Biofuel Potential in Sub-Saharan Africa:

Raising food yields, reducing food waste and utilising residues

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Executive summary

Considerable sustainable resource potential exists for liquid biofuels in sub-Saharan Africa. This report estimates the amounts of feedstocks that could be grown, collected and converted to liquid biofuels in the region. The main focus is on lignocellulosic feedstocks that could be grown in an environmentally, socially and economically sustainable fashion, without conflicting with food supplies or causing land use change that could release carbon into the atmosphere and contribute to global warming.

Three approaches to expanding biomass feedstocks hold particular promise. One is to collect more of the available residues from food crops and forest products. A second is to plant high-yielding trees and grasses on land made available through more intensive cultivation of farmland, with yields beyond those needed to supply projected food needs. A third is to plant bioenergy crops on land freed up by reduced waste and losses in the food chain, which can obviate the need to grow food no longer lost or wasted.

This report derives detailed estimates of biomass resource potential from these approaches for five countries in sub-Saharan Africa: Ghana, Mozambique, Nigeria, South Africa and Uganda. These countries reflect a variety of agricultural conditions and different degrees of economic development and might therefore be considered to be broadly representative of potentials in the region as a whole. Both theoretical potentials and stretch goals for 2050 are estimated for these countries, though the portion of potential that is actually realised will depend on economic, logistical and policy variables.

A survey of bioenergy activities in these countries shows limited technological readiness for production of advanced liquid biofuels from lignocellulosic feedstocks. South Africa has significant experience with relevant processes for biofuels synthesis, but the other countries do not. On the other hand, they all have a fair amount of experience with refining conventional biofuels from starch- and sugar-based feedstocks. This should facilitate their adoption of lignocellulosic processes that are being demonstrated elsewhere. Meanwhile, they can develop lignocellulosic feedstocks to supply industrial process heat and power.

If sustainable biomass feedstock potentials are totalled, assuming conversion to advanced liquid biofuel at typical efficiencies, they could supply the entire projected fuel needs for transport in 2050 in the countries as a group. Alternatively, they could supply nearly twice the projected requirements for industrial power and process heat. The biofuel potential would be reduced, however, if use of solid biomass outside the transport sector continues to grow in line with recent trends, particularly for residential cooking.

A variety of policies and measures could be implemented to help realise this potential. Farm and forest residue collection could be improved by sharing best practices in cost-effective logistics. Agricultural yields could be improved through extension services to spread modern farming techniques suited to local conditions, agroforestry approaches to cultivate a mix of high-yielding food and fuel crops, and the use of mobile telephony and banking to help farmers grow and market more produce at higher prices and thus incentivise their investment in yield-enhancing measures. Losses in the food chain could be reduced through better harvesting techniques, storage and cooling facilities, and transportation infrastructure to reduce food spoilage on the way from farm to table. Together, such measures can free up a substantial amount of land to plant with bioenergy crops for liquid biofuel, heat and power.

Introduction

Substantial resource potential exists to sustainably expand supplies of liquid biofuels in sub-Saharan Africa. This paper focuses on the potential in Ghana, Mozambique, Nigeria, South Africa and Uganda. Volumes of biofuel feedstock can be expanded through more systematic collection of agricultural residues, as well as through planting of sugarcane, other grasses and trees on land made available through more intensive cultivation of croplands and reduced waste and losses in the food chain. With a mix of conventional technologies using sugar- or starch-based feedstocks and advanced processes using lignocellulosic feedstocks that are being demonstrated at commercial scale (IRENA, 2016a), liquid biofuels could displace most petroleum-based transport fuel in the five countries considered as a group.

As food production expands to meet the nutritional needs of growing populations, there is also increased production of agricultural residues. If sustainable shares of these residues were fully collected while allowing for residues that are fed to animals for meat and dairy production, substantial amounts would be left over. These could provide fuel for combined heat and power plants, process heat for first-generation biofuel production, or lignocellulosic feedstock for second-generation biofuel processes.

Improving yields through modern agricultural practices, it should also be possible to grow the same amount of food on less land. The freed-up land could be planted with a mix of rapidly growing trees (short rotation coppice) for combined heat and power or second-generation biofuel, high-yielding conventional biofuel crops such as sugar cane, and grasses for lignocellulosic conversion.

Farmland needed for food production could be further reduced by managing the food chain more efficiently and by modifying food consumption habits. About one-third of food in sub-Saharan Africa is lost or wasted. If food losses and waste could be reduced or eliminated, obviating the need to grow this food, substantial further amounts of land could be made available for bioenergy and biofuel production.

In addition, forests in Africa produce wood for construction material, furniture, and a variety of other uses. Part of this wood is left over as a residual for possible conversion to bioenergy. Other wood, about five times as great in volume, is already used for energy, but this is not in general considered sustainable.

Potential for bioenergy from sustainable collection of agricultural residues

For every tonne of crop produced, an amount of residues is available in the field after harvest, of which a fraction can be practically and sustainably collected. This fraction is typically assumed to be between a quarter and a half, so that enough residue is left behind to regenerate the soil. In addition, a share of residues is attached to crops when they enter processing plants, most of which can also be collected.[1]

Multiplying the tonnage of each crop in each country (FAO, 2015) by tonnes of harvest and processing residue per tonne of crop (Smeets, Faaij and Lewandowki, 2004) and assuming an energy content of 15 gigajoules (GJ) per tonne, agricultural residues with an energy content of some 161 exajoules (EJ) was generated worldwide in 2010. Taking 25-50% of harvest residue and 90% of processing residue, 55 EJ to

[1] Muth, Bryden and Nelson (2013) suggest 2.25 tonnes per hectare (t/ha) of residue can be removed for each crop under 2011 land management practices or 25% of 9.17 t/ha in total residue (weighing residue t/ha for each crop in their Table 5 by crop shares in their Table 7); their Table 6 shows no-till practices raise sustainable collection by 43%, *i.e.*, to 35%, by 2030. World Bioenergy Association (2015) asserts that 50% of residue can be sustainably collected. Villamil and Nafziger (2015) report that removing 50% or 90% of residue with no-till planting reduces soil carbon and nitrogen stocks by only 6% to 7%.

90 EJ could have been used. With projected growth in food supply (Alexandratos and Bruinsma, 2012), assuming the mix of crops is constant, available agricultural residue could reach 79 EJ to 128 EJ globally by 2050.[2] Corresponding amounts of agricultural residue for the countries in focus are 0.25 EJ to 0.41 EJ in Ghana, 0.27 EJ to 0.45 EJ in Mozambique, 1.32 EJ to 2.17 EJ in Nigeria, 0.38 EJ to 0.59 EJ in South Africa, and 0.39 EJ to 0.61 EJ in Uganda (as shown in petajoules (PJ) in column 4 of Tables S-1 and S-2).

However, much of this residue would likely be used for animal feed. Dividing the supply of livestock between traditional grazing systems and higher-yield "mixed" systems in each country, and multiplying this by the amount of residue used to produce each tonne of livestock, 19 EJ of residue is seen to have been used for feed in 2010. With projected growth in demand for livestock for milk and meat consumption (Alexandratos and Bruinsma, 2012),[3] 33 EJ of residue could go to feed by 2050, leaving 46 EJ to 95 EJ to use for biofuel. For the focus countries in Africa, net available residue for biofuel would be 0.24 EJ to 0.40 EJ in Ghana, 0.25 EJ to 0.43 EJ in Mozambique, 1.24 EJ to 2.09 EJ in Nigeria, 0.21 EJ to 0.42 EJ in South Africa, and 0.31 EJ to 0.53 EJ in Uganda (as shown in PJ in column 6 of Tables S-1 and S-2).

Table S-1 Residue potential for 2050 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel (Primary Biomass)	40% to Biofuel (Energy Content)	Share of Liquid Fuel Use in 2014
Ghana	155	100	254	10	245	98	97%
Mozambique	174	100	274	19	255	102	336%
Nigeria	845	476	1 321	107	1 214	486	159%
South Africa	217	159	376	169	207	83	11%
Uganda	218	173	391	76	315	126	434%
WORLD	49 278	29 730	79 008	32 877	46 131	18 452	21%

IRENA analysis (Appendix I)

Table S-2 Residue potential for 2050 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel (Primary Biomass)	40% to Biofuel (Energy Content)	Share of Liquid Fuel Use in 2014
Ghana	309	100	409	10	399	160	158%
Mozambique	348	100	448	19	429	172	565%
Nigeria	1 690	476	2 166	107	2 059	824	269%
South Africa	434	159	593	169	424	170	23%
Uganda	437	173	610	76	534	214	737%
WORLD	98 555	29 730	128 285	32 877	95 409	38 163	43%

IRENA analysis (Appendix I)

[2] Projected yearly growth in global food supply is 1.3% through 2030 (ranging from 0.8% in developed countries to 2.4% in sub-Saharan Africa) and 0.7% from 2030 through 2050 (ranging from 0.3% to 1.9%).

[3] Projected annual growth in global meat consumption is 1.4% through 2030 (from 0.6% in developed countries to 2.7% in sub-Saharan Africa) and 0.9% from 2030 to 2050 (from 0.2% to 2.6%).

At 40% conversion efficiency in a lignocellulosic process, this residue would yield 18 EJ to 38 EJ of biofuel globally. That is roughly one-fifth to two-fifths of all the liquid fuel that was used for transport in 2014 and probably more than the 22 EJ of fuel used for marine shipping and aviation (IEA, 2014).[4] Advanced biofuel from residues could displace one-fifth of current transport fuel use in South Africa, all transport fuel use in Ghana, and several times current transport fuel use in Mozambique, Uganda and Nigeria.

Potential for bioenergy through sustainable intensification of agriculture (higher crop yields)

Growth in yields per hectare is responsible for some 80% of the increase in food production and residue potential in projections by the Food and Agriculture Organization of the United Nations (FAO). Another 10% is due to planting multiple crops on the same land each year. Only 10% of projected increased food production comes from expanding arable land (Alexandratos and Bruinsma, 2012). But yields could grow faster with expanded extension services and financial supports to help farmers in countries with lower crop yields adopt the practices that produce higher yields elsewhere, as suited to local conditions. With higher yields, less land would be needed for food and more could be used for biofuel feedstock.

The FAO projects that global average crop yield will rise from 4.2 t/ha in 2010 to 5.1 t/ha in 2050. But applying yield growth trends from 1961 through 2013, it could reach 6.6 t/ha by 2050 (FAO, 2015a). While 1 079 million hectares (Mha) would have to be planted in 2050 to meet world food needs at projected yields, just 839 Mha would be needed at the higher yields, freeing 240 Mha for biofuel crops.

FAO has also assessed the gap between current and potential crop yields, assuming the current mix of irrigated and "rain-fed" land. Globally, the average gap is 62.1 t/ha for sugars, 3.9 t/ha for cereals, 12.7 t/ha for root crops, and 0.6 t/ha for oil crops (FAO, 2015a). For each country, taking the land to meet food demand with current yields for each crop type and dividing by the ratio of actual to potential yield, IRENA calculated the amount of land required to meet food needs if the yield gap were closed. Closing the gap would entail raising average global crop yield to 10.4 t/ha in 2050 so that only 527 Mha would be needed for food, rather than the 1 079 Mha projected by the FAO, leaving 552 Mha for biofuel crops. If this land were planted with grasses yielding 150 gigajoules per hectare (GJ/ha), it could produce 83 EJ of biomass. Converted at 40% efficiency, this would yield 33 EJ of biofuel, or about one-third of current transport fuel use (IRENA, 2016). Closing the yield gap could make enough land available for advanced biofuels to displace about two-fifths of current liquid transport fuel use in South Africa and multiples of liquid transport fuel use in Ghana, Mozambique, Nigeria and Uganda (Tables S-3 and Y-1-5).

Table S-3 Biomass potential from higher yields in 2050 – yield gap closure case

Country	Land Freed (Mha)	Biomass Potential 150 GJ/ha (PJ/year)	40% to Advanced Biofuel (PJ/year)	Liquid Transport Fuel Use 2014 (PJ)	Potential Share of 2014 Fuel Use
Ghana	8.46	1 269	508	101	501%
Mozambique	6.84	1 026	410	30	1 352%
Nigeria	37.79	5 668	2 267	306	742%
South Africa	4.67	701	280	735	38%
Uganda	4.90	735	294	29	1 014%
WORLD	551.71	82 757	33 103	87 869	38%

IRENA analysis (Appendix II)

[4] Data for 2014 indicate 2.26 EJ for domestic navigation, 8.15 EJ for marine bunkers, 4.50 EJ for domestic aviation and 7.05 EJ for aviation bunkers, or a total of 21.96 EJ for marine and aviation use.

Potential for bioenergy on land freed by reducing waste and losses in the food chain

Large amounts of food are lost in production and distribution or wasted at the point of consumption. The FAO has found that one-third of food produced for human consumption is lost or wasted globally, amounting to 1.3 billion tonnes per year. Production and distribution losses have similar proportions in developed and developing countries, amounting to 31-33% in Europe and North America (280-300 kg of the 900 kg of food produced per capita per year) and 26-37% in sub-Saharan Africa and South/Southeast Asia (120-170 kg out of 460 kg of food produced per capita per year). But consumer food waste is much higher in developed countries (11-13%) than developing ones (1-2%) (Gustavsson *et al.*, 2011).

For each major region and food group, FAO data show percentage losses in agricultural production, postharvest handling and storage, processing and packaging, retail distribution, and consumption (Gustavsson *et al.*, 2011). From these, the total percentage and tonnage lost or wasted for each food group can be calculated. For crops directly consumed, tonnes lost or wasted can be divided by average yield in tonnes per hectare to find how many hectares could be liberated by eliminating the losses and waste. For meat and dairy products, one may calculate the amounts of different kinds of feed to produce each, then the area used to produce the feed, and finally (multiplying this area by share of product lost) the land spared.

Table S-4 Shares of food production lost at different food chain stages in Africa

Food Group	Total Loss All Stages Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	20%	6%	8%	3%	2%	1%
Fruits, Vegetables	57%	11%	9%	23%	12%	3%
Meat	32%	18%	1%	5%	7%	2%
Milk	26%	6%	11%	0%	9%	0%
Oil Crops, Pulse	32%	14%	8%	7%	2%	1%
Roots and Tubers	51%	16%	18%	12%	3%	1%
All (except Seafood)	36%	12%	9%	8%	6%	1%

Source: Gustavsson *et al.* (2011)

Globally, 442 Mha of land could be freed up in 2050 by eliminating losses and waste for crops directly consumed as food, and another 340 Mha freed up by eliminating losses and waste of meat and dairy products. With 782 Mha liberated in all, biofuel crops yielding 150 GJ/ha would provide 117 EJ of biomass, converting at 40% efficiency to 47 EJ of advanced biofuel. If the yield gap were closed, land freed by eliminating losses would decline to 553 Mha, biomass potential to 83 EJ and advanced biofuel potential to 33 EJ, still enough to displace one-third of current liquid transport fuel (IRENA, 2016b).

In Africa, potential land freed and corresponding biomass potential in 2050 are as follows, assuming that food yields per hectare increase as the FAO projects and that bioenergy crops typically yield 150 GJ/ha:

Table S-5 Potential land freed by reduced food waste in 2050 – FAO case (kha)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2 774	981	660	676	349	108
Mozambique	3 874	1 557	934	807	431	145
Nigeria	17 395	6 268	4 578	4 014	1 898	638
South Africa	5 685	2 766	593	982	1 060	284
Uganda	6 716	2 183	1 255	1 912	1 075	291

IRENA analysis (Appendix III)

Table S-6 Biomass potential on land freed by reduced food waste in 2050 – FAO case (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	416	147	99	101	52	16
Mozambique	581	234	140	121	65	22
Nigeria	2 609	940	687	602	285	96
South Africa	853	415	89	147	159	43
Uganda	1 007	327	188	287	161	44

IRENA Analysis (Appendix III)

If yields were to rise beyond what the FAO projects, so that lost or wasted food were produced on less land, reduced waste and losses would cause less land to be liberated, as follows:

Table S-7 Potential land freed by reduced food waste in 2050 – yield gap closure (kha)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	1 638	541	344	447	239	67
Mozambique	1 731	698	361	382	223	68
Nigeria	9 557	3 237	2 289	2 454	1 217	361
South Africa	4 241	2 089	365	750	823	215
Uganda	5 011	1 515	775	1 545	939	237

IRENA Analysis (Appendix III)

Table S-8 Biomass potential on land freed by reduced food waste 2050 – yield gap closure (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	246	81	52	67	36	10
Mozambique	260	105	54	57	33	10
Nigeria	1 434	485	343	368	183	54
South Africa	636	313	55	112	123	32
Uganda	752	227	116	232	141	35

IRENA Analysis (Appendix III)

It is interesting to consider the portion of this potential which might be obtained by implementation of global best practice, as indicated by the region with the lowest share of waste or loss for each food group at each stage of the food chain (Table S-9). Africa is at or near global best practice for most food groups in processing and packaging (except fruits and vegetables), distribution (except fruits, vegetables and milk) and consumption (where Africa represents global best practice for all food groups).

Table S-9 Shares of food production lost at different food chain stages – global best practice

Food Group	Total Loss All Stages Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	10%	2%	2%	3%	2%	1%
Fruits, Vegetables	29%	11%	4%	2%	8%	4%
Meat	14%	3%	0%	5%	4%	2%
Milk	5%	4%	1%	0%	0%	0%
Oil Crops, Pulse	13%	6%	0%	5%	1%	1%
Roots	27%	6%	7%	9%	3%	2%

Source: Gustavsson *et al.* (2011)

With waste and losses reduced to best practice levels, roughly half the biomass potential is obtained:

Table S-10 Biomass potential on land freed by food chain best practice – yield gap closure (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	120	36	18	30	23	13
Mozambique	122	35	15	39	21	12
Nigeria	694	211	107	191	117	68
South Africa	279	70	12	92	70	35
Uganda	359	123	41	61	87	48

IRENA Analysis (Appendix III)

In the African countries studied, with 40% efficient lignocellulosic conversion, potential for advanced biofuel on land freed by reduced food waste could approach or exceed 2014 transport fuel use in four of the countries, assuming FAO projections for crop yields. With the yield gap closed and all regions adopting regional best practices in food waste reduction, the shares would be about half as great (Table S-11).

