Recycling of Organic Waste for Energy and Smallholder Livelihood in The Gambia

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Basic Situation report

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Deliverable 2.2

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Content

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Executive summary

In the Gambia, according to the estimates shown in this report, the following agricultural residues were found accessible and available for briquetting: groundnut shells, maize cobs, coconut shells, sawdust, wood shavings and charcoal fines. The *annually* available amounts of these residues are 39,173 tonnes, 6,084 tonnes, 13.9 tonnes, 239 tonnes, 47 tonnes, and 1,884 tonnes, respectively.

The total residues potential is estimated at 83,088 tonnes, whereof 6,549 tonnes are already used. This means a total of 76,540 tonnes of available residues, representing 1,120 TJ. This amount of unused material emits 106,519 TCO_2eq in the atmosphere annually. Of this potential, 45,557 tonnes are accessible, representing a briquette production potential of 19,308 tonnes per year, with an energy content of 470 TJ. Emissions related to this briquette production are estimated at 69,151 T CO_2eq. The annually available charcoal fines amount has been estimated at 2,538 tonnes, of which 25.4 tonnes are used, so 2,512 tonnes are not used, representing 69 TJ. Charcoal fines do not degrade and therefore do not emit CO_2 due to their decomposition. The estimated quantity of charcoal fines available is 1,884 tonnes per year, equivalent to a potential briquette production of 2,077 tonnes per year (considering the binder proportion to be added). The energy content of these briquettes is 54 TJ. The total potential for briquette production from residues in The Gambia is therefore estimated at 21,385 tonnes annually.

Surveys conducted during the project established the average household size as 12.7 with only minor differences between Rural and Urban areas. Surveys also have shown that urban household use in average 1,55 kg Charcoal/day or 5,24 kg fire wood. The share of use is of 43% households using charcoal and 57% using firewood. Rural Households use in average 1,43 kg Charcoal/day or 4,7 kg fire wood. The share of use is of 15% Charcoal and 85% Firewood. These data combined with population statistics allow to calculate the amount of traditional fuel used both in rural & urban areas:

- Charcoal estimated total consumption:
    - 20 473 tonnes/year in urban areas
        - equivalent to 604 TJ/year
        - Responsible for 205 298/year TCO_2e emissions
    - 4 902 tonnes in rural areas.
        - equivalent to 145 TJ/year
        - Responsible for 49 158 TCO_2e emissions
- Firewood estimated total consumption:
    - 92 717 in urban areas
        - equivalent to 1 344 TJ
        - Responsible for 135 985 TCO_2e emissions
    - 90 573 in rural areas.
        - equivalent to 1 313 TJ
        - Responsible for 132 599 TCO_2e emissions
        -

Calculations suggest that charcoal (25,000 tonnes) represents only a minor share of the cumulative total of the domestic fuels used (209,000 tonnes). This proportion increases slightly when the energy content is considered, accounting for 750 TJ out of the 3,500 TJ consumed annually in the country as household fuel. But charcoal is responsible for nearly half of the GHG emissions associated with this sector (250,000 T CO_2eq compared to a total emission of 523,000 T CO_2eq). If briquettes substitute charcoal the emissions due to charcoal go down, emissions due to firewood remain the same, emission due to briquette production have to be taken into account, emission due to residues degradation go down. The reduction is about 140 413 TCO_2eyearly. This is a 22.3% reduction.

1 Introduction

It has been demonstrated that Solid Waste Management (SWM) is an important aspect in maintaining the public health in cities. Treatment and valorization of organic wastes (bio-waste) for carbon production could be one of the most promising options to stimulate waste collection. A variety of processes exist for converting biowaste to energy. Conversion of biomass into valuable liquids, gases and solids can be accomplished via biochemical (e.g., anaerobic digestion, enzymatic hydrolysis) and thermochemical (e.g. pyrolysis, torrefaction, gasification, and combustion) methods. The choice of conversion methods depends on the characteristics of the biomass (e.g., type, physiochemical properties and quantity), the desired form of the energy carrier, the end use requirements, the health and environmental standards, the economic conditions, and the project-specific factors

The use of biomass energy has many advantages, as it comes from familiar and affordable available resources, creates jobs, ensures diversification and energy security, and is deemed climate-friendly. Moreover, it has been shown that biomass energy is and will remain for the next decades the mainstay of domestic cooking in sub-Saharan Africa. In this context, the use of biomasses other than wood (ground nuts shells, coconut nuts shells, corn cobs, savanna straw, rice husk ...) is often proposed to produce substitutes for charcoal, in the form of briquettes. However, despite their many advantages (price, length of combustion, environmental sustainability, possibility of standardization ...) these fuels often fail to significantly substitute charcoal or firewood. Experience shows the implementation strategy is specific to each situation and must consider the opinions of users.

Against the aforementioned backdrop, CTCN launched a Technical Assistance intervention titled “Organic wastes for Energy and Smallholder livelihood” with a view to promoting agricultural production, energy supply and livelihood conditions in The Gambia. Its principal goal was to raise capacity in generating income through waste management of women’s groups, and to improve the waste management value and supply chain at scale. To this end, the project strives to provide short-term benefits at a pilot-scale, and longer-term benefits at local government area and potentially national scale. Direct beneficiaries of the technical assistance were more then be 225 women organized in women communities that have been trained in waste management and charcoal briquette making.

A briquette project is part of a social, economic and environmental reality.

The use of briquettes requires households to change their habits. In doing so, efforts are needed to learn to use the new fuel which, unlike what is often presented, is very different from the fuels to which households are used to (firewood and charcoal). The briquettes cooking behaviour often requires a change of cooking habits. To be agreeable to consumers, briquettes need to display properties comparable with established fuels – hence they need to contain charred material. For example, briquettes made of non-carbonised material have shown that they do not meet consumer expectations at all. Indeed, they are too powerful and lead to excessive fuel consumption. To be used they should be associated with very expensive stoves that are not available to households. It is therefore necessary to produce briquettes from carbonized material whose combustion behaviour is closer to the fuel already used by households.

The price at which the fuel will be sold is also very important. It depends on the combined cost of resource supply and production and competes with the cost of traditional fuels. Any fuel’s relative competitiveness must be gauged by the cooking efficiency it offers, i.e. the fuel cost of preparing a meal. Any fuel offered at a higher price than existing alternatives will struggle to find its market.

The fuels currently used (wood and charcoal) have an impact on the forest and the environment in general. In addition to contributing to deforestation, charcoal production likewise releases significant

quantities of GHG. Non-recovered residues, being prone to decomposition, equally cause GHG emissions.
These different aspects are interrelated and have implications at the national and regional levels. To assess the impact of a large-scale project, it is therefore necessary to know the initial situation. This is what this document aims to quantify:

- Household domestic fuels consumption habits: what are the used fuels types, in what quantity, what is the household average, what is the average meal size?
- The available resources: what resources (residues/waste) from agricultural or forestry, in what quantities, what availability, what accessibility... And what is the impact of these aspects on the raw material cost for briquette production?
- The waste recovery impact on traditional fuel consumption and the environment.

