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Crop residues as a potential renewable energy source for Malawi's cement industry

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Abstract

Crop residues have been undervalued as a source of renewable energy to displace coal in the national energy mix for greenhouse emission reduction in Malawi. Switching to crop residues as an alternative energy source for energy-intensive industries such as cement manufacturing is hampered by uncertainties in crop residue availability, cost and quality. In this study, future demand for energy and availability of crop residues was assessed, based on data at the sub-national level. Detailed energy potentials from crop residues were computed for eight agricultural divisions. The results showed that the projected total energy demands in 2020, 2025 and 2030 were approximately 177 810 TJ, 184 210 TJ and 194 096 TJ respectively. The highest supply potentials were found to be in the central and southern regions of Malawi, coinciding with the locations of the two clinker plants. Crop residues could meet 45–57% of the national total energy demand. The demand from the cement industry is only 0.8% of the estimated biomass energy potential. At an annual production of 600 000 t of clinker and 20% biomass co-firing with coal, 18 562 t of coal consumption would be avoided and 46 128 t of carbon dioxide emission reduction achieved per year. For sustainability, holistic planning and implementation would be necessary to ensure the needs of various users of crop residues are met. Furthermore, there would be a need to address social, economic and environmental barriers of the crop residue-based biomass energy supply chain. Future research should focus on local residue-to-product ratios and their calorific values.

Keywords: *biomass energy, clinker, energy-intensive industry, coal, CO_2 emissions*

Highlights

- *Crop residues are an under-exploited renewable energy source in Malawi.*
- *A potential substitute for coal in the cement industry is crop residues.*
- *Crop residues could meet about 50% of Malawi's energy demand.*
- *There is need for a holistic approach before a roll-out.*

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1. Introduction

1.1 Background

Biomass energy plays a significant role in human civilisation, and provided energy for about 2.6 billion people in 2012 (OEDC/ IEA, 2014). In 2016, global use of biomass energy was about 50 exajoules (EJ) (World Energy Congress, 2016). Biomass energy sources are rarely accounted for in national energy statistics despite their long history and increased interest in biomass energy research (Bentsen et al., 2014; OEDC/ IEA, 2014). The sustainable utilisation of biomass energy is in line with global strategies to reduce greenhouse gas (GHG) emissions (IPCC, 2011; United Nations Framework Convention on Climate Change, 2015).

As a renewable energy source, biomass energy, by replacing fossil fuels, has the potential to reduce GHG emissions from energy-intensive industries. Fossil fuels and industrial processes emit more than 60% of total global GHGs, of which the cement industry alone accounts for 5-7% (Benhelal et al., 2013). The cement industry is increasingly applying some best available technologies (BATs) in its effort to promote use of low-carbon technologies to displace coal and petroleum coke with alternative fuels for energy-intensive clinkering (Chinyama, 2011; WBCSD, 2014; CEMBUREAU, 2015). The rates of adoption of best available technologies are, however, not uniform. They range from 20% in sub-Saharan Africa to over 80% in European cement companies (Ionita et al., 2013). Uncertainties relating to availability, quality, cost, human capacity and impact of the alternative fuels on the final product are among the main reasons for this low uptake (Montalvo, 2007; Rahman et al., 2015).

The main objective of this study was to assess potential of biomass energy from crop residues as a low-carbon fuel for co-processing with coal in the Malawian cement industry. The study consolidated and built on previous biomass energy assessments by local and international experts (Lal, 2005; Jingura & Matengaifa, 2008; Duku et al., 2011; Owen et al., 2009; Zalengera et al., 2014; Bentsen et al., 2014). Unlike most of the previous studies, which used national data for assessment and projects, and not site specific data (Food and Agriculture Organisation (FAO), 2013; Bentsen et al., 2014; OEDC/ IEA, 2014), this study improves the accuracy of the projections by using data at subnational level. There are no local studies at that level, and projections were made on energy potential from the crop residues that could displace coal use in cement industry. This study is part of a wider and in-depth effort to model low-carbon manufacturing pathways for the cement industry in Malawi. Research in low-carbon manufacturing complements government's effort to reduce carbon dioxide emissions (Government of Malawi (GoM), 2015a; 2015b).

1.2 Malawi context

Malawi lies in the southern tip of the great East African Rift Valley and shares borders with Tanzania, Mozambique and Zambia. It is 118 484 square kilometres (km^2) in area, including 24 000 km^2 of water bodies (GoM, 2014). The country is divided into three geographical regions (North, Centre and South) and 28 administrative districts. The last population census, of 2008, reported 13.1 million people, the number is growing at 2.8% per annum and projected to reach 17.3 million in 2017, 19.1 million in 2020, 22.4 million in 2025, and 26.1 million in 2030 (National Statistical Office (NSO), 2008).

Malawi's National Energy Policy (NEP) was launched in 2003 with the aim of catalysing a holistic use of energy sources and supplies (GoM, 2003). This was followed by enactment of energy laws in 2004 (GoM, 2006). Although Malawi's energy supply is dominated by biomass energy in the form of firewood, charcoal and crop residues that meets the energy demand of over 80% of households (Owen, et al., 2009; Makungwa et al., 2013), there are no specific policies and strategies on biomass energy supply (Zulu, 2010; Gamula et al., 2013; Owen et al., 2013). Firewood and charcoal from unsustainable sources are among the major causes of deforestation and environmental degradation in Malawi (Hudak & Wessman, 2000; Zulu, 2010). In the period 2014 to 2015, Malawi's access to electricity was estimated to be between 10% and 12% of the total population (GoM, 2015a; Taulo et al., 2015; NSO & ICF, 2017; Sustainable Energy for All-Africa Hub, 2017; World Bank, 2017a). Grid electricity is from hydro and, in 2016; the generation capacity was 351 megawatts (MW) against a suppressed demand of 855 MW (GoM, 2016). Although there have been no major investments in electricity generation for many years, the future has looked promising since many private investors entered the power generation market (GoM, 2016). In order to meet increasing demand for energy in general and electricity in particular, there has been a need to assess the full diversity of energy resources in Malawi, such as biomass, coal, hydro, solar, wind, geothermal, petroleum and nuclear. A Draft National Energy Policy, which is still under review, is expected to provide the required stimulus in the energy sector.

