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A macro analysis of crop residue and animal wastes as a potential energy source in Africa

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Abstract
Africans are particularly disadvantaged when it comes to access to energy. A significant majority of the continents' inhabitants rely on biomass for their energy needs and are of necessity subsistence farmers. The production of four important crops in African countries, and the potential magnitude of residues for energy use from these, is analysed in this desktop study. It is clear that there is significant potential for using crop residues as a renewable energy resource in many parts of Africa, effectively combining the need for food and the need for energy. Energy policy must be formulated to leverage the opportunity; however, supporting energy data collected by governmental statistical processes will need to include this additional information.

Keywords: rural energy, crop residues, animal wastes

1. Introduction
Energy is a fundamental part of life. As living organisms, we require energy in order to function. Similarly, energy is required to assist in the provision of services that improve the quality of our lives. Technological ingenuity has provided many with a very high standard of life and with energy services readily available. The provision of these services in rural areas is, however, a particularly challenging topic. Rural populations are particularly poor and access to modern energy services is limited. These are mainly agrarian communities that gather and use the natural energy resources around them. Crop and animal residues are currently used as sources of energy, along with fuelwood and charcoal. There is, however, potential for far more effective use of these readily available residues.

2. The rural energy issue
The World Energy Council (WEC 2000) estimated that 1.6 billion of the World's people do not have access to commercial energy. Many of these are in Africa, and they are located primarily in rural areas. This topic was to some extent addressed in a previous WEC report (WEC 1999) on rural energy poverty. A migration to cities is underway yet this only exacerbates the problem. The newly urbanised cannot afford modern energy services (if they are available) and tend to remain reliant on traditional biomass energy sources. These are supplied from the surrounding rural areas, exerting major pressure on natural resources close to towns as well as those in rural areas.

There are neither accurate figures on rural populations nor on the amount and sources of energy they use. As a result, planning cannot be done with any degree of accuracy. Various continental programmes are, nevertheless, underway to improve conditions in Africa, for example, the NEPAD initiative. These programmes target the building of infrastructure and promote agricultural activities for food production. This study is intended to extend the impact of these programmes by highlighting the vast potential that crop residues and animal waste have for providing additional cost effective energy resources for Africa. Policy makers and implementers will be able to target the promotion of crops that provide not only food, but also energy.

2.1 Methodology
It is recognised that crops produce residues that can be used as an energy source, and these have been used during all of recorded history. However, a detailed quantification of the volumes available and

used, in the countries of Africa, has not yet been done. This analysis is a desktop and a theoretical attempt to quantify the total production of crop residues and of animal wastes, on the continent. The study makes exclusive use of agricultural data from the UN Food and Agricultural Organisation (FAO 2001). A separate investigation provided data on the amount of residue produced for each crop and animal waste produced, and these ratios were used to calculate the total potential waste produced. It is, however, recognised that for crop residues there are essentially three uses: as a soil fertility improver, as animal feed and as an energy source, each of which has a role to play. The first two are very important in maintaining balance, fertility and functionality in the rural system, and, depending on the residue, will reduce the amount available as an energy source.

No attempt has been made during this analysis to investigate fuelwood and charcoal potential. These fuels are a very important component of energy demand in Africa and are the subject of much study by organisations such as the FAO. Nevertheless, more in-depth study will still be required to accurately quantify volumes being utilised in rural areas of the continent. Such a study will, unfortunately, require significant financial and human resources for effective completion.

2.2 Crop residues

Crop residues can, for convenience, be divided into two categories – field and process residues (RWEDP 2003). Field residues are those that remain in the fields after harvesting of the crop. They are used for two essential functions – as a fertiliser and as fodder for livestock. There are some practical challenges in collecting field residues and all cannot be removed without adversely affecting soil fertility. One reference (Energy Saving Now! 2003) notes that about 35% of field residues could potentially be removed without affecting fertility. No allowance for non-usable biomass has been made in the calculations below, whether because of physical impediments to its removal or for soil fertility reasons.

Process residues are those that result from the processing of the crop. It is these residues that offer particular promise as an energy source. Examples are rice husks, maize cobs and husks and nut shells and husks. Some processing will be done in rural areas especially where the crop is produced by subsistence farmers. Whether such residues will be available as fuel, or are being currently utilised, is not known and this can only be determined through field research. It seems appropriate to focus on process residues, although field residue volumes will also be calculated.