The here presented results, analysis and evaluation are based on data gained by the surveys implemented by Mr. Aruna Jobe, Njagga Touray & Pierre Cooley in the framework of this Technical assistance.

2 Baseline information

2.1 Energy cost in Banjul & Serrekunda

Surveys were conducted in Greater Banjul to identify the prices of the different energy carriers available and to compare them. Attention has been paid to traditional fuels: firewood and charcoal. This price was also compared to the sales price of briquettes produced prior to the Technical Assistance (TA).
Results of this first survey are shown in Table 1 and illustrated in Figure 1 & Figure 2. It clearly appears the price of so called "traditional fuel" i.e. charcoal and firewood is lower compared to conventional fuels (i.e. fossil fuels). When traditional fuel prices are compared to briquette sales prices (for briquettes produced prior to the TA), it appears briquettes has prices comparable to the most expensive traditional fuels. Its price is at the same level as the higher quality charcoal while not having its standard. This is probably a reason why briquettes were not sold at higher volume and was consequently one of the main aspects the present TA has worked to improve. The sale of traditional fuels is illustrated by Picture 1 to Picture 6.

Fuel	Packaging	Consummer	Mass (kg)	Price (Dalasi/kg)	PCI (MJ/kg)	Price (Dalasi/kWh)
Diesel	Pump	51	0,8	61	43,0	5,1
Pétrole	Bottle	30	0,7	42	43,0	3,5
Benzine	Pump	52	0,8	68	43,0	5,7
Gaz 3kg	Bottle	200	3,0	67	49,4	4,9
Gaz 6kg	Bottle	400	6,0	67	49,4	4,9
Gaz 12kg	Bottle	700	12,0	58	49,4	4,3
Electricity T1	Na	10	1,0	10	0,0	10,1
Charcoal Quality 1	Small bag	15	1,1	13,6	33,0	1,7
Charcoal Quality 2	Small bag	13	0,8	15,6	33,0	1,9
Charcoal Quality 3	Small bag	10	0,9	11,3	33,0	1,4
Charcoal bag (selling price)	Big bag (selling price)	250	24,8	10,1	33,0	1,3
Charcoal bag (buying price)	Big bag (buying price)	220	24,8	8,9	33,0	1,1
Firewood	Bundel	25	4,1	6,1	18,4	1,6
Briquette	Cup	13	1,0	13,4	29,3	2,1

Table 1: Fuel prices in Banjul & Serrekunda

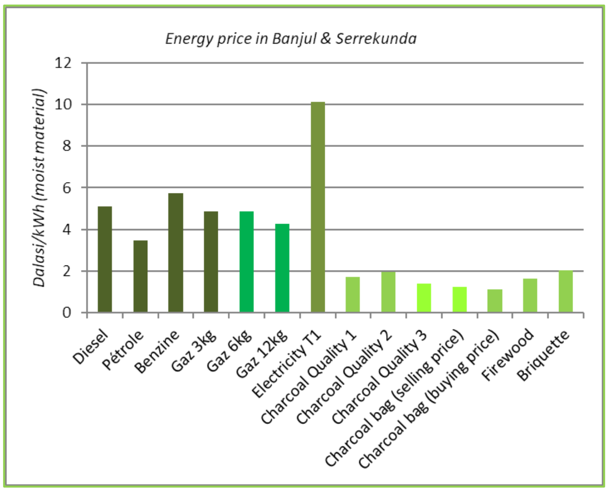

Figure 1: Energy price in Banjul & Serrekunda – fossil & traditional fuels prices (in Dalasi/ kWh) compared to briquette

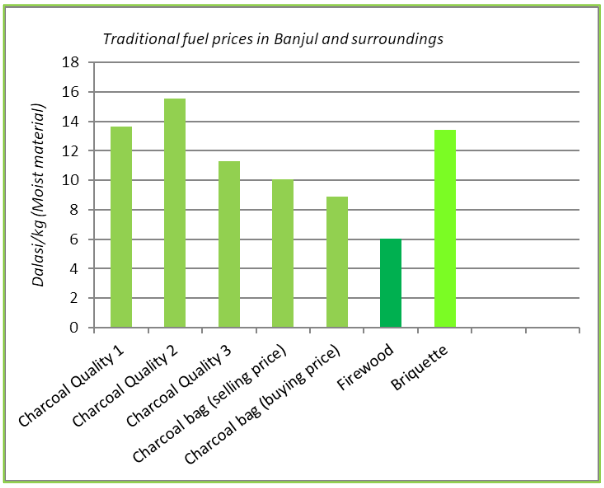

Figure 2: Traditional fuel price (in Dalasi/kg) compared to briquettes

Picture 1: Charcoal selling point

Picture 2: Fire Wood stock to be split into sticks

Picture 3: Fire Wood Sticks & Bundles for sale on Serrekunda Market

Picture 4: Fire Wood Sticks for sale on Serrekunda Market

Picture 5: Fire Wood Bundle for sale on Serrekunda Market

Picture 6: 3 charcoal qualities for sale on Serrekunda Market

2.2 Briquette production before TA

Prior to the TA, briquettes were produced by using the hammer & piston method. This was only the case for a few communities involved in WIG activities, before this CTCN TA. The productivity of this method was found to be very low: 2 kg/hour*worker (Picture 7, Picture 8 & Table 2). Indeed, press productivity measurements in Cameroon and in Madagascar have shown it is significantly higher, as compared to the hammer and piston method.

Picture 7: Hammer & piston briquette production technique - 1

Picture 8: Hammer & piston briquette production technique - 2

Production with piston & hammer								
Jour	Temps	Unit	N personnes	N Briquette	Mass	Unit	Mean Briquette mass	
Day 1	2	h	4	275	19,75	kg	71,8	
Day 2	2	h	4	171	12,75	kg	74,6	
Day 3	2	h	4	193	14,85	kg	76,9	
					Masse moyenne briquette		74,4	
					N briquette/kg		13,4	
					Prix (1 briquette = 1 DLS)		13,4	DLS/kg

Table 2: briquette productivity by hammer & piston system, mean mass and mean price

Picture 9: Open barrel pyrolysis (burning) technique

The carbonization yields of the techniques used prior to the CTCN Technical Assistance have likewise been evaluated. The technology consists of a large drum in which the material to be carbonized is ignited and then extinguished with water (Picture 4).

The obtained mass efficiency is 22.5% (see calculation file - Table 3).

