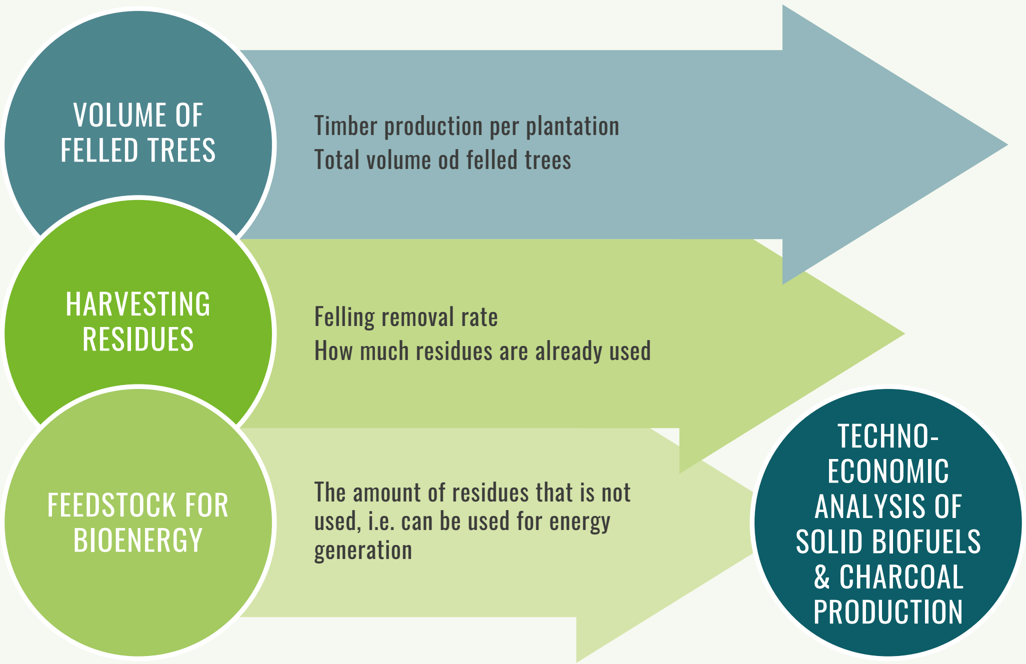
- crown (branches and leaves): 35 percent of the total tree volume;
- trunk volume: 65 percent of the total tree volume;
- rate of felling removal: 65 percent (considering that the primary goal of felling is timber production, the rate of felling removal is equivalent to the trunk volume);
- volume of tree crown collected and used as firewood (larger branches): 40 percent (this is conservative estimate);
- volume of tree crown that should be left on the plantation floor for sustainable soil stability and fertility is 20 percent.

The approach and calculation are illustrated in **Figure 37** and **Figure 38**.

The plantation harvesting residues potentially available was calculated by using the above described methodology. The data on the volume of timber extracted from Ndola, Ichimpe, Chati and Lamba plantations in 2018 was provided by ZAFFICO. The rate of felling removal is estimated at 35 percent, based on the tree form

FIGURE 37.

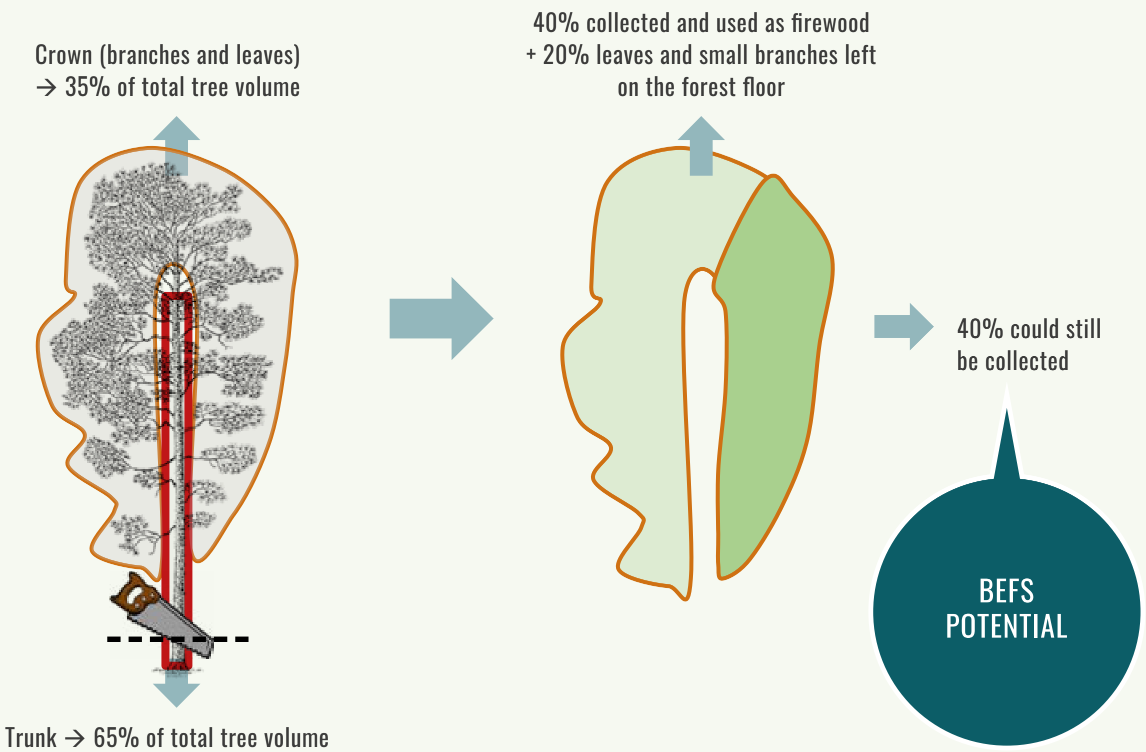
METHODOLOGY TO DETERMINE THE PLANTATION HARVESTING RESIDUES AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

FIGURE 38.

ILLUSTRATION OF PLANTATION HARVESTING RESIDUES AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

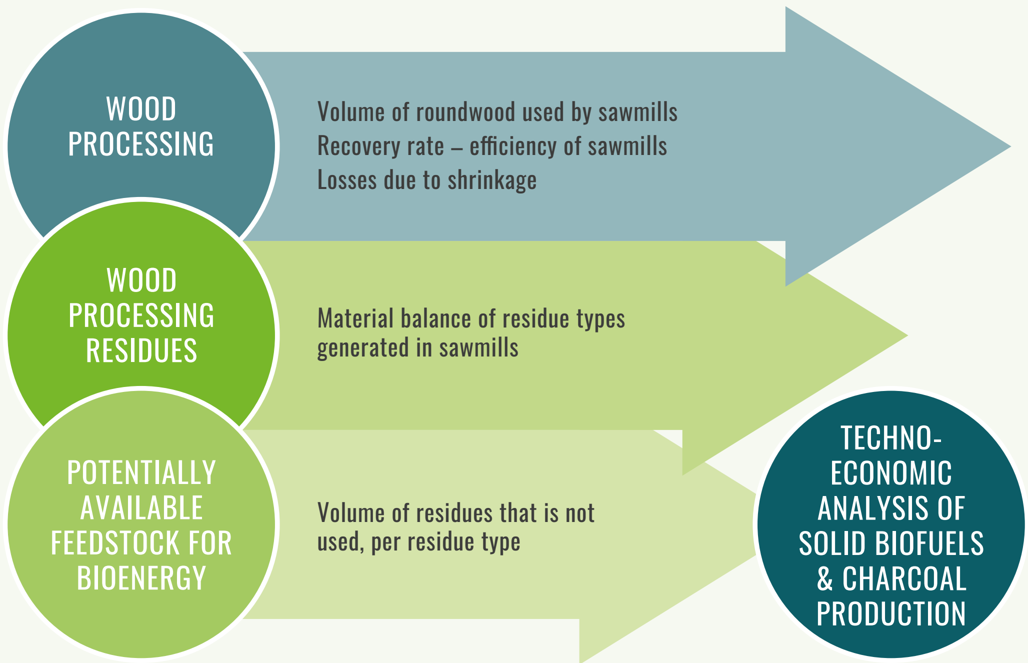
of the grown species. This was also the basis for estimating the volume of leaves and small branches that it is advisable to leave on the plantation grounds. Finally, the estimation of the harvesting residues currently used is based on the information provided by national experts from the Department of Forestry. In particular, the companies licensed for plantation harvesting also request in some cases an allowance for collecting the harvesting residues, which is then allocated and charged by ZAFFICO. The Department of Forestry estimates that approximately 10 to 20 percent of harvesting residues are collected by way of such allowances. In addition to these amounts, it is reasonable to assume that a certain amount of residues was collected but not registered. Finally, for the assessment we estimated that the total of 40 percent of harvesting residues are already being used. Therefore, the remaining 40 percent of the residues are still potentially available.

3.5.2.2 Wood processing residues

The amount of wood processing residues that is available for bioenergy can be calculated by subtracting the volume of residues being used from the total amount of residues generated. Due to the fact that in general the residues generated are not recorded in the sawmills, the amounts are calculated using the recovery rate, i.e. efficiency of sawmills and the material balances of the different types of residues generated in sawmills. The recovery rate is therefore the ratio of the volume of the product (saw wood) to the volume of the feedstock used (roundwood); residues generated in sawmills include chips/slabs, shavings and sawdust. There are also volume losses due to the shrinkage of wood as a result of moisture reduction. **Figure 39** illustrates the approach for assessing the availability of wood processing residues.

FIGURE 39.

METHODOLOGY TO DETERMINE THE VOLUME OF WOOD PROCESSING RESIDUES AVAILABLE FOR BIOENERGY



Source: Elaboration based on BEFS Assessment Results

Based on the above described methodology and data, the volume of the wood processing residues that is potentially available for bioenergy is calculated using the following formula:

$$\mathbf{WPR}_{Bio} = \sum WPR_{Tot-i} - WPR_{Used-i}$$

whereby

$$WPR_{Tot-i} = RWSM * MB_i$$

Where:

- WPR_{Bio} [m^3/year] = wood processing residues available for bioenergy;
- WPR_{Tot-i} [m^3/year] = volume of generated wood processing residues per type *I*;
- WPR_{Used-i} [m^3/year] = volume of used wood processing residues per type *I*;
- *RWSM* [m^3/year] = volume of roundwood used by sawmills;
- MB_i = share the residue type generated per m^3 of the processed roundwood (material balance);
- *i* = chips, slabs, sawdust, shavings.

The official data on the volume of roundwood processed by sawmills and the respective sawnwood in Zambia has not been recorded and published in a systematic manner. Therefore, the BEFS assessment was conducted based on the latest available data published by the Ministry of Lands and Natural Resources: Natural Capital Accounts for Forests Version 2.0, published in 2019. However, it should be noted that several other sources of information were also consulted and reviewed:

- Government of the Republic of Zambia (GRZ). 2019. *Natural Capital Accounts for Forests Version 2.0.* Ministry of Lands and Natural Resources, and Ministry of National Development Planning), Lusaka, Zambia;
- Ng'andwea, P., Mwitwab, J., Muimba-Kankolongob, A. & Ratnasingam, J. 2015. Forest Policy, Economics, and Markets in Zambia;
- FAOSTAT.2020. Forestry production and trade – Zambia. Available at: www.fao.org/faostatonnes/en/#data/FO.

As shown in **Table 29**, the data for roundwood processed by sawmills in Zambia as reported in the above listed sources are inconsistent and contain large discrepancies.

In line with the above described methodology, the total volume and type of residues generated by sawmills in Zambia was estimated using the conversion factors and material balances for sawmills in Zambia (**Table 30**).

Equivalent values of sawmills efficiency were confirmed by the BEFS focal point of the Forestry Department of the Ministry of Lands and Natural Resources, as well as the results from the questionnaire survey described above.

TABLE 29.

DATA ON ROUNDWOOD USED BY SAWMILLS AND SAWNWOOD PRODUCTION IN ZAMBIA PUBLISHED BY DIFFERENT SOURCES

NATURAL CAPITAL ACCOUNTS FOR FORESTS VERSION 2.0	UNIT	2010	2011	2012	2013	2014	2015
ROUNDWOOD USED BY SAWMILLS	m^3	2 450 440	2 000 852	2 199 389	4 322 688	3 179 790	3 816 096
WASTE (RESIDUES) FROM SAWMILLS	m^3	1 225 133	8 30 551	1 043 225	1 044 283	1 701 996	1 815 396
FOREST POLICY, ECONOMICS AND MARKETS IN ZAMBIA		2001	2005	2010			
INDUSTRIAL ROUNDWOOD DEMAND	m^3	140 000		650 000			
SAWNWOOD PRODUCTION	m^3	114 000	353 000	489 000			
FAOSTAT		2010	2011	2012	2013	2014	2015
INDUSTRIAL ROUNDWOOD PRODUCTION	m^3	1 455 000	1 455 000	1 455 000	1 455 000	1 455 000	1 455 000
SAWNWOOD PRODUCTION	m^3	157 000	157 000	157 000	157 000	157 000	157 000

Source: Elaboration based on BEFS Assessment Results

TABLE 30.

CONVERSION FACTORS AND WOOD RAW MATERIAL BALANCE FOR SAWMILL INDUSTRY IN ZAMBIA

DESCRIPTION	UNIT INPUT PER UNIT OUTPUT	SIZE OF ENTERPRISE			
		LARGE	MEDIUM	SMALL	AVERAGE ZAMBIA
SOFTWOOD – SAWNWOOD GREEN	m^3 rw/m^3 p	2	2.5	2.86	2.45
HARDWOOD – SAWNWOOD GREEN	m^3 rw/m^3 p	2.86	3.57	4	3.48
MATERIAL BALANCE SOFTWOOD					
SAWN TIMBER	percent	45%	35%	30%	36.7%
CHIPS/SLABS	percent	34%	22%	32%	29.3%
SHAVINGS	percent	8%	10%	0%	6%
SAWDUST	percent	5%	25%	30%	20%
SHRINKAGE LOSS	percent	8%	8%	8%	8%

Source: Forest Policy, Economics, and Markets in Zambia (Ng'andwea, P., Mwitwab, J., Muimba-Kankolongob, A. & Ratnasingam, J., 2015) Chapter 4

TABLE 31.

CURRENT USES OF WOOD PROCESSING RESIDUES – QUESTIONNAIRE SURVEY RESULTS

RESIDUE TYPE	USED BY THE FACILITY	GIVEN AWAY	SOLD	DISPOSED OR BURNT	USES
CHIPS	33.3%	63.3%	1.7%	1.7%	FUEL
SLABS	3.7%	23.3%	65.6%	7.5%	FUEL; FENCING; CARPENTRY
SAWDUST	1.8%	66.2%	13%	19%	CHICKEN RUN; FUEL
SHAVINGS	20%	28%	52%		CHICKEN RUN; FUEL
OTHER		33%	60%	10%	CARPENTRY; FUEL

Source: Elaboration based on BEFS Assessment Results

The results of the questionnaire survey conducted among the 57 sawmills across 14 districts of Zambia provided information about the current use of sawmill residues. Based on the results presented in **Table 31**, it was possible to determine the percentage of residues, which is potentially available for bioenergy (values presented in the column *Disposed or burnt*).

As shown in **Table 31**, more than 90 percent of chips and slabs are already being used as fuel (probably by as cooking fuels households); slabs and cut-offs are sold as firewood or given away for free. Regarding chips, part of them are used by sawmills and the other part is given away as fuel while shavings and sawdust are commonly used as chicken bedding. The category 'Other' probably includes larger pieces of wood and cut-offs, which can be used as feedstock in carpentry and as firewood.

3.5.3 Results

3.5.3.1 Harvesting residues from forest plantations

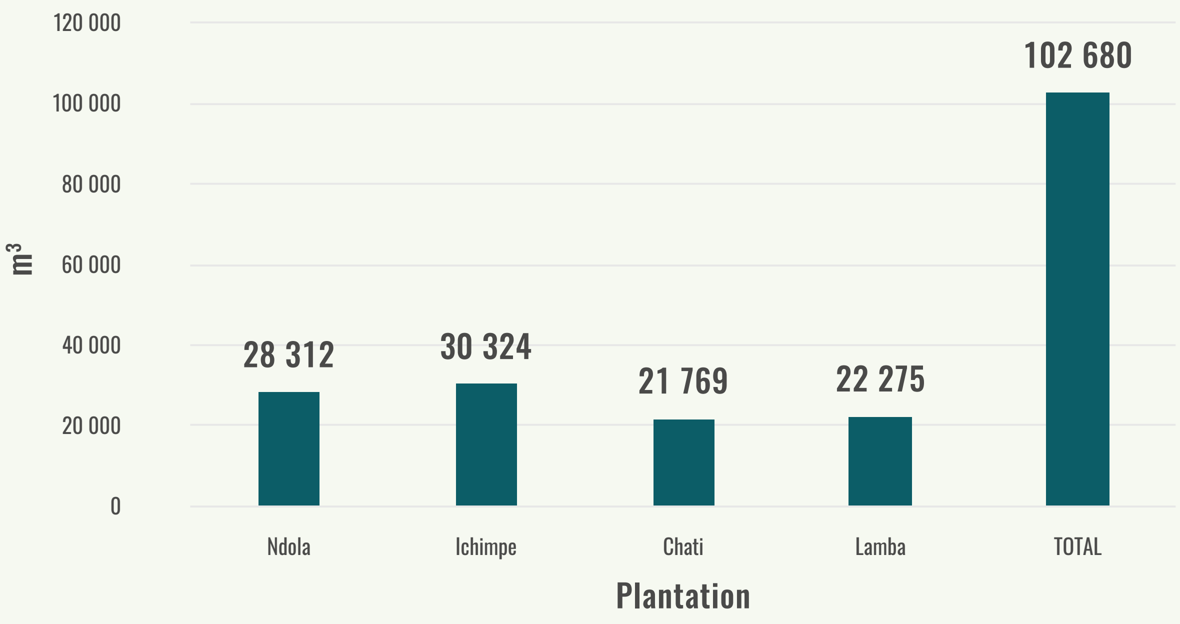
Based on the methodology described above and taking into account 451 500 m^3 of felled timber in Ndola, Ichimpe, Chati and Lamba plantations in 2018, it is estimated that the potentially available harvesting residues amount to approximately

102 700 m³. Assuming that the volume of 2018 felling represents the average annual felling, the equivalent volume or the harvesting residues is available on an annual basis.

Figure 40 and **Table 32** show that the largest volume of the potentially available residues are found in the area of Ichimpe plantation (30 324 m³), followed by Ndola (28 312 m³). In the case of residue density, the highest density is in Ndola where 35.57 m³ can be found per ha, followed by Chati where the density is around 26 m³/ha. In Ichimpe and Lamba the residue density is around 20 m³/ha. **Figure 41** shows the composition of residues according to the tree species. This composition may change from one year to another, depending on the plantation composition and the planned felling in one particular year.

FIGURE 40.

VOLUME OF AVAILABLE PLANTATION HARVESTING RESIDUES IN 2018



Source: Elaboration based on BEFS Assessment Results

TABLE 32.

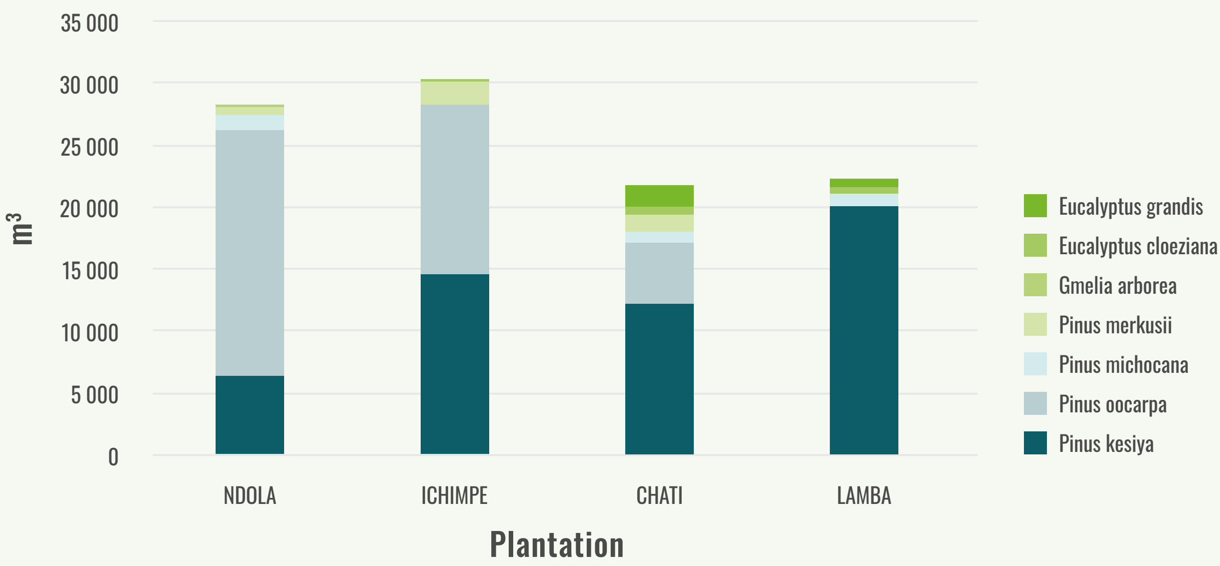
AVAILABLE PLANTATION HARVESTING RESIDUES: VOLUME AND DENSITY

PLANTATION	AVAILABLE RESIDUES (m³/year)	DENSITY OF RESIDUES (m³/ha)	AVAILABLE RESIDUES (tonnes/year)	DENSITY OF RESIDUES (tonnes/ha)
NDOLA	28 312	37.35	15 852	21.43
ICHIMPE	30 324	20.06	17 392	9.55
CHATI	21 769	25.76	12 848	14.76
LAMBA	22 275	19.30	13 270	11.15
TOTAL	**102 680**	**25.62**	**59 362**	**14.22**

Source: Elaboration based on BEFS Assessment Results

FIGURE 41.

VOLUME OF AVAILABLE PLANTATION HARVESTING RESIDUES IN 2018



Source: Elaboration based on BEFS Assessment Results

3.5.3.2 Wood processing residues

The assessment of the wood processing residues generated by sawmills in Zambia was based on data on the roundwood processed by sawmills from 2010 to 2015, and presented in the report *Natural Capital Accounts for Forests Version 2.0.* (GRZ, 2019).

The average annual volume of roundwood processed by sawmills amounts to 2 830 632 m³. Furthermore, based on the average recovery rate of sawmills in the country, annual sawnwood production is estimated at 1 038 842. Given the average conversion factors and material balance for the sawmill industry in Zambia, and the current uses of different types of wood processing residues, it is estimated that 145 715 m³ (72 858 tonnes) of residues would be available for bioenergy production annually.

As shown in **Table 33**, among the different residue types generated sawdust is currently the least used resource, although as much

TABLE 33.

WOOD PROCESSING RESIDUES AVAILABLE GENERATED BY SAWMILLS FOR BIOENERGY

RESIDUE TYPE	RESIDUE GENERATION	USED FOR OTHER PURPOSES	AVAILABLE FOR BIOENERGY	
	m³/year	m³/year	m³/year	tonnes/year
CHIPS/SLABS	829 375	791 224	38 151	19 076
SHAVINGS	169 838	169 838		
SAWDUST	566 126	458 562	107 564	53 782
TOTAL	**1 565 339**	**1 419 624**	**145 715**	**72 858**

Source: Elaboration based on BEFS Assessment Results

as 80 percent of it is already being used. On the other hand, wood shavings generated by sawmills are being utilised to their full capacity, primarily as bedding for poultry production but also partly as fuel. A certain amount of chips and slabs, approximately 5 percent of the total generated residues, still not being used could be harnessed for bioenergy production.

The detailed results on the amount and type of wood processing residues are presented in the Annex.

3.5.4 Summary of results

The results of the analysis show that somewhat less than 60 thousand tonnes of residues are generated in forest plantations, which are available for bioenergy production. It is relatively small amount when compared to the total energy demand for cooking fuels and electricity on the national level. However, the use of these residues for production of modern cooking fuels and/or improved charcoal production, could replace the currently used fuels (charcoal and firewood) on the local level, and thus reduce the demand for freshly cut wood.

The survey among the wood processing companies showed that the major part of processing residues is already being used, primarily as fuel. Nevertheless, it seems that certain share of sawdust is still available and could potentially be used for bioenergy production. A broader survey, which would encompass larger number of processing facilities would be needed to evaluate the exact potential and to determine what would be the optimal way to utilise it.

CHAPTER

4

BEFS ASSESSMENT: BIOENERGY TECHNOLOGIES

4.1 INTRODUCTION

The analysis in the energy end-use options sections generates economic, operating and financial results. These are built on the techno-economic assessment of the different energy pathways under the Zambian context. The economic set of results includes profitability, e.g. production costs and investment requirements. The production costs are compared to market prices and/or costs of technologies commonly used in the country for the specific energy option. Operating results include a comparison of the biomass requirement for the different plant scales versus the biomass available, as calculated in the biomass availability part of the BEFS assessment, as well as minimum profitable capacities. Financial results illustrate the financial viability of the energy end-use option, based on the net present value. Finally, the combination of the set of results mentioned above allowed us to make an estimation of the energy potential obtained for each pathway and make a comparison versus the country's energy demand and targets.

The assessments for each of the energy pathways were developed through a conceptual design approach based on 'knowledge', e.g. mass and energy balances, physical properties of substances and other physiochemical parameters (Douglas, 1988; Edgar, Himmelblau and Lasdon, 2001; Smith, 2005). Techno-economic coefficients were defined and used to carry out the mass and energy balance calculations, and equipment size estimation and energy requirements for the equipment in the case of each energy pathway. These coefficients were obtained through technology specific literature review (Bocci, Di Carlo and Marcelo, 2009; Grover and Mishra, 1996; McKendry, 2002; Rincón *et al.*, 2014; Rincón, Posada and Cardona, 2012; Tumuluru *et al.*, 2015; Walekhwa, Lars and Mugisha, 2014). Representative plant sizes and technologies were selected for the analysis, based on the literature review.

4.2 OBJECTIVE OF THE ENERGY END-USE OPTIONS ANALYSIS IN BEFS ASSESSMENT

The main objective of the energy end use option assessment for Zambia was to understand how the biomass potential identified in the BEFS natural resources assessment at the district level could be transformed into potentially profitable and technically feasible bioenergy options. Based on these results and considering the combination of feedstock, technologies, and profitable production conditions, the analysis evaluated to what extent Zambian renewable energy targets could be met by using sustainable bioenergy.

The analysis covered the following elements:

- identify profitable production conditions for off-grid electricity generation as well as briquettes, charcoal briquettes and biogas production;
- define competitive production conditions for selected residues, taking into account feedstock availability, quality and costs, and technology options;
- classify by rank the most promising feedstock, based on identified amounts of biomass, profitable production conditions and competitive feedstock conditions;
- estimate the potential contribution of bioenergy to the renewable energy targets, considering the combined energy production capacity obtained at the district level;
- estimate the potential woodfuel savings obtained by using improved charcoal technologies, and also identify the profitability of these technologies;
- estimate the potential production of liquid biofuels in Zambia from selected energy crops and their capability to meet the blending mandates.

4.3 METHODOLOGY

4.3.1 Technology selection

The bioenergy end-use options assessment covered biomass for electricity in the off-grid electricity options, biomass for liquid biofuels for transport and biomass for cooking. The following sections illustrate the technologies included within each of the assessment sub-components.

4.3.2 Off-grid electricity

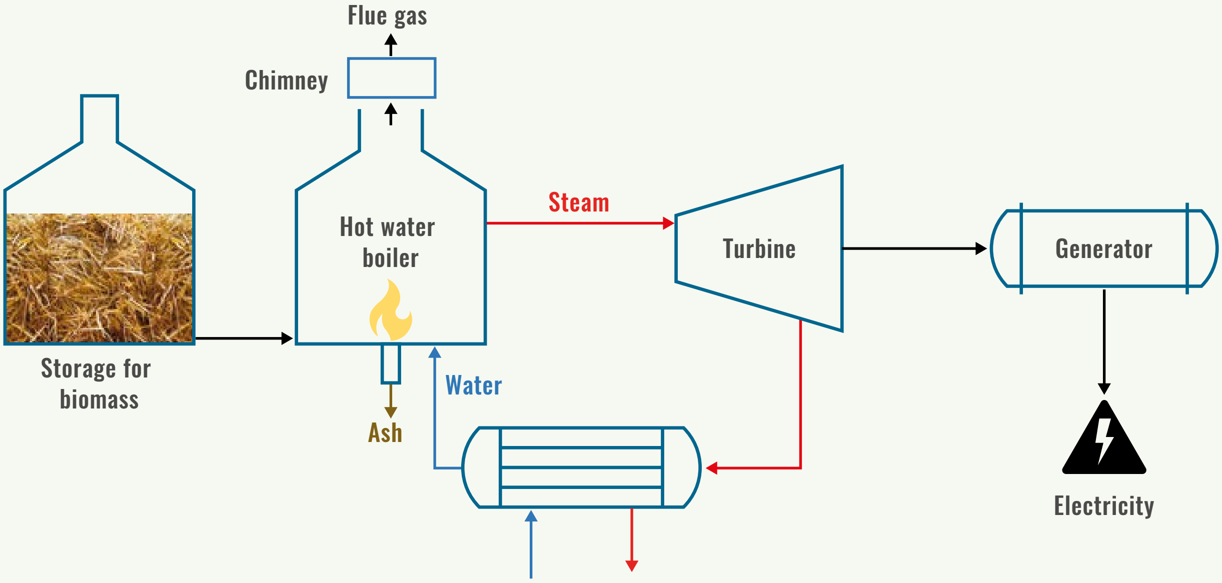
Overall biomass-based off-grid electricity technologies extract the energy potential contained in biomass through thermo-chemical conversion. Examples of these conversion methods are gasification, combustion, and pyrolysis. This step is usually followed by the conversion of chemical energy into electricity and finally, the distribution of this electricity through a mini-grid. In this assessment, the biomass options considered were crop residues and woody residues. The thermo-chemical conversion options were gasification and combustion, which are briefly described in **Figure 42** and **Figure 43**.

In a combustion system for electricity generation the biomass is burnt directly to release heat. The energy released during the combustion can later be utilized to generate electricity. The most straightforward configuration is in the case where the biomass is first dried and then burnt on a grate, furnace or boiler, which is fixed, moving, or fluidized. In the combustion chamber the biomass reacts with excess air, which subsequently leads to the release of heat. The heat is then used to produce steam. This steam passes through a turbo generator connected to a generator that produces the electricity. In brief, the whole system illustrated in **Figure 42** enables biomass residues to be converted into electricity.

Gasification is a thermo-chemical conversion method where biomass is combined with air at high temperatures to produce a mixture of gaseous products known as syngas, along with small amounts of char and ash (Basu, 2010). This process is different from combustion due to the

FIGURE 42.

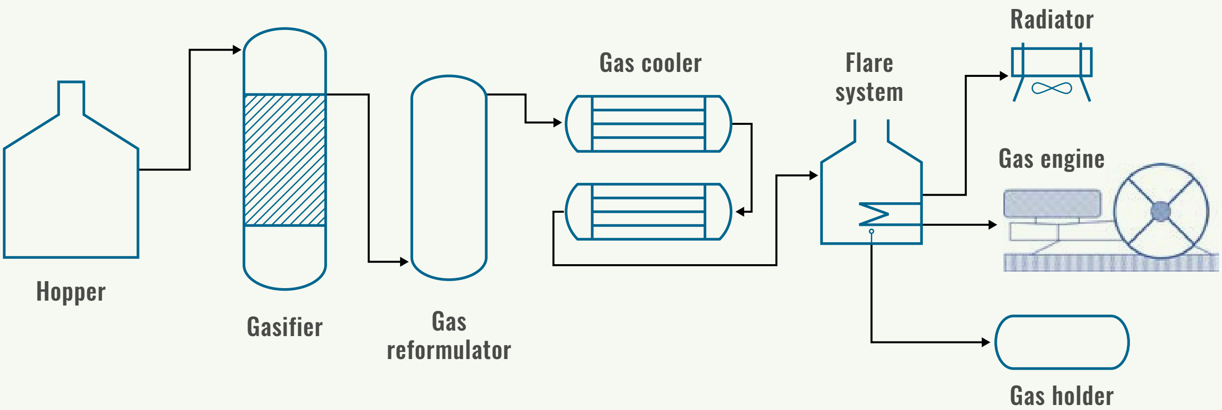
COMBUSTION SYSTEM



Source: Authors

FIGURE 43.

GASIFICATION SYSTEM



Source: Authors

fact that instead of being burnt, the biomass undergoes a process that produces syngas, which has superior fuel properties as compared to the original biomass. This process is done in a gasifier. During the conventional gasification to electricity process, biomass must first be dried before it goes into the gasifier. This assessment considers two gasifier technologies: fluidized bed and downdraft, whose selection depends on the specific characteristics of the used biomass option. After the gasifier process, the syngas produced is cleaned and cooled before it is used in a gas engine to generate electricity (see **Figure 43**).

Mini-grid distribution systems were included in the analysis for both off-grid electricity technology options. These off-grid systems represent a promising midpoint between stand-alone and central-grid electricity systems and could supply communities that cannot be connected to central grids for instance, due to

the cost of extending central-grid lines. At the same time, mini-grid solution avoids the need for supplying each customer with an individual stand-alone system. Moreover, the use of a mini-grids also facilitates the use of generation technologies, which are not considered feasible or economical on a smaller scale (MacGill and Watt, 2015).

4.3.3 Liquid biofuels for transport

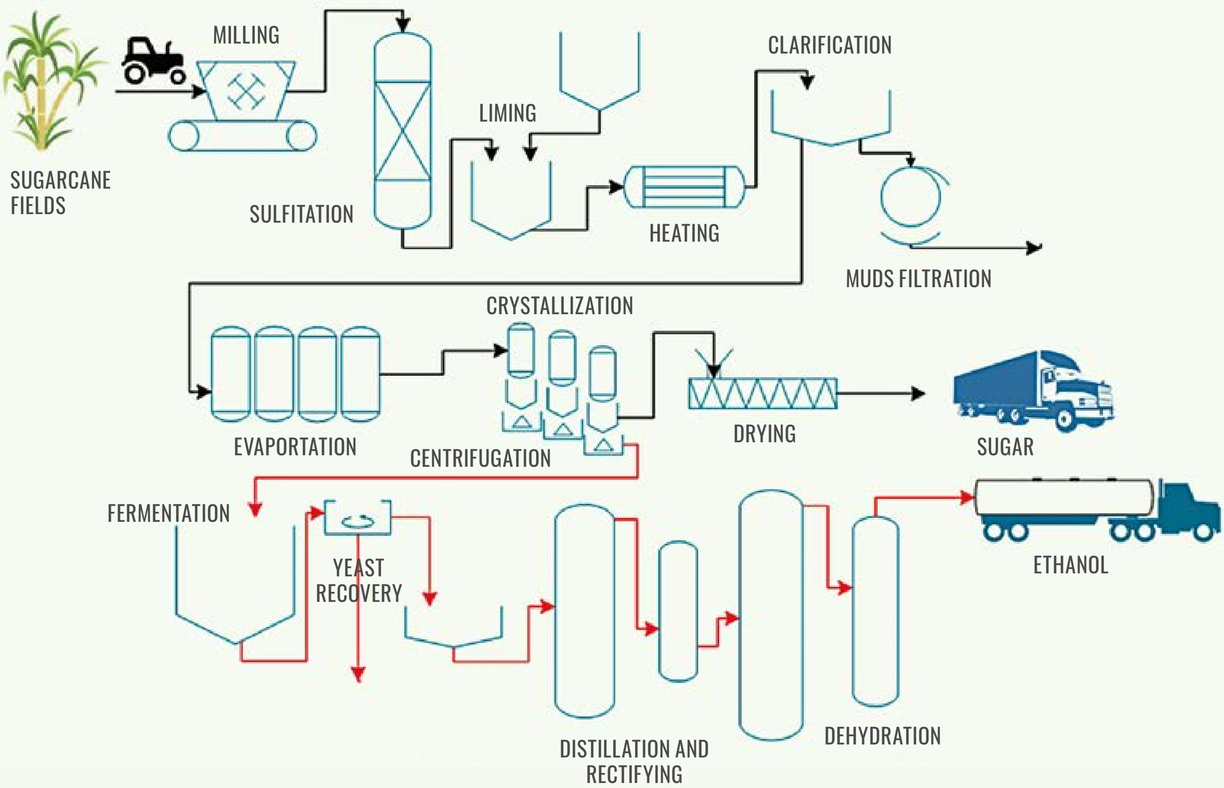
The transport assessment evaluated the viability to produce liquid biofuels for transport, namely ethanol and biodiesel. Crops (and molasses from sugarcane) are the feedstock used for the production of first-generation biofuels, which are ethanol and biodiesel. Ethanol can be blended with gasoline and biodiesel can be blended with diesel. The technologies and processes considered in the assessment are presented as follows.

Ethanol is a clear and colorless liquid and a short-chain alcohol. Despite the fact that ethanol contains less energy per litre than gasoline, it has a higher octane number. After it is blended with the biofuel, the gasoline properties improve. A standard requirement for blending ethanol with gasoline is the use of anhydrous grade ethanol (>98 percent purity). Therefore, the production of fuel ethanol requires additional and more complex steps compared to the ethanol used in the beverage industry.

Two types of feedstock are used in first-generation ethanol production, namely sugar and starchy feedstock. The first type is feedstock rich in sugars such as sugar cane, sugar beet, and sweet sorghum. The second type includes options rich in starch such as maize, cassava, potatoes, and grain sorghum. The difference between the two feedstock types makes ethanol production from starchy feedstock slightly more

FIGURE 44.

ETHANOL PRODUCTION SYSTEM



Source: Authors

complex. Nevertheless, the molecular structure of ethanol and consequently its fuel properties, are the same regardless the feedstock.

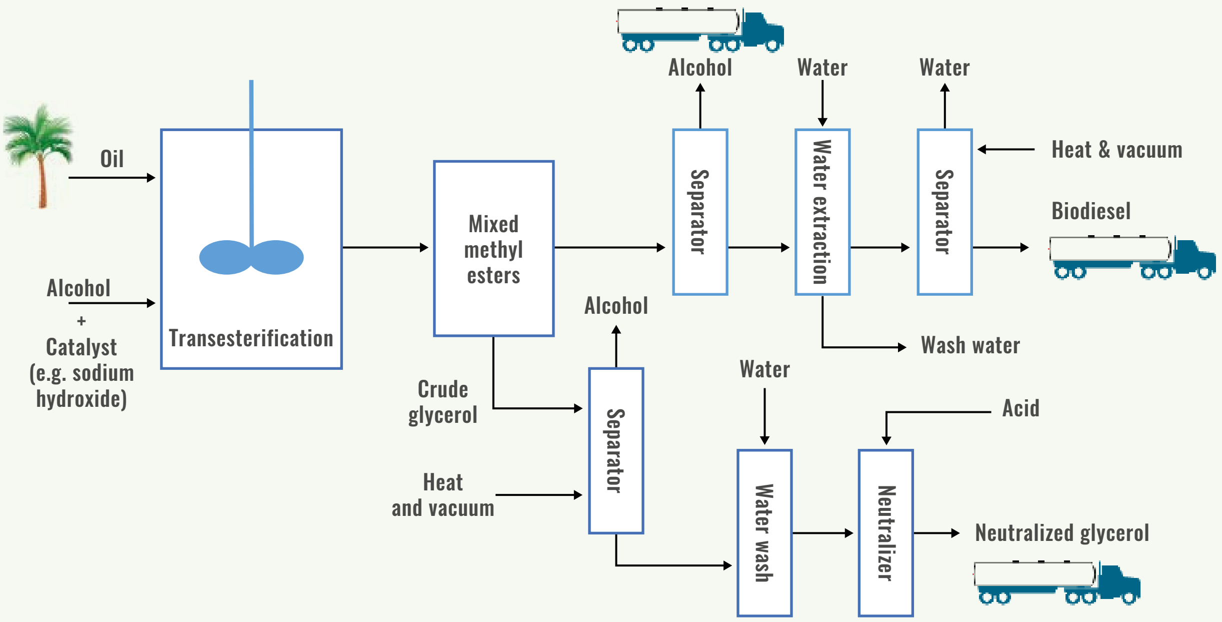
In simple terms, the fuel ethanol production process begins with a pretreatment process in which sugar or starch are recovered. The standard pretreatment process usually includes milling, clarification, and/or evaporation. In the case of sugar crops, after the pretreatment process the sugars are fermented. In the case of starchy feedstock, an additional step is required to convert the starch to sugar, which is followed by the fermentation step. After fermentation, distillation and dehydration systems are used to bring the ethanol to a level of purity so that it can be blended with the gasoline (Quintero *et al.*, 2008; Quintero, Rincón and Cardona, 2011), see **Figure 44**.

Biodiesel is defined as a clean-burning fuel with low viscosity and pour point[4]. This biofuel is composed of fatty alkyl esters produced by using different chemical routes according to the initial feedstock. Biodiesel is produced from different feedstocks, whose properties change according to their fatty acid profiles. Consequently, the fatty acid alkyl esters obtained are diverse and the quality of the biodiesel varies depending on the feedstock used to produce it. For instance, rapeseed biodiesel performs better in cold climates, while the performance of palm biodiesel is problematical during cold weather due to its cold flow properties. Blends of biodiesel and diesel fuel are used to improve combustion in compression ignition engines, reduce GHG emissions and improve fuel properties (Moncada, Rincón and Cardona, 2013; Rincón, Moncada and Cardona, 2014).

Conventional first-generation biodiesel production starts with a pretreatment of feedstock intended to extract the contained oils. Then, the triglycerides (contained in vegetable

FIGURE 45.

BIODIESEL PRODUCTION SYSTEM



Source: Authors

[4] The pour point is defined as the temperature at which a fuel stops flowing

oils or animal fats) catalytically react with short-chain alcohols (methanol or ethanol). This set of reactions is called transesterification. Following this process, the mixture is purified by using a combination of decantation and distillation in order to recover glycerol and obtain the final biodiesel product at 99 percent purity, see **Figure 45**.

Initially, liquid biofuels are blended with fossil fuels. Furthermore, mixing first-generation fuels with conventional fossil fuels reduces the overall cost of liquid biofuels, and at the same time reduces emissions while improving certain fuel properties. The International standard for identifying the concentration of liquid biofuels in blends is BXX nomenclature for biodiesel and EXX for ethanol. For example, B2, B5, B20 and B100 are fuels with a concentration of 2 percent, 5 percent, 20 percent and 100 percent of biodiesel, respectively. These are also the most commonly used blending levels around the world. Ethanol is also available as E85 (or flex fuel). It is important to note however that for higher blends, ethanol-based fuel should be used in flexible fuel vehicles designed to operate on up to 83 percent of any blend of gasoline and ethanol (US department of energy, 2020).

4.3.4 Fuels for cooking

Biomass can be used as a cooking fuel. Biogas, charcoal and briquettes are bioenergy options that have the potential to upgrade biomass fuel properties to a superior form of energy. Different technologies are used to perform the conversion of the relevant feedstock, ranging from biochemical processing to thermochemical processing. Possible feedstock options include woody residues, crop residues, and livestock residues. These options were analysed in the assessment. An overview of each option is presented in the following section.

4.3.4.1 Biogas

Biogas generally refers to a mixture of different gases such as methane, hydrogen, and carbon monoxide. These gases are produced during the breakdown of organic matter in the absence of oxygen, which is a biological process known as anaerobic digestion. This biological process requires the correct conditions such as temperature, water, and even the inoculation of bacteria. These factors are even more important if the quantity produced increases, which is why it is common to utilize agitation and temperature control systems with large-scale biogas production. Another critical factor is the feedstock quality. Ideally, there should be large amounts of organic matter available for digestion and an adequate carbon-to-nitrogen ratio. Therefore, the most common raw materials for biogas include livestock residues, specific crop residues, agricultural waste, municipal waste, green waste, and sewage sludge (Limousy, Jeguirim and Labaki, 2017; Lamers *et al.*, 2017).

Biogas is odorless and colorless and burns with a clear blue flame, similar to that of LPG gas. Its calorific value is 20 MJ/m^3 and burns with 60 percent efficiency in a conventional biogas stove (Arvanitoyannis and Tserkezou, 2008).

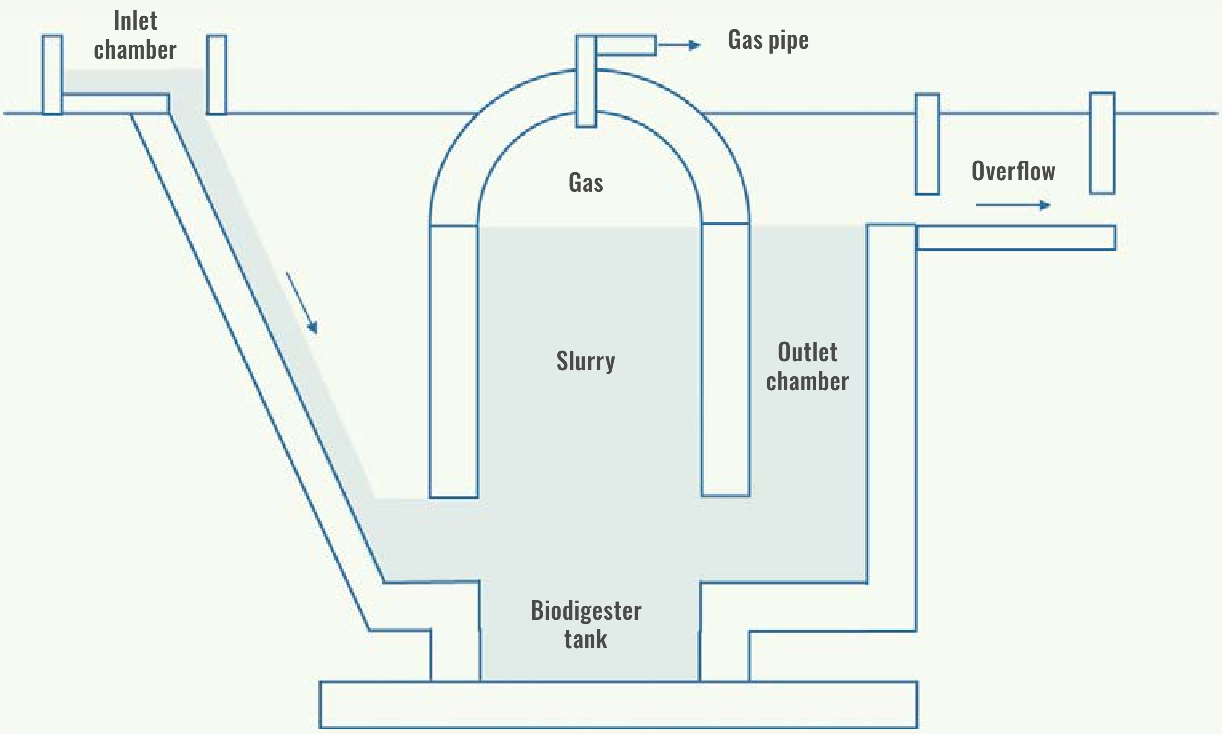
Biogas technology, mainly from livestock residues, has been widely used in rural areas for many years for cooking as well as for lighting using specially designed mantles. In this assessment the biogas systems were designed to produce biogas on a small-scale level, while taking into consideration the feedstock supply, the biogas production, as well as the digestate and biogas usage. The biogas systems considered include a number of diverse digester technologies (see **Figures 46–48**).

The fixed dome biogas digester consists of a digester with a fixed, non-movable gas holder that sits on top of the digester. As the volume of the gas produced augments, in turn the pressure of the gas expands and the difference in height between the slurry level in the digester and the slurry level in the compensation tank increases. This then pushes the slurry into the compensation tank where the excess overflows (see **Figure 46**). All steel components are made of stainless steel, hence the life of the plant is around 10 years. The plant is constructed underground to save space and protect it from physical damage.

The floating drum biogas digester consists of an underground digester and a moving gas holder. The gas holder floats either directly on the slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down according to the amount of gas

FIGURE 46.

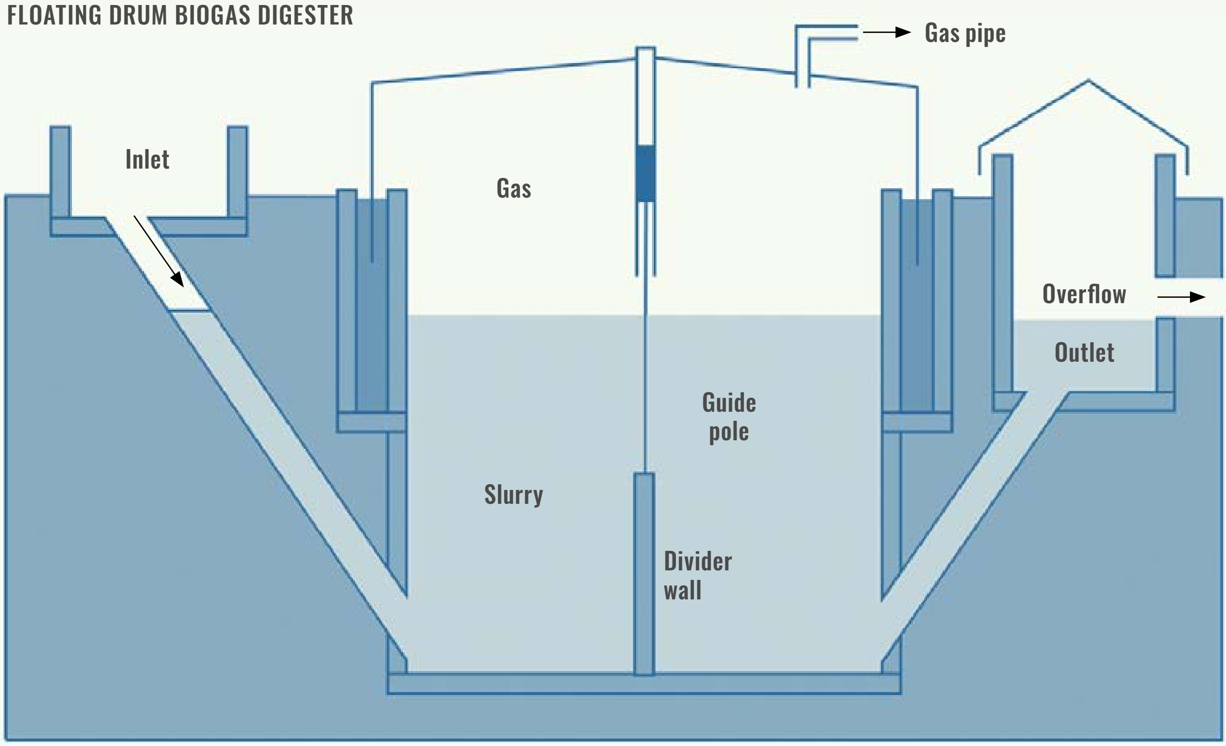
FIXED DOME BIOGAS DIGESTER



Adapted from (Vögeli et al*, 2014)*

FIGURE 47.

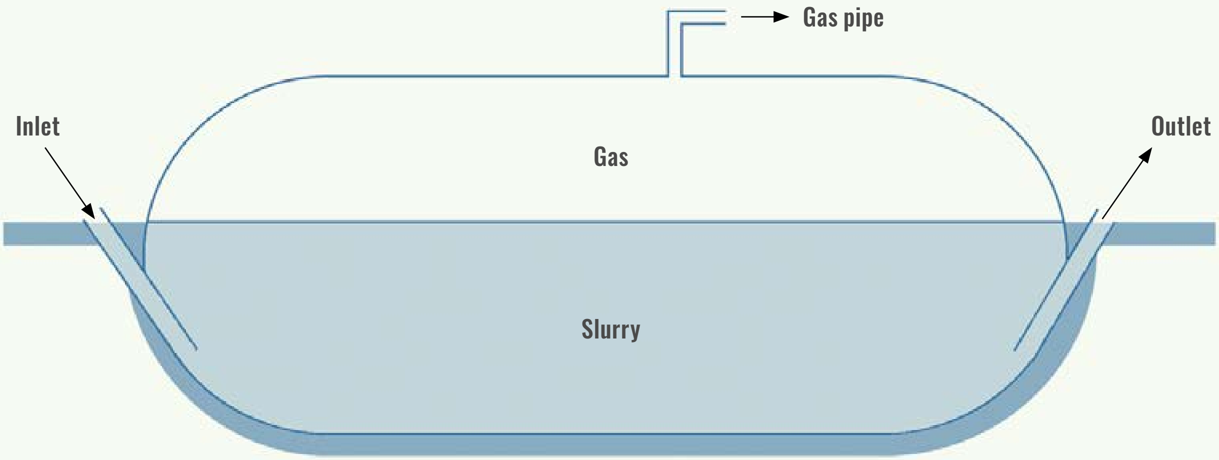
FLOATING DRUM BIOGAS DIGESTER



Adapted from (Vögeli et al*, 2014)*

FIGURE 48.

TUBULAR BIOGAS DIGESTER



Adapted from (Vögeli et al, *2014)*

stored (see **Figure 47**). It may be necessary to replace the steel or plastic components during the lifetime of the system. The lifespan of the drum is around 10 years.

The tubular or polyethylene bag consists of digesters built from two layers of polyethylene plastic in a tubular form. The tubular digester is placed in a trench with a slope to facilitate gravity flow (see **Figure 48**). It is the least expensive system and the easiest to construct, however its lifespan is a mere 5 years.

4.3.4.2 Improved charcoal technologies

Charcoal is used to describe the char produced by the slow pyrolysis of carbon rich substances such as wood, peat, bones, cellulose, or biomass with little or insufficient air (Nachenius *et al.*, 2013). The fuel is similar to fossil coal with similar fuel properties that are highly appreciated for their cooking purposes in developing countries. Traditionally, charcoal is produced using an earth mound kiln. This kiln has a low production efficiency, which in practical terms means that large amounts of raw material are required to produce the charcoal. Seven types of improved charcoal kilns were considered in the analysis. The spectrum of technology options reflects the range of the small, medium and larger technologies available for use and with varying production efficiencies. As the efficiency of the technology increases, the amount of biomass used to produce the charcoal is reduced (see brief description of each technology option below). Efficiencies in charcoal technology range from an absolute minimum of 5 percent to a maximum of 40 percent, while traditional technologies generally have a low efficiency. The technologies that were analysed took into account the improved efficiency technologies with an efficiency from 20 to 35 percent.

The oil drum kiln is easy to construct and is also suitable for charcoal production at the household level. This technology is able to handle small pieces of wood and residues when producing charcoal. The typical efficiency of this kiln is 20 percent (Burnette, 2010).

The Casamance kiln is an improved earth kiln where firing is done at the centre and carbonization occurs around the edge. The internal arrangement of the wood ensures constant air and gas flows in the mound. The chimney at one side of the mound encourages a very effective reverse, down-draft system. The resulting heat circulation improves the efficiency of the kiln, which is 28 percent (Kimaryo and Ngereza, 1989).

The improved charcoal pit kiln: installation and operation of this kiln requires digging a

pit and using a cover made with metal sheets. This kiln produces charcoal more quickly and efficiently than the traditional pit and earth clamp methods. This type of kiln is not suitable for rocky terrain as digging the pit would be both difficult and excessively time consuming (Paddon, 1986). The cover of the kiln is formed using three overlapping steel made structures. The open ends of the cover are blocked with mud. Metal tubes are set into the walls of the pit to provide 3 air inlets, 1 smoke outlet, and a steam release vent to allow for lighting. The efficiency of this technology is 30 percent (Kammen and Lew, 2005).

The portable steel kiln or transportable metal kiln is made of metal sheets. This type of kiln can be easily and frequently dismantled. As a result, it can be rolled along the forest floor to follow commercial timber extraction, plantation thinning or land clearing operations. In this way, the transportation of wood to a centralized processing site can be avoided. Two experienced men are required for the operation of the kiln and the total production cycle takes 2 to 3 days. The efficiency of this technology is 25 percent (Kammen and Lew, 2005).

The standard beehive kiln is built entirely of clay or sand bricks and mud mortar. It requires no steel except for a few bars of flat steel over doors as a reinforcement at the base of the dome, as in the case of the Brazilian furnace. It is robust and not easily damaged by overheating, and can resist unprotected in the sun and rain without corrosion or adverse effects for 5 to 8 years. The carbonization time is 9 days with a production of 5 tonnes per cycle. The efficiency of this technology is 33 percent (Kammen and Lew, 2005).

Missouri kiln is rectangular in shape, and constructed with concrete and fitted with large steel doors. The large doors allow for loading and unloading of the kiln with a front-end loader, thus considerably reducing the need for labour. The volume of the Missouri kiln is 180 m^3 and it produces 17.6 tonnes of charcoal during a 3-week production cycle. The efficiency of this technology is 33 percent (Kammen and Lew, 2005; Rautiainen, Havimo and Gruduls, 2012).

Somalia mound: the capacity of this kiln ranges between 10 and 35 tonnes of air-dry timber. The kiln is built by stacking timber upright on the ground into a circular mound two tiers high in the centre, with the larger pieces making up the lower tier. It is packed as closely as possible and the gaps are filled with smaller pieces of wood. When the stacking is complete the timber is covered with metal sheets made from 200-litre empty oil drums. The sheets are placed over the timber stack and overlap so that the edge of the lower one is underneath the edge of the sheet above it. Soil is placed over the thorny branch wood and metal sheets, forming a covering that is approximately 5 cm thick. In order to light the kiln a worker climbs to the top and removes part of the soil and some of the upper sheets to gain access to the timber charge. The carbonization process takes 4 to 10 days, depending on the kiln size and the condition of the timber. The efficiency of this technology is 42 percent (Kammen and Lew, 2005).

4.3.4.3 Briquette fuels

Briquetting is a technology used to increase the energy density of low bulk density biomass (e.g. densification from 150-200 kg/m^3 to 900-1300 kg/m^3). This operation is technically called 'compacting' or 'densification', and helps to convert waste materials into easy-to-handle. In principle, briquettes can be generated from a number of sources, including food processing residues, crop residues, woody residues, charcoal, peat, paper and plastics (Kozicki, 2015).

Briquettes are used as fuel for heating and cooking, or as fuel for generating electricity and/or steam. Pretreatment is one of the key steps in briquette production, and it must have an optimal particle size of 6-8 mm with a powdery component of 10-20 percent (< 4 mesh), and a moisture content of about 10 percent (Grover and Mishra, 1996). However, due to the diverse range of biomass that can be used for briquetting, and the particular properties associated with each type (e.g. heating value, size, moisture content and chemical composition), typically, pretreatment must ensure that the biomass conditions are suitable for production. In this context, pretreatment processes may involve drying to remove excess moisture, size reduction (cutting, grinding) and preheating biomass (not higher than 300°C) to help loosen fibers and soften its structure, which reduces the wear

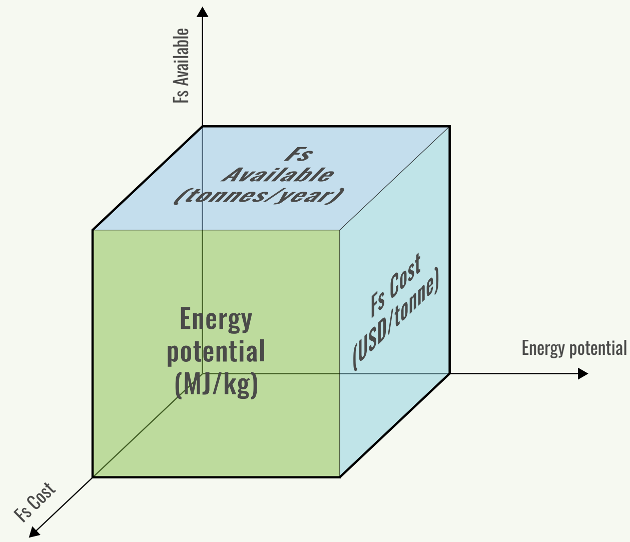
of the screw press (Grover and Mishra, 1996; Bhattacharya and Kumar, 2005).

Technologies for briquetting can be broadly classified into two main categories: hot press and cold press. Hot press options use high-pressure compression of biomass at more than 1 500 bar, thus increasing the temperature of biomass and consequently melting the lignin, while the biomass passes through a hole at a controlled rate. Once biomass leaves the holes, pressure is reduced and the lignin cools and solidifies, binding the biomass into a uniform and solid product. As a result, there is no need to use an external chemical binder, which is extra cost that can therefore be avoided (Hu *et al.*, 2014). However, it should be noted that external energy is required to perform this process under high pressure. The main hot press briquette machines are piston presses (smaller briquettes) and screw presses (larger briquettes). Hot press options are mostly preferred for large-scale operations where external energy can be easily acquired (Fulford and Wheldon, 2015; Bialleck and Rein, 2011).

Cold press options operate under lower pressure and require low or no external electricity, but use large amounts of binder. These options are used for materials with low amounts of lignin i.e. paper, charcoal, coal, and other (Fulford and Wheldon, 2015; Kaliyan and Morey, 2010) or simply when investments in hot press technologies are not feasible. In the case of cold press technologies, once the biomass has been pretreated it is then mixed with a binder such as starch, flour, clay or water. Next, the mixture is pressed into a mould, which then produces wet briquettes. These wet briquettes must subsequently be dried to allow for the binder to set in order to produce the final dried briquettes. This entire process can be done manually or electrically but the most common practice is to produce briquettes manually — the preferred option for small-scale producers (Ngusale *et al.*, 2014).

FIGURE 49.

FEEDSTOCK CHARACTERISTICS CONSIDERED IN BEFS ASSESSMENT



Source: Authors

4.3.5 Feedstock characteristics (quality, cost, availability)

Considering the large number of results obtained in the natural resources assessment section, it was unrealistic to conduct a techno-economic analysis for off-grid electricity and cooking fuel production for every single result obtained for each feedstock. Therefore, ranges were built based on direct and indirect natural resource results, which formed the basis for the techno-economic analysis for different points within defined ranges. Thus, instead of conducting a multitude of specific techno-economic (TE) analysis for each feedstock, the methodology used for techno-economic analysis allowed for the identification of specific conditions under which bioenergy pathways (i.e. combination of feedstock and technology) were considered to be promising. Thereafter, only certain feedstock were analysed for specific bioenergy pathways that could fulfil the set of specific TE conditions. The ranges were built using the amount of feedstock available, the cost of the feedstock, and the energy quality of the feedstock. Each type of feedstock analysed, can be found along these three dimensions according to the combination of its own features. In this assessment, a range of options is analysed based on these three dimensions (see **Figure 49**).

In the case of liquid biofuels, the smaller number of feedstock options (i.e. four) and the specific results obtained for the potential of crops production made the use of a range of analyses unnecessary .

4.3.6 Feedstock availability

The *feedstock availability* refers to the physical quantities available per year. District level results of the natural resources assessment made it possible to identify the absolute minimum and absolute maximum values of feedstock availabilities (see **Table 34** and **Table 35**).

Based on these values, national minimum (non-zero) and maximum values for feedstock availability were found to be 50 tonnes/year and 2 780 040 tonnes/year, respectively. However, this initial availability was re-examined, taking into account technical restrictions such as logistical

issues (e.g. transport, collection, and storage) and realistic plant capacities. The objective of both off-grid electricity and cooking fuel production would be to operate at small-scale and community-level capacities. However, a common factor for all technologies and feedstock options was the fact that 1 tonnes/year is considered

TABLE 34.

SUMMARIZED RESULTS OF THE CROP RESIDUES POTENTIAL

CROP-RESIDUE TYPE		AVAILABLE PER YEAR (TONNES/YEAR)		
		MIN	AVG	MAX
COTTON	STALK	103	153 590	307 078
FOREST PLANTATION RESIDUES		100	9 981	19 862
SUGARCANE	BAGASSE	50	1 716	3 382
SOYBEANS	STRAW	85	78 984	157 884
COTTON	HUSK	103	15 735	31 366
TOBACCO	STALK	77	19 556	39 035
WHEAT	STRAW	102	53 666	107 230
SOYBEAN	PODS	83	68 892	137 700
GROUNDNUTS	HUSK	103	17 877	35 650
SORGHUM	STALK	86	9 938	19 789
SUNFLOWER	STALK	74	28 867	57 659
MILLET	STAW/STALK	70	34 441	68 812
MAIZE	STOVER	115	1 392 078	2 784 040
MAIZE	COB	100	280 585	561 071
CASSAVA	STALK	96	439 049	878 001
RICE	HUSK	168	5 651	11 133
RICE	STRAW	148	17 373	34 599
POTATOES	LEAVES AND PEELS	50	32 233	64 416

Source: Own elaboration BEFS assessment

TABLE 35.

SUMMARIZED RESULTS OF THE LIVESTOCK RESIDUES POTENTIAL

LIVESTOCK	RESIDUE	AVAILABLE PER YEAR (tonnes/year)		
		MIN	AVG	MAX
LAYER CHICKEN	MANURE	0	5 895	11 790
CATTLE – HOUSEHOLDS	MANURE	0	82 529	165 057
CATTLE – COMMERCIAL	MANURE	0	15 384	30 768
GOATS	MANURE	0	891	1 782
PIGS – HOUSEHOLDS	MANURE	0	23 380	46 760
PIGS – COMMERCIAL	MANURE	0	7693	15 386

Source: Own elaboration BEFS assessment

inadequate to supply bioenergy processing plants at any scale. Furthermore, this would probably not be worth analysing from an economic standpoint.

Therefore, the minimum value in the range was reset to a larger number based on the technology option used. At the same time, limitations in terms of accessibility, collection, and transport would make mobilization of all quantities of residue available to one single bioenergy plant challenging.

4.3.7 Feedstock quality

As for the energy content of feedstock, each type will have its own chemical composition in terms of carbon, hydrogen, oxygen, nitrogen and sulphur. Relative quantities of these elements will determine the total potential energy contained in each particular feedstock. In addition, parameters such as moisture, fixed carbon and volatile carbon will determine how easy it will be to release this potential. The combination of all these parameters is measured by the calorific value of a feedstock, or its equivalent property, Low Heating Value (LHV).

In the BEFS analysis, LHV is used as an indicator for the 'energy quality' of each type of feedstock. In this assessment it is possible to distinguish two kinds of LHVs. The first is the LHV of feedstock, which is extracted during the biomass burning and is crucial for those options dedicated to producing energy directly from biomass, namely off-grid combustion and biomass briquettes. The second type of LHV is the one linked to fuel produced from the biomass source, such as biogas, syngas, and biomass charcoal. In this case, the chemical composition usually influences the energy quality of the derived fuel (see **Table 36**).

The energy obtained from feedstock with high energy potentials would be more valuable than those derived from low-energy feedstock. For example, bioenergy products obtained from stalk would be more valuable than bioenergy products derived from potato leaves and peels, independent of the cost or availability. In the case of derived fuels, as expected, the energy potential is higher than the source feedstock due to the chemical transformation of biomass. The efficiency of this transformation was also considered in calculations. In the BEFS assessment, a range from 10 MJ/kg to 20 MJ/kg was used as the energy potential of feedstock.

4.3.8 Feedstock cost

The natural resources assessment also includes indirect qualitative results, such as feedstock location, labour demand and accessibility of residues, together with residue yields and bulk density. These results fed into an additional level of analysis where collection costs were calculated.

For bioenergy production from biomass residues it can be assumed that initial feedstock costs are zero. This is primarily based on the fact that through bioenergy production the residues are in fact being upgraded into a higher value product (energy), which would otherwise pose an environmental problem requiring management. In any case, even if a residue producer is not

TABLE 36.

LHV FOR BIOMASS AND DERIVED FUELS

CROP-RESIDUE TYPE		DERIVATED FUELS		BIOMASS
		LHV SYNGAS (MJ syngas/kg biomass)[1]	LHV CHARCOAL (MJ charcoal/kg biomass)[2]	LHV BIOMASS (MJ biomass/kg biomass)[3]
MILLET	STALK	24.2	19.5	15.6
SORGHUM	STALK	23.7	19.6	15.8
SOYBEANS	PODS	23.3	20.2	16.5
COTTON	HUSK	22.3	20.7	17.2
CASSAVA	STALK	21.1	18.5	14.4
MAIZE	COB	20.5	19.1	15.1
TOBACCO	STALK	20.1	20.3	16.7
GROUNDNUTS	HUSK	20.1	20.1	16.4
RICE	HUSK	20.0	18.1	13.8
MAIZE	STOVER	18.3	19.4	15.5
SUNFLOWER	STALK	18.2	19.6	15.7
COTTON	STALK	17.3	22.2	19.1
FOREST PLANTATION RESIDUES		16.8	21.8	18.6
POTATOES	LEAVES AND PEELS	16.6	16.9	12.3
SOYBEAN	STRAW	16.2	20.8	17.4
WHEAT	STRAW	13.4	20.3	16.6
RICE	STRAW	13.0	17.9	13.6

Source:
*[1]calculated using methodology proposed by (Gautam, Adhikari and Bhavnani, 2010; Lv **et al.**, 2007)*
*[2]calculated using methodology proposed by (Sajdak **et al.**, 2013)*
*[3]Data collected from (CFNILSEN, 2020; Demirel, Gürdil and Gadalla, 2019; Ministry of agriculture food and rural affairs of Ontario, 2019; Morey, Tiffany and HatfieldR, 2006; Müller **et al.**, 2018; Okello, 2014).*

receiving a direct income from residues, the bioenergy producer needs to at least take responsibility for the collection and transport of residues to processing plants. In this sense, the cost of feedstock can be calculated as follows:

Feedstock cost (USD/tonne) =

= Collection cost (USD/tonne) +

+ Baling cost (USD/tonne) +

+ Transport cost (USD/tonne) +

+ Drying (USD/tonne) +

+ Milling (USD/tonne) +

+ Income feedstock producer (USD/tonne)

Where:

Collection costs: As previously stated, regardless of whether or not the crop residues are being offered free to bioenergy producers, they will nevertheless be expected to pay for the collection of the feedstock. In this sense, this cost will depend on the feedstock location. The feedstock located at processing plants or collected during harvesting is considered as already collected, resulting in a zero-collection cost. Nonetheless, if the residues are left in the field after the harvest, the bioenergy producer will have to bear the collection costs. Therefore, collection costs account for the expense of labour and machinery for gathering crop residues in the field. Given the requirements of increasing accessibility and collection rates of crop residues, as discussed in the natural resources

assessment, it is assumed that crop collection will be performed under a semi-mechanized mode, where manual labour is combined with mechanical labour. More specifically, in the case of pruning, the methodology developed by Velasquez-Marti (Velasquez-Marti *et al.*, 2011) was considered.

Transport cost: Once residues are collected, they need to be transported to the bioenergy processing plant. The transport cost depends on the distance as well as unitary costs. First, this parameter will be affected by the current feedstock uses, which will determine the collection distance. In other words, for the feedstock with a large number of competitive uses, bioenergy producers will need to travel even further and visit more collection sites in order to obtain the feedstock required. Moreover, transport costs will depend on the state of the roads in the country, fuel prices, type of vehicle and the salaries of the personnel employed to drive the vehicle and load and unload the charges. In this analysis, transport distances are considered to be an independent variable and will be analysed separately from the collection and baling costs. As a rule, transport distances for bioenergy projects beyond 25–50 km are uneconomical (Sultana and Kumar, 2012). However, for the sake of analysis and in order to understand the effect of transport costs on the unit production cost, a range varying from 3 times the maximum collection radius in the worst-case scenario (150 km) was selected as the upper boundary. For the minimum collection radius, a value of 0 km was selected. As a result, the resulting range of analysis for collection radius was established as 0 km to 150 km.

Drying and milling costs: In some cases, residues are simply too wet or their particle size is unacceptable for bioenergy production;

TABLE 37.

COLLECTION COSTS FOR SELECTED FEEDSTOCK

CROP-RESIDUE TYPE		COLLECTION STATUS	BULK DENSITY	HARVESTING MONTHS	AVAILABLE RESIDUE YIELD (tonnes/ha)		FEEDSTOCK COST
			kg/m^3		MIN	MAX	USD/tonne
SOYBEAN	PODS	COLLECTED	120	MAR–MAY	0.05	3.04	22.96
MAIZE	COB	COLLECTED	84	APR–JUN DEC–FEB	0.05	1.64	21.20
POTATOES	LEAVES & PEELS	COLLECTED	70	FEB–MAR	0.05	4.56	46.51
COTTON	STALK	SPREAD	160	JUN–AUG	0.05	9.17	19.25
SOYBEAN	STRAW	SPREAD	120	MAR–MAY	0.05	2.98	19.63
TOBACCO	STALK	SPREAD	80	FEB–MAY	0.05	38.53	19.89
WHEAT	STRAW	SPREAD	120	AUG–OCT	0.05	5.41	18.65
SORGHUM	STALK	SPREAD	80	MAR–JUN	0.05	3.27	22.57
SUNFLOWER	STALK	SPREAD	80	APR–MAY	0.05	3.17	21.01
MILLET	STAW/ STALK	SPREAD	84	MAR–JUN	0.05	8.05	19.51
MAIZE	STOVER	SPREAD	84	APR–JUN DEC–FEB	0.05	8.41	15.09
CASSAVA	STALK	SPREAD	75	ALL YEAR	0.05	4.68	11.33
RICE	STRAW	SPREAD	120	APR–MAY	0.05	3.55	22.25
FOREST PLANTATION RESIDUES		SPREAD	58	ALL YEAR	1.32	134	58.13
COTTON	HUSK	COLLECTED	160	JUN–AUG	0.05	0.93	15.95
GROUNDNUTS	HUSK	COLLECTED	70	MARCH	0.05	0.32	32.56
RICE	HUSK	COLLECTED	120	APR–MAY	0.05	1.07	18.12

Source: Own elaboration BEFS assessment

TABLE 38.