The best source of information on crop residues was found to be an analysis of previous work done in various Asian countries and summarised by Koopmans and Koppejan (1997). The paper provided a summary of the residue to production ratio (RPR) for a number of crops. The caveat is that different studies indicated varying RPR's for the same crop, and it seems that the data is for crops harvested in the Asian region. The volumes of residue potential calculated in this report must thus be treated with caution. Some African countries may have different RPR's for the crops studied but limited specific data could be found. The values are indicative only of the *potential* of residues available for use as an energy source. There can be some confusion about exactly how the RPR has been calculated, and the meaning of the ratio. In general, it appears that the ratio indicates the weight of residue produced per measure of crop. Thus, a RPR of 2.0 indicates that there will be two tons of residue for every one ton of crop. For sugar cane the crop is the cane and not the sugar ultimately produced.

The FAO data was evaluated and four crops were selected as being those with the greatest potential for providing a useful residue. These crops are:

- Coconuts
- Maize
- Rice
- Sugar cane

2.3 Animal wastes

Wastes from particularly ruminants offer potential both directly as a combustible fuel and as an input to produce biogas. Rural populations in a number of poorer countries burn dried dung as a fuel, and this is often a major energy source. India has pursued a programme to generate biogas from dung with some success. The advantage, from an environmental point of view, is that methane that would be naturally released is captured and used to provide heat for mainly cooking purposes. Methane is about 20 times more potent than carbon dioxide as a greenhouse gas and oxidising it while producing useable heat makes sense from a climatic point of view. The solid residue remaining from the fermentation process can still be used as a fertiliser.

The challenge in this study has been to quantify the energy potential from animal wastes in Africa.

3. Continental summary

The crop data for all African countries was extracted from the FAO database. The ratio of crop to residue obtained from Koopmans and Koppejan (1997) was used to calculate the total potential. Animal waste was more difficult to estimate. One reference (Xuereb 1997) indicated that the energy (biogas) produced annually from a single head of cattle equals 50 gallons of gasoline. To be conservative this was assumed to be a US gallon. The calculations for each crop and for cattle are presented in the sections below.

3.1 Crop residues

3.1.1 Coconuts

Coconuts are a major crop in many tropical African countries. The residues are essentially of two types: husks and shells. The RPR's for the two do vary but the consensus is that husks form about 40% and shells about 12% of the total crop (Koopmans and Koppejan 1997). These ratios have been used to calculate the potential as set out in Table 1.

Table 1: Coconut residues – tonnage potential (metric tons)

	Crop	*Husks*	*Shells*
Cameroon	4 800	1 920	576
Cape Verde	6 000	2 400	720
Comoros	75 000	30 000	9 000
Côte d'Ivoire	193 000	77 200	23 160
Ghana	305 000	122 000	36 600
Kenya	63 000	25 200	7 560
Liberia	7 000	2 800	840
Madagascar	84 000	33 600	10 080
Mauritius	1 900	760	228
Mozambique	300 000	120 000	36 000
Nigeria	158 000	63 200	18 960
Réunion	1 900	760	228
S Tome & Principe	29 000	11 600	3 480
Senegal	4 700	1 880	564
Seychelles	3 200	1 280	384
Sierra Leone	2 500	1 000	300
Somalia	10 000	4 000	1 200
Tanzania	350 000	140 000	42 000
Total	**1 599 000**	**639 600**	**191 880**

Koopmans and Koppejan (1997) indicate a calorific value of about 18 MJ/kg for husks and shells. Converting the data from Table 1 gives an indication of the energy content of these residues, which is tabulated in Table 2. The countries with the greatest energy potential from coconut residues are, in descending order, Tanzania, Ghana, Mozambique, Côte d'Ivoire, Nigeria, Madagascar, Comores and Kenya.