Charcoal Mass	kg	27,7	N bois dans la charge	N	0,0	Currency Yield	60	1
Powder Mass	kg	0,0	Masse moyenne des bois humides	kg	#DIV/0!	Charcoal	DLS	€
Uncooked wood	kg	0,0	Masse moyenne des bois anhydres	kg	#DIV/0!	Charcoal bag price @ production	tbd	#VALEUR!
Charcoal Volatile Matter Content	%	22,2	N sac de charbon	N	3	Bag mass	tbd	
Charcoal Fixed Carbon Content	%	60,0	Masse moyenne des sacs	kg	9,2	Moisture content	tbd	
In -Load			In - Fuel			Anhydrous mass	#####	
Load Mass (M Cg h)	kg	133,2	Fuel mass (M Cb h)	kg	0,0	Charcoal mass/kg (€/kg)	#####	#VALEUR!
Load Moisture Content (H Cg)	%	15,0	Fuel moisture content(H Cb)	%	0,0	Wood		
Load GHV	MJ/kg	18,4	Fuel GCV	MJ/kg	18,4	Load price (wood+Transport)	tbd	#VALEUR!
Anhydrous Mass (M Cg a)	kg	113,2	Anhydrous Mass (M Cb a)	kg	0,0	Load Mass	tbd	
Ash Content	%	4,0	Ash Content	%	4,0	Moisture content	tbd	
Anhydrous Energy content (EN Cg a)	MJ	2083,7	Anhydrous Energy content (En Cb a)	MJ	0,0	Anhydrous mass	#####	
Effective Calorific value	MJ/kg	14,65	Effective Calorific value	MJ/kg	17,66	Wood price/kg (€/kg)	#####	#VALEUR!
Effective energy content (EN Cg h)	MJ	1952	Effective energy content (En Cb h)	MJ	0	Price ratio	#####	#VALEUR!
Out - Commercial charcoal			Out - fines & small charcoal particles			Out - Uncooked		
Charcoal Mass (M Ch h)	kg	27,7	Charcoal fines & small charcoal particles (M	kg	0,0	Uncooked mass (M I h)	kg	0,0
Charcoal Moisture content	%	8,0	Charcoal fines & small charcoal particles mo	%	5,0	Uncooked moisture content (H I)	%	10,0
Charcoal GHV	MJ/kg	29,3	GHV fines & small charcoal particles	MJ/kg	29,3	Uncooked GHV	MJ/kg	18,4
Anhydrous mass (M Ch a)	kg	25,5	Anhydrous mass (M R a)	kg	0,0	Anhydrous Mass(M I a)	kg	0,0
Ash content	%	17,8	Ash content	%	17,8	Ash content	%	4,0
Anhydrous Energy content (En Ch a)	MJ	746,3	Anhydrous Energy content (En R a)	MJ	0,0	Anhydrous Energy content (En I a)	MJ	0,0
Effective Calorific value	MJ/kg	21,96	Effective Calorific value	MJ/kg	22,75	Effective Calorific value	MJ/kg	15,65
Effective energy content (En Ch h)	MJ	608	Effective energy content (En R h)	MJ	0	Effective energy content (En I h)	MJ	0
Rendements de carbonisation								
Mass Yield	22,5		Effective energy yield	31,16		Commercial yield	22,5	
(M Cha + M R a) / (M Cga + M Cba - M Ia)			(En Ch h + En R h + En I h) / (En Cg h + En Cb h)			M Cha / (M Cga + M Cba - M Ia)		
Mass yield (without fuel)	22,5		Fuel percentage in total mass	0,00		Commercial yield (without fuel)	22,5	
(M Cha + M R a) / (M Cga - M Ia)			(M Cb a) / (M Cg a + M Cb a)			M Cha / (M Cga - M Ia)		
Moist Mass yield	20,8		Energy Yield based on GHV	35,81		Weigthed commercial yield	#####	
(M Cg h + M Cb h) / (M Ch h + M R h + M I h)			(En Ch a + En R ha+ En I a) / (En Cg a + En Cb a)			M Cha * Px Ch a / (M Cga + M Cba - M Ia) * Px Cg a		

Table 3: charred dust yield production for groundnut shells, coconut shells & mango leaves – tbd: to be determined

2.3 Wood Stoves & Fuel use comparison

Boiling water tests were carried out to evaluate the most suitable stove for briquettes and compare the latter with traditional fuels. To this end, the water evaporation efficiency was calculated. It indicates the energy efficiency, the amount of energy required to evaporate a given amount of water. The energy used is calculated based on the mass of fuel used and its estimated moisture.

2.3.1 Tested Stoves

Picture 10: 3 Stones

Picture 11: traditional charcoal cooking stove

Picture 12: Improved firewood cooking stove

Picture 13: Sakanal, improved cooking stove

Picture 14: Jambar, improved cooking stove

2.3.2 Tested Fuels

The different fuel/stoves combinations which were tested are presented in Table 21. Only fuels suitable for stoves were tested.

	Firewood	Charcoal	Briquettes
3 Stones	X		
Traditionnal Firewood Stoves	X		
Traditionnal Charcoal Stove		X	X
Sakanal	X	X	X
Jambar		X	X

Table 4: Tested stove-fuel combinations

2.3.3 Results

It is known that household performance tests are fraught with high variability, which is why it is generally recommended to practice many simultaneous repetitions. The number of repetitions performed here (see Table 6) is probably a little too low compared to best practices, but it gives an indication. A proper comparison of the efficiency of the improved stoves used is beyond the scope of this intervention.

Similarly, the amount of fuel, more precisely the amount of energy used, influences the result of this test. The stove comparison should preferably be made using the same amount of energy for each stove. In this case, the operator was not instructed about the amount of fuel to be used and she used the amount of fuel she found appropriate for each “fuel-stove” combination. The charcoal or firewood amount was weighed and recorded, but the results are probably less reliable than they would otherwise have been.

The first finding is that the evaporation efficiencies obtained during these tests are very similar regardless of the stove or fuel/stove combinations considered. It is therefore unlikely that these results will be significantly different.

According to these trials, the best results obtained with firewood are those of the traditional wood stove (21.2%), followed by the "3 stones" fireplace (17.9%) and finally the Sakanal used with firewood (15.7%). The latter is a mixed stove allowing the use of both firewood and charcoal (& briquettes). It seems however that its use with firewood is not optimal, as the generated fire flames are not directly in contact with the pan. This finding should be confirmed by other measurements.
The yields obtained with charcoal are 19.6% for Jambar, and 18.1% for both the traditional stove & Sakanal. The yields obtained with briquettes are generally equal for the three tested stoves. Consequently, no fireplace outperforms the others when used with briquettes, and it seems very likely that the traditional stove will be the most used.