The agricultural sector accounts, on average, for about 30% of the gross domestic product, 76% of national exports, 78% of total employment, and supports 90% of people's livelihoods (FAO, 2015). The Ministry of Agriculture (MoA) provides policy direction for the agricultural sector, which is administratively decentralised into eight agricultural development divisions (ADDs), which operate through district agriculture development offices (DADOs) in the districts. Within each DADO, there are several extension planning areas (EPAs) and blocks, the level at which extension services are provided to smallholder farmers (Future Agricultures, 2008). There are a total of 153 EPAs and eight blocks per EPA. This setup provides an effective structure for data collection at farmers' level. This study examined data from the agriculture sector at ADD level to assess the availability and technical feasibility of using crop residues as an alternative fuel for the cement industry.

2. Methodology

2.1 Research scope

The study covers crop residues from maize, rice, tobacco, cotton and cassava only. Although the objective was to assess potential for industrial use of biomass energy in cement industry, a more holistic assessment of demand and supply was made to find out what contribution crop residues could make to the total energy supply and to ensure that crop residues demand for other uses were also taken into account. The total energy demand projections were based on published work (Taulo et al., 2015), where projections were made using model for analysis of energy demand.

2.2 Data collection

The main source of secondary data was the MoA's 1997 to 2015 annual crop production estimates, and other data at ADD level. The study covered all ADDs: Karonga and Mzuzu in the Northern Region, Kasungu, Lilongwe and Salima in the Central Region, and Machinga, Blantyre and Shire Valley in the Southern Region. Other data and conversion factors were sourced from NSO publications, FAO reports, manuals, handbooks and other published literature from credible online and printed sources, which were cited accordingly.

2.3 Data analysis and assumptions

There are many studies on national and global biomass availability, but only a few of these consider technical availability of the biomass and subnational variation in crop yields (Owen et al., 2009; Duku et al., 2011). Work published in Bentsen et al. (2014) asserted that most of the global and national studies show great variations in the reported figures of biomass energy assessments due to 'crude assumptions' and that there is therefore need for a critical review and refinement of the conventional methodology to minimise errors.

This section uses findings from the studies by Owen et al. (2009), Zalengera et al. (2014) and Bentsen et al. (2014) to improve the accuracy and reliability of the national energy estimates. The following steps were used in estimating energy potential of the crop residues:

- mean yield for a crop was calculated as the sum of production at ADDs divided by the area cultivated;
- residue to product ratios (RPRs) for maize and rice were calculated using formulae developed by Bentsen et al. (2014) as in Equations 1 and 2.

  $$\text{Maize: } RPR_{maize} = 2.656 \times e^{(-0.000103 \times Y)} \quad (1)$$

  $$\text{Rice: } RPR_{rice} = 2.45 \times e^{(-0.000084 \times Y)} \quad (2)$$

  where Y is crop yield in kilograms per hectare.

- Other RPRs, lower heating value (LHV) and average moisture content were based on literature (Lal, 2005; Biopact, 2006; Jingura & Matengaifa, 2008; Duku et al., 2011; Bentsen et al., 2014; Zalengera et al., 2014).

Energy potential from crop residues was based on Equation 3.

$$\text{Energy: } R_{residue} = M_{crop} \times RPR_{crop} \times CV_{crop} \quad (3)$$

where $E_{residue}$ is the energy potential of residues from a specific crop; M_{crop} is the tonnage of the crop produced; RPR_{crop} is the residue to product ratio for the crop; and CV_{crop} is lower heating value of the crop residue.

2.4 Cement manufacturing process

A simplified cement process flow diagram is shown in Figure 1, derived from widely available detailed sources. The process consists of four stages: quarrying, material preparation, clinkering and milling.

Quarrying in Stage 1 involves raw material such as limestone, clay, bauxite and iron. The materials are then crushed, weighed, milled and mixed in Stage 2. The mixture flows into Stage 3 where exhaust gases provide preheating, then enter the pre-calciner for further heating to about 800 °C. During this stage, calcination takes place, where limestone ($CaCO_3$) decomposes into calcium oxide or lime (CaO) and carbon dioxide (CO_2). The mixture of lime, silica, alumina and iron oxide is then heated further in a kiln to 1450 °C where reaction occurs to form new compounds comprising silicates, ferrites and aluminates of calcium. The intermediate product that is made from the compounds of calcium is called clinker. Coal, a carbon-intensive fossil fuel that releases CO_2 upon combustion, is used as the main fuel for this clinkering stage. The CO_2 emissions from the cement industry are, therefore, both process- and fuel-based.