RANGE OF ANALYSIS SUMMARY

END USE OPTION	PRODUCTION SCALE	MIN FEEDSTOCK AVAILABLE (tonnes/year)	MAX FEEDSTOCK AVAILABLE (tonnes/year)	MIN FEEDSTOCK COST (USD/tonne)	MAX FEEDSTOCK COST (USD/tonne)
BRIQUETTES	**SMALL – MEDIUM**	400	4 000	0	80
OFF-GRID ELECTRICITY	**SMALL – MEDIUM**	100	1 000	0	80
CHARCOAL	**SMALL – MEDIUM**	10	600	0	80
BIOGAS	**SMALL**	2	100	0	50
LIQUID BIOFUELS	**LARGE**	100 000	1 000 000	20	350

Source: Own elaboration BEFS assessment

therefore, before final storing the biomass must be dried and milled. Moreover, proper drying helps to increase the storability of biomass and reduce losses.

Feedstock producer income: During the initial stages of the analysis this value is assumed to be zero. However, the last part of each assessment will include the maximum profitable price that could be paid to feedstock producers by bioenergy plants independently, if feedstock is collected or sold at the market price.

In sum, the values found in **Table 38** are the collection costs calculated for the biomass residues used in this assessment.

The values used for calculating feedstock collection and costs results are summarized in **Table 37** – the feedstock is classified according to the collection costs. Based on these costs, a range of collection costs (0 to 60 USD/tonne) was identified. However, in light of the opinions of various experts that believe that global biomass feedstock prices may increase (Daioglou *et al.*, 2016), the feedstock range selected for this assessment was extended (0 to 80 USD/tonne).

Regarding the crops dedicated to liquid biofuel production, the specific production costs and market prices were calculated and reported respectively in the crop production analysis.

Residue availability and accessibility are the two main factors affecting bioenergy production.

The availability of residue is discussed in the natural resources section and is based on other competing uses.

The accessibility of residue is dependent on various parameters, including available residue density. This factor is an indicator of the current uses of residue. Residues with high yields currently have a low use rate and are easier to collect, while residues with low density currently have many different uses and are more difficult to collect. It can therefore be expected that producers need to travel further to collect low density residues, compared with high yield ones.

In sum, the values found in **Table 5** were used as the range for an analysis within the TE assessment to help cover the main features of all feedstock available.

4.3.9 Data collection

The data used for these components of the BEFS assessment was collected from local sources such as the Ministry of Energy, Ministry of Agriculture, Energy Regulation Board, and other sources in Zambia (BEFS Zambia Survey, 2019). Other specific technical parameters, efficiencies and biomass properties were obtained through a literature review, and will be directly cited throughout the report. The details of the data and the respective values are shown in **Annex 8**.

4.3.10 Financial viability

The financial viability serves as a decision-making supporting tool for future investors it can help determine the financial appealing of the various combinations of feedstock and technologies (in bioenergy pathways). Furthermore, it is an indirect way to measure how easy it will be to deploy the different bioenergy options in the field. The financial viability was calculated using three sequential steps:

4.3.10.1 Calculation of production costs

The production costing was carried out as a tool to measure how much each energy unit produced in the bioenergy factory costs. Overall the costs can be classified as: fixed costs, that is, those costs independent of the production quantities (e.g. labour costs, storage costs); variable costs, such as costs that vary with the production quantities (e.g. main feedstock costs, other raw material costs, utility costs); and operating expenses (i.e. annual depreciation, maintenance, plant overhead, and general and administrative costs). The allocation system used in the calculation of production costs was the traditional method. The share of each individual cost was determined, allowing to identify the largest contributors. Thus, it was possible to evaluate potential measures to reduce production costs.

4.3.10.2 Calculation of cash flows

The free cash flows were used for calculating the financial flows going in and coming out of the project over a fixed time period. In the assessment, the time horizon was fixed at 20 years for all technologies except for charcoal production, where it was fixed at five years due to the short life span of charcoal technologies. All of the calculations were considered as real cash flows due to the fact that the influence of inflation rates was excluded. Revenues, production costs, and operating expenses were taken into consideration for free cash flow calculations.

Revenues were calculated from the potential sales of each bioenergy product at their comparison prices. They were also used as part of the analysis to build scenarios to calculate the profitability of the different energy end-use options under different market conditions. Further explanations and the specific prices will be presented in each section.

4.3.10.3 Calculation of profitability

The figure of merit that is used in BEFS assessment, to estimate the economic value of an investment was the Net Present Value (NPV). The NPV equation presents the cumulative value (revenues – expenses) adjusted to the reference time, where the term $(1+i)^n$ is the discount factor, and is called the discount rate (El-Halwagi, 2012). For example, the discount rate collected for Zambia was 12 percent (BEFS Zambia Survey, 2019). This value was used for the liquid biofuel production assessment because of its large scale and the presence of formal industries. However,

in the case of off-grid electricity, briquettes and biogas production, it was decided to include two additional discount rates in the analysis due to their strong social component, the first one being the social discount rate whose standard value is six percent (Caplin and Leahy, 2004); the second one is the discount rate of ten percent. This falls within the standard for bioenergy projects developed in Africa, which ranges from 9 to 11 percent (Buchholz *et al.*, 2013; Walekhwa, Lars and Mugisha, 2014; Wicke *et al.*, 2011). In sum, the acceptance criterion for a bioenergy investment is that the NPV is greater than zero.

$$NPV = \sum_{i=0}^{n} \frac{\text{Annual cash flows}}{(1+r)^n}$$

4.3.10.4 Profitability zones maps

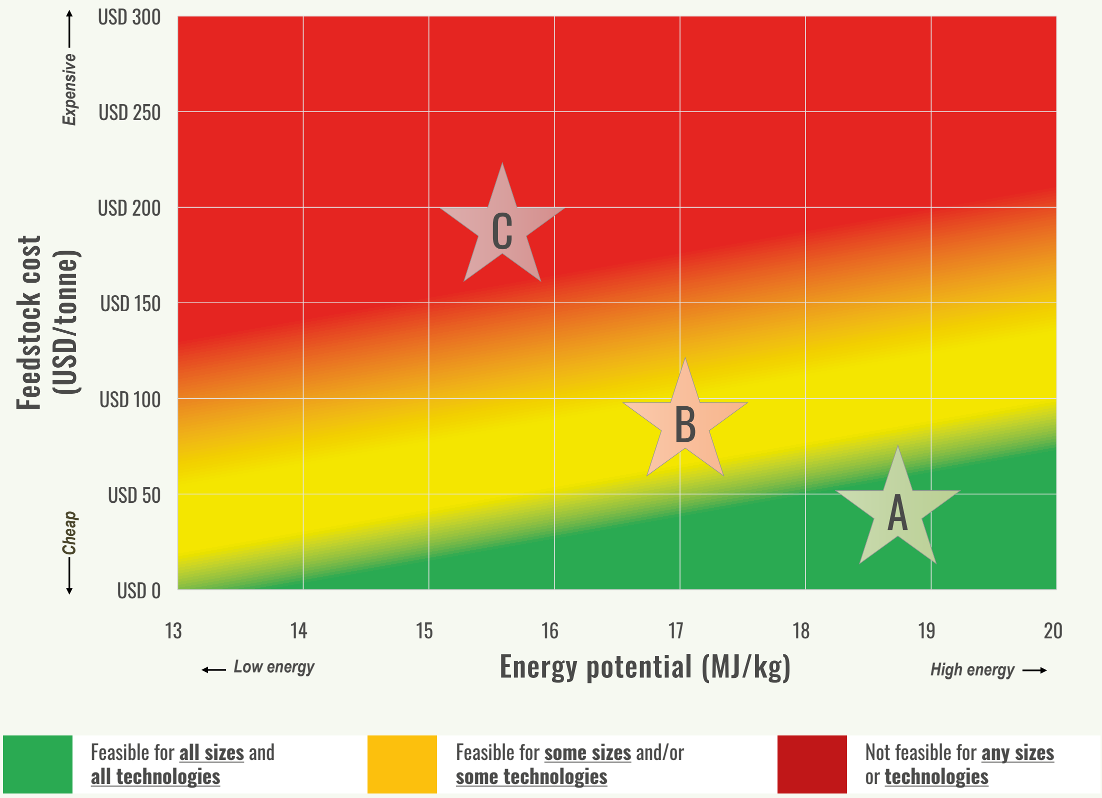
The results on production costs, financial viability and investment requirements are used to define which bioenergy-based technologies would be financially viable. Furthermore, the combined analysis of all of the elements previously mentioned has been illustrated in a Profitability Zone Map (PZM) (Rincon *et al.*, 2019).

In these profitability maps, the feedstock are positioned according to their energy potential and the feedstock costs are plotted on an X-Y chart. These maps are based on a specific comparison price scenario, as well as a specific technology and production conditions.

The maps are comprised of three zones marked by different colours and defined according to the maximum feedstock costs identified for each energy potential within each scenario (see **Figure 50**). The green zone includes

FIGURE 50.

PROFITABILITY ZONES MAP SAMPLE



Source: Own elaboration BEFS assessment

feedstock with energy potential and/or feedstock costs that fulfil the profitable production criteria for all technology options and plant sizes (see **Figure 50**, Zone A). The yellow zone encompasses feedstock that might be profitable under specific criteria: certain plant sizes or technologies (see **Figure 50**, Zone B). Finally, the red zone contains feedstock which do not meet profitability requirements at all (see **Figure 50**, Zone C). These Profitability Zones Maps are also useful for identifying the maximum price that any given feedstock would cost under a set of production conditions. For example, a bioenergy project using feedstock with the energy potential of 17 MJ/kg could be profitable if the price for that feedstock is less than 50 USD/tonnes, using any cogeneration technology and/or plant capacity. However, if the feedstock price is increased to 75 USD/tonnes, then the bioenergy project profitability might be at risk, and this option would therefore only be profitable when using specific technologies and plant sizes. Finally, if the price of this same feedstock were to increase to 120 USD/tonnes, the bioenergy production would not be profitable under any conditions and therefore the feedstock should not be considered as a viable option.

Moreover, these maps can help with the comparison of various feedstock options that may have similar prices but different energy potential. As a result, this will make it easier to understand which option would be more profitable and stable in terms of production.

4.4 OFF-GRID ELECTRICITY

Currently electricity in Zambia is mainly generated from hydropower stations. In fact, the installed electricity power generation capacity stands at 2.8 GW and over 80 percent comes from hydropower. In addition, thermal power and solar power are considered to be possible options (Ismail, Metcalfe and McPherson, 2019). Although hydropower generation has great potential, only a small portion of the population has access to electricity, mainly due to high installation costs and the fact that many areas are located far from the vicinity of the national grid. The Multi-Tier Framework (MTF) survey conducted by the World Bank in Zambia (Luzi *et al.*, 2019) shows that since 2017, 1.4 million Zambian households (42.4 percent of total) have access to electricity through either a national grid (37.7 percent of total) or off-grid (4.7 percent of total), whereas 1.9 million households (57.6 percent of total) have no access to electricity. Indeed, the differences in the access to electricity between urban and rural areas are substantial. While a majority of the urban households (74.8 percent of urban) have access to electricity through the national grid, most rural households (88.1 percent of rural) have no access to any form of electricity source (Luzi *et al.*, 2019). Along these lines, according to

the Ministry of Energy figures, as of 2019, the 67.3 percent of all Zambian urban households and 4.4 percent of rural households had access to electricity (MOE, 2019).

Zambia has been suffering from a shortage in electricity since 2015, reaching a power deficit of as much as 560 MW. This is mainly due to the low water levels in reservoirs and declining water flows in rivers, making the situation even more complicated given the fact that the demand for electricity increases by 200 MW annually (Khatiwada, Purohit and Ackom, 2019). In its efforts to maximize the power generated from limited water (Umar and Kunda-Wamuwi, 2019) ZESCO Limited has embarked on a countrywide power rationing scheme.

The BEFS assessment evaluates the viability of generating off-grid electricity from Zambian biomass residues by using two technologies, namely gasification and combustion. The assessment takes into consideration the electricity generation cost and also incorporates proxies to account for the charges for distributing electricity. Due to the fact that the electricity fees and potential consumptions of off-grid households in Zambia are uncertain, different electricity price scenarios and potential electricity demands should be taken into account.

The BEFS assessment also provides information on potential electricity generation in different districts in Zambia. As a response to different results, it proposes a technology allocation that is techno-economically suitable for the off-grid electricity generation. The results of the assessment will provide information for the Zambian government on the viability and ability of the country to generate biomass-based off-grid electricity, as well as meet the national targets for increasing electricity access.

4.4.1 Electricity comparison prices

As mentioned previously, Zambia has a low electrification rate, particularly in rural areas. In the cases where potential consumers do not have access to electricity, the fees they would potentially be charged are still unknown. Therefore, in order to obtain the comparison prices for off-grid electricity production, it was decided to use three scenarios with the possible electricity prices that generators could use for calculating the profitability of future investments.

The three scenarios that were considered during the BEFS assessment are as follows (see **Figure 51**):

Scenario 1 assumes that the expected price charged is the current electricity price paid by a typical household in the capital city, Lusaka, which is on average equivalent to 0.015 USD/kWh. This is considered to be the lowest electricity tariff that a consumer in Zambia would pay, and is the result of the low cost of electricity generation on a large scale and with subsidies. This situation is entirely different from the case analysed in BEFS assessment, which specifically targets rural communities. Furthermore, it was estimated that the Zambian power sector loses

FIGURE 51.

THREE PRICE SCENARIOS CONSIDERED IN BEFS ASSESSMENT

Scenario 1	Scenario 2	Scenario 3
Lusaka 0.015 USD/kWh	ZESCO 0.15 USD/kWh	Autonomous diesel plant 0.35 USD/kWh

Source: Elaboration based on BEFS Assessment Results

FIGURE 52.

LOAD LEVELS, INDICATIVE ELECTRIC APPLIANCES, AND ASSOCIATED CAPACITY TIERS

Source: Authors based on values methodology reported by (Bhatia and Angelou, 2014)

approximately USD 300–400 million caused by underpricing. As a result, there is insufficient revenue to cover operations, maintenance, and the capital expenditures required for plant refurbishment and expansion by the national electricity company ZESCO (Trimble *et al.*, 2016).

Scenario 2 shows the tariff that the national electricity company ZESCO estimates would help to bring tariffs closer to the cost of electricity, based on the values reported (Batidzirai, Moyo and Kapembwa, 2018). An average price of 0.15 USD/kWh was projected, which is the estimated intermediate price determined during this assessment.

Finally, **Scenario 3** estimates the price of electricity for the electricity generation cost of autonomous diesel plants at 0.35 USD/kWh (Batidzirai, Moyo and Kapembwa, 2018). This is the highest price that was considered during this study.

4.4.2 Electricity demand scenarios

Considering the lack of specific information available on the electricity access in rural areas, it was decided to base this section on the results of the multi-tier framework assessment for Zambia (Luzi *et al.*, 2019). Beyond the simple access or no access to electricity approach, the MTF of the World Bank defines this access according to a spectrum ranging from Tier 0 (no access) to Tier 5 (full access) using seven attributes: capacity, availability, reliability, quality, affordability, formality, and health and safety (see **Figure 52**). The final aggregate tier for a given household is based on the lowest tier attained by households among all of the attributes (Bhatia and Angelou, 2014).

More specifically, the results of the MTF for Zambia found that nationwide, 40.3 percent of Zambian households fall into the category of Tier 1 or above for electricity access. Indeed, 75.2 percent of urban households and 8.7 percent of rural households are found in Tier 1 or above, while grid users are mainly concentrated between Tier 3 and Tier 5. An alternative source of estimates were based on the findings of the BEFS team during the data collection process, where the current average demand of electricity for on-grid users in Zambia was estimated as 200 kWh/month/hh (BEFS Zambia Survey, 2019). The average demand would therefore be located above Tier 3, according to the values presented in **Table 39**.

The current Zambian grid infrastructure is available in 58.4 percent of the enumeration areas (EAs) in the country; however, only

TABLE 39.

ELECTRICITY AVAILABILITY, GENERATION HOURS PER DAY AND DEMAND CALCULATED FOR THE CONSIDERED TIERS

TIERS	TIER	MIN	MAX	SELECTED	ELECTRICITY AVAILABILITY	OPERATION GENERATION SYSTEM	DEMAND
		W	W	W	h/day	h/day	kWh/month/hh
TIER 0	0	0	3	0	0	0	0
TIER 1	1	3	49	26	4	5	3.12
TIER 2	2	50	199	125	4	5	14.94
TIER 3	3	200	799	500	8	9	119.88
TIER 4	4	800	1 999	1 399.5	16	17	671.76
TIER 5	5	2 000	> 2 500	2 250	23	24	1 552.50

Source: Elaboration based on BEFS Assessment Results based on (Bhatia and Angelou, 2014)

37.7 percent of Zambian households are connected to the grid. The low uptake rate of grid connection offers the possibility to increase the grid electrification rate by around 20 percent through connecting households that are "under the grid" that is, directly beneath the existing grid infrastructure (Luzi *et al.*, 2019).

Given that the main consumers of off-grid electricity systems in Zambia are currently concentrated between Tier 0 (no access) and 2, according to the BEFS assessment it can be assumed that these users will start moving from Tier 0 (no access) to Tier 1 and eventually to the Tier 3 level; thus corresponding to the current national average consumption. This selection is based on households with electricity-use profiles ranging from lighting only, to conventional consumption of typical households in urban areas. Based on the reported values (Bhatia and Angelou, 2014) calculations of the values presented in **Table 39** represent the electricity level access of a household per tier, the electricity availability, the operation of generation systems to estimate the demand per month at different tier levels.

4.4.3 Results for biomass based off grid-electricity generation

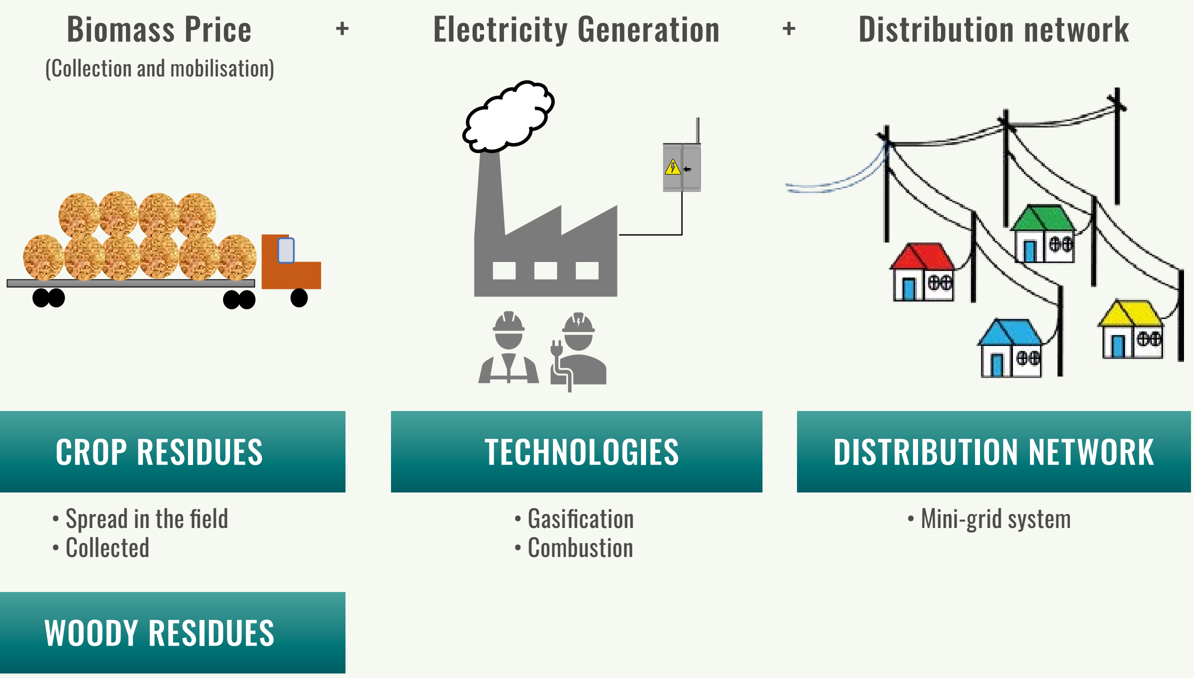
Biomass-based electricity generation on a small scale has been used throughout the world as an off-grid electricity solution, and offers the possibility to use locally produced biomass (Situmorang *et al.*, 2020). This method helps to avoid the need for fossil fuel acquisition and transport to the off-grid areas while at the same time adds value the locally produced biomass residues.

Traditionally in Zambia, the options of off-grid electricity generation used the most frequently have been PV systems and autonomous diesel generators (Matthew Woods, Rahul Barua, 2019). Although electricity generation from biomass was mentioned as one potential option in the Rural Electrification Master Plan (REMP) (Government of the Republic of Zambia, 2009), there has not been a single biomass power generation plant installed to date. As of 2017, there were plans to develop a biomass based gasification power plant with a 1 MWel capacity in Kitwe (Kaoma, Mwanza and Mpanga, 2017).

The off-grid electricity assessment includes the biomass collection and mobilization for the biomass residues used to supply the small electricity generation systems (see **Figure 53**). This is an important feature of the assessment because biomass procurement is frequently a distortion source for the stable operation of biomass-based off-grid electricity systems. For this reason, the availability and cost of biomass residues were included. Moreover, the electricity generation costs considered the technical and operational differences between combustion and gasification technologies. Finally, the electricity distribution cost in the BEFS assessment was also included; this particular feature is not

FIGURE 53.

COMPONENTS OF BEFS ASSESSMENT FOR OFF-GRID ELECTRICITY GENERATION



Source: Elaboration based on BEFS Assessment Results

often considered in the evaluation of electricity generation projects. The ratio between the number of potential consumers and the demand for electricity can nevertheless have a significant impact on capital investment needs, and therefore requires further discussion.

4.4.4 Production cost of electricity

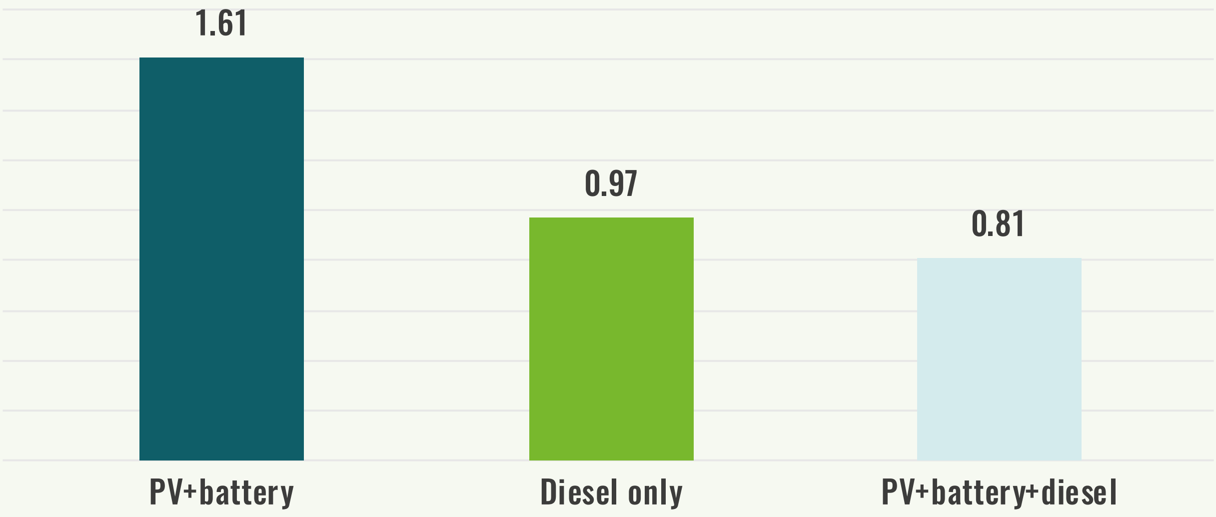
Firstly, it is essential to understand whether biomass-based electricity generation systems can be cost-competitive as compared to other renewable electricity technologies. The figure of merit used for this comparison was the Levelized Cost of electricity[5] (LCOE) (Ghose and Franchetti, 2018), which allows by definition a fair comparison between different technologies (Nissen and Harfst, 2019). However, this should not be confused with the generation cost of electricity, which will be used at a later time along with the three electricity price scenarios to calculate the profitability of biomass-based electricity generation. Therefore, the LCOEs for off-grid systems were calculated and compared to the cost of three renewable technologies used in Zambia: PV+batteries, diesel only, PV+battery+diesel (see **Figure 54**). In this specific case the LCOEs were calculated, excluding the distribution costs, to make all the systems comparable.

Figure 55 represents the LCOE (USD/kWh) for combustion and gasification systems, which are presented on the Y-axis. The results are divided into three sub-charts based on the energy potential of the feedstock being considered: low, medium, and high energy potential. There are two X-axis: the lower one represents the available feedstock range, and the upper X-axis shows the equivalent electricity that can be generated from the feedstock available at

[5] The LCOE is the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. An electricity price above this would yield a greater return on capital while a price below it would yield a lower return on capital or even a loss.

FIGURE 54.

LCOE FOR DIFFERENT SYSTEM TYPES IN ZAMBIA UPDATED TO 2019 VALUES (USD/kWh)



Source: International Renewable Energy Agency (IRENA), 2015

each energy potential level. It is worth noting that the electricity generation capacities are different for each energy potential level, but the feedstock range remains the same. This result demonstrates how higher energy potential feedstock can generate more electricity than lower energy potential ones. Moreover, the LCOEs were also calculated using three cost levels: low, medium, and high.

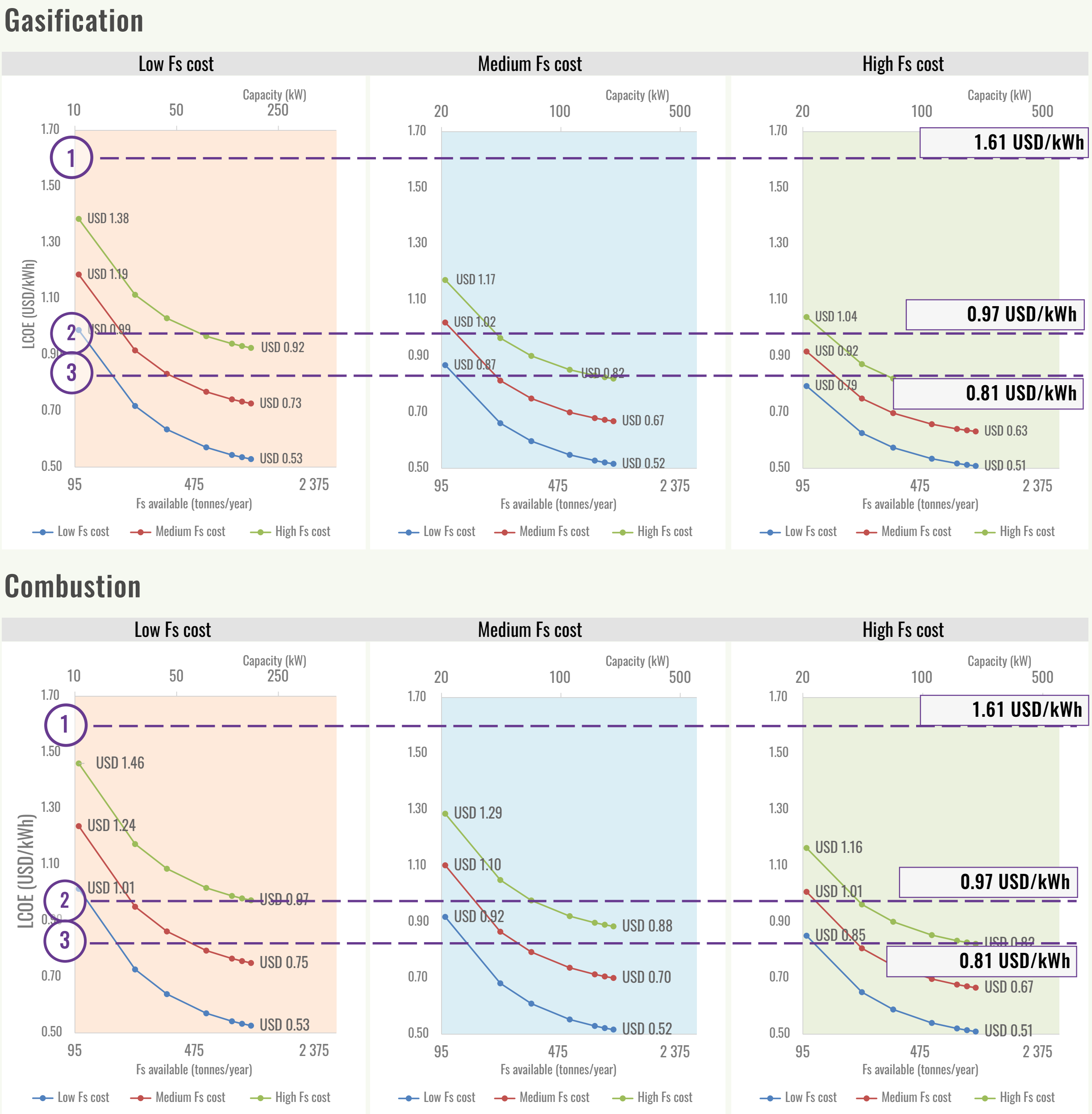
The LCOEs for renewable energies presented in **Figure 54** have been included in **Figure 55** as dotted lines to simplify their comparison. On the whole, it is evident that the LCOE for biomass-based systems is more economical than PV+battery systems and diesel generators, and in some instances less expensive than hybrid PV+battery+diesel systems. Indeed, one can conclude that biomass-based electricity generation systems are cost-competitive compared to other renewable and non-renewable electricity generation options. Moreover, biomass-based systems, as compared to the least expensive hybrid system, can be maintained and operated as a single system and furthermore, can function continuously regardless of weather conditions.

As mentioned previously, the electricity generation costs are different from those of the LCOEs. The next step represents a comparison of the electricity generation costs to the three electricity price scenarios (see **Figure 56**).

In order to evaluate the feasibility of a gasification and combustion technology in this case, these three scenario prices were compared to the calculated production cost. In **Figure 56** the distribution network costs have not been included. Clearly, price scenario 1 is not profitable

FIGURE 55.

LCOE FOR GASIFICATION AND COMBUSTION SYSTEMS IN ZAMBIA. (1) PV+BATTERY SYSTEMS (2) DIESEL ONLY GENERATORS, AND (3) PV+BATTERY+DIESEL

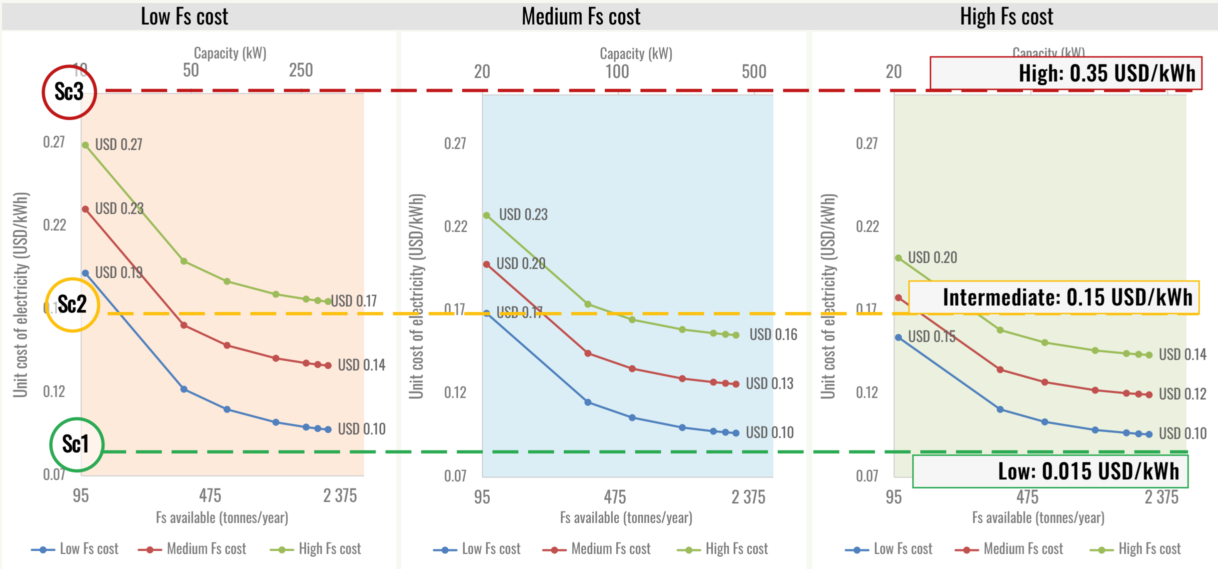


Source: Elaboration based on BEFS Assessment Results

because it is below all of the generation costs being considered; on the other hand, price scenario 3 is always profitable as it exceeds all of the generation cost options, while price scenario 2 is profitable for most of production cost options being considered except when the availability of feedstock is low. In the following sections the relationship between generation and electricity price scenarios will be presented with the aim to calculate the profitability. First, the effect of different energy demand levels and the distribution network costs will be explained.

FIGURE 56.

COMPARISON OF THE ELECTRICITY GENERATION COST FOR THREE PRICE SCENARIOS (ELECTICITY DISTRIBUTION COST EXCLUDED)



Source: Elaboration based on BEFS Assessment Results

4.4.5 Effect of energy tiers on capital investment and distribution network costs

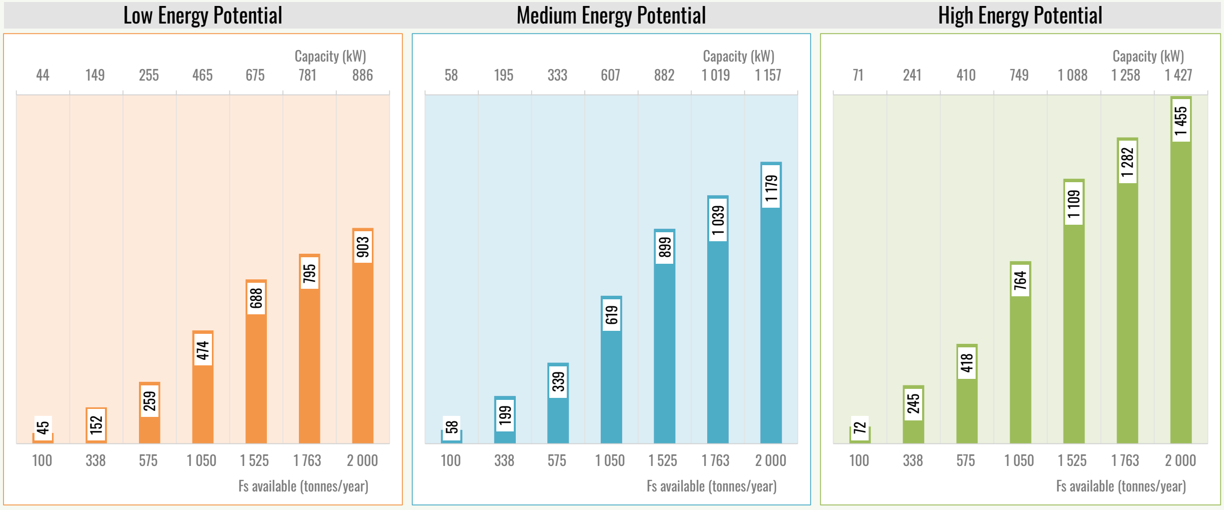
The electricity demand tier will determine the number of households that can be supplied by a given electricity generation system based on the energy potential of feedstock used. As an example, **Figure 57** represents the number of Tier 3 households (120 kWh/month/hh) that could potentially be supplied by gasification systems; it also makes an analysis of the same electricity demand for feedstock options within the three energy potential levels. Furthermore, it was observed that for the same quantity of feedstock available more households can be provided. Finally, it shows how using high energy potential feedstock makes it possible to supply, on average, 58 percent more households than when using low energy potential feedstock.

The effect of energy tiers represented in **Figure 57** is thoroughly explained by the differences in the electricity generation capacities of low energy potential and high energy potential based systems. The largest low energy potential system can have a capacity of up to 886 kW, while the largest high energy potential has 1.43 MW; moreover, this feature implies that capital investment will be increased accordingly. **Figure 58** illustrates the range of the number of houses that could potentially be supplied (left) and the investment required for a Tier 3 demand (right) with a low energy potential feedstock. It was found that with a minimum of 100 tonnes of this feedstock per year, 42 households can be supplied for and an investment of USD 26 554 would be required. On the other hand, with the maximum of available feedstock of 2 000 tonnes per year, 903 households could potentially be supplied with an investment of USD 481 423 needed.

In the case where the above calculations are extended to other energy potential options, **Figure 59** shows the variation in the capital investment for different electricity generation systems. As is to be expected, the largest variation is found in both the generation capacity and the number of households potentially supplied, as well as in the capital investment.

FIGURE 57.

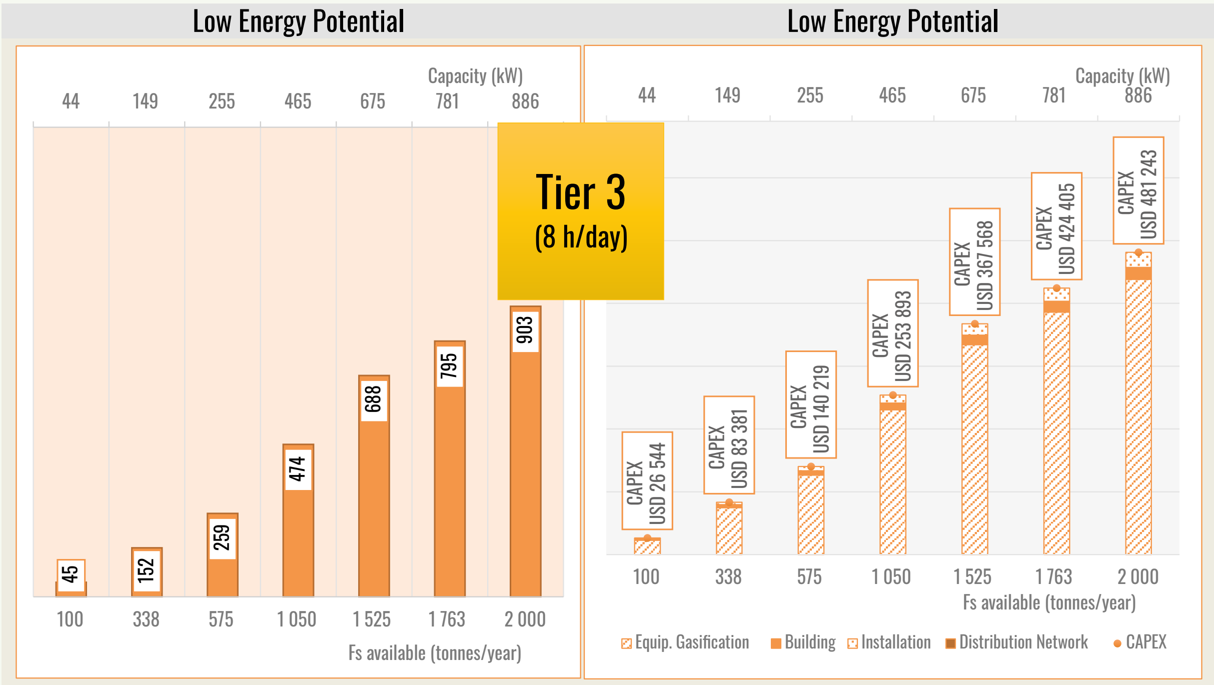
NUMBER OF HOUSEHOLDS SUPPLIED BY THE THREE ENERGY POTENTIAL LEVELS (TIER 3)



Source: Elaboration based on BEFS Assessment Results

FIGURE 58.

NUMBER OF HOUSEHOLDS SUPPLIED (LEFT) AND INVESTMENT REQUIRED (RIGHT) FOR A TIER 3 DEMAND AND FEEDSTOCK WITH LOW ENERGY POTENTIAL

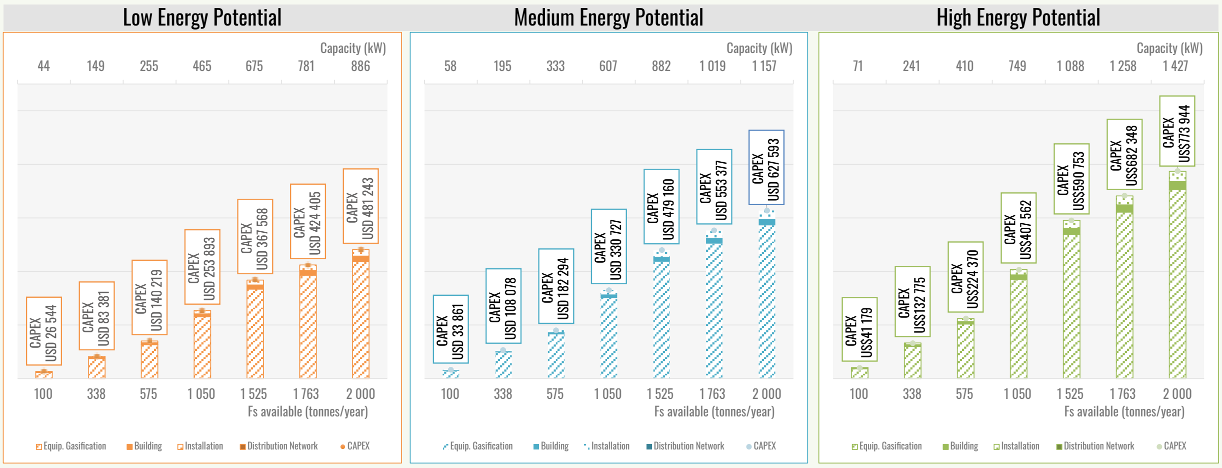


Source: Elaboration based on BEFS Assessment Results

Along these lines, the increment in the potential number of households supplied implies the need for a more extensive distribution system. This will also have a determinant effect on the total capital investment cost of the off-grid systems. **Figure 60** shows the impact of the distribution network on the total capital investment costs for medium energy potential gasification systems supplying Tier 3 households; the blue box represents the cost of distribution. The increment ratio of this distribution cost over the original capital investment is on average of 45 percent, and more specifically and considering the maximum amount of feedstock available (2 thousand tonnes per year), the total capital investment increases by 300 thousand dollars when the distribution network cost is added.

FIGURE 59.

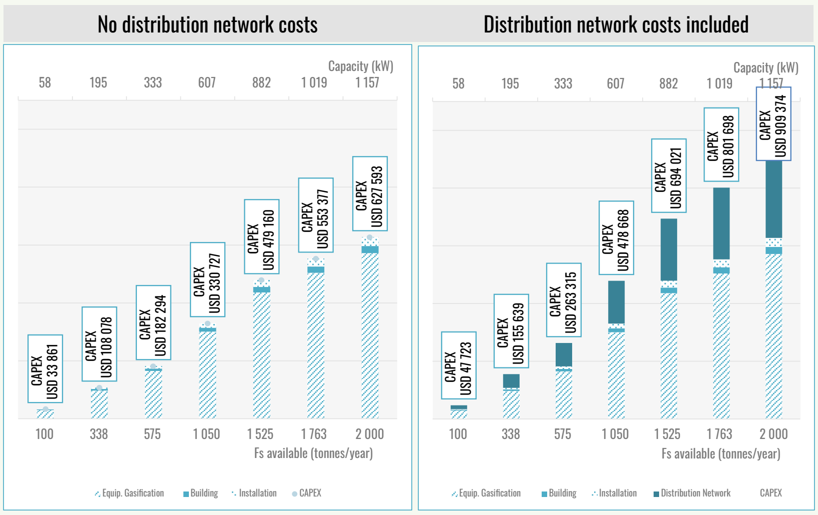
INVESTMENT COST FOR THE THREE ENERGY POTENTIAL LEVELS (TIER 3)



Source: Elaboration based on BEFS Assessment Results

FIGURE 60.

TOTAL COST OF INVESTMENT WITHOUT (LEFT) AND WITH (RIGHT) DISTRIBUTING NETWORK COSTS



Source: Elaboration based on BEFS Assessment Results

In sum, once the unit cost of electricity was recalculated and the distribution network cost was added, it was found that on average the total electricity generation cost increased by 0.012 USD/kWh, thus adding 10 percent to the total cost.

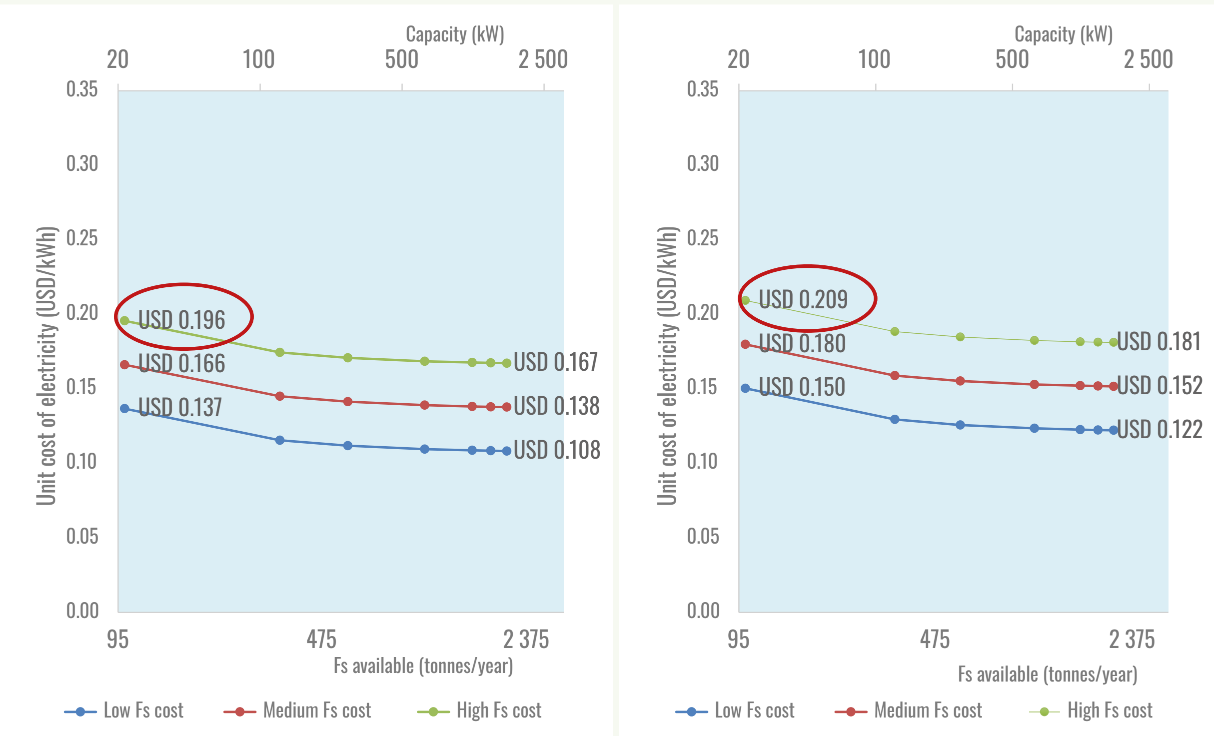
Finally, the effect of the electricity demand tiers on the distribution network costs was analysed. This was accomplished by calculating the number of Tier 1 (<3.12 kWh/month/hh, operating 5 h/day) and Tier 5 (1552 kWh/month/hh, operating 24 h/day) households potentially supplied by using the medium-energy potential off-grid electricity systems (see **Figure 62**). Subsequently, the distribution network costs needed for bringing electricity to the above number of households were estimated. In the first case, based on the assumption that all households would demand Tier 1 electricity mainly for lighting, the broadest possible coverage was obtained. It may be possible to reach more than 38 thousand households using the largest generation capacity, however, this would require a substantial potential investment in order to cover the distributions costs. On the other hand, there is a demand for Tier 5 electricity in households running appliances all day long. In this case, while taking into account the same amount of feedstock available it would be possible to supply 83 households. Consequently, the distribution network cost would be lower than in the first case.

Indeed, the potential electricity demands from households will have an impact on the investment required for the electricity systems, as well as on the number of households served. Tier 5 alternatives have the largest operating times combined with the lowest potential

FIGURE 61.

UNIT COST OF ELECTRICITY FOR A TIER 3 DEMAND WITH AND WITHOUT CONSIDERING DISTRIBUTION NETWORK COSTS

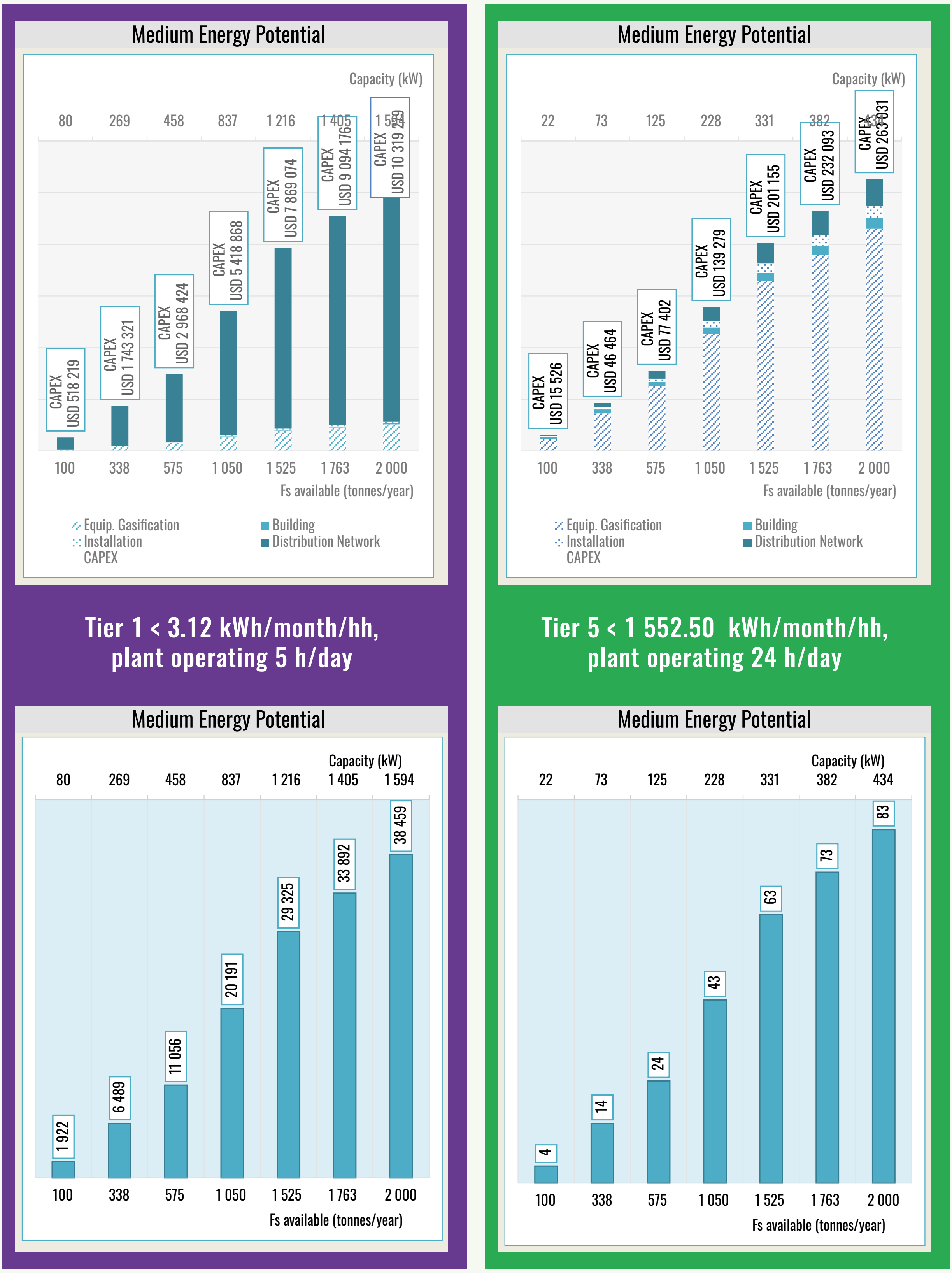
No distribution network costs	Distribution network costs included



Source: Elaboration based on BEFS Assessment Results

FIGURE 62.

TOTAL COST OF INVESTMENT INCLUDING DISTRIBUTION NETWORK COSTS FOR TIER 1 AND 5 FOR A MEDIUM ENERGY POTENTIAL



Source: Elaboration based on BEFS Assessment Results

FIGURE 63.

COMPONENTS OF PROFITABILITY CALCULATION

Biomass Price (Collection and mobilisation) + **Electricity Generation** + **Distribution network**

Source: Elaboration based on BEFS Assessment Results

consumers; as a result their total CAPEX are 2/3 smaller compared to Tier 1 alternatives. However, in the Tier 1 extreme the capital investment might be high, at the same time the potential consumers paying for the electricity could also be higher. Therefore, the price paid for electricity and the availability of consumers to pay will be a determinant for the sustainability of the off-grid systems and their future expansion. These features will be explored in the following section.

4.4.6 Electricity generation profitability

Once the production costs and the electricity comparison price scenarios were defined, it was possible to estimate profitability using the Net Present Value (NPV) as a figure of merit. Subsequently, the analysis estimated the NPV by using a range of feedstock properties and generation capacities (see **Figure 63**) and the results were differentiated for the two technology options (i.e. gasification and combustion). The following subsection presents the results for each electricity comparison price scenario.

4.4.6.1 Scenario 1: consumers paying an electricity price of 0.015 USD/kWh

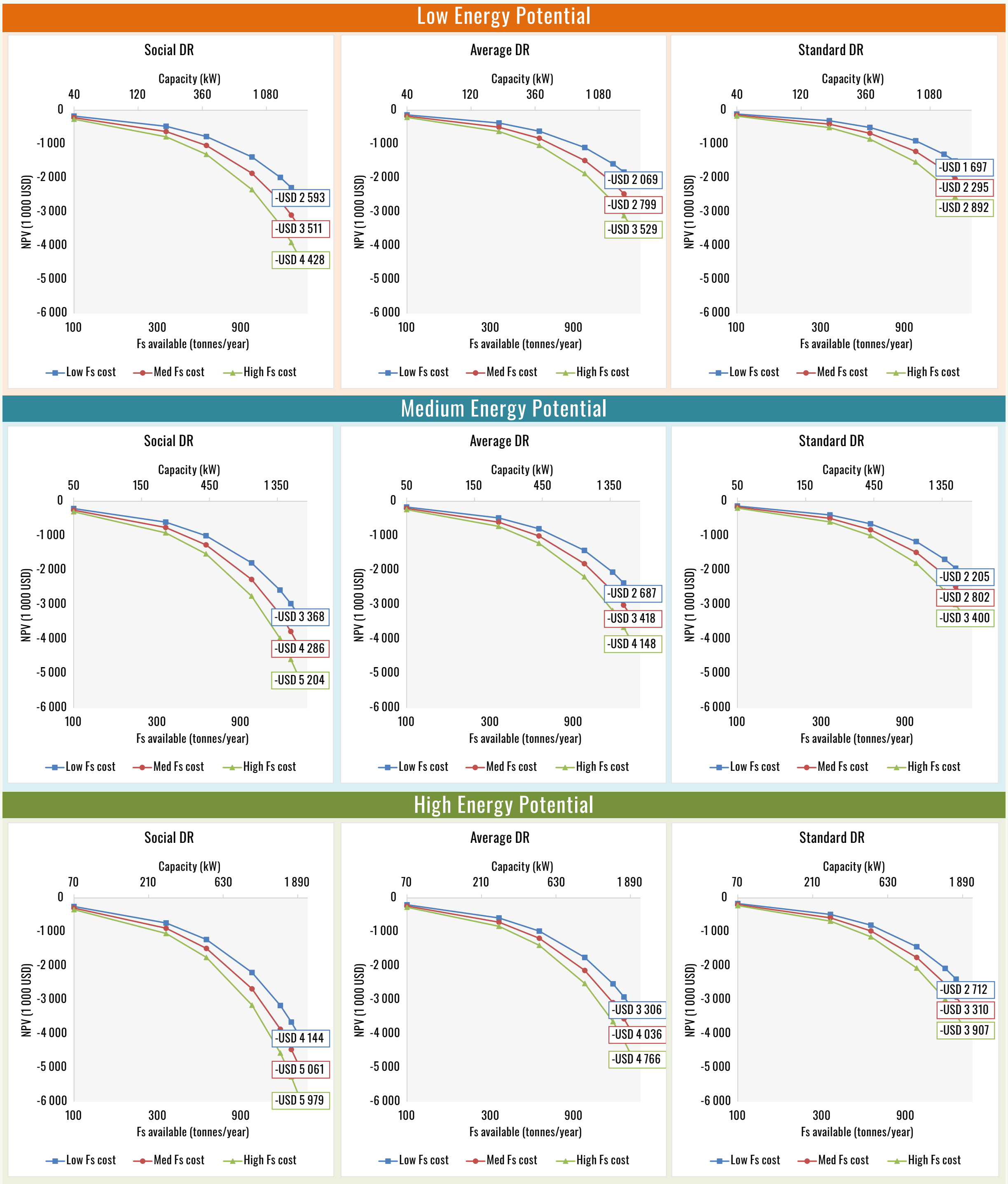
Figure 64 summarizes the NPV obtained for electricity generation using gasification technology and selling the electricity to potential consumers at 0.015 USD/kWh. In this case, results are provided for the Tier 3 energy demand, as in the previous sections. It presents the NPV for different electricity generation systems, three energy potential levels, and three possible discount rates.

The results demonstrate that no generation capacity or energy potential can be profitable when electricity is sold at the same price, currently being paid by consumers in on-grid urban areas. The same results were obtained for electricity generation using combustion technologies.

These results are easier to understand when the Profitability Zones Maps (PZM) is applied. The feedstock options available were used to populate each PZM based on a combination of the energy potential and the collection cost of each feedstock. The obtained PZMs, for both gasification and combustion technology shows that only the red

FIGURE 64.

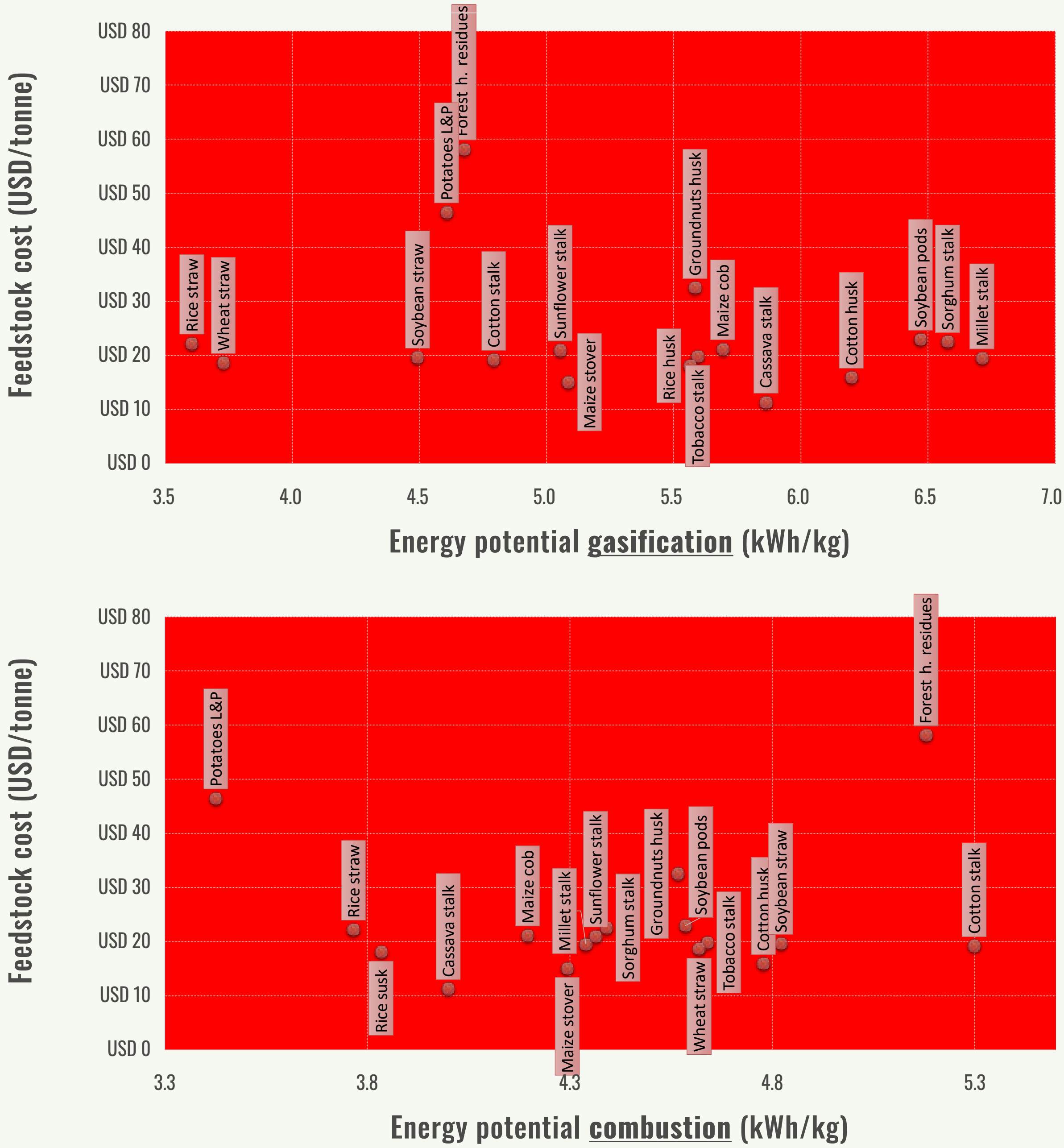
NPV FOR ELECTRICITY GENERATION FROM GASIFICATION, SELLING ELECTRICITY AT 0.015 USD/kWh



Source: Elaboration based on BEFS Assessment Results

FIGURE 65.

PZM FOR GASIFICATION AND COMBUSTION TECHNOLOGIES UNDER SCENARIO 1 ELECTRICITY PRICE



Source: Elaboration based on BEFS Assessment Results

area of the surface is visible. This means that with this low electricity price (0.015 USD/kWh) biomass based electricity will not be profitable, no matter which technology, capacity, or feedstock is used. **Figure 65** shows the PZM for gasification and combustion technologies.

It is worth mentioning that the feedstock location in the PZMs is different in the gasification and combustion charts. The difference in the X-axis data in both graphs clearly explains this difference. For example, in the case of the PZM for gasification it contains the LHV of the syngas produced from biomass, whereas for combustion, the LVH is associated directly with the biomass. Moreover, the different relative position in terms of energy

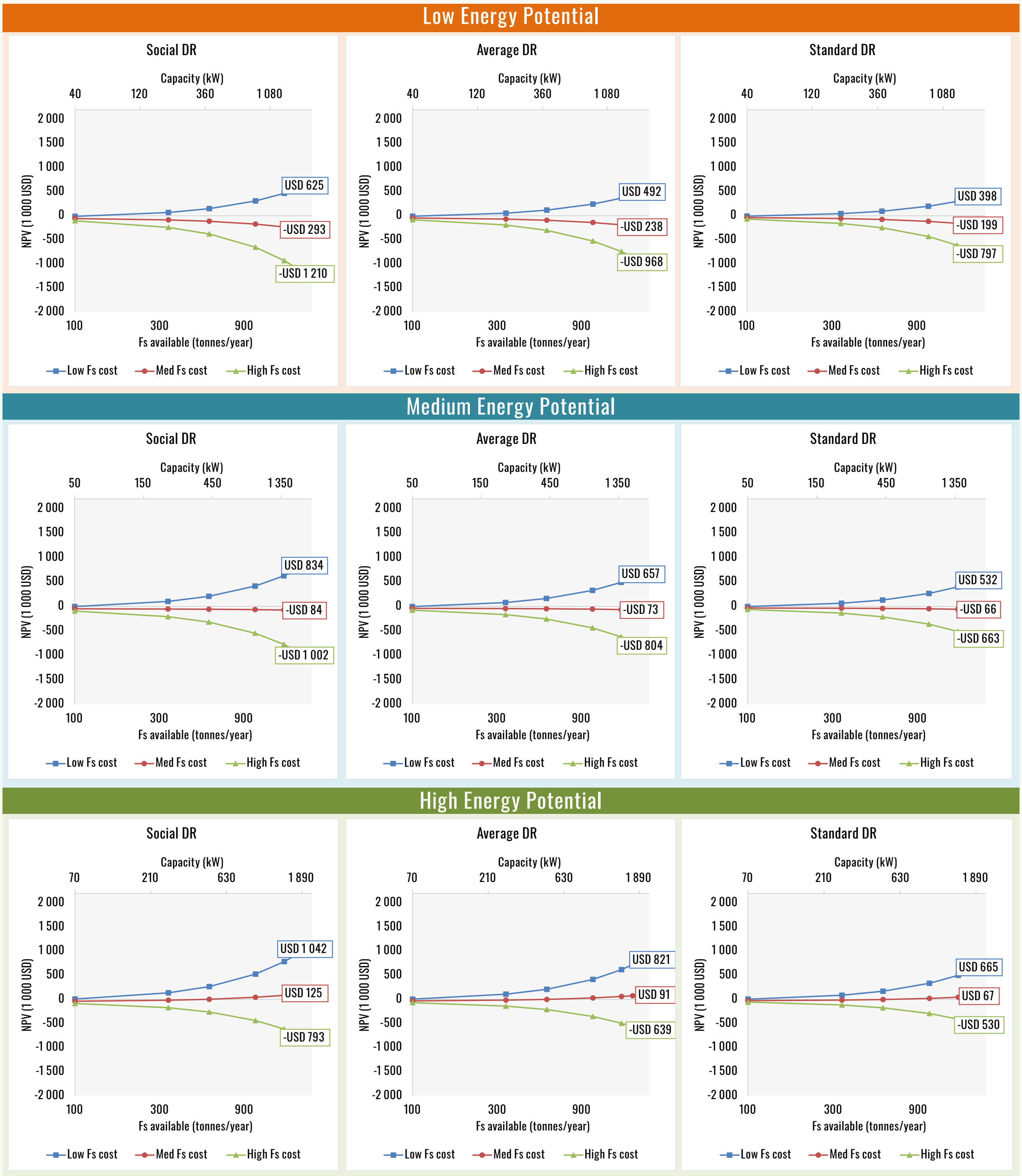
quality is an indicator of how the gasification process can enhance the fuel properties of certain biomass options.

4.4.6.2 Scenario 2: consumers paying an electricity price of 0.15 USD/kWh

Figure 66 summarizes the NPV obtained for electricity generation using a gasification

FIGURE 66.

NPV FOR ELECTRICITY GENERATION FROM GASIFICATION, SELLING ELECTRICITY AT 0.15 USD/kWh



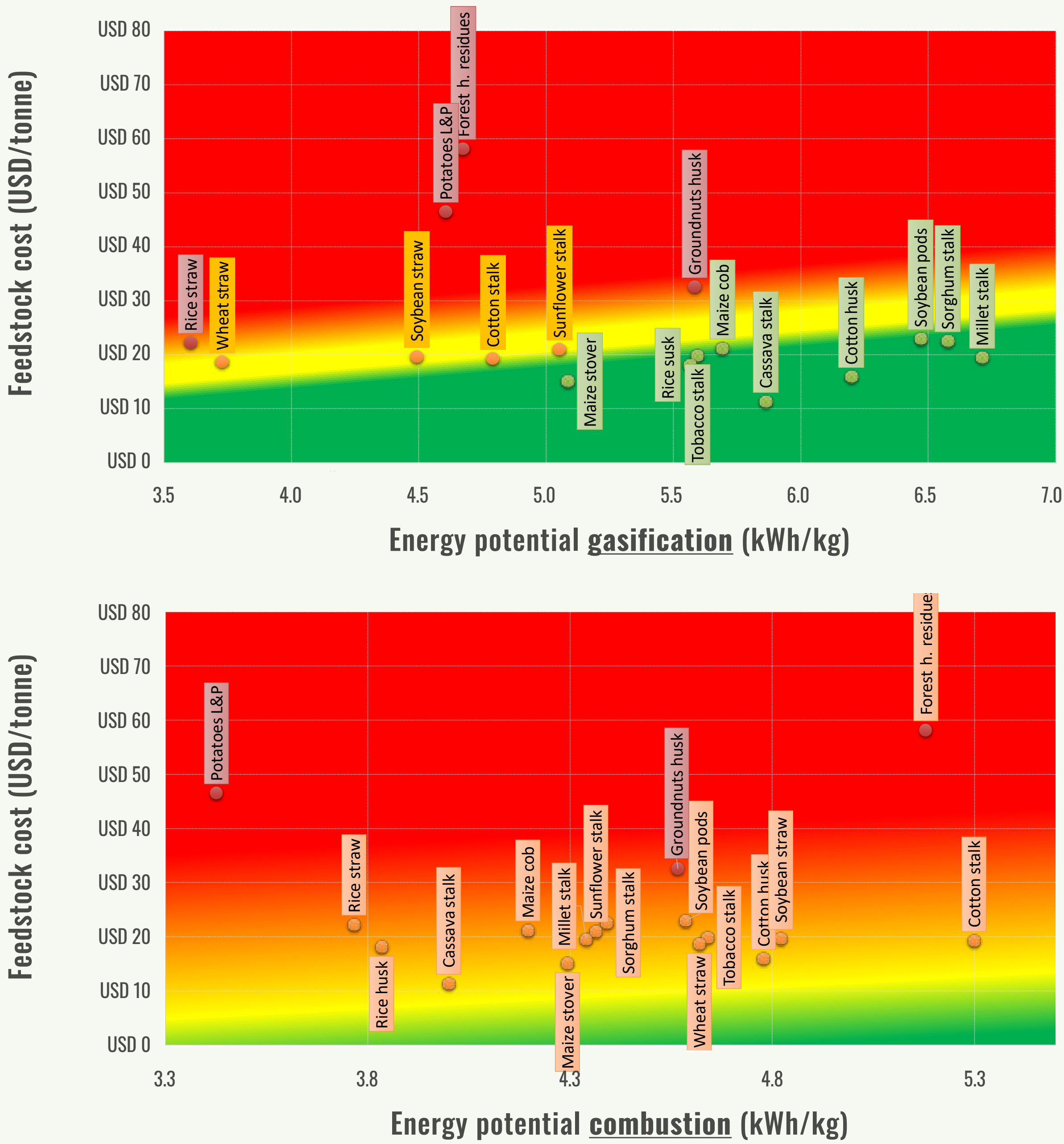
Source: Elaboration based on BEFS Assessment Results

technology and selling the electricity to potential consumers at 0.15 USD/kWh. In this case, the obtained results show that combinations of medium and high-energy potential feedstock, paying a maximum between 20–50 USD/tonne (depending on the energy potential), would potentially result in profitable options in the case of gasification. Conversely, in the case of combustion technologies, the maximum payable would range between 5–25 USD/tonne.

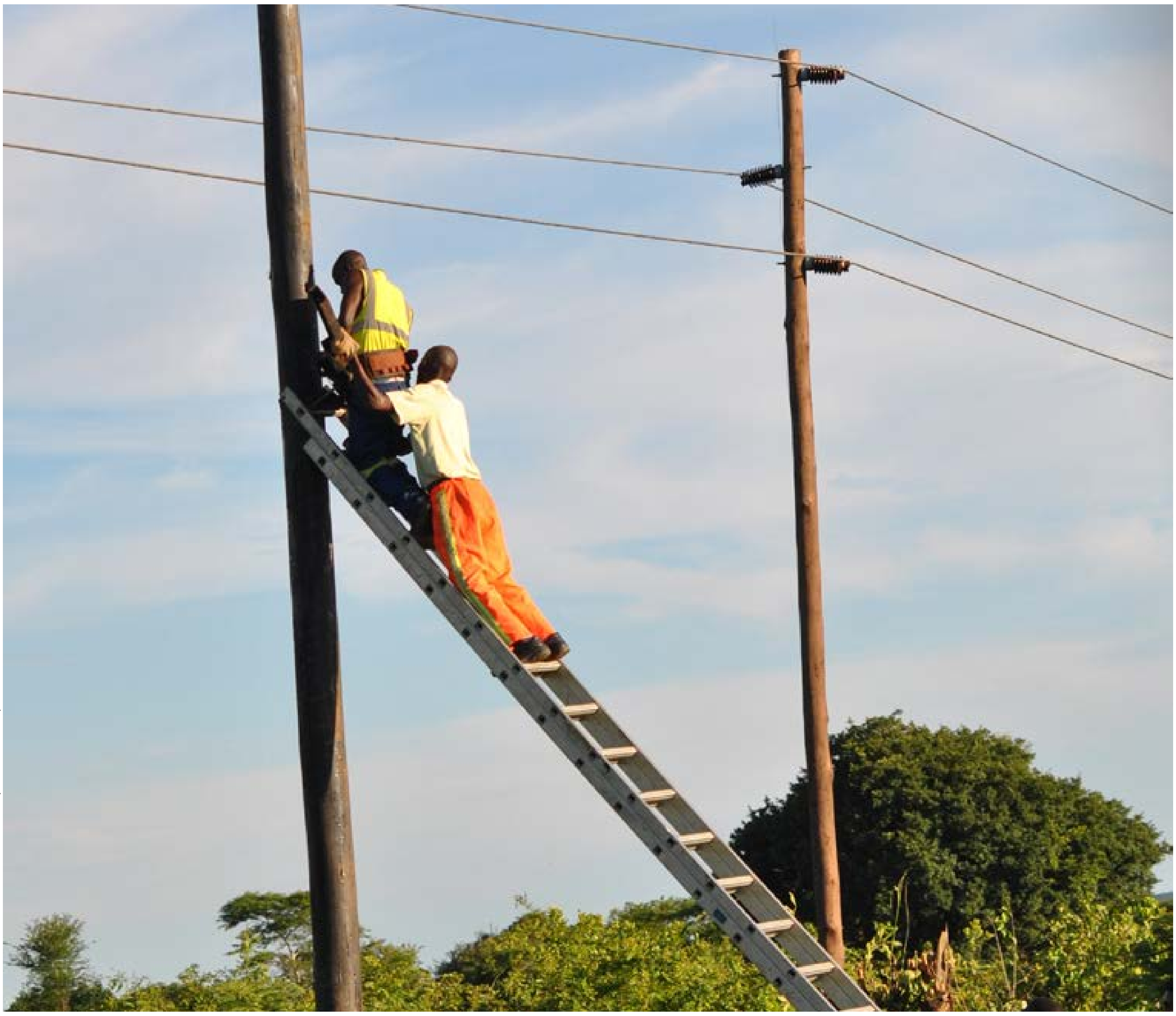
Figure 67 demonstrates that in the case of PZM for gasification and combustion technologies the profitable production conditions are less stringent for gasification.