Table S-11 Potential displacement of transport fuel by reduced food waste and losses

Country	Liquid Transport Fuel Use 2014 (PJ)	Biofuel Potential from Reduced Food Waste - FAO Yields (Share of 2014 Transport Fuel)	Biofuel Potential from Reduced Food Waste – No Yield Gap (Share of 2014 Transport Fuel)	Biofuel Potential of Best Practice Food Waste Reduction – No Yield Gap (Share of 2014 Transport Fuel)
Ghana	101	166 (164%)	98 (97%)	48 (47%)
Mozambique	30	232 (765%)	104 (343%)	49 (161%)
Nigeria	306	1 044 (341%)	574 (188%)	278 (91%)
South Africa	735	341 (46%)	254 (35%)	112 (15%)
Uganda	29	403 (1 389%)	301 (1 037%)	144 (495%)

Potential for bioenergy from productive forests

Substantial amounts of wood and wood-derived charcoal are used for energy purposes in the five African countries surveyed. However, it would seem that much of this fuel comes from sources that are not sustainable, as its collection is depleting local forests. Deforestation in the five countries as a group has ranged as high as 410 kilo-hectares (kha) in some years between 1990 and 2010 (FAO, 2015). Thus, to ensure a quite conservative estimate of sustainable bioenergy potential, it seems prudent to exclude wood used for fuel, which constitutes 84% of total current roundwood use. Rather, the focus should be on the potential for extracting wood residues from production and processing of wood by industry.

Koopmans and Koppejan (1997) estimate recovery rates for wood residues from logging in forests and from processing of wood products. They estimate that for logging in forests, 70% of the volume of wood extracted goes to industrial round wood production, while 30% ends up as logging residues. As a share of wood processed, they estimate that residue accounts for 50% in production of sawn wood and wood panels and for 10% in production of wood chips. Applying these recovery rates in each country, residues generated are calculated in Appendix IV. Assuming that at most half the logging residues are practically recoverable (Smeets and Faaij, 2007), while the rest is left on the forest floor as organic fertiliser, available residues for energy use are summed in Table S-12. Multiplying by an energy content of 19 GJ per tonne (Biomass Energy Centre, n.d.) energy potential in petajoules per year can be found.

Table S-12 Available residue volume and energy potential from forestry industry

Country	Total Wood Residue (kt/y)	Logging Residue (kt/y)	Wood Processing Residue (kt/y)			Potential Energy (PJ/y)
			Sawn Wood	Wood Panel	Wood Chip	
Ghana	652	170	255	227	-	12
Mozambique	285	164	120	1	-	5
Nigeria	2 061	1 009	1 001	48	3	39
South Africa	3 376	1 919	721	512	224	64
Uganda	694	464	220	10	-	13

IRENA Analysis (Appendix IV)

Energy security implications and possible policy options

Globally, analysis indicates sustainable potential for up to 288 EJ of primary biomass. This comes from residues (95 EJ), land freed by closing the yield gap (83 EJ), land freed by eliminating waste and losses in the food chain (83 EJ), and trees in forest land (27 EJ). This could provide 115 EJ of drop-in diesel fuel for jets, ships and trucks in a second-generation conversion process, exceeding liquid fuel use for transport worldwide in 2014. Alternatively, it could generate 230 EJ of heat, electricity and conventional biofuel. Additional biomass could come from more efficient use of pasture, degraded land and forest residues.

In the five African countries assessed, the potential for reducing fossil fuel reliance is also great:

- Table S-13 sums up the four main categories surveyed, assuming that 50% of harvest residues are collected, the yield gap is completely closed, waste and losses in the food chain are completely eliminated, and the full increment of forest biomass is collected. This may be regarded as the long-run theoretical potential.
- Table S-14 sums up the same three categories, assuming that 25% of harvest residues are collected, the yield gap is half closed, all regions reduce waste and losses in the food chain to the shares in each food group that obtain in the region with best practice, and half of the forest potential is collected. This may be seen as a “stretch goal” to be pursued within a time horizon such as 2050.
- Table S-15 compares the advanced biofuel potential to current and projected liquid transport fuel demand.[5]

[5] IEA (2014) projects transport fuel consumption in Africa will grow from 90 million tonnes oil equivalent (Mtoe) in 2012 to 111 Mtoe in 2020, 134 Mtoe in 2030 and 161 Mtoe in 2040. This implies annual demand growth of 2.65% in 2012-20, 1.9% in 2020-30 and 1.85% in 2030-40. Assuming growth in the 2030s persists apace in the 2040s, and

Table S-13 Advanced biofuel potential from residues, higher yields, reduced waste and forests

Country	Residues Potential with 50% Collection (PJ/year)	Potential from Closing Yield Gap (PJ/year)	Potential from Reduced Waste if Yield Gap Is Closed (PJ/year)	Forest Energy Wood Potential (PJ/year)	Total Primary Energy Potential (PJ/year)	Converted 40% to Advanced Biofuel (PJ/year)
Ghana	399	1 269	246	12	1 926	770
Mozambique	429	1 026	260	5	1 720	688
Nigeria	2 059	5 668	1 434	39	9 201	3 680
South Africa	424	701	636	64	1 825	730
Uganda	534	735	752	13	2 034	814
Total	**3 845**	**9 399**	**3 328**	**134**	**16 706**	**6 682**

Table S-14 Goals for advanced biofuel from residues, higher yields, reduced waste and forests

Country	Residues Potential with 25% Collection (PJ/year)	Potential Closing Half the Yield Gap (PJ/year)	Potential from Reduced Waste Best Practice if Yield Gap Closed (PJ/year)	Half the Forest Wood Potential (PJ/year)	Total Primary Energy Goal (PJ/year)	Converted 40% to Advanced Biofuel (PJ/year)
Ghana	245	635	120	6	1 006	402
Mozambique	255	513	122	3	893	357
Nigeria	1 214	2 834	694	20	4 762	1 905
South Africa	207	350	279	32	868	347
Uganda	315	368	359	7	1 049	419
Total	**2 236**	**4 700**	**1 574**	**67**	**8 577**	**3 431**

Table S-15 Stretch goals for advanced biofuel as share of projected liquid transport fuel use

Country	Converted 40% to Advanced Biofuel (PJ/year)	Liquid Transport Fuel Use 2014 (PJ)	Biofuel Share of 2014 Transport Fuel Use	Liquid Transport Fuel Use 2050 (PJ)	Biofuel Share of 2050 Transport Fuel Use
Ghana	402	101	397 %	280	144 %
Mozambique	357	30	1 176 %	76	468 %
Nigeria	1 905	306	623 %	1 161	164 %
South Africa	347	735	47 %	1 302	27 %
Uganda	419	29	1 446 %	125	336 %
Total	**3 431**	**1 202**	**286 %**	**2 945**	**117 %**

Looking at a stretch goal for 2050, advanced biofuels could entirely displace projected fossil fuel use for transport in the five countries studied. However, there is a wide disparity in fossil fuel displacement across the group. In relatively industrialised South Africa, advanced biofuels could meet just a quarter of projected transport fuel needs. In the other countries, which are much less industrialised, they could

looking at countries individually, average projected compound annual demand growth from 2014 through 2050 is 2.86% for Ghana, 2.60% for Mozambique, 3.78% for Nigeria, 1.60% for South Africa and 4.14% for Uganda.

meet all projected transport fuel demand and more – all of it in Ghana, nearly double the demand in Nigeria, more than double in Uganda and over five times the transport fuel demand in Mozambique.

In fact, the amount of solid biomass available for the transport sector will depend on the amount used in other sectors, particularly for residential heating and cooking. In the five African countries studied, primary solid biomass production grew an average of 2.82% annually from 3 900 PJ in 2000 to 5 700 PJ in 2014 (IEA/OECD, 2016). If this trend were to continue and demand for energy wood grew at the same pace, the liquid biofuel potential from wood would be substantially eroded, as shown in Tables S-16 and S-17. Yet even in this extremely pessimistic and conservative assessment, sufficient wood would remain available beyond heating and cooking needs to supply over half of liquid transport demand in 2050.

Table S-16 Goals for primary energy from residues, higher yields, reduced waste and forests – net of current and projected wood energy use

Country	Total Primary Energy Goal (PJ/year)	Current Wood Fuel Energy Value 2013 Updated to 2014 (PJ)	Current Remaining Primary Energy for Liquid Fuel 2014 (PJ)	Trend Projection Wood Fuel Energy Value 2050 (PJ/year)	Trend Remaining Primary Energy for Liquid Fuel 2050 (PJ)
Ghana	1 006	405	600	1 102	**-97**
Mozambique	893	163	730	445	**448**
Nigeria	4 762	629	4 133	1 712	**3 050**
South Africa	868	117	751	319	**549**
Uganda	1 049	406	642	1 105	**-57**
Total	**8 578**	**1 721**	**6 856**	**4 684**	**3 893**

Table S-17 Stretch goals for advanced biofuel as share of projected liquid transport fuel use – net of current and projected wood energy use

Country	Current Remaining Converted 40% to Advanced Biofuel (PJ)	Liquid Transport Fuel Use 2014 (PJ)	Current Remaining Biofuel Share of 2014 Transport Fuel Use	Trend Remaining Converted 40% to Advanced Biofuel (PJ)	Liquid Transport Fuel Use 2050 (PJ)	Trend Remaining Biofuel Share of 2050 Transport Fuel Use
Ghana	240	101	**237 %**	-39	280	**-14 %**
Mozambique	292	30	**961 %**	179	76	**235 %**
Nigeria	1 653	306	**541 %**	1 220	1 161	**105 %**
South Africa	300	735	**41 %**	220	1 302	**17 %**
Uganda	257	29	**886 %**	-23	125	**-18 %**
Total	**2 743**	**1 202**	**228 %**	**1 557**	**2 945**	**53 %**

And much of the wood demand is for use in traditional wood stoves, which are gradually being replaced by modern stoves that use wood more efficiently or run on biogas from anaerobic digestion of crop residues and manure. Both cooking and heating might be electrified as African economies develop, and growing shares of electricity might be provided by renewable resources. So with strong policies to promote renewable electricity, biogas production and more efficient stoves, wood use in homes could grow more slowly or decline, leaving more biomass available for advanced liquid biofuels.

In a medium-term perspective, as advanced technologies for liquid biofuels production mature, it is perhaps more realistic to focus on conventional use of wood for heat and power applications. Taking industrial demand for process heat and electricity as an important locus of potential bioenergy use, one can compare the stretch goal for bioenergy supply with current and projected demand for combined heat and power by industry. Industrial energy end use in 2014 may be derived for four of the countries from IEA/OECD (2016) and for Uganda from UN statistics (2016) as electricity demand plus 80% of fuel demand (assuming fuel is converted to heat and power). It can then be projected to 2050 using growth rates in IEA/OECD (2014). In the five countries surveyed as a group, the stretch goal for bioenergy could supply nearly twice the projected industrial needs for combined heat and power in 2050 (Table S-18).

Table S-18 Stretch goals for bioenergy as share of industrial heat and power needs

Country	Converted 80% to Combined Heat & Power (PJ/year)	Industrial Heat & Power 2014 (PJ)	Bioenergy Multiple of 2014 Industrial Heat and Power Use	Industrial Heat & Power 2050 (PJ)	Bioenergy Multiple of 2050 Industrial Heat and Power Use
Ghana	804	50	16.1 x	235	3.4 x
Mozambique	714	75	9.5 x	319	2.2 x
Nigeria	3 810	249	15.3 x	1 390	2.7 x
South Africa	695	1 005	0.7 x	1 441	0.5 x
Uganda	839	27	31.5 x	153	5.5 x
Total	**6 862**	**1 405**	**4.9 x**	**3 538**	**1.9 x**

In view of the large potential, it is useful to consider what portion of the potential might practically be developed and what policies and measures would hold the most promise for bringing it to market. Several courses of action could help to raise agricultural yields in Africa, which is key to raising supplies of residues and to freeing land for bioenergy crops. Capacity building and extension services could be expanded to spread indigenous expertise, modern farming techniques and high-yielding seed varieties that are suited to local conditions. Good practices on logistical approaches for cost-effective harvesting of farm and forest residues could be compiled and disseminated for farmers to consider. Agroforestry strategies for investing in cultivation of a mix of high-yielding food and fuel crops which are ecologically sustainable could be developed from successful experiences with stakeholders in the countries and spread through cooperatives or farmers' field schools, which already exist in many places (Nishimura, 2010). Growing use of mobile phones and electronic banking could facilitate extension services and marketing programmes to help farmers sell more produce at higher prices and thus incentivise agricultural investment (Goda, 2016; WFP, 2017). Secure land tenure should be in place, incorporating customary land rights that are sufficiently well specified and building on them where necessary so that farmers have the financial incentive to invest in sustainable land management and conservation, which are needed to raise yields and make agriculture more resilient to climate change.

A range of measures could also help to reduce food losses and waste. In sub-Saharan Africa, little food is wasted at the point of consumption, but much is lost due to spoilage. Food spoilage can be reduced through vaccination of livestock to limit disease-related losses, improved harvesting techniques, storage facilities for grain, and refrigeration of highly perishable meat, fruits and vegetables on the way to market. Improved and expanded road networks can bring more food to market while it remains fresh and saleable (Gustavsson *et al.*, 2011). Processing facilities near farms can reduce losses significantly and create new employment opportunities. Extension services and capacity building could help improve harvesting and processing techniques. Development assistance could help build better infrastructure.

Points of departure for development of advanced biofuel resources in Africa

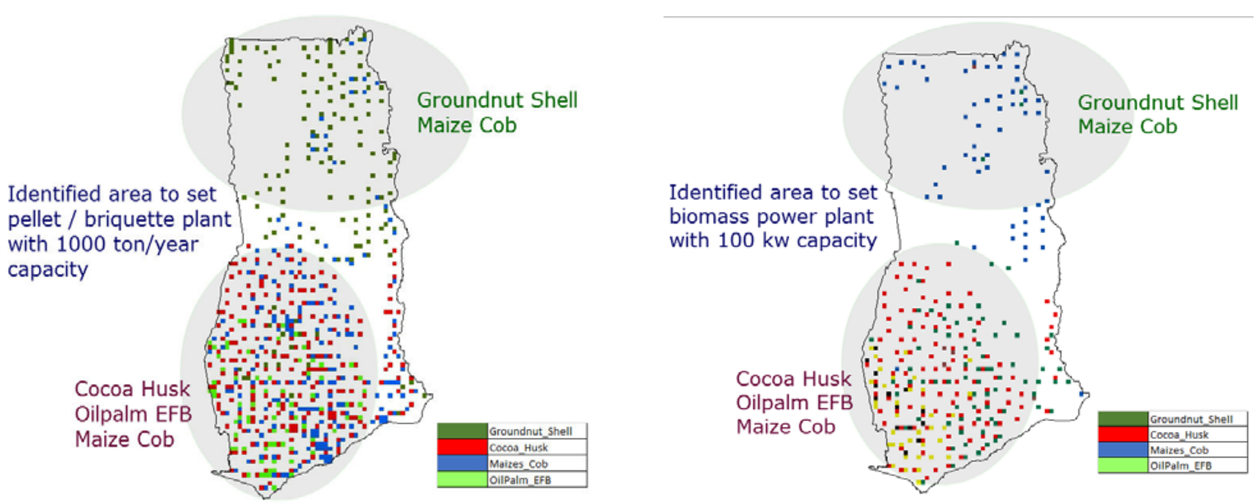
The African Union has provided an Africa Bioenergy Policy Framework and associated Guidelines to help member countries develop bioenergy in an environmentally friendly, socially responsible manner (African Union and UNECE, 2013). Governments of the five countries examined in this report have been making substantial efforts to develop the bioenergy sector and coordinate among various stakeholders in the sector.

While awaiting development of cost-effective options for conversion of lignocellulosic feedstocks to advanced biofuels, several countries in sub-Saharan Africa have been developing such feedstocks for use in combined heat and power applications. These are apt to be the feedstocks that the countries initially draw upon for conversion to advanced biofuels when the processes are deemed cost-effective.

Three of the countries have liquid biofuels mandates or targets. Nigeria and Mozambique have E10 ethanol blending targets, while South Africa has both E2 ethanol and B5 biodiesel mandates. These are being met mainly by conventional biofuels such as ethanol from cassava and sugarcane and biodiesel from jatropha and other oil seeds. Such biofuel crops have substantial residues that can be used to provide process heat for biofuel refining. The use of residual biomass from sugarcane processing, pulp and paper manufacturing, and wood production industries is also commonly encountered in these countries, mainly to supply internal heat and electricity demands in those industries.

A study for Ghana was supported by Japan's Ministry of Agriculture, Forestry and Fisheries to identify potential locations for bioenergy plants that could use locally produced feedstock without affecting local food security. A geographic information system (GIS) was used to find where farm residues available within a 12-kilometre radius would provide sufficient feedstock for a factory producing 1 000 tonnes of pellets per annum or a power plant with 100 kilowatts (kW) of generating capacity (Nakada, 2016).

Figure 1 Logistical matching of bioenergy feedstocks and applications in Ghana



Source: Nakada (2016) EFB = Empty Fruit Bunches

Cooperating with Germany, Ghana has conducted a detailed Biomass Supply Assessment to fuel a substantially larger power plant with 6 megawatts of capacity. The assessment was to identify the most suitable types and sources of biomass to optimise plant output (based on available quantities), supply variability, biomass quality, and costs of collecting, processing and transporting biomass to the site. It found that wood processing residues are the most cost-effective as they can be collected over a concentrated area and thus do not cost much to transport. It also found that seasonal fluctuation in feedstock availability is moderate, so a small storage facility can balance it out (Ackom, 2017).

Meanwhile, Ghana already relies substantially on biomass to supply energy to agroprocessing facilities. Myriad specific applications include boiling for processing palm oil, palm kernels and shea butter; roasting of shea nuts and groundnuts; drying of fruits, vegetables and mushrooms; and smoking of fish. More efficient facilities are promoted to reduce wood use and deforestation (Owusu-Takyi, 2017).

Technical readiness for advanced biofuel conversion in Africa

In evaluating the prospects for advanced biofuel markets in Africa, it is interesting to consider the technical readiness of countries to make use of advanced biofuel conversion processes once they have been shown to be cost-effective. Ideally, there would be direct experience with processes for conversion of lignocellulosic feedstocks such as wood and agricultural residues to biofuel. But also of value, from the viewpoint of technical readiness, is experience with other biofuel conversion processes.

Ghana's energy policy calls for sustainable bioenergy development and a 20% biofuels share in the transport fuel mix by 2030 (Iddrisu and Bhattacharyya, 2015). Caltech Ventures operates an ethanol refinery in Ghana with the capacity to produce 3 million liters (ML) of biofuel per annum from cassava (Ghana News Agency, 2017). The country's president aims to reconfigure its first sugarcane mill to produce ethanol from molasses, a residue of sugar production (My Joy Online, 2017). Most biofuel consumption is by processing companies milling rice (such as GADCO) and oil palm (such as Norpalm, BOPP, TOPP and GOPDC) (Egyir, 2017). A key issue in sustaining the supply of biofuel is the placement of adequate feedstock storage and distribution facilities in strategic regions. An expanded incentive structure and stakeholder coordination are necessary to ensure the growth of Ghana's biofuel industry.