2.5 An overview of the cement industry in Malawi

There are three cement plants in Malawi, namely, Lafarge Cement Malawi Limited (Lafarge), Shayona Cement Corporation (Shayona), and Cement Products Limited (CPL). The companies

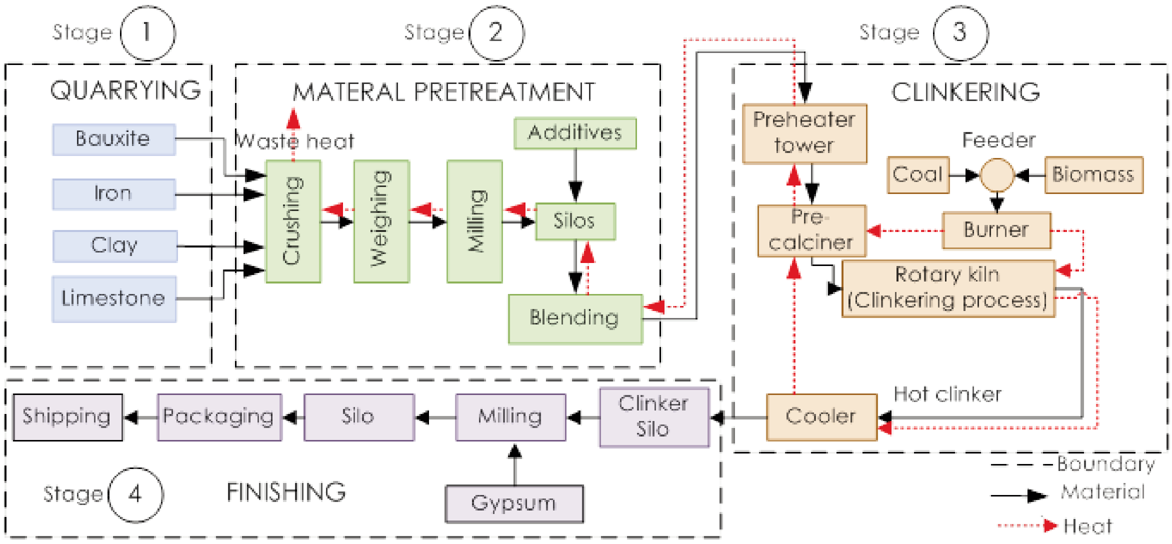

Figure 1: Material and thermal energy flows in the cement manufacturing process (Taylor, 1997; Labahn & Kohlhaas, 1983; Deolalkar, 2009; CEMBUREAU, 2015).

use imported clinker to produce cement because local production capacity is not able meet the needs of the cement industry. Shayona and CPL have recently invested in clinker production plants to meet their demand. The nature of operations is summarised in Table 1.

Malawi is expected to have capacity to produce more than 600 000 t of clinker per year when operating at full capacity once the new plants are commissioned by 2020, allowing for downtimes for maintenance and other losses (Chinamulungu, 2015; Jimu, 2015).

3. Results and analysis

3.1 Biomass energy demand

The NEP classifies energy users as households, agriculture, industry, transport and services (Government of Malawi, 2003). The categories were reduced to four for the purpose of comparison, by combining manufacturing industry and agriculture as industrial users (Owen et al., 2009). Figures 2 and 3 show energy demand based on the four user groups.

Figures 2 and 3 indicate that household was the largest energy user group at 84% in 2002 and 83% in 2008. Although the NEP had projected a steady decline in biomass in the energy mix, in reality it was only a slight decline during the period.

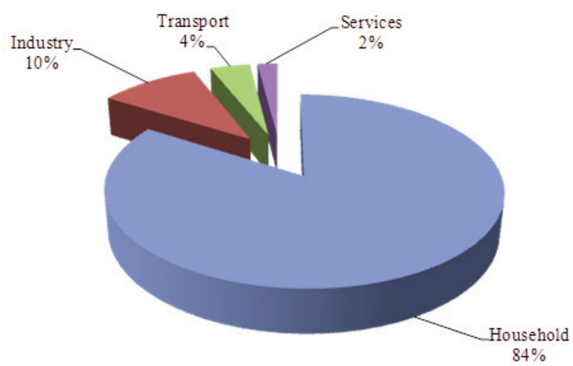

Figure 2: Malawi's energy demand in 2002 (Government of Malawi, 2003).

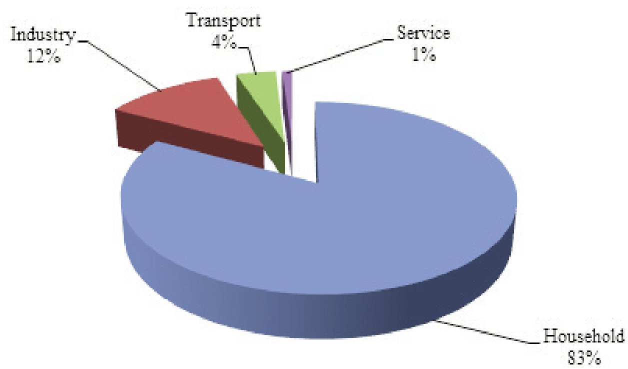

Figure 3: Malawi's energy demand in 2009 (Owen, et al. 2009).

Table 1: Cement plants in Malawi (Chinamulungu, 2015; Jimu, 2015; CemNet.com, 2017).

Name	Location	Status
Lafarge	Blantyre, Southern Region	Closed its clinker plant in 2002 and now operates only a milling plant using imported clinker.
Shayona	Kasungu, Central Region	Operates vertical shaft kilns to produce clinker and imports additional clinker. A rotary kiln is being installed with capacity to produce 1000 tonnes (t) of clinker per day.
CPL	Mangochi, Southern Region	Operates only a milling plant using imported clinker while a rotary kiln is being installed to produce 1000 t of clinker per day.

Table 2: Total energy demand in TJ (Taulo et al., 2015).