FIGURE 67.

PZM FOR GASIFICATION AND COMBUSTION TECHNOLOGIES UNDER SCENARIO 2 ELECTRICITY PRICE



Source: Elaboration based on BEFS Assessment Results



This feature is easily found in **Figure 67** by comparing the number of feedstock options located in green zones areas. Therefore, in the gasification case scenario only potato leaves and forest harvesting residues would not result as profitable (red zones) due to their low energy potential and high collection costs. On the other hand, rice straw could be profitable under a set of specific conditions (yellow zones). In the combustion case scenario, potato leaves, groundnut husk, and forest harvesting residues would not be profitable under any option. All other feedstock options are located in the yellow zone meaning that these options can still be profitable, however their production conditions are more stringent.

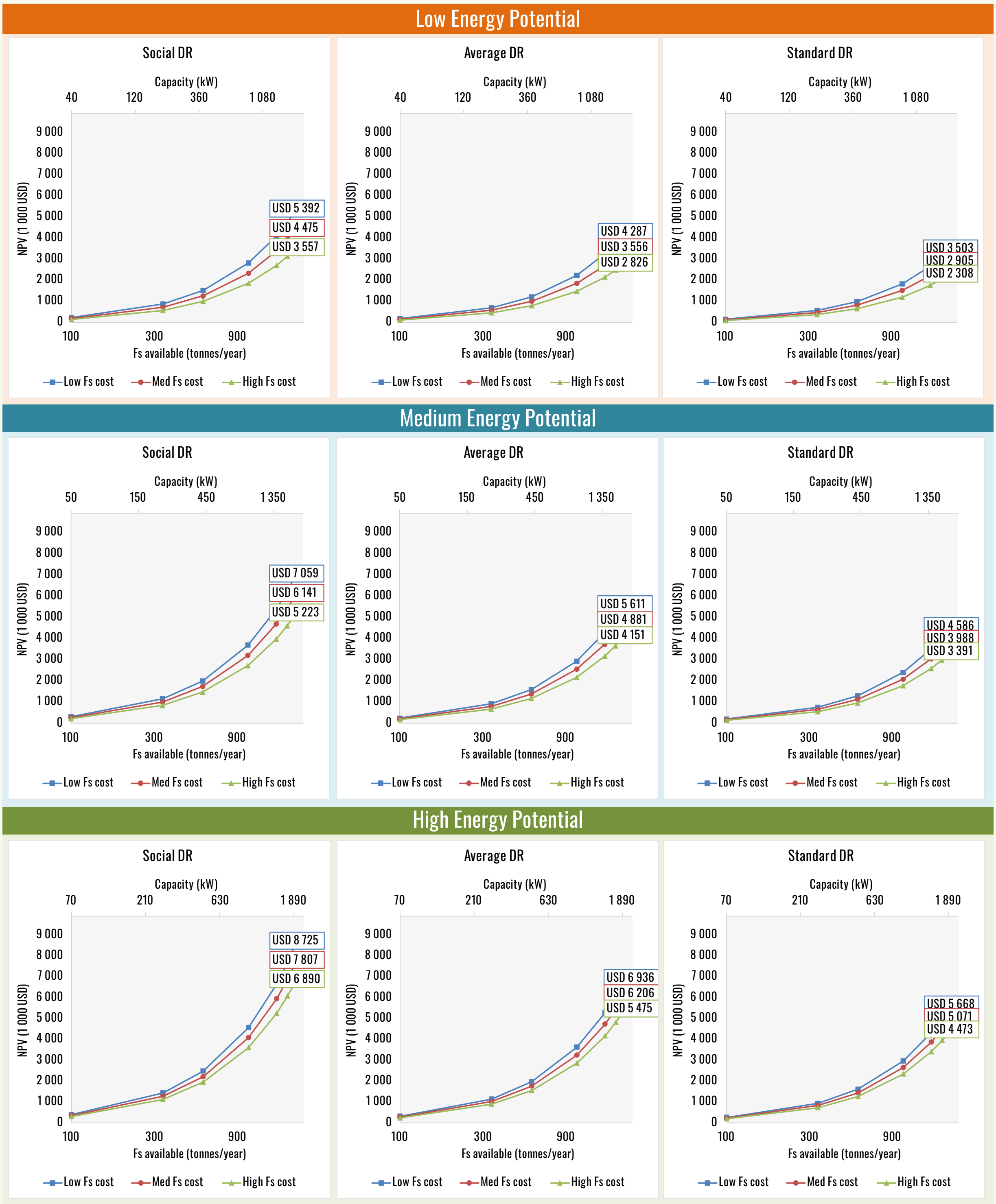
4.4.6.3 Scenario 3: consumers paying an electricity price of 0.35 USD/kWh

Figure 68 summarizes the NPV obtained for electricity generation using gasification technology and selling the electricity to potential consumers at 0.35 USD/kWh. In the case of gasification, the results obtained demonstrate that all feedstock at any energy potential and also paying the maximum price of 100 USD/tonne, would result in potentially profitable options. The same result was obtained for combustion.

The above results have been confirmed by the PZMs, as shown in the dominating green zones found in each of the maps. All of the options would result as profitable, including those options that did not result as profitable in previous scenarios.

FIGURE 68.

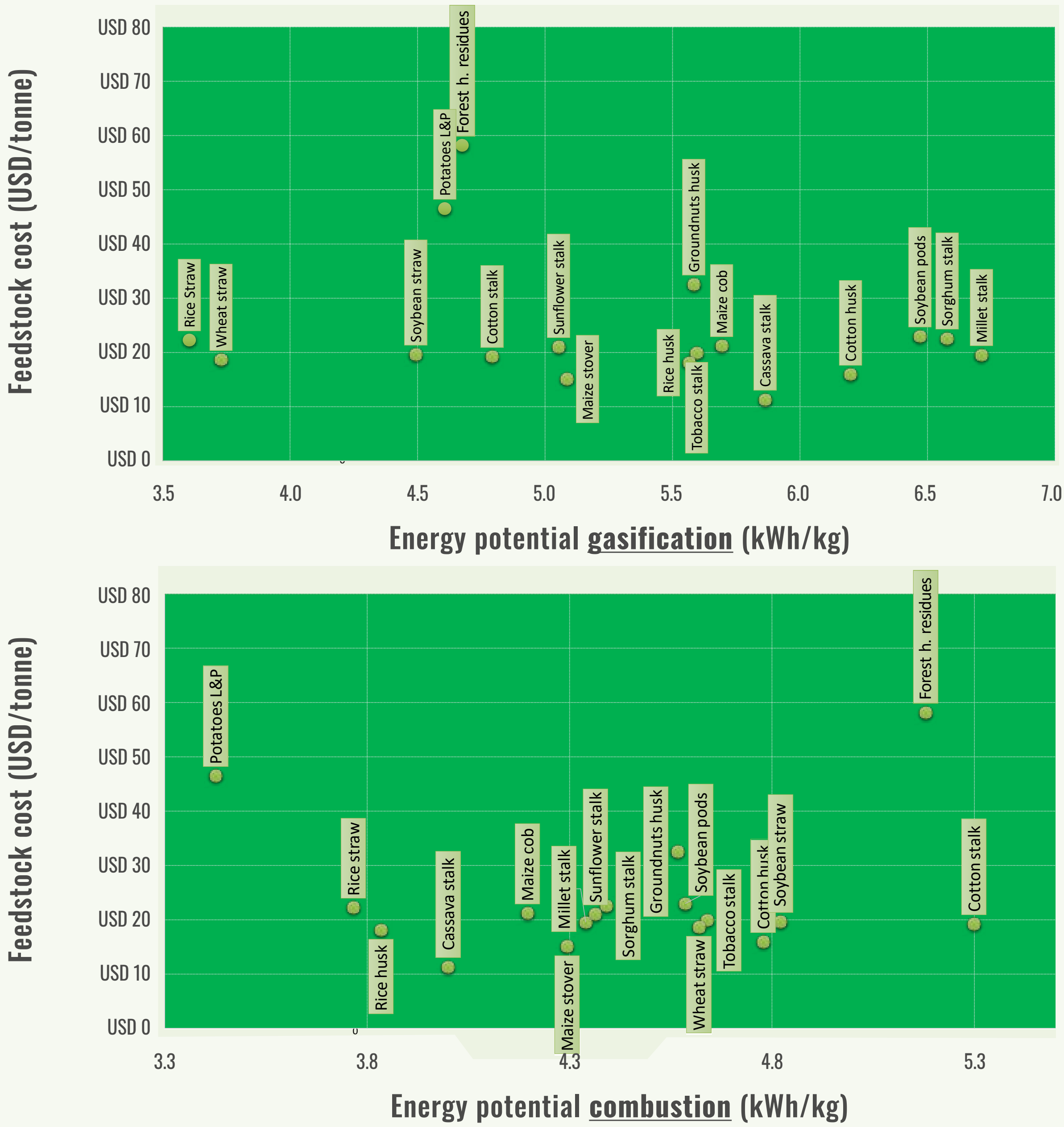
NPV FOR ELECTRICITY GENERATION FROM GASIFICATION FOR THREE DISCOUNT RATES (DR), SELLING ELECTRICITY AT 0.15 USD/kWh



Source: Elaboration based on BEFS Assessment Results

FIGURE 69.

PZM FOR GASIFICATION AND COMBUSTION TECHNOLOGIES UNDER SCENARIO 3 ELECTRICITY PRICE



Source: Elaboration based on BEFS Assessment Results

4.4.7 The most feasible electricity price scenario

Price scenario 3 (0.35 USD/kWh) would be the best option for an electricity generator as it is the most profitable, however, few customers in Zambia would be willing to pay such high tariffs; as a result, the potential market with this price scenario would be limited. From a consumer's point of view, price scenario 1 (0.015 USD/kWh) proposing the lowest price would be the most feasible option, although it has been proven that no biomass-based off-grid electricity generation is profitable. Moreover, one of the main barriers in Zambia preventing the massive access to on-grid electricity is connection fees that cannot

TABLE 40.

ESTIMATED MONTHLY PAYMENTS PER PAYMENT LEVEL AND INSTALLMENT PAYMENTS Xij

Xij	Xj = NUMBER OF INSTALLMENTS (months)		
Xi = Payment (USD)	Xi1	Xi2	Xi3
X1j	10.80	5.40	2.70
X2j	54.90	27.45	13.73
X3j	77.33	38.67	19.33

Source: Elaboration based on BEFS Assessment Results

be paid by the poorest rural households (Blimpo and Cosgrove-Davies, 2019).

In order to seek a compromise and find the most feasible and profitable option, it was decided to use the studies made on the electricity willingness-to-pay (WTP) in Zambia as a tool for determining the most acceptable scenario for electricity prices. The possibility of using technologies other than the biomass-based electricity used in the BEFS assessment was also taken into consideration.

Nevertheless, it was found that to some extent off-grid flexible payment options, such as the biomass-based electricity generation technologies, can help to face the high upfront connection costs. As a result, approximately 20 percent of rural households would be able to pay between USD 32.4 and USD 146, and 11 percent up to USD 232 (Luzi *et al.*, 2019).

A study conducted with the aim to evaluate the willingness of urban enterprises in Zambia to pay (Batidzirai, Moyo and Kapembwa, 2018) found that they would be willing to pay between 0.001-0.008 USD/kWh. This range is inferior to the lowest level being considered in this study and in practice, unrealistic. Two studies published by the World Bank in 2017 on electricity service access in Zambia state that overall the WTP would reach 0.09 USD/kWh in off-grid areas. Furthermore, the study mentions that households in southern Zambia in particular might be willing to pay as much as 0.17 USD/kWh (World Bank, 2017). The highest price quoted during the interviews was slightly higher than the price scenario 2 (0.15 USD/kWh) and 50 percent lower than the highest price included in this assessment.

In 2019, the World Bank's MTF also analysed the willingness of urban and rural households to pay, its objective being to understand whether price reduction and flexible payment periods could increase the adoption rate of the national grid (Luzi *et al.*, 2019). The study found that on average, 30 percent of rural households were not willing to pay for a grid connection under any payment plan or suggested price. However, up to 37 percent of rural households were willing to pay for the connection cost upfront, depending on the price. Nevertheless, it was concluded that off-grid flexible payment options, such as the biomass-based electricity generation technologies, could to some extent help to manage the high upfront connection costs. In sum, around 20 percent of rural households would be willing to pay between USD 32.4 and USD 146, and 11 percent up to USD 232.

This information was used to build the matrix presented in **Table 40**, which contains the monthly payments according to installment prices and periods; it was also used in **Table 41** and **Table 42**, which include consumer shares of payments and the number of installments.

TABLE 41.

SHARE OF PAYMENTS ai

ai = SHARE OF PAYMENT	%
a1	20%
a2	
a3	11%

Source: Elaboration based on BEFS Assessment Results

TABLE 42.

SHARE OF INSTALLMENT PER PAYMENT LEVEL bi

	INSTALLMENTS PAYMENTS (MONTHS)		
PAYMENT (USD)	bi1	bi2	bi3
b1j	6.0%	10.1%	5.4%
b2j	1.8%	12.9%	6.3%
b3j	6.0%	10.1%	5.4%

Source: Elaboration based on BEFS Assessment Results

Eq 1

$$Average\ payment\ per\ month = \sum_{LP}^{HP}\sum_{LI}^{HI} a_i * b_{ij} * X_{ij}$$

The Eq 1 calculated the average payment per month based on the approximate monthly payments and the respective shares, making it possible to estimate an average acceptable payment of 2.4 USD/month/hh.

The above-mentioned value could be considered as the average value that Zambian households would be willing to pay for electricity. Next, by using the three tiers and the Zambia average for the electricity demands, it was possible to calculate the payments for the three electricity price scenarios accordingly (see **Table 43**).

Based on these results, it was determined that the payment closer to the acceptable monthly payment would be Tier 1 and 2 for the consumers paying price scenario 2 tariffs (0.15 USD/kWh). This option has also proved to be affordable enough for electricity generators to pay for the operation, maintenance, loan and other costs; moreover, it is a feasible option for consumers under certain combinations of feedstock.

The above results accounts for 31 percent of the off-grid households willing to pay for electricity, amounting to about 650 thousand households. Initially, this would be the market size for the off-grid electricity options.

4.4.8 Minimum techno-economic conditions

Once the scenario two tariff of 0.15 USD/kW is defined it can be acceptable both for electricity generators and consumers. The minimum profitable production conditions for each feedstock option and technology option were calculated. These conditions are composed of the minimum electricity generation capacity and

TABLE 43.

ESTIMATED MONTHLY PAYMENTS FOR THE ELECTRICITY PRICE SCENARIOS ACCORDING TO THE ELECTRICITY CONSUMPTION TIER

		ELECTRICITY TARIFF (USD/kWh)		
CONSUMPTION	kWh/month/hh	Sc1 (0.02)	Sc2 (0.15)	Sc3 (0.35)
TIER 1	3.12	0.05	0.47	1.09
TIER 2	14.94	0.22	2.24	5.23
TIER 3	119.88	1.80	17.98	41.96
ZAMBIA AVERAGE	200	3.00	30.00	70.00

Source: Elaboration based on BEFS Assessment Results

TABLE 44.

GASIFICATION (LEFT) AND COMBUSTION (RIGHT) ELECTRICITY SYSTEM CAPACITIES FOR CROP-RESIDUE TYPES AVAILABLE IN ZAMBIA

FEEDSTOCK	MIN. CAP (kW)	MIN. OPERATION (h/day)
MILLET STRAW/STALK	188	9
SORGHUM STALK	253	9
SOYBEAN PODS	308	9
COTTON HUSK	158	9
CASSAVA STALK	120	9
MAIZE COB	383	9
TOBACCO STALK	290	9
RICE HUSK	245	9
MAIZE STOVER	182	9
COTTON STALK	271	10
SUNFLOWER STALK	213	11
SOYBEAN STRAW	192	12
WHEAT STRAW	133	17
GROUNDNUTS HUSK	NOT FEASIBLE	
FOREST PLANTATION RESIDUES	NOT FEASIBLE	
POTATOES L&P	NOT FEASIBLE	
RICE STRAW	NOT FEASIBLE	

	MIN. CAP (kW)	MIN. OPERATION (h/day)
COTTON HUSK	225	11
CASSAVA STALK	161	11
MAIZE STOVER	207	11
COTTON STALK	250	11
MILLET STRAW/STALK	251	12
TOBACCO STALK	217	12
SOYBEAN STRAW	201	12
WHEAT STRAW	133	12
SORGHUM STALK	263	13
SOYBEAN PODS	249	13
MAIZE COB	256	13
RICE HUSK	160	14
SUNFLOWER STALK	174	14
RICE STRAW	181	16
GROUNDNUTS HUSK	NOT FEASIBLE	
FOREST PLANTATION RESIUDES	NOT FEASIBLE	
POTATOES L&P	NOT FEASIBLE	

Source: Elaboration based on BEFS Assessment Results

the number of hours per day that must operate in order to reach at least the breakeven point (see **Table 44**). It is worth noting that, as predicted by the PZM, forest plantation residues and potato residues would not be profitable as feedstock options for electricity generation, neither using gasification or combustion technologies.

Moreover, the PZMs for combustion technologies also showed larger yellow zones than the gasification ones. This effect can withstand the most stringent conditions needed to obtain profitable production conditions, featured by a more significant number of minimum operation hours per day.

Once the minimum capacity for each feedstock and technology was determined it was also possible to calculate the capital investment needs (see **Figure 70**). It is evident that depending on the feedstock used the investment needs for gasification or combustion might vary,

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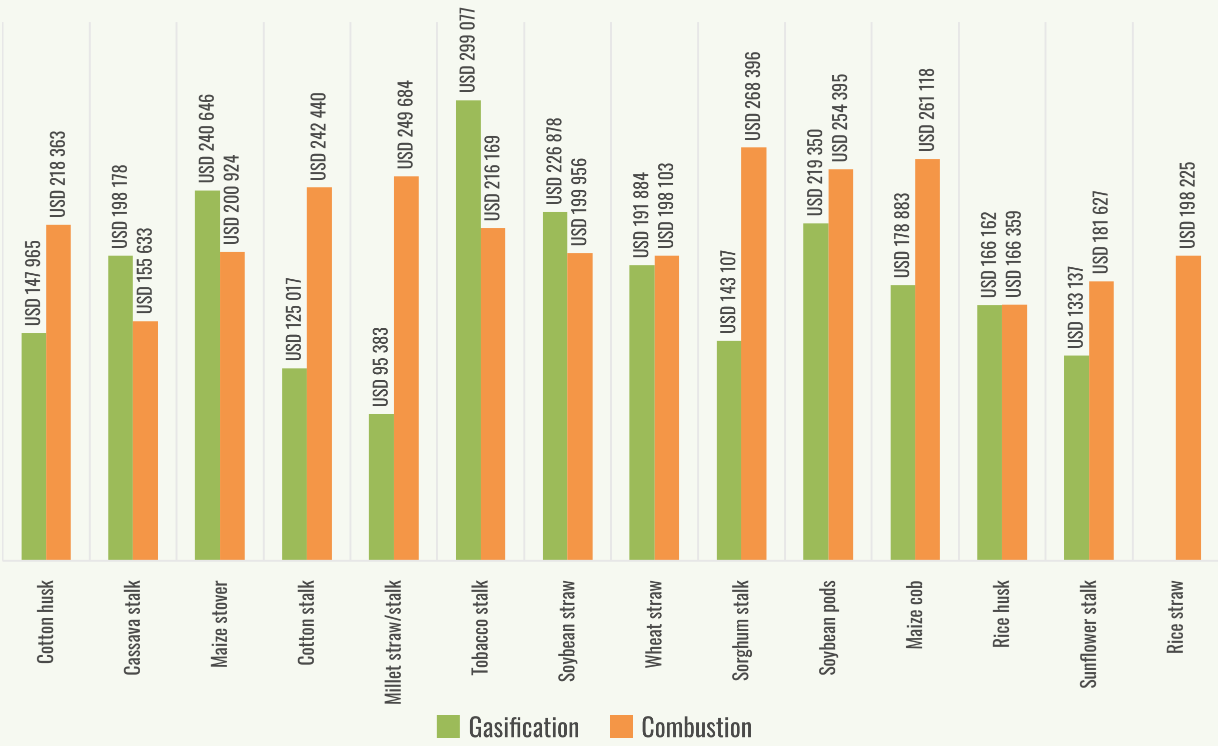
so one option may be preferable to the other. For example, if cotton stalk is used as feedstock, gasification is 50 percent less expensive than combustion technology, while when maize stover is used combustion will require a lower investment. This is explained by the differences in energy potential and well as the minimum profitable capacities calculated for each option.

FIGURE 70.

MINIMUM CAPITAL INVESTMENTS FOR POTENTIALLY PROFITABLE OFF GRID SYSTEMS (USD)



Source: Elaboration based on BEFS Assessment Results

4.4.9 Electricity generation potential

After calculating the minimum profitable capacities, they were compared to the feedstock available per district as estimated in the BEFS natural resources assessment. Moreover, both gasification and combustion technologies were taken into consideration together for electricity generation. The criteria for allocating one feedstock to gasification or combustion was based on the option that offered a lower upfront investment.

As a result, it was possible to calculate a total electricity capacity generation of 1 192 MWel across the country. The potential capacities for gasification and combustion technologies were also mapped on the province level. The map in **Figure 71** indicates the electricity generation capacity per province and the shares between gasification and combustion options. At the national level, the highest capacities were identified in the Eastern Province and Central Province. Gasification results as being the dominant technology, with a 57 percent average share. Moreover, it can be estimated that at national level the average capital investment needs for gasification to electricity technologies would reach 791 USD/kW, and 1 015 USD/kW for combustion options.

More specifically, at the district level (see **Figure 72**) it was possible to identify Kapiri Mposhi, Mkushi, Peatauke, Chipata and Lundazi as the most promising districts. However, it is important to note that their potential depends on feedstock accessibility and therefore the real availability should be evaluated in the field.

The total electricity capacities for gasification and combustion were calculated using a mixture of materials as feedstock. The potentially largest contributors are maize stove, maize cob, cotton stalk, cassava stalk; while other residue types would contribute by minor percentages. The distribution of used feedstock is presented in **Figure 73**.

FIGURE 71.

ELECTRICITY GENERATION CAPACITY POTENTIALS PER PROVINCE AND TECHNOLOGY

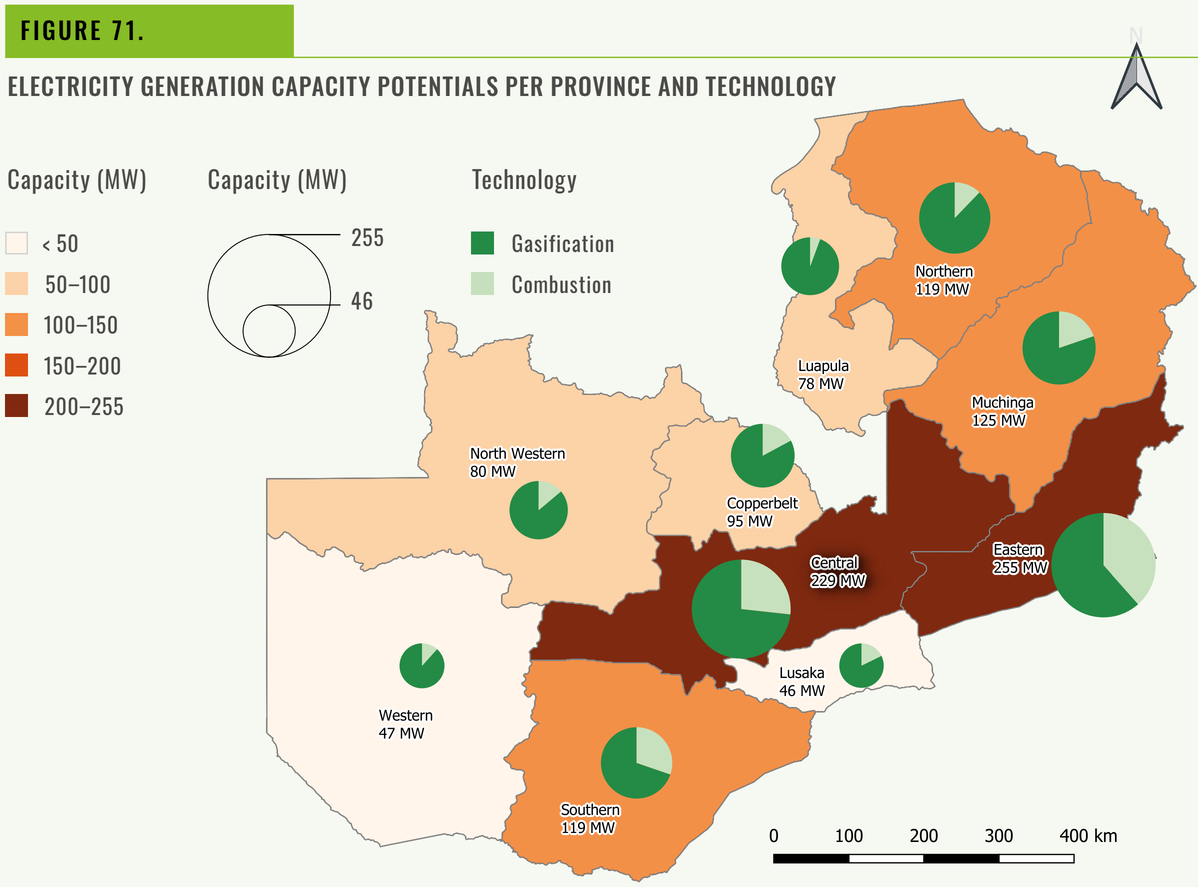
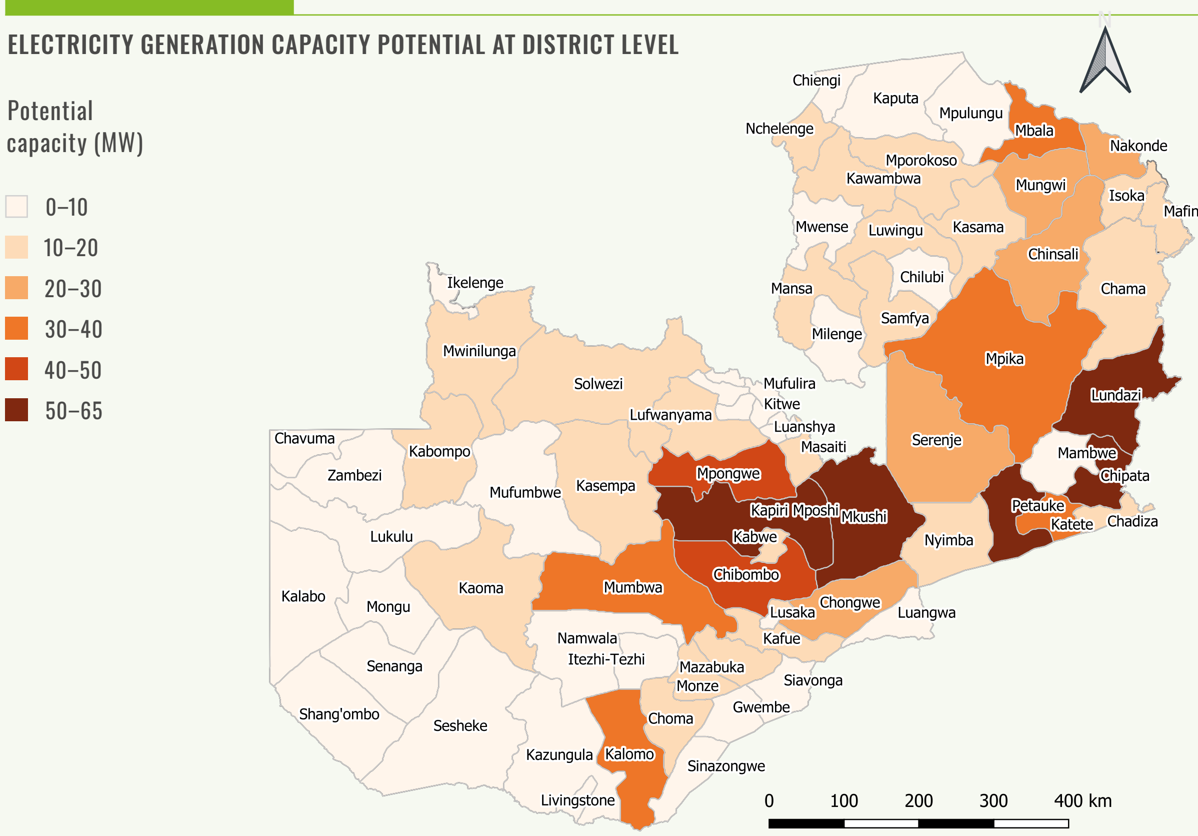


FIGURE 72.

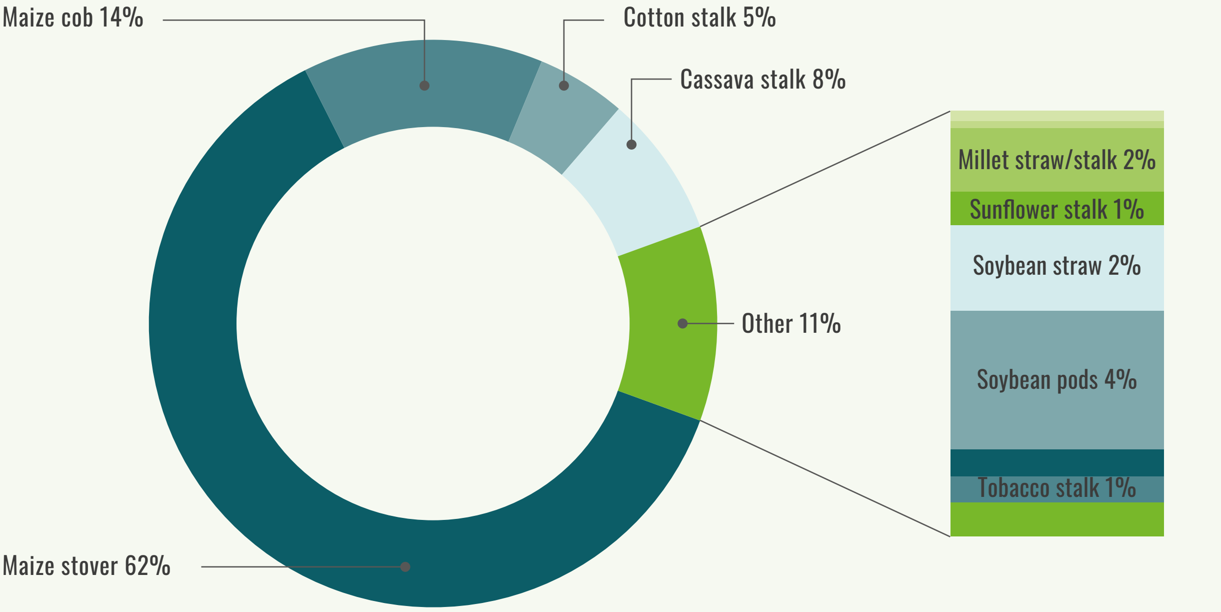
ELECTRICITY GENERATION CAPACITY POTENTIAL AT DISTRICT LEVEL



Source: Elaboration based on BEFS Assessment Results

FIGURE 73.

SHARE OF MAJOR FEEDSTOCK TYPES TO ELECTRICITY GENERATION



Source: Elaboration based on BEFS Assessment Results

4.4.10 Contribution to renewable energy targets

The total estimated number of rural households in Zambia was about 3.7 million in 2019 (MOE, 2019). Zambia set a target that to reach at least 50.6 percent of electricity access at the rural level (Ministry of Energy, 2019). This amounts a target of 1.88 million households. In order to analyse whether the off-grid electricity systems could contribute to these energy targets, the total number was estimated of rural households in Zambia to potentially be supplied at each tier level.

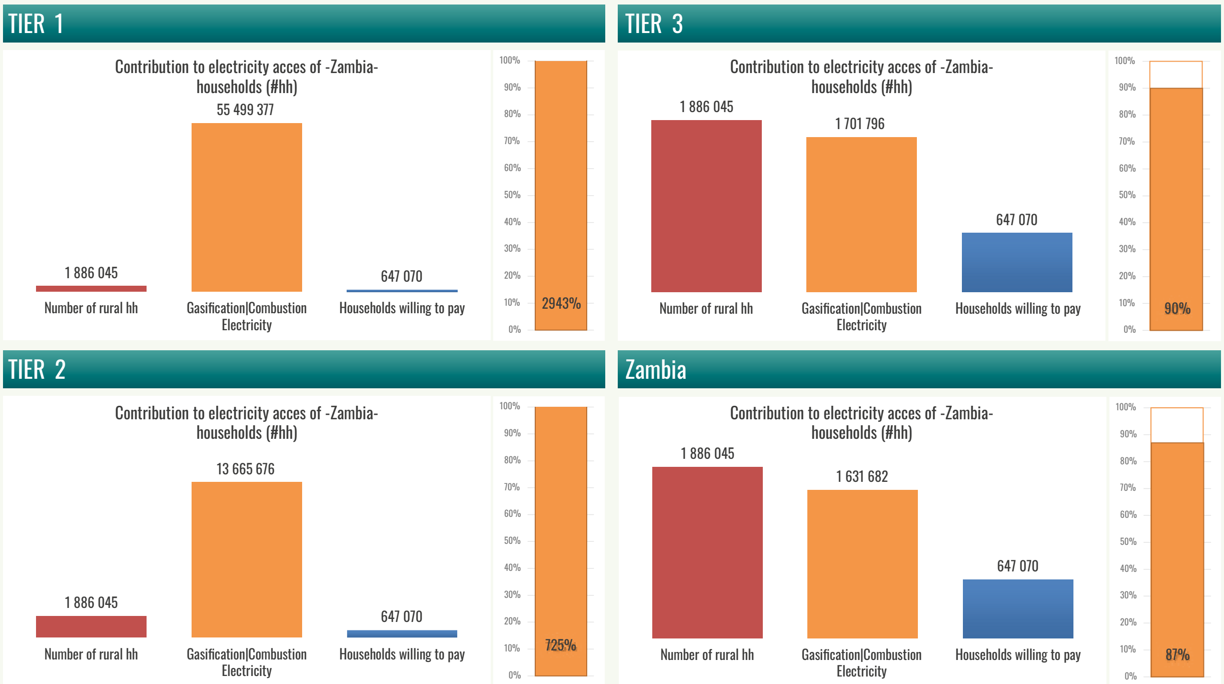
Figure 74 shows the variation in the number of rural households that might be supplied using the electricity generated from Zambian biomass residues using gasification and combustion technologies. In the Tier 1 diagram (see first chart), 2 943 percent represents the share of rural households that could potentially be supplied with the electricity generated. Another case scenario would be where the average consumption of rural households is similar to that of urban Zambian households; this would mean that 87 percent of the total target households could feasibly be reached. On the whole, in all of the above-mentioned cases it would be possible to supply the households identified as potentially willing to pay for electricity. The results shown in **Figure 74** indicate that the electricity generation capacity from residues in Zambia is high and at the same time could be a significant contributor to the electricity matrix in Zambia. In addition, it could possibly adapt to and supply the households, assuming that their demands increase as a result of the access to electricity.

4.4.11 Summary of results

There is significant potential for electricity generation in the off-grid areas of Zambia using the biomass residues available, and certain conditions of capacity, costs, and operation could result in profitable options. Both gasification and combustion technologies might be taken into consideration together for electricity generation.

FIGURE 74.

NUMBER OF HOUSEHOLDS POTENTIALLY SUPPLIED USING GASIFICATION AND COMBUSTION TECHNOLOGIES, UNDER TIER 1-3 AND ZAMBIA AVERAGE ELECTRICITY DEMANDS



Source: Elaboration based on BEFS Assessment Results

After allocating feedstock to gasification or combustion, it was found that the total electricity capacity across the country could be to 1 192 MWel. To deploy this potential, the average capital investment needs on the national level were estimate at 791 USD/kW for gasification and 1 015 USD/kW for combustion options.

At the national level, the highest capacities were identified in the Eastern and Central Province. Particularly, it was possible in Kapiri Mposhi, Mkushi, Peatauke, Chipata and Lundazi, which were identified as the most promising districts. On the other hand, the top biomass options for electricity generation comprise maize stove, maize cob, cotton stalk, cassava stalk.

Gasification was predicted as the dominant technology, with a 57 percent average share. However, gasification and combustion for electricity generation are technologies that require considerable upfront capital investments for households. From the standpoint of the households, these systems would become more affordable if they were required to pay for maintenance and service only, with no obligation to make an initial investment.

It is important to keep in mind that the extension of central grid lines to rural and off-grid areas is a high capital investment for the government. Therefore, the final decision on the best alternative to promote will depend on which option is more cost-competitive, and where policy interventions can be more effective. However, the BEFS assessment results shown indicate that the electricity generation capacity from biomass residues in Zambia could possibly adapt to and supply the households, assuming that their demands increase as a result of the access to electricity.

4.5 FUELS FOR COOKING

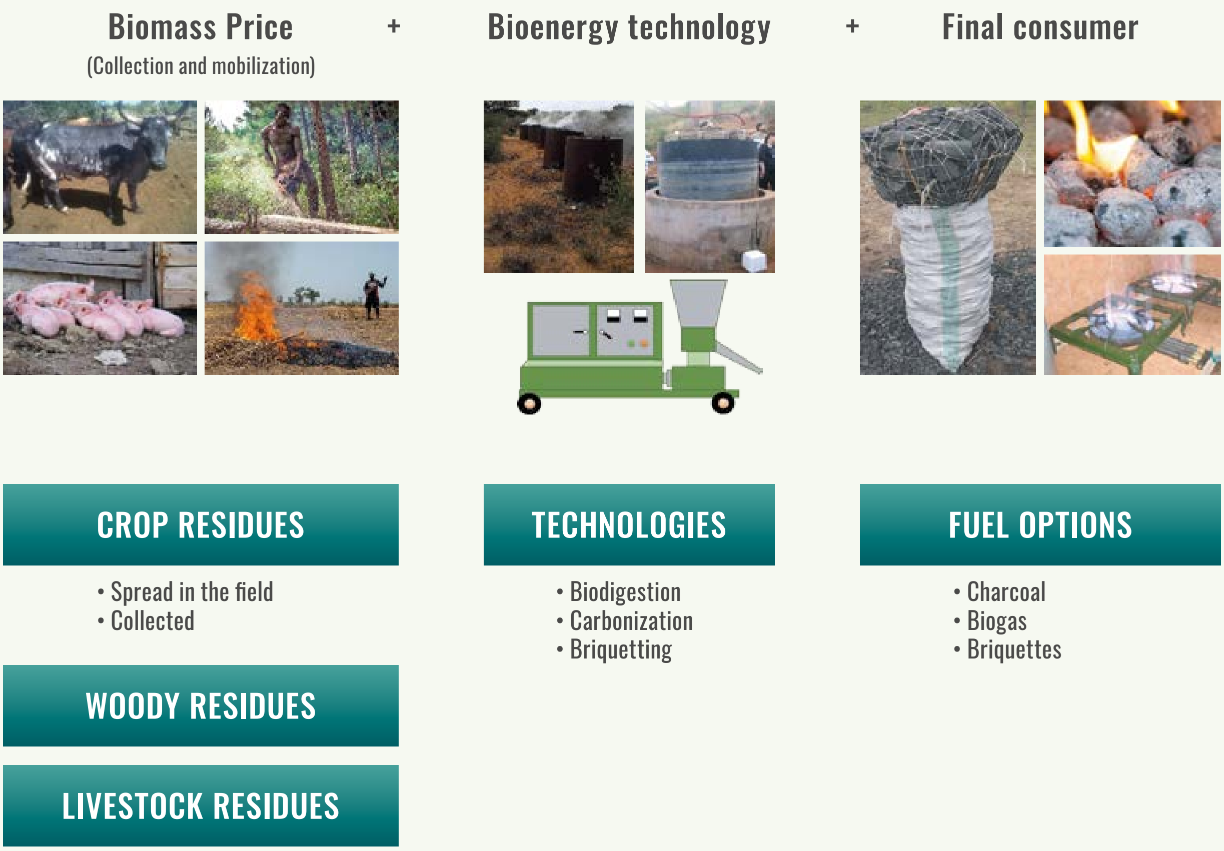
The major source of energy for cooking, used by people living in rural areas, in high-density areas and in the peri-urban areas of Zambia, at the household level is traditional woodfuel (i.e. charcoal and fuelwood; Luzi *et al.*, 2019). Charcoal production is mainly driven by urban demand, with a typical Lusaka household consuming an estimated 1.3 tonnes of charcoal per year. In order to produce this amount of charcoal, close to 8 tonnes of wood are required and as a result, the effects on forests can be negative (Gumbo *et al.*, 2013).

Different alternatives have been considered in Zambia aiming to reduce woodfuel dependency. One of these alternatives is domestic biogas production. This technology has been adopted for developing in countries across the world as an alternative to wood fuel, as well as the direct use of manure and crop residues for cooking fuel. Moreover, by using biogas it is possible to reduce pollution in kitchens, add value to livestock residues and contribute to reducing poverty in rural areas (Shane and Gheewala, 2017; Shane, Gheewala and Phiri, 2017).

Another option that might contribute to reducing the impact of charcoal production on natural forests residues is the use of improved charcoal technologies. Using this type of technology makes the charcoal production process more efficient. In other

FIGURE 75.

TECHNOLOGIES AND FEEDSTOCK INCLUDED IN FUELS FOR COOKING ASSESSMENT



Source: Elaboration based on BEFS Assessment Results based on BEFS Charcoal user manual

words, as compared to the traditional charcoal technologies, the same amount of charcoal can be produced by using less wood (Kammen and Lew, 2005).

The BEFS assessment evaluates the viability of biomass-based briquettes, charcoal briquettes, and domestic biogas production, while taking into consideration the production cost. It also incorporates proxies and methodologies to estimate comparison market prices (in the case of briquettes) and monetize the benefits obtained from biogas usage. The BEFS assessment also provides information on energy for cooking potential across different districts in Zambia. It also makes a feedstock allocation among biomass briquettes, charcoal briquettes, and biogas based on techno-economic criteria. Moreover, the BEFS assessment covers various improved charcoal technologies, as well as analyses the potential wood savings that might be obtained across the country due to improvements in technology. The assessment results will provide information for the Zambian government on the viability and ability of the country to produce biomass-based cooking fuels and their contribution to the national energy targets.

4.5.1 Cooking energy demand in Zambia

Regarding the cooking for energy demand, the values used in this assessment were collected in the country directly by the BEFS team (BEFS Zambia Survey, 2019). These values have been calculated by taking the energy demand for cooking fuels per capita at the residential level and factoring it into the average size of a Zambian household (5.2 persons/household) (Zambia Central Statistics Office, 2016).

TABLE 45.

FUELS AND ENERGY CONSUMED FOR COOKING IN ZAMBIA PER HOUSEHOLD (HH)

FUEL/ENERGY FORM	RURAL	URBAN	UNITS PER HOUSEHOLD
BRIQUETTES/PELLETS		2	kg/day/hh
FUEL WOOD	11		kg/day/hh
CHARCOAL	5	4	kg/day/hh
KEROSENE	0.81	3.24	kg/day/hh
LPG		1	kg/day/hh
ELECTRICITY	5	15	kWh/day/hh

Source: Elaboration based on values reported by (BEFS Zambia Survey, 2019; Zambia Central Statistics Office, 2016)

TABLE 46.

USEFUL COOKING ENERGY OBTAINED FROM DIFFERENT FUELS

FUEL	LHV (MJ/kg)	STOVE EFF (%)	USEFUL ENERGY
FUELWOOD	16.0	18%	2.9
CHARCOAL	30.0	22%	6.6
CROP RESIDUES	13.5	12%	1.6
LPG	45.5	70%	31.9
KEROSENE	43.0	55%	23.7
ELECTRICITY		75%	
BRIQUETTES	14.0	50%	7.0

Source: based on values reported by (Malla and Timilsina, 2014)

The values in **Table 45** were validated by using the fuelwood and charcoal consumption reported in the WISDOM Zambia report (Drigo, 2016) as well as the 2019 Biodigester Market Study in Zambia conducted by SNV Zambia (Energy for Agriculture (E4A) project and SNV Netherlands Development, 2019). This last report details the results of a survey conducted among 100 urban and rural households. In addition, in order to make the values comparable they were converted into cooking energy. First, this conversion requires a calculation of the useful energy obtained from burning different cooking fuels in their respective stoves (see **Table 46**).

It was therefore possible to obtain the results found in **Table 47**. Indeed, it is worth noting that the BEFS total energy consumption is slightly higher than the values reported by WISDOM Zambia and the Biodigester Market Study in Zambia. In the first case, the difference can be explained by the fact that WISDOM Zambia focuses on the two main cooking fuel options used in Zambia (i.e. fuelwood and charcoal). On the other hand, in the second case the values were similar to those obtained at the rural level. These values were further validated by the Ministry of Energy of Zambia and it was subsequently decided that the difference in the total energy demand was acceptable. As a result, it was possible to use the total cooking energy demand for rural households of 97.34 MJ/day/hh and for urban households of 100.22 MJ/day/hh.

4.5.2 Briquettes

The objective of the briquette assessment was to evaluate the use of briquettes as an alternative to the fuel options currently being used in Zambia. The analysis examines the potential profitability of briquette production using a range of production conditions and technology options. Based on these results as well as the biomass assessment results, the most suitable feedstock options were selected.

4.5.2.1 Production cost and profitability

The production costs of briquettes were calculated based on ranges within the following three parameters: i) feedstock availability, ii) energy potential and iii) feedstock cost.

As shown in **Figure 76**, all options could be cost competitive compared to the current market price of briquettes in Zambia of 168 USD/tonne (BEFS Zambia Survey, 2019). On the other hand, there is no variation in the production costs as a result of changes in feedstock energy potential.

TABLE 47.

SUMMARY OF COOKING FOR ENERGY DEMAND DATA

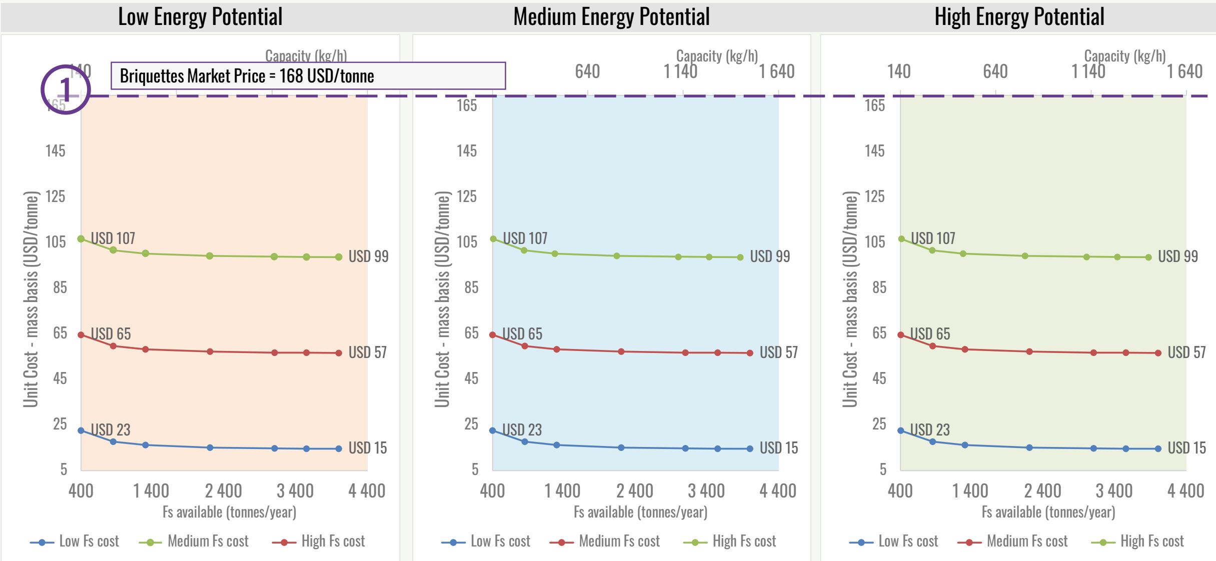
	WISDOM ZAMBIA REPORT, 2014		BIODIGESTER MARKET STUDY IN ZAMBIA, 2019	BEFS DATACOLLECTION, 2019		
FUEL	RURAL	URBAN	100 HH SURVEY	RURAL	URBAN	UNITS
FUELWOOD	15 590	8 102	10 501	11 563	0	MJ/year/hh
CHARCOAL	8 134	8 202	10 692	12 045	9 636	MJ/year/hh
LPG	0	0	4 969	0	2 070	MJ/year/hh
KEROSENE	0	0	1 149	6 992	4 981	MJ/year/hh
ELECTRICITY	0	0	774	4 928	14 783	MJ/year/hh
CROP RESIDUES	0	0	3 357	0	0	MJ/year/hh
BRIQUETTES	0	0	0	0	5 110	MJ/year/hh
TOTAL PER YEAR	**23.72**	**16.30**	**31.44**	**35.53**	**36.58**	**GJ/year/hh**
TOTAL PER DAY	**65.00**	**44.67**	**86.14**	**97.34**	**100.22**	**MJ/day/hh**

Source: Elaboration based on values reported by (BEFS Zambia Survey, 2019; Drigo, 2016; Energy for Agriculture (E4A) and SNV Netherlands Development, 2019; Zambia Central Statistics Office, 2016)

However, should Zambian households choose to use biomass briquettes to replace charcoal or fuelwood, the briquettes would need to burn for at least the same amount of time as the fuel currently being used and cost the same, or less. Therefore, the energy quality of briquettes would make a difference as it would affect the burning time as well as the cost.

FIGURE 76.

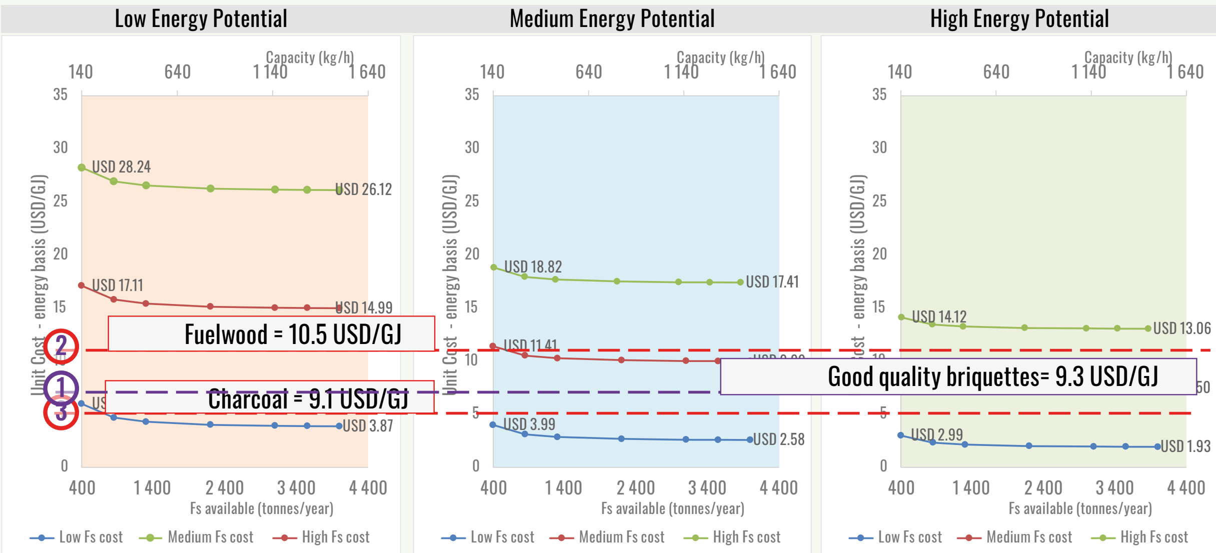
PRODUCTION COSTS OF BIOMASS BRIQUETTES (MASS BASIS)



Source: Elaboration based on BEFS Assessment Results

FIGURE 77.

PRODUCTION COSTS OF BIOMASS BRIQUETTES (ENERGY BASIS)



Source: Elaboration based on BEFS Assessment Results

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In this assessment the energy potential described in **Figure 76** was considered, as were the production costs in terms of energy compared with the value of good quality briquettes.

A good quality briquette is high in density, resistant to humidity, provides clean burning and most importantly, has high energy potential. It can be assumed that in the context of charcoal and fuelwood, which are the fuels to be substituted, a high energy briquette would produce 18 MJ/kg.

Figure 77 presents a comparison of the production costs of briquette production versus the market price converted to energy basis of good-quality briquettes, fuelwood and charcoal.

Once production costs and the comparative market price had been defined, it was possible to estimate the profitability by using the Net Present Value (NPV) as a figure of merit. Hence, the analysis estimated the NPV based on a range of feedstock properties, plant capacities and technology options, making it possible to create three scenarios for the purpose of gathering results:

- Scenario 1: Use of cold pressing technology
- Scenario 2: Use of a hot pressing technology
- Scenario 3: Use of charcoal briquetting technology

The following subsection presents the results obtained for each scenario.

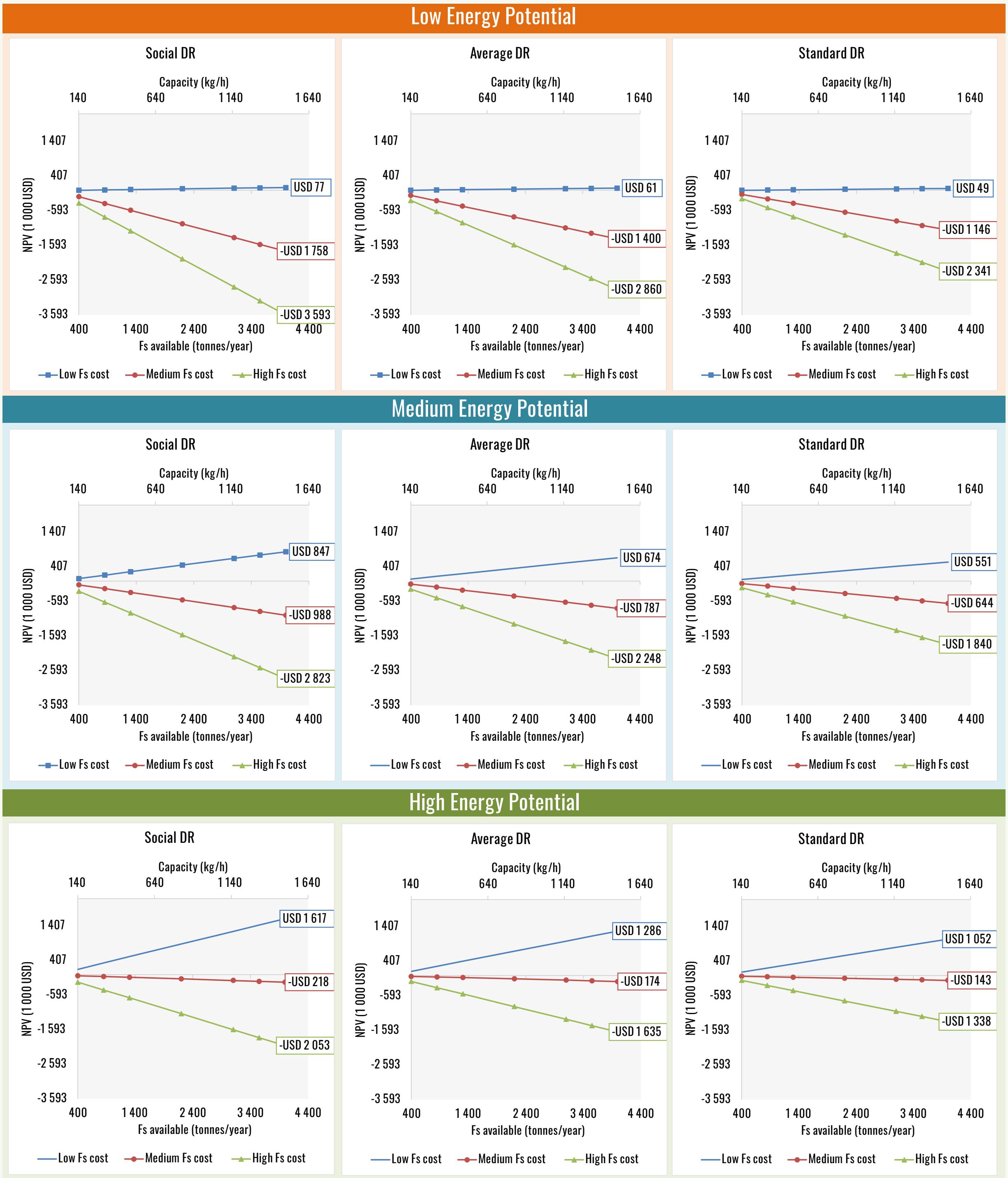
4.5.2.2 Scenario 1: use of cold pressing technology

Figure 78 summarizes the NPV obtained for briquette production scenarios by using cold pressing technology. In this case, the main technology modification was the use of a chemical binder to ensure the structural integrity of briquettes. The results obtained demonstrate that a combination of medium and high-energy potential feedstock at a cost of between 5 and 30 USD/tonne (depending on the energy potential) could result in potentially profitable options.

Once the available feedstock options were located in the PZM (see **Figure 79**), it was evident that only cotton husk and stalk and soybean straw would produce profitable results under all of the production conditions (green zone). Moreover, options such as cassava stalk, maize stover, wheat straw, and tobacco stalk could also be profitable; however, under a specific set of production conditions. It is advisable that other feedstock options be discarded for this technology modification.

FIGURE 78.

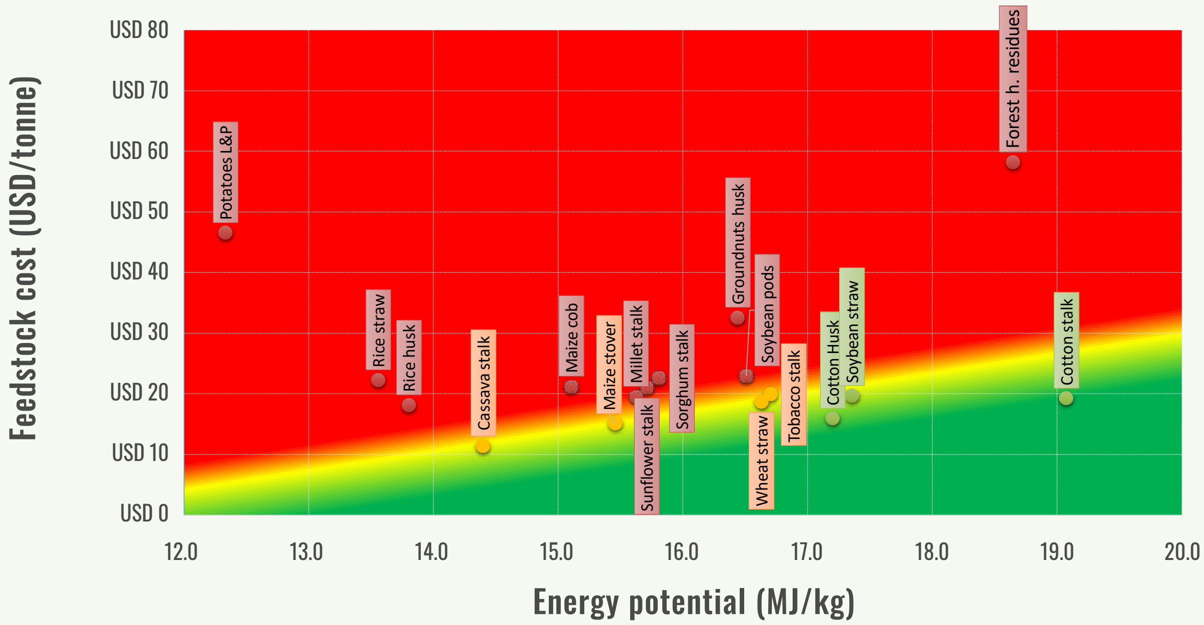
NPV FOR BRIQUETTES PRODUCTION USING COLD PRESSING TECHNOLOGY FOR THREE DISCOUNT RATES (DR)



Source: Elaboration based on BEFS Assessment Results

FIGURE 79.

PZM FOR BRIQUETTES PRODUCTION USING COLD PRESSING TECHNOLOGY



Source: Elaboration based on BEFS Assessment Results

4.5.2.3 Scenario 2: use of a hot pressing technology

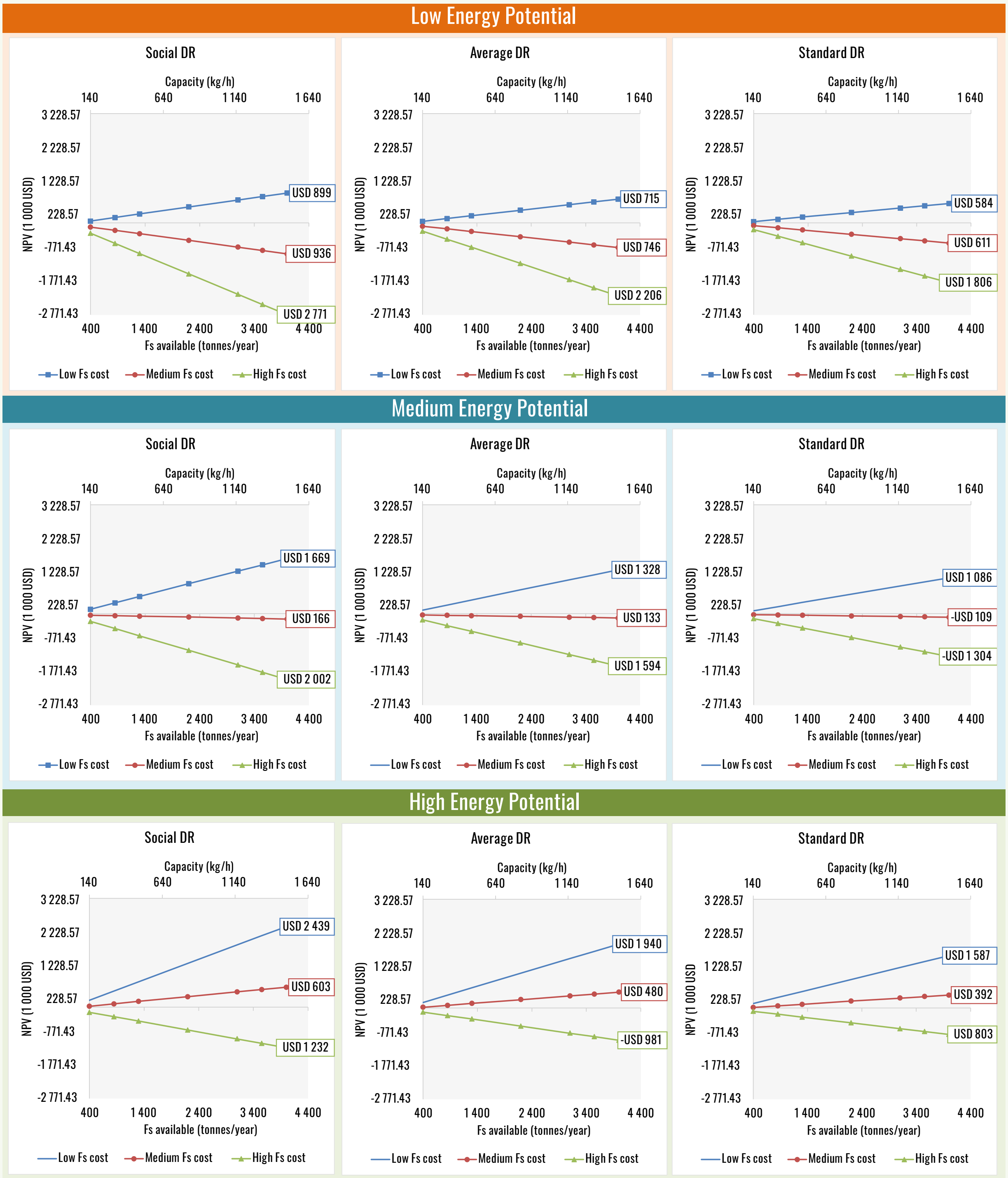
Figure 80 summarizes the NPV obtained for briquette production scenarios using hot pressing technology. In this case, the main technology modification would be the use of a mechanical device powered by electricity. However, due to electricity access restrictions in Zambia, it was important to include the cost of self-generated electricity in the production costs. As in Scenario 1, the results obtained demonstrate that a combination of medium and high-energy potential feedstock at a maximum cost of 10 to 40 USD/tonne (depending on the energy potential) could result in potentially profitable options.

The PZM obtained for Scenario 2 illustrates how, overall, the green zone is more significant than the one found in Scenario 1. In other words, a more substantial number of feedstock options could be considered for briquette production. In this case, cassava stalk, maize cob and stover, sunflower stalk, millet stalk, sorghum stalk, wheat straw, soybean pods, cotton husk and stalk and soybean straw could be profitable options. Rice husk is the only feedstock located in the yellow zone (see **Figure 81** below) and the other feedstock options would be discarded for this technology choice.

On average, the difference in profitability between cold pressing and hot pressing technologies in Zambia is 33 percent. **Figure 82** details a comparison between the operating expenditure of hot and cold pressing making it possible to check if, due to increased production capacity, it is more cost-effective to use electricity (the main feature of hot pressing) to produce good quality briquettes. This result coincides with literature available on briquette technology that states that cold pressing technologies are more cost-effective for small-scale production, while hot pressing is a better option for producing on a large scale (Fulford and Wheldon, 2015; Shyamalee, Amarasinghe and Senanayaka, 2015).

FIGURE 80.

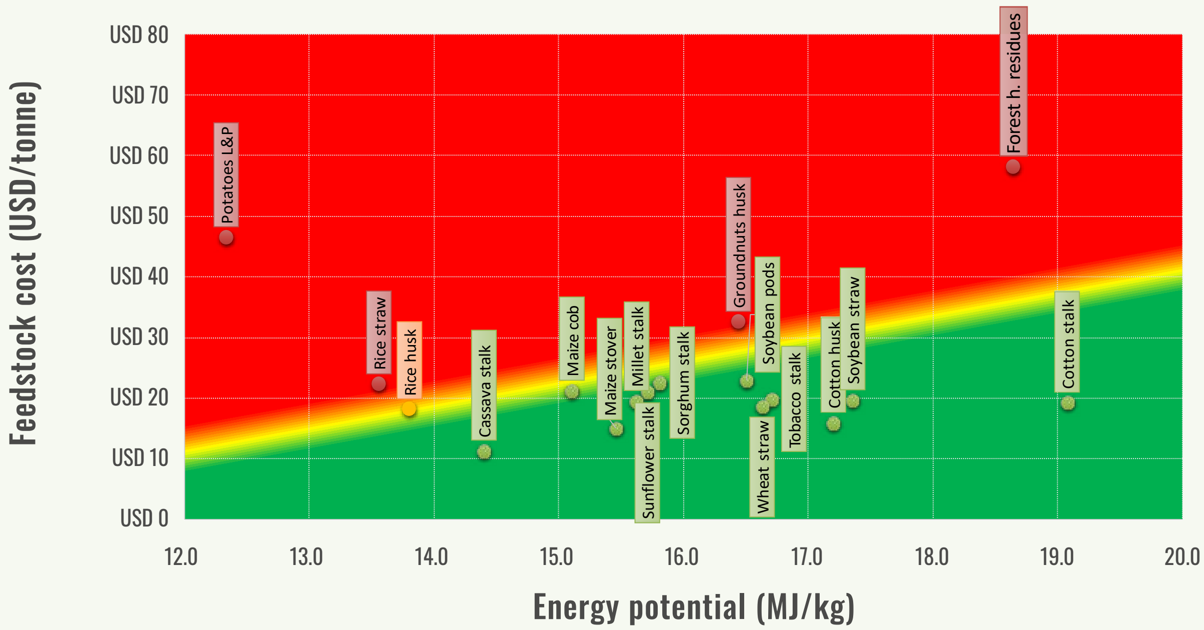
NPV FOR BRIQUETTES PRODUCTION USING HOT PRESSING TECHNOLOGY FOR THREE DISCOUNT RATES (DR)



Source: Elaboration based on BEFS Assessment Results

FIGURE 81.

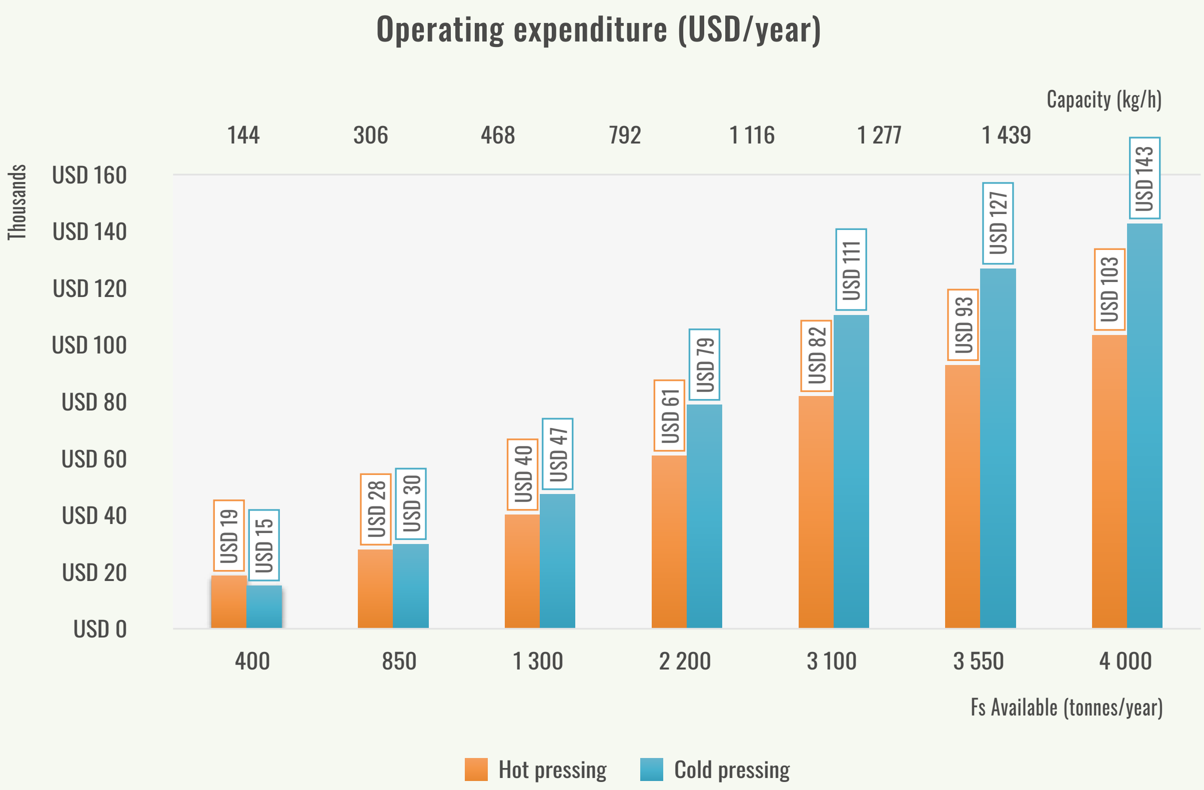
PZM FOR BRIQUETTES PRODUCTION USING HOT PRESSING TECHNOLOGY



Source: Elaboration based on BEFS Assessment Results

FIGURE 82.