Table 2: Coconut residues – energy potential (TJ)

	Husks	*Shells*
Cameroon	86	35
Cape Verde	108	43
Comoros	1 350	540
Côte d'Ivoire	3 474	1 390
Ghana	5 490	2 196
Kenya	1 134	454
Liberia	126	50
Madagascar	1 512	605
Mauritius	34	14
Mozambique	5 400	2 160
Nigeria	2 844	1 138
Réunion	34	14
S Tome & Principe	522	209
Senegal	85	34
Seychelles	58	23
Sierra Leone	45	18
Somalia	180	72
Tanzania	6 300	2 520
Total	**11 513**	**3 454**

3.1.2 Maize

Maize is a staple crop in much of Africa. Residues are stalks, cobs and husks. The stalks are generally left on the lands (they are a field residue). Cobs and husks are process residues. The availability of husks as fuel is questionable and they have been excluded from the analysis. The estimates of the total potential for cobs and stalks are tabulated below.

The RPR's for both cobs and stalks vary greatly and a lower and higher, as well as an average, for each are included. The literature (Koopmans and Koppejan 1997) showed a very wide range of ratios. The lower ratio for cobs is around 0.2, the upper ratio around 0.86. One study indicated a ratio of 1.8 which was ignored as being far out of line when compared with the other studies. The average was 0.376. For stalks, the respective values were 1.0, 3.7 and 2.09. Different authors seem to use different definitions of the RPR. As previously noted, one source (Energy Saving Now! 2003) believes that only 35% of the residue should be taken from the field without compromising the fertility of the soil. No account of this has been taken in the analysis presented in Table 3. The authors recognise that this is an adjustment that could be made to the calculations.

Using an indicative calorific value for maize residues (Koopmans and Koppejan 1997) of 14MJ/kg the, following countries, again noted in descending order of magnitude, have the largest energy potential from both maize cobs and stalks – South Africa, Egypt, Nigeria, Ethiopia, Tanzania, Malawi, Zimbabwe and Kenya. The energy potential is indicated in Table 4.

3.1.3 Rice

As for maize, husks and straw are potential residues from rice. The straw would normally be left in the field. According to the Tata Energy Research Institute (TERI 2003) rice straw is high in oxalic acid and silica which limits its use as fodder. The Institute

Table 3: Maize residues – tonnage potential (metric tons)

Crop data from FAOStats (2000 data)