In Mozambique, the National Biofuels Policy and Strategy of 2009 established a framework for biofuel deployment to jointly promote energy security and food security. In 2010, Nippon Biodiesel Fuel (NBF) started a jatropha contract-farming system in which seedlings are provided to about 100 groups of 60 farmers each. These farmers grow jatropha plants as fencing around their other crops and sell mature jatropha seeds to NBF, which refines the seeds to biodiesel. The biodiesel is then sold to the mobile phone company to power its antennas (Goda, 2016). In 2011, using the National Biofuels Policy and Strategy as a basis, an executive decree called for nationwide biofuel blends of E10 and B3 by 2015 (Netherlands Enterprise Agency, 2014).

The Nigerian Biofuel Policy and Incentives were officially released in 2007 (Ohimain, 2013). Their goal is to develop a bioethanol industry based on sugarcane and cassava for E10 national blending and export, as well as biodiesel production from palm oil and jatropha. The government has offered a number of incentives to stimulate Nigeria's biofuel industry, and a 60,000-hectare pilot project for bioethanol production was proposed (IRENA, 2016c). But as little progress has been made toward the E10 target in terms of industrial production, the Minister of State for Petroleum Resources has called for enhanced implementation efforts (The Nation, 2017a). Biofuels Nigeria subsequently signed an agreement with the Kogi state government for the offtake of a proposed plant with capacity to produce 36.5 ML of biodiesel per annum from feedstocks such as used cooking oil and jatropha (Ventures Africa, 2017). Moreover, the central bank announced in 2016 a USD50 billion equity investment fund to kick-start commercial biofuel production, with funding from state-owned companies, domestic investment banks, United Nations environment and development programmes (The Nation, 2017b). It is expected that once the economic viability of biofuel production in Nigeria is demonstrated, full-scale commercial production will be achieved through private-sector investment (Ogbonna, 2017).

In Uganda, the president has directed the minister of industry to propose a 10% ethanol blending law to support domestic production. Kakira Sugar has opened an ethanol plant with capacity to produce 60 kilolitres (kL) per day of ethanol from sugarcane molasses while providing 600 kW of electric generating capacity to its distilleries (All Africa, 2017). Kamtech Logistics has opened another plant that converts 15 tonnes of cassava to 4 kL of ethanol daily along with chicken feed and acetaldehyde for acetic acid (Daily Monitor, 2016).

South Africa introduced a Biofuels Industrial Strategy in 2007. This included a non-binding target of 2% penetration within five years for biodiesel made from soybean, sunflower or canola, or bioethanol from sugar beet or sugarcane. The strategy aimed to stimulate rural development and reduce poverty. It recommended investment in R&D to develop second-generation biofuels because the country has relatively little land availability. Regulations on the Mandatory Blending of Biofuels with Petrol and Diesel have more recently been enacted (IEA and IRENA, 2016).

Project Solaris, a joint initiative of Boeing and South African Airways (SAA), is producing biojet fuel from the energy-rich oilseeds of Solaris, a nicotine-free variety of tobacco. Solaris planted in Limpopo Province was certified as sustainable in 2015 by the Roundtable on Sustainable Biomaterials (RSB). In July 2016, flights took 300 passengers from Johannesburg to Cape Town on Boeing 737-800s using a blend of aviation fuel that was 30% biojet from Solaris, refined by AltAir Fuels and supplied by SkyNRG. These were Africa's first passenger flights with sustainable aviation biofuel (Biofuels Digest, 2016).

South Africa has experience producing liquid fuels from coal. In 1950, the South African Coal, Oil and Gas Corporation Limited (SASOL) built the SASOL I gasification plant to convert coal to diesel fuel, gasoline, chemicals and other products. Coal-to-liquids capacity expanded with construction of Sasol II in 1980 and Sasol III in 1982 (NETL, 2016). The SASOL technology involves both gasification of coal and conversion of synthetic gas (syngas) to liquid fuels, the latter through a Fischer-Tropsch (FT) process. This technology provides a major foundation for development of technologies for liquid biofuel production from lignocellulosic feedstocks, as the FT process is identical. But significant adaptation is required for the production of syngas from lignocellulosic feedstocks like farm and wood residues instead of coal, since such feedstocks have a higher oxygen content and lower energy density as well as different impurities.

South Africa's recently developed BioEnergy Atlas focuses on the potential for such second-generation bioenergy production at a gas-to-liquids (GTL) refinery called PetroSA in Mossel Bay. The plant uses natural gas as feedstock, but it is not clear whether enough new gas deposits will be available to keep it running full-time. Options are therefore being considered to replace part of the natural gas with syngas from lignocellulosic biomass sources such as wheat and forest residues (Hugo *et al.*, 2016).

As a group, the five countries in sub-Saharan Africa that were studied have considerable technical background to enable advanced biofuels production. South Africa has direct experience with major components of the technology required for conversion of lignocellulose to biofuel. Ghana, Mozambique, Nigeria and Uganda are acquiring experience with first-generation technologies for conversion of starch- and sugar-based feedstocks, which may help build capacity for advanced biofuels production at a later date. Technical capabilities in all the countries should progress as technologies for producing biofuels from lignocellulosic feedstocks are demonstrated elsewhere. Meanwhile, the countries can use their considerable biomass resources from agricultural crops and residues to supply heat and power, as well as transport fuels if desired, from the conventional plants and refining processes already available.

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Appendix I: Bioenergy potential from agricultural residues in sub-Saharan Africa

Table R-1 Residue potential for biofuel – summary table

The residue available for conversion to fuel in each country is calculated as the difference between the total residue and the residue required for animal feed. Total residue adds harvest residue and process residue. Calculations in tonnes, in tables that follow, are converted to energy terms assuming 15 GJ energy per tonne.

Residue potential for biofuel with 25% of harvest residue collected

Available residue is calculated for 2010 (Table R-1a) and projected to 2030 and 2050 (tables R-1b, R-1c).

Table R-1a Residue Potential for 2010 (PJ/year) – 25% Collection of Harvest Residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	115	74	189	7	**181**
Mozambique	74	43	117	7	**110**
Nigeria	627	353	980	82	**898**
South Africa	161	118	279	106	**173**
Uganda	93	74	167	28	**139**
WORLD	34 341	20 838	55 179	19 460	35 718

Table R-1b Residue potential for 2030 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	143	92	235	8	**227**
Mozambique	120	68	188	11	**177**
Nigeria	780	440	1 220	86	**1 134**
South Africa	200	147	347	136	**212**
Uganda	150	119	268	46	**223**
WORLD	43 914	26 597	70 510	25 180	45 330

Table R-1c Residue potential for 2050 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	155	100	254	10	**245**
Mozambique	174	100	274	19	**255**
Nigeria	845	476	1 321	107	**1 214**
South Africa	217	159	376	169	**207**
Uganda	218	173	391	76	**315**
WORLD	49 278	29 730	79 008	32 908	46 100

Residue potential for biofuel with 50% of harvest residue collected

Available residue is calculated for 2010 (Table R-1d) and projected to 2030 and 2050 (tables R-1e, R-1f).

Table R-1d Residue potential for 2010 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	229	74	303	7	**296**
Mozambique	149	43	191	7	**185**
Nigeria	1 254	353	1 607	82	**1 525**
South Africa	322	118	440	106	**334**
Uganda	187	74	260	28	**233**
WORLD	68 681	20 838	89 519	19 460	70 059

Table R-1e Residue potential for 2030 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	286	92	378	8	**370**
Mozambique	239	68	308	11	**296**
Nigeria	1 560	440	2 000	86	**1 914**
South Africa	401	147	547	136	**412**
Uganda	300	119	418	46	**373**
WORLD	87 828	26 597	114 424	25 180	89 244

Table R-1f Residue potential for 2050 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Ghana	309	100	409	10	**399**
Mozambique	348	100	448	19	**429**
Nigeria	1 690	476	2 166	107	**2 059**
South Africa	434	159	593	169	**424**
Uganda	437	173	610	76	**534**
WORLD	98 555	29 730	128 285	32 908	95 378

Table R-2 Crop production by type and country in 2010

The starting point for calculating the amounts of residue in each country is to tabulate the amounts of each crop that were grown in 2010, which can later be multiplied by amounts of residue per tonne of crop.

Crop (Thousand Metric Tonnes)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Apples				774	
Apricots				49	
Asparagus				1	
Avocados	8			78	
Bananas	70	314		384	591
Barley				241	
Bast fibres, other		4	1	1	
Beans, dry		170		54	454
Beans, green	26			25	
Berries not elsewhere specified				1	
Buckwheat				0	
Cabbages and other brassicas				146	
Carrots and turnips			207	151	
Cashew nuts, with shell	31	91	822		
Cassava	13 325	8 501	43 920		5 073
Castor oil seed		59		6	1
Cauliflowers and broccoli				20	
Cereals not elsewhere specified				21	
Cherries				0	
Chick peas					4
Chicory roots				22	
Chillies and peppers, dry	91		57	13	3
Chillies and peppers, green	90		598	1	
Cocoa, beans	681		388		15
Coconuts	286	271	206		
Coffee, green	1	1	2		185
Coir	39				
Cotton lint	9	39	150	12	29
Cottonseed	14	79	193	18	56
Cow peas, dry		38	2 534	5	88
Cucumbers and gherkins	0			22	
Eggplants (aubergines)	40				
Fibre crops not elsewhere specified				2	
Figs				2	
Fonio			82		

Crop (Thousand Metric Tonnes)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Fruit, citrus not elsewhere specified			3 800	10	
Fruit, fresh not elsewhere specified	67	132	1 227	61	52
Fruit, tropical fresh not elsewhere specified		22			
Garlic			1		
Ginger	0		164		0
Grapefruit (including pomelos)		11		388	
Grapes				1 305	
Groundnuts, with shell	507	117	3 247	84	287
Hops				0	
Karite nuts (shea nuts)	71		328		
Kola nuts	21		157		
Leeks, other alliaceous vegetables				1	
Lemons and limes	46	3		227	
Lettuce and chicory				38	
Lupins				18	
Maize	1 725	1 788	8 072	11 742	2 426
Maize, green			661	386	
Mangoes, mangosteens, guavas	80	29	845	55	
Melons, other (Including cantaloupes)	0			21	
Melonseed			473		
Millet	216	50	3 790	7	270
Mushrooms and truffles				12	
Nuts not elsewhere specified	1		7	15	
Oats	0			43	
Oil, palm	124		1 045		
Oil, palm fruit	2 037		8 167		
Oilseeds not elsewhere specified	0	34	0	13	44
Okra	51		1 065		
Onions, dry	103	71	1 295	523	183
Onions, shallots, green			217		
Oranges	580	30		1 427	
Palm kernels	39		1 133		
Papayas	45	43	758	13	
Peaches and nectarines				160	
Pears				353	
Peas, dry				1	17
Peas, green				12	
Pepper (piper spp.)	3				2

Crop (Thousand Metric Tonnes)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Pigeon peas					92
Pineapples	50	51	1 296	109	2
Plantains	3 573		2 692		9 554
Plums and sloes				62	
Potatoes		171	1 067	2 051	722
Pulses not elsewhere specified	23	210	56		
Pumpkins, squash and gourds		1		169	
Quinces				0	
Rapeseed				45	
Rice, paddy	449	236	4 195	3	219
Roots and tubers not elsewhere specified	0	9			
Rubber, natural	20		144		
Rye				2	
Seed cotton	26	121	416	30	94
Sesame seed		70	141		193
Sisal		1		1	0
Sorghum	321	394	6 439	209	401
Soybeans			425	597	192
Spices not elsewhere specified			5		
Strawberries				6	
Sugar cane	145	2 775	1 417	17 157	2 700
Sunflower seed		17		717	258
Sweet potatoes	124	893	3 300	62	2 719
Tangerines, mandarins, clementines, satsumas		0		145	
Taro (cocoyam)	1 386		3 085		
Tea		29		2	44
Tobacco, unmanufactured	4	67	16	12	25
Tomatoes	319	178	1 685	532	28
Vanilla					0
Vegetables, fresh not elsewhere specified	10	193	5 494	376	726
Watermelons				96	
Wheat		18	118	1 798	21
Yams	6 011		33 457		

Source: FAO (2015)

Table R-3 Harvest and process residues by country in 2010

Harvest and process residue factors, in tons of residue per tonne of crop (columns 3 and 5) can be multiplied by the amounts of each crop produced (from Table R-2) and the share of residues collected (assumed here to be 25% for harvest residues and 90% for process residues) to calculate amounts of harvest and process residues collected (shown in columns 4 and 6). A separate table is generated for each country, and specific factors are applied for each crop. Crops not produced are not shown.

Table R-3a Harvest and process residues in Ghana

(Ghana) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	3 331	0.2	2 159
Cottonseed	Cottonseed	13.3	46	0.1	1
Cottonseed	Seed cotton	13.3	88	0.1	2
Fruit	Avocados	2.0	4	0.2	2
Fruit	Bananas	2.0	36	0.2	13
Fruit	Fruit, fresh not elsewhere specified	2.0	34	0.2	12
Fruit	Lemons and limes	2.0	23	0.2	8
Fruit	Mangoes, mangosteens, guavas	2.0	41	0.2	14
Fruit	Melons, other (including cantaloupes)	2.0	0	0.2	0
Fruit	Oranges	2.0	294	0.2	104
Fruit	Papayas	2.0	23	0.2	8
Fruit	Pineapples	2.0	25	0.2	9
Groundnut	Groundnuts, with shell	2.3	296	0.3	137
Maize	Maize	1.5	647	0.2	279
Millet	Millet	2.3	126	0.1	27
Oats	Oats	1.5	0	0.2	0
Palm kernels	Palm kernels	3.0	29	0.5	16
Pulses	Beans, green	2.3	15	0.0	0
Pulses	Pulses not elsewhere specified	2.3	13	0.0	0
Rice	Rice, paddy	1.3	149	0.2	93
Sorghum	Sorghum	2.3	187	0.1	29
Spices	Chillies and peppers, dry	3.0	68	0.0	0
Spices	Chillies and peppers, green	3.0	68	0.0	0
Spices	Pepper (piper spp.)	3.0	2	0.0	0
Stimulants	Cocoa, beans	2.3	397	0.0	0
Stimulants	Coffee, green	2.3	1	0.0	0
Sugar cane	Sugar cane	0.3	10	0.2	26

(Ghana) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Sweet potatoes	Sweet potatoes	0.8	25	0.3	31
Treenuts	Cashew nuts, with shell	2.3	18	0.7	20
Treenuts	Nuts not elsewhere specified	2.3	1	0.7	1
Vegetables	Cucumbers and gherkins	0.4	0	0.2	0
Vegetables	Eggplants (aubergines)	0.4	4	0.2	7
Vegetables	Ginger	0.4	0	0.2	0
Vegetables	Okra	0.4	5	0.2	9
Vegetables	Onions, dry	0.4	11	0.2	19
Vegetables	Plantains	0.4	365	0.2	643
Vegetables	Tomatoes	0.4	33	0.2	57
Vegetables	Vegetables, fresh not elsewhere specified	0.4	1	0.2	2
Yams & other roots	Roots and tubers not elsewhere specified	0.7	0	0.2	0
Yams & other roots	Taro (cocoyam)	0.7	231	0.2	225
Yams & other roots	Yams	0.7	1 002	0.2	974

Source: Smeets, Faaij and Lewandowski (2004) and IRENA analysis

Table R-3b Harvest and process residues in Mozambique

(Mozambique) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	2 125	0.2	1 377
Cottonseed	Cottonseed	13.3	262	0.1	5
Cottonseed	Seed cotton	13.3	402	0.1	8
Fruit	Bananas	2.0	159	0.2	56
Fruit	Fruit, fresh not elsewhere specified	2.0	67	0.2	24
Fruit	Fruit, tropical fresh not elsewhere specified	2.0	11	0.2	4
Fruit	Grapefruit (including pomelos)	2.0	6	0.2	2
Fruit	Lemons and limes	2.0	2	0.2	1
Fruit	Mangoes, mangosteens, guavas	2.0	14	0.2	5
Fruit	Oranges	2.0	15	0.2	5
Fruit	Papayas	2.0	22	0.2	8

(Mozambique) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Fruit	Pineapples	2.0	26	0.2	9
Fruit	Tangerines, mandarins, clementines, satsumas	2.0	0	0.2	0
Groundnut	Groundnuts, with shell	2.3	68	0.3	32
Maize	Maize	1.5	670	0.2	290
Millet	Millet	2.3	29	0.1	6
Potatoes	Potatoes	0.7	29	0.3	51
Pulses	Beans, dry	2.3	99	0.0	0
Pulses	Cow peas, dry	2.3	22	0.0	0
Pulses	Pulses not elsewhere specified	2.3	122	0.0	0
Rice	Rice, paddy	1.3	78	0.2	49
Sorghum	Sorghum	2.3	230	0.1	35
Stimulants	Coffee, green	2.3	0	0.0	0
Stimulants	Tea	2.3	17	0.0	0
Sugar cane	Sugar cane	0.3	196	0.2	499
Sunflowers	Sunflower seed	0.0	0	0.3	5
Sweet potatoes	Sweet potatoes	0.8	183	0.3	225
Treenuts	Cashew nuts, with shell	2.3	53	0.7	60
Vegetables	Onions, dry	0.4	7	0.2	13
Vegetables	Pumpkins, squash and gourds	0.4	0	0.2	0
Vegetables	Tomatoes	0.4	18	0.2	32
Vegetables	Vegetables, fresh not elsewhere specified	0.4	20	0.2	35
Wheat	Wheat	1.3	6	0.2	3
Yams & other roots	Roots and tubers not elsewhere specified	0.7	1	0.2	1

Source: Smeets, Faaij and Lewandowski (2004) and IRENA analysis

Table R-3c Harvest and process residues in Nigeria

(Nigeria) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	10 980	0.2	7 115
Cereals, other	Fonio	1.5	31	0.3	18
Cottonseed	Cottonseed	13.3	642	0.1	12
Cottonseed	Seed cotton	13.3	1 383	0.1	26
Fruit	Fruit, citrus not elsewhere specified	2.0	1 929	0.2	684