COMPARISON BETWEEN HOT AND COLD PRESSING OPERATING EXPENDITURE



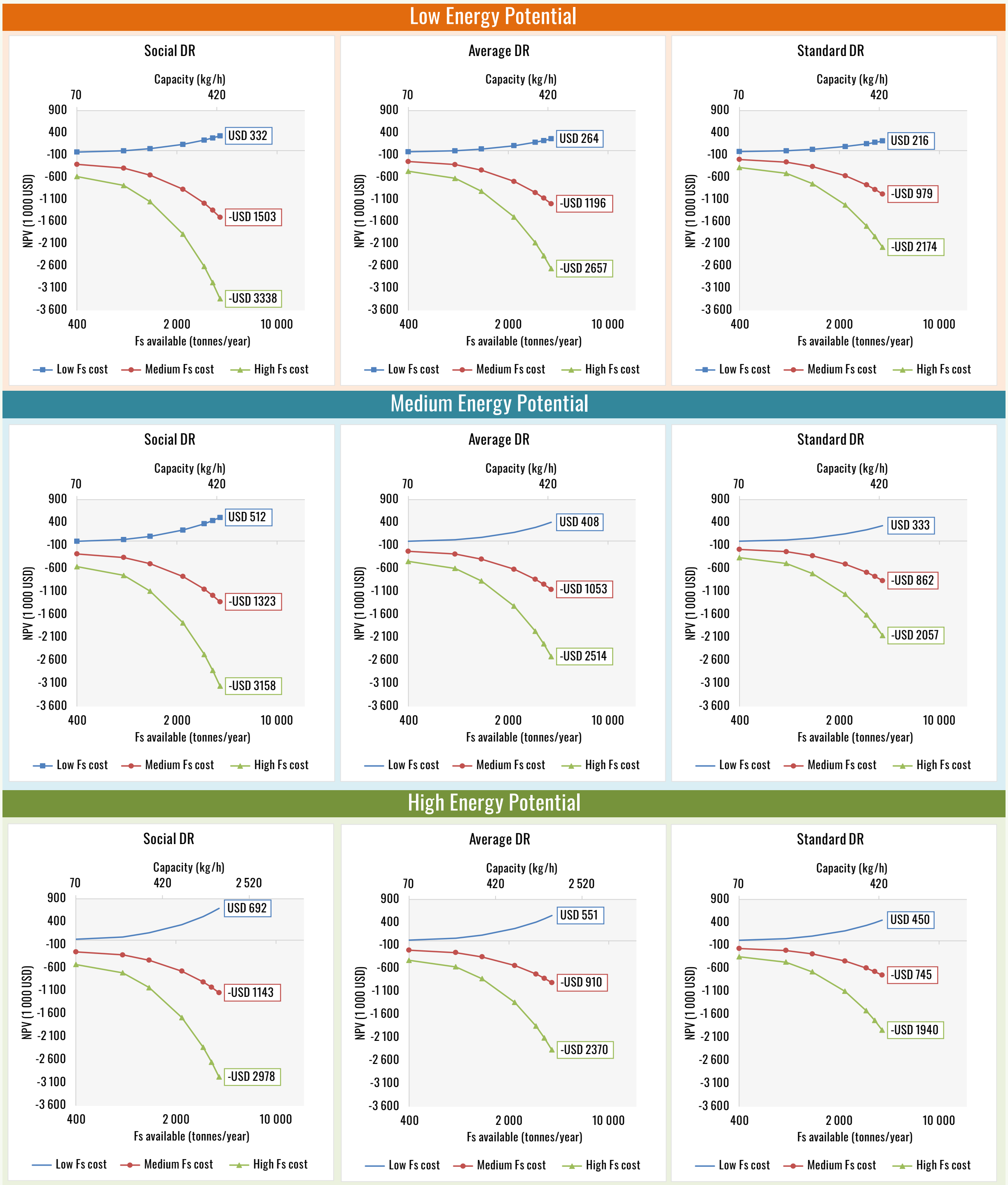
Source: Elaboration based on BEFS Assessment Results

4.5.2.4 Scenario 3: use of charcoal briquettes technology

Figure 83 summarizes the NPV obtained for charcoal briquettes production scenarios using hot pressing technology. In this case, the main technology modification added to a mechanical device powered by electricity would be for the

FIGURE 83.

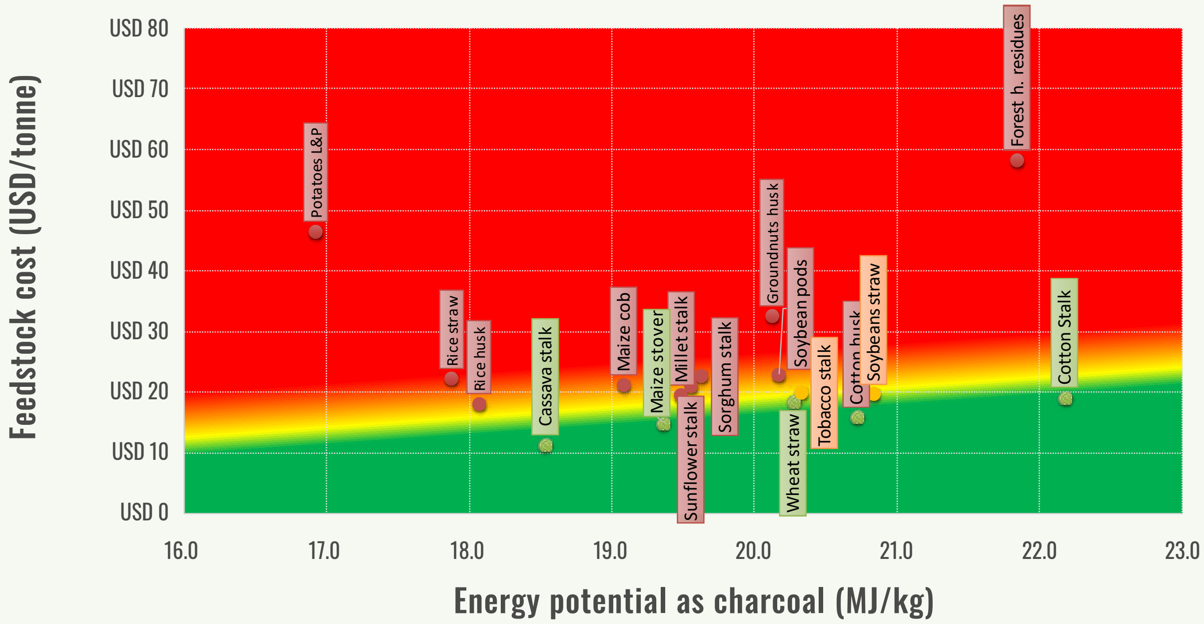
NPV FOR CHARCOAL BRIQUETTES PRODUCTION USING HOT PRESSING TECHNOLOGY



Source: Elaboration based on BEFS Assessment Results

FIGURE 84.

PZM FOR CHARCOAL BRIQUETTE PRODUCTION USING COLD PRESSING TECHNOLOGY



Source: Elaboration based on BEFS Assessment Results

carbonization of briquettes to obtain fuel that directly replaces wood charcoal.

The results obtained demonstrate that a combination of high energy potential feedstock, costing between 10 and 25 USD/tonne (depending on the energy potential), could result in profitable options.

After the carbonization process, the fuel properties of biomass improve. For this reason, the energy potential of feedstock options are found in different positions in the Scenario 3 PZM, as compared to other scenario PZMs (see **Figure 84**). However, the carbonization process experiences material losses that are linked to carbonization efficiency (i.e. 30 percent). These losses, along with the additional investment costs, affect the cost of the process as opposed to conventional biomass briquette production.

The green zone in the PZM occupies a comparatively smaller area, where cassava stalk, maize stover, wheat straw, and cotton stalk-based charcoal would be the most promising options.

Based on the results in **Figure 84** and from the standpoint of technology, hot pressing technology was identified as superior in terms of efficient use of biomass, which was estimated as available by the natural resources assessment.

However, it is important to stress the fact that charcoal briquetting represents the best feasible option, because no stove changes would be required for the consumers. This would allow for charcoal briquetting to be integrated into the current Zambian market more easily. For this reason, the results of this scenario will also be presented and discussed in the energy potential sections.

4.5.2.5 Energy potential from biomass briquettes produced using hot pressing technology

Out of 18 feedstock options in Zambia, 13 of those options proved to be suitable for briquette production using hot pressing technology. **Table 48** shows the minimum profit gained by producing biomass briquettes from different feedstock options. These capacities represent a technical constraint that relates, in turn, to the minimum feedstock amounts needed per district to supply a potentially profitable biomass briquette business.

TABLE 48.

MINIMUM PROFITABLE CONDITIONS FOR BIOMASS BRIQUETTE PRODUCTION

RANKING	CROP-RESIDUE TYPE		AVERAGE LHV (MJ/kg)	AVERAGE COLLECTION PRICE (USD/tonnes)	MINIMAL PRODUCTION CAPACITY (kg/h)
1	RICE	HUSK	13.80	18	380
2	MAIZE	COB	15.11	21	333
3	SORGHUM	STALK	15.81	23	301
4	SUNFLOWER	STALK	15.71	21	269
5	SOYBEAN	PODS	16.51	23	253
6	MILLET	STAW/STALK	15.62	20	245
7	TOBACCO	STALK	16.70	20	198
8	CASSAVA	STALK	14.40	11	190
9	MAIZE	STOVER	15.46	15	190
10	WHEAT	STRAW	16.63	19	182
11	SOYBEAN	STRAW	17.36	20	174
12	COTTON	HUSK	17.20	16	158
13	COTTON	STALK	19.08	19	158
15	GROUNDNUTS	HUSK	16.44	33	NOT PROFITABLE
16	FOREST PLANTATION RESIDUES		18.65	58	NOT PROFITABLE
17	POTATOES	LEAVES AND PEELS	12.33	47	NOT PROFITABLE
18	RICE	STRAW	13.56	22	NOT PROFITABLE

Source: Elaboration based on BEFS Assessment Results

Figure 85 provides information on the energy that could be extracted from the biomass briquettes produced in each province. The combination of all potential energy for cooking from biomass briquettes would be 26 540 thousand GJ/year.

The combined energy potential could satisfy 20 percent of Zambian households' demand for clean energy for cooking (see **Figure 86**). **Figure 85** shows that the highest potential for biomass is found in the Eastern and Central Provinces.

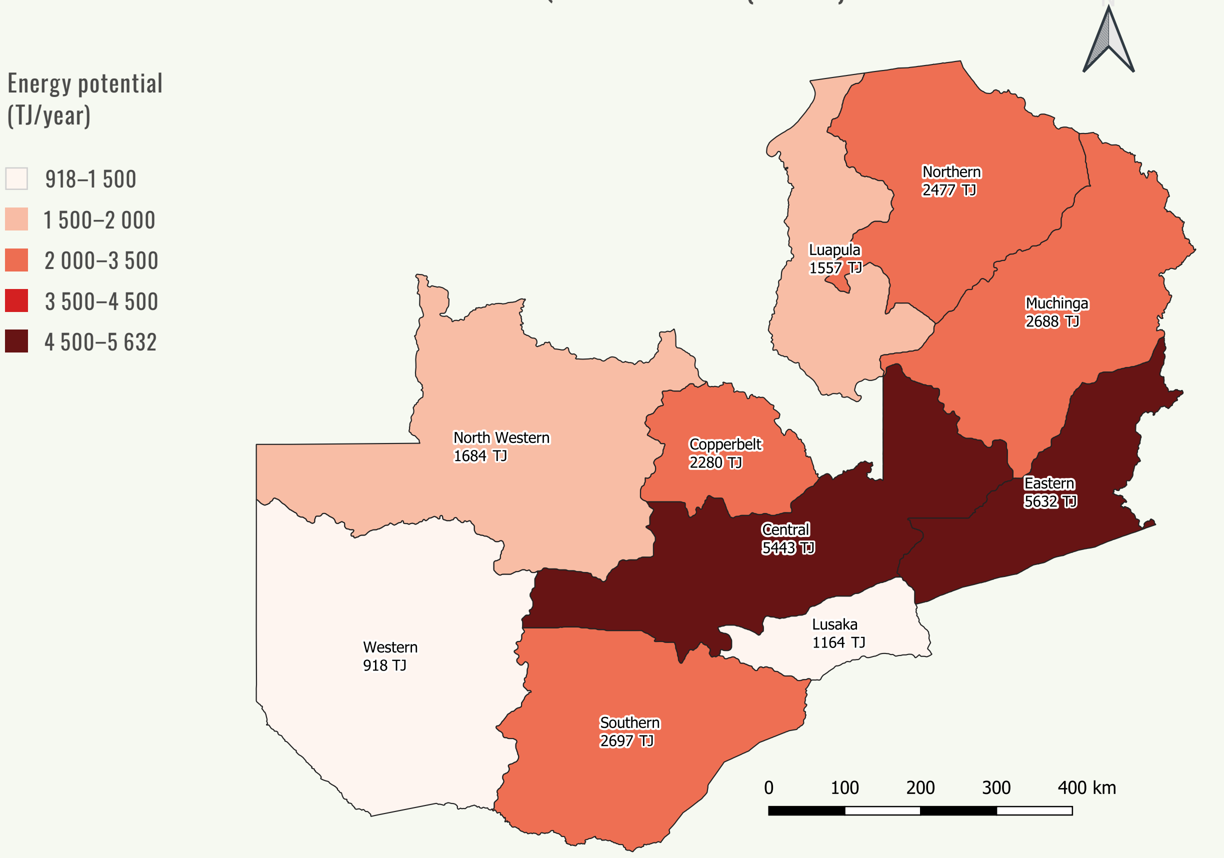
The contribution of different biomass options to energy generation is shown in **Figure 87**, with the top contributors being maize stover, maize cob, cotton stalk, soybean straw and cassava stalk. **Figure 87** is an indicator of the available feedstock and shows how maize residues could provide a continuous and stable supply of feedstock for briquette production.

Another useful indicator, presented in **Figure 88**, might be an initial investment required in order to attain the minimum profitable capacities[6]. For potential investors, the options with the smallest capacity and consequently the lowest investment, are more likely to be chosen. In this case, the best possibilities are cotton stalk, cotton husk, soybean straw, wheat straw, maize stover and cassava stalk.

[6] This is the smallest possible capacity that would allow for a producer to have a profitable business in a given context using certain feedstock options. It is also an indicator of how suitable a feedstock option would be for energy production. Thus, a small minimum profitable capacity usually means a low initial investment; as a result, it is more likely that potential investors would prefer this option.

FIGURE 85.

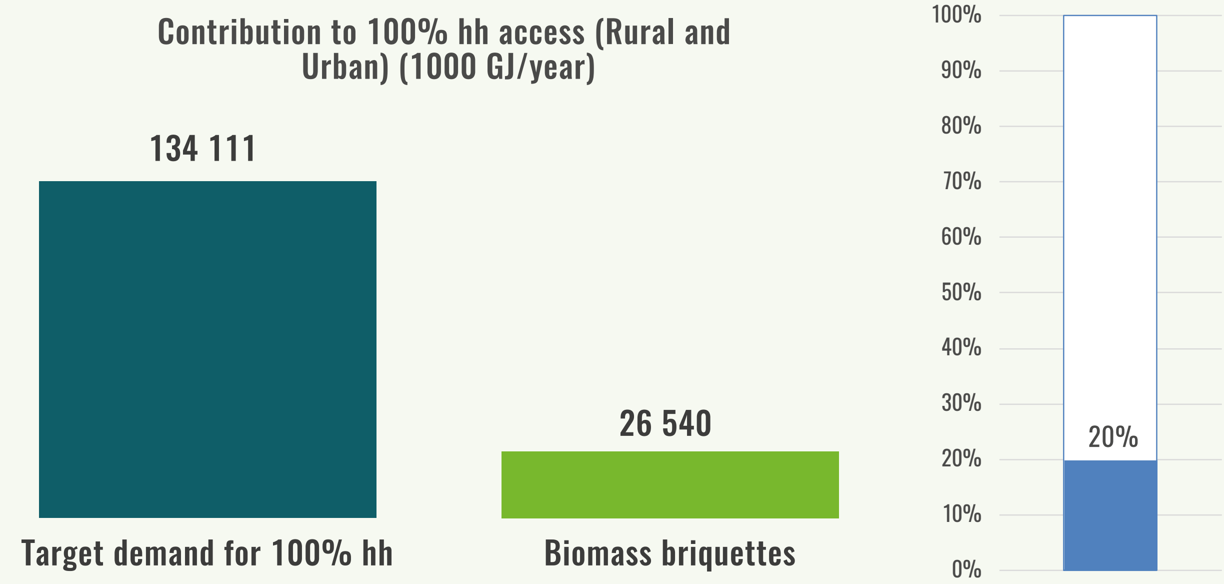
ENERGY POTENTIAL PRODUCTION FROM BIOMASS BRIQUETTES IN ZAMBIA (TJ/YEAR)



Source: Elaboration based on BEFS Assessment Results

FIGURE 86.

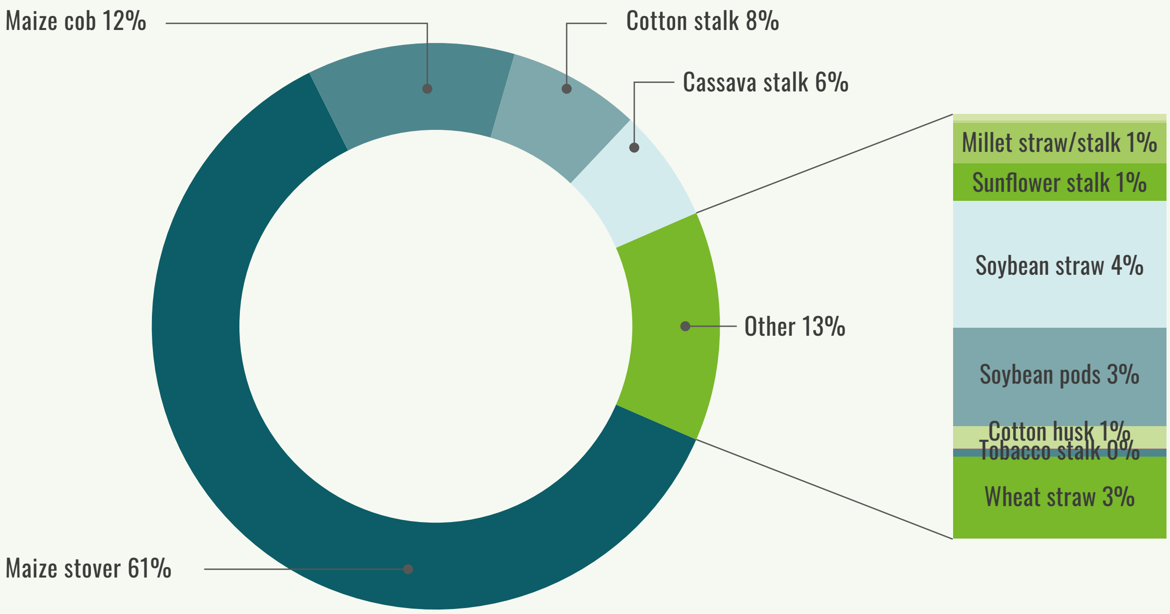
CONTRIBUTION OF BIOMASS BRIQUETTES TO CLEAN FUELS FOR NATIONAL COOKING TARGETS



Source: Elaboration based on BEFS Assessment Results

FIGURE 87.

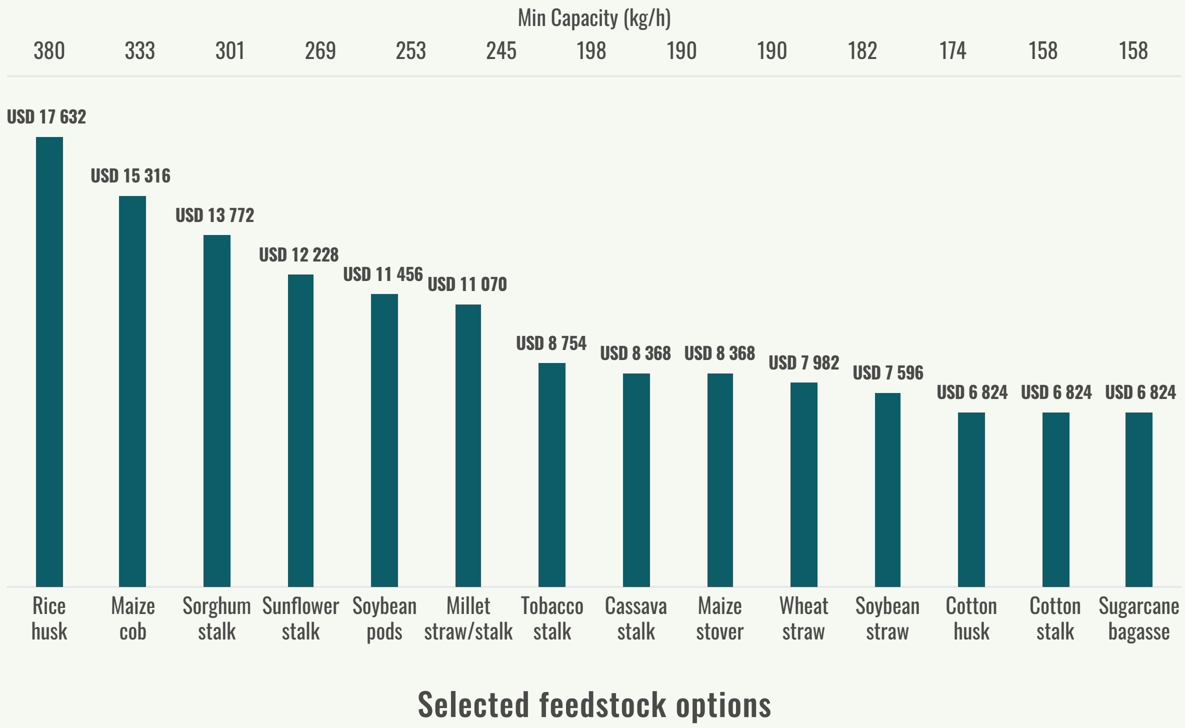
BIOMASS SHARE SUPPLYING BIOMASS BRIQUETTE PRODUCTION SYSTEMS



Source: Elaboration based on BEFS Assessment Results

FIGURE 88.

MINIMUM INVESTMENTS NEEDED PER FEEDSTOCK FOR BIOMASS BRIQUETTES PRODUCTION



Source: Elaboration based on BEFS Assessment Results

4.5.2.6 Energy potential from charcoal briquettes produced using hot pressing technologies

For charcoal briquette production, 8 out of 18 feedstock options were found to be suitable. The minimum profitable capacities are summarized in **Table 49**. From the charcoal briquettes produced using suitable feedstock it might be possible to produce 8 192 GJ/year of energy for cooking (see **Figure 89**).

The total energy potential from charcoal briquettes would contribute 6 percent of the 100 percent clean fuel energy target in Zambia (see **Figure 90**). Energy potential is directly linked to biomass availability and therefore, the Central and Eastern Provinces of Zambia are still the regions with the highest potential.

The contribution of different biomass options to energy generation is shown in **Figure 91**. The top contributors would be maize stover, cotton stalk, soybean straw, cassava stalk and wheat straw. This same list of options would offer the lowest initial investments (see **Figure 92**).

It is important to note that some feedstock options would be more cost-effective, for example, charcoal briquettes and others, such as biomass briquettes because of their minimum profitable capacities (and consequently lower initial investments). In fact, this is the case with charcoal briquettes produced from cassava and cotton stalks as well as maize stover. On the other hand, other options such as wheat straw and maize cob are processed the most effectively as biomass briquettes.

TABLE 49.

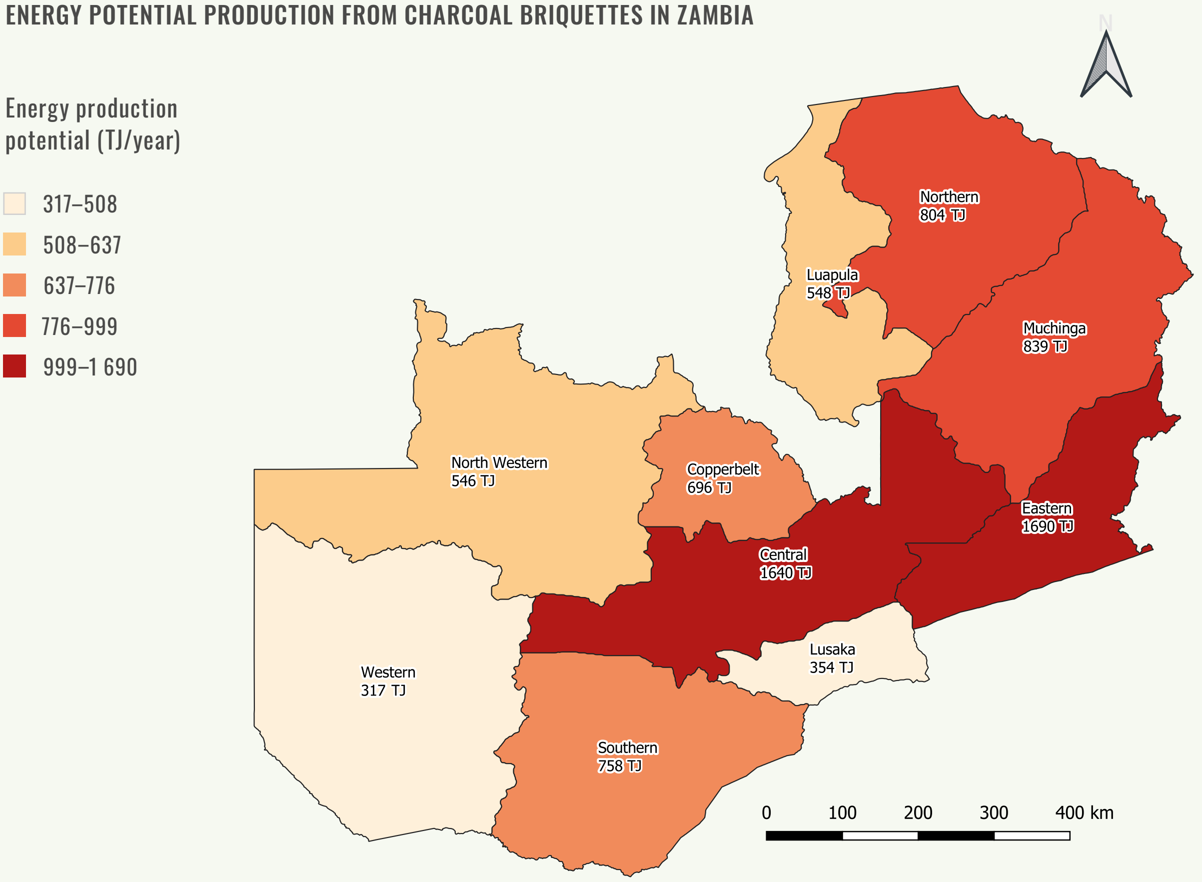
MINIMUM PROFIT FOR CHARCOAL BRIQUETTE PRODUCTION

RANKING	CROP-RESIDUE TYPE		AVERAGE LHV (MJ/kg)	AVERAGE COLLECTION PRICE (USD/tonne)	MINIMAL PRODUCTION CAPACITY (kg/h)
1	CASSAVA	STALK	18.53	11	91
2	COTTON	HUSK	20.71	16	106
3	MAIZE	STOVER	19.36	15	120
4	COTTON	STALK	22.17	19	120
5	WHEAT	STRAW	20.27	19	163
6	SOYBEAN	STRAW	20.83	20	167
7	TOBACCO	STALK	20.33	20	201
8	MILLET	STALK	19.49	20	248
9	RICE	HUSK	18.07	18	NOT PROFITABLE
10	MAIZE	COB	19.08	21	NOT PROFITABLE
11	SORGHUM	STALK	19.63	23	NOT PROFITABLE
12	SUNFLOWER	STALK	19.55	21	NOT PROFITABLE
13	SOYBEAN	PODS	20.17	23	NOT PROFITABLE
14	GROUNDNUTS	HUSK	20.12	33	NOT PROFITABLE
15	FOREST PLANTATION RESIDUES		21.84	58	NOT PROFITABLE
16	POTATOES	LEAVES AND PEELS	16.92	47	NOT PROFITABLE
17	RICE	STRAW	17.88	22	NOT PROFITABLE

Source: Elaboration based on BEFS Assessment Results

FIGURE 89.

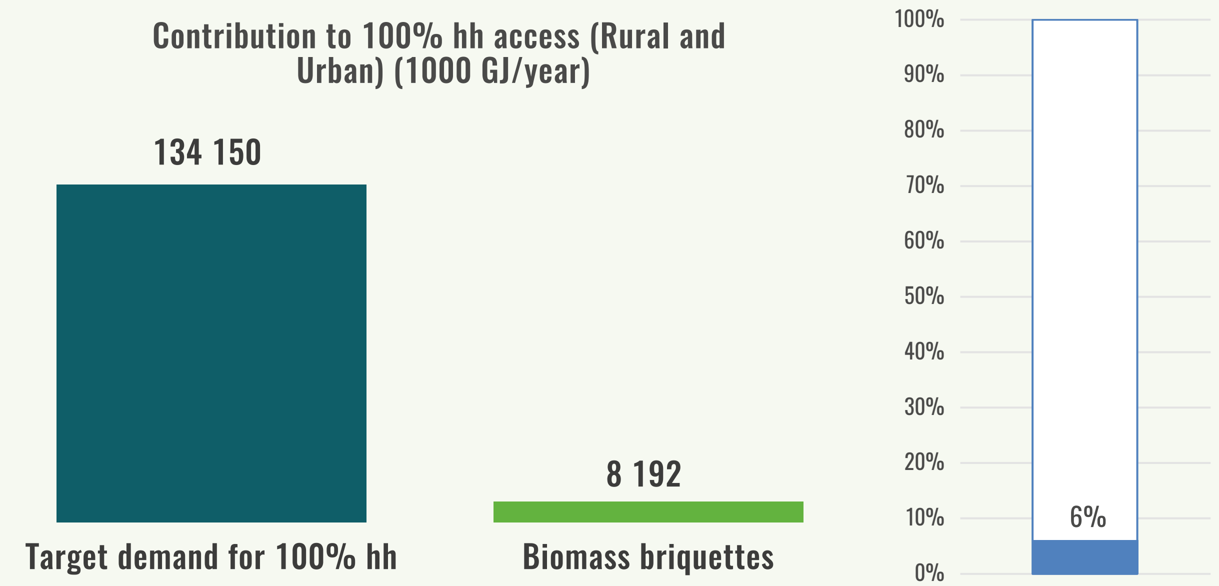
ENERGY POTENTIAL PRODUCTION FROM CHARCOAL BRIQUETTES IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

FIGURE 90.

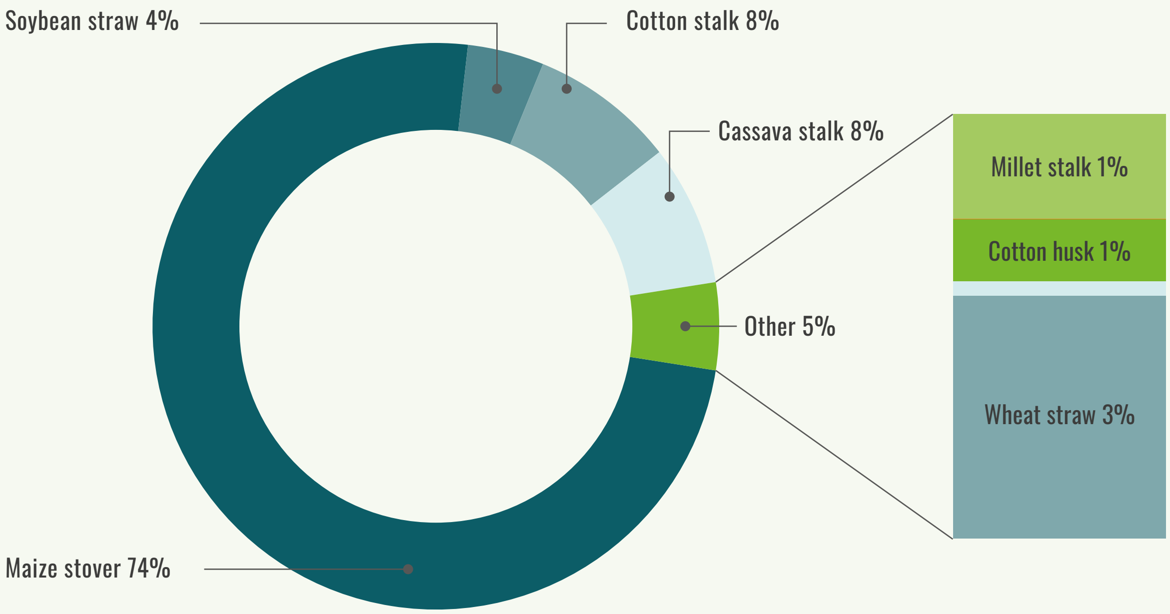
CONTRIBUTION OF CHARCOAL BRIQUETTES TO NATIONAL TARGETS FOR CLEAN FUELS FOR COOKING



Source: Elaboration based on BEFS Assessment Results

FIGURE 91.

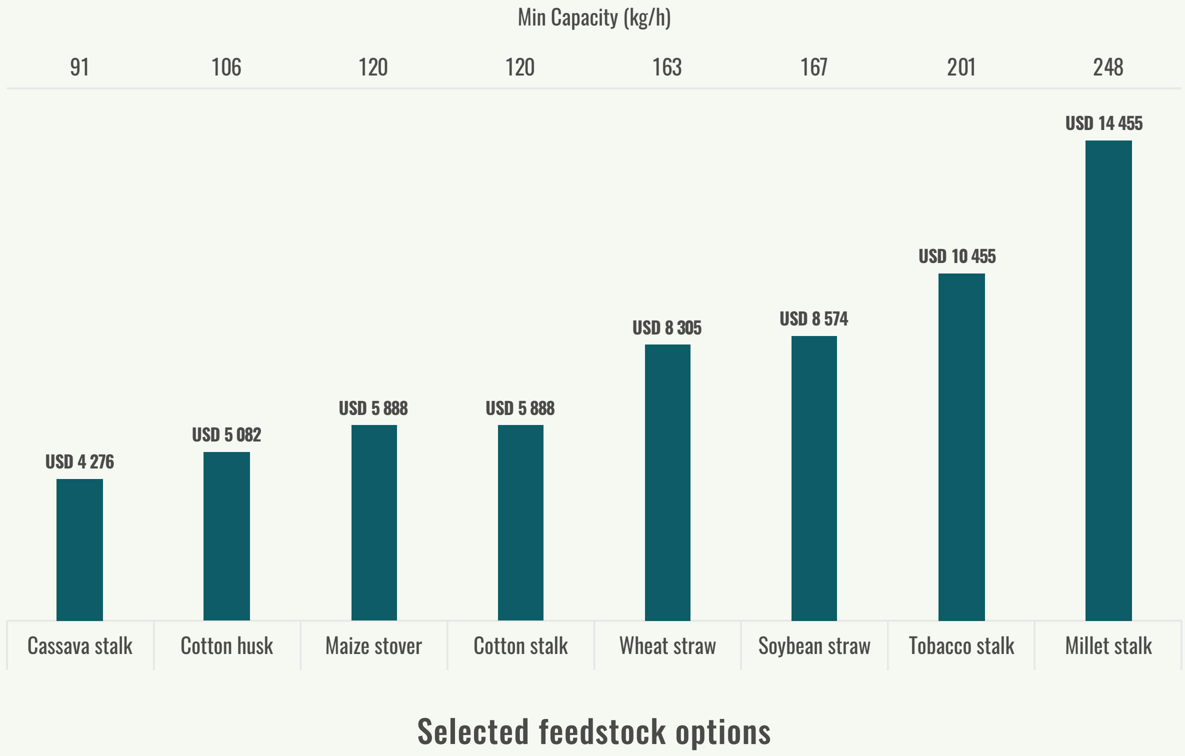
BIOMASS SHARE SUPPLYING CHARCOAL BRIQUETTE PRODUCTION SYSTEMS



Source: Elaboration based on BEFS Assessment Results

FIGURE 92.

MINIMUM INVESTMENT NEEDED PER FEEDSTOCK FOR BIOMASS BRIQUETTE PRODUCTION



Source: Elaboration based on BEFS Assessment Results

4.5.3 Biogas for cooking

The objective of the biogas assessment was to evaluate the use of livestock residues and selected crop residues as alternatives to the current fuel options used in Zambia (see the feedstock selection section).

This evaluation will present the potential benefits of biogas production for rural households in Zambia with a range of production conditions (as explained in previous sections). Three different types of biogas digester technologies will be reviewed: fixed dome, floating drum, and tubular (as described in the technology description section). The BEFS analysis presents the potential benefits of biogas for rural households. These elements were taken into consideration to evaluate favourable production conditions that, combined with the quantities during the natural resources assessment, were found to be potentially available. The assessment thus allowed for an estimate of the energy potential from biogas to be performed.

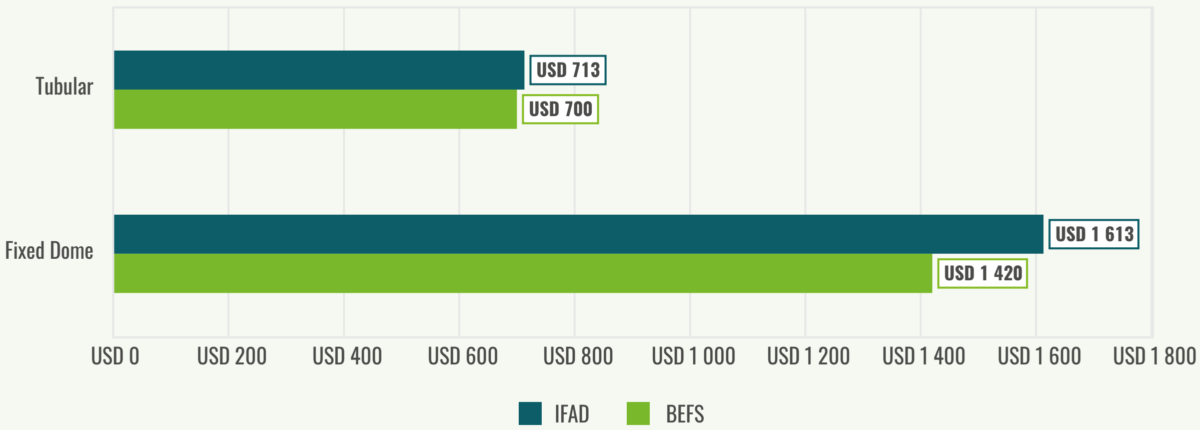
4.5.3.1 Capital investment in biogas digesters

One of the main elements of this assessment was the calculation of the capital investment required for the three biogas digester models. A calculation was performed using the current prices of different materials that would be required to build the different models. The capital investment costs obtained for the three models resulted in specific values for Zambia. In order to validate the BEFS model, **Figure 93** presents a comparison of the capital investment costs versus the values reported by IFAD, which was updated in 2020 (Antonio Rota and Sehgal, 2015). Overall, there was a 6 percent difference between BEFS model and IFAD model.

Figure 94 presents a comparison of the capital investment costs and the annual biogas production rates for different digester volumes. This was essential to making a fair comparison of all three options used during the same ten-year period. During this period the need to replace the tubular digester was foreseen, given that the tubular digester has an average life span of five years. However, the floating drum and fixed drum, which have a lifespan of over ten years would not need replacing. Thus, the results obtained indicate that the most capital intensive alternative for all of the digester volumes would be the floating drum (blue line), whereas the fixed dome option would be the least expensive (orange line). This difference can be explained by the fact that the tubular digester needs to be replaced, in addition to the relatively high cost of materials used for the floating drum.

FIGURE 93.

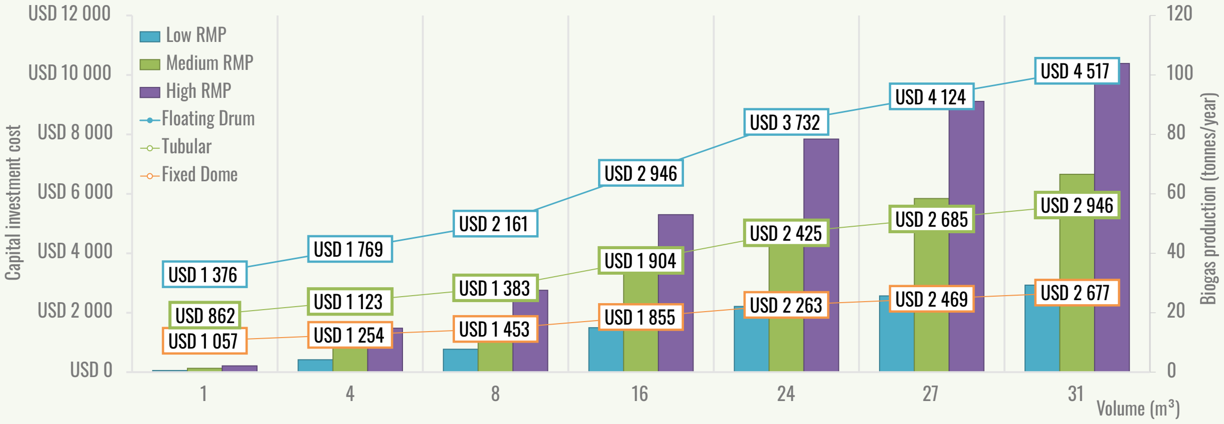
COMPARISON OF CAPITAL INVESTMENT COSTS PREDICTED FOR ZAMBIA VERSUS VALUES REPORTED BY IFAD



Source: Elaboration based on BEFS Assessment Results

FIGURE 94.

COMPARISON OF ESTIMATED CAPITAL INVESTMENT FOR BIOGAS DIGESTERS IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

Regarding biogas production rates, **Figure 94** demonstrates the importance of feedstock quality. Considering volume, digesters using high Realistic Methane Potential (RMP)[7] feedstock can produce more biogas than when using low RMP feedstock. Therefore, by using the best quality options it would be easier to fully satisfy the energy requirements of the households that supply feedstock.

4.5.3.2 Production costs of biogas production and profitability

The production costs of biogas for digester volumes were calculated using a range of 0.3 to 40 m³, which was considered a comprehensive range for biogas production at the small-scale level. Indeed, household-level digester volumes generally have a range of 4 to 10 m³. Other variables included in the production cost calculations were the three RMP levels and three feedstock cost levels. The production costs presented for each technology analysed are described in terms of energy, thus allowing for a comparison with competitive cooking fuels, such as fuelwood and charcoal.

Figure 95 shows the comparison of biogas production costs for the three digester technologies versus the prices of fuelwood and charcoal. Clearly, higher-quality feedstock would overall have the lowest production costs and would be more cost-competitive versus traditional fuels, in particular when using the fixed dome models.

4.5.3.3 Benefits for households

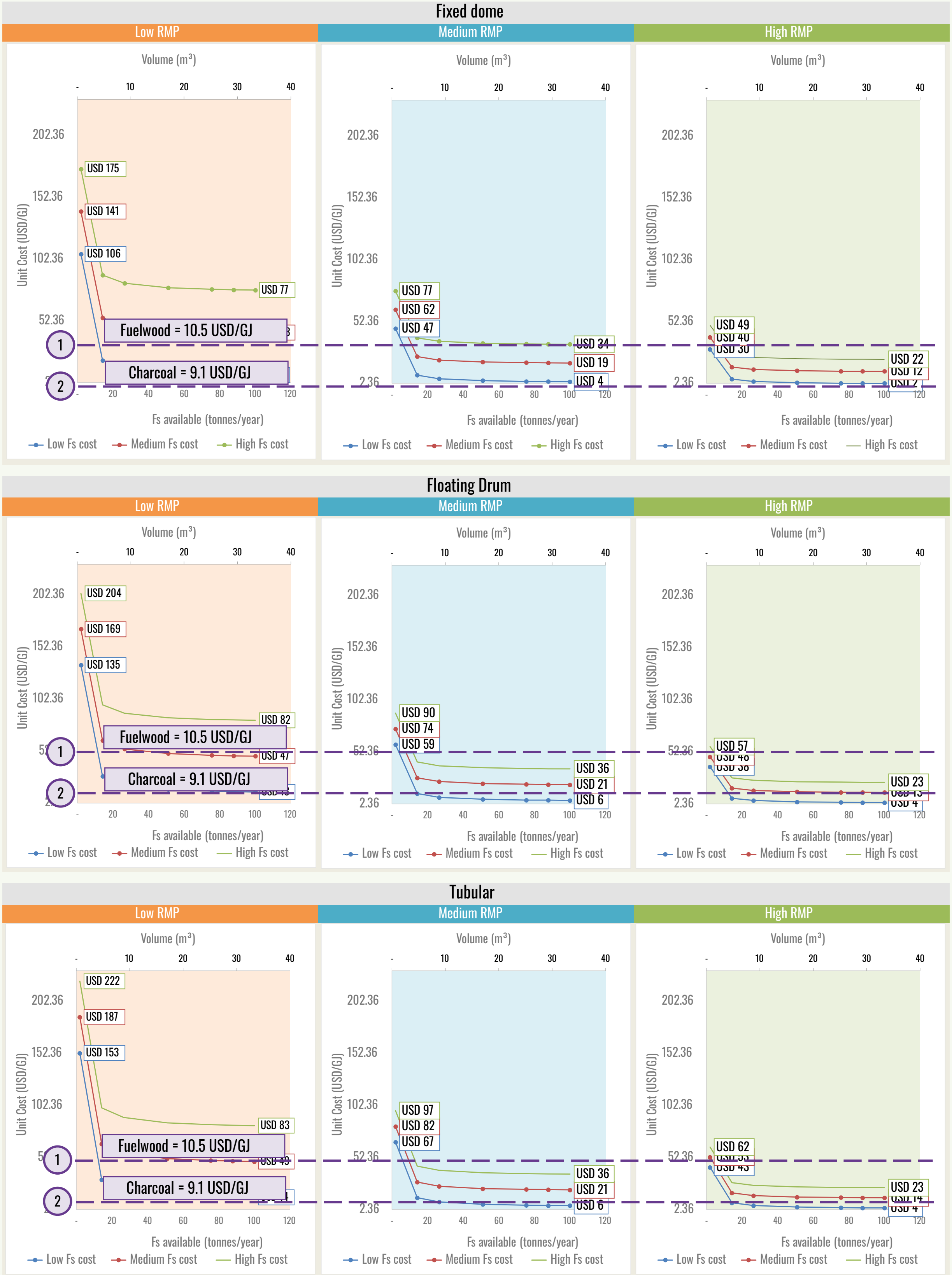
There is no comparison price scenario possible for the BEFS biogas assessment because the biogas would be produced directly by the householders and would not be sold to any customers. Therefore, in this case a socio-economic analysis was carried out rather than an economic and financial analysis. The benefits of biogas usage (i.e. lesser cooking time), the potential fertilizer replacement (i.e. bioslurry usage) and the time-saving benefits (i.e. no need to collect fuelwood) must offset the cost of producing biogas to make it a feasible option to replace fuelwood and charcoal in Zambia. More specifically, these benefits can be categorised as follows:

Cooking fuel replacement is based on the cooking fuel demand presented in previous sections. It was possible to estimate an equivalent target daily energy demand of 97 MJ/hh. **Table 50**

[7] The Realistic Methane Potential (RMP) indicates the potential to produce biogas under various production conditions. It considers the effect of parameters such as the hydraulic retention time, total volatile solids, methane yield, and the maximum specific growth rate of microorganisms. This model is used in BEFS assessment to account for the effects of environmental temperature, and the digester model will have on the biogas production capacity of each feedstock option. RMP units are m³ biogas/m³ feed/day, where m³ feed/day is the daily influent to the digester (Hashimoto *et al.* 1981).

FIGURE 95.

COMPARISON OF BIOGAS PRODUCTION COSTS FOR DIFFERENT DIGESTER TECHNOLOGIES FOR THREE RMP LEVELS



Source: Elaboration based on BEFS Assessment Results

TABLE 50.

ENERGY CONSUMPTION CALCULATION

		CONSUMPTION PER DAY	TOTAL EQUIVALENT USEFUL ENERGY	EQUIVALENT BIOGAS	UNIT PRICE	ENERGY EXPENDITURE
FUEL	**UNITS**	**tonnes/day**	**MJ/day/hh**	**m³/day**	**USD/unit**	**(USD/year)**
BRIQUETTES	kg/day	0.00	0.00	0.00	0.17	0.00
FUEL WOOD	kg/day	11.00	31.68	4.66	0.03	122.38
CHARCOAL	kg/day	5.00	33.00	4.85	0.13	229.95
KEROSENE	l/day	0.81	19.16	2.82	0.95	280.87
ELECTRICITY	kWh/day	5.00	13.50	4.00	0.15	273.75
ENERGY (MJ/day/hh)			**97.34**	**TOTAL ANNUAL ENERGY EXPENDITURE (USD/year)**		**906.94**

Source: Elaboration based on values collected by (BEFS Zambia Survey, 2019)

TABLE 51.

FERTILIZER EXPENDITURE IN TERMS OF QUANTITY AND MONEY

	PRICES PAID BY FARMERS COST (USD/kg)	FERTILIZER CONSUMPTION (kg/year)
NITROGEN	0.65	150
PHOSPHOROUS	0.60	100
POTASSIUM	0.63	65
NET FERTILIZER EXPENDITURE	315	

Source: Elaboration based on values collected by (BEFS Zambia Survey, 2019)

summarizes the values used for its calculation along with their monetary value of 906 USD/year;

Fertilizer replacement is based on data collected for the average fertilizer consumption, a potential fertilizer replacement of 315 kg/hh/year was estimated under the assumption of a annual fertilizer application rate of 49 kg/ha and an average area cultivated by a household of 1.91 ha (Jann Lay, Kerstin Nolte, 2018). **Table 51** summarizes the values used for the calculation along with their monetary value of 199 USD/year.

Time-saving accounts for the net balance between the time dedicated to fuelwood

TABLE 52.

TIME EXPENDITURE BALANCE

TIME SAVING	h/day	h/year
+FUELWOOD COLLECTION	1.00	365.00
+WATER COLLECTION	0.25	91.25
-DUNG COLLECTION	0.50	182.50
-MIXING IN THE BIODIGESTER	0.25	91.25
-COOKING USING BIOGAS	4.00	1 460.00
NET BALANCE OF TIME SAVINGS	4.00	1 460.00

Source: Elaboration based on values collected by (BEFS Zambia Survey, 2019)

collection and cooking versus the time that needs to be dedicated to all biodigester operation activities. Overall, the calculated time savings might reach 1 460 h/hh/year. **Table 52** summarizes the net balance of time savings. Using the obtained value, it was assumed that 20 percent of this time is dedicated to income generation. Thus, it was possible to calculate a monetary value of 147 USD/year.

4.5.3.4 Feedstock quality effect on biogas systems performance

In the BEFS assessment three levels of RMPs (low, medium, and high), as explained in previous sections, were taken into consideration. Depending on the RMP of each feedstock, these three levels will be able to produce different biogas rates and consequently impact the amount needed to meet the energy demand of households for cooking.

Figure 96 presents the cooking energy potentially supplied by low RMP biogas. Also, it shows digester volumes and the amounts needed in order to supply each of these systems. Indeed, sizes larger than 16 m^3 would most likely be able to supply more than 90 percent of the households' energy demands. A low RMP feedstock (RMP < 100) is for example, pig manure (RMP = 59), which would require a minimum of 51 tonnes of manure/year to operate digesters; 56 pigs would be required to supply this quantity.

Figure 97 presents the shares of cooking energy potentially supplied by medium RMP (RMP 101 to 150) biogas. In this case, to supply the 100 percent energy demands of at least one household, an 8 m^3 digester might be needed. A good example of medium RMP is sunflower stalk (RMP = 131); an 8 m^3 digester supplied with 14 tonnes/year of sunflower stalk would require at least 16 ha of land to grow the sunflower.

Finally, results for a high RMP feedstock (> 150) such as layer chicken (RMP = 191), indicate that a 5 m^3 digester would be needed to supply 100 percent of a rural household's energy needs (see **Figure 98**). For example, a 5 m^3 biogas digester would need 16 tonnes/year of high RMP layer chicken feedstock; such a supply would require at least 244 chickens.

FIGURE 96.

POTENTIAL BENEFITS FROM LOW RMP FEEDSTOCK (RMP < 100)

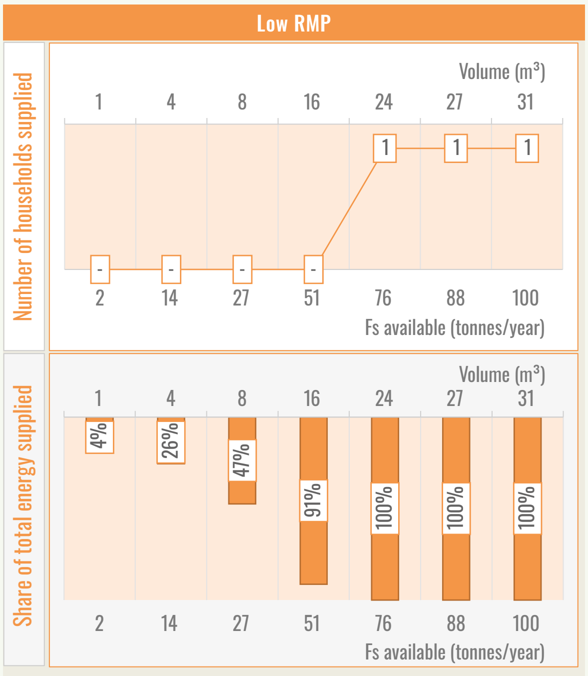
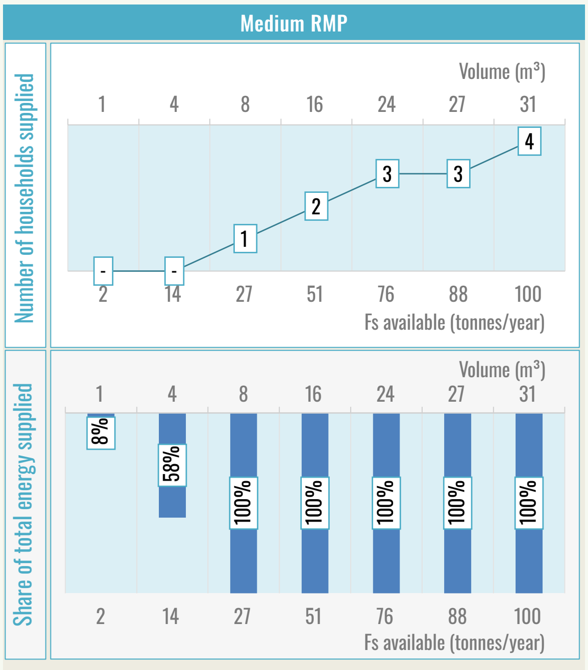


FIGURE 97.

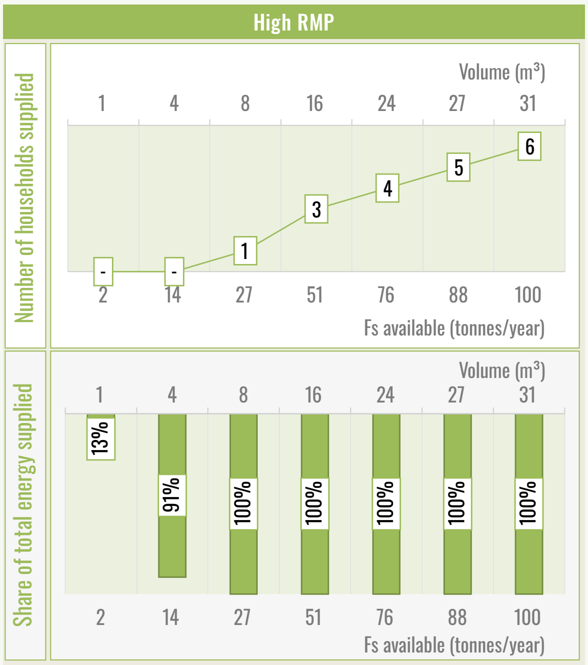
POTENTIAL BENEFITS FROM MEDIUM RMP FEEDSTOCK (RMP 100–150)



Source: Elaboration based on BEFS Assessment Results

FIGURE 98.

POTENTIAL BENEFITS FROM HIGH RMP FEEDSTOCK (RMP > 150)



Source: Elaboration based on BEFS Assessment Results

TABLE 53.

LIST OF SUITABLE FEEDSTOCK OPTIONS FOR CODIGESTION IN SMALL-SCALE BIOGAS PRODUCTION IN ZAMBIA

CROP	RESIDUE TYPE	CATEGORY	RMP	COLLECTION PRICE (USD/tonne)
SORGHUM	STALK	CROP RESIDUE	151	23
MAIZE	STOVER	CROP RESIDUE	83	15
SUNFLOWER	STALK	CROP RESIDUE	131	21
COTTON	STALK	CROP RESIDUE	127	19
POTATOES	LEAVES AND PEELS	CROP RESIDUE	60	47
WHEAT	STRAW	CROP RESIDUE	151	19
RICE	STRAW	CROP RESIDUE	132	22
LAYER CHICKEN	MANURE	MANURE	191	30
CATTLE	MANURE	MANURE	97	5
GOATS	MANURE	MANURE	81	16
PIGS	MANURE	MANURE	59	5

Source: Elaboration based on BEFS Assessment Results

4.5.3.5 Feedstock selection and co-digestion

Generally, at a small-scale biogas is produced from livestock residues, mainly cattle manure. Other feedstock, such as crop residues might also be suitable alternatives. To increase the production rates and take advantage of other locally available options, it is possible to use a scheme named codigestion, however, this mixture cannot be completely arbitrary. In order to understand at what ratio different feedstock can be mixed in codigestion systems, one rule of thumb is to consider the C:N ratio of components taken into account. During anaerobic digestion the different chemical components of feedstock (carbon, C; hydrogen, H; nitrogen, N; oxygen, O) are used selectively by different digestion bacteria, where the specific ratios of organic matter (carbon) to nitrogen are essential for optimal digestion and avoiding inhibitory effects. In this sense, C:N ratios higher than 23:1 are likely to be unsuitable for optimal digestion, while rates below 10:1 might inhibit the digestion process (Marchaim, 1992). A summary of suitable feedstock options for codigestion in biogas production is presented in **Table 53**.

4.5.3.6 The profitability of biogas production

After the production costs and monetary value of biogas were assessed, the benefits were defined. Furthermore, profitability was estimated by using the Net Present Value (NPV) as a figure of merit. Hence, the analysis determined the NPV by considering the different feedstock properties, plant capacities, as well as the three biogas digester models.

The most critical factor affecting the production costs was the investment required to build the digesters and consequently the mechanisms used to acquire the materials. Typically, countries address this issue by developing a biogas programme that supports householders with materials, labour for construction, or financing. It was therefore decided that the effect of a biogas programme under three scenarios would be analysed as follows:

- Scenario 1: No biogas programme;
- Scenario 2: A national biogas programme that pays for the construction labour costs;
- Scenario 3: A national biogas programme that provides households with construction material.

The following subsection presents the results for each scenario at the time of analysis.

4.5.3.7 Scenario 1: no biogas programme

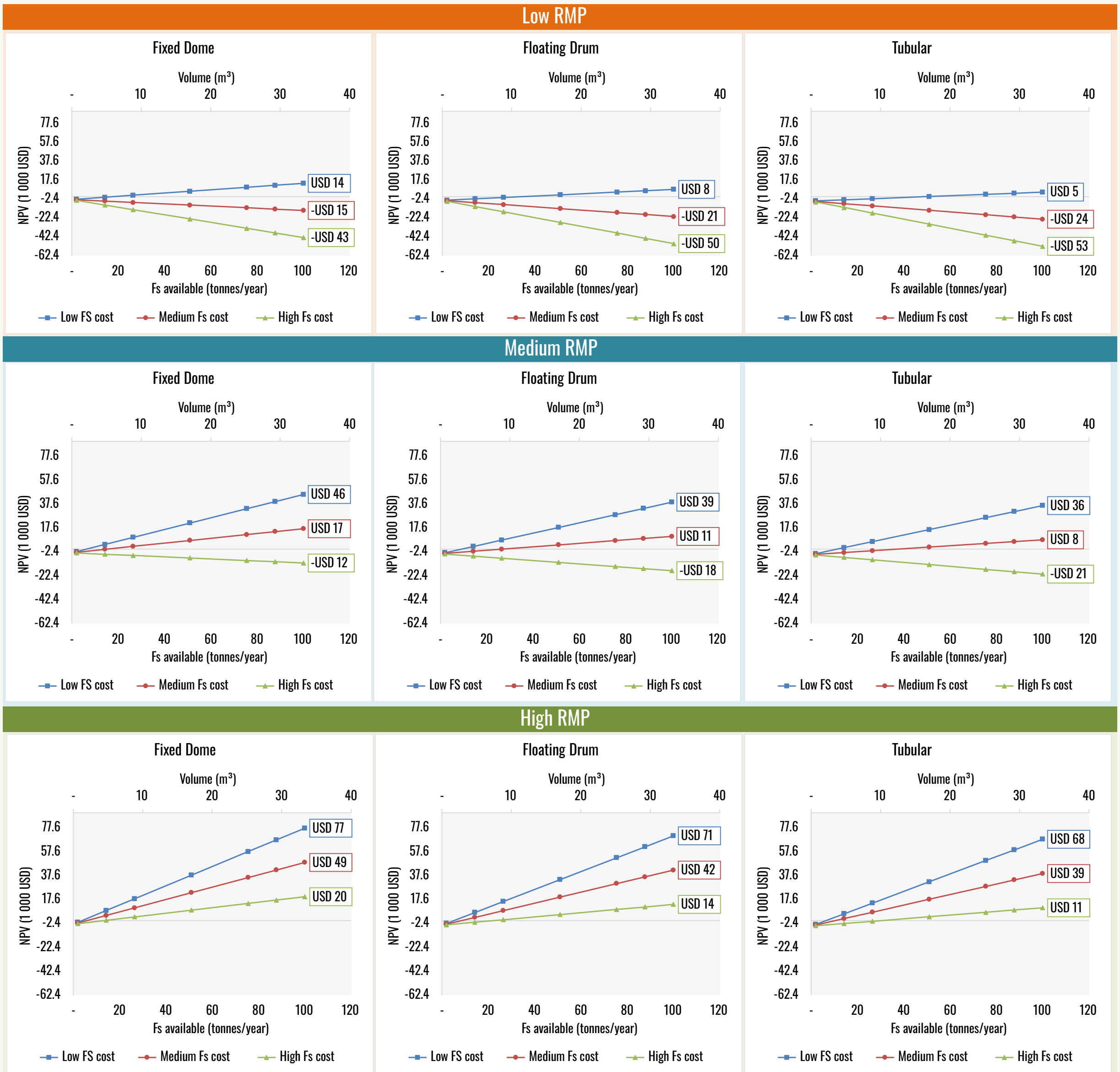
Figure 99 summarizes the NPVs obtained for biogas production, assuming there is no biogas programme operating in Zambia. In this case, households must pay for construction materials and labour costs. This scenario is the baseline.

The results obtained show that in the case where householders do not have the support of a biogas programme, the safest technologies to invest in would be the fixed dome and floating drum technologies. Moreover, the minimum feedstock quality should be a medium RMP, paying a maximum price between 1 and 30 USD/tonne (depending on the RMP).

Figure 100 shows the PZM obtained for scenario 1. Once the available feedstock options were located in the PZM, the ‘no feedstock option’ were subsequently included in the green zone. On the other hand, cattle manure,

FIGURE 99.

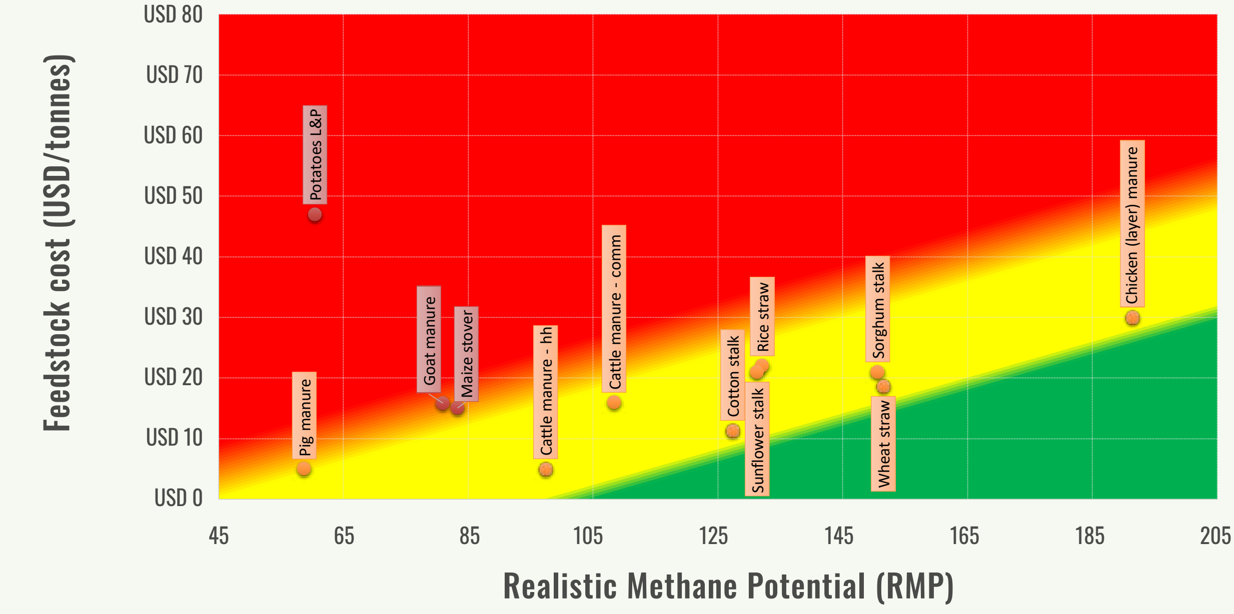
NPV FOR BIOGAS PRODUCTION UNDER SCENARIO 1 CONDITIONS FOR THREE RMP LEVELS



Source: Elaboration based on BEFS Assessment Results

FIGURE 100.

PZM FOR BIOGAS PRODUCTION UNDER SCENARIO 1 CONDITIONS



Source: Elaboration based on BEFS Assessment Results

cotton stalk, sunflower stalk, sorghum stalk, wheat straw, and layer chicken are found in the yellow region. This means that the production conditions where biogas benefits can offset the production costs, would only be possible when using certain technologies and plant capacities, as initially indicated in the NPV charts. Other feedstock options should be discarded regardless of the support of a biogas programme.

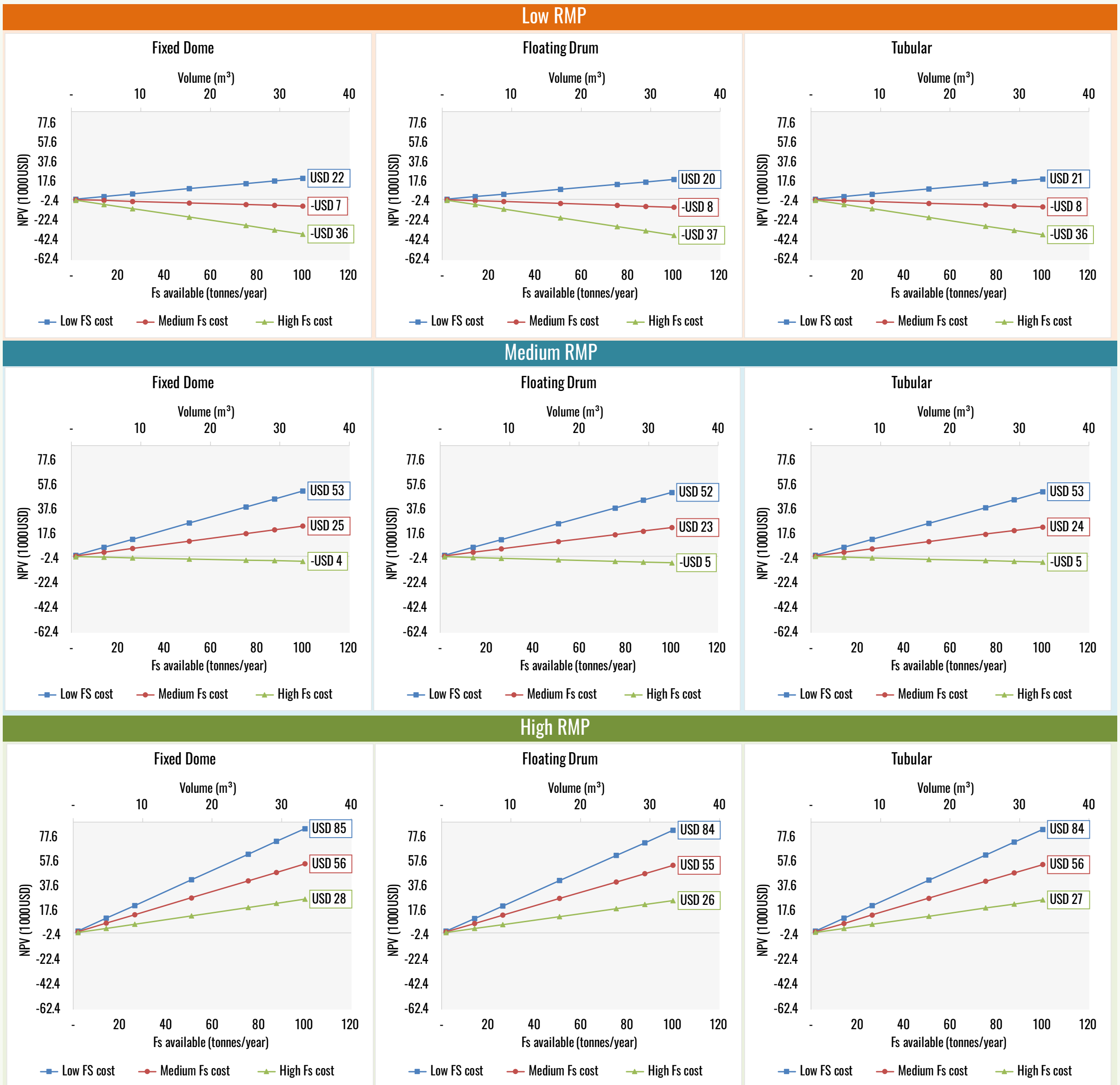
4.5.3.8 Scenario 2: a national biogas programme is paying for the construction labour costs

Figure 101 summarizes the NPV obtained for biogas production, assuming there is a biogas programme operating in Zambia. This programme would pay a workforce to take care of the building digesters (masons and supervisors) but farmers would still need to pay for construction materials. In this case, the benefits for households slightly increased compared to the baseline at an average of 9.7 percent for fixed dome, 5.0 percent for floating drum, and 8.28 percent for tubular digester. This change made the tubular digester option (more) viable in some cases.

The PZM for the scenario presented in **Figure 102** shows that cattle manure, cotton stalk, sorghum stalk, wheat straw, and layer chicken are in the green zone and could therefore be used for a wide range of types and sizes of and all technologies in biogas digester. Swine manure, rice straw, and sunflower stalk are less profitable options (yellow zone). Other feedstock options should be discarded under this scenario.

FIGURE 101.

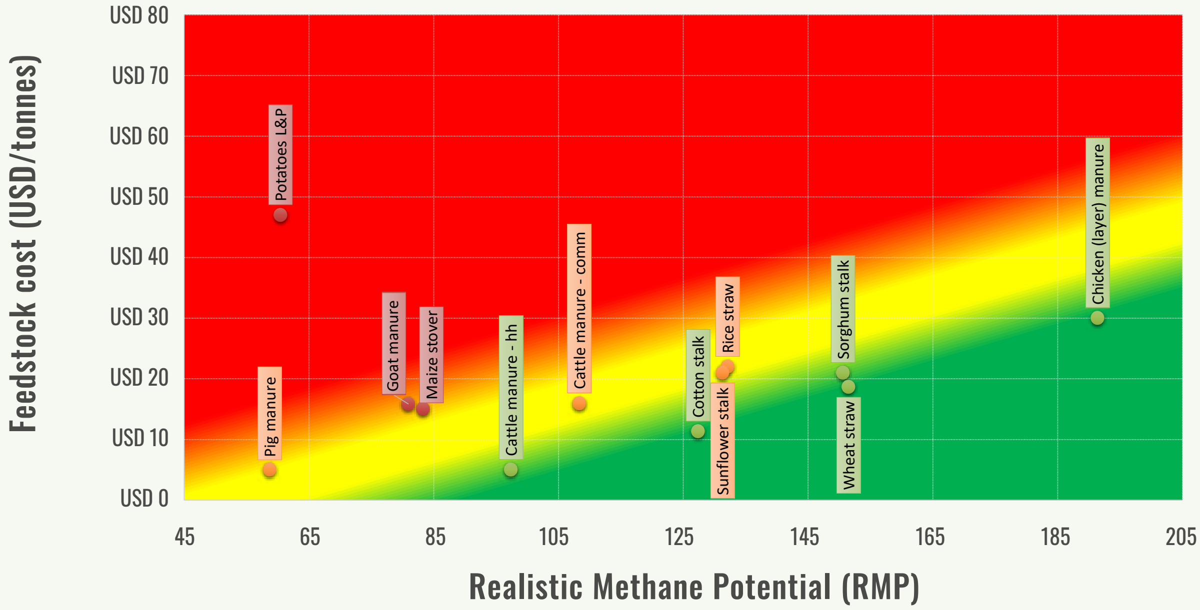
NPV FOR BIOGAS PRODUCTION UNDER SCENARIO 2 CONDITIONS FOR THREE RMP LEVELS



Source: Elaboration based on BEFS Assessment Results

FIGURE 102.

PZM FOR BIOGAS PRODUCTION UNDER SCENARIO 2 CONDITIONS



Source: Elaboration based on BEFS Assessment Results

4.5.3.9 Scenario 3: a national biogas programme providing households with construction materials

Figure 103 summarizes the NPV obtained for biogas production, assuming there is a biogas programme operating in Zambia. It would provide households with construction materials, but the farmers would still need to pay for the labour for construction. Under this scenario, the benefits to households increase dramatically compared to the baseline, by an average of 48 percent for fixed dome, 34 percent for floating drum, and 41 percent for tubular digester.