	Crop	Cobs			Stalks		
		Min	Max	Average	Min	Max	Average
Algeria	300	60	258	113	300	1 110	627
Angola	428 045	85 609	368 119	161 006	428 045	1 583 767	895 149
Botswana	6 000	1 200	5 160	2 257	6 000	22 200	12 548
Burkina Faso	350 000	70 000	301 000	131 650	350 000	1 295 000	731 938
Burundi	117 840	23 568	101 342	44 325	117 840	436 008	246 433
Cameroon	850 000	170 000	731 000	319 722	850 000	3 145 000	1 777 563
Cape Verde	11 000	2 200	9 460	4 138	11 000	40 700	23 004
Central Af. Rep.	100 700	20 140	86 602	37 878	100 700	372 590	210 589
Chad	86 684	17 337	74 548	32 606	86 684	320 731	181 278
Comoros	4 000	800	3 440	1 505	4 000	14 800	8 365
Congo, DR	1 184 000	236 800	1 018 240	445 353	1 184 000	4 380 800	2 476 040
Congo, Rep.	2 000	400	1 720	752	2 000	7 400	4 183
Côte d'Ivoire	571 018	114 204	491 075	214 784	571 018	2 112 767	1 194 141
Djibouti	13	3	11	5	13	48	27
Egypt	6 394 830	1 278 966	5 499 554	2 405 371	6 394 830	23 660 871	13 373 188
Eritrea	12 000	2 400	10 320	4 514	12 000	44 400	25 095
Ethiopia	2 600 000	520 000	2 236 000	977 972	2 600 000	9 620 000	5 437 250
Gabon	31 000	6 200	26 660	11 660	31 000	114 700	64 829
Gambia	21 458	4 292	18 454	8 071	21 458	79 395	44 874
Ghana	1 014 450	202 890	872 427	381 578	1 014 450	3 753 465	2 121 469
Kenya	1 800 000	360 000	1 548 000	677 057	1 800 000	6 660 000	3 764 250
Lesotho	102 000	20 400	87 720	38 367	102 000	377 400	213 308
Libyan AJ	450	90	387	169	450	1 665	941
Madagascar	150 000	30 000	129 000	56 421	150 000	555 000	313 688
Malawi	2 300 000	460 000	1 978 000	865 129	2 300 000	8 510 000	4 809 875
Mali	437 504	87 501	376 253	164 564	437 504	1 618 765	914 930
Mauritania	10 777	2 155	9 268	4 054	10 777	39 875	22 537
Mauritius	220	44	189	83	220	814	460
Morocco	95 000	19 000	81 700	35 734	95 000	351 500	198 669
Mozambique	1 018 860	203 772	876 220	383 237	1 018 860	3 769 782	2 130 691
Namibia	49 300	9 860	42 398	18 544	49 300	182 410	103 099
Niger	8 000	1 600	6 880	3 009	8 000	29 600	16 730
Nigeria	5 476 000	1 095 200	4 709 360	2 059 759	5 476 000	20 261 200	11 451 685
Rwanda	62 501	12 500	53 751	23 509	62 501	231 254	130 705
Réunion	17 000	3 400	14 620	6 394	17 000	62 900	35 551
S Tome & Principe	2 230	446	1 918	839	2 230	8 251	4 663
Senegal	66 132	13 226	56 874	24 875	66 132	244 688	138 299
Sierra Leone	8 902	1 780	7 656	3 348	8 902	32 937	18 616
Somalia	210 000	42 000	180 600	78 990	210 000	777 000	439 163
South Africa	10 584 269	2 116 854	9 102 471	3 981 199	10 584 269	39 161 795	22 134 353
Sudan	53 000	10 600	45 580	19 936	53 000	196 100	110 836
Swaziland	72 000	14 400	61 920	27 082	72 000	266 400	150 570
Tanzania	2 551 155	510 231	2 193 993	959 599	2 551 155	9 439 274	5 335 103
Uganda	1 096 000	219 200	942 560	412 253	1 096 000	4 055 200	2 292 010
Zambia	1 260 000	252 000	1 083 600	473 940	1 260 000	4 662 000	2 634 975
Zimbabwe	2 108 110	421 622	1 812 975	792 951	2 108 110	7 800 007	4 408 585
Total	**43 324 748**	**8 664 950**	**37 259 283**	**16 296 301**	**43 324 748**	**160 301 568**	**90 602 879**

Table 4: Maize residues – energy potential (TJ)

	Cobs			Stalks		
	Min	*Max*	*Average*	*Min*	*Max*	*Average*
Algeria	1	4	2	4	16	9
Angola	1 199	5 154	2 254	5 993	22 173	12 532
Botswana	17	72	32	84	311	176
Burkina Faso	980	4 214	1 843	4 900	18 130	10 247
Burundi	330	1 419	621	1 650	6 104	3 450
Cameroon	2 380	10 234	4 476	11 900	44 030	24 886
Cape Verde	31	132	58	154	570	322
Central Af. Rep	282	1 212	530	1 410	5 216	2 948
Chad	243	1 044	456	1 214	4 490	2 538
Comoros	11	48	21	56	207	117
Congo, DR	3 315	14 255	6 235	16 576	61 331	34 665
Congo, Rep	6	24	11	28	104	59
Côte d'Ivoire	1 599	6 875	3 007	7 994	29 579	16 718
Djibouti	0	0	0	0	1	0
Egypt	17 906	76 994	33 675	89 528	331 252	187 225
Eritrea	34	144	63	168	622	351
Ethiopia	7 280	31 304	13 692	36 400	134 680	76 122
Gabon	87	373	163	434	1 606	908
Gambia	60	258	113	300	1 112	628
Ghana	2 840	12 214	5 342	14 202	52 549	29 701
Kenya	5 040	21 672	9 479	25 200	93 240	52 700
Lesotho	286	1 228	537	1 428	5 284	2 986
Libyan AJ	1	5	2	6	23	13
Madagascar	420	1 806	790	2 100	7 770	4 392
Malawi	6 440	27 692	12 112	32 200	119 140	67 338
Mali	1 225	5 268	2 304	6 125	22 663	12 809
Mauritania	30	130	57	151	558	316
Mauritius	1	3	1	3	11	6
Morocco	266	1 144	500	1 330	4 921	2 781
Mozambique	2 853	12 267	5 365	14 264	52 777	29 830
Namibia	138	594	260	690	2 554	1 443
Niger	22	96	42	112	414	234
Nigeria	15 333	65 931	28 837	76 664	283 657	160 324
Rwanda	175	753	329	875	3 238	1 830
Réunion	48	205	90	238	881	498
S Tome & Principe	6	27	12	31	116	65
Senegal	185	796	348	926	3 426	1 936
Sierra Leone	25	107	47	125	461	261
Somalia	588	2 528	1 106	2 940	10 878	6 148
South Africa	29 636	127 435	55 737	148 180	548 265	309 881
Sudan	148	638	279	742	2 745	1 552
Swaziland	202	867	379	1 008	3 730	2 108
Tanzania	7 143	30 716	13 434	35 716	132 150	74 691
Uganda	3 069	13 196	5 772	15 344	56 773	32 088
Zambia	3 528	15 170	6 635	17 640	65 268	36 890
Zimbabwe	5 903	25 382	11 101	29 514	109 200	61 720
Total	**121 309**	**521 630**	**228 148**	**606 546**	**2 244 222**	**1 268 440**