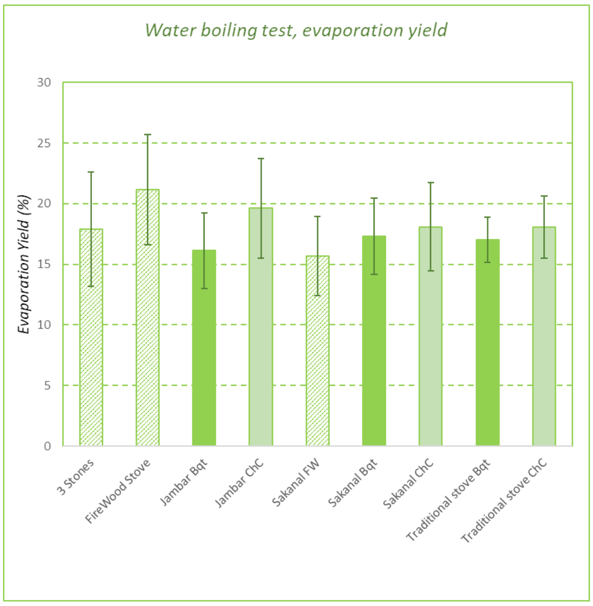

Figure 3: Water boiling test Yield, comparison of different stoves used with different fuels (fire wood - FW, charcoal - ChC, briquettes - Bqt)

Consequently, the water boiling test data from traditional stove (& 3 stones) were used to evaluate the fuel-requirements of briquettes and other fuels for evaporating one liter of water. Results are shown in Table 5. It follows that to evaporate 1 l of water, 1.1 kg of wood or 0.57 kg of charcoal or 0.84 kg of briquettes are necessary. In terms of mass, the amount of briquettes required is 149 % compared to charcoal, but only 73 % compared to firewood, all other parameters being equal. These findings may be used as corrective factors for cost-comparisons between different fuels available on the market.

Fuel needed to evaporate one 1 l water (kg)			
Fuel type	Mean	Std	Briquette ratio (%)
Firewood	1,1	0,45	73,4
Charcoal	0,57	0,04	148,8
Briquettes	0,84	0,10	100,0

Table 5: Firewood, Charcoal & Briquettes mass needed to evaporate 1 l water (mean values for traditional stoves & 3 Stones)

	Mean	Std	N
3 Stones	17,9	4,7	6
FireWood Stove	21,2	4,5	6
Jambar Bqt	16,1	3,1	9
Jambar ChC	19,6	4,1	7
Sakanal FW	15,7	3,2	6
Sakanal Bqt	17,3	3,1	5
Sakanal ChC	18,1	3,6	6
Traditional stove Bqt	17,0	1,9	6
Traditional stove ChC	18,1	2,6	5

Table 6: Water boiling test Yield, comparison of different stoves used with different fuels (fire wood - FW, charcoal - ChC, briquettes - Bqt) – Std, Standard deviation – N, Number of replication

2.4 Biomass resources

2.4.1 Residues availability

	Unit	Ground nuts	Maize	Mango...	Cashew nuts	Rice, paddy	Sorgho	Mils	Coco nut		Sawdust	Wood Shavir	Charcoal
2011	Tons/year	83858	23613	1300	2750	51136	20556	87234					
2012	Tons/year	119617	30106	1300	2800	54219	23146	116089					
2013	Tons/year	93862	33060	1358	2927	69704	30390	93799					
2014	Tons/year	80650	30289	1430	3060	46674	20289	76816					
2015	Tons/year	103081	35701	1441	3125	50187	25798	90174					
2016	Tons/year	109849	39467	1491	3094	59636	29372	101872					
Mean Value		98486	32039	1387	2959	55259	24925	94331			703	158	25375
Residues ratio	-	0,43	0,211	0,05	0,3	0,15	0,2	0,2			1	1	0,1
Residues amount	Tons/year	42349	6760	69	888	8289	4985	18866	21		703	158	2538
Share of used residues	%	7,5	10	7	10	10	5	5	33		66	70	1
Est share of accessible residues among unused	%	100	50	0	0	100	0	0	100		100	100	75
Share of unused residues	%	92,5	90,0	93,0	90,0	90,0	95,0	95,0	66,7		34,0	30,0	99,0
Amount of used residues	Tons/year	3176,2	676,0	4,9	88,8	828,9	249,3	943,3	6,9		464,0	110,6	25,4
Amount of unused residues	Tons/year	39173	6084	64	799	7460	4736	17923	14		239	47	2512
Amount of unused & accessibles residues	Tons/year	39173	3042	0	0	7460	0	0	13,9		239	47	1884
Est Amount of non accessible residues	Tons/year	0	3042	64	799	0	4736	17923	0		0	0	628
Est Amount of non accessible or used residues	Tons/year	3176	3718	69	888	829	4985	18866	7		464	111	653
Global Availability Share	%	93	45	0	0	90	0	0	67		34	30	74

Table 7: Average production of agricultural & forest residues – estimations based on Field measurements and questionnaires (wood & charcoal residues) and on FAO Stat yearly production surveys (agricultural residues)

The supply estimate of agricultural residues is based on data available from FAO Stat. - coconut shells being the sole exception, for which estimates are not included in this website and thus has to be based on field observations. Similarly, estimates of residues from wood- and charcoal production are based on field observations. These data are included in Table 7.

The available FAO stat data are about agricultural production. It is therefore necessary to apply a residue production ratio. The annual supply of agricultural residues can thus be estimated as 42,349 tonnes of groundnut shells, 6,760 tonnes of maize stalks, 69 tonnes of mango stalks, 888 tonnes of cashew nuts shells, 8,289 tonnes of rice husks, 4,985 tonnes of sorghum stalks, 18,866 tonnes of millet stalks and 21 tonnes of coconut husks.

Not all these residues are available, some are already used or inaccessible. Of the remainder, a certain portion is not suitable for briquette making. In order not to overestimate the actual available amount, additional corrective factors were applied. For example, it was estimated that 7,5% of peanut shells were already in use (chicken litter, compost, fuel, etc.), and their accessibility was estimated at 100%. The quantity available for briquette production is therefore 39,173 tonnes per year. Regarding mango pits, their accessibility was estimated to be nil due to their dispersion. For rice husks, it was estimated that they were fully accessible and 10% were used, but these residues are not of sufficient quality to be used for briquette production, so their potential was estimated to be zero. According to the estimates made, the following supplies were considered accessible <u>and</u> available: groundnut shell, maize cob, coconut shell, sawdust, wood chips and charcoal fines. The quantities of these residues available annually are estimated as 39,173 tonnes, 6,084 tonnes, 13.9 tonnes, 239 tonnes, 47 tonnes, and 1,884 tonnes, respectively.

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2.4.2 Groundnut shells specific case

A groundnut processing plant is located at Saro. This plant processes 35,000 tons of groundnuts annually. The groundnut shells are not currently used and are dumped on landfills, very close to the plant. Groundnuts are there sorted by women (gleaners) in order to recover the few seeds that production has allowed to pass.

Part of the shells is bagged and carted away on pick-ups to an unknown destination. Attempts to trace the use of the shells gave rise to some tensions.

At a meeting held in February, the plant manager stated an intention to recover shells for energy generation (scheduled to commence in 2018). However, no modification of the unit was in progress, and technical adjustments of this kind take a lot of time.

For a time, this resource was bought by Senegalese traders who allegedly use it in boilers (no more detail was obtained). An alternative explanation might be that shells are being used to feed livestock, which would likewise seem amazing because the shells' nutritional value is low. Maybe it's a bedding application. It was agreed to send a letter of request to the Director to authorize WIG to collect the shells. The current gleaners have no authorization. The letter has been sent but received no official answer.