The PZM for Scenario 3 (see **Figure 104**), shows a sharp increase in the green zone area. This situation indicates that all feedstock, apart from potato leaves, could potentially be viable for biogas production.

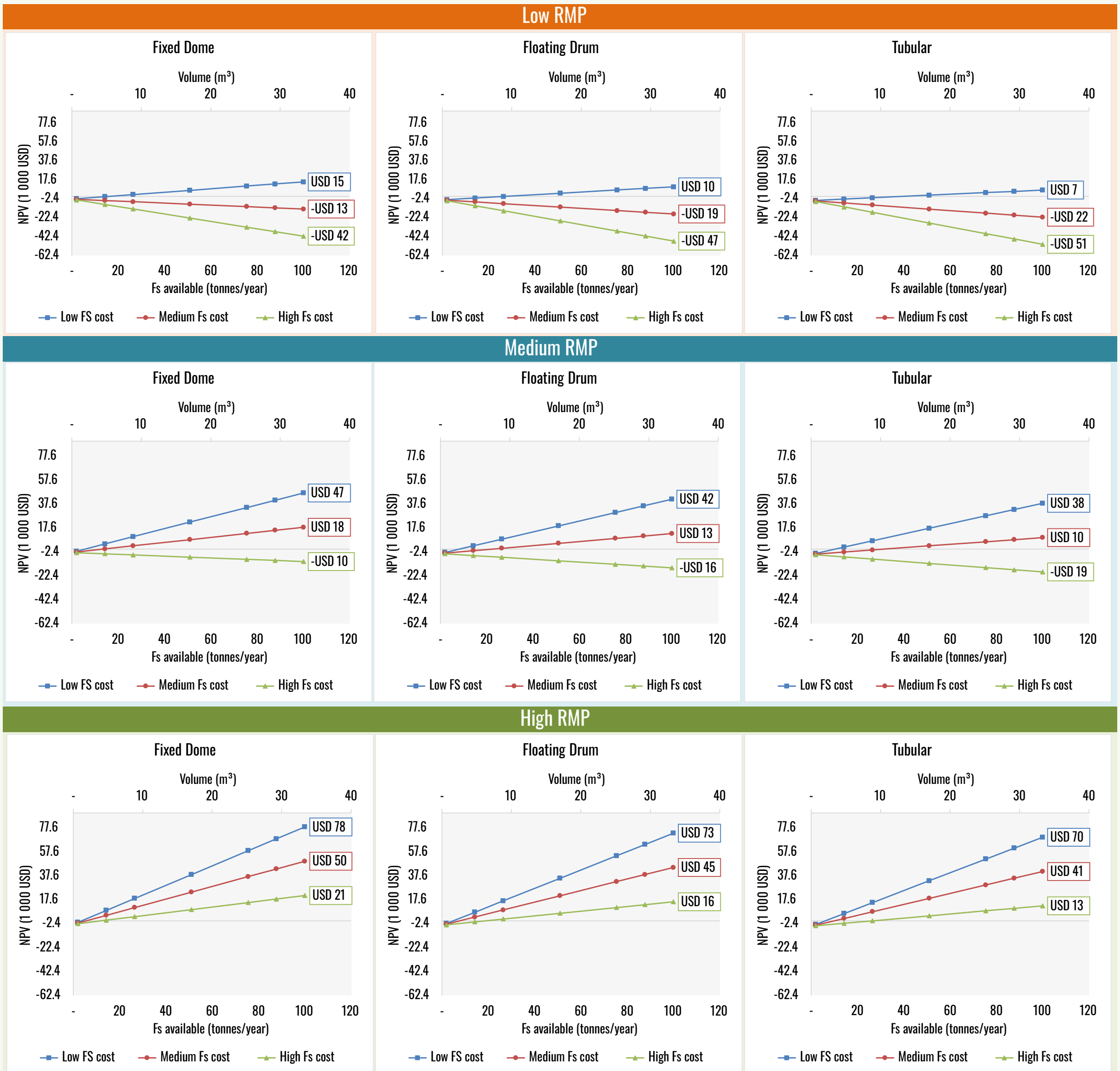
The results in **Figure 104** are an indicator of the noticeable effect of construction materials on the economic viability of digesters, and how the most cost-effective policy intervention for biogas programmes would work to support the construction of digesters. This result matches the practical evidence found in the biogas projects in developing countries, where households perceive digesters to be expensive options.

4.5.3.10 Most feasible scenario and minimum profitable conditions

Based on the above presented results, in order to make use of the potential to produce biogas in Zambia a biogas programme is needed, which provides technical support for the construction and maintenance of digesters. The level of subsidies required to support a programme and provide all farmers with construction materials could initially be an unfeasible alternative for the country. Therefore, Scenario 2 would be the most effective in a short-term situation. As for codigestion options, it can be assumed that households will collect them according to local availability at different rates. Also, farmers must respect the technical constraints of at least 50 percent of the primary substrate per digester feed. In this case, the crop residues used in codigestion do not offer the minimum profitable conditions. **Table 54** presents a summary of the minimum profitable conditions.

FIGURE 103.

NPV FOR BIOGAS PRODUCTION UNDER SCENARIO 2 CONDITIONS FOR THREE RMP LEVELS

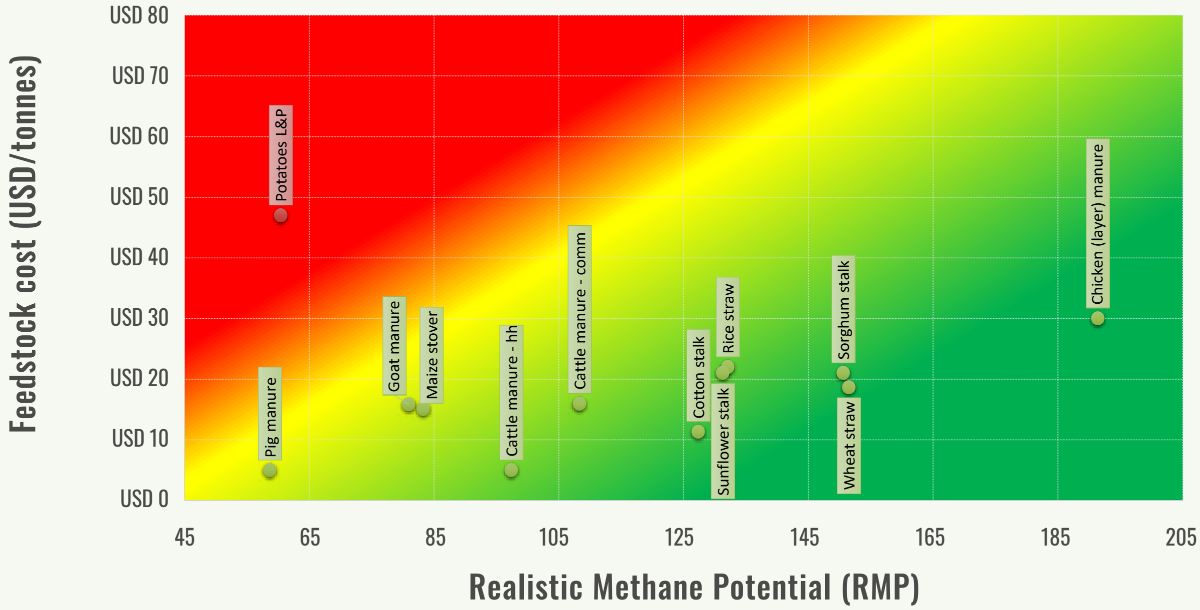


Source: Elaboration based on BEFS Assessment Results

In sum, under the identified production conditions, goat manure would not be profitable for biogas production due to the high collection cost. Layer chicken and pig manure biogas should be considered as an alternative for commercial farms that are more likely to have enough animals to produce the required amount of manure. According to the natural resources assessment, the farms with at least 122 animals are considered as commercial. Furthermore, the results indicate that the minimum capacity of layer chicken biogas is 4 m³, can be procured from 198 birds. The natural resources assessment shows that commercial pig farms raise at least 43 animals, which can provide manure for a biogas digester of 12 m³. Finally, for cattle manure the minimum capacity of digester is 3.8 m³, which must be supplied by at least

FIGURE 104.

PZM FOR BIOGAS PRODUCTION UNDER SCENARIO 3 CONDITIONS



Source: Elaboration based on BEFS Assessment Results

TABLE 54.

MINIMUM PROFITABLE CONDITIONS FOR MAIN SUBSTRATES USED IN BIOGAS PRODUCTION

CROP-RESIDUE TYPE		BIOGAS			
		MIN DIGESTER CAPACITY (m^3)	DAILY BIOGAS (m^3/day)	MIN NO. HEADS	TECHNOLOGY
CHICKENS	MANURE	4.1	11.4	198.0	FIXED DOME
CATTLE – HH	MANURE	3.8	5.3	7.0	FIXED DOME
GOAT	MANURE	**UNPROFITABLE**			
PIG	MANURE	12.2	10.5	43.0	FIXED DOME

Source: Elaboration based on BEFS Assessment Results

seven animals. Cattle manure should therefore be considered as the first option, due to the relatively low number of animals needed to provide an adequate quantity of manure for the biogas digester.

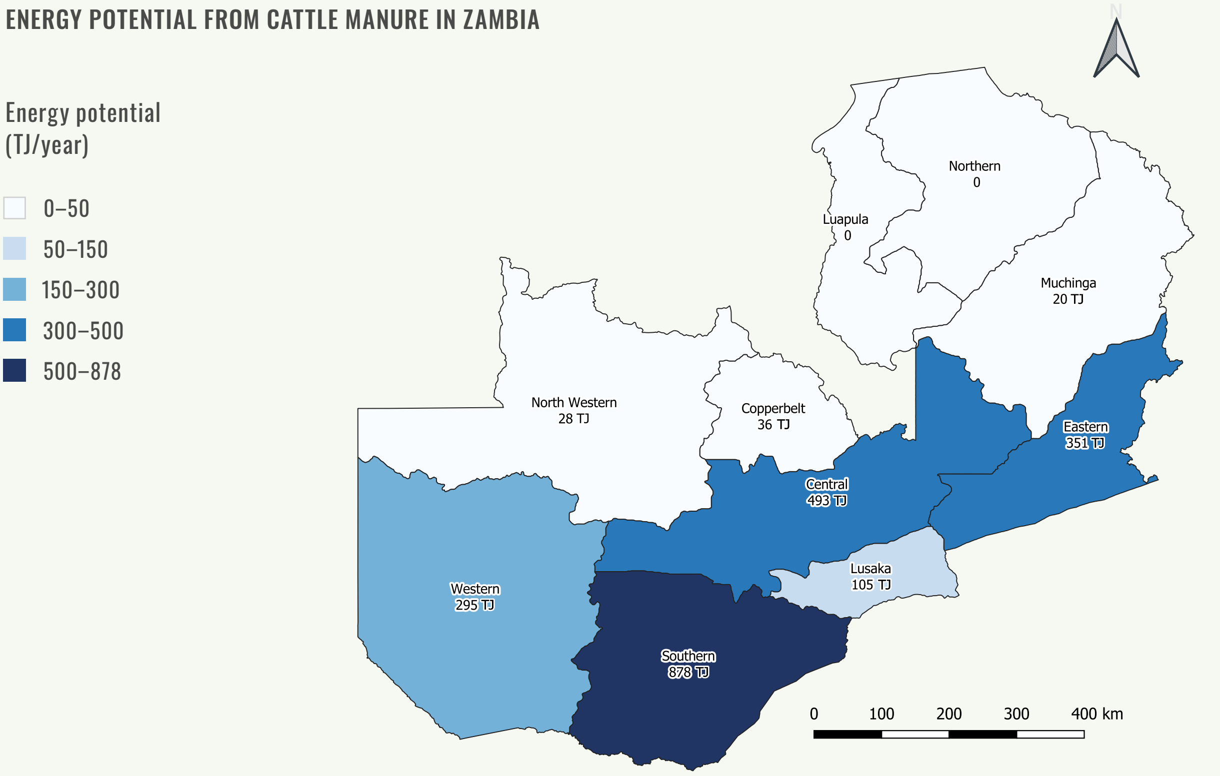
4.5.3.11 Energy potential and contribution to renewable energy targets

Based on the criteria presented above and the feedstock available, **Figure 29** shows the energy potential from biogas produced with cattle manure in Zambia. The total cooking energy that could be obtained from this biogas is 2207 TJ/year. This can contribute three percent to the estimated 74 158 TJ/year target energy demand of Zambian households, which is the equivalent of supplying more than 62 thousand rural households.

An option for a rise in the potential biogas production would be to increase the substrate volume through the codigestion of cattle manure

FIGURE 105.

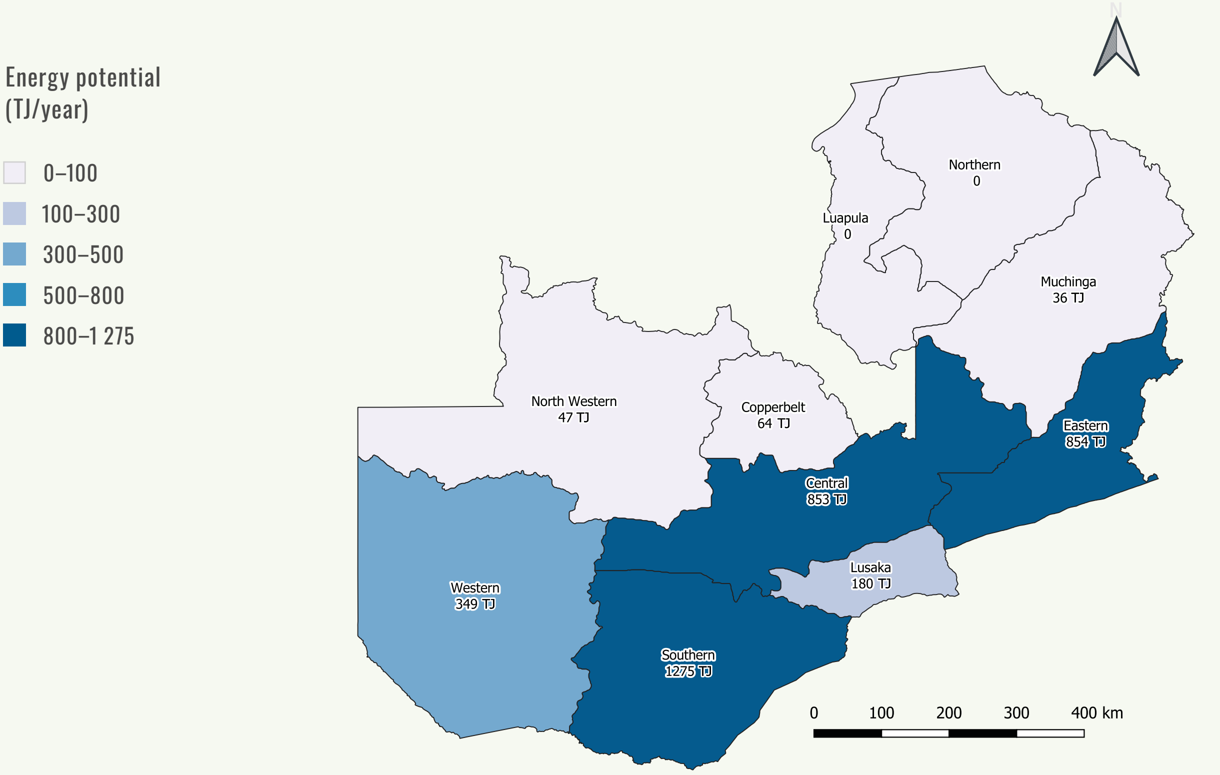
ENERGY POTENTIAL FROM CATTLE MANURE IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

FIGURE 106.

ENERGY POTENTIAL FROM BIOGAS OBTAINED FROM CODIGESTION OF CATTLE MANURE WITH CROP RESIDUES IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

together with another feedstock type. The BEFS assessment calculates different quantities of co-substrate that should be used across different districts for optimal codigestion. The approach considered technical constraints such as maintaining at least 50 percent of cattle manure in the final mixture and a C:N ratio ranging from 20 to 30. The results obtained were mapped and are shown in **Figure 106**. Thus, the total energy production from biogas would reach 3 658 TJ/year, which could satisfy five percent of the energy demand of Zambian households (100 thousand rural households).

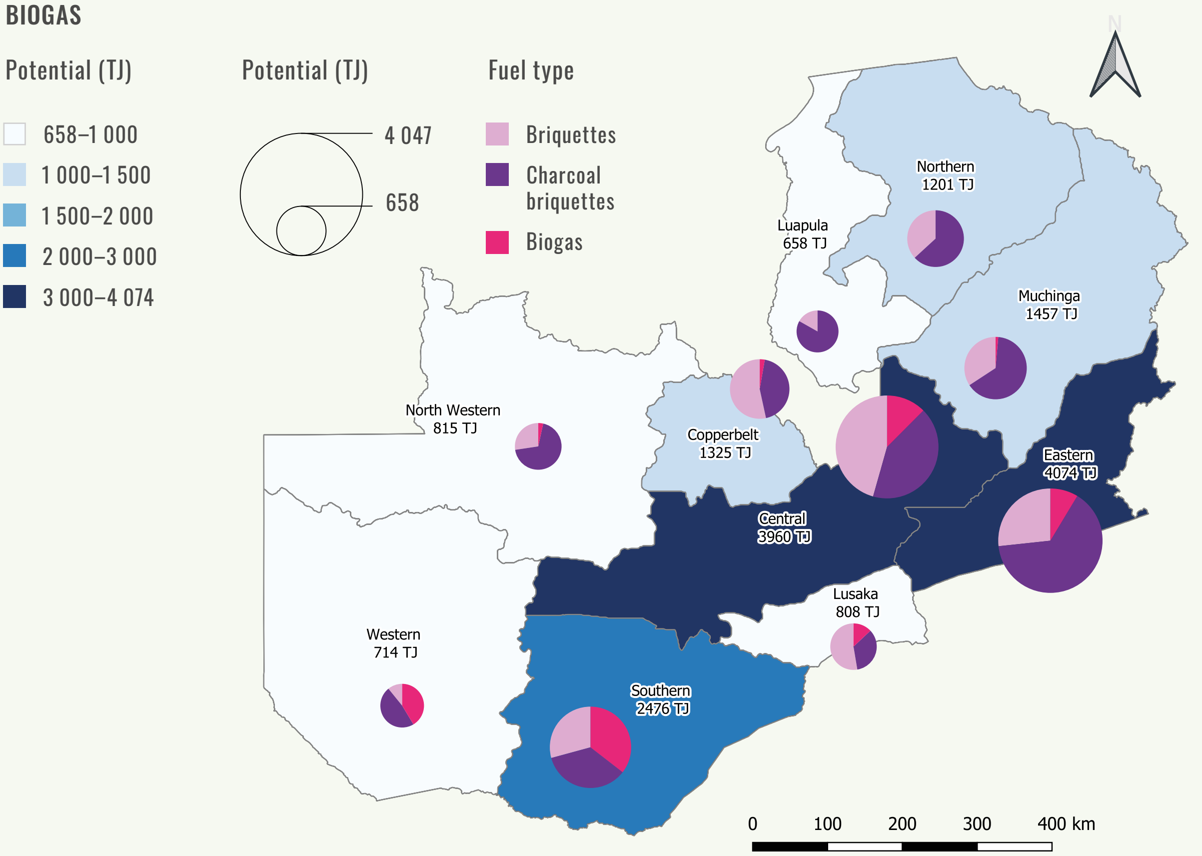
4.5.4 Combined energy potential for cooking

Considering the 100 percent access to modern clean cooking solutions target that has been established by the Zambian government, the BEFS assessment has shown that briquettes technologies would be in a better position than biogas to contribute to this target. This is explained mainly by the differences in feedstock availability where crop residues, particularly maize residues, offer more advantages than the biogas options.

However, under the appropriate conditions, it would be feasible to integrate the cooking fuel options discussed in this chapter. **Figure 107** details the energy potentials for cattle manure biogas, biomass briquettes, and charcoal briquettes across different Zambian provinces.

FIGURE 107.

ENERGY POTENTIAL FROM COST-EFFECTIVE OPTIONS COMBINING BIOMASS BRIQUETTES, CHARCOAL BRIQUETTES AND BIOGAS



Source: Elaboration based on BEFS Assessment Results

This information was obtained after selecting the cooking fuel technology for each feedstock option, which would allow for easier adoption, in terms of the smallest minimum profitable size and lowest investment cost. This approach favours the lowest possible investment cost rather than energy production. At a national level, it was estimated an average capital investment needs of 18.95 USD/tonnes/year for biomass briquettes, 20.33 USD/tonnes/year for charcoal briquettes and 0.62 USD/m^3/year for biogas produced using fixed dome digesters. Therefore, in most parts of the country charcoal briquettes would result as the most cost-effective option, particularly in the Eastern Province. The Central Province has the next highest potential. In these specific provinces, biomass briquettes and charcoal briquettes would be equally effective. Finally, in the Southern Province, biogas proved to be the most cost-effective option.

The total potential energy from alternative cooking fuels would reach 15 797 TJ/year, 47 percent from charcoal briquettes, 39 percent from biomass briquettes, and 14 percent from biogas. Therefore, a combined contribution of 12 percent to the Zambian energy targets of 100 percent household access to clean cooking fuels (see **Figure 108**) might be a possibility.

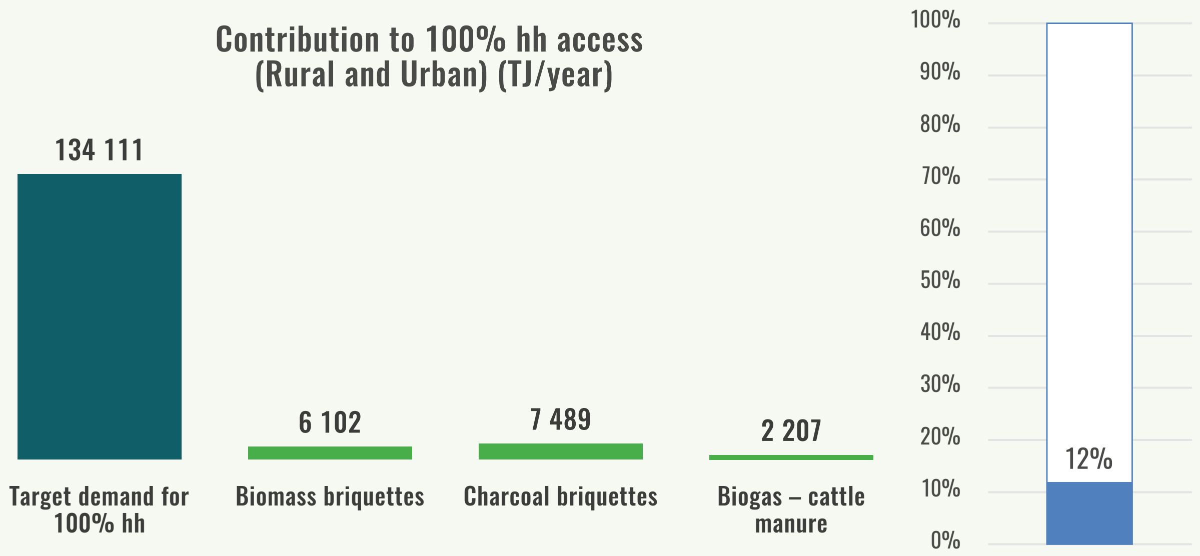
4.5.5 Improved charcoal production technologies

The charcoal assessment evaluates the cost and benefits of adopting improved charcoal production technologies in Zambia, comparing them with the traditional charcoal-making method. Furthermore, the assessment analyses the upfront capital cost required for the improved technologies, the financial viability from the standpoint of charcoal producers and the social and environmental benefits provided by these new technologies, as compared to existing charcoal production technologies. The results generated by the assessment provide information on the potential barriers facing producers when dealing with improved charcoal technologies, as well as help define how to effectively disseminate their introduction.

Moreover, the assessment builds on results generated from the evaluation of woody residues in terms of feedstock availability and cost. The

FIGURE 108.

CONTRIBUTION OF COST-EFFECTIVE OPTIONS COMBINING BIOMASS BRIQUETTES, CHARCOAL BRIQUETTES AND BIOGAS TO CLEAN FUELS FOR COOKING NATIONAL TARGETS



Source: Elaboration based on BEFS Assessment Results

collection and mobilization costs, the alternative improved technologies for the production of charcoal and the final market of the product are also included.

The results of the assessment will provide information for the Zambian government about the viability of the production of charcoal using improved technologies. In addition, they will provide information on the extent to which these technologies can contribute to reducing the country's fuelwood demand.

The aim of this assessment is to evaluate the technical, social and economic viability of improved charcoal technologies and compare them to traditional charcoal making. The results will provide information on the current production practices and opportunities for making improvements. Furthermore, these results will provide an indication of the requirements needed to enable producers to deploy more efficient "carbonization" technologies.

The assessment will provide information regarding:

- the viability of seven improved charcoal kilns ranging from small-scale or subsistence to medium and large-scale semi-industrial technologies;
- potential reduction in woodfuel consumption from forests due to the introduction of improved technologies, which are more efficient in charcoal production;
- viability of the production of charcoal from forest plantation and wood processing residues;
- potential benefits from viable technologies.

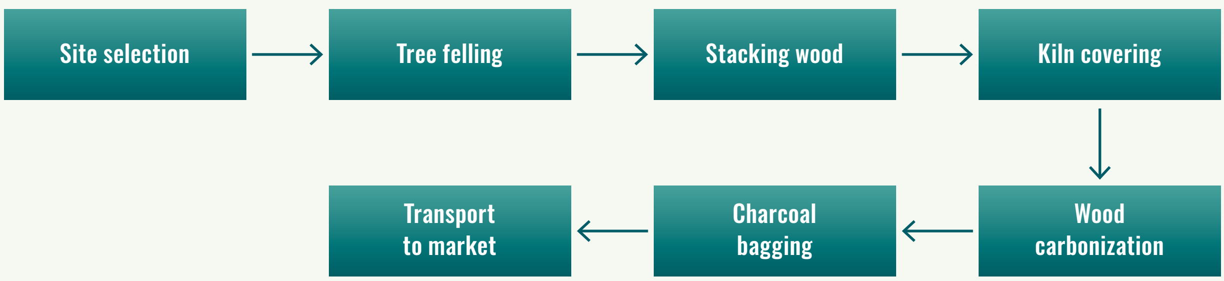
In addition, the assessment estimates the amount of wood savings that could be obtained as a result of the deployment of improved and more efficient technologies in charcoal production. To this end, information has been used about the country's annual demand for charcoal covering both the urban and rural market, as well as the volume of wood required to produce this amount of charcoal. Wood savings are realised by using improved and more efficient technologies requiring less input wood to produce enough charcoal to satisfy market demands.

4.5.5.1 Traditional charcoal making in Zambia

The earth kiln is the traditional technique for charcoal production currently being used in Zambia. The estimated efficiency of this type of charcoal kiln has a range of between 12 and 22 percent on a wet basis (Hibajene and Kalumiana, 2003). The efficiency of a kiln is defined as the mass of charcoal that a producer obtains from a kiln in relation to the mass of wood the producer initially has put into the kiln. In the case of Zambia, the average conversion efficiency of the earth kiln is estimated at 15 percent on a wet basis or 25 percent on a dry basis (Gumbo *et al.*, 2013).

FIGURE 109.

TRADITIONAL CHARCOAL MAKING PROCESS IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results based on (Gumbo et al.*, 2013; Hibajene and Kalumiana, 2003)*

The charcoal production process in Zambia begins with the selection of sites by the producers. Sites are selected according to two criteria: the availability of tree species suitable for charcoal production and, adequate space for the construction of the kiln. The following steps consist of cutting down the trees, stacking the wood, kiln covering, ignition and carbonization of the wood, harvesting of the charcoal, and bagging and transportation to the markets. Production is made in batches and for each batch an earth kiln will be constructed and then left in the field after the production is completed. Once the earth kiln is prepared and has been ignited, the process of carbonization of the wood will take at least two weeks. The steps of the charcoal production process are shown in **Figure 109**.

For BEFS analysis, the average conversion efficiency of charcoal production in Zambia with the traditional earth pit kiln is estimated at 15 percent. This efficiency can vary according to the size and performance of the kiln, patterns of stacking wood in the kiln, species composition, stem size, wood moisture content, climatic conditions and the level of experience of the charcoal producer (Gumbo *et al.*, 2013; Mwitwa and Makano, 2012).

4.5.5.2 Feedstock options

The option for feedstock taken into consideration for the charcoal assessment would be wood residues from forest plantations. The residues from wood processing industries were not included due to the low available volumes. The assessment will determine the feasibility of charcoal production with improved and more efficient technologies as defined in the scope.

In the case of residues from forest plantations, four forest plantations managed by ZAFFICO were covered and the share of residues not currently used was determined. Subsequently, this information was used to estimate the volume of residues potentially available for charcoal production throughout the country. Finally, both feedstocks were estimated in the natural resource assessment.

For the analysis of potential wood savings after the deployment of improved and more efficient charcoal technologies, the current charcoal production and the respective volumes of wood were taken into consideration.

4.5.5.3 Production costs

The charcoal production assessment was carried out by comparing the traditional charcoal production method with seven improved and more efficient technologies. The summary of the main characteristics of these improved technologies including the scale, efficiency and wood savings is shown in **Table 55**.

Even though all of the improved technologies show greater efficiency in the conversion of wood into charcoal and allow for some savings on wood, the economic viability of these

TABLE 55.

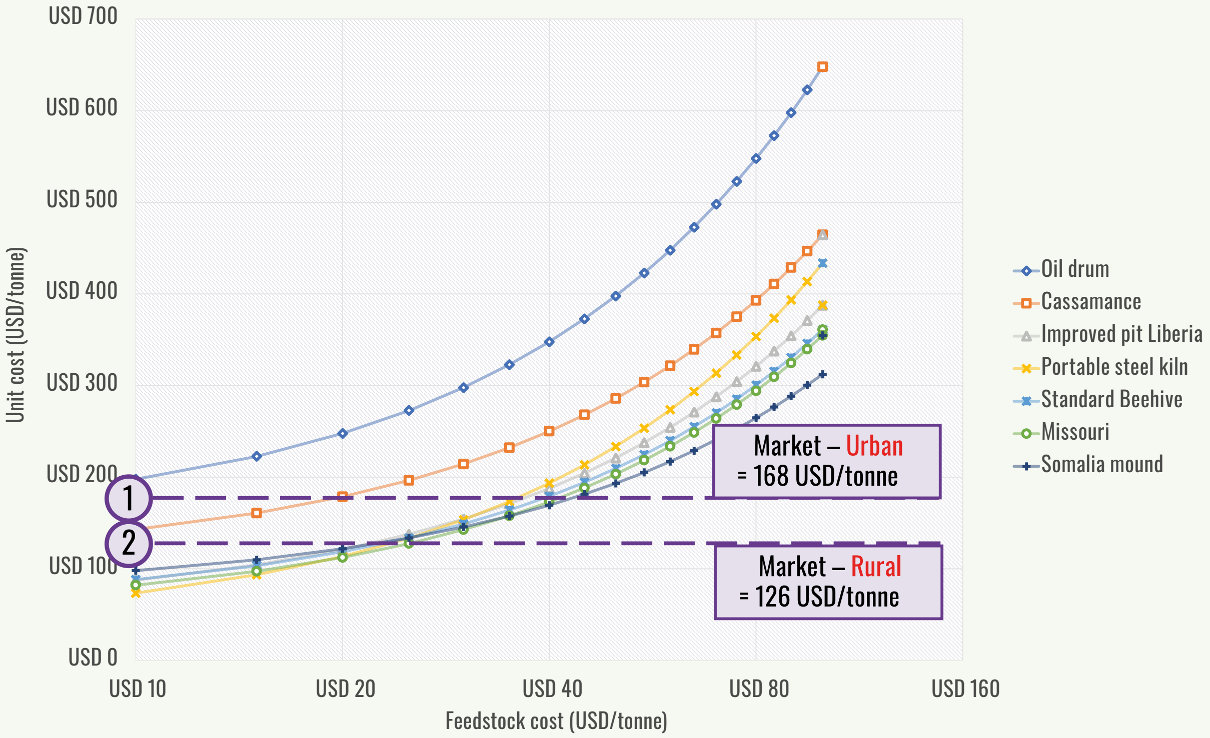
TRADITIONAL AND IMPROVED CHARCOAL PRODUCTION TECHNOLOGIES

CHARCOAL TECHNOLOGIES	SCALE OF THE TECHNOLOGY	EFFICIENCY (DRY BASIS)	WOOD SAVINGS (tonne of wood/tonne of charcoal)
TRADITIONAL EARTH KILN	SMALL	15%	0
CASAMANCE	SMALL	28%	4.36
OIL DRUM	SMALL	20%	2.69
IMPROVED PIT LIBERIA	SMALL	30%	4.36
STANDARD BEEHIVE	MEDIUM	33%	4.66
PORTABLE STEEL KILN	MEDIUM	25%	3.53
MISSOURI	LARGE	33%	4.66
SOMALIA MOUND	LARGE	42%	5.31

Source: Ministry of Energy and BEFS Charcoal tool (Food and Agriculture Organization of the United Nations, 2014a)

FIGURE 110.

PRODUCTION COST USD/TONNE CHARCOAL – MASS BASIS



Source: Elaboration based on BEFS Assessment Results

technologies must be determined. In other words, in view of the increased income for charcoal producers it is necessary to determine if the initial investment, production costs and additional labour requirements required by most of these technologies are justified.

To this end, the assessment compared the production cost of the improved charcoal technologies with the market price of charcoal. Given that in Zambia there is a significant difference between the rural and urban market price of charcoal, the comparison has been made with both prices. The results of this comparison are shown in **Figure 110**.

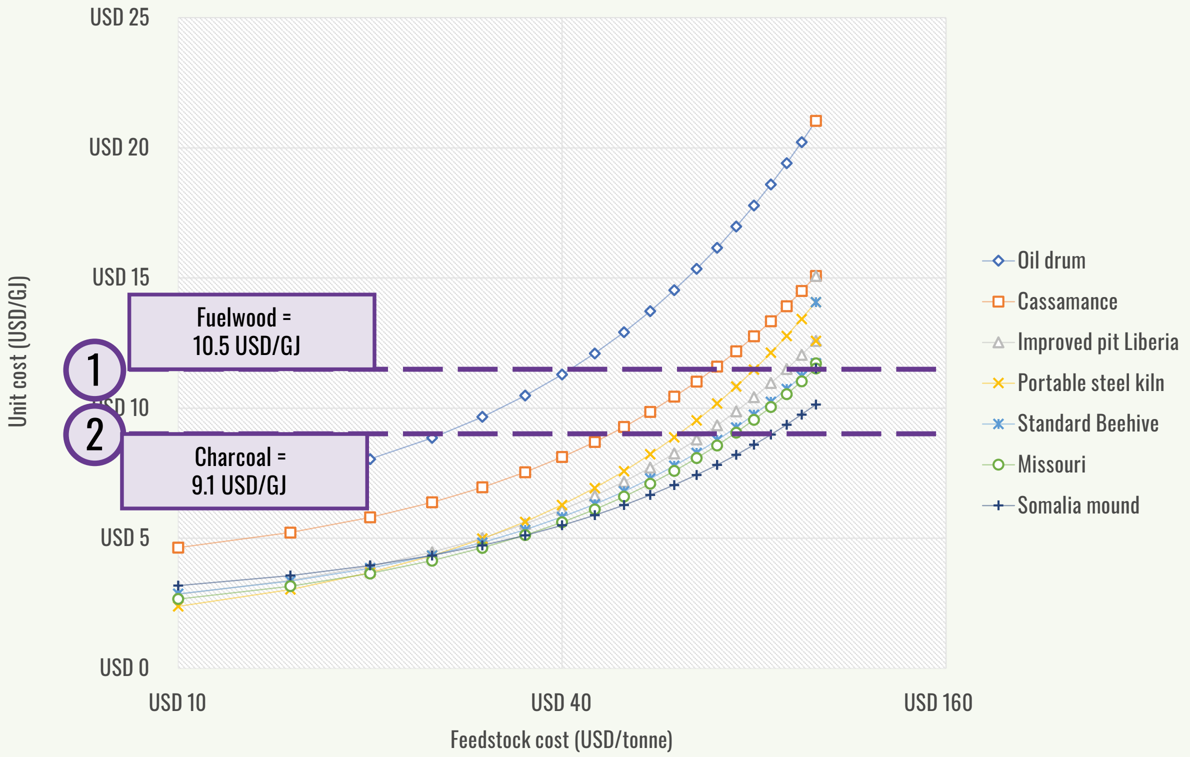
Figure 110 shows the different curves of the production cost of charcoal for each improved technology with respect to the feedstock cost. The feedstock cost represents the expenses involved in the collection, pre-treatment and mobilization of wood residues used for charcoal production. It is evident that the production cost for each technology improves as the feedstock cost decreases.

Figure 110 also compares the curves of production cost with the rural and urban market prices of charcoal, represented as dotted lines numbered one and two, respectively. In this sense, any production cost that is below the market price line is potentially viable for that specific market. In the case of the price of charcoal in the urban market, the average price is 168 USD/tonne. With this price, the improved pit Liberia, portable steel kiln, standard beehive, Missouri and Somalia mound can be competitive if they obtain feedstock at a cost below 40 USD/tonne. Casamance technology can be competitive in the case where the feedstock cost is below 25 USD/tonne. The oil drum technology shows production costs that are higher than the urban market price and, in any case, it would not be competitive.

The market price of charcoal in the rural area is on average 126 USD/tonne. At this price the production costs of both the oil drum and casamance technology are higher than the rural market price and would therefore, not be

FIGURE 111.

PRODUCTION COST USD/GJ – ENERGY BASIS



Source: Elaboration based on BEFS Assessment Results

competitive. Other improved technologies would be competitive in the case where the feedstock cost is lower than 30 USD/tonne.

Figure 111 makes a similar comparison with the production cost of charcoal on the basis of energy. The curves indicate for each improved technology the production cost in USD/GJ of energy delivered to the final user versus the feedstock cost of the wood used. The production cost curves are then compared to the price of fuelwood and the price of charcoal produced with the traditional earth kiln method, illustrated with the dotted lines in **Figure 111**. These prices are also expressed on an energy basis according to the amount of energy delivered to the final user.

The price of fuelwood is 10.5 USD/GJ of the energy provided. It is evident that most of the improved technologies show production costs to be lower than this price. e.g. the Somalia Mound technology shows that charcoal produced with this technology is still more competitive than fuelwood even for feedstock costs as high as 120 USD/tonne. In the case of the technology that shows the least competitive results, which is the case of the oil drum, it shows positive results for a feedstock cost below 40 USD/tonne.

The price of charcoal produced by the traditional earth kiln method is 9.1 USD/GJof the energy delivered to the end user. Once again, when compared to the Somalia mound technology we can see that the charcoal produced by this technology is more competitive than the charcoal produced with the traditional method, even with a feedstock cost of 110 USD/tonne. In the case of the oil drum, the technology requires a feedstock cost of below 30 USD/tonne in order to be competitive.

4.5.5.4 Profitability of the improved charcoal technologies

The profitability analysis for the improved technologies includes the feedstock price, charcoal production cost and the costs involved

in transporting charcoal to the final market. A differentiation has been made between the rural and urban markets due to the significant impact of transportation on the final price. The aspects considered in the profitability analysis are shown in **Figure 112**.

The profitability analysis was carried out for each of the seven improved technologies, keeping in mind two types of feedstock: woody residues from forest plantations located in the Copperbelt Province, and fuelwood currently destined for the production of charcoal to cover the demands in urban and rural markets.

The analysis of each technology includes the comparison of the feedstock cost with the production scale of the improved technology. In addition, profitability maps have been created such as the one shown in **Figure 113**, specific to the improved technology of the Somalia mound. The PZM map displays red, yellow and green areas. The red area shows that the combination of feedstock cost and the scale of the Somalia mound kiln is not profitable according to the financial analysis. The yellow area indicates that the combination could be profitable under certain circumstances, while the green area indicates that the option is profitable. As seen in **Figure 113**, the feedstock cost of forest plantation residues is estimated at between 120 and 140 USD/tonne; at this price the results demonstrate that the use of this feedstock is not profitable. In the case of fuelwood, the feedstock cost is 30 USD/tonne and therefore profitable at larger production scales.

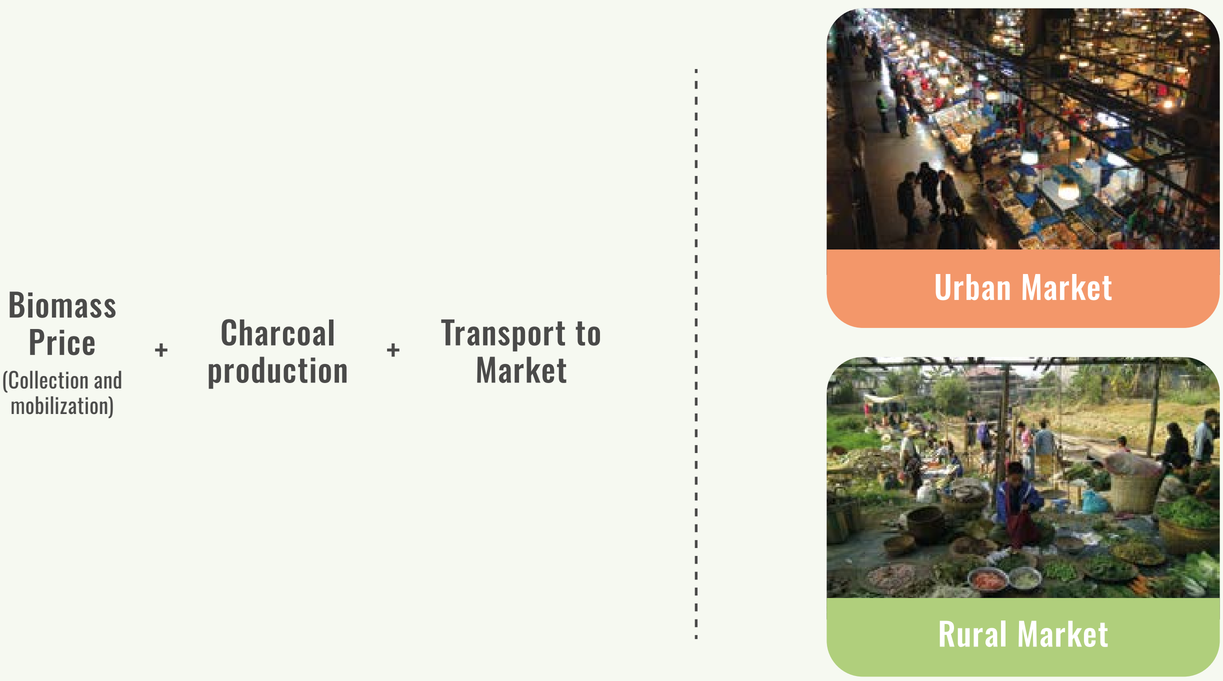
The same profitability map has been created for the other six improved technologies. The results are displayed in **Annex 11**.

The results of the analysis demonstrate that of the seven technologies evaluated, five show positive results for at least one of the target markets. The results of the profitability analysis for the five profitable technologies can be seen in **Table 56**.

It is clear that out of the three small-scale technologies, only the improved pit Liberia

FIGURE 112.

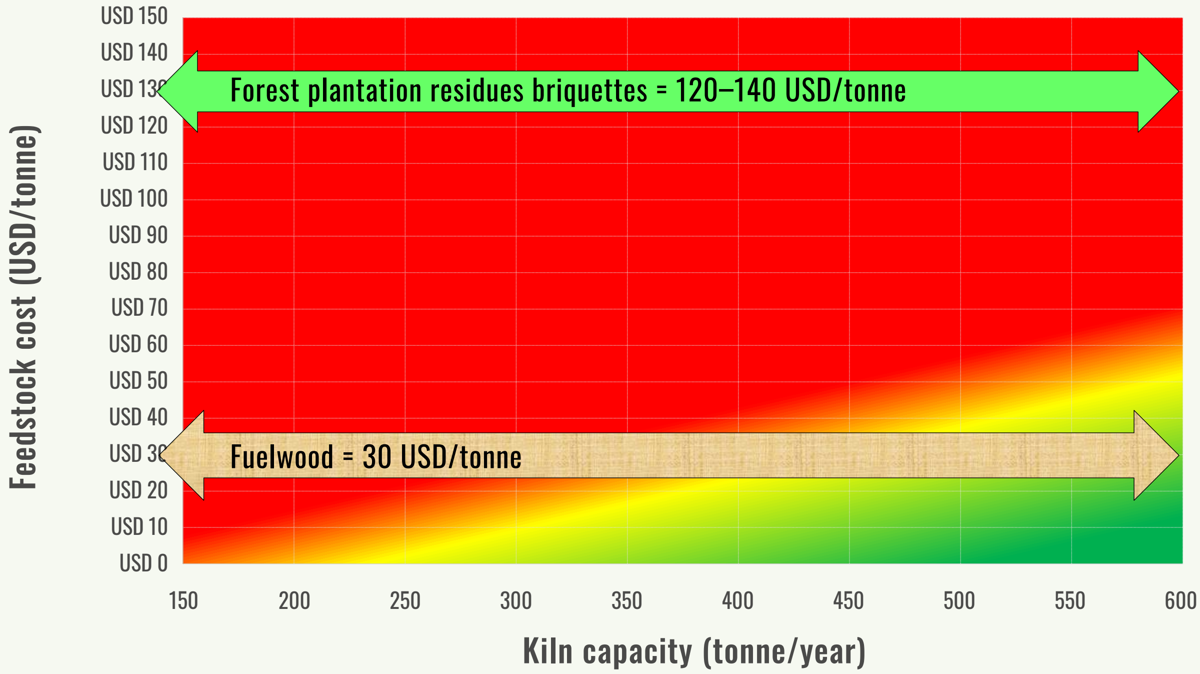
FACTORS CONSIDERED IN THE PROFITABILITY ANALYSIS OF IMPROVED CHARCOAL TECHNOLOGIES



Source: Elaboration based on BEFS Assessment Results

FIGURE 113.

PROFITABILITY MAP FOR THE SOMALIA MOUND TECHNOLOGY



Source: Elaboration based on BEFS Assessment Results

TABLE 56.

PROFITABILITY ANALYSIS OF IMPROVED CHARCOAL PRODUCTION TECHNOLOGIES

TECHNOLOGY	EFFCIENCY (%)	MIN CAPACITY (t/year)	MAX PAYABLE PRICE	MIN PRODUCT QUALITY (MJ/kg)	INVESTMENT (USD)	STANDARD CAPACITY (t/year)	PRODUCTION LEVEL	TARGET MARKET RURAL	TARGET MARKET URBAN
IMPROVED PIT LIBERIA	30%	>10	10	31	859	66	SMALL	✓	✗
PORTABLE STEEL KILN	25%	>150	30	25	504	183	MEDIUM	✓	✓
STANDARD BEEHIVE	33%	>151	30	25	6 691	203	MEDIUM	✓	✗
MISSOURI	33%	>152	35	22	16 932	305	LARGE	✓	✓
SOMALIA MOUND	42%	>153	40	25	3 744	383	LARGE	✓	✓

Source: Elaboration based on BEFS Assessment Results

technology shows positive results. However, these results are limited to the rural area market due to the additional costs of transportation in urban markets, thus making this option non-competitive. Some of the restrictions involved in this alternative are the scale of production that must be at least 10 tonnes/year and also the maximum feedstock cost that must be 10 USD/tonne.

In the case of medium-scale technologies, the

portable steel kiln is competitive in charcoal production for both rural and urban markets, while the standard beehive is competitive for rural markets only. Both technologies require a scale of charcoal production of more than 150 tonnes/year and can have a feedstock cost of maximum 30 USD/tonne. The main factor affecting the competitiveness of the standard beehive technology is the high level of investment required.

In the case of large-scale technologies, both appear to be competitive in both rural and urban markets. The Missouri technology requires a production capacity of at least 152 tonnes/year and can have a feedstock cost of up to 35 USD/tonne. On the other hand, the Somalia mound technology requires a charcoal production capacity of at least 153 tonnes/year and can have a feedstock cost of up to 40 USD/tonne. The advantage of the Somalia mound technology over the Missouri technology is that the level of investment required for the Somalia mound technology is much lower and therefore more affordable for charcoal producers.

4.5.5.5 Benefits of potentially profitable technologies

The deployment of improved technologies for charcoal production would have the effect of reducing the amount of wood required for producing the charcoal to meet the demands of Zambia's rural and urban markets, given their higher efficiency as compared to the traditional earth kiln method currently being used.

In fact, **Table 57** shows the estimation of the potential wood savings obtained by the deployment of these improved technologies. The calculations being used to reach these results assume that the traditional earth kiln method would be replaced by the improved technology representing a theoretical maximum. Intermediate wood savings would be achieved by a partial replacement of the use of the traditional earth kiln method.

The technology that produces the largest wood savings is the Somalia mound, which experiences a reduction in the consumption of wood to produce charcoal of 22 million cubic meters annually. It is worth noting that there is at least one improved charcoal technology available, profitable for each scale of production. This technology would allow for producers to increase their income and generate benefits by reducing the use of wood while meeting the demand for charcoal.

Based on the profitability assessment results and considering the option closest to the traditional technologies currently used in the country, the improved pit Liberia was recommended as the most suitable choice to be adopted for improving charcoal technology In Zambia. **Figure 114** shows the results at the provincial level of the savings that could potentially be achieved by the deployment of the improved pit Liberia option. The provinces where the highest levels of savings could be obtained would be the Central Province followed by the Lusaka and Northern Province.

TABLE 57.

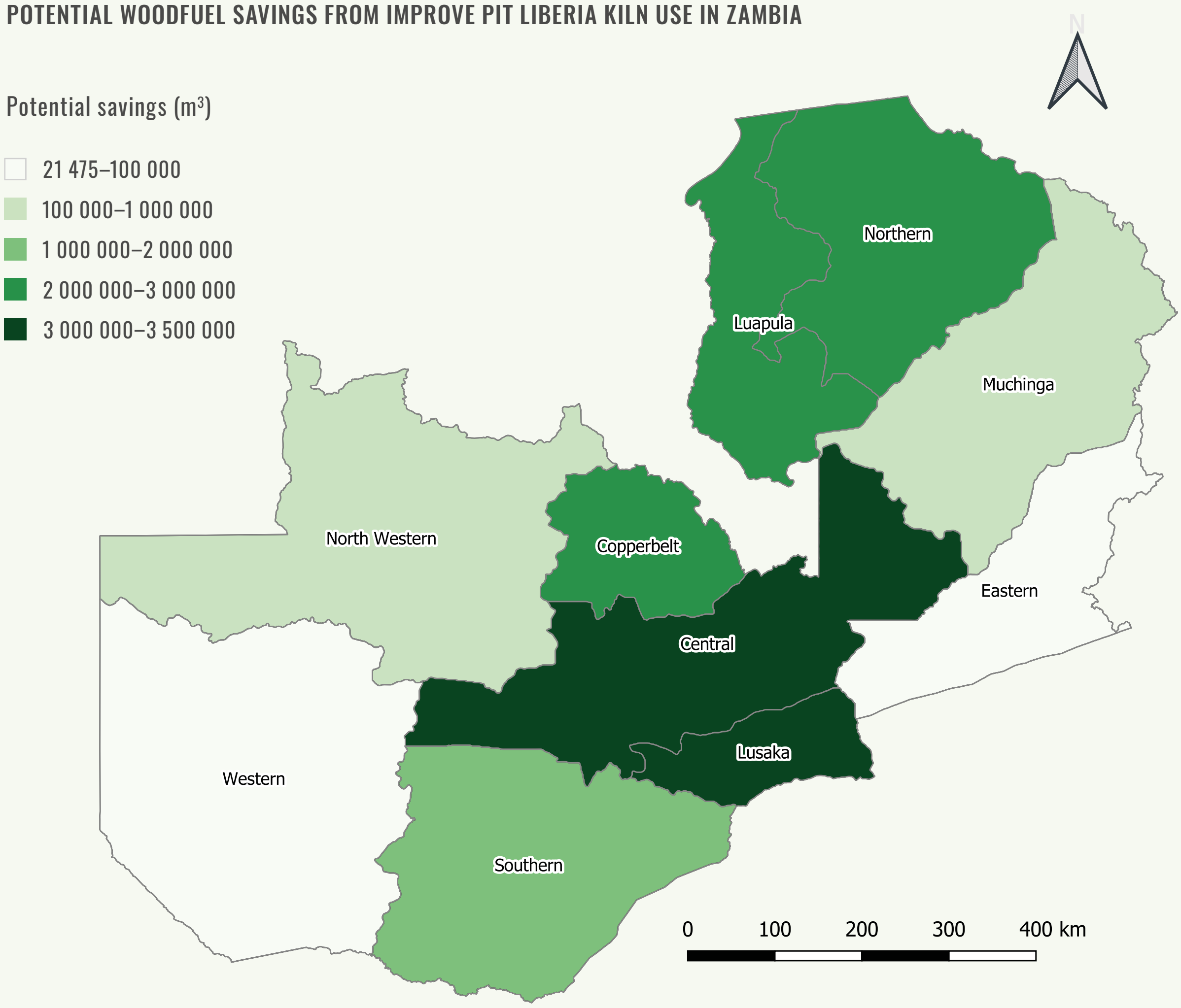
WOOD SAVINGS AS A RESULT OF THE DEPLOYMENT OF IMPROVED TECHNOLOGIES

IMPROVED TECHNOLOGIES	SCALE OF THE TECHNOLOGY	EFFICIENCY (DRY BASIS)	TOTAL WOOD SAVINGS (million m^3 per year)
IMPROVED PIT LIBERIA	SMALL	30%	17
STANDARD BEEHIVE	MEDIUM	33%	18
PORTABLE STEEL KILN	MEDIUM	25%	14
MISSOURI	LARGE	33%	18
SOMALIA MOUND	LARGE	42%	22

Source: Elaboration based on BEFS Assessment Results based on results of the charcoal assessment

FIGURE 114.

POTENTIAL WOODFUEL SAVINGS FROM IMPROVE PIT LIBERIA KILN USE IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

4.5.6 Summary of results

The results of the briquettes fuels analysis indicate that it is potentially profitable to add value to locally available biomass residues by producing briquettes. Furthermore, the results show that energy from briquettes could contribute up to 20 percent to the national clean energy for cooking targets. The most cost-effective option for briquette production was found to be the use of feedstock options with high energy potential and hot press technology (i.e. cotton stalk, cotton husk, soybean straw, wheat straw, maize stover and cassava stalk).

However, the need to acquire new types of stoves for customers would represent a barrier. Indeed, the production of charcoal briquettes to directly replace charcoal from wood to be used in current cooking stoves is a more feasible option, and it would help reduce pressure on forest resources. In this case, with the number of suitable types of feedstock being lower, their potential to contribute to clean energy for cooking targets resulted as a mere 6 percent.

Nevertheless, given that most feedstock has multiple energy purposes, defining the final use of the feedstock will depend on a combination of residue availability, as well as its performance

when it is produced using specific briquettes production technologies.

In conclusion, the most promising feedstock options are maize stover, maize cob, cotton stalk, soybean straw and cassava stalk. As for the production of charcoal briquettes, wheat straw could also be a potential option. In terms of procurement, the Central Province has the greatest potential to supply feedstock from large-scale producers and the Eastern Province could supply feedstock from small-scale producers. These differences will need to be taken into consideration when developing the residue supply chain as well as the procurement of feedstock.

The results obtained for biogas production in Zambia indicate that under certain circumstances, the benefits derived from biogas and the use of bioslurry would allow for rural households to reduce their consumption of fuelwood and charcoal, and to replace a share of the fertilizers being used.

Throughout different countries, examples can be found regarding how national biogas programmes support the development of biogas industries at various levels. In the case of Zambia and based on the options evaluated, assisting households with technical support for the construction and maintenance of biodigesters proved to be the option offering the most benefits for rural households. Finally, this option can be implemented in a relatively short amount of time.

The most cost-effective model for Zambia, considering the cost of construction and access to raw materials, is the fixed dome model. Regarding the feedstock options, the BEFS assessment examined the differences between the primary substrate and codigestion substrates. The primary substrate refers to livestock residues, whereas the codigestion substrates refer to selected crop residues. Cattle manure proved to be the best substrate for biogas production whereas chicken and pig manure require a far greater number of animals to provide a minimum quantity of manure for running the biogas digester. It would feasibly be easier to gather pig and chicken manure for biogas on a commercial farm. The use of codigestion substrates is limited by their availability at the district level, as well their prices. In conclusion, regarding the contribution to national renewable energy targets, cattle manure alone could contribute three percent to Zambia's national targets for clean energy for cooking. Once locally available sources of crop residue have been taken into account, this contribution could increase to six percent.

The total potential energy from alternative cooking fuels would reach 15 797 TJ/year, 47 percent from charcoal briquettes, 39 percent from biomass briquettes, and 14 percent from biogas. Therefore, a combined contribution of 12 percent to the Zambian energy targets of 100 percent household access to clean cooking fuels might be a possibility. To deploy this potential, at a national level, it was estimated that an average capital investment needs of 18.95 USD/tonnes/year for biomass briquettes, 20.33 USD/tonnes/year for charcoal briquettes and 0.62 USD/m^3/year for biogas produced using fixed dome digesters.

Finally, the use of improved charcoal production technologies has a strong potential to reduce fuelwood consumption as well as the pressure on natural forests. The deployment of improved technologies could improve the efficiency of the conversion of wood to charcoal, increase the income of charcoal producers and supply users with a higher quality product.

The results for forest plantation residues demonstrate that, due to the high collection cost, they could be considered for the production of briquettes. However, the results of the assessment of the profitability of charcoal from this type of feedstock have proven to be negative.

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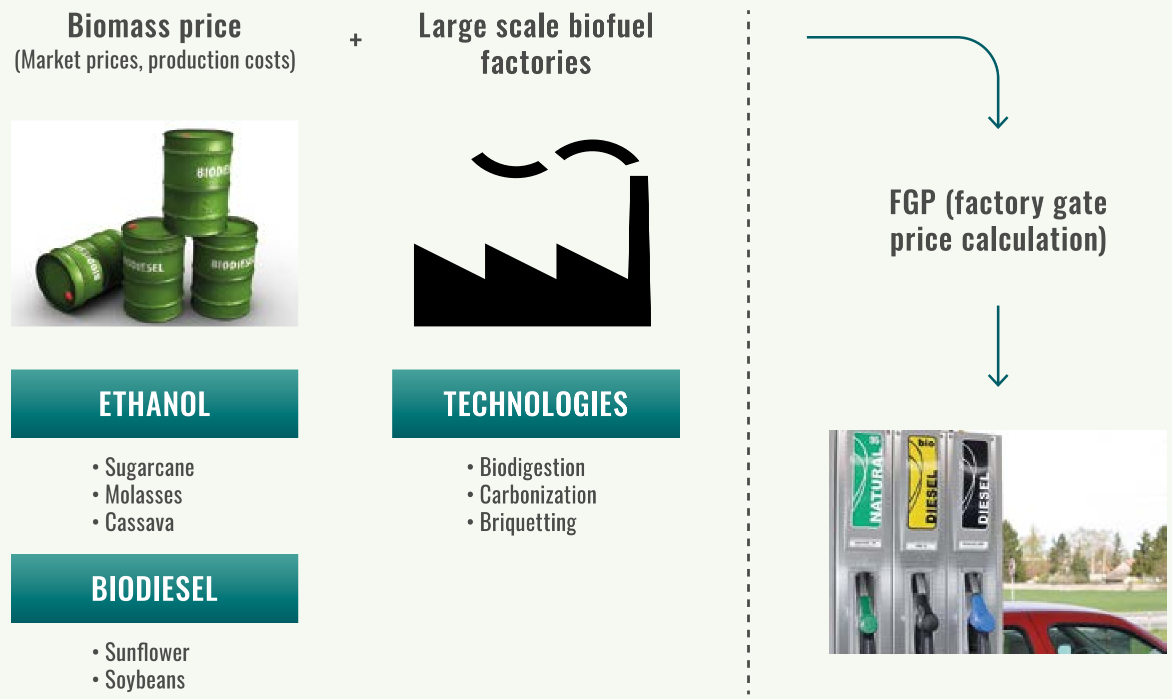
4.6 LIQUID BIOFUELS FOR THE TRANSPORT SECTOR

The Zambian government, together with the Ministry of Energy, has been investigating options available for the promotion of local production of liquid biofuels. The main objective is to reduce the country's dependence on fossil fuels, which are mostly imported or are refined locally using imported oil. For this reason, a target blending mandate is currently in place, which was defined in both the National Energy Policy 2018 and the Nationally Determined Contributions (NDC). This target blending mandate aims to achieve a blend of ethanol with gasoline and biodiesel with diesel in shares of 10 and 5 percent, respectively, by 2030.

The BEFS assessment of liquid biofuels evaluated the viability of producing liquid biofuels for transport, namely ethanol and biodiesel. This evaluation builds on an analysis of the results generated from the crops assessment in terms of feedstock availability and crops production costs. Furthermore, the assessment provides information on the economic feasibility and socio-economic parameters for the development of an ethanol or biodiesel industry, while taking into account the effect of the feedstock source on cost estimates, i.e. smallholder, combination smallholder-commercial or commercial. Moreover, it provides information on the potential level of production of liquid biofuels that can be achieved with the available biomass and, as a result, define the objectives of biofuel blend targets with fossil fuels as well target strategies. The results of the assessment will provide the Zambian government with information on the viability and ability of the country to produce liquid biofuels, and how it may reach the blending mandates targets for both ethanol and biodiesel.

FIGURE 115.

COMPONENTS OF THE LIQUID BIOFUEL ASSESSMENT



Source: own elaboration

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4.6.1 Fossil fuel consumption

The introduction of a blending mandate for the transport creates a demand for liquid biofuels that could be covered by internal production or by importing such biofuels. In the case of developing countries such as Zambia, there is a likelihood that the demand for fossil fuels will increase due to the growth of the population and the economy. For this reason, it is necessary to analyse the future demand for the fossil fuels and liquid biofuels that would be created by the blending mandate, since the country aims to cover this demand by using local production of feedstock to produce both ethanol and biodiesel. In the case of this assessment, the period up to 2030 has been considered.

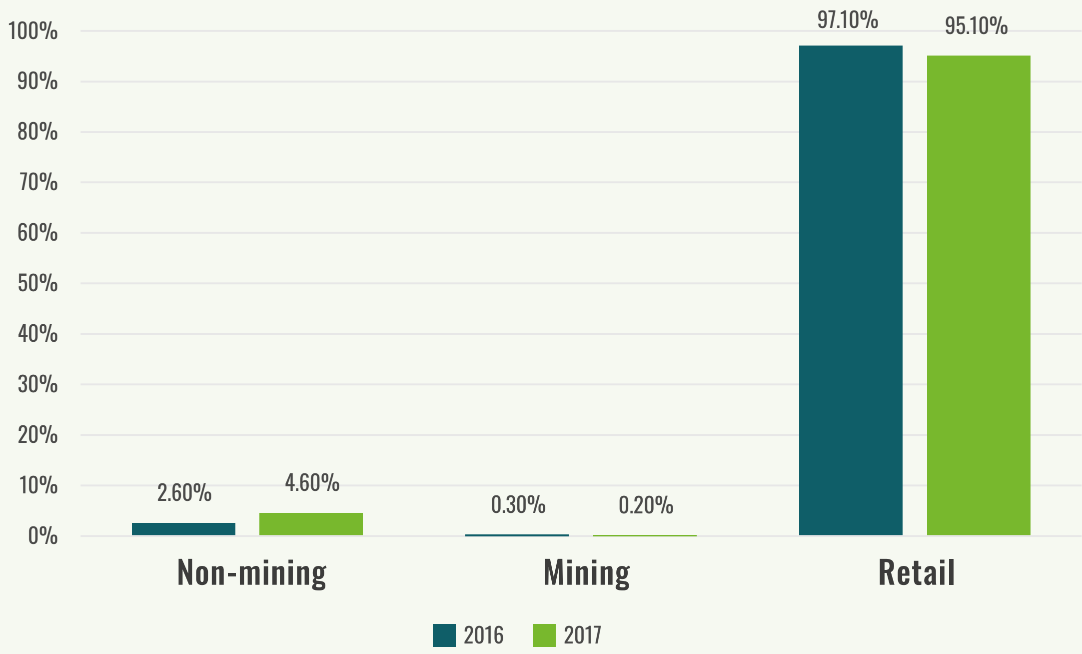
Figure 116 and **Figure 117** show the demand of each economic sector in the country for gasoline and diesel, respectively. The most important sectors are the mining, non-mining sectors that include industries and commercial sectors, and the retail sector that refers to the transport sector. It should be noted that almost all of the demand for petrol corresponds to the retail sector. In the case of diesel, the retail sector consumes between 37.5 and 39 percent of the country's diesel demand.

Figure 118 shows the trend in the consumption of both petrol and diesel by the retail sector during the period from 2010 to 2018. It can be noted that in less than 10 years annual diesel consumption has progressively increased from 80 million litres in 2010 to 100 million litres in 2018. In the case of petrol, the annual consumption has doubled from 150 million litres in 2010 to 419 million litres in 2018.

In order to forecast the increase in demand for both gasoline and diesel, it has been assumed that the growth in demand by the transport sector will follow the trend of recent years. The results of the projection of the demand can be seen in **Figure 119** and **Table 58**. According to these results, the demand for diesel in the

FIGURE 116.

CONSUMPTION OF PETROL BY ECONOMIC SECTOR, 2016 AND 2017



Source: Based on values reported by (Energy Regulation Board (ERB), 2016, 2017)

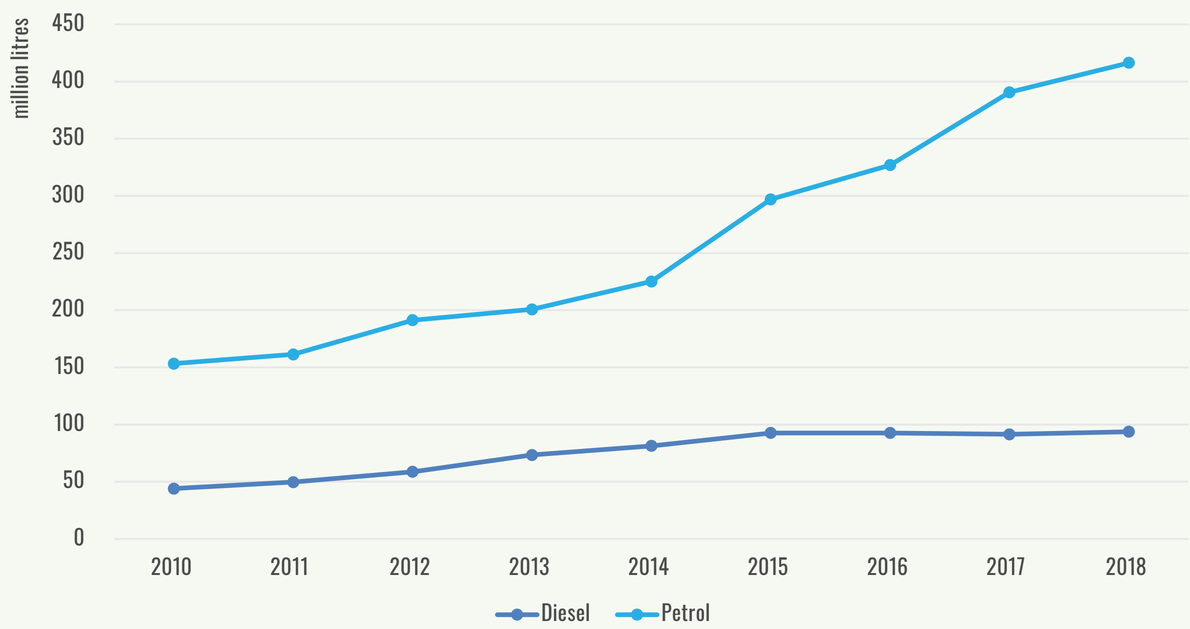
FIGURE 117.

CONSUMPTION OF DIESEL BY ECONOMIC SECTOR, 2016 AND 2017

Source: Based on values reported by (Energy Regulation Board (ERB), 2016, 2017)

FIGURE 118.

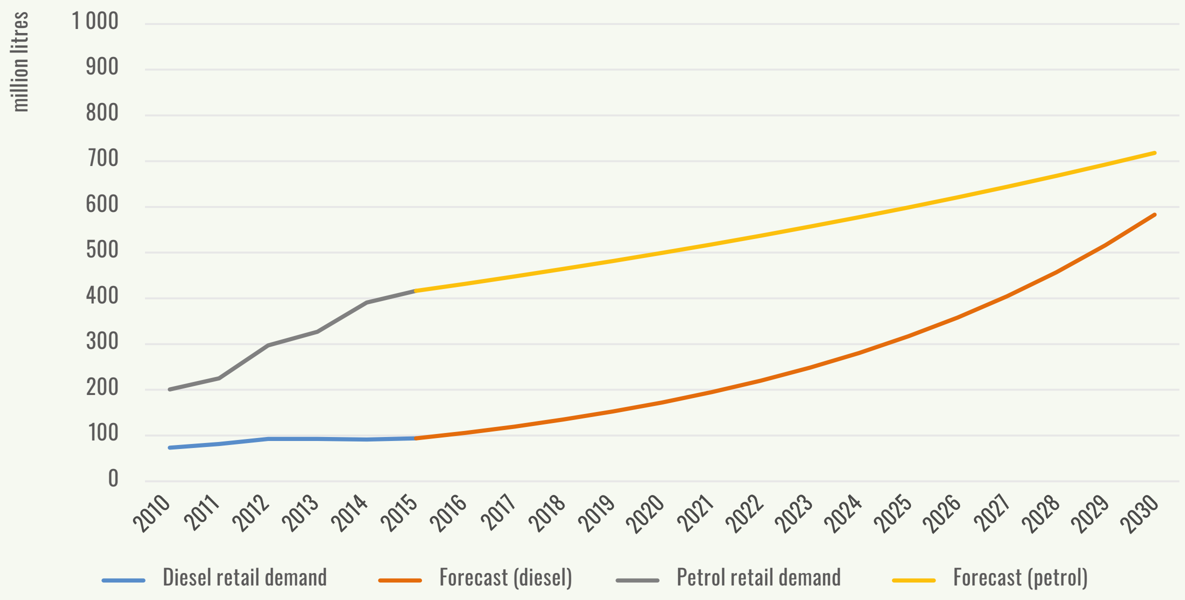
FOSSIL FUEL CONSUMPTION BY THE RETAIL SECTOR, FROM 2010 TO 2018



Source: Based on values reported by (Energy Regulation Board (ERB), 2014, 2015, 2016, 2017, 2018a)

FIGURE 119.

PROJECTED FOSSIL FUEL CONSUMPTION BY THE RETAIL SECTOR, FROM 2018 TO 2030



Source: Own elaboration based on values reported by (Energy Regulation Board (ERB), 2014, 2015, 2016, 2017, 2018a)

transport sector will reach 583 million litres/year by 2030. In the case of gasoline, the demand will reach 718 million litres/year by 2030. These results will allow to define the target production of the liquid biofuels that the country should produce to cover the demand created by a blending mandate.

4.6.1.1 Blending mandate and target liquid biofuel production

The Zambian government views biofuels as an important industry for reducing the petroleum import bill, while contributing to energy diversification and security. The National Energy Policy 2008 includes policy measures for the trade, production, and blending of biofuels. To support production, in 2009 blending ratios for ethanol and biodiesel were set at 10 percent and 5 percent, respectively (Hartley *et al.*, 2019). The same blending ratios are mentioned in the Nationally Determined Contributions respectively to be achieved by 2030.

Table 58 shows the target demand for liquid biofuels that would be created with blending mandates of 10 percent for ethanol (E10) and 5 percent for biodiesel (B5). The targets were calculated using the estimated demand of petrol and diesel of the transport sector. It can be noticed that the blending mandate would entail the production of 71.8 million litres/year of ethanol to be blended with gasoline and 29.15 million litres of biodiesel to be blended with diesel.

TABLE 58.