has further conducted research on using rice straw as an alternate to producing biogas from dung.

The RPR for straw varies widely, ranging from 1.4 to 3.28, with an average of 2.07. These values have been used to calculate the potential. Husks are indeed currently used as fuel, usually as pressed husk briquettes. Lower and upper ratios are given by Koopmans and Koppejan (1997) as 0.2 and 0.35 respectively, with a calculated average of 0.27.

The energy potential was calculated from an indicative calorific value of 14 MJ/kg, and is presented in Table 6. The countries with the highest potential are Egypt, Nigeria, Madagascar, Côte d'Ivoire and Mali.

Table 5: Rice residues – tonnage potential (metric tons)
Crop data from FAOStats (2000 data)

	Crop	*Husks*			*Straw*		
		Lower	*Upper*	*Average*	*Lower*	*Upper*	*Average*
Algeria	300	60	105	82	420	984	623
Angola	16 000	3 200	5 600	4 376	22 400	52 480	33 243
Burkina Faso	88 000	17 600	30 800	24 068	123 200	288 640	182 838
Burundi	51 678	10 336	18 087	14 134	72 349	169 504	107 371
Cameroon	68 000	13 600	23 800	18 598	95 200	223 040	141 284
Central Af. Rep.	21 000	4 200	7 350	5 744	29 400	68 880	43 632
Chad	130 521	26 104	45 682	35 697	182 729	428 109	271 183
Comoros	17 000	3 400	5 950	4 650	23 800	55 760	35 321
Congo, DR	337 800	67 560	118 230	92 388	472 920	1 107 984	701 847
Congo, Rep.	300	60	105	82	420	984	623
Côte d'Ivoire	1 161 518	232 304	406 531	317 675	1 626 125	3 809 779	2 413 286
Egypt	5 996 830	1 199 366	2 098 891	1 640 133	8 395 562	19 669 602	12 459 614
Gabon	800	160	280	219	1 120	2 624	1 662
Gambia	28 873	5 775	10 106	7 897	40 422	94 703	59 989
Ghana	209 750	41 950	73 413	57 367	293 650	687 980	435 798
Kenya	55 000	11 000	19 250	15 043	77 000	180 400	114 274
Liberia	200 000	40 000	70 000	54 700	280 000	656 000	415 540
Madagascar	2 300 000	460 000	805 000	629 050	3 220 000	7 544 000	4 778 710
Malawi	87 000	17 400	30 450	23 795	121 800	285 360	180 760
Mali	809 555	161 911	283 344	221 413	1 133 377	2 655 340	1 682 012
Mauritania	103 400	20 680	36 190	28 280	144 760	339 152	214 834
Mauritius	0	0	0	0	0	0	0
Morocco	25 200	5 040	8 820	6 892	35 280	82 656	52 358
Mozambique	157 937	31 587	55 278	43 196	221 112	518 033	328 146
Niger	73 000	14 600	25 550	19 966	102 200	239 440	151 672
Nigeria	3 277 000	655 400	1 146 950	896 260	4 587 800	10 748 560	6 808 623
Rwanda	11 654	2 331	4 079	3 187	16 316	38 225	24 214
Réunion	80	16	28	22	112	262	166
Senegal	239 786	47 957	83 925	65 581	335 700	786 498	498 203
Sierra Leone	199 134	39 827	69 697	54 463	278 788	653 160	413 741
Somalia	2 000	400	700	547	2 800	6 560	4 155
South Africa	3 000	600	1 050	821	4 200	9 840	6 233
Sudan	8 000	1 600	2 800	2 188	11 200	26 240	16 622
Swaziland	100	20	35	27	140	328	208
Tanzania	378 562	75 712	132 497	103 537	529 987	1 241 683	786 538
Uganda	108 000	21 600	37 800	29 538	151 200	354 240	224 392
Zambia	16 000	3 200	5 600	4 376	22 400	52 480	33 243
Zimbabwe	400	80	140	109	560	1 312	831
Total	**16 183 178**	**3 236 636**	**5 664 112**	**4 426 099**	**22 656 449**	**53 080 824**	**33 623 789**