Informally it was agreed that groundnut shells may be used with no restriction of amount. Ground nut shells, due to their huge potential, were foreseen as one of the major resources to be used by the project. Consequently, a solution had to be found to legally secure this supply. To this end, contacts have been made with the Ministry of Agriculture.

Picture 15: Saro groundnuts shells landfill

2.4.3 Waste around women groups locations

The women's groups survey aimed to assess the availability of resources in the neighbourhoods where the groups are located.

It appears that while the population can identify the various biomass-resources available, statements regarding their classification and quantity are far less reliable. Similarly, biomass-resources were found to be dispersed in almost every case, and the costs associated with their collection and transport to processing sites are hard to gauge. Due to the need for transport, related costs were found to impair the briquette value chain's economic viability. Moreover, more centralised resources are available.

2.4.4 Emissions due to biomass residues & briquettes production potential

	Unit	Ground nuts	Maize	Mango...	Cashew nuts	Rice, paddy	Sorgho	Mils	Coco nut		Sawdust	Wood Shavir	Charcoal
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Share of used residues	%	7,5	10	7	10	10	5	5	33		66	70	1
Est share of accessible resi	%	100	100	0	0	100	0	0	100		100	100	75
Share of unused residues	%	92,5	90,0	93,0	90,0	90,0	95,0	95,0	66,7		34,0	30,0	99,0
Amount of used residues	Tons/year	3176,2	676,0	4,9	88,8	828,9	249,3	943,3	6,9		464,0	110,6	25,4
Amount of unused residue	Tons/year	39173	6084	64	799	7460	4736	17923	14		239	47	2512
Amount of unused & acces	Tons/year	39173	6084	0	0	7460	0	0	13,9		239	47	1884
Est Amount of non accessil	Tons/year	0	0	64	799	0	4736	17923	0		0	0	628
Est Amount of non accessil	Tons/year	3176	676	69	888	829	4985	18866	7		464	111	653
Global Availability Share	%	93	90	0	0	90	0	0	67		34	30	74
Emissions due to Agricultural residues													
Unused residue amount	Tonnes/year	39173	6084	64	799	7460	4736	17923	14		239	47	2512
Est MC	%	15	12	15	15	10	12	12	25		35	35	5
Anhydrous Biomass	Tonnes/year	33297	5354	55	679	6714	4167	15772	10		155	31	2387
Est Carbon content	%	45	45	45	45	35	45	45	45		50	50	85
Est Carbon Mass	Tonnes/year	14984	2409	25	306	2350	1875	7097	5		78	15	2029
CO2/C ratio		3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67		3,67	3,67	3,67
Est CO2 Teq	Teq/year	54940	8834	90	1121	8616	6876	26024	17		285	56	0
Residues Energy content													
Considered GCV	MJ/kg	14,5	15,4	15	15	13,1	15,2	15,2	13,5		11	11	27,44
Est Energy Content	TJ/year	568,01	93,70	0,97	11,99	97,73	71,98	272,43	0,19		2,63	0,52	68,93
Solid biofuel potentiel													
Suitable for briquettes making		Yes	Yes	Yes	Yes	No	Probably	Probably	Yes		Probably	Yes	Yes
Production yield	%	40	30	30	30	NA	NA	NA	30		NA	30	100
Possible amount of brique	Tonnes/year	16453	1917	0	0	NA	NA	NA	4	0	NA	15	1978
Solid biofuel Energy content													
Considered ash content	%	10	8	8	4	60	10	10	8		2	2	7
Considered MC	%	5	5	5	5	5	5	5	5		5	5	5
GCV	MJ/kg	25,5	26	26	27	11,7	25	25	26		26	27	27,4
Energy content	TJ/year	420	50	NA	NA	NA	NA	NA	0,11		NA	0,40	54
Emissions due to Solid Biofuel transformation													
Anhydrous biomas at origi	Tonnes/year	33297	5354	55	679	6714	4167	15772	10		155	31	
Est Carbon content	%	45	45	45	45	45	45	45	45		45	45	
Est Carbon Mass at origin	Tonnes/year	14984	2409	25	306	3021	1875	7097	5		70	14	
Est fix charcoal fix carbon c	%	65	70	70	70	70	70	70	70		70	70	
Carbon Mass in charcoal	Tonnes/year	10694	1342	0	0				3			10	
Emitted C during carboniza	Tonnes/year	4289	1068	25	306				2			3	
Est CO2 proportion in carb	%	99	99	99	99	99	99	99	99		99	99	
Est CH4 proportion in carb	%	1	1	1	1	1	1	1	1		1	1	
C emitted Under CO2 form	Tonnes/year	4247	1057	24	303	0	0	0	2		0	3	
C emitted under CH4 form	Tonnes/year	43	11	0	3	0	0	0	0		0	0	
CO2/C ratio to Teq CO2		3,67	3,67	3,67	3,67	3,67	3,67	3,67	3,67		3,67	3,67	
CH4/C ratioto Teq CO2		102,67	102,67	102,67	102,67	102,67	102,67	102,67	102,67		102,67	102,67	
Téq CO2 due to CO2	Tonnes/year	15571	3876	90	1109	0	0	0	6		0	12	
Téq CO2 due to CH4	Tonnes/year	4404	1096	25	314	0	0	0	2		0	4	
Téq CO2 due to carbonisati	Tonnes/year	19974	4972	115	1423	0	0	0	8		0	16	
Téqu CO2 due to briquette	Tonnes/year	39212	4919	0	0	0	0	0	11		0	38	
Téqu CO2 due to charcoal c	Tonnes/year	59187	9891	0	0	NA	NA	NA	19		NA	54	0

Table 8: Available residues – Estimation of the current related emissions and calculation of the briquette production potential

	Total	Charcoal fines	Unit
Residues amount	83088	2538	Tonnes/year
Amount of Used residues	6548,8	25,4	Tonnes/year
Unused residue amount	76540	2512	Tonnes/year
Energy content of unused residues	1120	69	TJ/year
Est CO2 Teq from unused residues	106519	0	Téq CO2
Amount of unused & accessibles residues	53017	1884	Tonnes/year
Amount of used & non accessible residues	30071	653	Tonnes/year
Briquetting potentiel	19308	2077	Tonnes/year
Briquettes Energy content	470	54	TJ/year
Emissions due to briquette production	69151	0	Téq CO2
Briquettes production potential		21385	Tonnes/year

Table 9: Summary of residues availability for briquetting and current GHG emission of these

Table 8 further elaborates the figures presented in Table 7, and illustrates the approach used to estimate the energy-content of the various residues as well as the amount of briquettes that may be produced from the respective resources. CO_2 emissions related to the disposal of residues under current conditions were also estimated. These emissions were then compared to corresponding estimates, assuming the transformation of available residues into fuel briquettes. It must be noted that briquette production likewise generates emissions.