ESTIMATED DEMAND OF FOSSIL FUELS AND LIQUID BIOFUELS BY THE TRANSPORT SECTOR IN 2030

CURRENT AND ESTIMATED PETROL AND DIESEL DEMAND	PETROL (million litres/year)	DIESEL (million litres/year)
CURRENT DEMAND (2018)	419	371
ESTIMATED DEMAND (2030)	718	583
ESTIMATED TARGET ETHANOL AND BIODIESEL PRODUCTION	**ETHANOL (million litres/year)**	**BIODIESEL (million litres/year)**
BIOFUEL DEMAND E10 – B5 MANDATE (2030)	71.8 (E10)	29.15 (B5)
BIOFUEL DEMAND E20 – B10 MANDATE (2030)	143.7 (E20)	58.3 (B10)

Source: Elaboration based on BEFS Assessment Results using data from (Energy Regulation Board (ERB), 2018b)

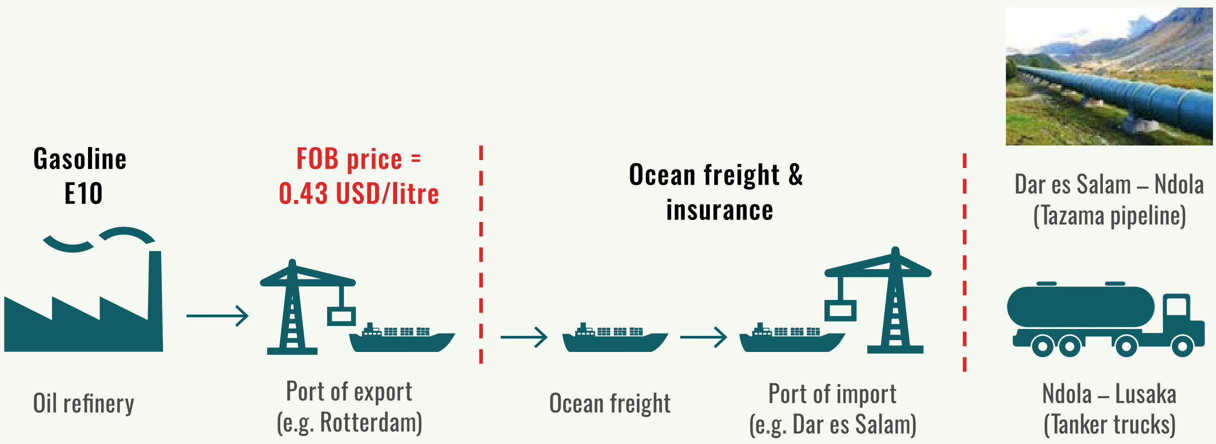
4.6.2 Estimation of comparison prices

Zambia is currently a net fuel importer and it is highly likely that all fuels and biofuel will continue to be imported in the future (see Energy Demand section). The current fuel imports scheme as summarized in **Figure 120** shows that once fuels are acquired at the origin port (e.g. Rotterdam port), they need to be transported to a nearby port in Zambia. In this case, the imported fuel arrives at the port of Dar es Salaam, Tanzania, after which it is transported to Zambia through the Tazama pipeline to the INDENI refinery located in Ndola. Upon arrival, the imported fuels are mixed with the locally refined fuels and subsequently distributed to filling stations using tanker trucks. When the blending mandate is operational the INDENI refinery will also perform the blending of fossil fuels and liquid biofuels.

Currently, the blending points are located in Ndola in the northern region of Zambia and Lusaka in the southern region. In addition to these locations, new blending depots will be constructed in Mongu, Mpika, and Solwezi. **Table 59** summarizes the import costs for fuel under the above described conditions.

FIGURE 120.

STRUCTURE FOR FUELS IMPORTS TO ZAMBIA



Source: Authors

TABLE 59.

COMPARISON PRICE FOR FOSSIL FUELS AND LIQUID BIOFUELS IN ZAMBIA

	FOB PRICE AT ROTTERDAM PORT[1]	OCEAN FREIGHT & INSURANCE & ADDITIONAL TANKER TRUCK COST[2]	PIPELINE COSTS[3]	TOTAL CIF PRICE IN ZAMBIA
DIESEL	USD 0.48	USD 0.26	USD 0.05	USD 0.79
GASOLINE	USD 0.43	USD 0.24	USD 0.04	USD 0.71
BIODIESEL	USD 0.68	USD 0.28	USD 0.02	USD 0.98
ETHANOL	USD 0.47	USD 0.25	USD 0.02	USD 0.74

Sources: i) Commodity3, 2019; Platts, 2019, ii) Estimation based on (UNCTAD, 2007), iii) Energy Regulation Board, 2019

4.6.3 Feedstock procurement options

Feedstock costs are the most critical factor that affect the production costs of liquid biofuel production, which usually ranges from 40 to 70 percent of the total production costs (OECD-FAO, 2019). Therefore, the procurement of feedstock is essential not only to maintain a sustainable production, but also to guarantee the economic viability of liquid biofuel plants. In this respect, the BEFS analysis considers three schemes for feedstock sourcing: out-growers, own production, and mixed (FAO, 2014).

- **Out-growers scheme.** Under this production scheme, the price paid at the processing gate to the out-growers, who are smallholder farmers, is the market price. A direct purchase agreement between the smallholders and the biofuel processors has presumably been put into place, without involving middlemen in the transaction;
- **Own production scheme**. Under this production scheme, the cost of feedstock at the factory gate is the feedstock production cost. The total feedstock production is obtained from plantations entirely owned by the liquid biofuels factory, which always produce a high input level of feedstock (large-scale or commercial farmers);
- **Mixed out-growers/own production scheme.** Under this scheme, the feedstock is partly supplied by out-growers and partly by commercial farmers (own producers). The shares have been defined according to

TABLE 60.

SUMMARY OF MAIN INPUT DATA USED FOR SELECTED BIOENERGY CROPS

		SUGARCANE	CASSAVA	SOYBEANS	SUNFLOWER
	PRODUCTION AVAILABLE FOR BIOENERGY (tonnes/year)	113 412	1 124 859	171 759	23 676
OUT-GROWERS	SHARE (%)	99%	99%	56%	94%
	YIELD (tonnes/ha)	132.00	20.00	2.26	1.13
	MARKET PRICE (USD/tonne)	30.91	95.48	320.00	230.00
COMMERCIAL PRODUCERS	SHARE (%)	1%	1%	44%	6%
	YIELD (tonnes/ha)	140.00	28.5	4.00	3.00
	PRODUCTION COST@ INTENSIFIED YIELD (USD/tonne)	21.68	47.51	356.00	220.88

Source: Own elaboration

the local distribution of smallholders and commercial producers previously identified in the BEFS crop assessment. The feedstock cost under this production scheme is calculated based on a combination of the price paid to the out-growers and the cost borne under the own production scheme.

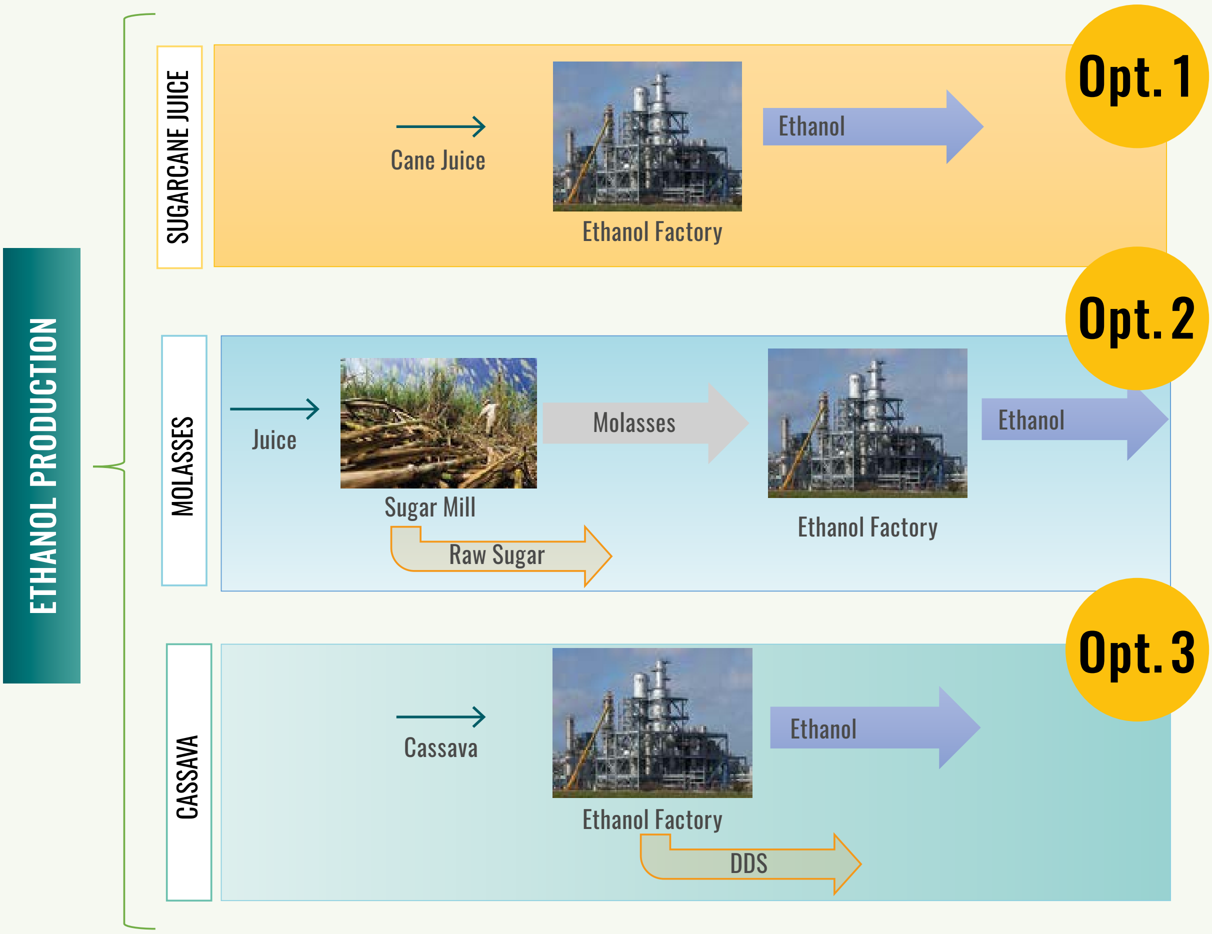
Using this methodology makes it possible to understand whether liquid biofuels can be produced competitively when smallholders are included in the production chain. A summary of the main parameters for the different options included in this assessment is presented in **Table 60**.

4.6.4 Ethanol analysis and results

The liquid biofuel assessment carried out for the ethanol production option begins with two feedstock families: sugar feedstock (i.e. sugarcane and sugar molasses) and starchy feedstock (i.e. cassava). The first family, whose sugars needed for fermentation are available after their extraction, is the most commonly used; however, additional steps are required for the starchy feedstock to be converted into sugar. As a consequence of these chemical differences between sugars and starches the ethanol production is slightly different, as explained in the technology description of this assessment. Moreover, as regards the ethanol production

FIGURE 121.

OPTIONS FOR THE PRODUCTION OF ETHANOL IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

from sugar feedstock, the system as well as the possible integration with conventional sugar mills play an essential role in the production costs and consequential economic viability of ethanol factories. All of these aspects have been taken into consideration and analysed in the three production options displayed in **Figure 121**.

The investment expenses for setting up the plant and the production costs must be considered for all of these options. Ethanol sales are the main source of income for the factory, however, in the case of options 1 and 3, additional incomes might come from electricity sales (option 1 only) and cassava dried distillers with solubles (DDS) sales (option 3). For the estimation of the benefits of by-products, the market prices were directly collected in the country (BEFS Zambia Survey, 2019).

4.6.4.1 Ethanol production from sugarcane (option 1)

With this option the factory uses sugarcane that has been directly collected in the field for the production of ethanol. This alternative process is a well-established technology around the world and most of the processing stages are widely known and operational in Zambia (e.g. sugarcane juice extraction, ethanol fermentation, and distillation). However, the most challenging part of the process can be the ethanol dehydration, which is necessary to obtain fuel-grade ethanol (>95 percent purity). Consequently, the highest investment levels in terms of technology will be required in this section.

Moreover, an additional critical factor for ethanol production is energy management, due to the massive thermal energy consumption that occurs throughout the process; modern ethanol factories include energy self-generation solutions such as cogeneration systems. During the sugar juice extraction process, the factory produces bagasse as a by-product that can be used in a combined heat and power (CHP) system to cover the demand for electricity and heat in the factory. The eventual electricity surplus can then be sold to the national grid. **Table 61** summarizes the performance of the CHP systems when supplying the energy demand of different plant capacities, ranging from 5 to 100 million litres/year. These capacities are considered to be standard for liquid biofuel production on a large scale (Knothe, Van Gerpen and Krahl, 2005).

TABLE 61.

SUMMARY OF CHP PERFORMANCE RESULTS

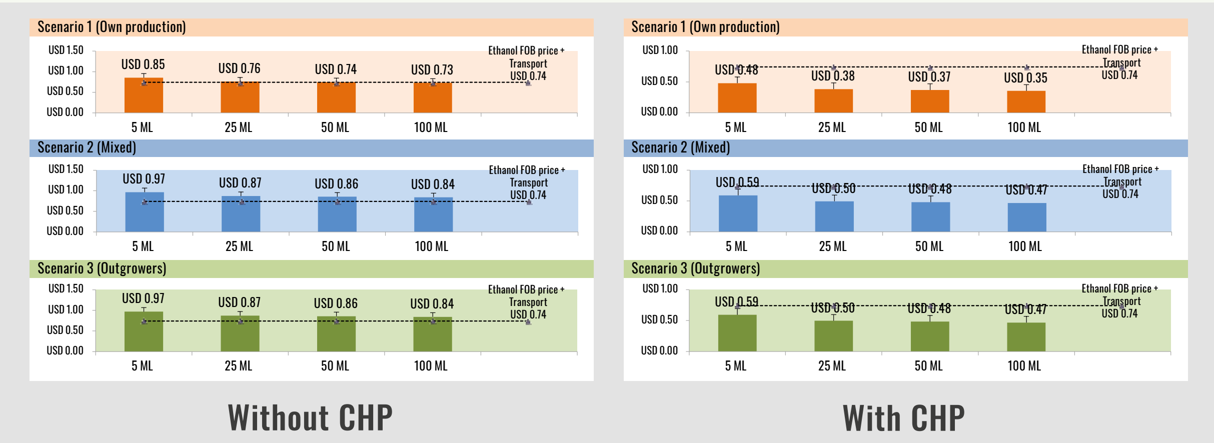
COGENERATION PERFORMANCE				
TECHNOLOGY	SEMI-ADVANCED-BACK-PRESSURE STEAM TURBINE			
	5 ML	**25 ML**	**50 ML**	**100 ML**
ELECTRICITY CAPACITY (kW)	537	2683	5366	10732
HEAT CAPACITY (MW)	3	15	30	60
PLANT HEAT DEMAND SUPPLIED	**FULLY SUPPLIED**	**FULLY SUPPLIED**	**FULLY SUPPLIED**	**FULLY SUPPLIED**
PLANT ELECTRICITY DEMAND SUPPLIED	**SURPLUS**	**SURPLUS**	**SURPLUS**	**SURPLUS**
COST OF COGENERATION SYSTEM				
	5 ML	**25 ML**	**50 ML**	**100 ML**
INVESTMENT (USD)	902 394	4 511 971	9 023 943	18 047 885
FIXED O&M (USD/year)	20 928	104 638	209 277	418 554
VARIABLE O&M (USD/year)	46	228	456	912
TOTAL COST COGENERATION (USD/year)	**66 093**	**330 465**	**660 930**	**1 321 860**
ENERGY COST AVOIDED (USD/year)	**621 438**	**3 107 189**	**6 214 378**	**12 428 756**
REVENUE ELECTRICITY SELLING (USD/year)	**661 270**	**3 306 352**	**6 612 705**	**13 225 409**

Source: Elaboration based on BEFS Assessment Results

Figure 122 presents a comparison of ethanol production costs (USD/litre ethanol) for the different procurement schemes with the four selected plant capacities. In addition, **Figure 122** shows a comparison of the influence of CHP systems with the production costs. Based on the results obtained it is evident how initially, without CHP systems, most of the production costs would be higher than the ethanol comparison price. This situation changes once the effect of CHP systems is implemented, due to the benefits obtained from energy savings and credits from potential electricity sales. These savings and credits in turn deduct the energy demand share from the costs shares (see **Figure 123**). For this reason, energy management should be considered a critical factor for the future development of ethanol production in Zambia.

FIGURE 122.

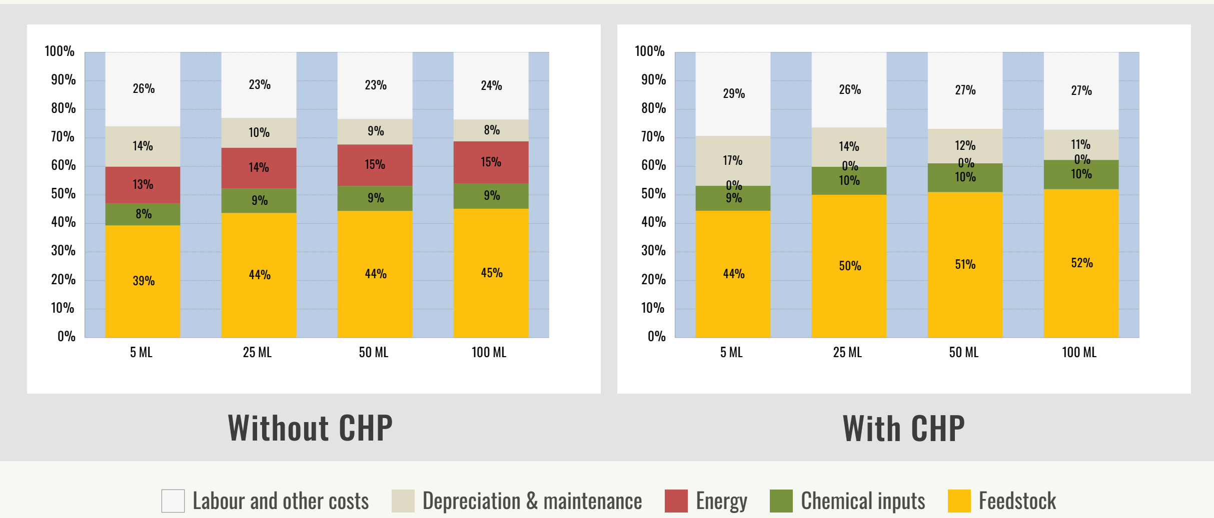
ETHANOL PRODUCTION COST FROM SUGARCANE (USD/LITRE ETHANOL)



Source: Elaboration based on BEFS Assessment Results

FIGURE 123.

COMPOSITION OF PRODUCTION COSTS FOR ETHANOL PRODUCTION FROM SUGARCANE

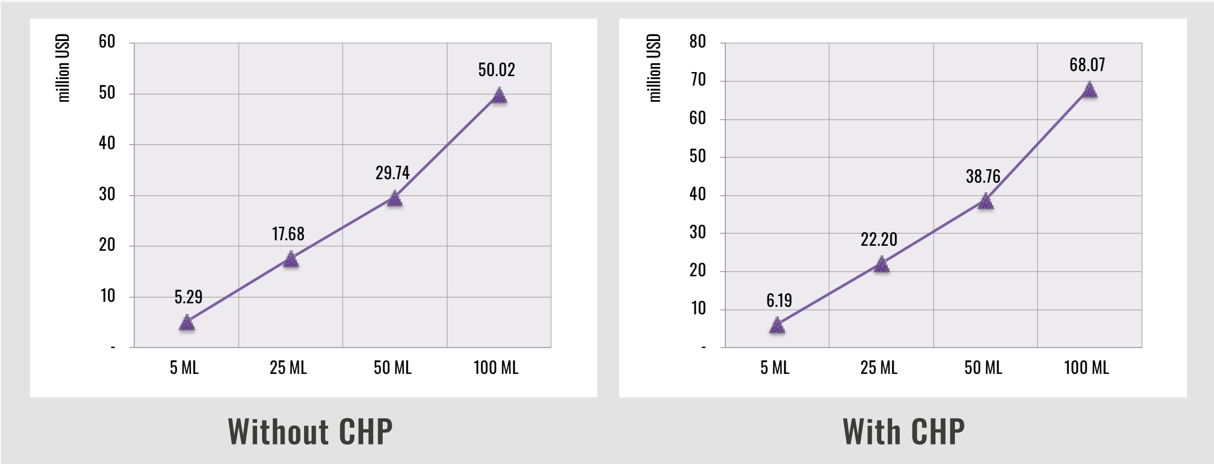


Source: Elaboration based on BEFS Assessment Results

It is also worth mentioning that overall, the capital investment required for ethanol production from sugarcane ranges from USD 5 to 50 million for 5 to 50 million litres/year factories, respectively. Nevertheless, in order to obtain the benefits of the cogeneration of heat and power there will be an added capital investment cost for each plant capacity; in fact, 36 percent must be added to the original investment costs in order to pay for the CHP systems (see **Figure 124**). Indeed, the investment expenditure requirements could be a deciding factor for the development of a Zambian liquid biofuels industry. Furthermore, the investment costs would probably represent a constraint during the initial development and future expansion of national blending mandates from E10 to E20.

FIGURE 124.

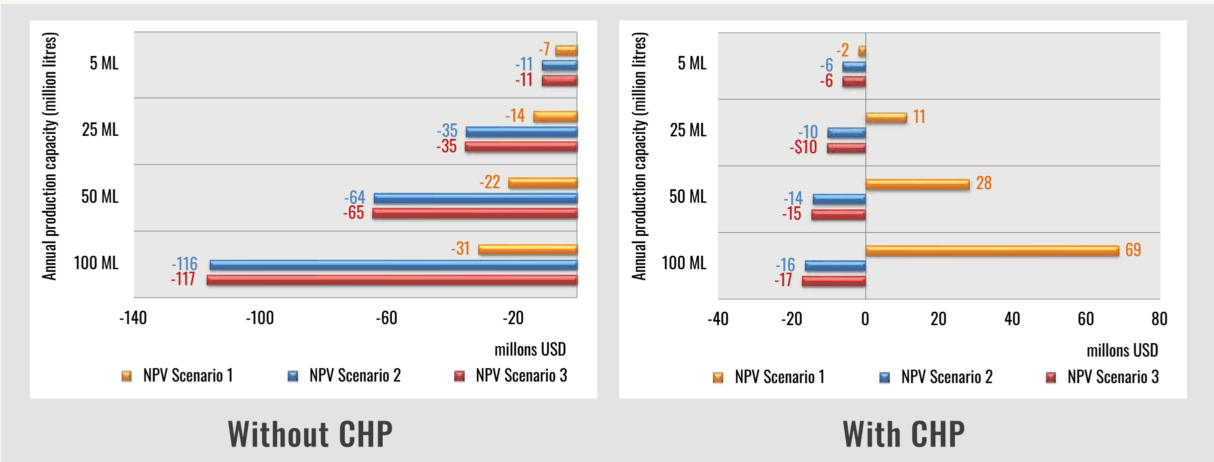
COMPARISON OF INVESTMENT COSTS AFTER INCLUDING CHP SYSTEMS (MILLION USD)



Source: Elaboration based on BEFS Assessment Results

FIGURE 125.

PROFITABILITY OF ETHANOL FACTORIES FROM SUGARCANE (NPV, MILLION USD)



Source: Elaboration based on BEFS Assessment Results

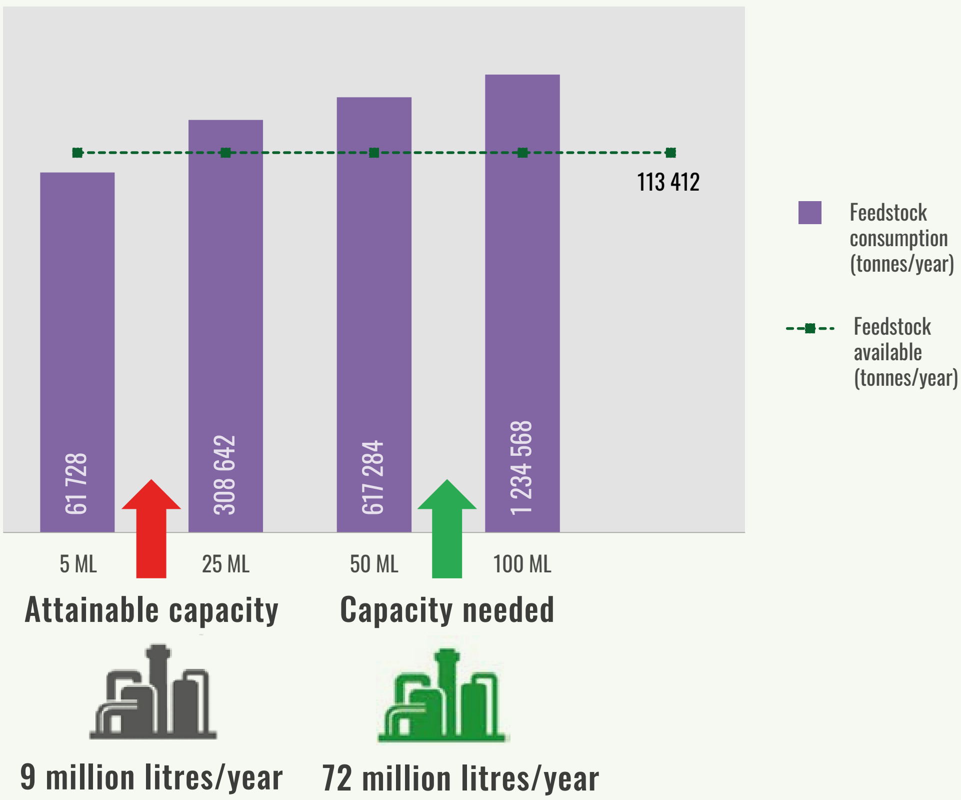
Once the production costs and investment requirements were calculated, it was possible to estimate the potential profitability for ethanol factories. **Figure 125** shows the results for the NPV that were calculated over a period of 20 years. In the case where the profitability is calculated based on a comparison price of 0.74 USD/litre ethanol without CHP systems, a procurement scenario would not be feasible. In fact, when the CHP systems were included the only scenario that resulted as potentially profitable was the feedstock own-production option. This indicates that sugarcane-based ethanol factories would require additional income sources in order to become economically sustainable. In effect, the overall profitability was almost triplicated, however, where options were paying a market price for sugarcane (out-growers and mixed) the annual profits were still negative. As a consequence, after alternative income sources and their additional capital expenditures had been calculated, the NPV global results still proved to be negative.

The above results are of particular interest because 99 percent of the sugarcane in Zambia is procured from out-growers. Therefore, the sugarcane-based ethanol factories should take into account not only the processing plants but also the dedicated sugarcane producers for their future investment plans, in order to establish profitable projects. This would result in an additional increase in the initial investments; otherwise, prices higher than 0.74 USD/litre for ethanol might be required to promote ethanol from sugarcane in Zambia.

Another deciding factor is the comparison of feedstock availability and the quantities needed per plant size. **Figure 126** presents a

FIGURE 126.

ATTAINABLE AND REQUIRED PRODUCTION OF ETHANOL FOR A E10 MANDATE – SUGARCANE JUICE



Source: Elaboration based on BEFS Assessment Results

comparison of feedstock consumption (purple bars) and feedstock available. The sugarcane estimated as potentially available in the BEFS crop assessment was 113 412 tonnes/year, which is enough to supply 9 million litres/year ethanol production. However, the ethanol needed to satisfy an E10 blending mandate amounts to 72 million litres/year and therefore, the sugarcane potential that would be sustainable for ethanol production could only supply 13 percent of the target demand.

Considering the projected ethanol price, while taking into account the most profitable scheme (i.e. own production) and the need for larger feedstock amounts, sugarcane could be used directly. If Zambia were to decide to use sugarcane as the main ethanol feedstock, it would require an extensification of the sugarcane plantations. It is important that extensification programmes be led by the ethanol producers in order to maintain profitability. It has been estimated that to produce the 72 million litres/year of ethanol more than 890 thousand tonnes/year of sugarcane would be needed; based on a yield of 140 tonnes/ha yield this would be the equivalent of almost 7 300 ha. Consequently, should sugarcane be used directly in the future for ethanol industry development in Zambia, the impact of extensification on natural resources, land availability and investment possibilities must be closely considered.

4.6.4.2 Ethanol production from molasses (option 2)

Sugarcane molasses is one of the most versatile feedstock options for ethanol production, both for beverages and fuel ethanol. It is particularly good feedstock for ethanol production because the sugars needed for the fermentation are readily available, no juice extraction is needed, and the amount of water to evaporate after fermentation is lower. This results in lower capital investment needs and energy consumption levels as compared to ethanol production from sugarcane, thus reducing production costs.

However, the main drawback of molasses as an ethanol feedstock is the variability in the sucrose content, in other words, the sugar molecule converted to ethanol or refined until table sugar is obtained. Molasses are a by-product of the sugar industry, as a result, their quality (measured in sucrose content) depends on variables such as the international sugar price, sugar demand, current inventories and other. Therefore, a sugar mill would most likely decide to recover as much sucrose as possible, thus impacting the sucrose amounts available for ethanol production in molasses. Although stand-alone ethanol factories could make contracts with sugar mills to pay differentiated prices according to sugar content in molasses, this situation might in fact still cause disruption in the production for molasses-based ethanol factories (Castañeda-Ayarza and Cortez, 2017). These issues are often resolved when sugar mills are integrated with ethanol factories, which would create a synergy between the two market possibilities for sugar mill (i.e. sugar and ethanol). Furthermore, the decisions on which product should be given priority have an internal impact only, and are made in the company's best interest. Both of these options are described in **Figure 127**.

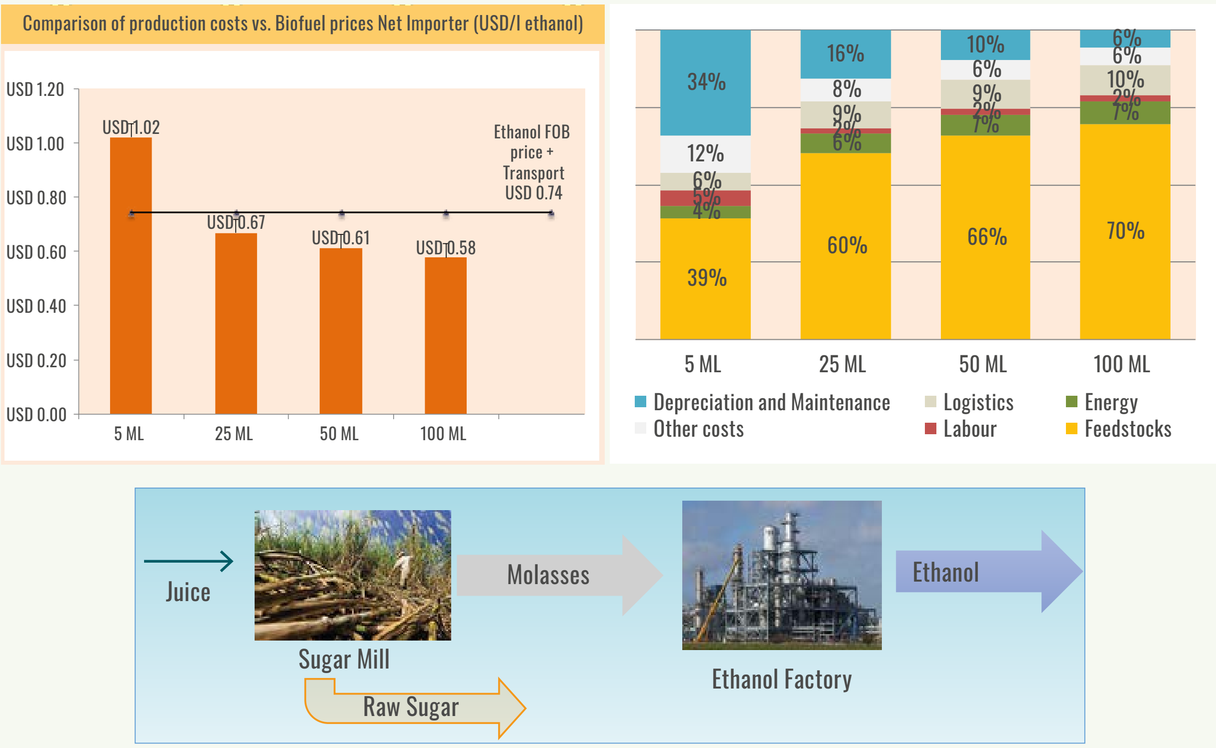
In the case of ethanol produced from molasses at stand-alone factories, they would need to buy molasses at a market price of 126 USD/tonne (BEFS Zambia Survey, 2019). Under this market price, the production cost would range from 0.58 to 1.02 USD/litre ethanol (see **Figure 127**). Moreover, **Figure 127** shows a large share of feedstock in the production costs, which range from 40 to 70 percent depending on the plant capacity.

Otherwise, in the case where an ethanol factory is integrated with the sugar mill the factory would not need to buy molasses, thus, the production costs would be reduced to between 0.22 and 0.67 USD/litre ethanol (see **Figure 128**.). The share attributed to feedstock is in this case highly reduced, the remaining cost being associated with other raw materials only.

From the integrated ethanol factory standpoint, the situation described in **Figure 128** would be ideal and furthermore assure the profitability for different plant capacity options. Nevertheless, this high profitability is artificial and it is important to understand how this integration might impact the economic viability of sugar mills, ultimately paying for the investments.

FIGURE 127.

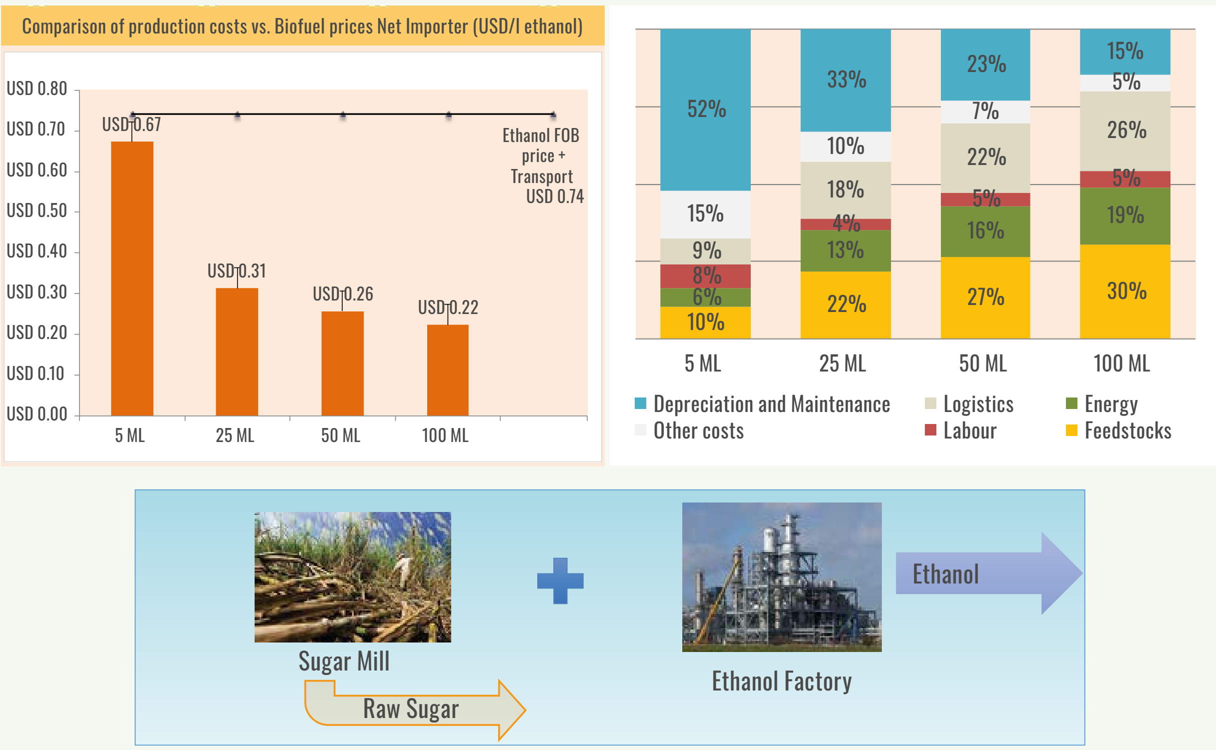
PRODUCTION COST FOR STAND-ALONE ETHANOL PRODUCTION FROM MOLASSES



Source: Elaboration based on BEFS Assessment Results

FIGURE 128.

PRODUCTION COST FOR ETHANOL PRODUCTION FROM MOLASSES IN INTEGRATED SUGAR-MILL AND ETHANOL FACTORIES



Source: Elaboration based on BEFS Assessment Results

Table 62 presents an abridged financial analysis of a typical Zambian sugar mill with a crushing capacity of 3.3 million tonnes of sugarcane/year (Zambia Sugar PLC, 2017), which would allow the mill to produce 399 000 tonnes of sugar/year and 116 000 tonnes of molasses/year. Therefore, a sugar mill of this type, assuming the same financial trend continues over a period of 20 years, would have an NPV of USD 182 million. It is worth noting that the estimated annual revenues from sugar and molasses sales would reach USD 246 million.

The effect of additional expenses, financial costs, and other capital investments attributed to the integration of 56 million litres/year[8] have been included in the income statement presented in **Table 63**. The overall effect of the attached ethanol factory is to increase the annual production costs of each good sold (COGS) from USD 195 million to USD 221 million.

TABLE 62.

FINANCIAL ANALYSIS FOR SUGAR MILLS BEFORE ETHANOL PRODUCTION

	Incremental Income Statement	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Annuity
			Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	
	Revenue		246.33	246.33	246.33	246.33	246.33	246.33	246.33	246.33	246.33	246.33	246.33
	Sugar		232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40
	Molasses		13.93	13.93	13.93	13.93	13.93	13.93	13.93	13.93	13.93	13.93	13.93
-	COGS		195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85
	Sugar milling cost		195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85
=	Gross Income		50.48	50.48	50.48	50.48	50.48	50.48	50.48	50.48	50.48	50.48	50.48
-	Operating Expenses		24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96
	Finance cost		24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96
=	Operating Income (EBITDA)		25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52
-	Depreciation & Amortization		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
=	Operating Income (EBIT)		25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52
-	Income Tax		3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
=	Net Operating Profit After Taxes (NOPAT)		22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46
Adjustments													
+	Depreciation (not a cash flow)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
-	Net Capital Expenditures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	New warehouse & Equipment												
	Salvage warehouse & Equipment												
-	Net Working Capital Investment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	+ Net Increase in Accounts Receivable												
	+ Net Income in Invenotry												
	- Net Increase in Accounts Payable												
Free Cash Flow		0.00	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46
Terminal Value												167.75	Annuity starting period 1
Evaluation Cash Flow		0.00	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	190.20	
	NPV (Million USD)	180.90											

Source: Elaboration based on BEFS Assessment Results

[8] This is the potential ethanol production from 116 000 tonnes/year of molasses, assuming a conversion rate of 0.44 l ethanol/kg molasses.

TABLE 63.

FINANCIAL ANALYSIS FOR SUGAR MILLS AFTER ETHANOL PRODUCTION

Incremental Income Statement		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10		Annuity
			Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD	Million USD		
	Revenue		**273.91**	**273.91**	**273.91**	**273.91**	**273.91**	**273.91**	**273.91**	**273.91**	**273.91**	**273.91**		**273.91**
	Raw Sugar		232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40	232.40		232.40
	Ethanol		41.51	41.51	41.51	41.51	41.51	41.51	41.51	41.51	41.51	41.51		41.51
-	COGS		204.80	204.80	204.80	204.80	204.80	204.80	204.80	204.80	204.80	204.80		204.80
	Sugar milling cost		195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85	195.85		195.85
	Inputs (Materials and utilities)		5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48		5.48
	Labour and miscellaneous costs		0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59		0.59
	Storage		2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87		2.87
=	Gross Income		69.12	69.12	69.12	69.12	69.12	69.12	69.12	69.12	69.12	69.12		69.12
-	Operating Expenses		14.23	14.23	14.23	14.23	14.23	14.23	14.23	14.23	14.23	14.23		14.23
	Plant overhead		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
	General and administrative cost		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
	Loan interest		0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34		0.34
	Mainteinance		1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41		1.41
	Sugar finance cost		12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48
=	Operating Income (EBITDA)		54.88	54.88	54.88	54.88	54.88	54.88	54.88	54.88	54.88	54.88		54.88
-	Depreciation & Amortization		1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55		1.55
	Ethanol plant equipment, building and installation		1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55		1.55
=	Operating Income (EBIT)		53.33	53.33	53.33	53.33	53.33	53.33	53.33	53.33	53.33	53.33		53.33
-	Income Tax		6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40		6.40
=	Net Operating Profit After Taxes (NOPAT)		46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93		46.93
Adjustments														
+	Depreciation (not a cash flow)		2	2	2	2	2	2	2	2	2	2		
-	Net Capital Expenditures	18	0	0	0	0	0	0	0	0	0	0		
	New equipment, building & installation	18												
-	Net Working Capital Investment													
Free Cash Flow		-18	48	48	48	48	48	48	48	48	48	48		47
Terminal Value												350.55	Annuity starting period 1	
Evaluation Cash Flow		-18	48	48	48	48	48	48	48	48	48	399		
	NPV (Million USD)	369.24												

Source: Elaboration based on BEFS Assessment Results

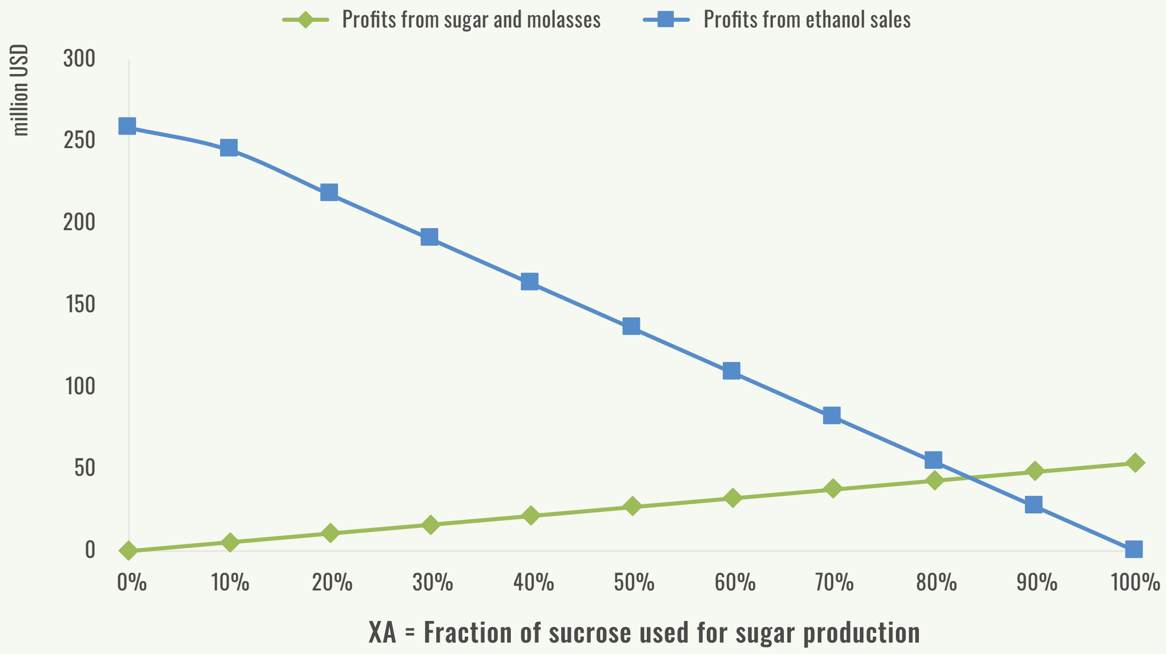
Moreover, the higher value of ethanol compared to molasses would allow for an increase in annual revenues of from USD 246 million to USD 274 million. As a result, the NPV for 20 years would be USD 369 million (see **Table 63**).

Indeed, it would make sense from a financial standpoint for a sugar mill to invest in ethanol production and give added value to molasses rather than sell them directly. After this change the overall profitability could almost be duplicated. Moreover, as previously explained, for integrated ethanol-sugar factories a strong relationship exists between the prices of sugar and ethanol, and the amount of sucrose is dedicated to ethanol or sugar production.

Figure 129 presents a diagram showing the sensitivity of the profit margins obtained in the sugar mill under the two production options analysed in the BEFS assessment, and the fraction of sucrose used for sugar production. Firstly, it was based on the conditions (prices, production costs, and efficiencies) used to prepare the financial analysis in **Figure 132**. Secondly, the left extreme results represents

FIGURE 129.

SENSITIVITY OF THE INTEGRATED SUGAR MILL–ETHANOL FACTORY PROFITS TO THE FRACTION OF SUCROSE USED FOR SUGAR PRODUCTION (XA)



Source: Elaboration based on BEFS Assessment Results

operations where the mill produces small quantities of sugar and dedicates most of the sucrose to ethanol, while the right extreme results show a process mostly devoted to sugar and molasses production, and not ethanol production. Given the current situation of low sugar prices (Sikuka, 2019), it could be more profitable for sugar mills to dedicate most of their sucrose to ethanol production rather than to sugar.

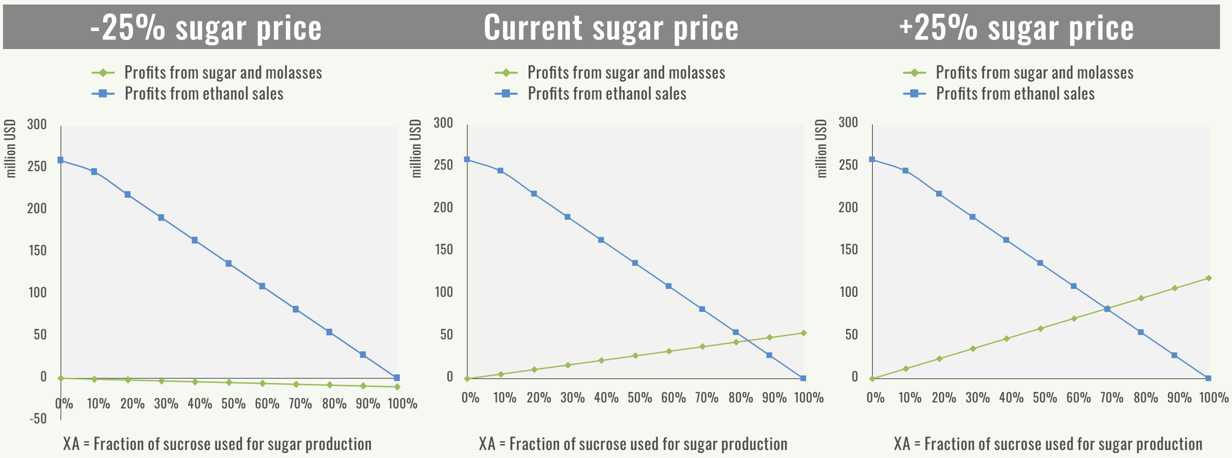
In practice, most integrated sugar-mill ethanol factories operated by modifying the production rates according to variations in sugar and ethanol prices (Anand and Daniel, 2009). **Figure 130** provides additional charts showing a 25 percent sugar price reduction as well as a 25 percent sugar price increment, so as to illustrate their effects on profits. Overall, it is worth noting that ethanol production could still be a promising investment for sugar mills and at the same time compensate the future investments, as it is the most profitable option for the factory in most cases.

The above results support the case whereby sugar mills investing in ethanol factories would obtain high profitability. However, sugar mills usually have commitments regarding the quantities of sugar and molasses they need to produce in order to supply the local market and exports (Sikuka, 2019). Therefore, for an accurate estimate of the potential ethanol production, it can be assumed that sugar production levels will remain the same and that only molasses would be available. **Figure 131** shows the distribution of end-uses for molasses during the period from 2011 to 2017. During this period of time, on average 36 percent of molasses was sold, 43.5 percent was exported, and 20.3 percent were discarded as waste.

In the case where the shares and the quantities estimated for a future intensification are combined in the natural resources assessment, the total molasses production in Zambia would reach 136 576 tonnes. However, the assumption could be made that when using discarded molasses, the annual minimum amount

FIGURE 130.

SENSITIVITIES UNDER VARIATION IN SUGAR PRICES



Source: Elaboration based on BEFS Assessment Results

FIGURE 131.

USES FOR MOLASSES REPORTED DURING PERIOD FROM 2011 TO 2017 BY ZAMBIA SUGAR PLC

Source: Elaboration based on values reported by (Zambia sugar plc, 2017)

available for ethanol production would reach only 28 841 tonnes. Upon completion of the technical consultations carried out in Zambia, the local experts agreed that the quantities dedicated to exports were variable and could potentially be used alternatively. Therefore, based on the profitability figures previously discussed, all exported molasses could feasibly be allocated to ethanol production. As a result, the total amount available for ethanol production would reach 87 528 tonnes; this value could be considered the maximum possible

TABLE 64.

POTENTIAL ETHANOL PRODUCTION FROM MOLASSES IN ZAMBIA

	MOLASSES (tonnes/year)	ETHANOL (million litres/year)	INVESTMENT NEEDED (million USD)	SHARE FOR E10 TARGET
MIN	28 481	14	9.78	19%
MAX	87 528	42	30.06	59%
AVERAGE		29	20.89	41%

Source: Elaboration based on BEFS Assessment Results

ethanol production from molasses. **Table 64** summarizes the potential ethanol production capacities based on the quantities mentioned and their potential contribution. In sum, for the estimated target ethanol demand of 72 million litres/year for an E10 mandate, the contribution required to meet this target could range from 19 to 59 percent.

Consequently, based on the potential economic benefits that ethanol production would bring to sugar mills, and considering the uncertainties in the molasses export markets, a realistic assumption for ethanol potential from molasses would be an average production of 29 million litres/year, thus contributing 41 percent to the E10 target.

4.6.4.3 Ethanol production from cassava (option 3)

Another suitable option for ethanol production is cassava, which is a starchy feedstock like maize. In fact, a well-established technology for ethanol production is already in place for this feedstock (Nguyen, Gheewala and Garivait, 2007). For instance, Thailand has been using cassava for an ethanol production that has reached an installed capacity of 2.7 billion litres/year, thus making it one of the pillars of its national biofuel policy (Preechajarn and Prasertsri, 2018). In Asia, other countries have installed ethanol factories in their territories as well, such as in Viet Nam and China (Marx, 2019).

Compared to ethanol from molasses, starch-based ethanol processing tends to require additional stages and materials, which as a result could increase its comparative capital investment costs. However, it offers the possibility to obtain added value products such as dried distillers with solubles (DDS) as by-products, which can be sold as animal feed or for other uses (Liu *et al.*, 2014; Sánchez and Cardona, 2008). **Figure 132** provides an illustration of how tradeoffs and the influence of by-products over the production cost have been analysed.

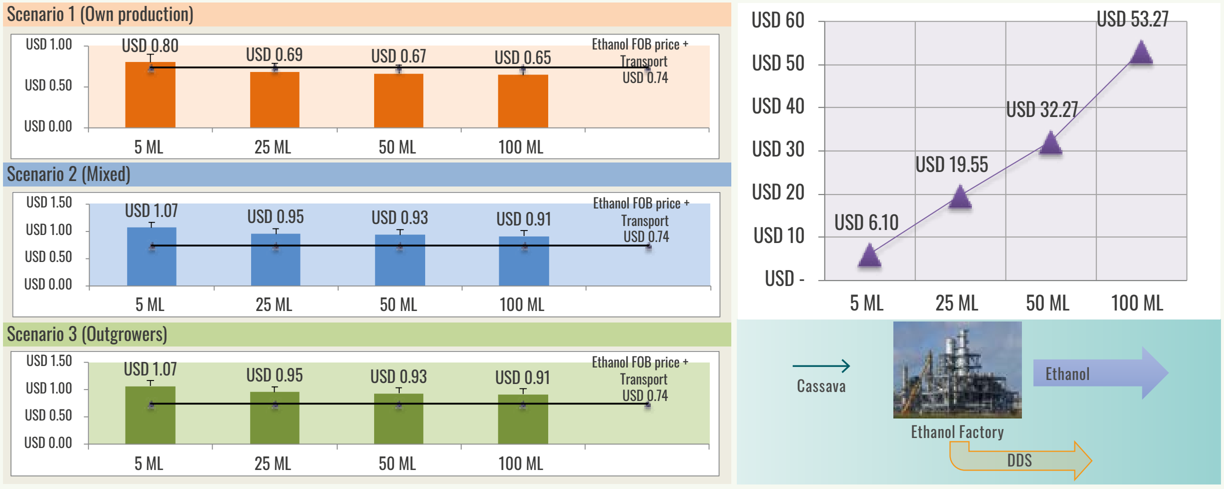
Furthermore, **Figure 132** shows the production costs for ethanol production under the three procurement options considered in the BEFS assessment. Overall, ethanol production is not cost-effective for out-growers but on the other hand, marginally cost-effective for the own-production option. However, 99 percent of the cassava in Zambia is produced by small and medium-scale farmers (see **Table 60**), as a result, in the short term the out-growers option would not be feasible. Capital investment costs range from USD 6.1 to 53.3 million. These costs are on average 15 percent higher than the costs for ethanol production from sugarcane, as can be expected due to the additional processing stages.

Figure 133 shows the production cost for ethanol production after discounting the credits from DDS selling. A conservative assumption could be that DDS would be sold as animal feed at the price of 100 USD/tonne, which might allow for a credit of up to 0.4 USD/litre ethanol. Due to the fact that cassava is currently produced mostly by smallholder farmers, the cost of production of a 72 million litres/year per factory would be closer to scenario 3 where all cassava is supplied by out-growers. As can be seen in **Figure 133**, the cost would be closer to a range of between USD 0.5–0.52 per litre.

The effect of by-products highly reduces the production costs and makes the out-growers option cost-effective. The main advantage

FIGURE 132.

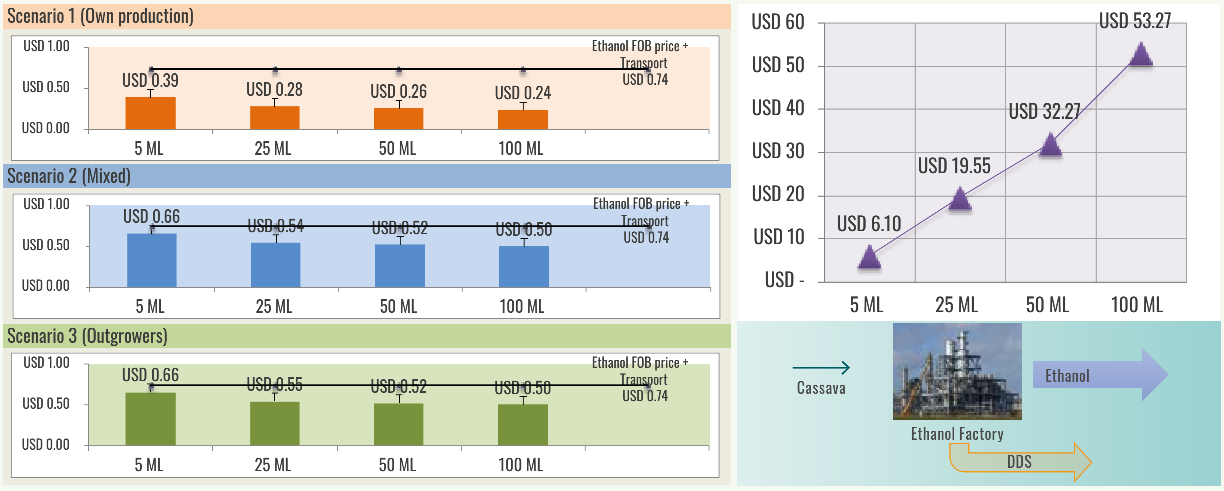
PRODUCTION COST FOR STAND-ALONE ETHANOL PRODUCTION FROM CASSAVA – EXCLUDING BY-PRODUCTS CREDITS



Source: Elaboration based on BEFS Assessment Results

FIGURE 133.

PRODUCTION COST FOR STAND-ALONE ETHANOL PRODUCTION FROM CASSAVA – INCLUDING BY-PRODUCTS CREDITS



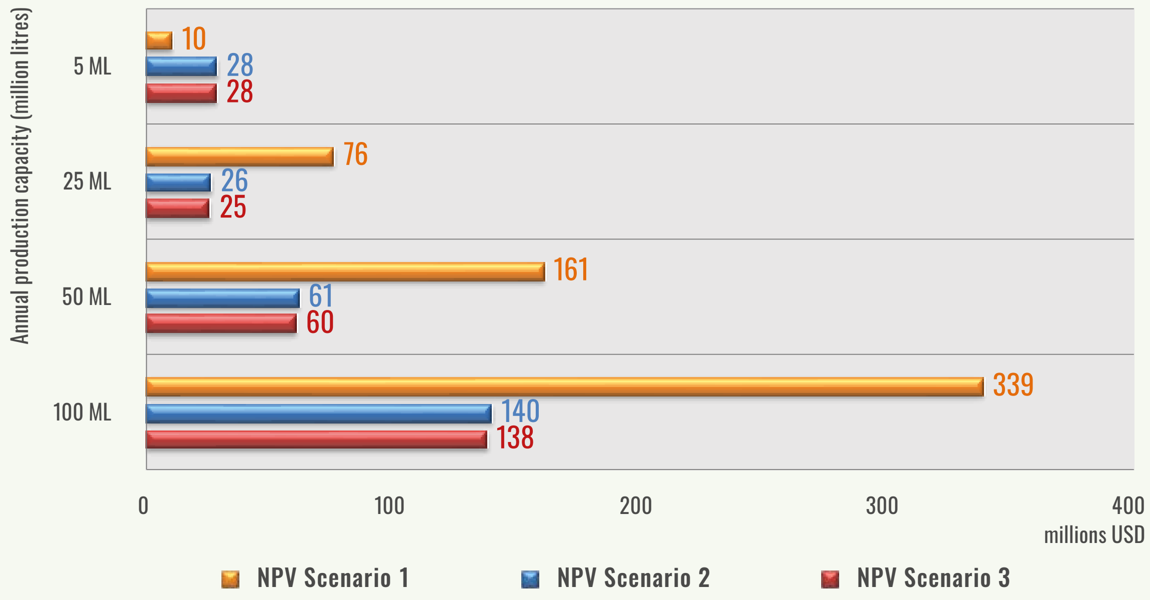
Source: Elaboration based on BEFS Assessment Results

of DDS as a by-product is that it is already part of the process and would require no additional capital investment. Thus, the financial profitability would be positive for the most feasible procurement options, reaching typically 50 million litres/year factories NPV, the equivalent of USD 60 million (see **Figure 134**).

Overall among the four feedstock options, cassava is the most available feedstock in Zambia. The predictions that more than 1.1 million tonnes would potentially be available indicate that it would be sufficient to supply up to 100 million litres/year ethanol factories. Indeed, the quantities available would be enough to produce 202 million litres/year ethanol, which exceeds by almost three times the demand created by an E10 mixing (i.e. 72 million litres/year). In sum, after reaching the goals defined by the E10 mandate the country could consider increasing the mandate or even exporting cassava-based ethanol.

FIGURE 134.

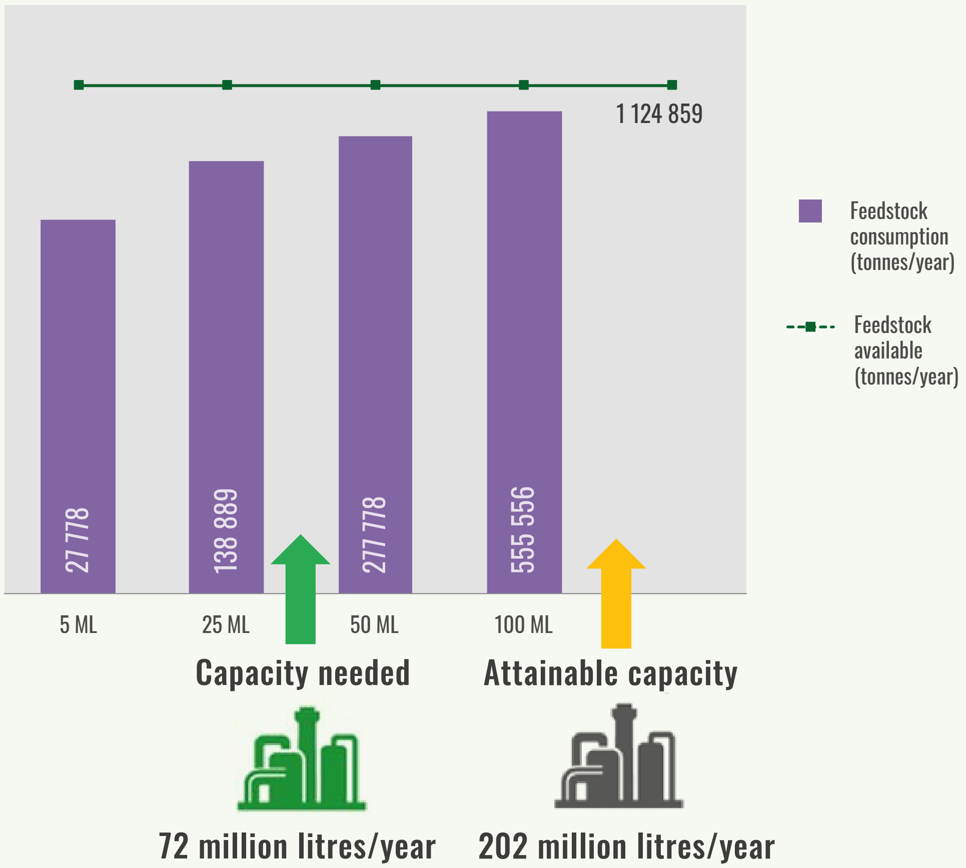
PROFITABILITY OF ETHANOL FACTORIES FROM CASSAVA INCLUDING BY-PRODUCTS CREDITS (NPV, MILLION USD)



Source: Elaboration based on BEFS Assessment Results

FIGURE 135.

ATTAINABLE AND REQUIRED PRODUCTION OF ETHANOL FOR A E10 MANDATE – CASSAVA



Source: Elaboration based on BEFS Assessment Results

4.6.4.4 Ethanol production options for Zambia

A comparison of each feedstock's principal techno-economic results is necessary so as to establish the best feedstock option for the production of ethanol in Zambia. **Table 65** shows a comparison of the three feedstock options that could meet the Zambian E10 mandate. On the whole, cassava proved to be the best option based on its ability to meet the E10 mandate, and also because of its availability and potential production capacity.

Furthermore, it is worth making an analysis of which option would perform better in the case where feedstock availability does not represent a constraint. **Table 66** presents a selection of techno-economic results, using the same comparison basis of 72 million litres/year capacity (E10 mandate target production). From a technical standpoint, ethanol production from molasses would be the most straightforward choice for Zambia, as it would demand less feedstock and a smaller capital investment. Nevertheless, cassava would offer the most significant potential profitability. Moreover, considering the number of farms needed to supply the 72 million litres/year production, cassava ethanol would require at least 50 000 small farms, while sugarcane would require around 18 000. Regarding the smallholders' involvement in the biofuels business, cassava ethanol could prove to be a positive option, as it would create a market as well as an alternative source of income. At the same time, the management, coordination and setting up of a supplying chain for cassava would be challenging for the country.

Based on these results, cassava and molasses would be the best feedstock options for the production of ethanol, both technically and financially. Regarding sugarcane as a feedstock option, it must be taken into account that the quantities available for direct ethanol production would be low due to the current high crop yields in the sugar industry in Zambia, in addition to its current uses.

TABLE 65.

PERFORMANCES COMPARISON FOR ETHANOL FEEDSTOCK CANDIDATES

PARAMETER	SUGARCANE JUICE	SUGARCANE MOLASSES	CASSAVA
QUANTITY AVAILABLE (tonnes/year)	113 412	58 000	112 4859
PERCENT E10 MANDATE SUPPLIED	13%	41%	282%
SHARE SUPPLIED BY OUTGROWERS	99%	0%	99%
MAX ETHANOL CAPACITY (million litres/year)	9	9.7	202
CO-PRODUCT	ELECTRICITY	NONE	DDS

Source: Elaboration based on BEFS Assessment Results

TABLE 66.

TECHNO-ECONOMIC COMPARISON FOR A 72 MILLION LITRES/YEAR ETHANOL PRODUCTION

PARAMETER	SUGARCANE JUICE	SUGARCANE MOLASSES	CASSAVA
FEEDSTOCK NEEDED (tonnes/year)	889 191	191 254	400 000
AREA NEEDED (ha)	7286	0	20 000
NUMBER OF FARMS SUPPLYING	18 215	0	50 000
INVESTMENT NEEDED	52	24	67
EXPECTED NPV (million USD)	46	57	95

Source: Elaboration based on BEFS Assessment Results

Table 67 presents the minimum profitable production conditions, based on BEFS assessment for molasses and cassava, defined as the most promising feedstock options for ethanol production. Once these conditions are established, the potential location of ethanol factories can be analysed according to the districts showing the most significant potential for additional production, as indicated in the crop production assessment.

TABLE 67.

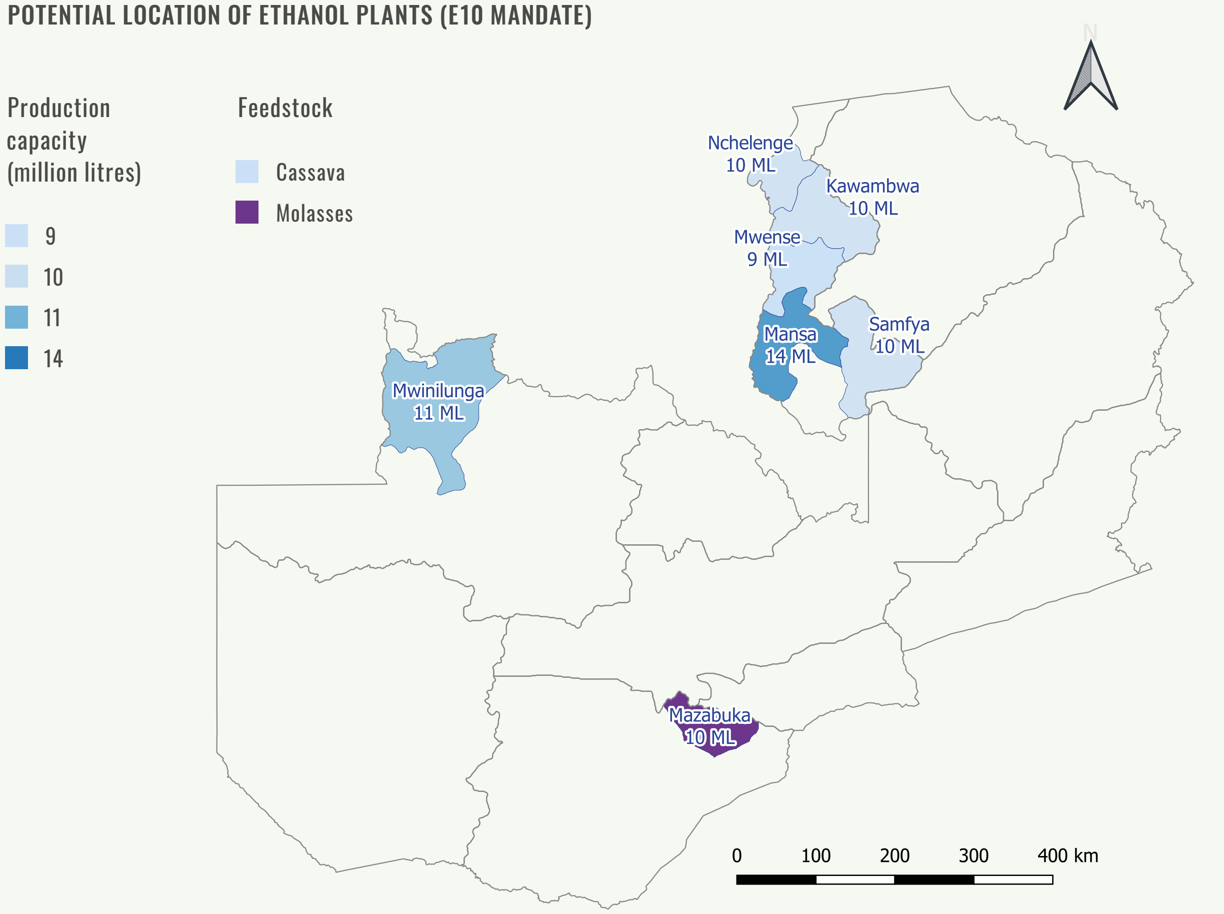
MINIMUM PROFITABLE PRODUCTION REQUIREMENTS

PARAMETER	SUGARCANE MOLASSES	CASSAVA
MIN. CAPACITY (million litres/year)	5	5
MIN FEEDSTOCK (tonnes/year)	13 281	27 728
MAX PAYABLE PRICE (USD/tonne)	NOT APPLY	100–120
MAIN REQUIREMENT	FULL INTEGRATION WITH SUGAR MILL	SELLING CASSAVA DDS

Source: Elaboration based on BEFS Assessment Results

FIGURE 136.

POTENTIAL LOCATION OF ETHANOL PLANTS (E10 MANDATE)



Source: Elaboration based on BEFS Assessment Results

Figure 136 shows the potential locations in Zambia where it might be possible to produce ethanol under the minimum required conditions. Indeed, seven possible locations for ethanol from cassava have been identified: Mansa, Mwinilunga, Nchelenge, Kawambwa, Samfya, Mungwi and Mbala districts, where ethanol factories ranging from 9.6 to 13.8 million litres/year could feasibly be built. Moreover, it can be assumed that in the Mazbuka district in particular, it might be possible to establish a molasses ethanol factory of 10 million litres/year. **Table 68** provides a summary of the locations, capacities, and potential investment needs, and furthermore shows how a combination of the ethanol factories could have a production capacity of 74 million litres/year. This type of production would require a USD 70 million investment.

TABLE 68.

SUMMARY OF POTENTIAL LOCATION FOR ETHANOL FACTORIES IN ZAMBIA

NO.	DISTRICT	ETHANOL CAPACITY (million litres/year)	FEEDSTOCK	CAPITAL INVESTMENT (million USD)
1	MANSA DISTRICT	13.8	CASSAVA	11.87
3	MWINILUNGA DISTRICT	10.9	CASSAVA	10.18
4	MAZABUKA	10.0	MOLASSES	20.89
5	NCHELENGE	10.4	CASSAVA	9.92
6	KAWAMBWA	9.8	CASSAVA	9.56
7	SAMFYA	9.7	CASSAVA	9.51
8	MBALA DISTRICT	9.6	CASSAVA	9.42

Source: Elaboration based on BEFS Assessment Results

4.6.5 Biodiesel analysis and results

The liquid biofuel assessment carried out for the biodiesel production option comprises two oilseed feedstock options: soybean and sunflower seeds. Zambia has a relatively modern oilseed milling sector including a variety of products such as vegetable oils (i.e. soybean oil, sunflower seeds oil, cottonseed oil), protein meal and cake. Oleochemical derivatives such as fatty acid oils and lecithin can also be obtained from soybean and other oils (McKee, 2019).

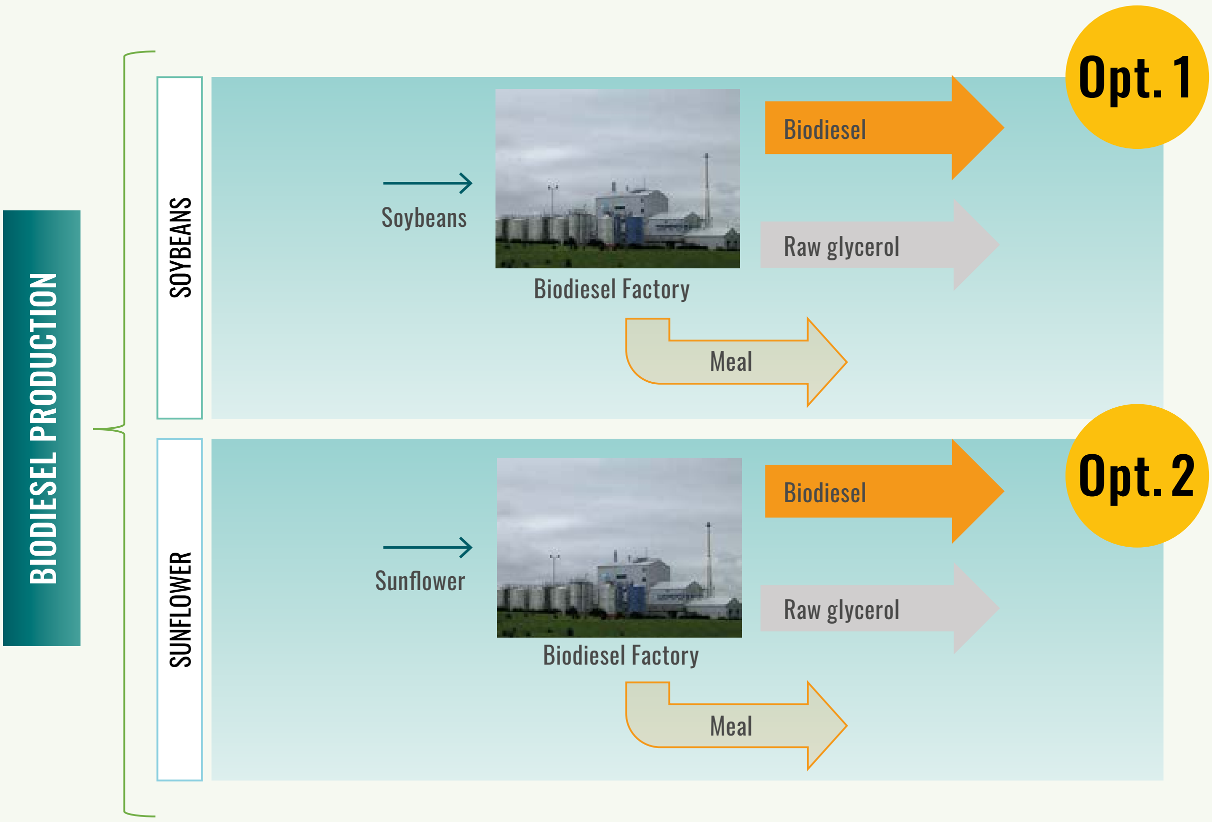
From a technical standpoint, this type of industrial development is an indicator of the country's capability to develop a biodiesel industry, given the fact that the essential processing components and the know-how is available there. The development of the oleochemical sector also implies that there are different markets for oilseed, which in fact might impact feedstock prices and as a result, biodiesel competitivity.