(Nigeria) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Fruit	Fruit, fresh not elsewhere specified	2.0	623	0.2	221
Fruit	Mangoes, mangosteens, guavas	2.0	429	0.2	152
Fruit	Papayas	2.0	385	0.2	136
Fruit	Pineapples	2.0	658	0.2	233
Groundnut	Groundnuts, with shell	2.3	1 894	0.3	877
Maize	Maize	1.5	3 027	0.2	1 308
Maize	Maize, green	1.5	248	0.2	107
Millet	Millet	2.3	2 211	0.1	478
Palm kernels	Palm kernels	3.0	850	0.5	459
Potatoes	Potatoes	0.7	178	0.3	317
Pulses	Cow peas, dry	2.3	1 478	0.0	0
Pulses	Pulses not elsewhere specified	2.3	32	0.0	0
Rice	Rice, paddy	1.3	1 390	0.2	868
Sorghum	Sorghum	2.3	3 756	0.1	580
Soybeans	Soybeans	2.3	248	0.2	80
Spices	Chillies and peppers, dry	3.0	43	0.0	0
Spices	Chillies and peppers, green	3.0	449	0.0	0
Spices	Spices not elsewhere specified	3.0	4	0.0	0
Stimulants	Cocoa, beans	2.3	226	0.0	0
Stimulants	Coffee, green	2.3	1	0.0	0
Sugar cane	Sugar cane	0.3	100	0.2	255
Sweet potatoes	Sweet potatoes	0.8	675	0.3	832
Treenuts	Cashew nuts, with shell	2.3	479	0.7	540
Treenuts	Nuts not elsewhere specified	2.3	4	0.7	4
Vegetables	Carrots and turnips	0.4	21	0.2	37
Vegetables	Garlic	0.4	0	0.2	0
Vegetables	Ginger	0.4	17	0.2	29
Vegetables	Okra	0.4	109	0.2	192
Vegetables	Onions, dry	0.4	132	0.2	233
Vegetables	Onions, shallots, green	0.4	22	0.2	39
Vegetables	Plantains	0.4	275	0.2	485
Vegetables	Tomatoes	0.4	172	0.2	303
Vegetables	Vegetables, fresh not elsewhere specified	0.4	561	0.2	989

(Nigeria) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Wheat	Wheat	1.3	39	0.2	22
Yams & other roots	Taro (cocoyam)	0.7	514	0.2	500
Yams & other roots	Yams	0.7	5 576	0.2	5 420

Source: Smeets, Faaij and Lewandowski (2004) and IRENA analysis

Table R-3d Harvest and process residues in South Africa

(South Africa) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Barley	Barley	1.5	90	0.3	58
Cereals, other	Buckwheat	1.5	0	0.3	0
Cereals, other	Cereals not elsewhere specified	1.5	8	0.3	5
Cottonseed	Cottonseed	13.3	61	0.1	1
Cottonseed	Seed cotton	13.3	99	0.1	2
Fruit	Apples	2.0	393	0.2	139
Fruit	Apricots	2.0	25	0.2	9
Fruit	Avocados	2.0	40	0.2	14
Fruit	Bananas	2.0	195	0.2	69
Fruit	Berries not elsewhere specified	2.0	0	0.2	0
Fruit	Cherries	2.0	0	0.2	0
Fruit	Fruit, citrus not elsewhere specified	2.0	5	0.2	2
Fruit	Fruit, fresh not elsewhere specified	2.0	31	0.2	11
Fruit	Grapefruit (including pomelos)	2.0	197	0.2	70
Fruit	Grapes	2.0	662	0.2	235
Fruit	Lemons and limes	2.0	115	0.2	41
Fruit	Mangoes, mangosteens, guavas	2.0	28	0.2	10
Fruit	Melons, other (including cantaloupes)	2.0	10	0.2	4
Fruit	Oranges	2.0	724	0.2	257
Fruit	Papayas	2.0	7	0.2	2
Fruit	Peaches and nectarines	2.0	81	0.2	29
Fruit	Pears	2.0	179	0.2	64

(South Africa) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Fruit	Pineapples	2.0	55	0.2	20
Fruit	Plums and sloes	2.0	31	0.2	11
Fruit	Strawberries	2.0	3	0.2	1
Fruit	Tangerines, mandarins, clementines, satsumas	2.0	74	0.2	26
Fruit	Watermelons	2.0	49	0.2	17
Groundnut	Groundnuts, with shell	2.3	49	0.3	23
Maize	Maize	1.5	4 403	0.2	1 902
Maize	Maize, green	1.5	145	0.2	62
Millet	Millet	2.3	4	0.1	1
Oats	Oats	1.5	16	0.2	8
Potatoes	Potatoes	0.7	342	0.3	609
Pulses	Beans, dry	2.3	31	0.0	0
Pulses	Beans, green	2.3	14	0.0	0
Pulses	Cow peas, dry	2.3	3	0.0	0
Pulses	Lupins	2.3	10	0.0	0
Pulses	Peas, dry	2.3	1	0.0	0
Rapeseed	Rapeseed	3.0	34	0.3	12
Rice	Rice, paddy	1.3	1	0.2	1
Rye	Rye	1.9	1	0.2	0
Sorghum	Sorghum	2.3	122	0.1	19
Soybeans	Soybeans	2.3	348	0.2	113
Spices	Chillies and peppers, dry	3.0	10	0.0	0
Spices	Chillies and peppers, green	3.0	1	0.0	0
Stimulants	Tea	2.3	1	0.0	0
Sugar cane	Sugar cane	0.3	1 210	0.2	3 088
Sunflowers	Sunflower seed	0.0	0	0.3	194
Sweet potatoes	Sweet potatoes	0.8	13	0.3	16
Treenuts	Nuts not elsewhere specified	2.3	9	0.7	10
Vegetables	Asparagus	0.4	0	0.2	0
Vegetables	Cabbages and other brassicas	0.4	15	0.2	26
Vegetables	Carrots and turnips	0.4	15	0.2	27
Vegetables	Cauliflowers and broccoli	0.4	2	0.2	4
Vegetables	Chicory roots	0.4	2	0.2	4
Vegetables	Cucumbers and gherkins	0.4	2	0.2	4
Vegetables	Leeks, other alliaceous	0.4	0	0.2	0

(South Africa) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
	vegetables				
Vegetables	Lettuce and chicory	0.4	4	0.2	7
Vegetables	Mushrooms and truffles	0.4	1	0.2	2
Vegetables	Onions, dry	0.4	53	0.2	94
Vegetables	Peas, green	0.4	1	0.2	2
Vegetables	Pumpkins, squash and gourds	0.4	17	0.2	30
Vegetables	Tomatoes	0.4	54	0.2	96
Vegetables	Vegetables, fresh not elsewhere specified	0.4	38	0.2	68
Wheat	Wheat	1.3	596	0.2	340

Source: Smeets, Faaij and Lewandowski (2004) and IRENA analysis

Table R-3e Harvest and process residues in Uganda

(Uganda) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	1 268	0.2	822
Cottonseed	Cottonseed	13.3	187	0.1	4
Cottonseed	Seed cotton	13.3	311	0.1	6
Fruit	Bananas	2.0	300	0.2	106
Fruit	Fruit, fresh not elsewhere specified	2.0	26	0.2	9
Fruit	Pineapples	2.0	1	0.2	0
Groundnut	Groundnuts, with shell	2.3	167	0.3	77
Maize	Maize	1.5	910	0.2	393
Millet	Millet	2.3	157	0.1	34
Potatoes	Potatoes	0.7	120	0.3	214
Pulses	Beans, dry	2.3	265	0.0	0
Pulses	Chick peas	2.3	3	0.0	0
Pulses	Cow peas, dry	2.3	51	0.0	0
Pulses	Peas, dry	2.3	10	0.0	0
Pulses	Pigeon peas	2.3	54	0.0	0
Rice	Rice, paddy	1.3	73	0.2	45
Sorghum	Sorghum	2.3	234	0.1	36
Soybeans	Soybeans	2.3	112	0.2	36
Spices	Chillies and peppers, dry	3.0	2	0.0	0
Spices	Pepper (piper spp.)	3.0	1	0.0	0
Spices	Vanilla	3.0	0	0.0	0

(Uganda) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Stimulants	Cocoa, beans	2.3	9	0.0	0
Stimulants	Coffee, green	2.3	108	0.0	0
Stimulants	Tea	2.3	26	0.0	0
Sugar cane	Sugar cane	0.3	190	0.2	486
Sunflowers	Sunflower seed	0.0	0	0.3	70
Sweet potatoes	Sweet potatoes	0.8	556	0.3	685
Vegetables	Ginger	0.4	0	0.2	0
Vegetables	Onions, dry	0.4	19	0.2	33
Vegetables	Plantains	0.4	976	0.2	1 720
Vegetables	Tomatoes	0.4	3	0.2	5
Vegetables	Vegetables, fresh not elsewhere specified	0.4	74	0.2	131
Wheat	Wheat	1.3	7	0.2	4

Source: Smeets, Faaij and Lewandowski (2004) and IRENA analysis

Table R-4 Growth rates for crop output

Separate rates of growth in crop output are assumed for each country, according to projections by the FAO. Output is assumed to grow more slowly from 2030 to 2050 than from 2010 through 2030, as populations and food requirements stabilise. The rates of growth are applied to estimates of collectable residue in 2010 (calculated by crop in Table R-3, summed in columns 2-4 of Table R-1a) to project collectable residue in 2030 and 2050 (columns 2-4 of Tables R-1b, R-1c).

Country	Annual Growth in Crop Output 2010-2030	Annual Growth in Crop Output 2030-2050	Information: Calories per Capita in 2010
Ghana	1.1%	0.4%	2 755
Mozambique	2.4%	1.9%	2 126
Nigeria	1.1%	0.4%	2 786
South Africa	1.1%	0.4%	2 979
Uganda	2.4%	1.9%	2 294

Source: Alexandratos *et al.* (2012)

Table R-5 Livestock production by type and country in 2010 (tonnes)

Livestock production in 2010 is shown as the basis for projecting livestock production in 2030 and 2050, which is multiplied by residue consumed per tonne of livestock to find total residue eaten by livestock.

Crop (Item)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Beef	24 769	19 600	293 200	785 390	125 300
Dairy	37 340	75 545	469 937	3 102 333	1 120 000
Mutton	0	0	0	160 866	39 642
Pork	16 993	93 800	234 000	277 967	108 000
Poultry	44 720	23 948	286 000	1 286 718	44 850

Source: FAO (2015)

Table R-6 Growth rates for livestock output

FAO-projected growth rates for livestock output are applied to livestock production in 2010 (Table R-5) to calculate livestock production in 2030 and 2050, from which residue eaten by livestock can be found.

Country	Annual Growth in Livestock 2010-2030	Annual Growth in Livestock 2030-2050
Ghana	1.1%	1.1%
Mozambique	2.7%	2.6%
Nigeria	1.1%	1.1%
South Africa	1.1%	1.1%
Uganda	2.7%	2.6%

Source: Alexandratos *et al.* (2012)

Table R-7 Livestock feed demand coefficients

For each livestock type and production system (mixed or pastoral), livestock residue demand intensity (in tonnes of residue per tonne of livestock) is calculated as the product of feed conversion efficiency (tonnes of feed per tonne of livestock) and residue feed share (tonnes of residue per tonne of feed). Insofar as livestock feeds from pasture, there is no consumption of residues from agricultural crops. Multiplying the amounts of livestock (from tables R-5 and R-6) by the fraction of livestock raised in a mixed system and the residue intensity, it is possible to calculate the amounts of residue consumed by livestock (Table R-8). Residue intensity is assumed to be the same in 2050 as in 2030, the latest year of relevant FAO projections.

Table R-7a Livestock feed demand coefficients for Ghana

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.63	0.68	62	46	0.32	0.32	12.5	9.7
Beef	Pastoral	0.37	0.33	117	89	0.00	0.00	0.0	0.0
Dairy	Mixed	0.49	0.55	4	4	0.45	0.45	1.0	0.9
Dairy	Pastoral	0.51	0.45	5	5	0.00	0.00	0.0	0.0
Mutton or goat	Mixed	0.64	0.73	20	15	0.05	0.05	0.6	0.5
Mutton or goat	Pastoral	0.36	0.27	23	17	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7b Livestock feed demand coefficients for Mozambique

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.30	0.30	32	27	0.22	0.22	2.2	1.8
Beef	Pastoral	0.70	0.70	81	73	0.02	0.02	0.9	0.8
Dairy	Mixed	0.40	0.54	2	3	0.32	0.32	0.3	0.5
Dairy	Pastoral	0.60	0.46	5	5	0.01	0.01	0.0	0.0
Mutton or goat	Mixed	0.15	0.30	21	18	0.06	0.06	0.2	0.3
Mutton or goat	Pastoral	0.85	0.70	25	22	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7c Livestock feed demand coefficients for Nigeria

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.63	0.68	62	46	0.32	0.32	12.5	9.7
Beef	Pastoral	0.37	0.33	117	89	0.00	0.00	0.0	0.0
Dairy	Mixed	0.49	0.55	4	4	0.45	0.45	1.0	0.9
Dairy	Pastoral	0.51	0.45	5	5	0.00	0.00	0.0	0.0
Mutton or goat	Mixed	0.64	0.73	20	15	0.05	0.05	0.6	0.5
Mutton or goat	Pastoral	0.36	0.27	23	17	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7d Livestock feed demand coefficients for South Africa

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.30	0.30	32	27	0.22	0.22	2.2	1.8
Beef	Pastoral	0.70	0.70	81	73	0.02	0.02	0.9	0.8
Dairy	Mixed	0.40	0.54	2	3	0.32	0.32	0.3	0.5
Dairy	Pastoral	0.60	0.46	5	5	0.01	0.01	0.0	0.0
Mutton or goat	Mixed	0.15	0.30	21	18	0.06	0.06	0.2	0.3
Mutton or goat	Pastoral	0.85	0.70	25	22	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7e Livestock feed demand coefficients for Uganda

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.56	0.65	50	41	0.19	0.19	5.3	5.0
Beef	Pastoral	0.44	0.35	148	111	0.00	0.00	0.0	0.0
Dairy	Mixed	0.69	0.75	3	3	0.28	0.28	0.6	0.5
Dairy	Pastoral	0.31	0.25	5	4	0.00	0.00	0.0	0.0
Mutton or goat	Mixed	0.65	0.74	21	17	0.05	0.05	0.6	0.6
Mutton or goat	Pastoral	0.35	0.26	23	17	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	7	0.60	0.60	4.0	3.9
Poultry	Mixed	1.00	1.00	4	4	0.60	0.60	2.4	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-8 Residue demand for animal feed

Residue demand for feed is calculated as the product of tonnes of livestock of each type (from tables R-5 and R-6), the share of each type raised in mixed systems (from Table R-7) and residue intensity (tonnes of residue per tonne of livestock, also from Table R-7). The total residue used for feed in each country, in tonnes, is then converted to petajoules of energy equivalent, assuming 15 MJ per tonne, in column 5 of tables R-1a, R-1b, and R-1c.

Country	Livestock Type	System	Residue Demand for Feed (Tonnes)		
			2010	2030	2050
Ghana	Beef	Mixed	308 407	300 200	373 623
Ghana	Beef	Pastoral	0	0	0
Ghana	Dairy	Mixed	35 511	40 620	50 555
Ghana	Dairy	Pastoral	0	0	0
Ghana	Mutton or goat	Mixed	0	0	0
Ghana	Mutton or goat	Pastoral	0	0	0
Ghana	Pork	Mixed	56 078	69 371	86 337
Ghana	Poultry	Mixed	90 941	110 480	137 502

Country	Livestock Type	System	Residue Demand for Feed (Tonnes)		
			2010	2030	2050
Mozambique	Beef	Mixed	42 249	60 850	101 674
Mozambique	Beef	Pastoral	17 806	27 110	45 298
Mozambique	Dairy	Mixed	23 730	65 238	109 005
Mozambique	Dairy	Pastoral	3 375	4 358	7 281
Mozambique	Mutton or goat	Mixed	0	0	0
Mozambique	Mutton or goat	Pastoral	0	0	0
Mozambique	Pork	Mixed	309 540	524 186	875 856
Mozambique	Poultry	Mixed	48 649	80 787	134 987
Nigeria	Beef	Mixed	3 650 735	3 553 579	4 422 716
Nigeria	Beef	Pastoral	0	0	0
Nigeria	Dairy	Mixed	446 920	511 224	636 260
Nigeria	Dairy	Pastoral	0	0	0
Nigeria	Mutton or goat	Mixed	0	0	0
Nigeria	Mutton or goat	Pastoral	0	0	0
Nigeria	Pork	Mixed	772 200	955 241	1 188 847
Nigeria	Poultry	Mixed	581 601	706 561	879 372
South Africa	Beef	Mixed	1 692 949	1 781 177	2 216 819
South Africa	Beef	Pastoral	713 502	793 545	987 630
South Africa	Dairy	Mixed	974 513	1 957 018	2 435 667
South Africa	Dairy	Pastoral	138 618	130 725	162 698
South Africa	Mutton or goat	Mixed	32 888	69 929	87 032
South Africa	Mutton or goat	Pastoral	0	0	0
South Africa	Pork	Mixed	917 290	1 134 723	1 412 254
South Africa	Poultry	Mixed	2 613 876	3 170 821	3 946 343
Uganda	Beef	Mixed	662 014	1 066 910	1 782 687
Uganda	Beef	Pastoral	0	0	0
Uganda	Dairy	Mixed	627 772	1 020 326	1 704 851
Uganda	Dairy	Pastoral	0	0	0
Uganda	Mutton or goat	Mixed	25 614	41 074	68 630
Uganda	Mutton or goat	Pastoral	0	0	0
Uganda	Pork	Mixed	427 680	724 249	1 210 138
Uganda	Poultry	Mixed	109 216	181 101	302 599

Appendix II: Bioenergy potential from higher agricultural yields in sub-Saharan Africa

Table Y-1 Biomass potential from land freed by higher crop yields – summary

The amount of land freed up for bioenergy production in each country is calculated as the difference between land required in the FAO base case scenario, which fully provides for anticipated food needs, and reduced amounts of land required in the more ambitious yield growth scenarios. In the "trend" scenario, crop yields continue to improve at the same absolute pace as they have improved historically. In the "GAP" scenario, the yield gap between current and potential yields, as calculated by the FAO, is completely closed through yield improvements. Land freed, shown in the second column from the right, is multiplied by a notional yield of 150 GJ/ha to arrive at primary biomass potential from using this land.

Subsequent tables show the data used to calculate the figures in these summary tables. Land needed for food in each case (in hectares) equals food required (in tonnes) divided by yield (tonnes per hectare). Table Y-2 shows the calculation of food required. Tables Y-3 and Y-4 show the calculation of yields.