Energy user group	*Annualgrowth rate*	*Base year 2008*	*Projections 2020*	*2025*	*2030*
Household	-0.86	144 668	130 425	124 912	119 632
Industry	4	14 948	23 932	29 117	35 425
Transport	6.04	8 648	17 480	23 436	31 423
Service	2.46	4 462	5 973	6 745	7 616
Total	–	172 726	177 810	184 210	194 096

According to the NSO Third Integrated Household Survey of 2012 and the United Nations Development Programme Human Development Report of 2016 on Malawi, the poverty level has stagnated around 50% for many years (NSO, 2013; United Nations Development Programme, 2016). The poverty status is further confirmed in the report by the World Bank (2017b), which states, 'poverty in the rural is rising and majority of the poor remain locked in low productivity subsistence' (World Bank, 2017b). Due to poverty, the majority of the rural poor depend on firewood for their own use and sale (Kamanga et al., 2009).

The energy mix is expected to change because there are plans to massively expand electricity generation capacity between 2020 and 2030 to attract investments in the industrial sector (GoM, 2016). Table 2 shows the energy demand projections for the four main energy user groups.

Three energy demand scenarios were done: reference, moderate and accelerated growth. The moderate demand scenario was chosen for the study, where it was found that the demand from households would decline from 83% to 61% of the total between 2008 and 2030 (Taulo et al., 2015). This was attributed to the decline in the contribution of biomass energy in the energy mix. However, total energy demand was expected to grow from 172 726 TJ in 2008 to 194 096 TJ by 2030.

Various studies (Madlool et al., 2011; Rahman et al., 2013; UNDP/UNEP/UNEP Risøe Centre, 2008) have shown that the energy required to produce one tonne of clinker in the dry process ranges from 2.9 GJ to 4.6 GJ, although the final value depends on kiln technology and energy efficiency (Madlool et al. 2011). Using an energy intensity of 4.0 GJ/t clinker, the target annual volume of 600 000 t of clinker would require 2 400 million GJ of energy for the clinkering process, as presented in Table 3.

Table 3: Projected demand biomass energy for cement industry.

Description of quantities	*Amounts*
Annual cement production (t)	600 000
Energy intensity (TJ/t of clinker)	0.004
Energy required for clinkering (TJ)	2400
Amount of energy to be replaced(TJ)	480
Calorific value of coal* (TJ/t)	0.025
Emission factor† (t/TJ)	96.1
Amount of coal displaced (t)	18 562
CO_2 emission avoided (t)†	46 128

* National Energy Policy (GoM, 2003)
† Emission factor from IPCC (2006: Table 2.2)

By 2020, the energy demand from cement at 20% coal replacement represented only 0.27% of the total energy demand or 2% of industrial user demand. Table 3 also shows that 46 128 t of CO_2 per annum could be avoided if crop residues were used to displace coal in the clinkering process.

3.2 Biomass energy supply

3.2.1 Crop production estimates

Table 4 presents crop production figures based on the averages from 1997 to 2015, while Table 5 shows only the production in 2015.

The crop production figures are of similar magnitude, with the exception of cassava, which recorded a 63% rise when the average crop production is compared with 2015 crop production. The percentage contribution of cassava in overall biomass fuel is, however, quite low at RPR value of 0.2, so would not significantly influence results of 2015. The long-term mean for the period 1997 to 2015, therefore, still remains a good indicator of what a typical production year would look like when estimating ener-

Table 4: Crop production in agriculture development divisions averaged from 1997 to 2015 (t/year).

Crop	*Agriculture development division*								*Nat. total*
	Karonga	*Mzuzu*	*Kasungu*	*Salima*	*Lilongwe*	*Machinga*	*Blantyre*	*Shire Valley*	
Maize	80 502	251 934	533 349	126 785	537 309	348 095	383 913	59 403	2 321 289
Rice	16 588	5 127	787	15 803	6 146	25 970	11 857	7 592	89 223
Tobacco	2 945	22 143	42 625	2 683	28 025	10 470	5 200	19	114 109
Cotton	2 958	168	1 282	13 261	4 280	18 851	4 795	25 042	70 437
Cassava	258 183	718 273	289 007	565 725	222 122	320 890	546 022	15 938	3 026 159

Table 5: Crop production in agriculture development divisions for the year 2015 (t).

Crop	*Agriculture development division*								*Nat. total*
	Karonga	*Mzuzu*	*Kasungu*	*Salima*	*Lilongwe*	*Machinga*	*Blantyre*	*Shire Valley*	
Maize	119 772	206 248	524 618	111 298	578 044	203 618	385 777	30 432	2 159 807
Rice	19 537	4 153	326	16 334	3 541	21 352	18 410	10 249	93 901
Tobacco	4 414	25 808	40 405	1 905	33 332	5 419	4 304	0	115 587
Cotton	5 580	60	911	13 794	6 322	19 114	5 491	27 776	79 048
Cassava	518 544	1 009 359	556 326	876 347	364 557	396 136	1 217 275	19 335	4 957 879

gy potential in a typical year or making a rapid energy assessment for an ADD. The consistency in annual crop production implies predictable crop residue availability.

3.2.2 Crop residues to production ratios and lower heating value estimates

There is need to provide RPRs and LHVs for each crop to estimate energy potential from crop residues, as was shown in Equation 3. Table 6 shows RPR values (Lal, 2005; Duku et al., 2011; Biopact, 2006; Zalengera et al., 2014; Jingura & Matengaifa, 2008), while Table 7 shows LHVs for maize, rice, tobacco, cotton and cassava (Duku et al., 2011; Biopact, 2006; Zalengera et al., 2014; Bentsen et al., 2014; Jingura & Matengaifa, 2008). In Table 6, the RPR values for maize and rice were calculated using formulae in Bentsen (2014), as given in Equations 1 and 2, while the RPR values for tobacco, cotton and cassava were sourced from values used for the local study by Zalengera et al. (2014). For consistency, the lower heating values in Table 7 were also sourced from Bentsen et al. (2014) and Zalengera et al. (2014), with the exception of cassava which was sourced from Biopact (2006) as it was not considered in the study by Zalengera et al. (2014).