Table 6: Rice residues – energy potential (TJ)

	Husks			*Straw*		
	Lower	*Upper*	*Average*	*Lower*	*Upper*	*Average*
Algeria	1	1	1	6	14	9
Angola	45	78	61	314	735	465
Burkina Faso	246	431	337	1 725	4 041	2 560
Burundi	145	253	198	1 013	2 373	1 503
Cameroon	190	333	260	1 333	3 123	1 978
Central Af. Rep.	59	103	80	412	964	611
Chad	365	640	500	2 558	5 994	3 797
Comoros	48	83	65	333	781	494
Congo, DR	946	1 655	1 293	6 621	15 512	9 826
Congo, Rep.	1	1	1	6	14	9
Côte d'Ivoire	3 252	5 691	4 447	22 766	53 337	33 786
Egypt	16 791	29 384	22 962	117 538	275 374	174 435
Gabon	2	4	3	16	37	23
Gambia	81	141	111	566	1 326	840
Ghana	587	1 028	803	4 111	9 632	6 101
Kenya	154	270	211	1 078	2 526	1 600
Liberia	560	980	766	3 920	9 184	5 818
Madagascar	6 440	11 270	8 807	45 080	105 616	66 902
Malawi	244	426	333	1 705	3 995	2 531
Mali	2 267	3 967	3 100	15 867	37 175	23 548
Mauritania	290	507	396	2 027	4 748	3 008
Mauritius	0	0	0	0	0	0
Morocco	71	123	96	494	1 157	733
Mozambique	442	774	605	3 096	7 252	4 594
Niger	204	358	280	1 431	3 352	2 123
Nigeria	9 176	16 057	12 548	64 229	150 480	95 321
Rwanda	33	57	45	228	535	339
Réunion	0	0	0	2	4	2
Senegal	671	1 175	918	4 700	11 011	6 975
Sierra Leone	558	976	762	3 903	9 144	5 792
Somalia	6	10	8	39	92	58
South Africa	8	15	11	59	138	87
Sudan	22	39	31	157	367	233
Swaziland	0	0	0	2	5	3
Tanzania	1 060	1 855	1 450	7 420	17 384	11 012
Uganda	302	529	414	2 117	4 959	3 141
Zambia	45	78	61	314	735	465
Zimbabwe	1	2	2	8	18	12
Total	**45 313**	**79 298**	**61 965**	**317 190**	**743 132**	**470 733**

3.1.4 Sugar cane

Sugar is grown in a significant number of African countries. While some residues remain in the field, it is the process residue bagasse that offers promise as a fuel. Indeed, in many sugar mills, the bagasse is used for steam production for process heat, and in some instances, electricity is also produced. The data can be misleading as the crop data from the FAO refers to the mass of cane produced, and is not the mass of sugar produced. Lower ratios are

Table 7: Sugar cane residues – tonnage potential (metric tons)
Crop data from FAOStats (2000 data)