Table Y-1a Biomass potential from land freed by higher crop yields in Ghana

Ghana	Land Needed for Food Production (Thousand Hectares)						Land Freed (kha)	Biomass Potential (PJ)
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		
2010_Baseline	2 819	534	2 771	335	91	6 549		
2030_FAO	4 256	855	4 285	448	143	9 987		
2030_Trend	3 205	705	2 251	464	112	6 738	3 249	487
2030_Gap	896	339	255	240	78	1 809	8 178	1 227
2050_FAO	4 549	945	4 393	418	157	10 462		
2050_Trend	2 678	639	1 574	415	98	5 405	5 057	759
2050_Gap	1 009	395	275	237	90	2 006	8 456	1 268

Source: FAO (2015) and IRENA analysis

Table Y-1b Biomass potential from land freed by higher crop yields in Mozambique

Mozambique	Land Needed for Food Production (Thousand Hectares)						Land Freed (kha)	Biomass Potential (PJ)
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		
2010_Baseline	4 755	1 669	656	626	32	7 737		
2030_FAO	6 225	2 320	879	724	43	10 192		
2030_Trend	4 385	1 375	926	810	51	7 547	2 645	397
2030_Gap	775	555	210	321	28	1 889	8 302	1 245
2050_FAO	5 482	2 113	743	557	39	8 934		
2050_Trend	3 329	1 023	814	676	51	5 893	3 042	456
2050_Gap	873	646	227	316	32	2 094	6 840	1 026

Source: FAO (2015) and IRENA analysis

Table Y-1c Biomass potential from land freed by higher crop yields in Nigeria

Nigeria	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass Potential
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		
2010_Baseline	21 182	3 877	1 874	2 796	777	30 507	(kha)	(PJ)
2030_FAO	34 747	6 752	3 148	4 053	1 333	50 033		
2030_Trend	24 813	5 387	3 229	4 086	948	38 463	11 570	1 736
2030_Gap	7 433	2 305	636	2 754	723	13 852	36 181	5 427
2050_FAO	37 136	7 461	3 228	3 787	1 460	53 072		
2050_Trend	20 231	4 792	3 140	3 571	835	32 569	20 503	3 075
2050_Gap	8 368	2 683	686	2 711	835	15 282	37 789	5 668

Source: FAO (2015) and IRENA analysis

Table Y-1d Biomass potential from land freed by higher crop yields in South Africa

South Africa	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass Potential
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		
2010_Baseline	7 065	2 093	123	146	249	9 676	(kha)	(PJ)
2030_FAO	7 307	1 974	114	124	217	9 735		
2030_Trend	7 329	1 747	127	143	220	9 567	169	25
2030_Gap	2 947	1 208	66	72	205	4 496	5 239	786
2050_FAO	6 929	1 929	110	114	205	9 286		
2050_Trend	6 350	1 441	121	134	205	8 250	1 036	155
2050_Gap	3 003	1 268	68	71	205	4 614	4 672	701

Source: FAO (2015) and IRENA analysis

Table Y-1e Biomass potential from land freed by higher crop yields in Uganda

Uganda	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass Potential
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		
2010_Baseline	3 211	1 139	619	801	50	5 819	(kha)	(PJ)
2030_FAO	4 903	1 846	968	1 081	79	8 877		
2030_Trend	4 635	1 553	1 104	1 233	91	8 616	262	39
2030_Gap	1 616	379	231	259	51	2 536	6 342	951
2050_FAO	4 318	1 681	818	832	72	7 721		
2050_Trend	3 994	1 307	1 026	1 043	91	7 460	261	39
2050_Gap	1 819	441	250	254	59	2 823	4 897	735

Source: FAO (2015) and IRENA analysis

Table Y-2 Calculation of food crop requirements

Crop needs by food type in each country (in tables Y2c-g) are calculated by multiplying projected population (Table Y-2a) by projected food crop demand per capita for each type of crop (Table Y-2b).

In Table Y-2b, adjustment factors account for cereal allocation to processing and tonnes of sugar cane required for each ton of sugar; no adjustment is made for other crops, for which factors are set to 1.0.

Table Y-2a Population projections (thousand people)

Country	element	unit	2010	2030	2050
Ghana	Population	1 000	24 392	36 537	45 670
Mozambique	Population	1 000	23 391	35 907	59 929
Nigeria	Population	1 000	158 423	257 815	440 355
South Africa	Population	1 000	50 133	54 711	63 405
Uganda	Population	1 000	33 425	59 846	104 078

Source: FAO (2015)

Table Y-2b Annual food and crop demand per capita (kilograms)

Country	Commodity	Food Demand (Kg/capita)			Adjustment Factor (Food demand ➔ Crop demand)			Crop Demand (Kg/capita)		
		2006	**2030**	**2050**	**2010**	**2030**	**2050**	**2006**	**2030**	**2050**
Others	Cereals	125	142	154	1.6	1.6	1.7	195	227	255
Others	Roots	184	189	186	1.0	1.0	1.0	184	189	186
Others	Sugar	10.7	13	15	8.9	8.9	8.9	95	115	133
Others	Pulses	10.5	12.5	13.5	1.0	1.0	1.0	11	13	14
Others	Oil crop	9.4	11.6	13.5	1.0	1.0	1.0	9	12	14
Others	Meat	10.1	12.4	16	1.0	1.0	1.0	10	12	16
Others	Milk, Dairy	31	33	37	1.0	1.0	1.0	31	33	37
Others	Other	126	132	148	1.0	1.0	1.0	126	132	148
Others	Total	2 238	2 530	2 740	1.0	1.0	1.0	2 238	2 530	2 740
S. Africa	Cereals	167	166	166	3.5	4.1	4.2	591	682	695
S. Africa	Roots	77	73	72	1.0	1.0	1.0	77	73	72
S. Africa	Sugar	34	33	33	8.9	8.9	8.9	301	292	292
S. Africa	Pulses	2.9	3	3.1	1.0	1.0	1.0	3	3	3
S. Africa	Oil crop	19	20	21	1.0	1.0	1.0	19	20	21
S. Africa	Meat	80	87	91	1.0	1.0	1.0	80	87	91
S. Africa	Milk, Dairy	202	215	222	1.0	1.0	1.0	202	215	222
S. Africa	Other	458	488	509	1.0	1.0	1.0	458	488	509
S. Africa	Total	3 360	3 430	3 490	1.0	1.0	1.0	3 360	3 430	3 490

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2c Projected food demand in Ghana (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2010	4 760	4 488	2,311	256	229	246	756	3 073	54 589
2030	8 288	6 905	4,206	457	424	453	1 206	4 823	92 439
2050	9 330	6 796	4,853	493	493	585	1 352	5 407	100 111

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2d Projected food demand in Mozambique (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2010	4 565	4 304	2 216	246	220	236	725	2 947	52 349
2030	8 145	6 786	4 134	449	417	445	1 185	4 740	90 845
2050	9 169	6 679	4 770	485	485	575	1 329	5 314	98 385

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2e Projected food demand in Nigeria (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2010	30 918	29 150	15 011	1 663	1 489	1 600	4 911	19 961	354 551
2030	58 483	48 727	29 680	3 223	2 991	3 197	8 508	34 032	652 272
2050	65 837	47 954	34 246	3 481	3 481	4 125	9 539	38 157	706 413

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2f Projected food demand in South Africa (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2010	29 629	3 860	15 094	145	953	4 011	10 127	22 961	168 447
2030	37 313	3 994	15 988	164	1 094	4 760	11 763	26 699	187 659
2050	38 024	3 939	15 988	170	1 149	4 979	12 146	27 848	190 941

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2g Projected food demand in Uganda (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2010	6 523	6 150	3 167	351	314	338	1 036	4 212	74 805
2030	13 576	11 311	6 890	748	694	742	1 975	7 900	151 410
2050	15 283	11 131	7 949	808	808	958	2 214	8 857	163 978

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-3 Definition of yield growth scenarios

Three scenarios of yield growth are defined. Table Y-3a shows a scenario based on FAO yield growth projections. Table Y-3b shows a scenario based on the historical trend of yield growth, based on regression analysis of global yields by crop from 1961 through 2013 (the regression curve slope shows the average annual increase in yield in tonnes per hectare). Table Y-3c shows a scenario based on the FAO's assessment of the "yield gap" between actual and potential yields on rain-fed and irrigated land. For each crop, the ratio of actual to potential yield is calculated by taking a weighted average yield of hectares in different yield categories (assuming that hectares yielding <10%, 10-25%, 25-40%, 40-55%, 55-70%, 70-85% and >85% of potential respectively yield 5%, 17.5%, 32.5%, 47.5%, 62.5%, 77.5% and 92.5% of potential respectively) and dividing by total hectares.

Table Y-3a Yield growth scenario from FAO projections

Country	Region	Yield Growth per Annum		Yield Growth index		
		2010-2030	2030-2050	2010	2030	2050
Ghana	Sub-Saharan Africa	0.7%	0.3%	1.00	1.15	1.21
Mozambique	Sub-Saharan Africa	1.6%	1.2%	1.00	1.36	1.74
Nigeria	Sub-Saharan Africa	0.7%	0.3%	1.00	1.15	1.21
South Africa	Developed countries	1.0%	0.4%	1.00	1.22	1.31
Uganda	Sub-Saharan Africa	1.6%	1.2%	1.00	1.36	1.74
World average	All regions	1.0%	0.5%	1.00	1.21	1.33

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-3b Historical trend of yield growth by crop (global, 1961-2013)

Item	Correlation	Slope (t/ha)	Intercept	Annual %
Cereals	1.00	0.045	-87	1.16%
Roots	0.94	0.075	-137	0.50%
Pulses	0.95	0.006	-10	0.61%
Oil Crops	0.98	0.009	-17	1.26%
Vegetables primary	1.00	0.189	-362	0.97%
Fibre crops primary	0.97	0.009	-16	1.03%
Fruit except melons	0.90	0.060	-110	0.53%
Sugar	0.98	0.599	-1 138	0.87%
Total	1.00	0.064	-122	1.07%

[Yield] = [Year] * [slope] + [intercept] per IRENA regression analysis

Table Y-3c Yield gap (difference between actual and potential yield, as share of potential)

Country	Cereals	Roots	Oil Crops	Pulses	Sugar Cane	Sugar Beet	Sugars
Ghana	0.82	0.53	0.66	0.95	0.67	0.53	0.53
Mozambique	0.91	0.67	0.82	0.82	0.81	0.53	0.53
Nigeria	0.81	0.41	0.70	0.82	0.68	0.53	0.53
South Africa	0.67	0.53	0.50	0.53	0.23	0.53	0.23
Uganda	0.76	0.82	0.85	0.82	0.82	0.53	0.53

[Yield GAP] = ([potential yield] – [actual yield]) / [potential yield] per IRENA statistical analysis.

Table Y-4 Projected crop yields by country for different yield growth scenarios

Projected crop yields are shown for each country, as follows, for three distinct scenarios:

Yield gap closure case: Future crop yields reaching the full productive potential of rain-fed and irrigated lands are calculated by dividing 2010 crop yields by the ratio of current to potential yield, which is [1 - yield gap] from Y-3c. Values are the same for 2030 and 2050 since the gap is independent of time.

Historical trend case: Future crop yields with continuation of the historical trend of yield growth are calculated by adding to 2010 crop yields the historical annual increment in yield from Table Y-3b for 20 or 40 years. Yield values are not allowed to exceed those in the yield gap closure case.

FAO projection case: Future crop yields according to FAO projections are calculated by multiplying 2010 crop yields by yield increase indices from Table Y-3a. Again, yield values are not allowed to exceed those in the yield gap closure case.

Table Y-4a Projected crop yields for Ghana (tonnes per hectare)

	Cereal	Oil Crops	Pulses	Roots	Sugars
2010_Baseline	1.7	0.4	0.1	13.4	25.4
2030_FAO	1.9	0.5	0.1	15.4	29.3
2030_Trend	2.6	0.6	0.2	14.9	37.4
2030_Gap	9.2	1.2	1.8	28.7	54.0
2050_FAO	2.1	0.5	0.1	16.3	30.9
2050_Trend	3.5	0.8	0.3	16.4	49.4
2050_Gap	9.2	1.2	1.8	28.7	54.0

Source: FAO (2015) and IRENA analysis

Table Y-4b Projected crop yields for Mozambique (tonnes per hectare)

	Cereal	Oil Crops	Pulses	Roots	Sugars
2010_Baseline	1.0	0.1	0.4	6.9	69.8
2030_FAO	1.3	0.2	0.5	9.4	95.2
2030_Trend	1.9	0.3	0.5	8.4	81.8
2030_Gap	10.5	0.8	2.1	21.1	148.4
2050_FAO	1.7	0.2	0.7	12.0	121.7
2050_Trend	2.8	0.5	0.6	9.9	93.8
2050_Gap	10.5	0.8	2.1	21.1	148.4

Source: FAO (2015) and IRENA analysis

Table Y-4c Projected crop yields for Nigeria (tonnes per hectare)

	Cereal	Oil Crops	Pulses	Roots	Sugars
2010_Baseline	1.5	0.4	0.9	10.4	19.3
2030_FAO	1.7	0.4	1.0	12.0	22.3
2030_Trend	2.4	0.6	1.0	11.9	31.3
2030_Gap	7.9	1.3	5.1	17.7	41.0
2050_FAO	1.8	0.5	1.1	12.7	23.5
2050_Trend	3.3	0.7	1.1	13.4	41.0
2050_Gap	7.9	1.3	5.1	17.7	41.0

Source: FAO (2015) and IRENA analysis

Table Y-4d Projected crop yields for South Africa (tonnes per hectare)

	Cereal	Oil Crops	Pulses	Roots	Sugars
2010_Baseline	4.2	0.5	1.2	26.5	60.6
2030_FAO	5.1	0.6	1.4	32.2	73.7
2030_Trend	5.1	0.6	1.3	28.0	72.5
2030_Gap	12.7	0.9	2.5	55.8	78.1
2050_FAO	5.5	0.6	1.5	34.6	78.1
2050_Trend	6.0	0.8	1.4	29.5	78.1
2050_Gap	12.7	0.9	2.5	55.8	78.1

Source: FAO (2015) and IRENA analysis

Table Y-4e Projected crop yields for Uganda (tonnes per hectare)

	Cereal	Oil Crops	Pulses	Roots	Sugars
2010_Baseline	2.0	0.3	0.6	7.7	63.7
2030_FAO	2.8	0.4	0.8	10.5	86.8
2030_Trend	2.9	0.4	0.7	9.2	75.7
2030_Gap	8.4	1.8	3.2	43.7	135.3
2050_FAO	3.5	0.5	1.0	13.4	110.9
2050_Trend	3.8	0.6	0.8	10.7	87.6
2050_Gap	8.4	1.8	3.2	43.7	135.3

Source: FAO (2015) and IRENA analysis

Appendix III: Bioenergy potential from reduced food waste in sub-Saharan Africa

Table W-1 Biomass potential from land freed by reduced food waste - summary

For crops consumed directly, land potentially freed (thousand ha or kha) equals food waste (tonnes, Table W-7) divided by crop yield (t/ha, Table W-10b). For milk and meat, land freed is food waste multiplied by unit land demand (hectares per tonne, Table W-9b). Land freed is converted to potential biomass at a notional 150 GJ/ha (assuming typical crop yield of 15 t/ha and energy content of 10 GJ/t).

Tables W-1a-d assume **FAO projections of crop yields**. Tables W-1a-b show land freed and biomass potential by food type with projected FAO yields. Tables W-1c-d show these by stage of the food chain.

Table W-1a Potential land freed by reduced food waste, by food type – FAO case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Ghana	2010	2 215	325	801	264	78	218	43	475	11
Ghana	2030	2 330	351	864	285	84	235	47	453	11
Ghana	2050	2 774	361	888	293	87	242	341	549	14
Mozambique	2010	2 628	524	715	410	352	58	54	507	9
Mozambique	2030	3 175	618	844	484	415	68	64	669	15
Mozambique	2050	3 874	705	962	551	473	77	104	981	22
Nigeria	2010	15 644	3 149	4 181	2 901	919	1 034	1 249	2 103	108
Nigeria	2030	16 609	3 398	4 513	3 131	992	1 116	1 348	2 000	110
Nigeria	2050	17 395	3 494	4 641	3 220	1 020	1 148	1 311	2 426	135
South Africa	2010	5 213	679	41	318	21	154	78	3 790	131
South Africa	2030	4 985	694	42	325	21	158	80	3 524	141
South Africa	2050	5 685	700	42	328	21	159	190	4 082	163
Uganda	2010	3 572	333	570	395	365	1 059	111	698	43
Uganda	2030	4 250	392	672	465	430	1 249	131	849	62
Uganda	2050	6 716	447	766	530	490	1 424	1 625	1 332	102

Table W-1b Potential biomass on land freed by reduced food waste, by food type – FAO case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Ghana	2010	332	49	120	40	12	33	7	71	2
Ghana	2030	349	53	130	43	13	35	7	68	2
Ghana	2050	416	54	133	44	13	36	51	82	2
Mozambique	2010	394	79	107	62	53	9	8	76	1
Mozambique	2030	476	93	127	73	62	10	10	100	2
Mozambique	2050	581	106	144	83	71	12	16	147	3
Nigeria	2010	2 347	472	627	435	138	155	187	315	16
Nigeria	2030	2 491	510	677	470	149	167	202	300	16
Nigeria	2050	2 609	524	696	483	153	172	197	364	20
South Africa	2010	782	102	6	48	3	23	12	568	20
South Africa	2030	748	104	6	49	3	24	12	529	21
South Africa	2050	853	105	6	49	3	24	28	612	25
Uganda	2010	536	50	86	59	55	159	17	105	6
Uganda	2030	638	59	101	70	64	187	20	127	9
Uganda	2050	1 007	67	115	80	73	214	244	200	15

Table W-1c Potential land freed by reduced food waste, by food chain stage – FAO case (kha)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2010	2 215	822	552	501	257	83
Ghana	2030	2 330	854	594	532	265	86
Ghana	2050	2 774	981	660	676	349	108
Mozambique	2010	2 628	1 028	683	556	267	95
Mozambique	2030	3 175	1 253	809	667	331	116
Mozambique	2050	3 874	1 557	934	807	431	145
Nigeria	2010	15 644	5 611	4 128	3 630	1 702	573
Nigeria	2030	16 609	5 904	4 447	3 876	1 778	604
Nigeria	2050	17 395	6 268	4 578	4 014	1 898	638
South Africa	2010	5 213	2 562	544	884	962	261
South Africa	2030	4 985	2 426	551	849	913	247
South Africa	2050	5 685	2 766	593	982	1 060	284
Uganda	2010	3 572	1 240	741	941	505	146
Uganda	2030	4 250	1 479	879	1 113	605	173
Uganda	2050	6 716	2 183	1 255	1 912	1 075	291

Table W-1d Potential biomass on land freed by reduced food waste, by food chain stage – FAO (PJ)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2010	332	123	83	75	39	12
Ghana	2030	349	128	89	80	40	13
Ghana	2050	416	147	99	101	52	16
Mozambique	2010	394	154	103	83	40	14
Mozambique	2030	476	188	121	100	50	17
Mozambique	2050	581	234	140	121	65	22
Nigeria	2010	2 347	842	619	545	255	86
Nigeria	2030	2 491	886	667	581	267	91
Nigeria	2050	2 609	940	687	602	285	96
South Africa	2010	782	384	82	133	144	39
South Africa	2030	748	364	83	127	137	37
South Africa	2050	853	415	89	147	159	43
Uganda	2010	536	186	111	141	76	22
Uganda	2030	638	222	132	167	91	26
Uganda	2050	1 007	327	188	287	161	44

Tables W-1e-h assume enhanced crop yields to **close the "yield gap"** between the actual and potential yields the FAO has identified. Tables W-1e-f show land freed and biomass potential by food type with the yield gap closed. Tables W-1g-h show these by stage of the food chain. Land freed is less in the yield gap closure case than in the FAO's base case because yields are higher; reducing waste saves less land. Fruits and vegetables are unaffected because the FAO yield gap closure case does not consider them.