3.2.3 Total energy potential from crop residues

Table 8 shows the energy potential based on the crop production averaged for the period 1997 to 2015. Data used was from Tables 5, 6 and 7. In a typical year, Lilongwe, Kasungu, Blantyre and Machinga ADDs were the top four maize-producing areas, accounting for 77.7% of the total energy from maize crop residues.

3.2.4 Energy projections: 2020–2030

It was necessary to compute crop production estimates to determine the projections. Maize was selected for detailed analysis because of its huge biomass resource potential. It accounted for 82.1% of biomass energy and it was grown nationwide by 97% of smallholder farmers. This is in line with global patterns, where maize is one of the largest sources of crop residues used for biomass energy (Eisentraut, 2010). For the remaining crops, which accounted for only 17.9% of the crop volume, it was assumed that the increase was proportional to the percentage increase in the cultivated area for a given scenario. The following assumptions were made to project crop production:

- Maize is Malawi's staple food, with a per capita consumption of 133 kg (Minot, 2010). It was assumed that the government would continue to meet food security by ensuring that the

Table 6: Residue-to-product ratios for various crops.

Crop	*Lal (2005)*	*Duku et al. (2011)*	*Biopact (2006)*	*Zalengera et al. (2014)*	*Jingura & Matengaifa (2008)*	*Values used in this study*
Maize	1.0	1.5	2.67	1.5	1.4	2.25
Rice	1.5	1.5	0.28	1.5	–	2.23
Tobacco	–	–	–	1.0	–	1.00
Cotton	1.5	–	3.39	3.5	2.1	3.50
Cassava	–	–	–	0.2	–	0.20

Table 7: Lower heating values in GJ/t.

Crop	*Duku et al. (2011)*	*Biopact (2006)*	*Zalengera et al. (2014)*	*Bentsen et al. (2014)*	*Jingura & Matengaifa (2008)*	*Values used in this study*
Maize	15.48	12.46	15.48	17.9	13	17.9
Rice	15.56	16.01	15.56	17.5	–	17.5
Tobacco	–	–	16.1	–	–	16.1
Cotton	–	16.21	17.9	–	15.9	17.9
Cassava	–	17.5		–	–	17.5

Table 8: Total energy potential from crop residues* based on a typical year in TJ.

Crop	Karonga	Mzuzu	Kasungu	Salima	Lilongwe	Machinga	Blantyre	Shire Valley	Total
	Agriculture development division								
Maize	2661.4	8485.5	17646.1	4299.4	18343.9	12393.1	13197.4	2180.8	79556.7
Rice	534.6	161.4	27.9	507.8	178.2	884.0	405.5	251.3	2963.9
Tobacco	42.5	314.4	602.1	38.5	395.0	147.0	74.5	4.6	1614.5
Cotton	159.3	9.1	69.1	714.1	230.5	1004.3	258.2	1348.5	3751.0
Cassava	608.9	1668.2	617.1	1207.9	474.3	685.2	1165.9	34.0	9002.9
								Total	96 899.0

* The crop production was based on average for 1997 to 2015 (Table 5).

required maize volume for the population was produced in Malawi. Since arable land is scarce, the expansion of agricultural land was expected to remain a major constraint to increasing the cultivated area (Owen et al., 2009; FAO, 2012).

- In 2006, the government launched a farm input subsidy programme (FISP) to improve food security by supporting smallholder farmers (Denning et al., 2009). The FISP resulted in steep increase in maize yields, as shown in Figure 4, and also increased the use of hybrid and composite maize seeds and the decline of the local variety of maize, as shown in Figure 5.
- From 2009 to 2014, maize yields of 3 t/ha and 2 t/ha were consistently achieved for hybrid and composites respectively (Figure 4). The inconsistency in 2015 could be attributed to prolonged dry spells experienced in many parts of the country, which resulted in lower yields in that year (World Bank, 2016). Trends in the area under cultivation in Figure 5 show a steady decline of the local maize variety and increase of both the hybrid and composite varieties. Since the hybrid and composite yields per hectare are higher than for the local variety, the prospects of increased volumes of maize production and associated crop residues are high.
- Using the population projections from NSO (2008) and a per capita maize consumption of 133 kg annum, corresponding volumes of maize were projected as shown in column 2 of Table 9. Demand for maize for 2020, 2025 and 2030 are estimated at 3.30, 3.87 and 4.51 million tonnes respectively.
- The maize yields of 2, 2.5 and 3 t/ha used in the scenarios are estimates from Figure 4; the corresponding cultivated areas required are calculated for the three scenarios from required maize quantities and corresponding yield per hectare.

Table 9 shows the projections of cultivated areas under the three scenarios.

Scenario 1: This is the business as usual scenario. The average yields of 2 t/ha and total area under cultivation is increasing proportional to 2.26 million hectares by 2030. This assumes either a failure to sustain FISP or the ineffectiveness of the FISP in the long term.

Scenario 2: A sustained national average yield of 2.5 t/ha was assumed, but the total cultivated area does not increase beyond 1.81 million hectares by 2030. Continuation of the FISP at current levels was assumed.