	Crop	*Lower*	*Upper*	*Average*
Algeria	2 000	282	660	525
Angola	330 000	46 530	108 900	86 625
Burkina Faso	400 000	56 400	132 000	105 000
Burundi	174 000	24 534	57 420	45 675
Cameroon	1 350 000	190 350	445 500	354 375
Cape Verde	12 500	1 763	4 125	3 281
Central Af. Rep.	90 000	12 690	29 700	23 625
Chad	315 000	44 415	103 950	82 688
Congo, DR	1 669 000	235 329	550 770	438 113
Congo, Rep.	450 000	63 450	148 500	118 125
Côte d'Ivoire	1 155 000	162 855	381 150	303 188
Djibouti	52	7	17	14
Egypt	15 668 300	2 209 230	5 170 539	4 112 929
Ethiopia	2 300 000	324 300	759 000	603 750
Gabon	176 000	24 816	58 080	46 200
Ghana	140 000	19 740	46 200	36 750
Kenya	4 750 000	669 750	1 567 500	1 246 875
Liberia	250 000	35 250	82 500	65 625
Madagascar	2 200 000	310 200	726 000	577 500
Malawi	2 000 000	282 000	660 000	525 000
Mali	300 000	42 300	99 000	78 750
Mauritius	5 500 000	775 500	1 815 000	1 443 750
Morocco	1 326 000	186 966	437 580	348 075
Mozambique	440 000	62 040	145 200	115 500
Niger	140 000	19 740	46 200	36 750
Nigeria	682 000	96 162	225 060	179 025
Rwanda	40 000	5 640	13 200	10 500
Réunion	1 930 000	272 130	636 900	506 625
Senegal	889 000	125 349	293 370	233 363
Sierra Leone	21 000	2 961	6 930	5 513
Somalia	220 000	31 020	72 600	57 750
South Africa	24 008 124	3 385 145	7 922 681	6 302 133
Sudan	4 981 781	702 431	1 643 988	1 307 718
Swaziland	4 436 000	625 476	1 463 880	1 164 450
Tanzania	1 355 000	191 055	447 150	355 688
Uganda	1 550 000	218 550	511 500	406 875
Zambia	1 600 000	225 600	528 000	420 000
Zimbabwe	4 227 500	596 078	1 395 075	1 109 719
Total	**87 078 257**	**12 278 034**	**28 735 825**	**22 858 042**

around 0.14 and upper ratios around 0.33, with 0.26 being the average (Koopmans and Koppejan, 1997). The tonnage potential is shown in Table 7.

Energy potential from bagasse using a calorific value of 7MJ/kg (Koopmans and Koppejan 1997) shows that the countries with the most potential with current levels of crop production are South Africa, Egypt, Mauritius, Sudan, Swaziland, Kenya and Zimbabwe. The energy potential is tabulated in Table 8.

Table 8: Sugar cane residues – energy potential (TJ)

	Lower	Upper	Average
Algeria	2	5	4
Angola	326	762	606
Burkina Faso	395	924	735
Burundi	172	402	320
Cameroon	1 332	3 119	2 481
Cape Verde	12	29	23
Central Af. Rep.	89	208	165
Chad	311	728	579
Congo, DR	1 647	3 855	3 067
Congo, Rep.	444	1 040	827
Côte d'Ivoire	1 140	2 668	2 122
Djibouti	0	0	0
Egypt	15 465	36 194	28 791
Ethiopia	2 270	5 313	4 226
Gabon	174	407	323
Ghana	138	323	257
Kenya	4 688	10 973	8 728
Liberia	247	578	459
Madagascar	2 171	5 082	4 043
Malawi	1 974	4 620	3 675
Mali	296	693	551
Mauritius	5 429	12 705	10 106
Morocco	1 309	3 063	2 437
Mozambique	434	1 016	809
Niger	138	323	257
Nigeria	673	1 575	1 253
Rwanda	39	92	74
Réunion	1 905	4 458	3 546
Senegal	877	2 054	1 634
Sierra Leone	21	49	39
Somalia	217	508	404
South Africa	23 696	55 459	44 115
Sudan	4 917	11 508	9 154
Swaziland	4 378	10 247	8 151
Tanzania	1 337	3 130	2 490
Uganda	1 530	3 581	2 848
Zambia	1 579	3 696	2 940
Zimbabwe	4 173	9 766	7 768
Total	**85 946**	**201 151**	**160 006**