Table W-1e Potential land freed by reduced food waste, by food type – yield gap closure case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Ghana	2030	1 249	74	464	113	5	235	47	302	10
Ghana	2050	1 638	80	503	122	5	242	341	333	11
Mozambique	2030	1 184	77	374	116	99	68	64	379	8
Mozambique	2050	1 731	112	545	168	145	77	104	568	12
Nigeria	2030	8 976	727	3 067	1 069	200	1 116	1 348	1 356	93
Nigeria	2050	9 557	787	3 322	1 158	217	1 148	1 311	1 503	111
South Africa	2030	3 871	280	24	199	12	158	80	2 999	119
South Africa	2050	4 241	303	26	216	13	159	190	3 208	126
Uganda	2030	2 665	129	161	96	103	1,249	131	737	60
Uganda	2050	5 011	188	234	139	150	1 424	1 625	1 152	98

Table W-1f Potential biomass on land freed by reduced food waste, by food type – yield gap closure case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Ghana	2030	187	11	70	17	1	35	7	45	1
Ghana	2050	246	12	75	18	1	36	51	50	2
Mozambique	2030	178	12	56	17	15	10	10	57	1
Mozambique	2050	260	17	82	25	22	12	16	85	2
Nigeria	2030	1 346	109	460	160	30	167	202	203	14
Nigeria	2050	1 434	118	498	174	33	172	197	225	17
South Africa	2030	581	42	4	30	2	24	12	450	18
South Africa	2050	636	45	4	32	2	24	28	481	19
Uganda	2030	400	19	24	14	15	187	20	111	9
Uganda	2050	752	28	35	21	22	214	244	173	15

Table W-1g Potential land freed by reduced food waste, by food chain stage – yield gap closure case (kha)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2030	1 249	446	277	310	168	49
Ghana	2050	1 638	541	344	447	239	67
Mozambique	2030	1 184	474	248	264	152	46
Mozambique	2050	1 731	698	361	382	223	68
Nigeria	2030	8 976	3 006	2 139	2 337	1 153	341
Nigeria	2050	9 557	3 237	2 289	2 454	1 217	361
South Africa	2030	3 871	1 933	326	665	751	196
South Africa	2050	4 241	2 089	365	750	823	215
Uganda	2030	2 665	870	416	769	486	124
Uganda	2050	5 011	1 515	775	1 545	939	237

Table W-1h Potential biomass on land freed by reduced food waste, by food chain stage – yield gap closure case (PJ)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2030	187	67	42	46	25	7
Ghana	2050	246	81	52	67	36	10
Mozambique	2030	178	71	37	40	23	7
Mozambique	2050	260	105	54	57	33	10
Nigeria	2030	1 346	451	321	351	173	51
Nigeria	2050	1 434	485	343	368	183	54
South Africa	2030	581	290	49	100	113	29
South Africa	2050	636	313	55	112	123	32
Uganda	2030	400	131	62	115	73	19
Uganda	2050	752	227	116	232	141	35

Table W-2 Biomass potential from land freed by food waste best practice - summary

Land freed by applying global best practice for waste and loss reduction equals total land encumbered by waste and losses (thousand ha or kha, Table W-1) less land still encumbered with best practice applied. For crops consumed directly, land still encumbered equals food waste (in kilotonnes [kt], tables W-6a-e(ii)) divided by crop yield (t/ha, Table W-9b). For milk and meat, land still encumbered is food waste multiplied by unit land demand (hectares per tonne, Table W-8b). Land freed is converted to potential biomass at a notional 150 GJ/ha (assuming typical crop yield of 15 t/ha and energy content of 10 GJ/t).

Tables W-2a-d assume **FAO projections of crop yields**. Tables W-2a-b show land freed and biomass potential by food type with projected FAO yields. Tables W-2c-d show these by stage of the food chain.

Table W-2a Potential land freed by food waste best practice, by food type – FAO case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Ghana	2010	1 068	165	418	111	33	110	22	207	2
Ghana	2030	1 126	178	451	120	36	119	24	197	2
Ghana	2050	1 342	183	464	123	37	122	172	239	3
Mozambique	2010	1 239	266	373	173	148	29	27	221	2
Mozambique	2030	1 493	314	440	204	175	34	32	291	3
Mozambique	2050	1 813	358	502	232	199	39	52	427	4
Nigeria	2010	7 477	1 600	2 182	1 222	387	521	629	916	20
Nigeria	2030	7 952	1 727	2 355	1 319	418	563	679	871	20
Nigeria	2050	8 304	1 776	2 422	1 356	430	579	661	1 056	25
South Africa	2010	2 301	345	21	134	9	78	40	1 650	24
South Africa	2030	2 200	353	22	137	9	80	40	1 534	26
South Africa	2050	2 507	356	22	138	9	80	96	1 777	30
Uganda	2010	1 688	169	297	166	154	534	56	304	8
Uganda	2030	2 003	199	351	196	181	630	66	370	11
Uganda	2050	3 192	227	400	223	206	718	819	580	19

Table W-2b Potential biomass on land freed by food waste best practice, by food type - FAO (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Ghana	2010	160	25	63	17	5	16	3	31	0
Ghana	2030	169	27	68	18	5	18	4	30	0
Ghana	2050	201	27	70	18	5	18	26	36	0
Mozambique	2010	186	40	56	26	22	4	4	33	0
Mozambique	2030	224	47	66	31	26	5	5	44	0
Mozambique	2050	272	54	75	35	30	6	8	64	1
Nigeria	2010	1 122	240	327	183	58	78	94	137	3
Nigeria	2030	1 193	259	353	198	63	84	102	131	3
Nigeria	2050	1 246	266	363	203	64	87	99	158	4
South Africa	2010	345	52	3	20	1	12	6	248	4
South Africa	2030	330	53	3	21	1	12	6	230	4
South Africa	2050	376	53	3	21	1	12	14	267	4
Uganda	2010	253	25	45	25	23	80	8	46	1
Uganda	2030	301	30	53	29	27	94	10	55	2
Uganda	2050	479	34	60	34	31	108	123	87	3

Table W-2c Potential land freed by food waste best practice, by food chain stage – FAO case (kha)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2010	1 068	298	163	338	171	97
Ghana	2030	1 126	316	175	355	178	102
Ghana	2050	1 342	390	201	388	231	132
Mozambique	2010	1 239	367	160	423	182	107
Mozambique	2030	1 493	440	190	510	224	130
Mozambique	2050	1 813	528	220	617	285	163
Nigeria	2010	7 477	2 266	1 055	2 304	1 167	684
Nigeria	2030	7 952	2 420	1 137	2 445	1 227	723
Nigeria	2050	8 304	2 511	1 167	2 570	1 297	759
South Africa	2010	2 301	563	115	782	563	278
South Africa	2030	2 200	543	116	744	533	264
South Africa	2050	2 507	621	128	837	616	305
Uganda	2010	1 688	557	197	429	320	185
Uganda	2030	2 003	660	233	510	381	219
Uganda	2050	3 192	1 078	372	689	672	382

Table W-2d Potential biomass on land freed by food waste best practice, by food chain stage – FAO case (PJ)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2010	160	45	24	51	26	15
Ghana	2030	169	47	26	53	27	15
Ghana	2050	201	59	30	58	35	20
Mozambique	2010	186	55	24	63	27	16
Mozambique	2030	224	66	28	76	34	20
Mozambique	2050	272	79	33	92	43	24
Nigeria	2010	1 122	340	158	346	175	103
Nigeria	2030	1 193	363	171	367	184	108
Nigeria	2050	1 246	377	175	385	195	114
South Africa	2010	345	84	17	117	84	42
South Africa	2030	330	81	17	112	80	40
South Africa	2050	376	93	19	126	92	46
Uganda	2010	253	83	30	64	48	28
Uganda	2030	301	99	35	77	57	33
Uganda	2050	479	162	56	103	101	57

Tables W-2e-h assume enhanced crop yields to **close the "yield gap"** between actual and potential yields that the FAO has identified. Tables W-2e-f show land freed and biomass potential by food type with the yield gap closed. Tables W-2g-h show these by stage of the food chain. Land freed is less in the yield gap closure case than in the FAO base case because yields are higher; reducing waste saves less land. Fruits and vegetables are unaffected because FAO's yield gap closure case does not consider them.

Table W-2e Potential land freed by food waste best practice, by food type – yield gap closure case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Ghana	2030	605	38	242	48	2	119	24	131	2
Ghana	2050	798	41	262	51	2	122	172	145	2
Mozambique	2030	558	39	195	49	42	34	32	165	2
Mozambique	2050	814	57	284	71	61	39	52	247	2
Nigeria	2030	4 354	369	1 600	450	84	563	679	590	17
Nigeria	2050	4 627	400	1 734	488	91	579	661	655	20
South Africa	2030	1 691	142	13	84	5	80	40	1 306	22
South Africa	2050	1 860	154	14	91	6	80	96	1 397	23
Uganda	2030	1 261	66	84	40	43	630	66	321	11
Uganda	2050	2 396	96	122	59	63	718	819	502	18

Table W-2f Potential biomass on land freed by food waste best practice, by food type – yield gap closure case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Ghana	2030	91	6	36	7	0	18	4	20	0
Ghana	2050	120	6	39	8	0	18	26	22	0
Mozambique	2030	84	6	29	7	6	5	5	25	0
Mozambique	2050	122	9	43	11	9	6	8	37	0
Nigeria	2030	653	55	240	68	13	84	102	89	3
Nigeria	2050	694	60	260	73	14	87	99	98	3
South Africa	2030	254	21	2	13	1	12	6	196	3
South Africa	2050	279	23	2	14	1	12	14	210	3
Uganda	2030	189	10	13	6	6	94	10	48	2
Uganda	2050	359	14	18	9	9	108	123	75	3

Table W-2g Potential land freed by food waste best practice, by food chain stage – yield gap closure case (kha)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2030	605	173	92	172	106	60
Ghana	2050	798	242	119	197	153	87
Mozambique	2030	558	160	70	179	95	53
Mozambique	2050	814	233	102	263	139	78
Nigeria	2030	4 354	1 330	672	1 176	744	432
Nigeria	2050	4 627	1 404	713	1 272	782	455
South Africa	2030	1 691	419	69	566	426	211
South Africa	2050	1 860	468	81	610	469	233
Uganda	2030	1 261	418	137	245	297	164
Uganda	2050	2 396	820	272	404	578	322

Table W-2h Potential biomass on land freed by food waste best practice, by food chain stage yield gap closure case (PJ)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Ghana	2030	91	26	14	26	16	9
Ghana	2050	120	36	18	30	23	13
Mozambique	2030	84	24	11	27	14	8
Mozambique	2050	122	35	15	39	21	12
Nigeria	2030	653	199	101	176	112	65
Nigeria	2050	694	211	107	191	117	68
South Africa	2030	254	63	10	85	64	32
South Africa	2050	279	70	12	92	70	35
Uganda	2030	189	63	21	37	44	25
Uganda	2050	359	123	41	61	87	48

Table W-3 Food production by item and country in 2010

Data on the amounts of each food item produced in 2010 are used to project food requirements by food type in 2030 and 2050 (in Table W-5) using projected growth rates in food needs (from Table W-4).

Table W-3a Crop production by crop and country in 2010 (thousand tonnes)

Crop (Item)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Apples				774	
Apricots				49	
Asparagus				1	
Avocados	8			78	
Bananas	70	314		384	591
Barley				241	
Bast fibres, other		4	1	1	
Beans, dry		170		54	454
Beans, green	26			25	
Berries not elsewhere specified				1	
Buckwheat				0	
Cabbages and other brassicas				146	
Carrots and turnips			207	151	
Cashew nuts, with shell	31	91	822		
Cassava	13 325	8 501	43 920		5 073
Castor oil seed		59		6	1
Cauliflowers and broccoli				20	
Cereals not elsewhere specified				21	
Cherries				0	
Chick peas					4
Chicory roots				22	
Chillies and peppers, dry	91		57	13	3
Chillies and peppers, green	90		598	1	
Cocoa, beans	681		388		15
Coconuts	286	271	206		
Coffee, green	1	1	2		185
Coir	39				
Cotton lint	9	39	150	12	29
Cottonseed	14	79	193	18	56
Cow peas, dry		38	2 534	5	88
Cucumbers and gherkins	0			22	
Eggplants (aubergines)	40				
Fibre crops not elsewhere specified				2	
Figs				2	

Crop (Item)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Fonio			82		
Fruit, citrus, not elsewhere specified			3 800	10	
Fruit, fresh, not elsewhere specified	67	132	1 227	61	52
Fruit, tropical fresh, not elsewhere specified		22			
Garlic			1		
Ginger	0		164		0
Grapefruit (including pomelos)		11		388	
Grapes				1 305	
Groundnuts, with shell	507	117	3 247	84	287
Hops				0	
Karite nuts (shea nuts)	71		328		
Kola nuts	21		157		
Leeks, other alliaceous vegetables				1	
Lemons and limes	46	3		227	
Lettuce and chicory				38	
Lupins				18	
Maize	1 725	1 788	8 072	11 742	2 426
Maize, green			661	386	
Mangoes, mangosteens, guavas	80	29	845	55	
Melons, other (including cantaloupes)	0			21	
Melonseed			473		
Millet	216	50	3 790	7	270
Mushrooms and truffles				12	
Nuts not elsewhere specified	1		7	15	
Oats	0			43	
Oil, palm	124		1 045		
Oil, palm fruit	2 037		8 167		
Oilseeds not elsewhere specified	0	34	0	13	44
Okra	51		1 065		
Onions, dry	103	71	1 295	523	183
Onions, shallots, green			217		
Oranges	580	30		1 427	
Palm kernels	39		1 133		
Papayas	45	43	758	13	
Peaches and nectarines				160	
Pears				353	

Crop (Item)	Ghana	Mozambique	Nigeria	South Africa	Uganda
Peas, dry				1	17
Peas, green				12	
Pepper (piper spp.)	3				2
Pigeon peas					92
Pineapples	50	51	1 296	109	2
Plantains	3 573		2 692		9 554
Plums and sloes				62	
Potatoes		171	1 067	2 051	722
Pulses, not elsewhere specified	23	210	56		
Pumpkins, squash and gourds		1		169	
Quinces				0	
Rapeseed				45	
Rice, paddy	449	236	4 195	3	219
Roots and tubers, not elsewhere specified	0	9			
Rubber, natural	20		144		
Rye				2	
Seed cotton	26	121	416	30	94
Sesame seed		70	141		193
Sisal		1		1	0
Sorghum	321	394	6 439	209	401
Soybeans			425	597	192
Spices, not elsewhere specified			5		
Strawberries				6	
Sugar cane	145	2 775	1 417	17 157	2 700
Sunflower seed		17		717	258
Sweet potatoes	124	893	3 300	62	2 719
Tangerines, mandarins, clementines, satsumas		0		145	
Taro (cocoyam)	1 386		3 085		
Tea		29		2	44
Tobacco, unmanufactured	4	67	16	12	25
Tomatoes	319	178	1 685	532	28
Vanilla					0
Vegetables, fresh, not elsewhere specified	10	193	5 494	376	726
Watermelons				96	
Wheat		18	118	1 798	21
Yams	6 011		33 457		

Source: FAO (2015)

Table W-3b Livestock production by type and country in 2010 (tonnes)

Livestock Type	Ghana	Mozambique	Nigeria	South Africa	Uganda
Beef	24 769	19 600	293 200	785 390	125 300
Dairy	37 340	75 545	469 937	3 102 333	1 120 000
Mutton	0	0	0	160 866	39 642
Pork	16 993	93 800	234 000	277 967	108 000
Poultry	44 720	23 948	286 000	1 286 718	44 850

Source: FAO (2015)

Table W-4 Projected rates of growth in crop and livestock output

Table W-4a Projected growth rates for crop output

Separate rates of growth in crop output are assumed for each country, according to projections by the FAO. Output is assumed to grow more slowly from 2030 through 2050 than from 2010 through 2030, as populations and food requirements stabilise. The rates of growth are applied to baseline data for 2010 (from Table W-3a, summed by type in the 2010 row of the W-5 tables) to project crop output by type in 2030 and 2050 (in remaining rows of the W-5 tables).

Country	Annual Growth in Crop Output 2010-2030	Annual Growth in Crop Output 2030-2050	Information: Calories per Capita in 2010
Ghana	1.1%	0.4%	2 755
Mozambique	2.4%	1.9%	2 126
Nigeria	1.1%	0.4%	2 786
South Africa	1.1%	0.4%	2 979
Uganda	2.4%	1.9%	2 294

Source: Alexandratos *et al.* (2012)

Table W-4b Projected growth rates for livestock output

FAO-projected growth rates for livestock output are applied to livestock production in 2010 (Table W-3b) to calculate livestock production in 2030 and 2050 (in W-5 tables).