Table 9 summarizes the most important values from Table 8. Estimates related to briquette production from non-carbonised residues must be treated differently from briquettes produced from charcoal fines. Thus, the total of non-carbonized residues is estimated at 83,088 tonnes, of which 6,549 tonnes are already used. This means a total of 76,540 tonnes of available residues, representing 1,120 TJ of thermal energy. This amount of unused material releases 106,519 T CO2eq into the atmosphere annually. Of the total potential, 53,017 tonnes are accessible (including 7,460 tonnes rice husks), representing a briquette production potential of 19,308 tonnes per year (with an energy content of 470 TJ). Emissions related to this briquette production are estimated at 69,151 T CO2eq. The annually available charcoal fines amount has been estimated at 2,538 tonnes, of which 25.4 tonnes are used – leaving a potential 2,512 tonnes (equivalent to 69 TJ). Charcoal fines do not degrade and therefore do not emit CO_2 due to their decomposition. The estimated quantity of charcoal fines available is 1,884 tonnes per year, representing a potential briquette production of 2,077 tonnes annually (considering the binder proportion to be added). The energy content of these briquettes is 54 TJ.

The total potential for briquette production from residues in The Gambia is therefore estimated at 21,385 tonnes per year.

3 Fuel consumption

3.1 Surveys

Surveys have been conducted to assess the household fuel consumption. During these surveys, questions were asked about the users and their households' characteristics, size of women's groups, number of persons interviewed, number of persons per household as well as the availability of resources around the group location and consumption habits.

Information gathered during the mission identified the main fuels in the Gambia and the form in which they are sold. Charcoal can be sold in cups or bags. Firewood can be sold as sticks, bundles or cart-loads. Gas is to be had in either 3.6 or 12 kg Bottles. Briquettes can be sold individually, in pots or in bags.

For each of these fuels, test participants were asked to indicate the consumed amounts and related costs. Some estimates had to be made in order to account for the masses of the forms in which fuels are sold..

Based on the elements discussed in section 2, a database was established. It is available in Excel format. The main results of his analysis are presented in section 3.2.

3.2 Data based analysis

3.2.1 Gambian population

Study of the Gambian Office for Statistic gives the following figures:

- Total population 1 857 181
- Urban Population: 1 073 827 (57,8%)
- Rural Population 783 354 (42,2 %)

3.2.2 Share of rural and urban households

Surveys conducted during the project established the average household size as 12.7 with only minor differences between Rural and Urban areas. Households were found to use one single fuel-type instead of several. Based on the population share between rural and urban areas, this allows to estimate the following share of households:

- 84,590 households in Urban areas
- 62,140 households in Rural areas

3.2.3 Households fuels consumption

The surveys allowed the TA to estimate the average characteristics of Gambian household regarding traditional fuels. Results are shown in Table 10. Accordingly, urban households on average consume 1.55 kg Charcoal/day or 5.24 kg fire wood. 43% households were found to use charcoal, whereas 57% use firewood. Rural households display more parsimonious use of wood-based fuels, with average shares 1.43 kg Charcoal/day versus 4.7 kg firewood. Overall, 15% of households were found to use charcoal while 85% stick to firewood.

These data combined with population figures and the relative shares of rural and urban households enable calculations of the amount of traditional fuels consumed both in rural & urban areas:

- Charcoal estimated total consumption: 20,473 tonnes in urban areas and et 4,902 tonnes in rural areas.
- Firewood estimated total consumption: 92,717 tonnes in urban areas and 90,573 tonnes in rural areas.

It appears that the total firewood consumption is equivalent in urban and rural areas. But, the total consumption of charcoal is much higher in urban areas than in rural areas.

The Gambian charcoal total consumption is estimated at 25,375 tonnes annually, whereas the firewood consumption was shown to stand at 183,291 tonnes, annually.

Traditionnal fuel consumption estimation		
		Unit
Urban		
Share of charcoal users	43	%
Share of Firewood users	57	%
Avearge Charcoal Consumption	1,55	kg/day*household
Average fire wood consumption	5,24	kg/day*household
Est. total Charcoal Consumption	56091	kg/day
Est. total Charcoal Consumption	20473	Tonnes/year
Est. Total FW Consumption	254020	kg/day
Est. Total FW Consumption	92717	Tonnes/year
Rural		
Share of charcoal users	15	%
Share of Firewood users	85	%
Avearge Charcoal Consumption	1,43	kg/day*household
Average fire wood consumption	4,70	kg/day*household
Est. total Charcoal Consumption	13431	kg/day
Est. total Charcoal Consumption	4902	Tonnes/year
Est. Total FW Consumption	248146	kg/day
Est. Total FW Consumption	90573	Tonnes/year
Total consumption		
Total consumption Charcoal	69522	kg/day
	25375	Tonnes/year
Total consumption FW	502166	kg/day
	183291	Tonnes/year

Table 10: traditional fuel consumption estimation

3.2.4 GHG emissions due to traditional fuel production & consumption

Table 11 shows how the energy equivalent of the used fuel masses was calculated. The calculation method related to the production and consumption of these fuels is also presented.

Resulting values are summarized in Table 21. For the energy content estimate it was presumed that the calorific value of wood, considering its estimated moisture content, is 14.5 GJ/tonne and that the calorific value of charcoal is 29.5 GJ/tonne. The energy conversion has been made based on the wet calorific value considering MC of 5% for the charcoal and 20% for firewood. Estimation of GHG have considered the methane emission of the charcoal production and the major impact of this gas on the greenhouse effect (28 times the CO_2 effect).

Emission due to traditionnal fuels production & use (burning)				
		Firewood		
	Unit	Urban	Rural	Total
Fire wood mass	Tonnes/year	92717	90573	183291
Est MC	%	20	20	20
Anhydrous wood	Tonnes/year	74174	72459	146632
Est Carbon content	%	50	50	50
Est Carbon Mass	Tonnes/year	37087	36229	73316
CO2/C ratio		3,67	3,66	3,66
Est CO2 Teq	Teq/year	135985	132599	268337
		Charcoal		
	Unit	Urban	Rural	Total
Charcoal mass	Tonnes/year	20473	4902	25375
Est MC	%	5	5	5
Anhydrous wood	Tonnes/year	19450	4657	24107
Est carbonisation yield	%	20	20	20
Anhydrous wood at origin	Tonnes/year	97248	23286	120533
Est Carbon content	%	50	50	50
Est Carbon Mass at origin	Tonnes/year	48624	11643	60267
Est fix charcoal fix carbon content	%	85	85	85
Carbon Mass in charcoal	Tonnes/year	16532	3959	20491
Emitted C during carbonization	Tonnes/year	32092	7684	39776
Est CO2 proportion in carbonisatior	%	97,5	97,5	97,5
Est CH4 proportion in carbonisatior	%	2,5	2,5	2,5
C emitted Under CO2 form	Tonnes/year	31289	7492	38782
C emitted under CH4 form	Tonnes/year	802	192	994
CO2/C ratio to Teq CO2		3,67	3,67	3,67
CH4/C ratioto Teq CO2		37,33	37,33	37,33
Téq CO2 due to CO2	Tonnes/year	114728	27471	142199
Téq CO2 due to CH4	Tonnes/year	29952	7172	37124
Téq CO2 due to carbonisation	Tonnes/year	144681	34643	179324
Téqu CO2 due to charcoal burning f	Tonnes/year	60618	14515	75133
Téqu CO2 due to charcoal consump	Tonnes/year	205298	49158	254456
		Charcoal & Firewood together		
Téqu CO2 due to FW & charcoal cor	Tonnes/year	341284	181757	522794