3.2 Animal waste

As previously noted, animal wastes are used as fuels in many poorer countries. In general, dung is dried and then burned but some countries have invested in projects to build biodigesters to produce a useable gas from the wastes. India in particular has undertaken a major initiative to build digesters in many rural villages. Similar initiatives could be undertaken in Africa, although there are factors that will mitigate against major implementation. Biogas projects need a steady stream of (preferably wet) dung to function. Feedlots provide the most effective ways of collecting dung, while free-range will prove virtually impossible. Much of the livestock farming in Africa is free-range and collecting dung and moving it to the digesters will most likely prove to be unsuccessful.

Xuereb (1997) indicates that the biogas energy that can be produced annually from a single head of cattle is equivalent to that contained in 50 gallons of gasoline. The FAO animal data indicated a total of 222.9 million head of cattle in Africa. Using a factor of 130 MJ/gal and the total cattle population indicated above, the total potential is a staggering 1450 PJ of energy. This is equivalent to 11 billion gallons of gasoline.

Unfortunately, the practicality of wide scale utilisation of this resource in Africa is a major challenge.

4. Summary assessment of energy potential

The total potential available from crop residues in Africa has been shown in the analysis above. In general, woody biomass has a calorific value of around 14 MJ/kg. Two exceptions are bagasse which is 7 MJ/kg and coconut husks and shells, where the literature indicates a CV of about 18 MJ/kg. Applying these factors to the totals provides the results already indicated in Tables 2, 4, 6 and 8. These are large numbers. To place this energy potential into perspective the total final consumption of energy in South Africa in 2001 is estimated at 2362 PJ (IEA 2003). Using the average crop residues for Africa could thus potentially provide an amount of energy virtually equal to the South African final energy demand. An important caveat is that a significant percentage of the residues (80%) are field residues, and most of these are from maize stalks, which could be impossible to utilise in any effective manner. This is obvious from the information tabulated in Tables 4 and 9.

An adjustment for field residues left to enhance fertility, and that required for fodder, needs to be incorporated in the analysis. This will be specifically applicable to maize stalks and rice straw. A full agricultural analysis should be conducted to determine the optimal percentage of stalks and straw that can be removed without negatively affecting soil fertility, but this is beyond the scope of this macro study.

5. Conclusions and recommendations

This paper presents a very rough *estimate* of the potential of crop residues as an energy source in

Table 9: Crop residues – energy potential (PJ)

	Lower	*Higher*	*Average*
Coconut husks			11.51
Coconut shells			3.45
Maize cobs	121.31	521.63	228.15
Maize stalks	606.55	2244.22	1268.44
Rice husks	45.31	79.30	61.97
Rice straw	317.19	743.13	470.73
Bagasse	85.95	201.15	160.01
Total	**1176.31**	**3789.43**	**2204.26**

Africa. The exercise has been a purely mathematical evaluation of existing data. There are many shortcomings in the methodology, not least the quality of the crop data and the applicability of the ratios used to calculate the energy potential. It is well known that crop residues are indeed utilised in many countries. Of more practical concern is whether major exploitation of this resource is indeed feasible or whether it is currently taking place in an optimal manner. Quantification is, however, a very difficult exercise.

If the authors have, through this paper, raised awareness of the potential for crop residues amongst governments and other institutions, then some good may come of the exercise. It is suggested that governments review the analysis and determine for themselves whether there is merit in investigating the actual situation in their country. It may be appropriate to identify opportunities for improving technologies for utilising crop residues. This may, for example, be the development of appropriate briquetting systems for rice husks, or the review of options for biogas digesters in rural communities.

Further analyses of data on a country level are possible. Using the approach used in this evaluation will be relatively simple. However, delving deeper into the reality in each country will be costly and time consuming, particularly if accurate utilisation patterns are to be determined. A better approach may be to address government policy towards encouraging the planting of those crops and keeping methods for animal husbandry, which have the maximum potential to provide an energy source. An extension would be to assist rural communities through agricultural outreach programmes, and through making efficient equipment available as appropriate. This implies that appropriate policy measures are designed and implemented.

Ultimately, it will be up to individuals to implement measures to utilise this resource more effectively.

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