The liquid biofuel assessment was carried out on the production of biodiesel and the two main oilseed crops in Zambia: soybean and sunflower seeds seed were evaluated. The two options are shown in **Figure 137**.

In both options the biodiesel factory needs to take into account the investment costs for setting up the plant as well as the cost of producing biodiesel. The sources of income from the factory are defined by comparison prices for biodiesel and the potential sales of secondary products, raw glycerol and oilseed meal. The market prices of these products were collected in the country for the estimation of revenues.

FIGURE 137.

OPTIONS FOR THE PRODUCTION OF BIODIESEL IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

4.6.5.1 Biodiesel production from soybeans (option 1)

Soybean is the first type of feedstock being considered for biodiesel production in Zambia. The oil content in soybeans is approximately 37 to 63 percent and is used as a base for oleochemical feedstock for different products including food, detergents, paints and biodiesel.

Soybean seeds are rich in protein, mainly globulins (90 percent); after the oil extraction, heat treatment is usually needed to deactivate enzymes. This step is necessary to avoid the reduced digestibility of feedstock (Mailer, 2004).

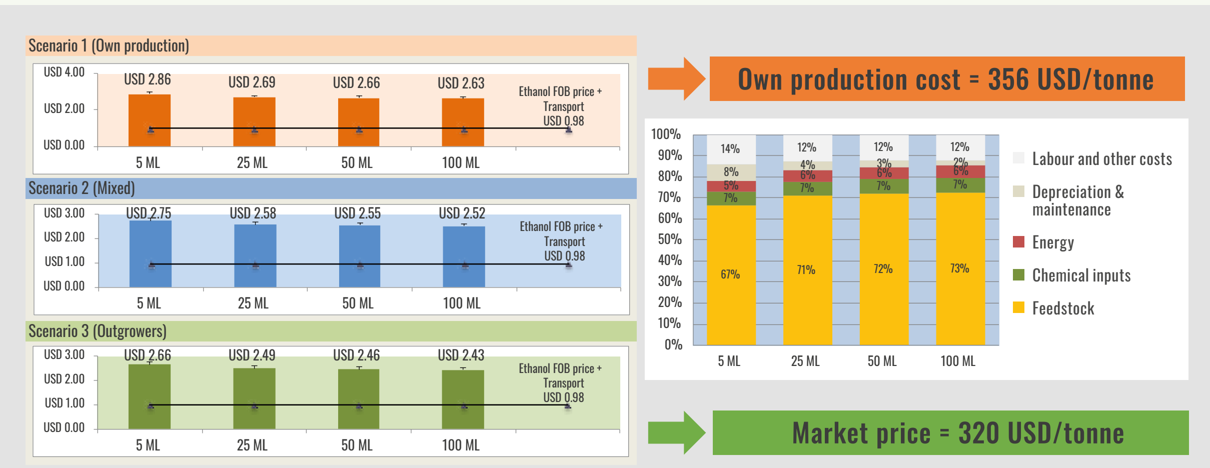
This option offers the opportunity for the factory to use soybeans collected directly in the field for biodiesel production. This process would operate in a similar way to the current vegetable oil refineries, by replacing the same stages with those dedicated to biodiesel production. Therefore, it would still be possible to obtain soybean meal as well as the main biodiesel product and raw glycerol by-product. Moreover, from an energy management standpoint, it is possible to valorise the soybean husk in a combined heat and power (CHP) system, thus covering the factory's demand for electricity and heat. Finally, the electricity surplus could be sold to the national grid.

The production costs for biodiesel from soybeans and for plant capacities ranging from 5 to 100 million litres/year are presented in **Figure 138**. The biodiesel comparison prices include import costs while results that have been considered in previous sections are presented in the three procurement scenarios. **Figure 138** shows the results before having discounted the credits obtained from selling by-products. For all of the procurement scenarios the production costs completely off-set the comparison prices with values ranging from 2.43 to 2.85 USD/litre of biodiesel.

Due to the fact that biodiesel production is similar to ethanol production, the possibility of using by-products as additional income streams for the biodiesel factory was also considered. Their effect was measured by discounting the by-product credits obtained from selling soybean meal, raw glycerol, and electricity to subsequently be applied to the production costs (see **Figure 139**). Additional capital investments from CHP systems and discounts from self-supplying energy were also taken into account. Overall, it is possible to obtain discounts of 0.41 USD/litre for biodiesel from soybean meal and raw glycerol sales and 0.25 USD/litre for biodiesel from electricity sales.

FIGURE 138.

BIODIESEL PRODUCTION COST FROM SOYBEAN (USD/LITRE BIODIESEL) BEFORE DISCOUNTING BY-PRODUCT CREDITS



Source: Elaboration based on BEFS Assessment Results

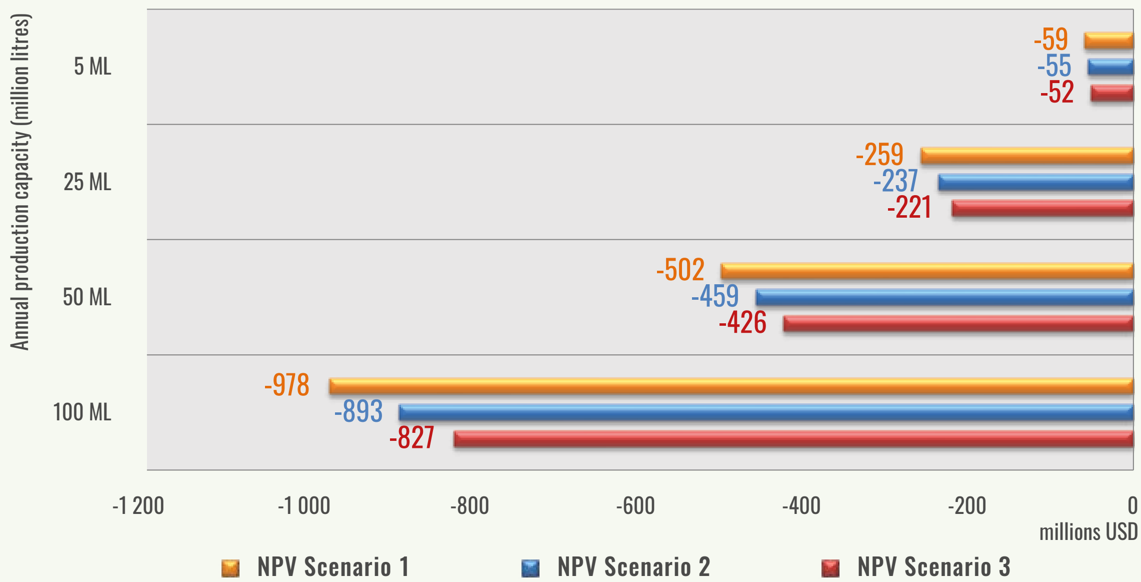
FIGURE 139.

BIODIESEL PRODUCTION COST FROM SOYBEAN (USD/LITRE BIODIESEL) (UP) AND CAPITAL INVESTMENT COSTS (DOWN) BEFORE AND AFTER DISCOUNTING BY-PRODUCT CREDITS

Source: Elaboration based on BEFS Assessment Results

FIGURE 140.

PROFITABILITY OF ETHANOL FACTORIES FROM SOYBEANS (NPV, MILLION USD)



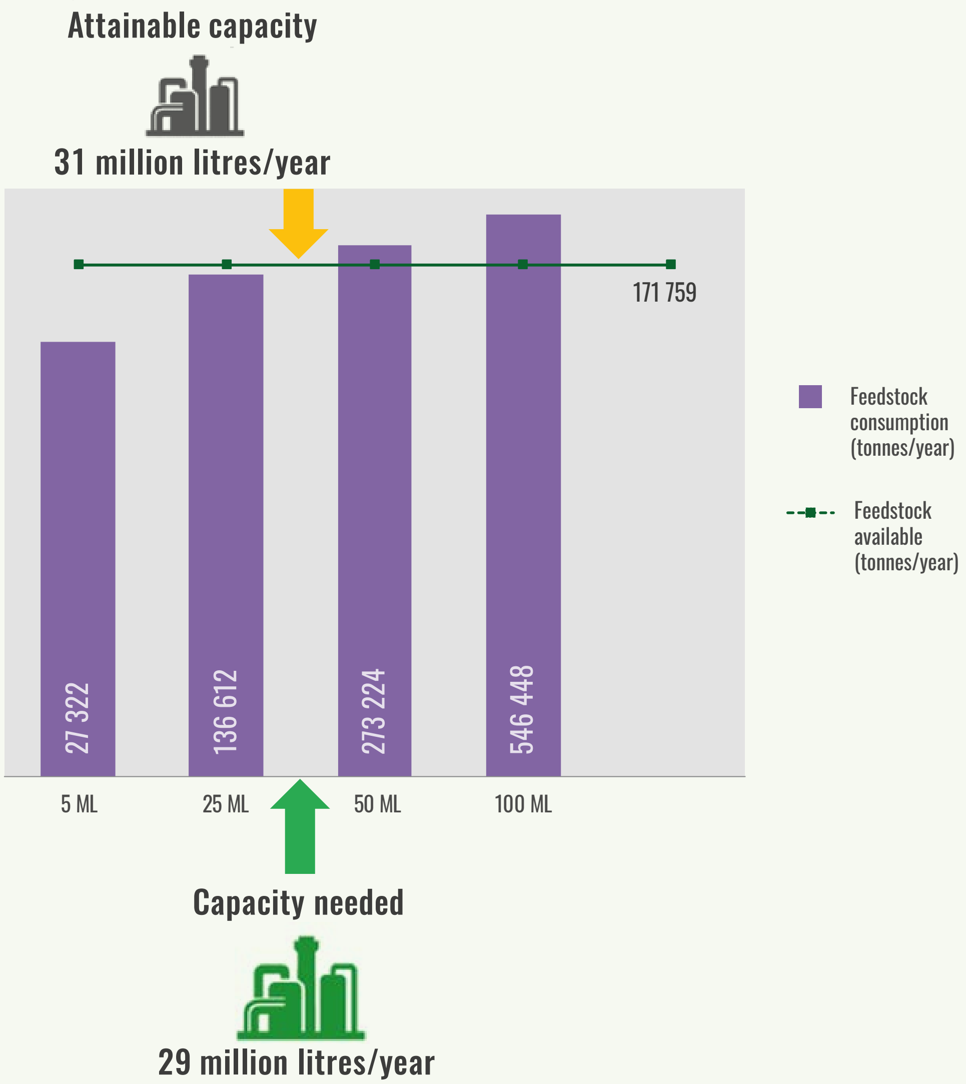
Source: Elaboration based on BEFS Assessment Results

As a result, the production costs of an average 28 percent can also be reduced; nevertheless, production costs for all scenarios are still higher than the comparative biodiesel price. In the end, the profitability was not positive in any of the cases, as shown in **Figure 140**.

In all case scenarios the reason for the high production costs obtained can be directly explained by the influence of the soybean price on the total production costs (68 to 74 percent). The price of soybean ranges from 320 to 356 USD/tonne, moreover, production costs for farmers were higher than the market price. These values are indicative of the severe price volatility in the soybean sector in Zambia, particularly between 2017 to 2018 where farmgate soybean prices fell from over 400 USD/tonne to below 150 USD/tonne, due to overproduction and the lack of easily accessible export markets (McKee, 2019). Furthermore, during the the 10 year period from 2010 to 2020 international prices fluctuated from between 200 and 400 USD/tonne (OECD-FAO, 2019).

FIGURE 141.

ATTAINABLE AND REQUIRED PRODUCTION OF BIODIESEL FOR A B5 MANDATE – SOYBEANS



Source: Elaboration based on BEFS Assessment Results

The next step is to take the feedstock availability factor into consideration. The soybean potentially available for biodiesel production estimated in the BEFS crop assessment was 171 759 tonnes/year. This quantity would be enough to produce 31 million litres/year of biodiesel. The biodiesel needed to satisfy the B5 blending mandate is 29 million litres/year, therefore the biodiesel that could be produced would satisfy 108 percent of the target demand (see **Figure 141**).

Zambia would initially be able to produce enough soybean to supply the required target biodiesel production. However, the economic results show that soybeans are in fact too valuable to be used for biodiesel production. The high market prices for these seeds and the current alternative uses imply that soybean should not be considered as feedstock by the biodiesel industries. An additional sensitivity analysis performed for this case proved that in order to produce biodiesel at a cost lower than 0.98 USD/litre biodiesel, the maximum payable price for soybeans would be 50 USD/tonne. In Zambia, this is just one-fourth of the minimum international price for soybean from 2010 to 2020 and one-half of the minimum price historically (OECD-FAO, 2019).

4.6.5.2 Biodiesel production from sunflower seeds seeds (option 2)

Sunflower seed was the second option considered for biodiesel production in Zambia. This oilseed is a good choice for biodiesel production due to its high oil content, which is usually more than 40 percent, and the comparative simplicity of oil extraction (Abitogun *et al.*, 2010; Demirbas, 2003).

Development of the sunflower seeds oleochemical industry in Zambia has been limited, mainly due to the status of sunflower as a rotation crop, mostly grown together with other staple crops such as maize and groundnut. The industries dedicated to sunflower seeds oil extraction are small associations where the main target has been to produce sunflower seeds oil for self-consumption (Farmbiz Africa, 2019; Feed the future, 2019). Consequently, it is evident that the industrialization level of sunflower seed derivatives in Zambia is low.

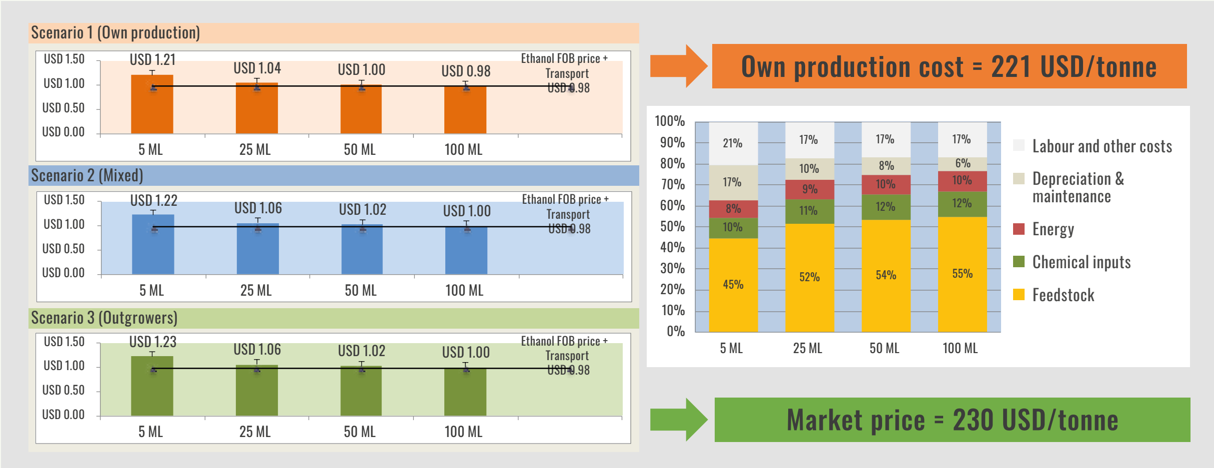
Biodiesel production from sunflower seeds is however a well-known process that usually uses high linoleic oil varieties. It is indeed similar to biodiesel production from soybean, thus making it possible to obtain by-products namely sunflower seeds meal and raw glycerol. However, the quantities of sunflower seeds husk produced are not enough to supply the amounts required by a CHP system. Therefore, this alternative will not be included in the assessment.

Figure 142 presents the costs of producing biodiesel from sunflower seeds for the three procurement scenarios considered in BEFS assessment before discounting by-products. On the whole, the production cost ranges from 0.98 to 1.22 USD/litre for biodiesel due to the proximity between market and production costs. The results obtained for own produced and outgrower scenarios are similar, as should be expected, due to the low level of development existing in Zambia's sunflower seeds production industry.

Furthermore, it is also important to note that production costs versus the cost of imported biodiesel are not competitive. A more detailed analysis of the production costs shows that the feedstock represents between 44 and 51 percent of the production cost of biodiesel. This is an indication that the market price and production cost of sunflower seeds are high and

FIGURE 142.

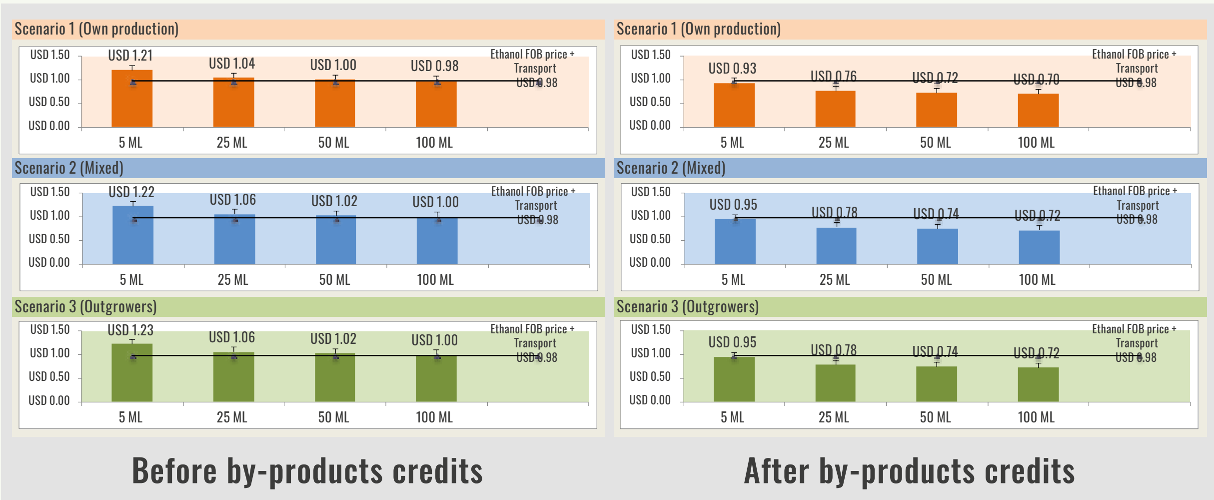
BIODIESEL PRODUCTION COST FROM SUNFLOWER SEEDS (USD/LITRE BIODIESEL) BEFORE DISCOUNTING BY-PRODUCT CREDITS



Source: *Elaboration based on BEFS Assessment Results*

FIGURE 143.

BIODIESEL PRODUCTION COST FROM SUNFLOWER SEEDS (USD/LITRE BIODIESEL) AFTER DISCOUNTING BY-PRODUCT CREDITS



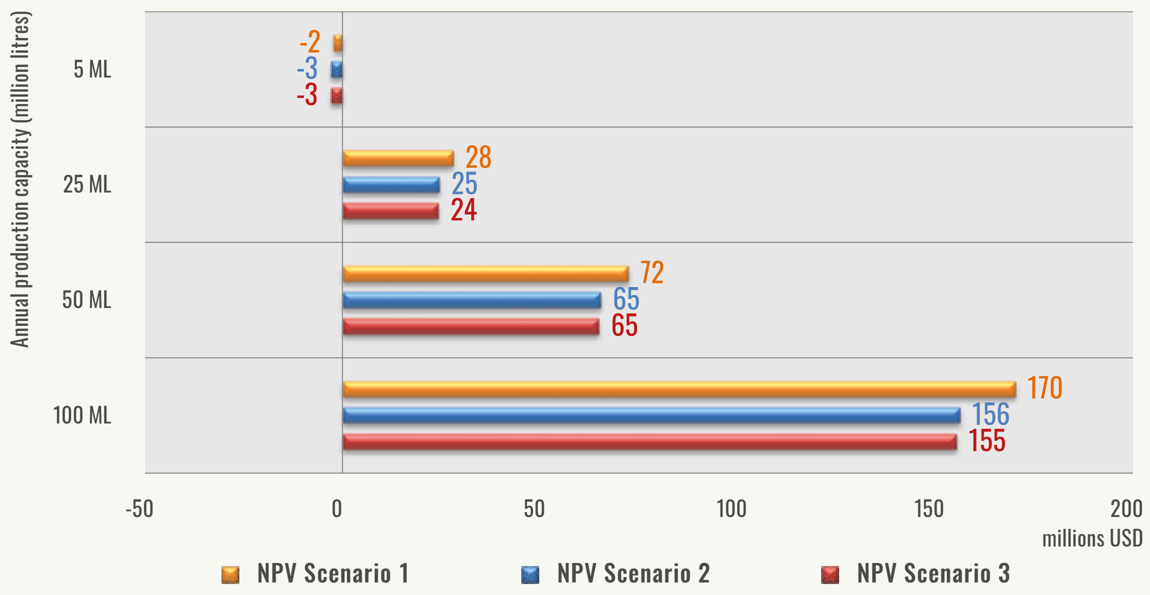
Source: *Elaboration based on BEFS Assessment Results*

that additional profits from by-products would be needed.

Figure 143 shows the production cost after applying the discounts obtained from selling by-products such as sunflower seeds meal and raw glycerol, therefore it may be possible to apply an average discount of 0.28 USD/litre of biodiesel. No additional investment would be required for obtaining the by-products and consequently, the overall profit would not be impacted. Ultimately there would be profits, particularly for factories producing more than 25 million litres biodiesel/year, as shown in **Figure 144**.

FIGURE 144.

PROFITABILITY OF ETHANOL FACTORIES FROM SUNFLOWER SEEDS (NPV, MILLION USD)



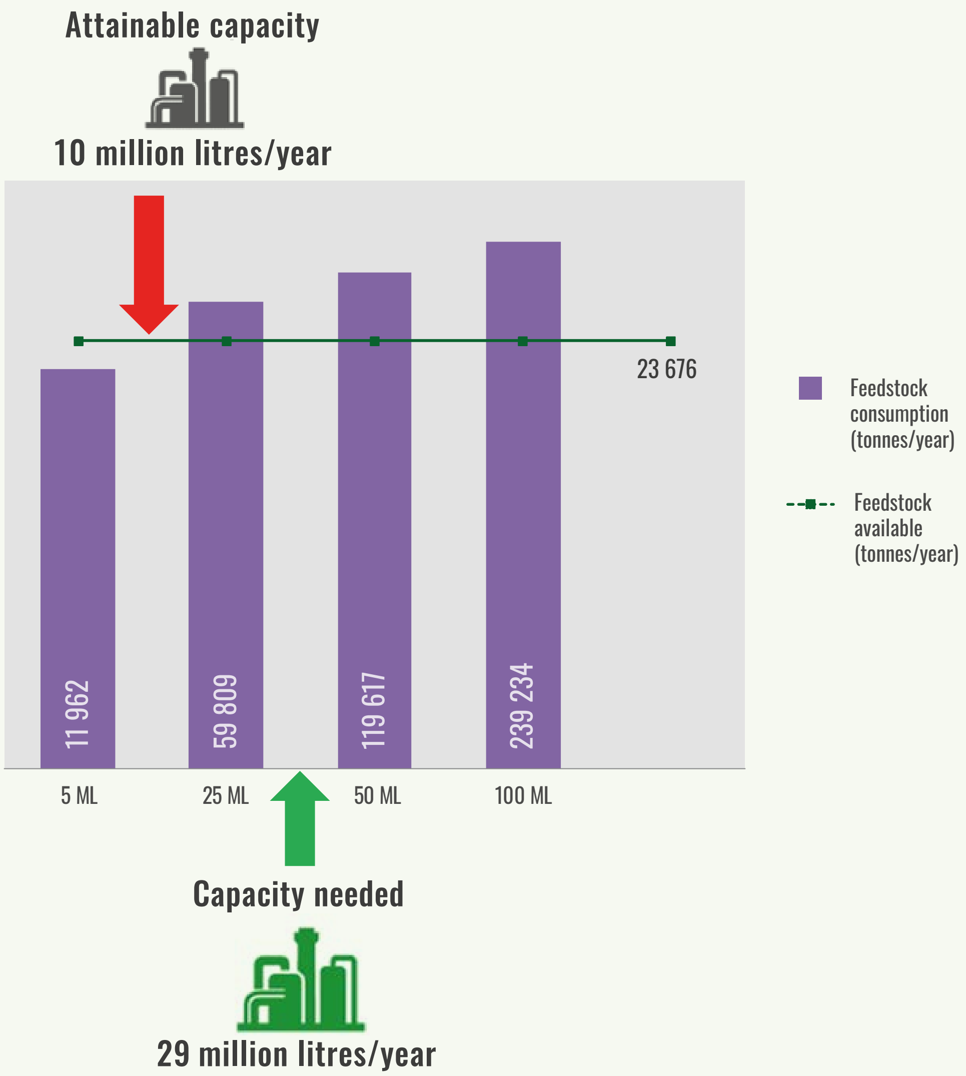
Source: Elaboration based on BEFS Assessment Results

The next step is to examine the feedstock availability factor. The amount of sunflower seeds potentially available for biodiesel production was estimated by the BEFS crop assessment as 23 676 tonnes/year. This quantity would be enough to produce 10 million litres/year of biodiesel. A comparison with the biodiesel needed to satisfy a B5 blending mandate (i.e. 29 million litres/year) demonstrates that it could be feasible to supply 34 percent of this target demand (see **Figure 145**).

In sum, from a profitability standpoint sunflower seeds biodiesel production would be a possibility, in particular for factories larger than 25 million litres, however the sustainable quantities available would not be enough to supply a factory of this size.

FIGURE 145.

ATTAINABLE AND REQUIRED PRODUCTION OF BIODIESEL FOR A B5 MANDATE – SUNFLOWER SEEDS



Source: Elaboration based on BEFS Assessment Results

4.6.5.3 Biodiesel production options for Zambia

Finally, the main techno-economic results obtained for biodiesel production in Zambia have been summarized. **Table 69** shows a comparison of the potential of the two types of feedstock that meet the Zambian B5 mandate. Based on its ability to meet the B5 mandate, soybean would be the best feedstock option due to its greater availability and potential production capacity.

The performance of the two-feedstock options, while making the assumption that there is an adequate feedstock supply to produce the biodiesel required by the B5 mandate, is analysed in this next step. **Table 70** presents a selection of techno-economic results for the same comparison based on a 29 million litres/year capacity (target production under the B5 mandate).

From a technical point of view, biodiesel production from soybean would be easier because the soybean sector in the country has already been developed and soybean produces higher yields than sunflower seeds.

TABLE 69.

PERFORMANCE COMPARISON FOR ETHANOL FEEDSTOCK CANDIDATES

	SOYBEANS	SUNFLOWER SEEDS
QUANTITY AVAILABLE (tonnes/year)	171 759	23 676
PERCENTAGE OF E10 MANDATE SUPPLIED	108%	34%
SHARE SUPPLIED BY OUTGROWERS	56%	94%
MAX BIODIESEL CAPACITY (million litres/year)	31	10
CO-PRODUCT	SOYBEAN MEAL RAW GLYCEROL ELECTRICITY	SUNFLOWER MEAL RAW GLYCEROL

Source: Elaboration based on BEFS Assessment Results

TABLE 70.

TECHNO-ECONOMIC COMPARISON FOR A 29 MILLION LITRES/YEAR BIODIESEL PRODUCTION

	SOYBEANS	SUNFLOWER SEEDS
FEEDSTOCK NEEDED (tonnes/year)	158 470	69 378
AREA NEEDED (ha)	52 965	55 851
NUMBER OF FARMS SUPPLYING	95 000	118 738
INVESTMENT NEEDED	32	**23**
EXPECTED NPV (million USD)	0	10

Source: Elaboration based on BEFS Assessment Results

However, in previous sections it has been proven that soybeans are too costly to be used for biodiesel production, therefore sunflower seeds would be a safer investment. Considering the number of farms needed to supply 29 million litres/year of biodiesel, both options would require at least 50 000 farms. Similar to the cassava case scenario, the establishment of supply chains to coordinate such a high number of farms could be challenging.

Based on the above results, sunflower seeds would be the only profitable option. **Table 71** presents the minimum profitable production conditions based on the BEFS assessment. The low availability of sunflower seeds will be further discussed.

The minimum quantity needed to supply the mininum profitable capacity almost duplicate the 23 thousand tonnes predicted as potentially available for sunflower seeds biodiesel production. Therefore, Zambia would not be able to produce enough sunflower seeds to supply a profitable biodiesel industry. This statement is also supported by **Figure 146** where the maximum biodiesel production capacities achievable in the top sunflower seeds producing districts is presented.

In the best case scenario, it might be possible to establish three production hubs with a maximum production capacity of 5.8 million litres/year. However, the collection distances might reach 200 km, which is not advisable as a procurement area for biofuel industries. In sum, in none of the cases would it be possible to produce the minimum 25 million litres/year of biodiesel; furthermore, it might be more difficult logistically to supply smaller quantities of sunflower seeds for processing.

TABLE 71.

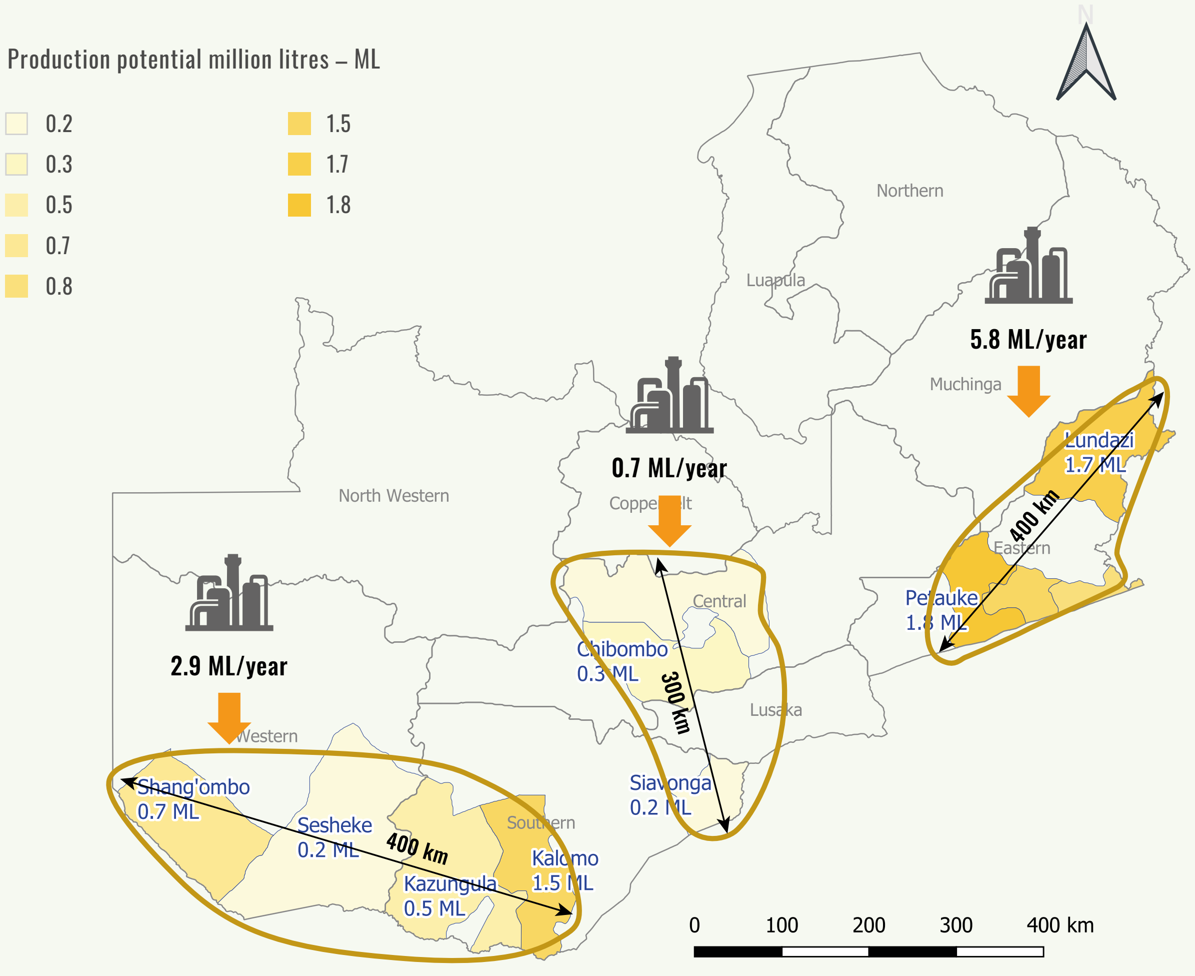
MINIMUM PROFITABLE PRODUCTION REQUIREMENTS

PARAMETER	SUNFLOWER
MIN. CAPACITY (million litres/year)	25
MIN FEEDSTOCK (tonnes/year)	59 809
MAX PAYABLE PRICE (USD/tonne)	<228
MAIN REQUIREMENT	SELLING SUNFLOWER SEEDS MEAL AND RAW GLYCEROL

Source: Elaboration based on BEFS Assessment Results

FIGURE 146.

DISTRIBUTION OF THE MAXIMUM POTENTIAL PRODUCTION IN ZAMBIA



Source: Elaboration based on BEFS Assessment Results

4.6.6 Summary of results

Overall, the results obtained for ethanol production indicate that there is enough cassava and sugarcane molasses would provide a sustainable supply for the E10 mandate. Cassava in particular might be the long-term alternative for the ethanol industry in Zambia. Nevertheless, the supply chain to collect and mobilise the massive amounts of cassava still need further development. Alternatively, a comparatively low investment is needed to produce ethanol from molasses. In the short term, this situation might facilitate local ethanol production and if molasses from other non-feed markets were to be diverted to ethanol production, quantities produced and profit for sugar mills could increase. The best potential locations for ethanol factories would be Mwinlunga, Nchelenge, Kawambwa, Mansa, Samfya, Mungwi and Mbala districts. Moreover, in Mazabuka it might also be possible for sugar-mills to build an ethanol factory to further add value the production of molasses. The combination of ethanol factories in these locatin could reach production capacity of 74 million litres/year requiring USD 70 million capital investment.

For biodiesel production, the soybean option would be able to supply the target capacity needed for a B5 mandate. On the other hand, the high market prices for soybean and its current alternative uses imply that biodiesel industries would not consider using soybean as a feedstock.

From an economic standpoint, sunflower is a good alternative to soybean. Furthermore, the biodiesel industry would enhance the added value of sunflower seeds in Zambia, giving it an alternative market. Nevertheless, intensified sunflower seeds production might not be enough to supply a B5 blending mandate. In the best-case scenario, the establishment of three production hubs might be possible where the maximum production capacity would be 5.8 million litres/year, with a combined capacity of around 10 million litres/year. However, the collection distances could reach 200 km, which would not be advisable as a procurement area for biofuel industries. In sum, neither soybean biodiesel or sunflower seeds biodiesel would be able to produce the biodiesel required by the B5 mandate.

During the development of a Zambian liquid biofuel industry investment requirements may also be a deciding factor, not only in terms of the factories' construction but also in terms of the blending infrastructure. All of these constraints should be considered throughout the initial development, deployment and future expansion of national blending mandates.

CHAPTER

5

OVERALL CONCLUSIONS

COOKING FUELS AND ELECTRICITY OPTIONS

Crop residues

Crop residues are found both at field and processing level. A total of more than 8 million tonnes of crop residues (71 percent maize, 6.8 percent cassava, 6 percent cotton) are generated per year across the country.

The seven districts of Mkushi, Kapiri-Mposhi and Chibombo in the Central Province, Chipata, Lundazi and Petauke in the Eastern Province, and Mpongwe in the Copperbelt Province are found to have the highest amounts of residues potentially available for further use. To the extent possible, a survey of food processing facilities was carried out. The results obtained showed that the amount of residues generated and available is overall much smaller than the residues generated at field level. Within rice mills, 11 000 tonnes of rice husks generated each year are not used.

Livestock residues

Cattle were found to offer the highest potential in terms of available manure, followed by pigs, chicken and goats. At country level, a total of 2 504 901 tonnes of cattle manure could potentially be available for use, with the highest concentrations found in Mumbwa and Chibombo districts in the Central Province and Kalomo district in the Southern Province. A total of 572 532 tonnes of pig manure per year was estimated to be available, with the highest potential found in Kafue district in the Lusaka Province, and Katete, Petauke and Chipata

districts in the Eastern Province. In the case of chicken manure, commercial producers of layer chickens could supply 34 643 tonnes of manure per year at national level, with the highest potential in Lusaka Province, the Central Province and Copperbelt Province. There is also some potential from commercial goat farms, that would result in a total of 18 718 tonnes of manure, concentrated in Chibombo, Mumbwa and Kapiri Mposhi districts in the Central Province.

Woody residues

Just under 60 000 tonnes of residues are found to be generated during harvesting of forest plantations and could be available for further use such as the production of bioenergy. This is a relatively small amount when compared to the total energy demand for cooking and electricity at national level. However, using these residues to produce modern cooking fuels or improved charcoal could, at the local level, reduce the demand for freshly cut wood.

ELECTRICITY FROM GASIFICATION AND COMBUSTION

Two biomass-based technologies were considered in the analysis, namely gasification and combustion. The analysis found that there is significant potential to generate electricity through biomass gasification and combustion in Zambia, considering the quantities of crop residues estimated as available for bioenergy or other use. A total capacity of 1 192 MWel could be supplied across the country. Gasification technology would contribute to 57 percent of the total electricity production capacity, with the remaining share coming from combustion. To deploy this potential, It was estimated that at national level the average capital investment needs for gasification to electricity technologies would be 791 USD/kW, and 1 015 USD/kW for combustion options. In terms of feedstock, the main crop residues for gasification and combustion would be maize stover, maize cob, cotton stalk and cassava stalk. Provinces with the highest potential to produce electricity were the Eastern Province and Central Province. The Eastern province could potentially supply a total generation capacity of 255 MW and the Central Province of 229 MW, followed by the Southern, Nothern and Muchinga Provinces which could each supply potential generation capacities between 110 and 120MW. The Western, Central, Copperbelt and Luapula Provinces would supply generation capacities between 45 and 95 MW per province.

Considerable upfront investment is required to deploy biomass-based gasification and combustion technologies for the generation of electricity The extension of central grid lines to rural and off-grid areas require high capital investment. Therefore, the final decision on the best alternative to promote will depend on which option is more cost-competitive, and where policy interventions can be more effective. The analysis shows which options could be more affordable.

COOKING FUELS

Biomass and charcoal briquettes, and domestic biogas were assessed as possible bioenergy technologies to substitute current cooking fuels. Improved charcoal technologies were considered as options to reduce fuelwood consumption as well as the pressure on natural forests.

Briquettes

Briquette production using feedstock options with high energy potential and hot pressing technology are found to be profitable. The potential contribution to the clean energy cooking target could be as high as 23 percent, but the need to acquire new stoves would represent a market barrier. Charcoal briquettes would avoid the need to acquire new stoves, while replacing some of the current use of wood based charcoal. In the case of charcoal briquettes, the number of suitable feedstock types is smaller and the potential contribution to clean energy for

cooking targets is reduced to 7 percent. Thus, the most promising feedstock options for biomass briquettes production are maize stover, maize cob, cotton stalk, soybean straw and cassava stalk. As for the production of charcoal briquettes, wheat straw could also be a potential option. In terms of procurement, the Central Province has the greatest potential to supply feedstock from large-scale producers and the Eastern Province could supply feedstock from small-scale producers. These differences will need to be taken into consideration when developing the residue supply chain as well as the procurement of feedstock.

Biogas

The analysis shows that the most cost-effective biogas technology, considering the cost of construction and access to raw materials, would be the fixed dome model. In the case of chicken, the minimum profitable size would be 4 m^3 which required around 200 chicken. In the case of pigs, the minimum profitable size would be 12 m^3 which requires 47 pigs. In the case of cattle, the minum profitable size would be 4 m^3 which would require 7 cattle. Given the number of chicken and pigs required, only commercial farms would have sufficient amount of manure to operate the digesters. In the case of households, community digesters could be an option with more than one household supplying the digesters. Cattle based biogas production could be an option at household level in certain parts of the country, while still more feasible for dairy farms where cattle is kept in stables or where daily grazing is practised. A way to improve biogas production potential, is to use both manure and suitable crop residues (sorghum stalk, maize stover, sunflower stalk, cotton stalk and rice straw) as feedstock in a co-digestion system. Nevertheless, if the crop residues were to be used for this, the feedstock would not be available for other energy options. The analysis identified different possible combinations to be used across different districts for optimal co-digestion. Regarding the contribution to national renewable energy targets, cattle manure alone could contribute three percent to Zambia's national targets for clean energy for cooking. Once locally available sources of crop residue have been taken into account, this contribution could increase to six percent.

COMBINED ENERGY POTENTIAL

In conclusion, the assessment shows that due to the differences in feedstock availability, briquetting technologies (both biomass and charcoal options) would be a more cost-effective bioenergy option than biogas in Zambia. The total potential energy from alternative cooking fuels could reach 15 797 TJ/year, distributed as follows: 47 percent from charcoal briquettes, 39 percent from biomass briquettes, and 14 percent from biogas. This would be equivalent to a contribution of 14 percent to the country's clean cooking target. In most parts of the country, charcoal briquettes would result in the most cost-effective option, particularly in the Eastern Province. The second province with high potential is the Central Province where both biomass briquettes and charcoal briquettes would be equally effective. However, in the Southern Province biogas would be the most cost-effective option. To deploy this potential, at a national level, it was estimated that an average capital investment needs of 18.95 USD/tonnes/year for biomass briquettes, 20.33 USD/tonnes/year for charcoal briquettes and 0.62 USD/m^3/year for biogas produced using fixed dome digesters.

Improved charcoal technologies

The deployment of improved technologies could increase the efficiency of the conversion of wood to charcoal, increase the income of charcoal producers, and supply users with a higher quality product. Based on the analysis and on the in-country consultations, it was concluded that the most suitable charcoal technology could be the Liberia pit technology or a similar technology with an efficiency of 30 percent. By doubling the conversion efficiency, introducing this improved technology could potentially result in an overall saving of 17 million m^3 of wood compared to

traditional charcoal production. The provinces where the most savings could be made are the Central Province, followed by Lusaka Province and the Northern Province.

TRANSPORT

Crops

Considering current production and consumption trends, only four crops were identified as suitable feedstock for ethanol and biodiesel production. These were sugarcane and cassava for ethanol, and soybean and sunflower seed for biodiesel. The analysis started by looking at intensification options as a strategy to source additional feedstock for the production of liquid biofuels. This first approach aimed to minimize possible impacts on land use and the types of crop grown. Regarding sugarcane, an additional 1 130 tonnes per year could be produced. This amount would have to be sourced from smallholder farmers who have the potential to increase yields. Commercial farming already produces very high yields leaving no room for a further increase. Molasses, one of the by-products of sugar production, could also be a possible ethanol feedstock. Nevertheless, currently molasses is already used for feed, export, etc. As a result only a small share (possibly up to 20 percent) could be available for ethanol production.

Cassava presents more opportunities for intensification. An additional 1.1 million tonnes of cassava could be produced annually. The highest potential for the additional production of cassava was found in Samfya, Kawambwa and Nchelenge and Mansa districts in Luapula Province; Mungwi district in the Northern Province; and Mwinilunga district in the North-Western Province. Each of these districts could produce over 60 000 additional tonnes of cassava per year.

An additional 172 000 tonnes of soybean could be produced through yield intensification per year. The districts with the greatest potential to increase yields are Mkushi and Chibombo in the Central Province, and Lundazi in the Eastern Province. These three districts could jointly produce an additional 15 thousand tonnes per year. In the Central Province, production is almost equally divided between large-scale farms and small and medium-scale farms, while in the Eastern Province almost all potential for additional production lies with small and medium-scale farms.

In the case of sunflower seed, an additional 23 700 tonnes could be produced annually at national level through yield intensification. The districts with the highest potential for additional production are Lundazi, Petauke and Katete in the Eastern Province, and Kalomo in the Southern Province. Each of these districts could reach an additional production of over 3 thousand tonnes per year. Most of this would be from smallholders.

Ethanol

The amount of ethanol required to meet the E10 blending mandate would be 72 million litres per year. The analysis shows that only the cassava and molasses-based ethanol could be profitable. A total of 10 to 29 million litres per year could be produced from molasses in Mazabuka district. The rest of the ethanol would be produced from cassava, which has the largest potential for increased yields. Districts with the highest potential include Mansa that could produce 14 milion litres per year and Mungwi and Mwinilunga which could produce 11 million litres per year. The combined achievable potential could reach 74 million litres per year (10 million litres from molasses and the rest from cassava) and would require an USD 70 million investment. When considering cassava, the supply chain to collect and mobilise the massive amounts of feedstock required still need further development.

Biodiesel

The amount of biodiesel (i.e. 25 million litres per year) required for the B5 mandate cannot be produced profitably in Zambia. Soybean based biodiesel was found not to be viable. A limited amount could be produced from sunflower reaching a total of 9.3 million litres. The potential biodiesel production would be spread across the

provinces in the south of the country ranging from 0.2 million litres per district to 1.8 million litres per district. In the best case scenario, it might be possible to establish three production hubs with a maximum production capacity of 5.8 million litres per year. However, the collection distances might reach 200 km, which is not advisable as a procurement area for biofuel industries. Nevertheless, even if all the above-mentioned potential were to be combined, it still would not be possible to reach the target production of 25 million litres of biodiesel per year. In sum, no combination of biodiesel from soybean or sunflower seeds would allow to reach the B5 bleanding mandate. Production could possibly at best reach a B2 production level.

CONCLUDING REMARKS

The analysis of selected bioenergy supply chains in Zambia has shown which options could potentially be viable and profitable. The next step would be to carry out detailed district level 'ground truthing' and conduct feasibility studies at local level to verify the findings. Feasibility studies and deploying pilot plants could be a starting point.

The enabling of feedstock supply chains would need close attention. Investments will be required to support all elements of the feedstock supply chain to ensure a supply to the bioenergy plant, the creation of jobs and an improvement in farmers' livelihoods.

Investment requirements may also be a deciding factor in the development of a Zambian liquid biofuel industry, not only in terms of the factories' construction but also in terms of the blending infrastructure. All of these constraints should be considered during the initial development, deployment and future expansion of national blending mandates.

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ANNEX 1

LIVESTOCK RESIDUES RESULTS AT A DISTRICT LEVEL

TABLE A1

AVAILABLE MANURE AT A DISTRICT LEVEL ACCORDING TO TYPE OF LIVESTOCK: CATTLE, PIGS AND GOATS

PROVINCE	DISTRICT	HOUSEHOLD CATTLE MANURE	COMMERCIAL CATTLE MANURE	COMMERCIAL GOATS MANURE	COMMERCIAL PIG MANURE	HOUSEHOLD PIG MANURE
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
CENTRAL	CHIBOMBO	148 326	27 650	2 736	2 667	18 203
	KABWE	8 949	1 668	152	124	847
	KAPIRI MPOSHI	135 251	25 212	1 704	1 312	8 954
	MKUSHI	25 163	4 691	417	758	5 174
	MUMBWA	165 057	30 768	1 782	1 314	8 967
	SERENJE	2 762	515	577	891	6 085
	SUBTOTAL	**485 508**	**90 504**	**7 368**	**7 066**	**48 230**
COPPERBELT	CHILILABOMBWE	0	0	24	18	223
	CHINGOLA	3 033	1 151	151	138	1 693
	KALULUSHI	6 185	2 347	125	1 016	12 485
	KITWE	262	99	19	266	3 265
	LUANSHYA	1 991	755	86	365	4 479
	LUFWANYAMA	8 006	3 038	558	1 131	13 894
	MASAITI	4 194	1 591	343	443	5 446
	MPONGWE	24 864	9 435	589	951	11 687
	MUFULIRA	0	0	34	68	835
	NDOLA	192	73	12	91	1 115
	SUBTOTAL	**48 726**	**18 490**	**1 940**	**4 488**	**55 121**
EASTERN	CHADIZA	31 414	378	105	32	11 516
	CHIPATA	109 313	1 316	316	90	32 110
	KATETE	83 932	1 010	165	124	44 356
	LUNDAZI	52 465	632	147	40	14 123
	MAMBWE	3 588	43	23	9	3 250
	NYIMBA	14 650	176	103	17	6 163
	PETAUKE	94 528	1 138	250	131	46 769
	SUBTOTAL	**389 889**	**4 693**	**1 109**	**443**	**158 287**

PROVINCE	DISTRICT	HOUSEHOLD CATTLE MANURE	COMMERCIAL CATTLE MANURE	COMMERCIAL GOATS MANURE	COMMERCIAL PIG MANURE	HOUSEHOLD PIG MANURE
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
LUAPULA	CHIENGI	0	0	21	0	0
	KAWAMBWA	1 263	282	55	12	645
	MANSA	2 005	447	42	82	4 217
	MILENGE	0	0	13	24	1 223
	MWENSE	1 106	247	48	36	1 839
	NCHELENGE	0	0	44	24	1 230
	SAMFYA	2 671	596	63	32	1 639
	SUBTOTAL	**7 044**	**1 571**	**286**	**209**	**10 792**
LUSAKA	CHONGWE	47 118	12 113	1 016	3 947	7 070
	KAFUE	48 257	12 406	894	15 386	27 560
	LUANGWA	936	241	264	192	343
	LUSAKA	43	11	3	18	33
	SUBTOTAL	**96 354**	**24 770**	**2 178**	**19 543**	**35 006**
MUCHINGA	CHAMA	0	0	18	95	7 662
	CHINSALI	9 928	609	100	109	8 850
	ISOKA	8 609	528	40	77	6 199
	MAFINGA	18 439	1 131	85	35	2 820
	MPIKA	4 333	266	71	84	6 823
	NAKONDE	12 118	743	67	27	2 208
	SUBTOTAL	**53 428**	**3 278**	**381**	**427**	**34 563**
NORTHERN	CHILUBI	147	3	15	1	63
	KAPUTA	0	0	7	3	362
	KASAMA	2 353	51	11	30	3 271
	LUWINGU	1 424	31	27	29	3 164
	MBALA	17 677	383	47	53	5 680
	MPOROKOSO	1 722	37	17	28	3 049
	MPULUNGU	36	1	7	9	962
	MUNGWI	7 877	171	20	101	10 831
	SUBTOTAL	**31 236**	**678**	**151**	**255**	**27 383**
NORTH WESTERN	CHAVUMA	2 489	125	13	4	805
	IKELENGE	629	32	15	4	748
	KABOMPO	12 946	651	71	11	2 238
	KASEMPA	379	19	56	38	7 540
	MUFUMBWE	4 397	221	54	7	1 362
	MWINILUNGA	12 229	615	64	15	2 946
	SOLWEZI	4 033	203	131	39	7 690
	ZAMBEZI	25 244	1 270	27	19	3 791
	SUBTOTAL	**62 343**	**3 135**	**429**	**137**	**27 120**

PROVINCE	DISTRICT	HOUSEHOLD CATTLE MANURE	COMMERCIAL CATTLE MANURE	COMMERCIAL GOATS MANURE	COMMERCIAL PIG MANURE	HOUSEHOLD PIG MANURE
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
SOUTHERN	CHOMA	78 559	8 707	848	409	8 333
	GWEMBE	24 146	2 676	157	162	3 298
	ITEZHI-TEZHI	117 285	13 000	266	172	3 497
	KALOMO	154 840	17 162	1 230	961	19 566
	KAZUNGULA	63 932	7 086	187	426	8 666
	LIVINGSTONE	770	85	14	2	37
	MAZABUKA	59 829	6 631	418	780	15 880
	MONZE	127 555	14 138	687	719	14 638
	NAMWALA	111 297	12 336	236	502	10 224
	SIAVONGA	18 974	2 103	375	158	3 220
	SINAZONGWE	42 700	4 733	318	182	3 704
	SUBTOTAL	**799 886**	**88 658**	**4 736**	**4 471**	**91 065**
WESTERN	KALABO	56 962	159	18	0	2 137
	KAOMA	25 273	70	46	2	24 693
	LUKULU	26 199	73	5	0	957
	MONGU	52 275	146	7	1	8 004
	SENANGA	41 455	116	19	0	3 035
	SESHEKE	45 439	127	31	1	7 849
	SHANGOMBO	46 285	129	13	0	1 247
	SUBTOTAL	**293 890**	**819**	**140**	**4**	**47 922**
TOTAL		**2 268 305**	**236 597**	**18 718**	**37 042**	**535 490**

ANNEX 2

LAYER CHICKEN RESIDUES RESULTS AT A PROVINCE LEVEL

TABLE A2

LAYER CHICKEN HEADS AND MANURE AVAILABLE FROM COMMERCIAL PRODUCTION AT A PROVINCE LEVEL – TONNES PER YEAR

	NUMBER OF HEADS	MANURE PRODUCED tonnes/year
CENTRAL PROVINCE	315 550	13 061
COPPERBELT PROVINCE	211 527	8 755
EASTERN PROVINCE	12 007	497
LUAPULA PROVINCE	4 335	179
LUSAKA PROVINCE	316 491	13 100
MUCHINGA PROVINCE	6 081	252
NORTHERN PROVINCE	0	0
NORTH WESTERN PROVINCE	27 040	1 119
SOUTHERN PROVINCE	36 942	1 529
WESTERN PROVINCE	0	0
TOTAL	**929 973**	**38 493**

ANNEX 3

CROP RESIDUES RESULTS AT A DISTRICT LEVEL

TABLE A3

CROP RESIDUES AVAILABLE AT A DISTRICT LEVEL ACCORDING TO THE TYPE OF RESIDUE – TONNES OF AVAILABLE RESIDUES PER YEAR

PROVINCE	DISTRICT	MAIZE (MAIZE, POPCORN, MAIZE FOR SEED)		SORGHUM	RICE		MILLET	SUN-FLOWER	GROUND-NUTS
		STOVER + HUSK	COB	STALK	STRAW	HUSK	STRAW/ STALK	STALK	HUSK
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
CENTRAL	CHIBOMBO	90 482	23 025	224	12	4	124	1 477	710
	KABWE	23 234	3 894	16	12	4	229	139	93
	KAPIRI MPOSHI	129 423	30 951	110	162	51	4 985	1 314	1 535
	MKUSHI	136 799	26 738	835	197	62	3 613	1 251	546
	MUMBWA	67 871	10 156	42	4	1	134	36	642
	SERENJE	68 358	11 437	1 397	119	38	2 211	229	691
	SUBTOTAL	**516 167**	**106 201**	**2 624**	**505**	**160**	**11 297**	**4 445**	**4 217**
COPPERBELT	CHILILABOMBWE	3 881	692	12	1	0	44	3	63
	CHINGOLA	13 755	1 724	8	7	2	92	27	114
	KALULUSHI	11 366	1 395	52	2	1	29	7	196
	KITWE	8 226	1 543	17	1	0	13	22	78
	LUANSHYA	9 378	1 920	5	11	3	11	3	166
	LUFWANYAMA	51 444	9 591	272	29	9	37	32	511
	MASAITI	39 033	7 099	211	67	21	95	67	338
	MPONGWE	100 236	20 290	489	31	10	98	70	571
	MUFULIRA	9 281	1 645	29	7	2	53	6	106
	NDOLA	14 695	2 363	7	7	2	11	12	112
	SUBTOTAL	**261 293**	**48 262**	**1 102**	**163**	**51**	**483**	**250**	**2 256**

SOYABEAN		COTTON		IRISH POTATOES	TOBACCO (VIRGINIA, BURLEY)	SWEET POTATOES	WHEAT	BARLEY	CASSAVA
STRAW	PODS	STALK	HUSK	LEAVES AND PEELS	STALK	LEAVES AND PEELS	STRAW	STRAW	STALK
tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
15 437	12 645	17 628	1 926	2 748	1 412	2 180	11 607	609	254
4 252	5 766	228	25	506	562	119	6 790	422	9
3 037	5 899	10 227	1 118	56	1 188	3 083	880	1	208
40 748	22 191	678	74	330	3 303	2 167	29 335	1 151	1 057
3 100	4 589	26 535	2 900	81	447	222	0	0	61
5 544	4 556	1 865	210	1 950	993	3 170	4 291	0	12 143
72 119	**55 648**	**57 162**	**6 253**	**5 671**	**7 904**	**10 943**	**52 904**	**2 183**	**13 733**
2	7	4	0	18	1	650	0	0	104
1 625	1 129	8	1	51	3	208	1 970	0	334
47	78	1	0	2	0	114	0	0	3
169	150	0	0	3	8	166	311	0	67
57	69	27	3	4	2	246	0	0	91
357	365	96	11	45	65	1 179	0	0	367
326	374	91	10	60	101	1 114	0	0	425
32 750	18 302	914	100	514	70	801	15 624	1 694	16
567	393	24	3	10	12	225	1 100	0	208
644	474	18	2	8	0	410	2	0	167
36 544	**21 339**	**1 182**	**130**	**714**	**263**	**5 112**	**19 007**	**1 694**	**1 782**

PROVINCE	DISTRICT	MAIZE (MAIZE, POPCORN, MAIZE FOR SEED)		SORGHUM	RICE		MILLET	SUN-FLOWER	GROUND-NUTS
		STOVER + HUSK	COB	STALK	STRAW	HUSK	STRAW/ STALK	STALK	HUSK
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
EASTERN	CHADIZA	40 980	9 735	16	25	7	5	3 664	472
	CHIPATA	138 895	27 877	0	77	25	58	8 239	2 730
	KATETE	66 911	11 996	228	9	2	555	5 732	763
	LUNDAZI	121 114	28 987	78	411	182	705	9 701	1 875
	MAMBWE	12 307	2 679	128	904	269	27	438	169
	NYIMBA	25 975	4 759	13	19	6	16	1 992	400
	PETAUKE	138 216	23 294	12	7	7	362	9 611	1 922
	SUBTOTAL	**544 399**	**109 326**	**475**	**1 453**	**498**	**1 727**	**39 376**	**8 332**
LUAPULA	CHIENGI	16 974	1 267	21	1 211	325	0	29	593
	KAWAMBWA	40 927	5 742	54	139	37	1 371	7	722
	MANSA	28 102	4 799	31	638	171	493		840
	MILENGE	9 524	1 330	876	29	9	153	56	317
	MWENSE	12 740	1 581	0	355	95	327	10	631
	NCHELENGE	14 001	1 136	12	76	24	94	6	322
	SAMFYA	18 869	2 187	35	127	40	174	12	624
	SUBTOTAL	**141 136**	**18 043**	**1 030**	**2 575**	**703**	**2 613**	**121**	**4 049**
LUSAKA	CHONGWE	70 004	10 519	236	14	4	165	243	304
	KAFUE	46 909	6 511	430	13	4	137	80	144
	LUANGWA	1 601	165	13	43	14	3	27	12
	LUSAKA	1 964	264	3	1	0	0	3	5
	SUBTOTAL	**120 478**	**17 458**	**683**	**69**	**22**	**305**	**352**	**465**
MUCHINGA	CHAMA	26 471	5 216	3 064	3 131	874	1 028	415	378
	CHINSALI	47 913	9 074	54	3 449	1 076	5 601	60	1 010
	ISOKA	50 590	10 113	254	312	202	1 795	177	415
	MAFINGA	53 526	10 183	14	319	86	1 011	32	400
	MPIKA	85 321	17 680	202	79	21	5 659	832	1 071
	NAKONDE	61 897	12 336	154	747	201	3 777	345	240
	SUBTOTAL	**325 718**	**64 602**	**3 742**	**8 037**	**2 460**	**18 872**	**1 862**	**3 514**
NORTHERN	CHILUBI	3 382	590	17	322	102	90	8	114
	KAPUTA	11 337	2 075	47	2 497	693	59	0	269
	KASAMA	42 533	9 411	81	481	153	3 367	111	1 018
	LUWINGU	26 624	5 932	36	32	10	1 970	61	1 044
	MBALA	97 850	12 170	331	36	12	4 091	1 295	801
	MPOROKOSO	32 715	6 048	21	24	8	4 231	40	700
	MPULUNGU	27 039	3 928	84	319	101	1 167	76	215
	MUNGWI	44 028	10 789	73	7 137	1 916	5 820	78	1 189
	SUBTOTAL	**285 509**	**50 943**	**689**	**10 849**	**2 995**	**20 794**	**1 670**	**5 350**

SOYABEAN		COTTON		IRISH POTATOES	TOBACCO (VIRGINIA, BURLEY)	SWEET POTATOES	WHEAT	BARLEY	CASSAVA
STRAW	PODS	STALK	HUSK	LEAVES AND PEELS	STALK	LEAVES AND PEELS	STRAW	STRAW	STALK
tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
3 609	5 714	6 973	795	20	511	268	0	0	13
3 678	4 591	41 969	4 585	158	4 185	382	0	0	382
2 207	3 095	32 431	3 611	9	163	217	71	0	38
8 498	10 964	43 579	5 248	78	707	590	0	0	639
110	199	11 510	1 257	24	118	64	0	0	61
178	212	4 275	467	4	0	63	4	0	44
1 067	1 069	22 427	2 527	54	119	85	60	0	53
19 346	**25 844**	**163 164**	**18 491**	**346**	**5 804**	**1 670**	**135**	**0**	**1 230**
13	15	0	0	0	4	160	0	0	11 549
77	78	0	0	177	0	418	0	0	11 489
95	94	7	1	7	45	1 312	0	0	24 909
30	37	145	16	33	74	51	0	0	6 714
74	75	0	0	0	0	293	0	0	15 302
13	16	6	1	0	4	368	0	0	21 894
146	146	0	0	17	22	655	0	0	21 001
448	**461**	**158**	**18**	**234**	**150**	**3 256**	**0**	**0**	**112 859**
6 847	6 174	789	88	5 837	514	416	9 205	1 488	79
13 101	8 381	837	91	2 048	112	1	9 004	529	51
1	1	7	1	0	2	2	0	0	0
772	520	67	8	332	0	19	694	287	4
20 721	**15 076**	**1 700**	**188**	**8 217**	**628**	**437**	**18 903**	**2 304**	**135**
315	321	20 171	2 204	924	1 317	140	0	0	106
295	292	26	3	57	10	645	0	0	10 434
162	163	382	43	19	128	109	0	0	2 188
467	471	512	58	6	66	788	0	0	1 185
909	923	551	62	68	258	1 049	0	0	2 185
191	194	23	3	20	14	452	0	0	6
2 339	**2 363**	**21 664**	**2 372**	**1 094**	**1 792**	**3 184**	**0**	**0**	**16 104**
4	5	0	0	0	4	34	0	0	939
2	2	0	0	0	0	23	0	0	7 661
1 342	1 067	132	15	18	55	1 535	1 470	0	12 679
155	147	51	6	24	17	139	0	0	5 020
342	415	194	22	74	86	850	143	0	11 355
289	294	0	0	72	0	262	0	0	9 797
40	49	9	1	5	30	240	0	0	2 757
1 018	1 022	68	8	16	24	992	0	0	12 319
3 191	**3 001**	**454**	**51**	**209**	**215**	**4 075**	**1 612**	**0**	**62 528**

PROVINCE	DISTRICT	MAIZE (MAIZE, POPCORN, MAIZE FOR SEED)		SORGHUM	RICE		MILLET	SUN-FLOWER	GROUND-NUTS
		STOVER + HUSK	COB	STALK	STRAW	HUSK	STRAW/ STALK	STALK	HUSK
		tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
NORTH WESTERN	CHAVUMA	4 482	714	4	194	52	60	9	10
	IKELENGE	3 103	621	8	59	16	0	1	12
	KABOMPO	27 861	5 967	42	30	10	78	14	623
	KASEMPA	41 435	8 580	1 621	500	159	322	427	153
	MUFUMBWE	28 376	5 748	414	50	16	4	7	1 068
	MWINILUNGA	31 366	6 279	36	103	33	75	33	179
	SOLWEZI	56 065	10 433	319	209	56	393	12	335
	ZAMBEZI	10 780	2 344	6	76	20	39	0	82
	SUBTOTAL	**203 468**	**40 687**	**2 450**	**1 222**	**362**	**971**	**503**	**2 461**
SOUTHERN	CHOMA	40 622	12 513	13	9	3	0	706	391
	GWEMBE	10 175	1 964	604	216	69	437	137	65
	ITEZHI-TEZHI	17 204	3 704	26	1	0	29	259	183
	KALOMO	108 184	28 222	648	38	12	350	3 798	1 155
	KAZUNGULA	10 365	6 643	584	268	85	369	154	261
	LIVINGSTONE	955	227	33	8	3	8	7	3
	MAZABUKA	34 466	11 116	76	0	0	34	636	133
	MONZE	42 642	10 464	133	0	0	48	222	435
	NAMWALA	22 509	5 574	5	12	4	11	106	502
	SIAVONGA	4 716	2 143	1 740	2 644	840	1 132	757	69
	SINAZONGWE	4 560	3 203	424	45	14	96	67	38
	SUBTOTAL	**296 399**	**85 774**	**4 285**	**3 241**	**1 030**	**2 515**	**6 851**	**3 234**
WESTERN	KALABO	5 832	812	248	2 564	847	2 033	402	45
	KAOMA	39 306	6 449	398	602	238	327	66	550
	LUKULU	7 070	1 517	77	449	121	85	21	80
	MONGU	6 020	654	221	4 051	1 168	81	26	17
	SENANGA	4 506	961	124	545	389	248	52	31
	SESHEKE	8 845	657	239	121	45	528	123	208
	SHANGOMBO	6 210	1 407	273	142	45	486	706	74
	SUBTOTAL	**77 788**	**12 456**	**1 580**	**8 473**	**2 852**	**3 788**	**1 397**	**1 004**
TOTAL		**2 772 354**	**553 752**	**18 660**	**36 587**	**11 133**	**63 364**	**56 827**	**34 883**
%SMALL & MEDIUM-SCALE FARMS		92%	90%	94%	100%	100%	87%	95%	99%
%LARGE-SCALE FARMS		8%	10%	6%	0%	0%	13%	5%	1%

SOYABEAN		COTTON		IRISH POTATOES	TOBACCO (VIRGINIA, BURLEY)	SWEET POTATOES	WHEAT	BARLEY	CASSAVA
STRAW	PODS	STALK	HUSK	LEAVES AND PEELS	STALK	LEAVES AND PEELS	STRAW	STRAW	STALK
tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year
2	2	0	0	0	0	21	0	0	2 619
4	5	0	0	4	0	18	0	0	4 298
11	13	53	6	15	43	126	0	0	4 402
292	294	2 881	324	108	1 947	674	0	0	167
65	81	3	0	13	10	350	0	0	2 767
146	133	128	14	17	67	103	420	0	13 972
386	366	33	4	567	35	1 278	0	0	3 950
24	30	0	0	0	45	257	0	0	11 587
931	**923**	**3 097**	**349**	**723**	**2 147**	**2 829**	**420**	**0**	**43 762**
184	1 023	3 505	388	13	3 000	1 339	1 458	480	31
68	84	2 319	253	282	853	44	0	0	16
35	42	1 605	175	59	179	188	0	0	256
1 014	738	3 666	412	454	2 375	757	722	612	28
244	238	876	99	347	1 053	14	850	0	0
223	153	725	81	30	114	4	627	0	23
2 728	6 527	2 386	261	334	121	196	6 588	0	1 348
290	484	2 615	286	11	79	2 194	180	0	31
16	19	3 389	370	2	64	498	0	0	59
595	739	1 919	274	1 731	3 935	237	0	0	8
2 370	1 609	2 751	395	134	406	93	3 824	0	62
7 766	**11 656**	**25 756**	**2 993**	**3 396**	**12 179**	**5 562**	**14 249**	**1 091**	**1 864**
249	310	1 119	126	249	756	72	0	0	12 959
208	164	604	68	68	1 446	341	0	0	17 120
10	12	39	4	9	27	0	0	0	8 642
32	37	73	8	10	37	42	0	0	16 783
127	158	335	38	75	226	37	0	0	6 996
192	239	507	57	113	342	19	0	0	1 147
378	469	1 958	220	437	1 323	58	0	0	124
1 196	**1 389**	**4 635**	**522**	**960**	**4 157**	**569**	**0**	**0**	**63 771**
164 600	**137 700**	**278 973**	**31 366**	**21 565**	**35 240**	**37 636**	**107 230**	**7 273**	**317 766**
27%	42%	99%	99%	31%	73%	99%	0%	0%	100%
73%	58%	1%	1%	69%	27%	1%	100%	100%	0%

ANNEX 4

ADDITIONAL PRODUCTION OF CROPS AT A DISTRICT LEVEL

TABLE A4

ADDITIONAL PRODUCTION OF SUNFLOWER, SOYBEAN FOR BIODIESEL AND CASSAVA FOR ETHANOL AT A DISTRICT LEVEL

PROVINCE	DISTRICT	SUNFLOWER ADDITIONAL PRODUCTION	SOYBEAN ADDITIONAL PRODUCTION	CASSAVA ADDITIONAL PRODUCTION
		tonnes/year	tonnes/year	tonnes/year
CENTRAL	CHIBOMBO	1 609	15 603	784
	KABWE	140	8 037	32
	KAPIRI MPOSHI	1 039	11 896	1 051
	MKUSHI	283	22 302	2 787
	MUMBWA	552	6 894	156
	SERENJE	11	4 602	31 126
	SUBTOTAL	**3 634**	**69 334**	**35 935**
COPPERBELT	CHILILABOMBWE	0	- 0	266
	CHINGOLA	25	408	1 061
	KALULUSHI	0	25	163
	KITWE	0	274	679
	LUANSHYA	0	813	237
	LUFWANYAMA	15	2 747	1 007
	MASAITI	0	38	1 078
	MPONGWE	36	12 421	2 207
	MUFULIRA	1	136	529
	NDOLA	0	242	427
	SUBTOTAL	**76**	**17 105**	**7 653**
EASTERN	CHADIZA	1 858	9 768	45
	CHIPATA	43	9 832	977
	KATETE	3 509	8 154	100
	LUNDAZI	3 564	22 799	1 627
	MAMBWE	0	606	157
	NYIMBA	6	114	114
	PETAUKE	4 209	2 844	250
	SUBTOTAL	**13 190**	**54 117**	**3 270**

PROVINCE	DISTRICT	SUNFLOWER ADDITIONAL PRODUCTION tonnes/year	SOYBEAN ADDITIONAL PRODUCTION tonnes/year	CASSAVA ADDITIONAL PRODUCTION tonnes/year
LUAPULA	CHIENGI	2	2	36 042
	KAWAMBWA	0	7	54 542
	MANSA	0	12	76 761
	MILENGE	0	4	18 106
	MWENSE	0	0	48 558
	NCHELENGE	0	0	58 034
	SAMFYA	1	9	54 112
	SUBTOTAL	**3**	**35**	**346 155**
LUSAKA	CHONGWE	79	8 321	559
	KAFUE	203	10 069	129
	LUANGWA	45	0	0
	LUSAKA	6	565	11
	SUBTOTAL	**332**	**18 956**	**700**
MUCHINGA	CHAMA	0	0	271
	CHINSALI	11	30	36 986
	ISOKA	1	14	13 382
	MAFINGA	3	20	3 034
	MPIKA	7	22	20 471
	NAKONDE	0	2	12 975
	SUBTOTAL	**21**	**87**	**87 120**
NORTHERN	CHILUBI	0	0	28 026
	KAPUTA	0	0	24 549
	KASAMA	21	157	33 857
	LUWINGU	0	25	42 085
	MBALA	5	11	53 215
	MPOROKOSO	311	3	28 595
	MPULUNGU	0	0	12 889
	MUNGWI	- 12	43	61 725
	SUBTOTAL	**324**	**239**	**284 940**
NORTH WESTERN	CHAVUMA	0	0	6 636
	IKELENGE	0	0	12 770
	KABOMPO	0	6	34 844
	KASEMPA	9	18	428
	MUFUMBWE	0	0	7 010
	MWINILUNGA	13	10	60 517
	SOLWEZI	- 0	30	10 007
	ZAMBEZI	0	0	29 356
	SUBTOTAL	**22**	**64**	**161 569**

PROVINCE	DISTRICT	SUNFLOWER ADDITIONAL PRODUCTION tonnes/year	SOYBEAN ADDITIONAL PRODUCTION tonnes/year	CASSAVA ADDITIONAL PRODUCTION tonnes/year
SOUTHERN	CHOMA	90	622	80
	GWEMBE	0	0	40
	ITEZHI-TEZHI	251	2	654
	KALOMO	4 034	262	79
	KAZUNGULA	759	171	0
	LIVINGSTONE	2	122	69
	MAZABUKA	349	3 956	7 230
	MONZE	45	388	119
	NAMWALA	2	0	151
	SIAVONGA	172	381	21
	SINAZONGWE	0	1 279	160
	SUBTOTAL	**5 704**	**7 183**	**8 603**
WESTERN	KALABO	0	0	45 534
	KAOMA	- 1	16	43 375
	LUKULU	0	0	25 038
	MONGU	0	3	42 521
	SENANGA	0	1 088	29 192
	SESHEKE	80	1 397	2 935
	SHANGOMBO	291	2 134	317
	SUBTOTAL	**370**	**4 638**	**188 913**
TOTAL		**23 677**	**171 759**	**1 124 859**