Scenario 3: This considered a sustained national average yield of 3.0 t/ha. The cultivated areas were

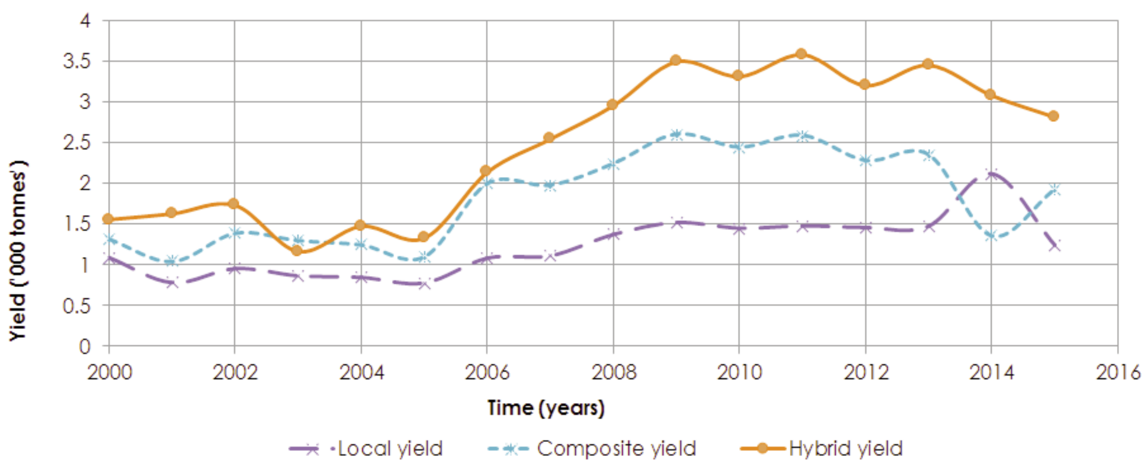

Figure 4: Maize yield/ variety of maize for 2000–2015 for Karonga Agriculture Development Division (Data source: Ministry of Agriculture (2016)).

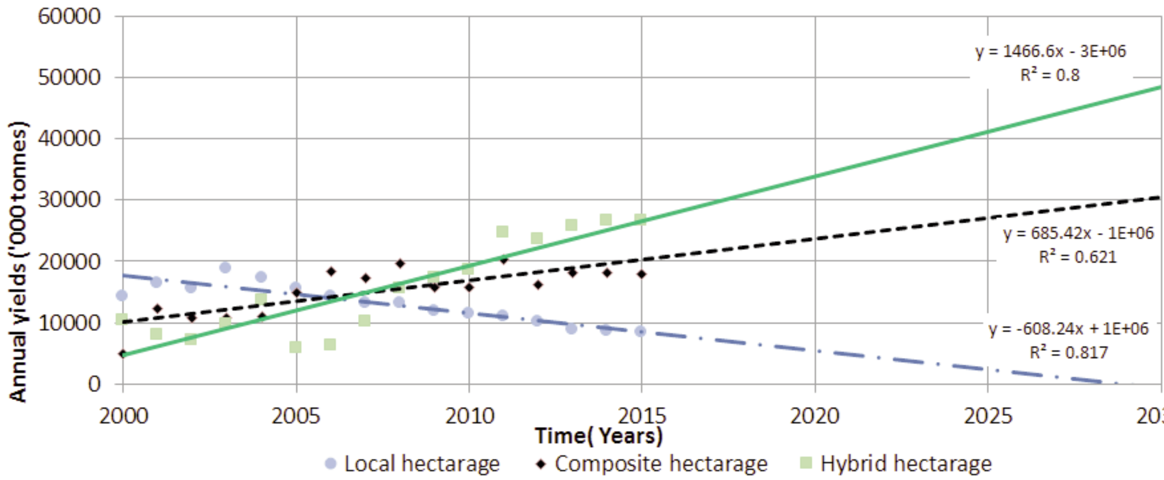

Figure 5: Projected trends in volumes of maize seed varieties for Karonga Agriculture Development Division. (Data source: Ministry of Agriculture (2016)).

Table 9: Projections of the cultivated area for maize under different scenarios

Period of projection	*Projected population (millions)**	*Maize demand (million t)*	*Cultivated area (million ha)*		
			Scenario 1 2 t/ha	*Scenario 2 2.5 t/ha*	*Scenario 3 3 t/ha*
2020	19.1	3.30	1.65	1.32	1.10
2025	22.4	3.87	1.94	1.55	1.29
2030	26.1	4.51	2.26	1.81	1.50

* Based on data from NSO (2008).

expected to increase to 1.5 million hectares by 2030. This assumed scaling up of the FISP; currently not all smallholder farmers benefit from the programme.

The results in Table 9 show that operating in Scenario 1 would require expansion of cultivated area to meet the demand for maize to feed the population. Since Scenarios 2 and 3 emphasise on productivity improvement, they would require 450 000 ha and 700 000 ha less compared with Scenario 1. Scenario 2 and 3 are, therefore, more plausible. However, a more conservative Scenario 2 is applied.

Table 10 presents projected crop production and crop residues to 2030 for maize, rice, tobacco, cotton and cassava, while Table 11 presents the corre-

Table 10: Projected annual crop production and corresponding crop residues (tonnes).

Crop	*2020*		*2025*		*2030*	
	Crop	*Residues*	*Crop*	*Residues*	*Crop*	*Residues*
Maize	3 300 000	7 425 000	3 870 000	8 707 500	4 510 000	10 147 500
Rice	126 842	282 858	148 751	331 715	173 351	386 572
Tobacco	162 221	162 221	190 241	190 241	221 702	221 702
Cotton	100 136	350 475	117 432	411 011	136 852	478 982
Cassava	4 302 061	860 412	5 045 145	1 009 029	5 879 484	1 175 897

Table 11: Total energy projections from crop residues (TJ).

Residue source	*Year of projection*			*Top producer Agriculture Devt Division*			
	2020	*2025*	*2030*	*1st*	*2nd*	*3rd*	*4th*
Maize	132 908	155 864	181 640	Lilongwe	Kasungu	Blantyre	Machinga
Rice	4 950	5 805	6 765	Machinga	Karonga	Salima	Blantyre
Tobacco	2 612	3 063	3 569	Kasungu	Lilongwe	Mzuzu	Machinga
Cotton	6 273	7 357	8 574	Shire Valley	Machinga	Salima	Blantyre
Cassava	15 057	17 658	20 578	Mzuzu	Salima	Blantyre	Machinga
Total energy supply (TJ)	161 800	189 747	221 127				
Available energy	80 900	94 873	110 563				

sponding projected energy potential from crop residues based on the top four ranked ADDs.