Country	Annual Growth in Livestock 2010-2030	Annual Growth in Livestock 2030-2050
Ghana	1.1%	1.1%
Mozambique	2.7%	2.6%
Nigeria	1.1%	1.1%
South Africa	1.1%	1.1%
Uganda	2.7%	2.6%

Source: Alexandratos *et al.* (2012)

Table W-5 Projected food production by food type and country

The baseline data for 2010 (from Table W-3) are grouped here by food type. Projected growth rates (from Table W-4) are then applied to estimate food production by food type in 2030 and 2050.

Table W-5a Projected food production in Ghana (thousand tonnes per year)

Ghana	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	2 711	20 847	3 106	23	4 519	639	189	188	32 222
2030	3 374	25 946	3 865	29	5 625	795	235	234	40 103
2050	3 654	28 102	4 187	31	6 092	862	292	291	43 511

Table W-5b Projected food production in Mozambique (thousand tonnes per year)

Mozambique	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	2 486	9 574	768	418	635	444	156	99	14 578
2030	3 994	15 384	1 234	672	1 020	713	266	168	23 451
2050	5 820	22 416	1 798	979	1 486	1 039	444	281	34 263

Table W-5c Projected food production in Nigeria (thousand tonnes per year)

Nigeria	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	22 697	84 828	15 775	2 589	10 617	11 223	859	1 827	149 849
2030	28 248	105 576	19 633	3 223	13 214	13 968	1 069	2 273	186 500
2050	30 595	114 350	21 265	3 490	14 312	15 129	1 330	2 829	202 426

Table W-5d Projected food production in South Africa (thousand tonnes per year)

South Africa	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	14 065	2 112	1 511	77	5 727	2 435	2 770	3 182	31 879
2030	17 505	2 629	1 880	96	7 127	3 030	3 448	3 960	39 675
2050	18 960	2 847	2 036	104	7 720	3 282	4 291	4 929	44 169

Table W-5e Projected food production in Uganda (thousand tonnes per year)

Uganda	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	3 337	8 514	1 125	656	10 198	936	318	1 122	26 206
2030	5 362	13 682	1 807	1 054	16 387	1 504	543	1 912	42 250
2050	7 813	19 935	2 633	1 535	23 878	2 192	907	3 194	62 087

Table W-6 Waste coefficients by stage of the food chain (waste as share of food)

This table shows the share of food lost or wasted at each stage of the food chain in Africa, as well as the total fraction of food wasted. Table W-6a indicates FAO estimates of actual shares lost or wasted. Table W-6b shows shares that would be lost or wasted if the region attained best practice for each crop and food chain stage among all regions globally. The FAO estimates losses and waste at each stage of the food chain (agricultural production, post-harvest handling and storage, processing and packaging, distribution, and consumption) as shares of volumes received from the previous stage. In the table, adjusted values for losses and waste at each stage of the food chain are recalculated as shares of original production volumes and summed to the total share of food lost or wasted. (For agricultural production losses, adjusted values are higher than the original ones because they express loss as a share of reported net production rather than as a share of gross production prior to the loss.)

The shares of food lost or wasted (from this table) are then multiplied by the amounts of food produced (from Table W-5) to arrive at amounts of food lost or wasted by food type and loss stage (in Table W-7).

Data come from the FAO's *Global Food Losses and Food Waste: Extent, Causes and Prevention* (2011). The report was prepared by experts at the Swedish Institute for Food and Biotechnology – SIK (Jenny Gustavsson, Christel Cederberg, Ulf Sonesson) and the FAO (Robert van Otterdijk, Alexandre Meybeck). For more information, see "Annex 4: Weight percentages of food losses and waste (in percentage of what enters each step)" in the FAO report.

Table W-6a Actual food chain loss and waste coefficients for Africa

Food Type	Total Waste and Losses	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption Waste
Cereals	0.20	0.06	0.08	0.03	0.02	0.01
Fruits, Vegetables	0.57	0.11	0.09	0.23	0.12	0.03
Meat	0.32	0.18	0.01	0.05	0.07	0.02
Milk	0.26	0.06	0.11	0.00	0.09	0.00
Oil Crops, Pulse	0.32	0.14	0.08	0.07	0.02	0.01
Roots	0.51	0.16	0.18	0.12	0.03	0.01

Source: Gustavsson *et al.* (2011)

Table W-6b Global best practice loss and waste coefficients by food type and food chain stage

Food Type	Total Waste and Losses	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption Waste
Cereals	0.10	0.02	0.02	0.03	0.02	0.01
Fruits, Vegetables	0.29	0.11	0.04	0.02	0.08	0.04
Meat	0.14	0.03	0.00	0.05	0.04	0.02
Milk	0.05	0.04	0.01	0.00	0.00	0.00
Oil Crops, Pulse	0.13	0.06	0.00	0.05	0.01	0.01
Roots	0.27	0.06	0.07	0.09	0.03	0.02

Source: Gustavsson *et al.* (2011)

TABLE W-7 PROJECTED FOOD WASTE BY FOOD TYPE AND STAGE OF THE FOOD CHAIN

Food waste by food type (cereals, roots, oil crops, pulses, fruits, vegetables, meat and dairy) and stage of the food chain (production, post-harvest, processing, distribution, consumption and total) is found by multiplying food production (from Table W-5) by shares of each food type lost at each stage (Table W-6). In the first table (i) for each country (W-7a-e(i)) total food waste is calculated, using Table W-6a. In the second table (ii) for each (W-7a-e(ii)), best practice food waste is shown, using Table W6b.

Table W-7a (i) ***Total*** **food waste by food type and food chain stage in Ghana (thousand tonnes)**

Ghana	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	549	173	217	87	48	24
Cereal2030	683	215	270	109	60	29
Cereal2050	740	233	292	118	65	32
Root2010	10 713	3 394	3 752	2 564	727	276
Root2030	13 333	4 224	4 670	3 191	904	344
Root2050	14 441	4 575	5 058	3 457	979	372
Oil2010	979	424	248	229	53	26
Oil2030	1 218	527	309	284	65	32
Oil2050	1 320	571	335	308	71	35
Pulse2010	7	3	2	2	0	0
Pulse2030	9	4	2	2	0	0
Pulse2050	10	4	2	2	1	0
Fruits2010	2 589	502	407	1 028	524	128
Fruits2030	3 223	625	506	1 280	653	159
Fruits2050	3 491	677	548	1 386	707	173
Vegetable2010	366	71	58	145	74	18
Vegetable2030	456	88	72	181	92	23
Vegetable2050	494	96	78	196	100	24
Meat2010	60	33	1	9	12	3
Meat2030	74	41	2	12	16	4
Meat2050	93	52	2	15	19	5
Dairy2010	50	12	21	0	17	0
Dairy2030	62	15	26	0	21	0
Dairy2050	77	19	32	0	26	0

Table W-7a (ii) *Best practice* food waste by food type and food chain stage in Ghana (kt)

Ghana	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	279	55	54	93	51	25
Cereal2030	347	69	67	116	64	31
Cereal2050	376	75	73	125	69	34
Root2010	5 591	1 331	1 459	1 939	523	339
Root2030	6 958	1 656	1 816	2 413	651	421
Root2050	7 536	1 794	1 967	2 613	706	456
Oil2010	412	198	0	155	30	29
Oil2030	513	247	0	193	37	36
Oil2050	556	267	0	209	40	39
Pulse2010	3	1	0	1	0	0
Pulse2030	4	2	0	1	0	0
Pulse2050	4	2	0	2	0	0
Fruits2010	1 305	502	181	87	340	196
Fruits2030	1 625	625	225	108	423	243
Fruits2050	1 760	677	244	117	459	264
Vegetable2010	185	71	26	12	48	28
Vegetable2030	230	88	32	15	60	34
Vegetable2050	249	96	34	17	65	37
Meat2010	26	6	0	9	7	3
Meat2030	32	7	0	12	9	4
Meat2050	40	9	1	15	11	5
Dairy2010	9	7	1	0	1	0
Dairy2030	11	8	1	0	1	0
Dairy2050	14	11	1	0	1	0

Table W-7b (i) *Total* food waste by food type and food chain stage in Mozambique (thousand tonnes)

Mozambique	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	503	159	199	80	44	22
Cereal2030	809	255	320	129	71	35
Cereal2050	1 178	371	466	187	103	51
Root2010	4 920	1 558	1 723	1 178	334	127
Root2030	7 906	2 504	2 769	1 892	536	204
Root2050	11 519	3 649	4 035	2 757	781	297
Oil2010	242	105	61	57	13	6
Oil2030	389	168	99	91	21	10
Oil2050	567	245	144	132	30	15
Pulse2010	132	57	33	31	7	3
Pulse2030	212	92	54	49	11	6
Pulse2050	309	133	78	72	17	8
Fruits2010	364	71	57	144	74	18
Fruits2030	584	113	92	232	118	29
Fruits2050	851	165	134	338	172	42
Vegetable2010	254	49	40	101	51	13
Vegetable2030	409	79	64	162	83	20
Vegetable2050	595	115	94	236	121	29
Meat2010	49	28	1	8	10	3
Meat2030	84	47	2	13	18	5
Meat2050	141	78	3	22	29	8
Dairy2010	26	6	11	0	9	0
Dairy2030	45	11	19	0	15	0
Dairy2050	74	18	31	0	25	0

Table W-7b (ii) *Best practice* food waste by food type and food chain stage in Mozambique (kt)

Mozambique	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	256	51	50	85	47	23
Cereal2030	411	82	80	137	76	37
Cereal2050	599	119	116	200	110	54
Root2010	2 567	611	670	890	240	155
Root2030	4 126	982	1 077	1 431	386	250
Root2050	6 011	1 431	1 569	2 085	563	364
Oil2010	102	49	0	38	7	7
Oil2030	164	79	0	62	12	12
Oil2050	239	115	0	90	17	17
Pulse2010	55	27	0	21	4	4
Pulse2030	89	43	0	34	6	6
Pulse2050	130	62	0	49	9	9
Fruits2010	183	71	25	12	48	27
Fruits2030	295	113	41	20	77	44
Fruits2050	429	165	59	29	112	64
Vegetable2010	128	49	18	9	33	19
Vegetable2030	206	79	29	14	54	31
Vegetable2050	300	115	42	20	78	45
Meat2010	21	5	0	8	6	3
Meat2030	37	8	1	13	10	5
Meat2050	61	13	1	22	17	8
Dairy2010	5	4	0	0	0	0
Dairy2030	8	6	1	0	1	0
Dairy2050	14	10	1	0	1	0

Table W-7c (i) *Total* food waste by food type and food chain stage in Nigeria (thousand tonnes)

Nigeria	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	4 596	1 449	1 816	731	403	197
Cereal2030	5 720	1 803	2 260	910	502	246
Cereal2050	6 195	1 953	2 448	985	543	266
Root2010	43 592	13 809	15 269	10 434	2 956	1 123
Root2030	54 254	17 187	19 004	12 986	3 679	1 398
Root2050	58 763	18 615	20 583	14 065	3 985	1 514
Oil2010	4 972	2 151	1 262	1 161	267	131
Oil2030	6 188	2 677	1 571	1 445	332	163
Oil2050	6 702	2 900	1 701	1 565	360	176
Pulse2010	816	353	207	191	44	21
Pulse2030	1 016	439	258	237	55	27
Pulse2050	1 100	476	279	257	59	29
Fruits2010	6 083	1 180	956	2 415	1 232	301
Fruits2030	7 571	1 468	1 189	3 006	1 533	374
Fruits2050	8 200	1 590	1 288	3 256	1 661	405
Vegetable2010	6 430	1 247	1 010	2 553	1 302	318
Vegetable2030	8 003	1 552	1 257	3 178	1 621	396
Vegetable2050	8 668	1 681	1 362	3 442	1 755	429
Meat2010	272	151	6	43	57	15
Meat2030	339	189	7	53	71	19
Meat2050	421	235	9	66	88	23
Dairy2010	483	117	201	2	162	1
Dairy2030	601	145	250	2	202	2
Dairy2050	748	181	311	3	252	2

Table W-7c (ii) ***Best practice*** **food waste by food type and food chain stage in Nigeria (kt)**

Nigeria	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	2 335	463	454	778	429	210
Cereal2030	2 906	576	565	969	534	262
Cereal2050	3 148	624	612	1 049	579	284
Root2010	22 749	5 415	5 938	7 889	2 130	1 377
Root2030	28 313	6 739	7 390	9 819	2 651	1 714
Root2050	30 666	7 299	8 005	10 635	2 871	1 857
Oil2010	2 094	1 007	0	789	150	148
Oil2030	2 606	1 253	0	982	187	185
Oil2050	2 823	1 357	0	1 063	202	200
Pulse2010	344	165	0	129	25	24
Pulse2030	428	206	0	161	31	30
Pulse2050	463	223	0	175	33	33
Fruits2010	3 067	1 180	425	204	799	459
Fruits2030	3 817	1 468	529	254	995	572
Fruits2050	4 134	1 590	572	275	1 077	619
Vegetable2010	3 242	1 247	449	215	845	486
Vegetable2030	4 035	1 552	559	268	1 051	604
Vegetable2050	4 370	1 681	605	290	1 139	655
Meat2010	119	26	2	43	32	16
Meat2030	146	32	2	53	40	19
Meat2050	183	40	3	66	50	24
Dairy2010	88	66	9	2	9	2
Dairy2030	110	82	11	2	11	2
Dairy2050	136	103	14	3	14	3

Table W-7d (i) *Total* food waste by food type and food chain stage in South Africa (thousand tonnes)

South Africa	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	2 848	898	1 125	453	250	122
Cereal2030	3 544	1 117	1 400	564	311	152
Cereal2050	3 839	1 210	1 517	611	337	165
Root2010	1 085	344	380	260	74	28
Root2030	1 351	428	473	323	92	35
Root2050	1 463	464	513	350	99	38
Oil2010	476	206	121	111	26	13
Oil2030	593	256	150	138	32	16
Oil2050	642	278	163	150	34	17
Pulse2010	24	11	6	6	1	1
Pulse2030	30	13	8	7	2	1
Pulse2050	33	14	8	8	2	1
Fruits2010	3 281	636	515	1 303	664	162
Fruits2030	4 084	792	641	1 621	827	202
Fruits2050	4 423	858	695	1 756	896	219
Vegetable2010	1 395	271	219	554	282	69
Vegetable2030	1 736	337	273	689	352	86
Vegetable2050	1 881	365	295	747	381	93
Meat2010	877	489	19	138	183	49
Meat2030	1 092	608	24	171	228	60
Meat2050	1 359	757	30	213	283	75
Dairy2010	841	203	350	3	283	3
Dairy2030	1 047	253	436	4	352	3
Dairy2050	1 303	315	542	4	438	4

Table W-7d (ii) *Best practice* food waste by food type and food chain stage in South Africa (kt)

South Africa	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	1 447	287	281	482	266	130
Cereal2030	1 801	357	350	600	331	162
Cereal2050	1 951	387	379	650	359	176
Root2010	566	135	148	196	53	34
Root2030	705	168	184	244	66	43
Root2050	764	182	199	265	71	46
Oil2010	201	96	0	76	14	14
Oil2030	250	120	0	94	18	18
Oil2050	270	130	0	102	19	19
Pulse2010	10	5	0	4	1	1
Pulse2030	13	6	0	5	1	1
Pulse2050	14	7	0	5	1	1
Fruits2010	1 654	636	229	110	431	248
Fruits2030	2 059	792	285	137	536	308
Fruits2050	2 230	858	309	148	581	334
Vegetable2010	703	271	97	47	183	105
Vegetable2030	875	337	121	58	228	131
Vegetable2050	948	365	131	63	247	142
Meat2010	382	83	6	138	105	50
Meat2030	475	103	7	172	131	63
Meat2050	592	128	9	214	163	78
Dairy2010	153	115	16	3	16	3
Dairy2030	191	144	20	4	20	4
Dairy2050	238	179	25	5	24	5

Table W-7e (i) ***Total*** **food waste by food type and food chain stage in Uganda (thousand tonnes)**

Uganda	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	676	213	267	107	59	29
Cereal2030	1 086	342	429	173	95	47
Cereal2050	1 582	499	625	252	139	68
Root2010	4 375	1 386	1 533	1 047	297	113
Root2030	7 031	2 227	2 463	1 683	477	181
Root2050	10 244	3 245	3 588	2 452	695	264
Oil2010	354	153	90	83	19	9
Oil2030	570	246	145	133	31	15
Oil2050	830	359	211	194	45	22
Pulse2010	207	89	52	48	11	5
Pulse2030	332	144	84	78	18	9
Pulse2050	484	209	123	113	26	13
Fruits2010	5 843	1 133	918	2 320	1 183	289
Fruits2030	9 389	1 821	1 475	3 728	1 901	464
Fruits2050	13 681	2 653	2 149	5 432	2 770	676
Vegetable2010	536	104	84	213	109	27
Vegetable2030	862	167	135	342	175	43
Vegetable2050	1 256	244	197	499	254	62
Meat2010	101	56	2	16	21	6
Meat2030	172	96	4	27	36	10
Meat2050	287	160	6	45	60	16
Dairy2010	297	72	123	1	100	1
Dairy2030	506	122	210	2	170	2
Dairy2050	845	204	351	3	284	3

Table W-7e (ii) *Best practice* food waste by food type and food chain stage in Uganda (kt)

Uganda	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	343	68	67	114	63	31
Cereal2030	552	109	107	184	101	50
Cereal2050	804	159	156	268	148	72
Root2010	2 283	543	596	792	214	138
Root2030	3 669	873	958	1 272	344	222
Root2050	5 346	1 272	1 395	1 854	501	324
Oil2010	149	72	0	56	11	11
Oil2030	240	115	0	90	17	17
Oil2050	349	168	0	132	25	25
Pulse2010	87	42	0	33	6	6
Pulse2030	140	67	0	53	10	10
Pulse2050	204	98	0	77	15	14
Fruits2010	2 946	1 133	408	196	768	441
Fruits2030	4 734	1 821	655	315	1 233	709
Fruits2050	6 897	2 653	955	458	1 797	1 033
Vegetable2010	270	104	37	18	70	41
Vegetable2030	435	167	60	29	113	65
Vegetable2050	633	244	88	42	165	95
Meat2010	44	10	1	16	12	6
Meat2030	75	16	1	27	21	10
Meat2050	125	27	2	45	34	17
Dairy2010	54	41	6	1	6	1
Dairy2030	92	69	10	2	10	2
Dairy2050	154	116	16	3	16	3

Table W-8 Livestock feed demand coefficients

For each livestock type and production system (mixed or pastoral), livestock feed demand intensity (in tonnes of feed per tonne of livestock) is calculated as the product of system share, feed conversion efficiency (tonnes of feed per tonne of livestock) and grass or crop feed factor (tonnes of grass or crop per tonne of feed). Multiplying feed demand intensity (tonnes of feed per tonne of livestock) by land required per tonne of feed (Table W-9b), the product is land required per tonne of livestock. Multiplying this by tonnes of milk or meat wasted (Table W-7), one may calculate potential land liberated (Tables W-1a, W-1c, W-1e and W-1g). Feed intensities are assumed to be the same in 2050 as in 2030, the latest year of relevant FAO projections. System shares are from Bouwman (2005), Tables 2, 4 and 10.