ANNEX 5

GROSS MARGIN ANALYSIS FOR THE ANALYSED LIQUID BIOFUELS FEEDSTOCK

TABLE A5

GROSS MARGIN ANALYSIS FOR SOYBEANS – YIELD AT 0.75 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.9
Yield (tonnes/ha)	0.75
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				3 345	320	270	345	420
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Soya grain – revenue per ha	tonne	0.75	3 344.80	2 508.60	240.00	202.50	258.75	315.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	70.00	13.00	910.00	87.06	87.06	87.06	87.06
Herbicides								
Glyphosate	litres	3.00	65.00	195.00	18.66	18.66	18.66	18.66
Stellar Star	litres							
Insecticides								
Lambda Cyhalothlin	litres							
Malathion								
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
D Compound	bag (50 kg)							
Innoculant	grammes							
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha	1.00	371.20	371.20	35.51	35.51	35.51	35.51
Ripping	rows							
Labour								
Labour (land prep., harvest)	man-days	70.00	29.27	2 048.69	196.00	196.00	196.00	196.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20 kg)	15.00	3.48	52.20	4.99	4.99	4.99	4.99
Transport	tonne/km	19.13	2.90	55.46	5.31	5.31	5.31	5.31
Insurance								
Insurance (% of total revenue)	% of TR	0.01		25.09	2.40	2.03	2.59	3.15
Total Variable Costs (TVC)				**3 657.64**	**349.93**	**349.56**	**350.12**	**350.68**
Interest rate @23.93%	% of TVC	23.93%		875.27	83.74	83.65	83.78	83.92
Interest rate @9.79%	% of TVC	9.79%		358.08	34.26	34.22	34.28	34.33

TABLE A6

GROSS MARGIN ANALYSIS FOR SOYBEANS – YIELD AT 1 tonne/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.9
Yield (tonnes/ha)	1
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				3 345	320	270	345	420
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Soya grain – revenue per ha		1.00	3 344.80	3 344.80	320.00	270.00	345.00	420.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	75.00	13.00	975.00	93.28	93.28	93.28	93.28
Herbicides								
Glyphosate	litres	3.00	65.00	195.00	18.66	18.66	18.66	18.66
Stellar Star	litres							
Insecticides								
Lambda Cyhalothlin	litres							
Malathion								
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
D Compound	bag (50 kg)	3.00	287.00	861.00	82.37	82.37	82.37	82.37
Innoculant	grammes							
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha	1.00	371.20	371.20	35.51	35.51	35.51	35.51
Ripping	rows							
Labour								
Labour (land prep., harvest)	man-days	73.00	29.27	2 136.49	204.40	204.40	204.40	204.40
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20 kg)	20.00	3.48	69.60	6.66	6.66	6.66	6.66
Transport	tonne/km	25.50	2.90	73.95	7.07	7.07	7.07	7.07
Insurance								
Insurance (% of total revenue)	% of TR	0.01		33.45	3.20	2.70	3.45	4.20
Total Variable Costs (TVC)				**4 715.70**	**451.15**	**450.65**	**451.40**	**452.15**
Interest rate @23.93%	% of TVC	23.93%		1 128.47	107.96	107.84	108.02	108.20
Interest rate @9.79%	% of TVC	9.79%		461.67	44.17	44.12	44.19	44.27

TABLE A7

GROSS MARGIN ANALYSIS FOR SOYBEANS – YIELD AT 1.75 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.9
Yield (tonnes/ha)	1.75
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				3 345	320	270	345	420
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Soya grain – revenue per ha		1.75	3 344.80	5 853.40	560.00	472.50	603.75	735.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	80.00	17.50	1 400.00	133.94	133.94	133.94	133.94
Herbicides						0.00		
Glyphosate	litres	3.00	65.00	195.00	18.66	18.66	18.66	18.66
Stellar Star	litres							
Insecticides								
Lambda Cyhalothlin	litres	1.00	140.00	140.00	13.39	13.39	13.39	13.39
Malathion		2.00	95.00	190.00	18.18	18.18	18.18	18.18
Fungicides								
Copperoxchloride	kg	2.00	50.00	100.00	9.57	9.57	9.57	9.57
Metalaxyl	kg	1.00	193.00	193.00	18.46	18.46	18.46	18.46
Ferilisers								
D Compound	bag (50 kg)	4.00	287.00	1 148.00	109.83	109.83	109.83	109.83
Innoculant	grammes	80.00	0.08	6.40	0.61	0.61	0.61	0.61
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha							
Ripping	rows	1.00	290.00	290.00	27.74	27.74	27.74	27.74
Labour								
Labour (land prep., harvest)	man-days	75.00	29.27	2 195.03	210.00	210.00	210.00	210.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20 kg)	35.00	3.48	121.80	11.65	11.65	11.65	11.65
Transport	tonne/km	44.63	2.90	129.41	12.38	12.38	12.38	12.38
Insurance								
Insurance (% of total revenue)	% of TR	0.01		58.53	5.60	4.73	6.04	7.35
Total Variable Costs (TVC)				**6 167.18**	**590.02**	**589.14**	**590.46**	**591.77**
Interest rate @23.93%	% of TVC	23.93%		1 475.81	141.19	140.98	141.30	141.61
Interest rate @9.79%	% of TVC	9.79%		603.77	57.76	57.68	57.81	57.93

TABLE A8

GROSS MARGIN ANALYSIS FOR SOYBEANS – YIELD AT 3 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.9
Yield (tonnes/ha)	3
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				3 345	320	270	345	420
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Soya grain – revenue per ha		3.00	3 344.80	10 034.40	960.00	810.00	1 035.00	1 260.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	100.00	17.50	1 750.00	167.42	167.42	167.42	167.42
Herbicides								
Glyphosate	litres	3.00	65.00	195.00	18.66	18.66	18.66	18.66
Stellar Star	litres	1.00	620.00	620.00	59.32			
Insecticides								
Lambda Cyhalothlin	litres	1.00	140.00	140.00	13.39	13.39	13.39	13.39
Malathion		2.00	95.00	190.00	18.18	18.18	18.18	18.18
Fungicides								
Copperoxchloride	kg	2.00	50.00	100.00	9.57	9.57	9.57	9.57
Metalaxyl	kg	1.00	193.00	193.00	18.46	18.46	18.46	18.46
Ferilisers								
D Compound	bag (50 kg)	4.00	287.00	1 148.00	109.83	109.83	109.83	109.83
Innoculant	grammes	100.00	0.09	9.28	0.89	0.89	0.89	0.89
Land Preparation								
Fuel	litres	100.00	12.86	1 285.66	123.00	123.00	123.00	123.00
oil	litres	5.00	58.00	290.00	27.74	27.74	27.74	27.74
Ploughing	ha							
Ripping	rows							
Labour								
Labour (land prep., harvest)	man-days	30.00	29.27	878.01	84.00	84.00	84.00	84.00
Irrigation								
Electricity	0.98 USD/mm	40.00	10.24	409.74	39.20	39.20	39.20	39.20
Post-harvest activities								
Packaging	bags (20 kg)	60.00	3.48	208.80	19.98	19.98	19.98	19.98
Transport	tonne/km	76.50	2.90	221.85	21.22	21.22	21.22	21.22
Insurance								
Insurance (% of total revenue)	% of TR	0.01		100.34	9.60	8.10	10.35	12.60
Total Variable Costs (TVC)				**7 739.69**	**740.46**	**679.65**	**681.90**	**684.15**
Interest rate @23.93%	% of TVC	23.93%		1 852.11	177.19	162.64	163.18	163.72
Interest rate @9.79%	% of TVC	9.79%		757.72	72.49	66.54	66.76	66.98

TABLE A9

GROSS MARGIN ANALYSIS FOR SOYBEANS – YIELD AT 4 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.9
Yield (tonnes/ha)	4
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				3 345	320	270	345	420
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Soya grain – revenue per ha		4.00	3 344.80	13 379.20	1 280.00	1 080.00	1 380.00	1 680.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	110.00	17.50	1 925.00	184.17	184.17	184.17	184.17
Herbicides								
Glyphosate	litres	3.00	65.00	195.00	18.66	18.66	18.66	18.66
Stellar Star	litres	1.00	620.00	620.00	59.32	59.32	59.32	59.32
Insecticides								
Lambda Cyhalothlin	litres	1.00	140.00	140.00	13.39	13.39	13.39	13.39
Malathion		2.00	95.00	190.00	18.18	18.18	18.18	18.18
Fungicides								
Copperoxchloride	kg	2.00	50.00	100.00	9.57	9.57	9.57	9.57
Metalaxyl	kg	1.00	193.00	193.00	18.46	18.46	18.46	18.46
Ferilisers								
D Compound	bag (50 kg)	6.00	287.00	1 722.00	164.75	164.75	164.75	164.75
Innoculant	grammes	110.00	0.09	10.21	0.98	0.98	0.98	0.98
Land Preparation								
Fuel	litres	105.00	12.68	1 331.40	127.38	127.38	127.38	127.38
oil	litres	5.00	58.00	290.00	27.74	27.74	27.74	27.74
Ploughing	ha							
Ripping	rows							
Labour								
Labour (land prep., harvest)	man-days	35.00	29.27	1 024.35	98.00	98.00	98.00	98.00
Irrigation								
Electricity	0.98 USD/mm	45.00	10.24	460.96	44.10	44.10	44.10	44.10
Post-harvest activities								
Packaging	bags (20 kg)	80.00	3.48	278.40	26.64	26.64	26.64	26.64
Transport	tonne/km	102.00	2.90	295.80	28.30	28.30	28.30	28.30
Insurance								
Insurance (% of total revenue)	% of TR	0.01		133.79	12.80	10.80	13.80	16.80
Total Variable Costs (TVC)				**8 909,91**	**852,42**	**850,42**	**853,42**	**856,42**
Interest rate @23.93%	% of TVC	23,93%		2 132,14	203,98	203,51	204,22	204,94
Interest rate @9.79%	% of TVC	9,79%		872,28	83,45	83,26	83,55	83,84

TABLE A10

GROSS MARGIN ANALYSIS FOR SUNFLOWER – YIELD AT 1 tonne/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.5
Yield (tonnes/ha)	1
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				2 400.00	229.14	180.00	350.00	410.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sunflower grain – revenue per ha		1.00	2 400.00	2 400.00	229.14	180.00	350.00	410.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	5.00	20.00	100.00	9.55	9.55	9.55	9.55
Herbicides								
Glyphosate	litres							
Atrazin	litres							
Insecticides								
Karate	litres							
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
D Compound	bag (50 kg)	2.00	287.00	574.00	54.80	54.80	54.80	54.80
Urea	bag (50 kg)	1.50	320.00	480.00	45.83	45.83	45.83	45.83
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha	1.00	371.20	371.20	35.44	35.44	35.44	35.44
Weeding		1.00	185.60	185.60	17.72	17.72	17.72	17.72
Ripping	rows							
Labour								
Labour (land prep., harvest)	man-days	50.00	29.33	1 466.35	140.00	140.00	140.00	140.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (25 kg)	25.00	3.48	87.00	8.31	8.31	8.31	8.31
Transport	tonne/km	25.50	2.90	73.95	7.06	7.06	7.06	7.06
Insurance								
Insurance (% of total revenue)	% of TR	0.01		24.00	2.29	1.80	3.50	4.10
Total Variable Costs (TVC)				**3 362.10**	**321.00**	**320.51**	**322.21**	**322.81**
Interest rate @29.93%	% of TVC	23.93%		804.55	76.81	76.70	77.10	77.25
Interest rate @9.79%	% of TVC	9.79%		329.15	31.43	31.38	31.54	31.60

TABLE A11

GROSS MARGIN ANALYSIS FOR SUNFLOWER – YIELD AT 2 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.5
Yield (tonnes/ha)	2
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				2 400.00	229.14	180.00	350.00	410.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sunflower grain – revenue per ha		2.00	2 400.00	4 800.00	458.28	360.00	700.00	820.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	6.00	20.00	120.00	11.46	11.46	11.46	11.46
Herbicides								
Glyphosate	litres	2.00	65.00	130.00	12.41	12.41	12.41	12.41
Atrazin	litres	1.00	65.00	65.00	6.21	6.21	6.21	6.21
Insecticides								
Karate	litres	1.00	28.50	28.50	2.72	2.72	2.72	2.72
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
D Compound	bag (50 kg)	3.00	287.00	861.00	82.20	82.20	82.20	82.20
Urea	bag (50 kg)	3.00	320.00	960.00	91.66	91.66	91.66	91.66
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha							
Weeding								
Ripping	rows	100.00	2.90	290.00	27.69	91.66	91.66	91.66
Labour								
Labour (land prep., harvest)	mandays	40.00	29.33	1 173.08	112.00	112.00	112.00	112.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (25 kg)	50.00	3.48	174.00	16.61	16.61	16.61	16.61
Transport	tonne/km	51.00	2.90	147.90	14.12	14.12	14.12	14.12
Insurance								
Insurance (% of total revenue)	% of TR	0.01		48.00		3.60	7.00	8.20
Total Variable Costs (TVC)				**3 997.48**	**377.08**	**444.65**	**448.05**	**449.25**
Interest rate @29.93%	% of TVC	23.93%		956.60	90.23	106.40	107.22	107.50
Interest rate @9.79%	% of TVC	9.79%		391.35	36.92	43.53	43.86	43.98

TABLE A12

GROSS MARGIN ANALYSIS FOR SUNFLOWER – YIELD AT 3 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.5
Yield (tonnes/ha)	3
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				2 400.00	229.14	180.00	350.00	410.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sunflower grain – revenue per ha		3.00	2 400.00	7 200.00	687.42	540.00	1 050.00	1 230.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
Seed	kg	7.00	20.00	140.00	13.37	13.37	13.37	13.37
Herbicides								
Glyphosate	litres	2.70	65.00	175.50	16.76	16.76	16.76	16.76
Atrazin	litres	1.20	65.00	78.00	7.45	7.45	7.45	7.45
Insecticides								
Karate	litres	1.20	28.50	34.20	3.27	3.27	3.27	3.27
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
D Compound	bag (50 kg)	4.00	287.00	1 148.00	109.61	109.61	109.61	109.61
Urea	bag (50 kg)	5.00	320.00	1 600.00	152.76	152.76	152.76	152.76
Land Preparation								
Fuel	litres							
oil	litres							
Ploughing	ha							
Weeding								
Ripping	rows	120.00	2.90	348.00	33.23	91.66	91.66	91.66
Labour								
Labour (land prep., harvest)	man-days	45.00	29.33	1 319.71	126.00	126.00	126.00	126.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (25kg)	75.00	3.48	261.00	24.92	24.92	24.92	24.92
Transport	tonne/km	76.50	2.90	221.85	21.18	21.18	21.18	21.18
Insurance								
Insurance (% of total revenue)	% of TR	0.01		72.00	6.87	5.40	10.50	12.30
Total Variable Costs (TVC)				**5 398.27**	**515.40**	**572.36**	**577.46**	**579.26**
Interest rate @29.93%	% of TVC	23.93%		1 291.81	123.34	136.97	138.19	138.62
Interest rate @9.79%	% of TVC	9.79%		528.49	50.46	56.03	56.53	56.71

TABLE A13

GROSS MARGIN ANALYSIS FOR CASSAVA – YIELD AT 8 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	2.5
Yield (tonnes/ha)	8
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				1.000.00	95.48	85.00	105.00	115.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Cassava tubers – revenue per ha		8.00	1 000.00	8 000.00	763.80	680.00	840.00	920.00
Cassava cuttings (planting material)	bundles	100.00	15.00	1 500.00	143.51	13.73	1.31	0.13
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	bundles	20.00	15.00	300.00	28.64	28.64	28.64	28.64
Herbicides								
Glyphosate	litres							
Atrazin	litres							
Insecticides								
Karate	litres							
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
Chicken manure	kg							
N								
P	kg							
K	kg							
Land Preparation								
Ploughing	ha	1.00	928.01	928.01	88.60	88.60	88.60	88.60
Planting	ha	1.00	696.01	696.01	66.45	66.45	66.45	66.45
First weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Second weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Labour								
Labour (harvest)	man-days	40.00	29.33	1 173.08	112.00	112.00	112.00	112.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20kg)	400.00	3.48	1 392.02	132.90	132.90	132.90	132.90
Transport from the field	km/t	204.00	2.90	591.61	56.48	56.48	56.48	56.48
Insurance								
Insurance (% of total revenue)	% of TR	0.01		80.00	7.64	6.80	8.40	9.20
Total Variable Costs (TVC)				**7 944.76**	**758.53**	**757.69**	**759.29**	**760.09**
Interest rate @29.93%	% of TVC	23.93%		1 901.18	181.52	181.32	181.70	181.89
Interest rate @9.79%	% of TVC	9.79%		777.79	74.26	74.18	74.33	74.41

TABLE A14

GROSS MARGIN ANALYSIS FOR CASSAVA – YIELD AT 28.5 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	28.5
Yield (tonnes/ha)	8
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				1.000.00	95.48	85.00	105.00	115.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Cassava tubers – revenue per ha		28.50	1 000.00	28 500.00	2 721.05	2 422.50	2 992.50	3 277.50
Cassava cuttings (planting material)	bundles	100.00	15.00	1 500.00				
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	bundles	20.00	15.00	300.00	28.64	28.64	28.64	28.64
Herbicides								
Glyphosate	litres							
Atrazin	litres							
Insecticides								
Karate	litres							
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
Chicken manure	kg	4 200.00	0.40	1 680.00	160.40	160.40	160.40	160.40
N								
P	kg							
K	kg							
Land Preparation								
Ploughing	ha	1.00	928.01	928.01	88.60	88.60	88.60	88.60
Planting	ha	1.00	696.01	696.01	66.45	66.45	66.45	66.45
First weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Second weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Labour								
Labour (harvest)	man-days	142.50	29.33	4 179.09	399.00	399.00	399.00	399.00
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20 kg)	1 425.00	3.48	4 959.06	473.47	473.47	473.47	473.47
Transport from the field	km/t	726.75	2.90	2 107.60	201.22	201.22	201.22	201.22
Insurance								
Insurance (% of total revenue)	% of TR	0.01		285.00	27.21	24.23	29.93	32.78
Total Variable Costs (TVC)				**17 918.80**	**1 710.81**	**1 707.82**	**1 713.52**	**1 716.37**
Interest rate @29.93%	% of TVC	23.93%		4 287.97	409.40	408.68	410.05	410.73
Interest rate @9.79%	% of TVC	9.79%		1 754.25	167.49	167.20	167.75	168.03

TABLE A15

GROSS MARGIN ANALYSIS FOR CASSAVA – YIELD AT 30.2 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	30.2
Yield (tonnes/ha)	8
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				1 000.00	95.48	85.00	105.00	115.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Cassava tubers – revenue per ha		30.20	1 000.00	30 200.00	2 883.36	2 567.00	3 171.00	3 473.00
Cassava cuttings (planting material)	bundles	100.00	15.00	1 500.00	143.51	13.73	1.31	0.13
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	bundles	20.00	15.00	300.00	28.64	28.64	28.64	28.64
Herbicides								
Glyphosate	litres							
Atrazin	litres							
Insecticides								
Karate	litres							
Fungicides								
Copperoxchloride	kg							
Metalaxyl	kg							
Ferilisers								
Chicken manure	kg							
N		150.00	9.43	1 413.98	135.00	135.00	135.00	135.00
P	kg	33.00	9.28	306.24	29.24	29.24	29.24	29.24
K	kg	124.50	9.28	1 155.36	110.31	110.31	110.31	110.31
Land Preparation								
Ploughing	ha	1.00	928.01	928.01	88.60	88.60	88.60	88.60
Planting	ha	1.00	696.01	696.01	66.45	66.45	66.45	66.45
First weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Second weeding	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Labour								
Labour (harvest)	man-days	151.00	29.33	4 428.36	422.80	422.80	422.80	422.80
Irrigation								
Electricity	0.98 USD/mm							
Post-harvest activities								
Packaging	bags (20 kg)	1 510.00	3.48	5 254.86	501.71	501.71	501.71	501.71
Transport from the field	km/t	770.10	2.90	2 233.32	213.23	213.23	213.23	213.23
Insurance								
Insurance (% of total revenue)	% of TR	0.01		302.00	28.83	25.67	31.71	34.73
Total Variable Costs (TVC)				**19 802.18**	**1 890.62**	**1 887.46**	**1 893.50**	**1 896.52**
Interest rate @29.93%	% of TVC	23.93%		4 738.66	452.43	451.67	453.11	453.84
Interest rate @9.79%	% of TVC	9.79%		1 938.63	185.09	184.78	185.37	185.67

TABLE A16

GROSS MARGIN ANALYSIS FOR SUGARCANE – YIELD AT 25 tonnes/ha

Assumptions

Distance to Market (km)	25.5 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	30.2
Yield (tonnes/ha)	25
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				323.70	30.91	25.00	33.00	37.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sugarcane – revenue per ha	yield (tonnes/ha)	25.00	323.70	8 092.40	772.63	625.00	825.00	925.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	cuttings	10 000.00	0.58	5 800.07	553.76	553.76	553.76	553.76
Agrochemicals								
Herbicides, insecticides, fungicides	litres				0.00	0.00	0.00	0.00
Ferilisers								
Urea	kg							
DAP (D-compound here)	kg							
MOP	kg							
Labour								
Land preparation	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Planting	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Weeding	ha	1.00	2 784.03	2 784.03	265.81	265.81	265.81	265.81
Harvesting	ha	1.00	4 640.06	4 640.06	443.01	443.01	443.01	443.01
Labour								
Labour (harvest)	man-days			0.00	0.00	0.00	0.00	0.00
Irrigation								
Electricity	0.98 USD/mm							
Packaging	bags (20 kg)			0.00	0.00	0.00	0.00	0.00
Transport from the field	km/t	637.50	2.90	1 848.77	176.51	176.51	176.51	176.51
Insurance								
Insurance (% of total revenue)	% of TR	0.01		80.92	7.73	6.25	8.25	9.25
Total Variable Costs (TVC)				**17 937.89**	**1 712.63**	**1 711.15**	**1 713.15**	**1 714.15**
Interest rate @29.93%	% of TVC	23.93%		4 292.54	409.83	409.48	409.96	410.20
Interest rate @9.79%	% of TVC	9.79%		1 756.12	1 756.12	1 756.12	1 756.12	1 756.12

TABLE A17

GROSS MARGIN ANALYSIS FOR SUGARCANE – YIELD AT 122 tonnes/ha

Assumptions

Distance to Market (km)	122 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	30.2
Yield (tonnes/ha)	122
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				323.70	30.91	25.00	33.00	37.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sugarcane – revenue per ha	yield (tonnes/ha)	122.00	323.70	39 490.90	3 770.41	3 050.00	4 026.00	4 514.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	cuttings	10 000.00	0.58	5 800.07	553.76	553.76	553.76	553.76
Agrochemicals								
Herbicides, insecticides, fungicides	litres	6.20	90.00	558.00	53.28	53.28	53.28	53.28
Ferilisers								
Urea	kg	100.00	6.40	640.00	61.10	61.10	61.10	61.10
DAP (D-compound here)	kg	187.00	5.74	1 073.38	102.48	102.48	102.48	102.48
MOP	kg	154.00	6.06	933.24	89.10	89.10	89.10	89.10
Labour								
Land preparation	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Planting	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Weeding	ha	1.00	2 784.03	2 784.03	265.81	265.81	265.81	265.81
Harvesting	ha	1.00	4 640.06	4 640.06	443.01	443.01	443.01	443.01
Labour								
Labour (harvest)	man-days					0.00	0.00	0.00
Irrigation								
Electricity	0.98 USD/mm	20.00	30.29	605.74				
Post-harvest activities								
Transport from the field	km/t	3 111.00	2.90	9 022.01	861.38	861.38	861.38	861.38
Insurance								
Insurance (% of total revenue)	% of TR	0.01		394.91	37.70	30.50	40.26	45.14
Total Variable Costs (TVC)				**29 235.47**	**2 733.44**	**2 726.23**	**2 735.99**	**2 740.87**
Interest rate @29.93%	% of TVC	23.93%		6 996.05	654.11	652.39	654.72	655.89
Interest rate @9.79%	% of TVC	9.79%		2 862.15	267.60	266.90	267.85	268.33

TABLE A18

GROSS MARGIN ANALYSIS FOR SUGARCANE – YIELD AT 140 tonnes/ha

Assumptions

Distance to Market (km)	122 (RALS, 2015 Survey Report)
Transport cost (ZMK/tonne/km)	30.2
Yield (tonnes/ha)	140
Exchange rate ZMK:USD (average 2018)	10.4525

				MARKET PRICE				
				ZMK/t (2018)	USD/t (2018)	USD/t (SENSITIVITY ANALYSIS)		
				323.70	30.91	25.00	33.00	37.00
ITEM	**UNIT**	**RATE/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Sugarcane – revenue per ha	yield (tonnes/ha)	140.00	323.70	45 317.42	4 326.70	3 500.00	4 620.00	5 180.00
VARIABLE COSTS		**inputs/ha**	**Unit Price**	**ZMK/ha**	**USD/ha**	**USD/ha**	**USD/ha**	**USD/ha**
Agricultural inputs								
propagation material (cuttings)	cuttings	10 000.00	0.58	5 800.07	553.76	553.76	553.76	553.76
Agrochemicals								
Herbicides, insecticides, fungicides	litres	6.20	90.00	558.00				
Ferilisers								
Urea	kg	100.00	6.40	640.00				
DAP (D-compound here)	kg	187.00	5.74	1 073.38	102.48	102.48	102.48	102.48
MOP	kg	154.00	6.06	933.24	89.10	89.10	89.10	89.10
Labour								
Land preparation	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Planting	ha	1.00	1 392.02	1 392.02	132.90	132.90	132.90	132.90
Weeding	ha	1.00	2 784.03	2 784.03	265.81	265.81	265.81	265.81
Harvesting	ha	1.00	4 640.06	4 640.06	443.01	443.01	443.01	443.01
Labour								
Labour (harvest)	man-days				0.00	0.00	0.00	0.00
Irrigation								
Electricity	0.98 USD/mm	40.00	30.29	1 211.48	115.67	115.67	115.67	115.67
Post-harvest activities								
Transport from the field	km/t	3 570.00	2.90	10 353.13	988.47	988.47	988.47	988.47
Insurance								
Insurance (% of total revenue)	% of TR	0.01		453.17	43.27	35.00	46.20	51.80
Total Variable Costs (TVC)				**31 230.59**	**2 867.37**	**2 859.11**	**2 870.31**	**2 875.91**
Interest rate @29.93%	% of TVC	23.93%		7 473.48	686.16	684.18	686.86	688.20
Interest rate @9.79%	% of TVC	9.79%		0.00	0.00	0.00	0.00	0.00

ANNEX 6

FOREST PLANTATION HARVESTING RESIDUES AVAILABILITY

TABLE A19

AVAILABLE PLANTATION HARVESTING RESIDUES PER PLANTATION AND TREE SPECIES: VOLUME AND DENSITY

PLANTATION	SPECIES	RESIDUES (m^3)	RESIDUES DENSITY (m^3/ha)	RESIDUES (tonnes)	RESIDUES DENSITY (tonnes/ha)
NDOLA	*Pinus kesiya*	6 410	17.24	3 801	10.22
	Pinus oocarpa	19 862	23.21	10 924	12.77
	Pinus michocana	1 090	8.96	599	4.93
	Pinus merkusii	808	134.73	469	78.14
	Gmelia arborea	141	0.00	58	0.00
ICHIMPE	*Pinus kesiya*	14 528	19.98	8 615	11.85
	Pinus oocarpa	13 713	31.87	7 542	17.53
	Pinus michocana	0	0.00	0	0.00
	Pinus merkusii	1 851	39.73	1 073	23.04
	Eucalyptus cloeziana	131	3.76	94	2.69
	Eucalyptus grandis	101	4.96	68	3.32
CHATI	*Pinus kesiya*	12 154	48.88	7 207	28.99
	Pinus oocarpa	5 029	56.27	2 766	30.95
	Pinus michocana	801	31.93	441	17.56
	Pinus merkusii	1 455	35.65	844	20.68
	Eucalyptus grandis	242	0.00	162	0.00
	Eucalyptus grandis	1 447	2.71	970	1.82
	Eucalyptus cloeziana	642	1.85	459	1.32
LAMBA	*Pinus kesiya*	2 579	78.16	1 530	46.35
	Pinus oocarpa	0	0.00	0	0.00
	Pinus michocana	0	0.00	0	0.00
	Pinus merkusii	0	0.00	0	0.00
	Pinus kesiya	17 568	44.56	10 418	26.42
	Pinus oocarpa	0	0.00	0	0.00
	Pinus michocana	1 024	65.65	563	36.11
	Pinus merkusii	0	0.00	0	0.00
	Eucalyptus grandis	647	2.13	433	1.43
	Eucalyptus cloeziana	456	2.50	326	1.79
TOTAL / AVERAGE		**102 680**	**24.25**	**59 362**	**13.50**

ANNEX 7

WOOD PROCESSING RESIDUES RESULTS

TABLE A20

SURVEY RESULTS: AMOUNT AND TYPE OF WOOD PROCESSING RESIDUES PRODUCED BY SAWMILLS IN ZAMBIA

NO.	PROVINCE	DISTRICT	NUMBER OF FACILITIES INTERVIEWED	RESIDUES GENERATED	AVAILABLE RESIDUES	SAWDUST	CUT-OFF	OTHERS	CHIPS
				t/year	t/year	t/year	t/year	t/year	t/year
1	**EASTERN**	NYIMBA	3	24.76	1.6	0.76	0.84		
2	**COPPERBELT**	NDOLA	14	764.16	29.47	23.47		6	
3	**COPPERBELT**	KITWE	7	200.52	5.292	5.29			
4	**COPPERBELT**	MUFULIRA	8	620.32	65.97	58.59	7.38		
5	**LUSAKA**	LUSAKA	3	2 156.04	408.86	289.8	119.06		
6	**NORTH WESTERN**	SOLWEZI	4	33.24	1.26	1.26			
7	**NORTH WESTERN**	KABOMPO	2	1 486.8	74.34	30.24	44.1		
8	**NORTH WESTERN**	MANYINGA	1	480					
9	**WESTERN**	KAOMA	4	499.8	36.12	16.38	19.74		
10	**WESTERN**	MONGU	3	80.80	0.2				0.2
11	**WESTERN**	SENANGA	1	1 045.2	176.13	32.13	144		
12	**WESTERN**	SIOMA	3	599	76	76			
13	**WESTERN**	SESHEKE	4	918.6	305.07	106.47	198.6		
	TOTAL		**57**	**7 830**	**1 104**	**640.39**	**533.72**	**6**	**0.2**

ANNEX 8

PRICES COLLECTED IN THE COUNTRY AND USED IN BIOENERGY TECHNOLOGIES ASSESSMENT

TABLE A21

DATA COLLECTED FOR THE ENERGY END USE OPTIONS TECHNO-ECONOMIC ASSESSMENT

ITEM		VALUE	UNIT
RAW MATERIALS	METHANOL	500.00	USD/tonne
	NAOH	750.00	USD/tonne
	AMMONIA	524.00	USD/tonne
	YEAST	4 136.36	USD/tonne
	SULFURIC ACID	275.00	USD/tonne
	HEXANE	1 100.00	USD/tonne
	LIME	235.00	USD/tonne
	ALPHA-AMYLASE	15 000.00	USD/tonne
	GLUCOAMYLASE	3 500.00	USD/tonne
	COAL	55.00	USD/tonne
	BIODIESEL STORAGE COST	0.10	USD/litre/year
	ETHANOL STORAGE COST	0.10	USD/litre/year
	DDGS	100.00	USD/tonne
	OILSEED MEAL	120.00	USD/tonne
	MOLASSES PRICE	126.00	USD/tonne
CONSTRUCTION MATERIAL COSTS	BOLTS AND NUTS	0.05	USD/Pcs
	BRICKS	0.29	USD/Pcs
	CEMENT 50 kg BAG	4.54	USD/Bags
	CLOVES	1.22	USD/kg
	ELBOW (GI OR PVC)	0.60	USD/Pcs
	FLATS	0.49	USD/m
	G.I. 2" NIPPLE 1/2"	0.59	USD/Pcs

CONSTRUCTION MATERIAL COSTS	G.I. 6" NIPPLE 1/2"	0.59	USD/Pcs
	GAS TAP	8.83	USD/Pcs
	GAS PIPE GI	2.37	USD/m
	GI GAS OUTLET PIPE	2.37	USD/m
	GI SOCKET 0,5"	8.30	USD/Pcs
	GRAVEL	8.11	USD/m^3
	INLET PIPE	2.37	USD/m
	IRON ANGLE (5mm)	1.03	USD/m
	IRON BAR (Ø 6 AND 8)	0.31	USD/kg
	METAL ELBOW 1/2"	0.60	USD/Pcs
	METAL TUBE 1/2"	0.03	USD/cm
	MS PIPE	2.95	USD/m
	PRESSURE MANOMETER	335.92	USD/pcs
	PAINT	12.52	USD/litre
	PLASTIC HUB 1/2"	4.62	USD/Pcs
	PLASTIC VALVE 1/2"	4.20	USD/Pcs
	BICYCLE INNER TUBE	0.72	USD/m
	POLYETHELENE SHEET (0,2 mm THICK)	12.60	USD/m
	PVC ELBOW 1/2"	0.60	USD/Pcs
	PVC NIPPLE 1/2"	0.60	USD/Pcs
	PVC T 1/2"	0.59	USD/Pcs
	PVC TUBE 1/2"	2.97	USD/m
	PVC TUBE 6"	14.23	USD/m
	NET CYCLONE 4" FEET	33.52	USD/roll
	SAND	5.60	USD/m^3
	H2S FILTER	186.48	USD/pcs
	SQUARE PLATE	12.99	USD/Pcs
	TEE JOINT (GI, AL OR PVC)	0.83	USD/Pcs
	TEFLON	0.39	USD/Pcs
	TEFLON TAPE	0.36	USD/Rolls
	WATER DRAIN	12.50	USD/Pcs
	ZINC SHEETS	20.16	USD/kg
	GAS STOVE	24.28	USD/Pcs
	GAS LAMP	17.80	USD/pcs
	MIXER DEVICE	23.72	USD/pcs
	CONCRETE	93.67	USD/m^3
	METAL SHEET (THICKNESS 30 mm)	24.33	USD/m^2
	OIL DRUM (200 LITER)	30.00	USD/unit
	ANGLE IRON FOR FRAME 40 x 40 x 5 mm	24.00	USD/unit
	STEEL SHEET DENSITY	23.84	kg/m^2

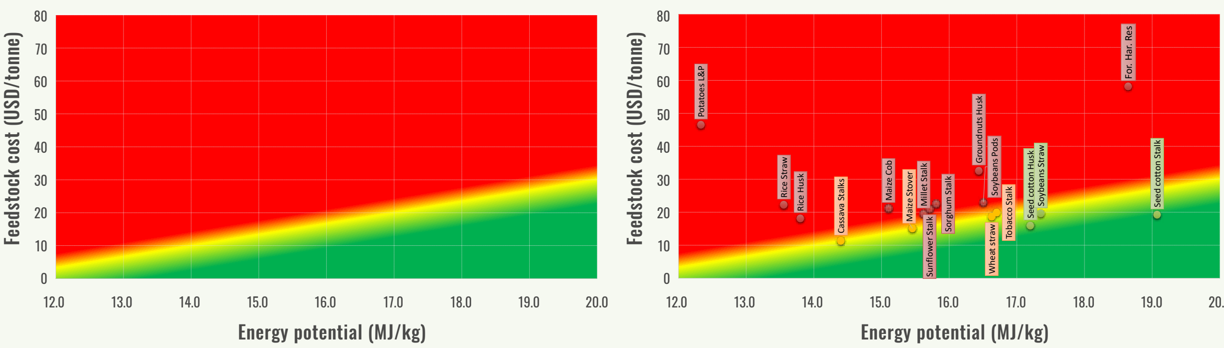
LOGISTICS	DISTANCE FROM PORT TO MAIN CITY	316.00	km
	PIPELINE TRANSPORT COST OF FUELS	0.02	USD/litre any fuel
		0.04	USD/litre gasoline
		0.05	USD/litre diesel
	BIOMASS AND CHARCOAL TRANSPORT PRODUCTION SITE TO ROAD	0.74	USD/tonne/km
	TRANSPORT ROAD TO MARKET	0.37	USD/tonne/km
	SHARE SS PRODUCERS	0.43	Assumed ss recieve price at production site
	SHARE LARGE PRODUCERS	0.83	Assumed ss recieve price at Market
UTILITIES	HEAT CARRIER	5.18	USD/tonne steam
	WATER	0.70	USD/m^3
	ELECTRICITY	0.42	USD/kWh
WAGES	UNSKILLED WORKER	0.50	USD/person-hour
	SKILLED WORKER	3.50	USD/person-hour
	AGRICULTURAL WORKER-FARM (UNSKILLED)	0.35	USD/h
	AGRICULTURAL WORKER-FARM (SKILLED)	1.38	USD/h
FUELS	BRIQUETTES/PELLETS – RURAL	0.00	USD/kg
	FUEL WOOD – RURAL	0.03	USD/kg
	CHARCOAL – RURAL	0.13	USD/kg
	KEROSENE – RURAL	0.95	USD/litre
	LPG – RURAL	1.76	USD/kg
	BRIQUETTES/PELLETS – URBAN	0.17	USD/kg
	FUEL WOOD – URBAN	0.84	USD/kg
	CHARCOAL – URBAN	0.17	USD/kg
	KEROSENE – URBAN	0.95	USD/l
	LPG – URBAN	1.76	USD/kg
	DIESEL FOB PRICE	0.48	USD/litre
	GASOLINE FOB PRICE	0.43	USD/litre
	BIODIESEL FOB PRICE	0.68	USD/litre
	ETHANOL FOB PRICE	0.47	USD/litre
	DIESEL ZAMBIA PRICE	1.03	USD/litre
	GASOLINE DIESEL PRICE	1.20	USD/litre

ANNEX 9

BUILDING OF PROFITABILITY ZONES MAPS

FIGURE A1

PROFITABILITY ZONE MAPS FOR CROP RESIDUES



In order to build the Profitability Zones Map (PZM), Algorithm 1 was developed. This method automatizes the graphic representation of the sensitivity analysis performed for the NPV over the biomass costs, energy potential, technology modifications, and generation capacity. The inputs of Algorithm 1 are the ordinary least square (OLS) regressions coefficients β1, β2, β0', β1', β2', β0'', β1'' and β2'', the minimum (minCost) and maximum biomass costs (maxCost), the minimum (minLHV) and maximum Lower Heating Values (maxLHV), the list of biomass options suitable for bioenergy production (biomassParametersList) and the numbers of points that will be used in each axis (mapResolution). For this example, the main variables used will be the Energy potential (as LHV) range (13–20 MJ/kg) and cost range (0–300 USD/tonne. The output is the profitability the zones map built under the specific techno-economic conditions of the country. These conditions are represented by the OLS coefficients which were previously obtained from the sensitivity analysis of the NPV results above-mentioned.

The algorithm starts defining the step sizes that later will be used in axis x and y increments (line 1). Then, it proceeds to initialize by making all variables equal to zero (lines 2-5). After this point, the algorithm runs a loop while the maxLHV and maxCost were reached. Within these loops, it was necessary to calculate the NPV for each technology modification using the OLS regression coefficients and the two defined variables values for each step (lines 10-12). Once obtained the NPVtech1, tech2, tech3 results, these values were normalized using a scoring system scoring as (-1) for negative NPVs, (1) for positive NPVs and (0) for NPVs =0 (lines 13-15). The summation of the scores obtained for each

ALGORITHM 1

ALGORITHM FOR CALCUATING THE PROFITABILITY ZONE MAPS

Algorithm 1 Calculate profitability zones maps

Input: $\beta_0, \beta_1, \beta_2, \beta'_0, \beta'_1, \beta'_2, \beta''_0, \beta''_1, \beta''_2$: ordinary least squares regression coeficients

$minCost$: minimum biomass cost

$maxCost$: maximum biomass cost

$minLHV$: minimum Lower Heating Value (LHV)

$maxLHV$: maximum Lower Heating Value (LHV)

$biomassParametersList$: list of biomass costs and LHVs for each biomass residues selected

$mapResolution$: number of points used in each axis to control the map graphical quality

Output: $profitabilityZoneMap$

\# Calculate increment size for x and y axis

$xAxisStep = \frac{maxLHV-minLHV}{mapResolution}$, $yAxisStep = \frac{maxCost-minCost}{mapResolution}$

\# Initialize variables

$profitabilityZoneMap.biomassItems = \emptyset$

$profitabilityZoneMap.gradient = \emptyset$ # space where colors to produce the gradient effect are stored

$LHV = \emptyset$ # variable to control the range of LHV values

$cost = \emptyset$ # variable to control the range of biomass cost values

\# Draw the heatmap background

$LHV = minLHV$

while ($LHV \leq maxLHV$) **do**

  $cost = minCost$

  while ($cost \leq maxCost$) **do**

   # Calculate Net Present Value for each technology variation

   $NPV_{tech1} = \beta_0 + \beta_1 * cost + \beta_2 * LHV$

   $NPV_{tech2} = \beta'_0 + \beta'_1 * cost + \beta'_2 * LHV$

   $NPV_{tech3} = \beta''_0 + \beta''_1 * cost + \beta''_2 * LHV$

   # Normalize the scores with the function $getScore$ as follows:

   # (0) if the input variable is 0

   # (1) if the input variable is > 0 or

   # (-1) if the input variable is < 0.

   $score_{tech1} = getScore(NPV_{tech1})$

   $score_{tech2} = getScore(NPV_{tech2})$

   $score_{tech3} = getScore(NPV_{tech3})$

   $cellScore = score_{tech1} + score_{tech2} + score_{tech3}$

   # Get background gradient

   if $cellScore == -3$ **then**

    $cellColor = RED$

   else if $cellScore == 3$ **then**

    $cellColor = GREEN$

   else

    # Use the $cellScore$ value to render a smooth transition

    # between RED and GREEN creating a gradient effect

    $cellColor = getColorGradient(RED, GREEN, cellScore)$

   end if

   # Assign the $cellColor$ within the $profitabilityZoneMap.gradient$

   $profitabilityZoneMap.gradient[LHV][cost] = cellColor$

   $cost = cost + yAxisStep$

  end while

  $LHV = LHV + xAxisStep$

end while

\# Populate the gradient with the $biomassParametersList$

for all $item \in biomassParametersList$ **do**

  # Place each parameter within the $profitabilityZoneMap.biomassItems$

  # according to its LHV and $cost$ including a label with its name

  $profitabilityZoneMap.biomassItems.append(item.LHV, item.cost, item.label)$

end for

$draw(profitabilityZoneMap)$

technology variation was defined as the cellscore (lines 16). According to the value obtained in the cellscore, it was possible to obtain a maximum of 3 and minimum of -3. In the first case, the cell was assigned with a green color while in the second case red. The colors for all values in between were automatically generated by a gradient color function (lines 17-23). The loops are repeated for each increment of cost and LHV variables defined by the yAsixStep and xAxisStep, respectively. Once the loop generates the gradient map, the next step was to populate the map with the biomassParametersList, where the specific cost and LHV values of each entry helped the algorithm to locate them in the gradient map. Moreover, the name of each biomass residue was used as the label of the point generated (lines 29-31). Finally, the algorithm draws the map containing the gradients which represent the profitability zones with the biomass residues located in it (line 32).

Algorithm 1 was implanted in a visual basic macro for Microsoft Excel. As follows it is provided a numerical example of the calculations to obtain the cellcolor results.

TABLE A22

EXAMPLE OF CALCULATIONS FOR OBTAINING THE PROFITABILITY ZONE MAPS

LHV = 13, COST 150	LHV = 13, COST 75	LHV = 13, COST 50
NPV TECH 1 = -26.94E6 NPV TECH 2 = -22.4E6 NPV TECH 3 = -20.2E6 SCORE TECH1 = -1 SCORE TECH2 = -1 SCORE TECH3 = -1	NPV TECH 1 = -7.05E6 NPV TECH 2 = -2.51E6 NPV TECH 3 = 0.26E6 SCORE TECH1 = -1 SCORE TECH2 = -1 SCORE TECH3 = 1	NPV TECH 1 = -0.42E6 NPV TECH 2 = 4.13E6 NPV TECH 3 = 6.36E6 SCORE TECH1 = -1 SCORE TECH2 = 1 SCORE TECH3 = 1
CELL SCORE = - 3	**CELL SCORE = - 2**	**CELL SCORE = 2**
CELLCOLOR = RED	CELLCOLOR = YELLOW	CELLCOLOR = GREEN

ANNEX 10

BIOMASS SAVINGS FROM IMPROVED CHARCOAL TECHNOLOGIES

FIGURE A2

BIOMASS SAVINGS OBTAINED FROM USING SMALL SCALE IMPROVED CHARCOAL TECHNOLOGIES COMPARED TO TRADITIONAL OPTIONS

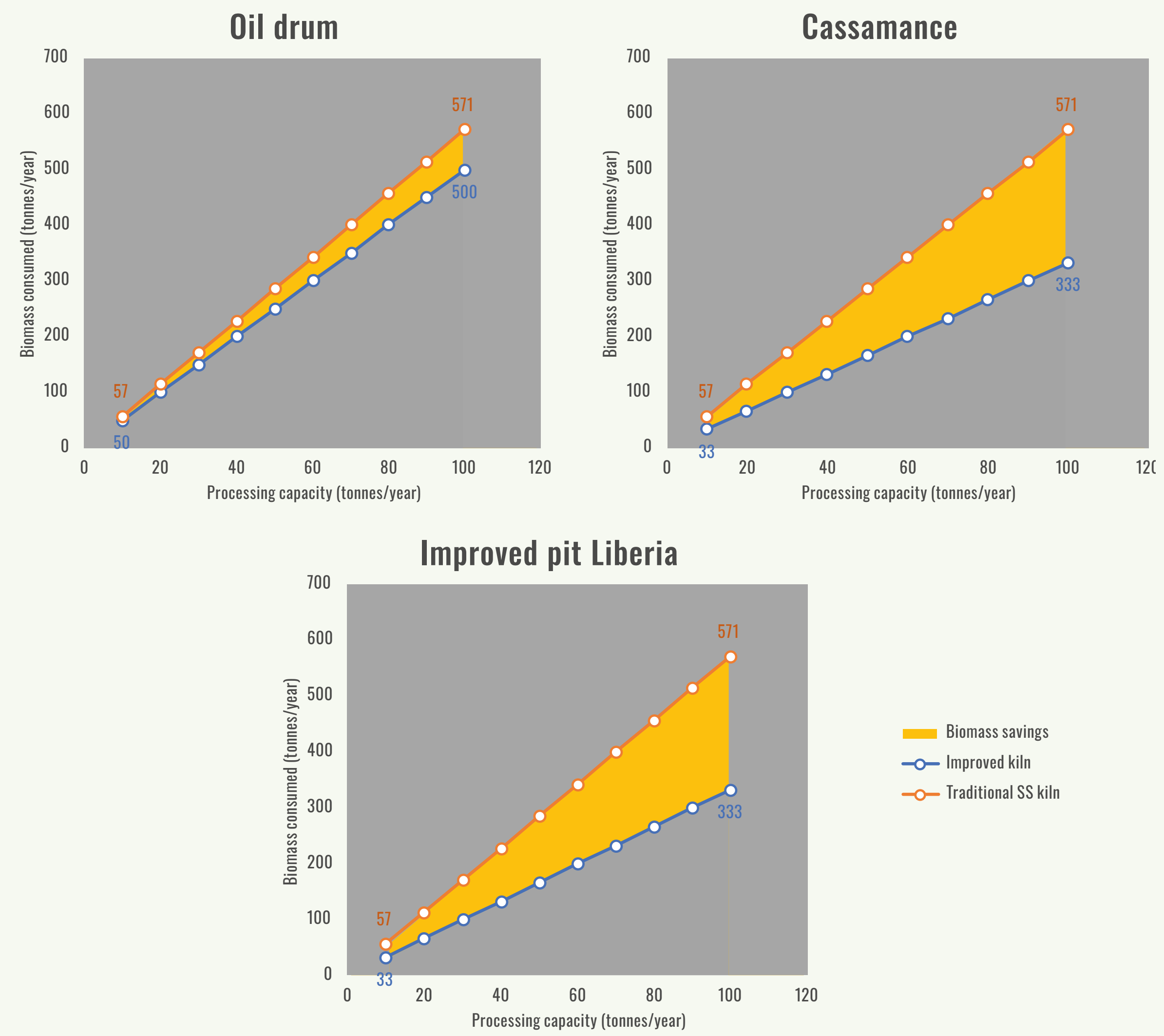
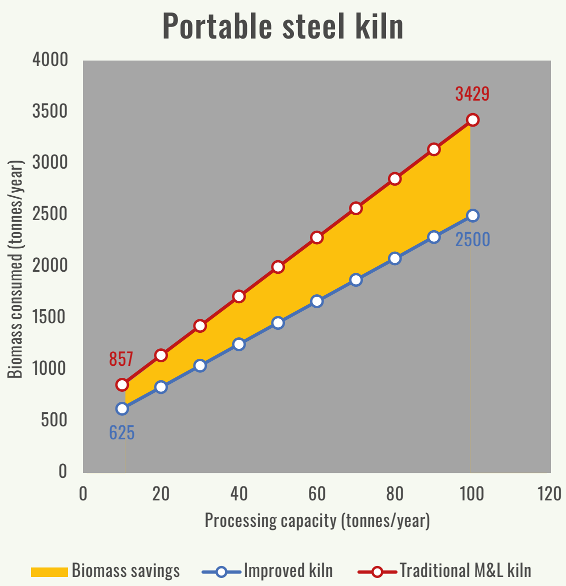


FIGURE A3

BIOMASS SAVINGS OBTAINED FROM USING MEDIUM SCALE IMPROVED CHARCOAL TECHNOLOGIES COMPARED TO TRADITIONAL OPTIONS



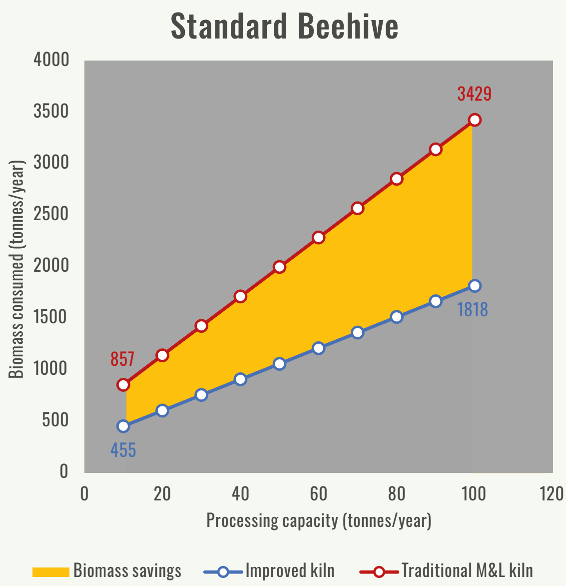
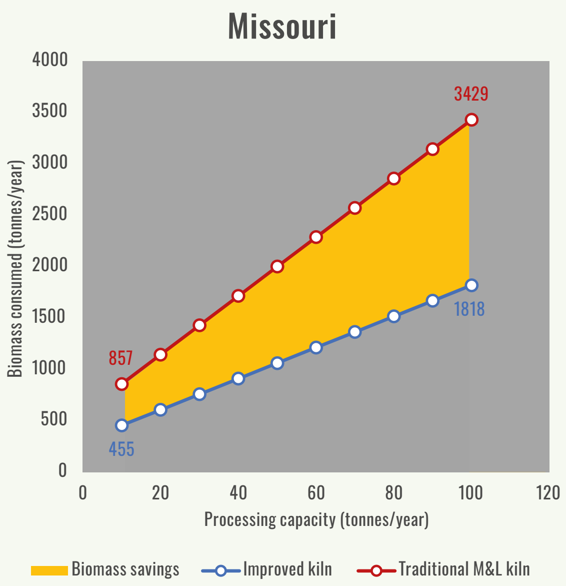
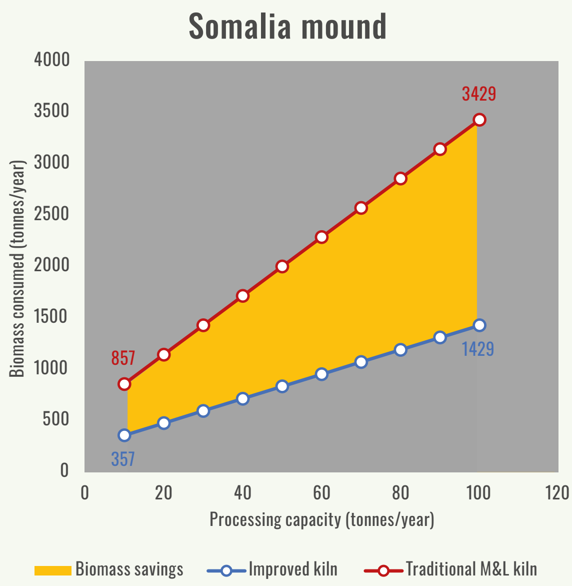


FIGURE A4

BIOMASS SAVINGS OBTAINED FROM USING LARGE SCALE IMPROVED CHARCOAL TECHNOLOGIES COMPARED TO TRADITIONAL OPTIONS





ANNEX 11

PROFITABILITY ZONES MAPS FOR IMPROVED CHARCOAL TECHNOLOGIES

FIGURE A5

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING OIL DRUM TECHNOLOGY

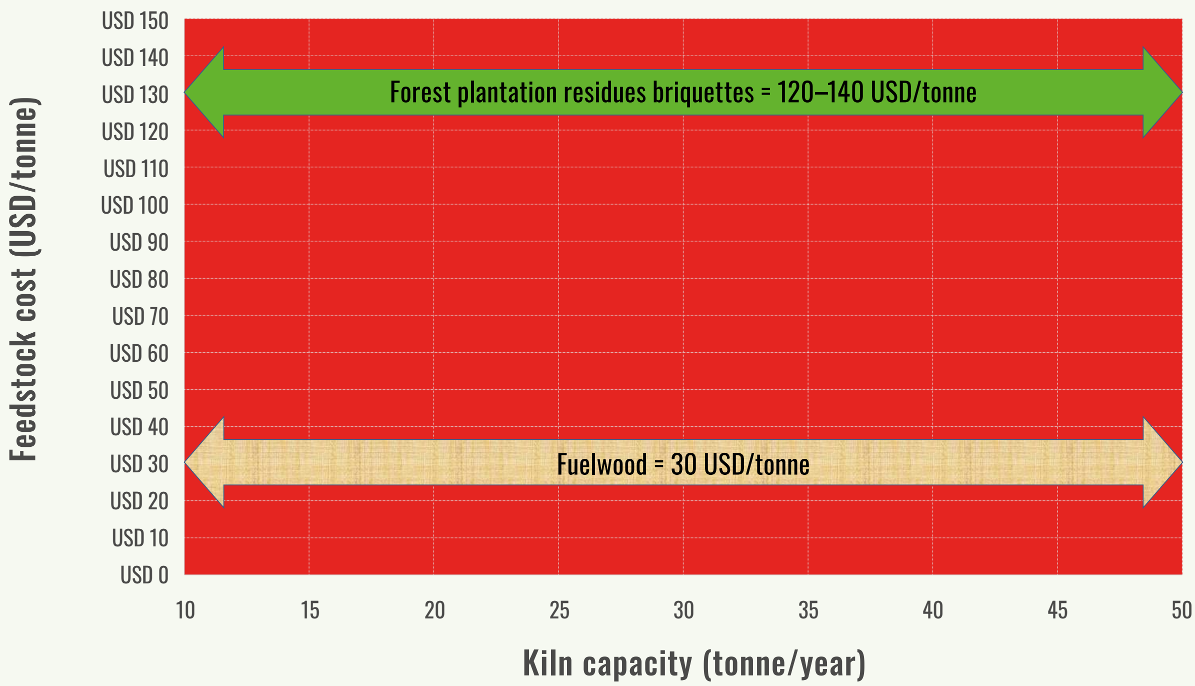


FIGURE A6

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING CASSAMANCE TECHNOLOGY

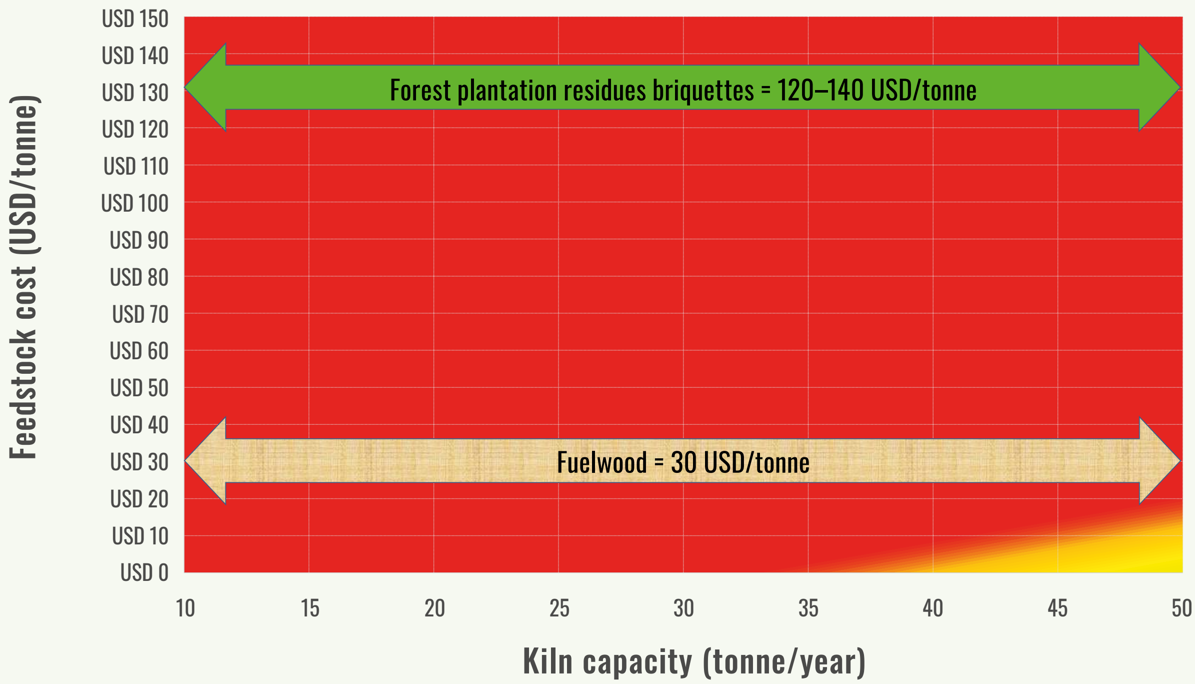


FIGURE A7

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING IMPROVED LIBERIA PIT TECHNOLOGY

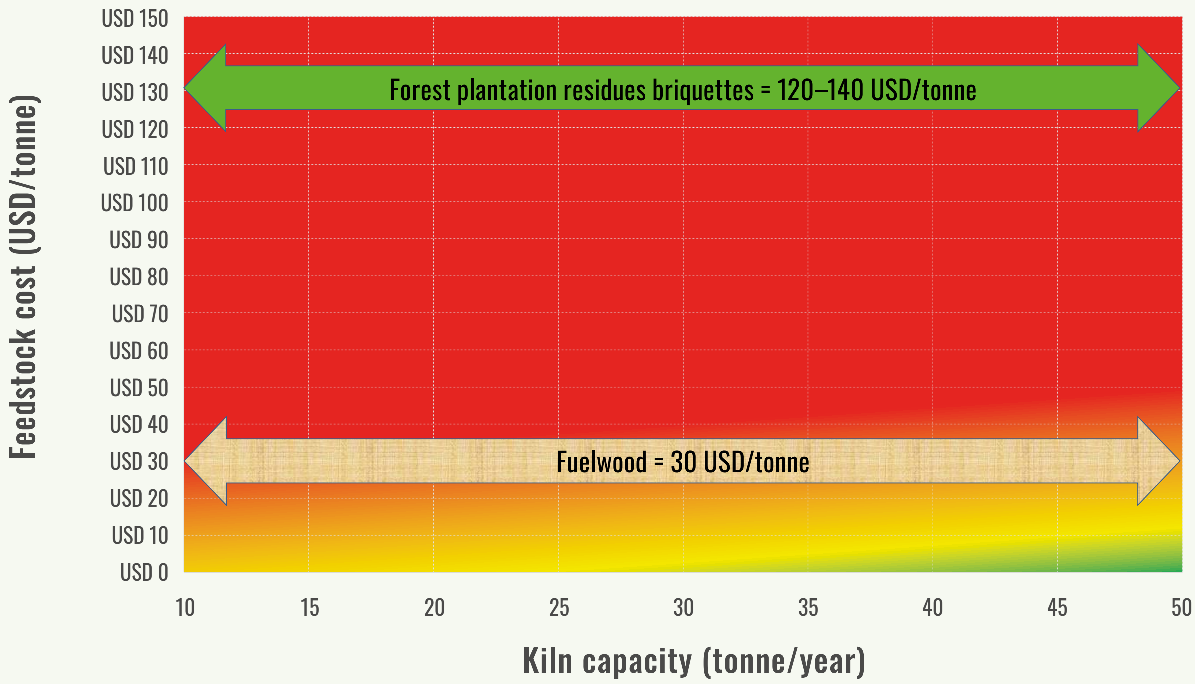


FIGURE A8

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING PORTABLE STEEL KILN TECHNOLOGY

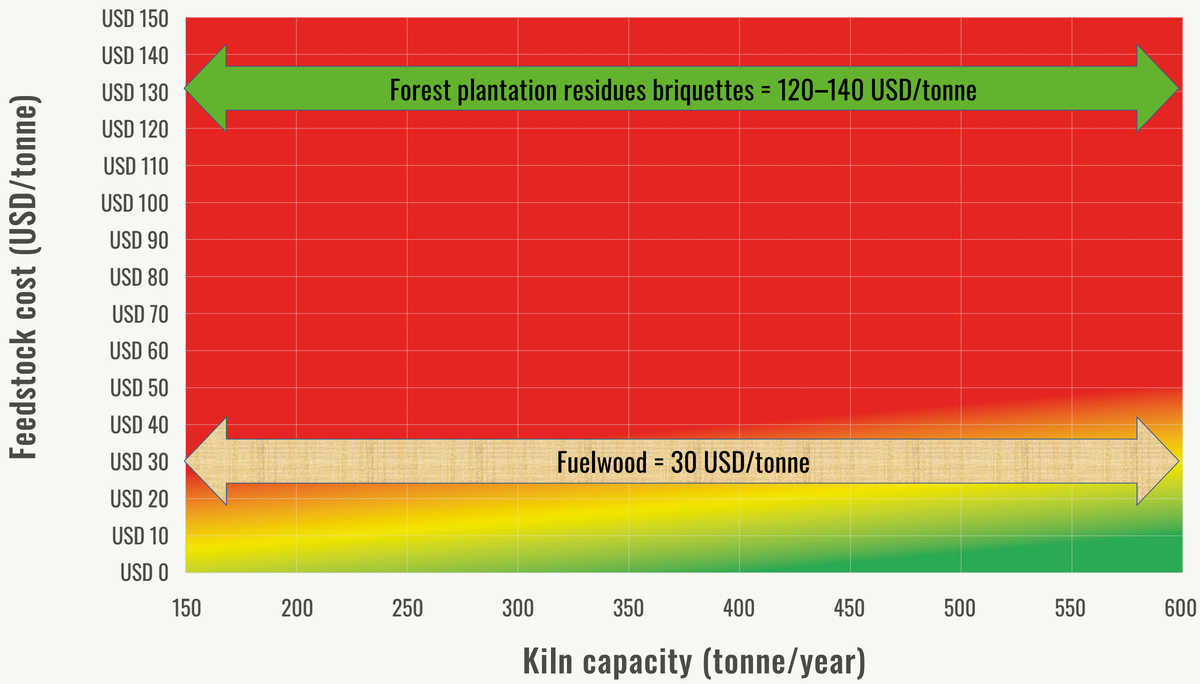


FIGURE A9

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING STANDRAD BEEHIVE KILN TECHNOLOGY

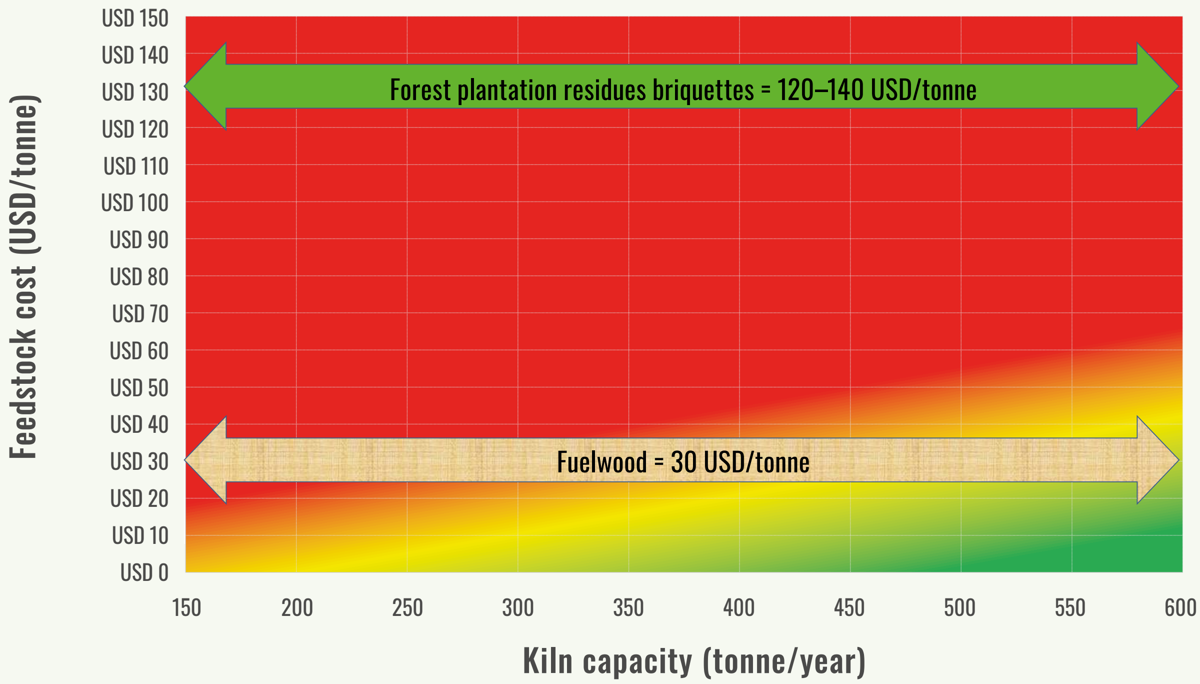


FIGURE A10

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING MISSOURI KILN TECHNOLOGY

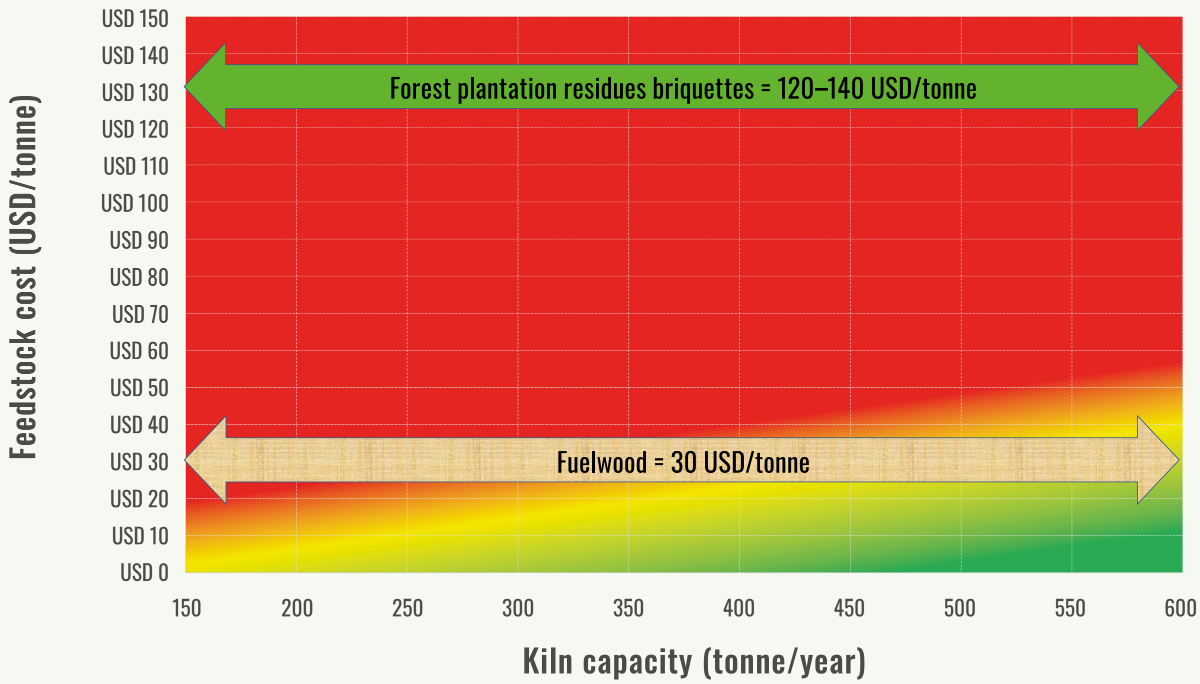
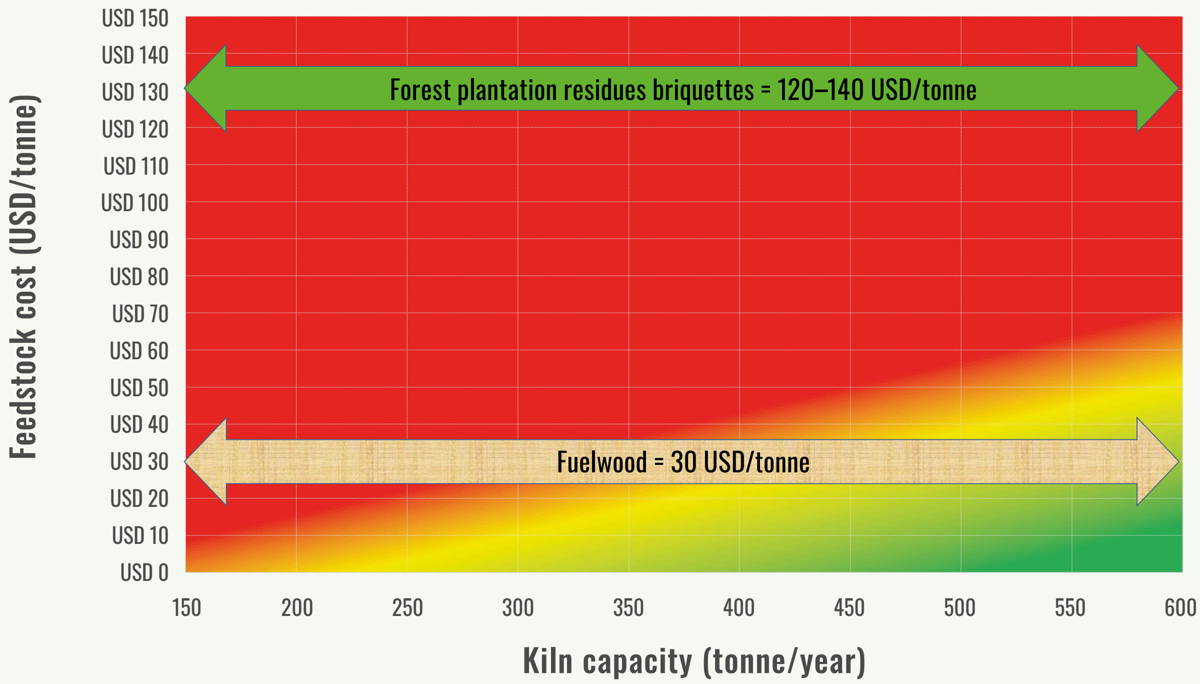


FIGURE A11

PROFITABILITY ZONES MAP FOR CHARCOAL PRODUCTION IN ZAMBIA USING SOMALIA MOUND KILN TECHNOLOGY



Zambia is richly endowed with a wide range of biomass sources including woodlands, forests, agricultural residues and livestock waste. Biomass based energy contributes significantly to the country's total energy consumption supplying over 70 percent of the country's energy needs. Woodfuel provides reliable and readily available energy and is also an important source of livelihood employing approximately 500 000 people along various stages of the charcoal value chain.

Due to the current extraction and consumption methods, the use of biomass energy has been linked with detrimental environmental effects such as deforestation and forest degradation as well as climate change, due to the loss of carbon sinks. Inefficient utilisation of biomass contributes significantly to deforestation which is estimated at between 79 000–150 000 ha per year, and negatively affects the health and income of rural households that depend on forest products for their livelihoods.

The situation is exacerbated by the fact that access to sustainable energy forms is still limited. For example, only 31 percent of the population has access to electricity. In addition Zambia, like many countries in sub-Saharan Africa, has experienced increasingly unreliable rainfall patterns and more frequent and prolonged droughts over the past two decades, with climate change impacts increasing. For a country heavily reliant on hydropower, this has reduced the country's capacity to generate power.

Unsustainable woodfuel production coupled with limited access to energy has added increasing pressure on biomass resources in Zambia. Sustainable bioenergy strategies and alternative bioenergy solutions need to be defined and integrated into current efforts of the country to increase stable and sustainable access to energy. This report assesses the country context and defines which bioenergy options can be viable considering a number of solutions for electricity production, cooking fuels and transport fuels at the provincial and district level. Possible options originating from crop residues, livestock residues and forest plantation harvesting residues are identified, having netted out agriculture and forestry needs. The assessment now needs to be followed by local verification and investment to deploy an initial set of bioenergy projects and test the findings on the ground.

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