Table 11: Firewood and charcoal use in mass, energy equivalent and related emissions calculation for urban and rural areas

Thus, the 92,717 tonnes of fuelwood used in urban areas are equivalent to 1,344 TJ and emit 135,985 T CO2eq over the course of their production and consumption. The 90,573 tonnes of fuelwood consumed in rural areas are equivalent to 1,313 TJ and emit 132,599 T CO2eq over their entire life-cycle. The 20,473 tonnes of charcoal consumed in rural areas are equivalent to 604 TJ and emit 205,298 T CO2e during their production and consumption. The 4,902 tonnes of charcoal consumed in rural areas are equivalent to 145 TJ and emit 49,158 T CO2e during their production and consumption. In total, domestic fuel consumption in The Gambia represents 3,406 TJ (3.4 PJ) and is responsible for the emission of 523,041 CO_2.

These different figures are illustrated in Figure 4 to Figure 6, suggesting that charcoal is only a small share of the mass of the domestic fuels used, about 25,000 tonnes out of 209,000 tonnes. This proportion is slightly higher when the energy content is considered: 750 TJ out of the 3,500 TJ consumed annually in the country in terms of domestic fuels. But charcoal is responsible for nearly half of the GHG emissions associated with this sector (250,000 T CO2eq compared to a total emission of 523 000 T CO2eq).

Estimated Woodfuels consumption in the Gambia (Tonnes/year)		
FW Urban	92717	
FW Rural	90573	
Charcoal Urban	20473	
Charcoal Rural	4902	
Estimated woodfuels energy used in the Gambia		Moist GCV (GJ/tonne)
FW Urban	1344	14,5
FW Rural	1313	14,5
Charcoal Urban	604	29,5
Charcoal Rural	145	29,5
Total	3406	Tj
	3	PJ
Estimated Teq CO2/year due from Woodfuels consumption		
FW Urban	135985	
FW Rural	132599	
Charcoal Urban	205298	
Charcoal Rural	49158	
Total	523041	

Table 12:Summary of wood fuels (wood & charcoal) consumption (in mass & in Energy) & related GHG emission

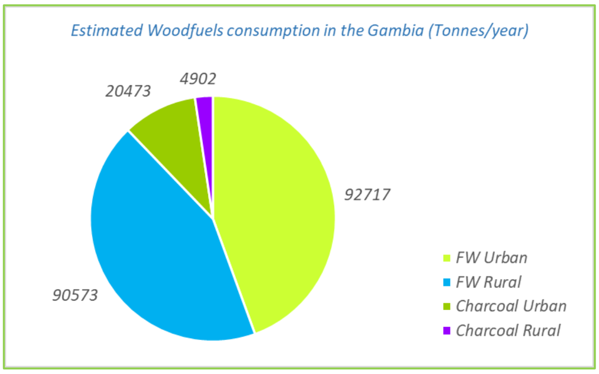

Figure 4: Estimated mass of wood fuels consumption in the Gambia (Tones/year)

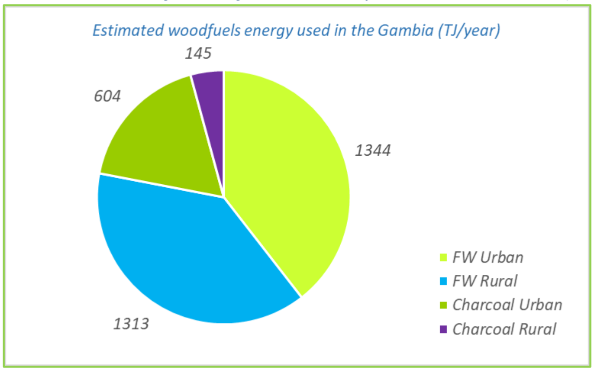

Figure 5: Estimated Energy content of wood fuels consumption in the Gambia (TJ/year)

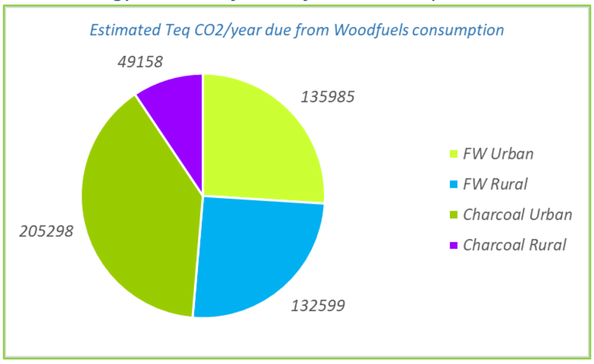

Figure 6: Estimated GHG emissions due to wood fuels consumption in the Gambia (TCO2e)

4 Balance between current situation and briquettes use instead of urban charcoal

Table 13 compares emissions related to the current state of affairs ("current situation") and a projection assuming the use 21,385 tonnes of briquettes produced from the identified residue potential ("Urban charcoal substitution"). This briquette amount could replace 14,444 tonnes of charcoal in urban areas (considering the conversion factor – replacing one 1 kg charcoal requires 1.48 kg briquettes) which would lead to a reduction of 71% of the urban charcoal consumption, or 57% of the national charcoal consumption.

Current situation			Consumption	
	Urban	Rural	Total	Unit
Charcoal	20473	4902	25375	Tonnes/year
Firewood	92717	90573	183291	Tonnes/year
Briquette	0	0	0	Tonnes/year
Residues (unused)	-	-	76540	Tonnes/year
Charcoal fines	-	-	2512	Tonnes/year
Urban charcoal substitution			**Consumption**	
	Urban	Rural	Total	Unit
Charcoal	6024	4902	10926	Tonnes/year
Firewood	92717	90573	183291	Tonnes/year
Briquette	21385	0	21385	Tonnes/year
Residues (used or non accessible)			30071	Tonnes/year
Charcoal fines			653	Tonnes/year

Table 13: Fuel consumption (mass) for the current situation and a scenario which includes the of briquettes in substitution to urban charcoal

Table 14 calculates current GHG emission levels (including charcoal production & consumption, FW production & consumption, decomposition of organic residues). Charcoal fines are considered as a non-emitting material (almost no degradation). When briquettes are used as a substitute for charcoal, they reduce emissions from charcoal production and use. Emissions from the use of fuelwood are not affected. However, emissions from briquette production and the reduction of emissions from the degradation of agricultural residues (part of which is used to produce briquettes) must be considered. The total reduction would amount to 140,413 T CO2eq annually, equivalent to 22.3%. Corresponding values may be gleaned from Figure 7 and Figure 8. The values likewise show that the use of 1 ton briquettes would help avoid the emission of 6.5 T CO2eq.