Table W-8a Grass feed for livestock

Country	Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Grass Feed Factor (Tonnes Grass per Tonne Feed)		Grass Intensity (Tonnes Grass per Tonne Livestock)	
			2010	2030	2010	2030	2010	2030	2010	2030
Ghana	Beef	Mixed	0.63	0.68	62	46	0.60	0.60	23.6	18.5
Ghana	Beef	Pastoral	0.37	0.33	117	89	0.95	0.95	40.9	27.5
Ghana	Dairy	Mixed	0.49	0.55	4	4	0.45	0.45	0.9	0.9
Ghana	Dairy	Pastoral	0.51	0.45	5	5	0.95	0.95	2.5	1.9
Ghana	Mutton or goat	Mixed	0.64	0.73	20	15	0.85	0.85	10.9	9.1
Ghana	Mutton or goat	Pastoral	0.36	0.27	23	17	0.90	0.90	7.3	4.2
Ghana	Pork	Mixed	1.00	1.00	7	7	0.00	0.00	0.0	0.0
Ghana	Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0
Mozam-bique	Beef	Mixed	0.30	0.30	32	27	0.60	0.60	5.8	4.9
Mozam-bique	Beef	Pastoral	0.70	0.70	81	73	0.93	0.93	52.7	47.1
Mozam-bique	Dairy	Mixed	0.40	0.54	2	3	0.45	0.45	0.4	0.7
Mozam-bique	Dairy	Pastoral	0.60	0.46	5	5	0.93	0.93	2.8	2.1
Mozam-bique	Mutton or goat	Mixed	0.15	0.30	21	18	0.80	0.80	2.6	4.4
Mozam-bique	Mutton or goat	Pastoral	0.85	0.70	25	22	0.90	0.90	19.1	14.0
Mozam-bique	Pork	Mixed	1.00	1.00	7	7	0.00	0.00	0.0	0.0
Mozam-bique	Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0

Country	Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Grass Feed Factor (Tonnes Grass per Tonne Feed)		Grass Intensity (Tonnes Grass per Tonne Livestock)	
			2010	2030	2010	2030	2010	2030	2010	2030
Nigeria	Beef	Mixed	0.63	0.68	62	46	0.60	0.60	23.6	18.5
Nigeria	Beef	Pastoral	0.37	0.33	117	89	0.95	0.95	40.9	27.5
Nigeria	Dairy	Mixed	0.49	0.55	4	4	0.45	0.45	0.9	0.9
Nigeria	Dairy	Pastoral	0.51	0.45	5	5	0.95	0.95	2.5	1.9
Nigeria	Mutton or goat	Mixed	0.64	0.73	20	15	0.85	0.85	10.9	9.1
Nigeria	Mutton or goat	Pastoral	0.36	0.27	23	17	0.90	0.90	7.3	4.2
Nigeria	Pork	Mixed	1.00	1.00	7	7	0.00	0.00	0.0	0.0
Nigeria	Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0
South Africa	Beef	Mixed	0.30	0.30	32	27	0.60	0.60	5.8	4.9
South Africa	Beef	Pastoral	0.70	0.70	81	73	0.93	0.93	52.7	47.1
South Africa	Dairy	Mixed	0.40	0.54	2	3	0.45	0.45	0.4	0.7
South Africa	Dairy	Pastoral	0.60	0.46	5	5	0.93	0.93	2.8	2.1
South Africa	Mutton or goat	Mixed	0.15	0.30	21	18	0.80	0.80	2.6	4.4
South Africa	Mutton or goat	Pastoral	0.85	0.70	25	22	0.90	0.90	19.1	14.0
South Africa	Pork	Mixed	1.00	1.00	7	7	0.00	0.00	0.0	0.0
South Africa	Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0
Uganda	Beef	Mixed	0.56	0.65	50	41	0.75	0.75	21.0	19.9
Uganda	Beef	Pastoral	0.44	0.35	148	111	0.95	0.95	61.2	37.1
Uganda	Dairy	Mixed	0.69	0.75	3	3	0.65	0.65	1.3	1.2
Uganda	Dairy	Pastoral	0.31	0.25	5	4	0.95	0.95	1.3	1.1
Uganda	Mutton or goat	Mixed	0.65	0.74	21	17	0.85	0.85	11.6	11.0
Uganda	Mutton or goat	Pastoral	0.35	0.26	23	17	0.90	0.90	7.2	4.0
Uganda	Pork	Mixed	1.00	1.00	7	7	0.00	0.00	0.0	0.0
Uganda	Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0

Source: Bouwman (2005) and IRENA analysis

Table W-8b Crop feed for livestock

Country	Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Crop Feed Factor (Tonnes Crop per Tonne Feed)		Crop Intensity (Tonnes Crop per Tonne Livestock)	
			2010	2030	2010	2030	2010	2030	2010	2030
Ghana	Beef	Mixed	0.63	0.68	62	46	0.03	0.03	1.3	1.0
Ghana	Beef	Pastoral	0.37	0.33	117	89	0.00	0.00	0.0	0.0
Ghana	Dairy	Mixed	0.49	0.55	4	4	0.05	0.05	0.1	0.1
Ghana	Dairy	Pastoral	0.51	0.45	5	5	0.00	0.00	0.0	0.0
Ghana	Mutton or goat	Mixed	0.64	0.73	20	15	0.00	0.00	0.1	0.1
Ghana	Mutton or goat	Pastoral	0.36	0.27	23	17	0.00	0.00	0.0	0.0
Ghana	Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Ghana	Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0
Mozam-bique	Beef	Mixed	0.30	0.30	32	27	0.13	0.13	1.2	1.0
Mozam-bique	Beef	Pastoral	0.70	0.70	81	73	0.01	0.01	0.5	0.5
Mozam-bique	Dairy	Mixed	0.40	0.54	2	3	0.18	0.18	0.2	0.3
Mozam-bique	Dairy	Pastoral	0.60	0.46	5	5	0.01	0.01	0.0	0.0
Mozam-bique	Mutton or goat	Mixed	0.15	0.30	21	18	0.04	0.04	0.1	0.2
Mozam-bique	Mutton or goat	Pastoral	0.85	0.70	25	22	0.00	0.00	0.0	0.0
Mozam-bique	Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Mozam-bique	Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0
Nigeria	Beef	Mixed	0.63	0.68	62	46	0.03	0.03	1.3	1.0
Nigeria	Beef	Pastoral	0.37	0.33	117	89	0.00	0.00	0.0	0.0
Nigeria	Dairy	Mixed	0.49	0.55	4	4	0.05	0.05	0.1	0.1
Nigeria	Dairy	Pastoral	0.51	0.45	5	5	0.00	0.00	0.0	0.0
Nigeria	Mutton or goat	Mixed	0.64	0.73	20	15	0.00	0.00	0.1	0.1
Nigeria	Mutton or goat	Pastoral	0.36	0.27	23	17	0.00	0.00	0.0	0.0
Nigeria	Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
Nigeria	Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0

Country	Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Crop Feed Factor (Tonnes Crop per Tonne Feed)		Crop Intensity (Tonnes Crop per Tonne Livestock)	
			2010	2030	2010	2030	2010	2030	2010	2030
South Africa	Beef	Mixed	0.30	0.30	32	27	0.13	0.13	1.2	1.0
South Africa	Beef	Pastoral	0.70	0.70	81	73	0.01	0.01	0.5	0.5
South Africa	Dairy	Mixed	0.40	0.54	2	3	0.18	0.18	0.2	0.3
South Africa	Dairy	Pastoral	0.60	0.46	5	5	0.01	0.01	0.0	0.0
South Africa	Mutton or goat	Mixed	0.15	0.30	21	18	0.04	0.04	0.1	0.2
South Africa	Mutton or goat	Pastoral	0.85	0.70	25	22	0.00	0.00	0.0	0.0
South Africa	Pork	Mixed	1.00	1.00	7	7	0.50	0.50	3.3	3.3
South Africa	Poultry	Mixed	1.00	1.00	4	4	0.50	0.50	2.0	2.0
Uganda	Beef	Mixed	0.56	0.65	50	41	0.01	0.01	0.3	0.3
Uganda	Beef	Pastoral	0.44	0.35	148	111	0.00	0.00	0.0	0.0
Uganda	Dairy	Mixed	0.69	0.75	3	3	0.02	0.02	0.0	0.0
Uganda	Dairy	Pastoral	0.31	0.25	5	4	0.00	0.00	0.0	0.0
Uganda	Mutton or goat	Mixed	0.65	0.74	21	17	0.00	0.00	0.0	0.0
Uganda	Mutton or goat	Pastoral	0.35	0.26	23	17	0.00	0.00	0.0	0.0
Uganda	Pork	Mixed	1.00	1.00	7	7	0.40	0.40	2.6	2.6
Uganda	Poultry	Mixed	1.00	1.00	4	4	0.40	0.40	1.6	1.6

Source: Bouwman (2005) and IRENA analysis

Table W-9 Land intensity of livestock feed

Table W-9a shows FAO projections of how much crop or grass is produced per hectare for animal feed. Animal feed yields for 2030 and 2050 are found by applying indices from Table W-10 to 2010 values. Dividing the amounts of feed required per tonne of livestock, from Table W-8, by these feed crop yields, one obtains livestock unit land demands in hectares of land per tonne of animal product in Table W-9b.

For milk and meat, amounts of land freed by avoiding losses and waste (thousand hectares, tables W-1 and W-2) can be calculated by multiplying these unit land demands (hectares per tonne, Table W-9b) by amounts lost or wasted (thousand tonnes, Table W-7).

Table W-9a Animal feed yield (tonnes of feed per hectare)

Country	Feed Crop Yield			Feed Grass Yield		
	2010	2030	2050	2010	2030	2050
Ghana	1.7	2.0	2.1	20.2	24.6	26.9
Mozambique	1.1	1.6	2.0	20.2	24.6	26.9
Nigeria	1.8	2.1	2.2	20.2	24.6	26.9
South Africa	4.7	5.7	6.1	28.8	35.0	37.6
Uganda	2.4	3.3	4.2	20.2	24.6	26.9

Source: FAO (2015)

Table W-9b Livestock unit land demand (hectares of land per tonne of meat or milk)

Hectares of land required to feed each tonne of livestock (the inverse of livestock yield in tonnes per hectare) is found by dividing livestock feed intensity coefficients (tonnes of grass or crop feed per tonne of livestock, from rightmost columns of tables W-8a and W-8b) by feed yields (tonnes of feed per hectare, from Table W-9a).

		2010		2030		2050	
		Meat	Milk	Meat	Milk	Meat	Milk
Ghana	Feed grass	4.10	0.17	2.93	0.14	2.93	0.14
	Feed crop	3.85	0.06	3.15	0.05	2.99	0.04
Mozam-bique	Feed grass	3.97	0.16	3.48	0.14	3.48	0.14
	Feed crop	6.29	0.18	4.47	0.20	3.49	0.15
Nigeria	Feed grass	4.10	0.17	2.93	0.14	2.93	0.14
	Feed crop	3.63	0.05	2.98	0.04	2.83	0.04
South Africa	Feed grass	2.79	0.11	2.01	0.08	1.87	0.08
	Feed crop	1.53	0.04	1.22	0.05	1.13	0.05
Uganda	Feed grass	5.00	0.13	3.56	0.11	3.56	0.11
	Feed crop	1.92	0.01	1.38	0.01	1.08	0.01

Table W-10 Current and projected crop yields (FAO projections)

Crop yields (tonnes per hectare) are projected for each type of crop in Table W-10b, based upon growth rates in Table W-10a. Where crops are consumed directly, rather than as animal feed, amounts of land freed by avoiding losses and waste (tables W-1 and W-2) can be calculated by taking the amount of food lost or wasted (Table W-7) and dividing by these yields (Table W-10b).

Table W-10a Yield growth scenario from FAO projections

FAO assumptions about annual increase in yields are shown in this table for 2010-2030 and 2030-2050. The same increase is assumed for all crops and for all countries in a region – a simplification of reality. Indices of yield (2010 yield = 100) are calculated for 2030 and 2050 based upon these annual increases.

Country	Yield Growth Per Annum		Yield Growth index		
	2010-2030	2030-2050	2010	2030	2050
Ghana	0.7%	0.3%	1.00	1.15	1.21
Mozambique	1.6%	1.2%	1.00	1.36	1.74
Nigeria	0.7%	0.3%	1.00	1.15	1.21
South Africa	1.0%	0.4%	1.00	1.22	1.31
Uganda	1.6%	1.2%	1.00	1.36	1.74
World Average	1.0%	0.5%	1.00	1.21	1.33

Source: Alexandratos *et al.* (2012)

Table W-10b Projected crop yields in FAO yield growth scenario (tonnes per hectare)

FAO data on 2010 crop yields for each country and crop type are projected out to 2030 and 2050 using the general indices of yield improvement developed in Table W-10a.

Country	Year	Cereals	Roots	Sugars	Pulses	Oil Crops	Fruits	Vegetables
Ghana	2010	1.7	13.4	25.4	0.1	3.7	11.9	8.4
	2030	1.9	15.4	29.3	0.1	4.3	13.7	9.7
	2050	2.1	16.3	30.9	0.1	4.5	14.4	10.2
Mozambique	2010	1.0	6.9	69.8	0.4	0.6	6.3	4.7
	2030	1.3	9.4	95.2	0.5	0.8	8.6	6.4
	2050	1.7	12.0	121.7	0.7	1.0	11.0	8.2
Nigeria	2010	1.5	10.4	19.3	0.9	1.7	5.9	5.1
	2030	1.7	12.0	22.3	1.0	2.0	6.8	5.9
	2050	1.8	12.7	23.5	1.1	2.1	7.1	6.3
South Africa	2010	4.2	26.5	60.6	1.2	1.5	21.3	17.8
	2030	5.1	32.2	73.7	1.4	1.8	25.9	21.7
	2050	5.5	34.6	78.1	1.5	2.0	27.8	23.3
Uganda	2010	2.0	7.7	63.7	0.6	0.9	5.5	4.8
	2030	2.8	10.5	86.8	0.8	1.2	7.5	6.6
	2050	3.5	13.4	110.9	1.0	1.6	9.6	8.4

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table W-10c Projected crop yields in yield gap closure scenario (tonnes per hectare)

FAO analysis of yields that could be obtained if the yield gap were closed are shown in the table below. Yields for fruits and vegetables are unaffected because the FAO does not consider the yield gap for these crops.

Country	Year	Cereals	Roots	Sugars	Pulses	Oil Crops	Fruits	Vegetables
Ghana	2010	1.7	13.4	25.4	0.1	3.7	11.9	8.4
	2030	9.2	28.7	54.1	1.8	10.8	13.7	9.7
	2050	9.2	28.7	54.1	1.8	10.8	14.4	10.2
Mozambique	2010	1.0	6.9	69.8	0.4	0.6	6.3	4.7
	2030	10.5	21.1	148.6	2.1	3.4	8.6	6.4
	2050	10.5	21.1	148.6	2.1	3.4	11.0	8.2
Nigeria	2010	1.5	10.4	19.3	0.9	1.7	5.9	5.1
	2030	7.9	17.7	41.1	5.1	5.8	6.8	5.9
	2050	7.9	17.7	41.1	5.1	5.8	7.1	6.3
South Africa	2010	4.2	26.5	60.6	1.2	1.5	21.3	17.8
	2030	12.7	55.8	78.1	2.5	3.0	25.9	21.7
	2050	12.7	55.8	78.1	2.5	3.0	27.8	23.3
Uganda	2010	2.0	7.7	63.7	0.6	0.9	5.5	4.8
	2030	8.4	43.7	135.5	3.2	6.0	7.5	6.6
	2050	8.4	43.7	135.5	3.2	6.0	9.6	8.4

Source: Alexandratos *et al.* (2012)

Appendix IV: Bioenergy potential from productive forests in sub-Saharan Africa

TABLE F-1 Wood production by country in 2013 (thousand cubic metres)

Annual data on logging volume are available from country reports in FAOSTAT (FAO 2015a). Annual data on production of sawn wood, wood panels and wood chips are also available from FAOSTAT.

Country	Total Roundwood	Energy Wood	Industrial Roundwood	Sawn Wood	Wood Panels	Wood Chips
Ghana	43 035	41 448	1 587	511	453	-
Mozambique	18 251	16 724	1 527	239	2	-
Nigeria	73 832	64 414	9 418	2 002	97	54
South Africa	29 906	12 000	17 906	1 443	1 024	4 032
Uganda	45 933	41 600	4 333	440	21	-
TOTAL	210 957	176 186	34 771	4 635	1 597	4 086

TABLE F-2 Residue from wood production by country in 2013 (thousand cubic metres)

Logging residue is assumed to equal 30% of total wood logged for industrial roundwood, which is industrial roundwood production shown in Table F-1 divided by 0.7. Residue from sawn wood and wood panel production is assumed to be 50% of wood processed for such production, which equals the amount produced per Table F-1. Residue from wood chip production is assumed to account for 10% of wood processed into wood chips, which is the wood chip production amount in Table F-1 divided by 0.9. The assumed logging and process residue shares are taken from Koopmans and Koppejan (1997).

Country	Total Wood Residue	Logging Residue	Sawn Wood Residue	Wood Panel Residue	Wood Chip Residue
Ghana	1 644	680	511	453	-
Mozambique	895	654	239	2	-
Nigeria	6 141	4 036	2 002	97	6
South Africa	10 589	7 674	1 443	1 024	448
Uganda	2 318	1 857	440	21	-
TOTAL	21 587	14 901	4 635	1 597	454

TABLE F-3 Residue from wood production by country in 2013 (thousand metric tonnes)

To convert from cubic metres to tonnes of residue, a wood density of 0.5 t/m^3 is assumed as average of wood density values in FAO (1997) for species indicated in FAO (2015b) and Republic of Ghana (2016).

Country	Total Wood Residue	Logging Residue	Sawn Wood Residue	Wood Panel Residue	Wood Chip Residue
Ghana	822	340	255	227	-
Mozambique	448	327	120	1	-
Nigeria	3 070	2 018	1 001	48	3
South Africa	5 294	3 837	721	512	224
Uganda	1 159	929	220	10	-
TOTAL	10 793	7 451	2 317	798	227

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