There is potential to produce 161 800 TJ, 189 747 TJ and 221 127 TJ of energy from crop residues in 2020, 2025 and 2030 respectively. Kasungu, Lilongwe and Machinga are the dominant potential suppliers of energy from crop residues. Table 11 shows that maize and tobacco crop residues from Kasungu and Lilongwe ADDs could be potential energy sources for the Kasungu factory, while maize crop residues from Blantyre and Machinga, as well as rice crop residues from Machinga, Salima and Blantyre, could be potential energy sources for the Mangochi factory. The study assumes only 50% of the potential energy would be technically available for energy purposes (Owen et al., 2009).

4. Discussion

The results and analysis shown by demand in Table 3 and energy potential in Tables 8 and 10 indicate that Malawi could produce biomass energy from crop residues to satisfy the needs of the cement industry. Industrial energy users such as the cement companies would, however, require assurance regarding availability, quality consistency and competitive price of the crop residues before committing to switch from their traditional energy sources (Montalvo, 2007; Rahman et al., 2015). Some of these pertinent issues are discussed in this section.

4.1 Reliability of the energy potential estimates

From the assessment, it was observed that yield per crop between and within ADD varied significantly. Levels 1 to 5 in Figure 6 indicate that there is reduction in the level of details and increase in uncertainties. The level at which data is collected should, therefore, match the requirements where it is intended to be used. For instance, where the information needed is for rapid assessment at national level, use of aggregate quantities and default conversion factors at level 5 could suffice. At a project level, however, a more detailed approach would be necessary. It would be incorrect to use national average or global default values to compute energy potential for a specific user group without recognising local circumstances (Bentsen et al., 2014). This study quantifies the availability of crop residues and related energy potential at ADD level using appropriate residues to production ratios and crop production statistics at ADD level by taking advantage of the existing data collection systems in the Ministry of Agriculture.

The use of crop statistics at ADD level not only improves the level of confidence of the energy potential estimates, but it also enables identification of locations where crop residues are available for the intended use. The location is also linked to transportation costs and lead time.

4.2 Sustained availability of crop residues

Scenarios 2 and 3 were developed with land constraint in mind and assumed improved crop yields per hectare as the means to achieve increased crop production, instead of expanding the cultivated area (Owen et al., 2009; FAO, 2012; Zalengera et al., 2014). The availability of crop residues depends on smallholder farmers who account for 80% of total crop production (FAO, 2015). The smallholder farmers need continued support, through the FISP, on farm inputs and extension services to sustain the high maize yields recorded in the recent past (Denning et al., 2009).

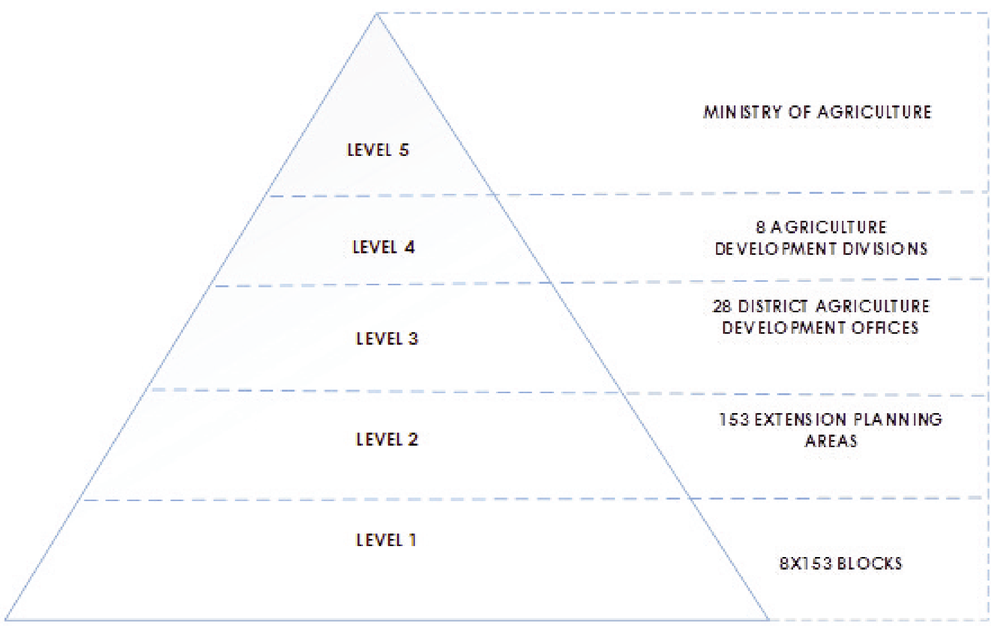

Figure 6: A bottom-up process of generating annual crop estimates in the Ministry of Agriculture.

4.3 Quality of fuel from crop residues: conversion to briquettes and pellets

Industrial energy users require energy sources of consistent quality in terms of their physical properties and calorific values. One way of improving the quality of crop residues as an energy source is by densifying the materials to form pellets or briquettes. Densified fuels are easier to store and transport, and could be made to meet specifications as required by the industrial users, such as pellet geometry, dimensions and their corresponding energy contents.