GHG Emissions	Current situation	Urban charcoal substitution
Charcoal	254456	109563
Firewood	268585	268585
Briquette	0	69151
Residues (unused)	106519	41849
Charcoal fines	0	0
Somme	629560	489148
	Teq CO2	%
Difference	140413	22,3

Table 14: GHG emissions related to the current situation and a scenario which includes the of briquettes in substitution to urban charcoal

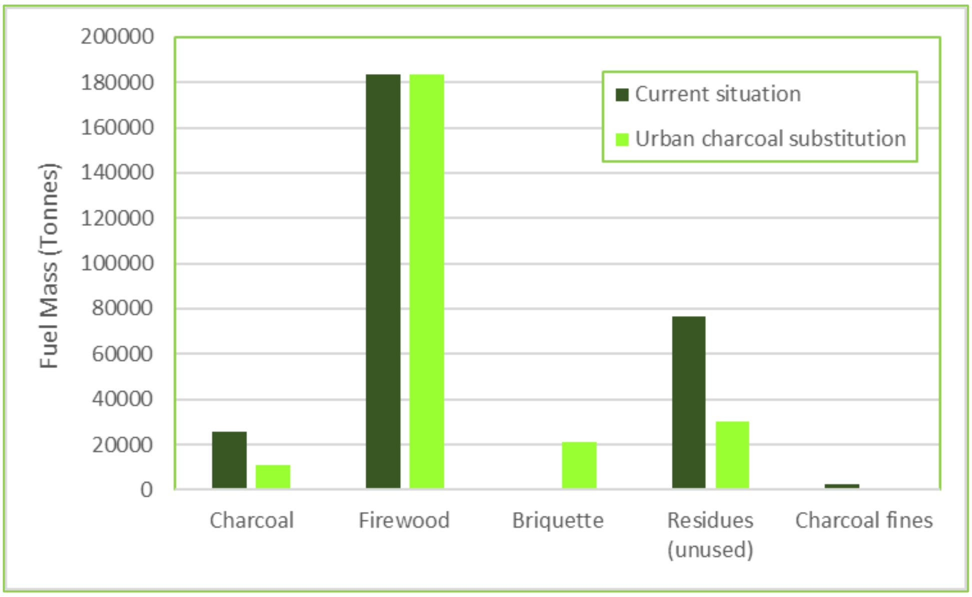

Figure 7: Fuel consumption (mass) for the current situation and a scenario which includes the of briquettes in substitution to urban charcoal

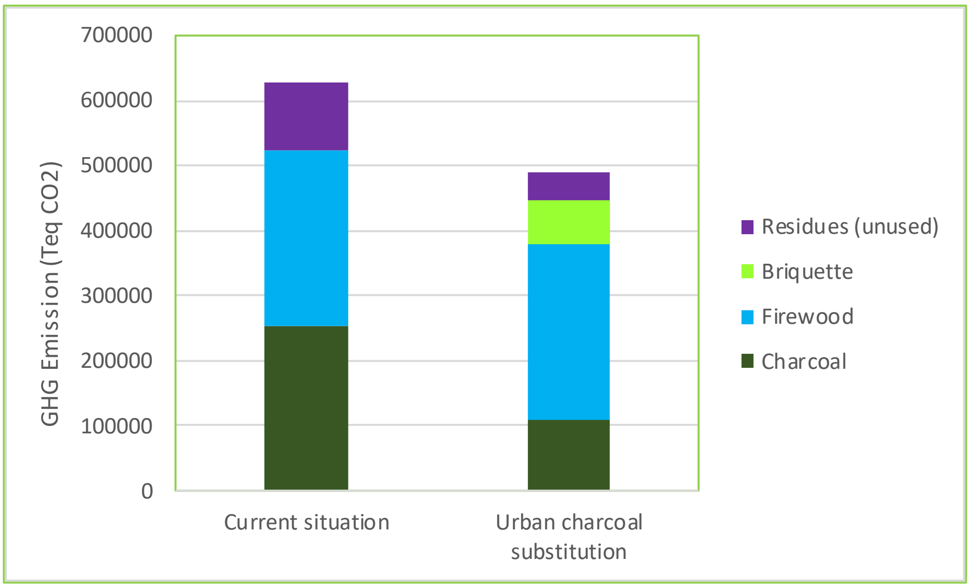

Figure 8: GHG emissions related to the current situation and a scenario which includes the of briquettes in substitution to urban charcoal

5 Annex 1: Basic situation questionnaire for fuel consumption

Study on waste management situation in the Gambia with focus on potential Biofuels, 2018, Njagga Touray, Jainaba Sanneh, Malanding

Report provided in a separate document

5 Annex 2: Basic situation questionnaire for fuel consumption

The Gambia Natural (Forest) Resource assessment study, Pierre Colley

Report provided in a separate document

5 Annex 3: Basic situation questionnaire for fuel consumption

Date			If already briquette user, opinion about briquettes in comparison to charcoal							
Women group number			/hat are briquettes used for (all cooking or only Ataya or Thiouray							
Group Name										
Location										
Number of members			Opinion on briquettes compared to charcoal							
New group yes/No										
Estimated distance from Brikama										
Estimated distance from WIG										
Available resource	linked to a mapp & take pictures									
						Very Dry/middle dry/wet				
		location	distance fror	Amount	Unit	Drying stage	Cost for tran	Unit	Prices	
1	Coco nut shells							Dls/		Dls/
2	Groundnut shells							Dls/		Dls/
3	Charcoal fines							Dls/		Dls/
4	Sawdust							Dls/		Dls/
5	Sawmill residues							Dls/		Dls/
6	Small branches							Dls/		Dls/
7	corn cobs							Dls/		Dls/
8	Mango pits							Dls/		Dls/
9	Fish meals							Dls/		Dls/
10	Others, specify							Dls/		Dls/
Charpowder numbers	5,75 Dls/kg	or	0,43	Dls/Bqt						
Starch	2,4 Dls/kg briquette	or	0,17	Dls/Bqt	Interest in bying charpowder			YES	NO	
Total production costs at WG	8,1 dls/kg Not per cup	or	0,6	Dls/Bqt						
1 kg	13,5 briquettes									

Women name							
Number of poeple in the household							
Fuel use	Example	Amount	period of use	Unit	Cost		Stove
Charcoal	Cups					Dls/cup	
	Bags					Dls/bag	
	Other:						
Firewood	Sticks					Dls/stick	
	Bundles						
	Other:						
Gaz	3 kg					Dls/bottel	
	6 kg					Dls/bottel	
	12 kg					Dls/bottel	
	Other:						
Briquette	Briquette unit					Dls/unit	
	Cups					Dls/cup	
	Bags					Dls/bags	
	Other:						
Others							
Sawdust	Bags					Dls/bag	Bag weigth
Comments							

Fuel consumption survey, Data collection at individual women