The crop residues value chain in Figure 7 is an opportunity for government to implement part of its rural transformation initiatives as outlined in the Malawi Growth and Development Strategy II (GoM, 2011). By supporting the establishment of small energy enterprises that manufacture briquettes and pellets as industrial fuels, jobs would be created and rural people economically empowered. At the same time, the industry would be assured of good quality and environmentally clean fuel. However, smallholder farmers would rarely put value on the crop residues, so there would be a need for awareness raising and training to assist smallholder farmers to view crop residues as a by-product of crops production to be considered as a commodity for trade and exchange (Berazvena, 2013). Furthermore, a proper investment appraisal needs to be done to ensure that there is return on the investment as shown in Figure 7.

4.4 Environmental issues

Use of crop residues as a fuel in cement manufacture would result in GHG emissions reduction from the substituted coal. This was estimated at 18 532.8 tonnes of coal, which translates to 46 128 tonnes in avoided CO_2 emission per year between 2020 and 2030. Over-exploitation of crop residues as an energy source and the economic opportunity by farmers to sell the crop residues could, however, result in the decline of soil organic that, in turn, could impact the soil's water-holding capacity and the vitality of soil micro-organisms, leading to an eventual loss of productivity (Lal, 2005; Bentsen et al., 2014).

4.5 Impact of the study in the Southern African Development Community

Most crop residues in Malawi and other countries in the Southern African Development Community (SADC) are, in general, burnt to clear the field or as part of pest and disease control. This mindset perpetuates the notion that crop residues are materials with no value (Berazvena, 2013). Building awareness at farmer's level will be critical to change the mindset so that the energy potential of crop residues could be harnessed as a renewable energy resource for domestic and industrial uses, not only in Malawi, but across the SADC region. In 2015/2016 season, the SADC region produced 20 million tonnes of maize, accounting for 70% of total cereal production (FEWSNET, 2016); with the possibility of generating about 740 000 TJ of clean energy from maize crop residues.

5. Conclusions

This investigation assessed current and future energy potentials from crop residues in Malawi that could be used to displace coal as a fuel in the cement industry. The results show that between 45% and 57% of the national total energy demand could technically be met by use of crop residues. Furthermore, the analysis of the estimated demand from the cement industry was found to be 0.59% of the technically available energy potential. Therefore, the excess capacity of more than 99% of production is available for other uses; for example, crop residues can replace firewood and charcoal, most of which are from unsustainable resources. The results further show that Kasungu and Lilongwe Agriculture Development Divisions (ADDs) can supply the crop residues to the cement factory in Kasungu district, while Machinga, Blantyre and Salima ADDs can supply fuel for the

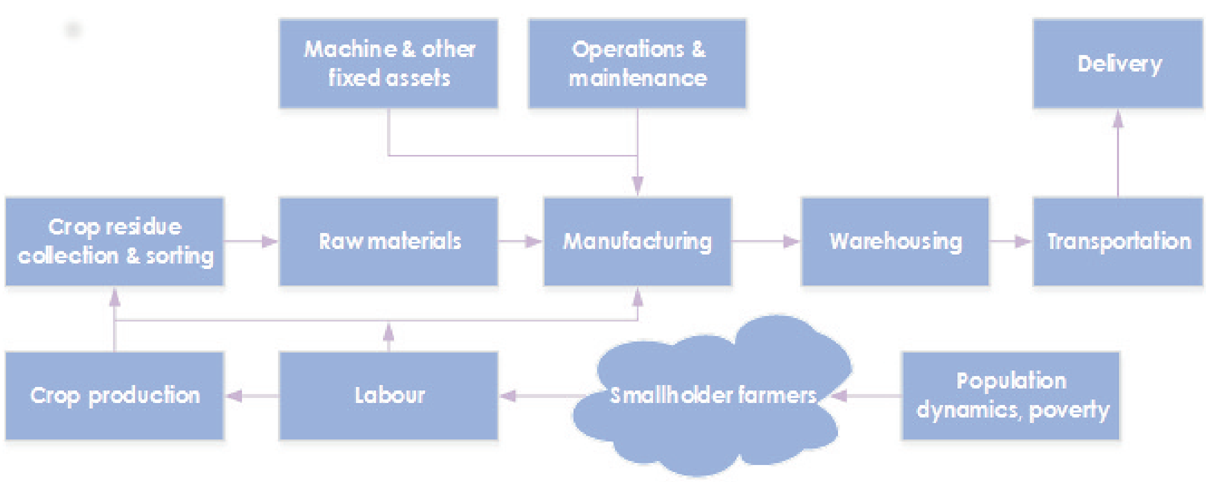

Figure 7: Crop residue value chain.

factory in Mangochi district. Most of this fuel is from maize crop residues that contribute 82.1% of the total energy potential from crop residues in Malawi. The success of maize crop residues as a reliable source of biomass energy depends on sustained yields of at least 2.5 t/ha, so proper planning and continued support farm input subsidy by government is critical. In addition, the government could support the establishment of rural energy enterprises to produce briquettes and pellets from crop residues as industrial fuels. The intervention would likely improve rural livelihoods and reduce greenhouse gas (GHG) emissions from the cement industry. Furthermore, GHG emission reduction projects such as this qualify to access funding from agencies that support projects that address global climate issues. Lessons from this study could benefit other sub-Saharan countries. Currently, the SADC could produce maize 740 000 TJ of renewable energy annually from maize crop residues alone. There are numerous stakeholders in the supply chain and many social, economic and environmental challenges that need to be addressed before the switch to crop residues can be made. Long-term sustainability-related issues also need to be addressed, considering the alternative uses of the crop residues. There is, therefore, a need to undertake economic assessments to complement technical assessments. Finally, there are still a few gaps in terms of locally derived residue product ratios and lower calorific values. Hence, there will be a need for increased physical and chemical characterisation of crop residues to support quality improvements of future energy assessments. Some of the critical parameters that were identified are residue-to-crop ratios, calorific values, ash content, moisture contents and bulk densities.

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