Ministry of Foreign Affairs

Study opportunities for circular use of agricultural residues in Benin

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Study opportunities for circular use of agricultural residues in Benin

Final Report

Contract details

Netherlands Enterprise Agency (RVO)

Study opportunities for circular use of agricultural residues in Benin (Ref IUC: 202205079/ PST22BJ02)

Presented by

Trinomics B.V.

Westersingel 34

3014 GS Rotterdam

The Netherlands

Contact person

Chris Whyte

T: +27 824158138

E: chris.whyte@acenfoundation.org

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In association with:

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1 Executive summary

The Netherlands Enterprise Agency (RVO) appointed Trinomics in July 2022 to study opportunities for circular use of agricultural residues in Benin, which Trinomics has done in association with local consultants in Benin and in close discussions with the International Fertilizer Development Center (IFDC) project on Communal Approach to the Agricultural Market in Benin (ACMA); kindly facilitated through the Embassy of the Kingdom of the Netherlands (EKN) in Benin.

Essentially the study focussed on understanding the potential availability of agricultural residues in the current ACMA focus areas to address circular economy opportunities that could maximise benefits to the region and the beneficiaries in these areas. These are not direct measurements, but an extrapolation from available information on agricultural activities with an extension decided upon by the study team to do an additional rapid assessment of other available organic residues that could serve as supplementary feedstocks to technical applications. A database was developed of potential Dutch technology providers who were contacted to assess their appetite in future participation in project development using residues and was complemented by the study team's own technology divisions in the circular agriculture sector.

Five of the most suitable circular project opportunities were selected to undertake a rapid financial feasibility assessment such as to illustrate the potential application and projected return on investment. More than a million tons per annum of available residues identified in the region could unlock multiple investment and project opportunities of different types and specifically resolving key issues in Benin such as access to clean energy and reducing imports of expensive synthetic fertilizers. The results of this analysis show the clear potential of these applications for the region with recommendations to follow some of these through to implementation.

2 Introduction

2.1 The project and its aims

In the context of rising global and national ambitions to consume and produce more sustainably, the circular economy offers a solution to mitigate negative impacts of climate change and to create sound and sustainable economic development across multiple diverse sectors in any region. This study aims to support Benin in its ambition to exploit the potential related to the circular economy in the agricultural sector, and specifically with a focus on the problematic area of agricultural residues.

Through a comprehensive inventory assessment of material flows, circular practices and relevant national regulation combined with the analysis of best practices, this study will develop concrete business opportunities for Beninese and Dutch stakeholders with the highest potential to enhance circularity in the ACMA supported agricultural value chains. The aim is not to replicate any of the interventions of the ACMA project developments, but rather to build on the work that has been done in-country addressing agricultural residues for future circular economic applications that have multiple benefits and sustainable outcomes for local stakeholders.

The promotion of the circular economy does not yet appear directly in the priorities of the Beninese Government, which is currently in charge of many ongoing or future projects. However, Benin is part of the international efforts and multilateral agreements related to achieving the Sustainable Development Goals, Climate Change and Biodiversity. In the field of agriculture in particular, extensive reforms are underway through the National Programme for the Development of Plantations and Field Crops and the development of value chains. This vision for the development of the agricultural sector is coupled with a desire to support the private sector through improving competitiveness and youth entrepreneurship and introducing specific measures to encourage research and innovation. Overall, Benin aims to move forward in making its economy more resilient, sustainable, and circular, placing innovative initiatives, particularly in favour of the agricultural sector and the environment, as priority in the country's strategy.

The exact aim of this project is to assimilate and digest all information available pertaining to agricultural residues in the region and suggest specific circular outcomes, through technology and practices, that maximise the value back into the sector following circular and regenerative principles. Following several years of implementation with ACMA2, a key outcome is the development of flagship projects, including all stakeholders, farmers, and processors, to improve productivity and sustainability.

2.2 Methodology

The assignment was structured into the following phases:

1. An analysis of the current waste streams and current applications of these streams in the ACMA supported value chains;
2. The identification of opportunities to promote circularity in the ACMA supported value chains; and
3. A feasibility study for the development of waste recovery pilots.

Importantly, the development of this project has been based on the outcomes of the first two phases and is aligned with the 3rd phase of the ACMA project. The methodology followed during each of these steps is detailed below.

The analysis of the current waste streams and current applications of these streams in the ACMA supported value chains has been undertaken via an extensive desk research and some interviews to complement published information. The following steps were followed:

- Developing an inventory of organic/agricultural waste streams, based on the outcomes of the ACMA2 study and the Quick Scan.
- Identifying activities for recovering the waste streams that are currently applied and/or those that are being developed. Here, a small number of interviews with farmers, food processing firms and waste operators has been undertaken to complement the desk research. This includes inputs from 30 producers across different crop types, 13 breeders (beef, goats, and poultry) and 9 crop processors.
- Undertaking an inventory of national regulations on the use of waste from agri-food activities.

The identification of opportunities to promote circularity in the ACMA supported value chains rested on desk research and targeted interviews to fill in the main knowledge gaps identified. This part of the analysis has been broken down into the following activities:

- Identifying circular best practices that can be applied at various stages in the ACMA supported agricultural value chains.
- Identifying opportunities and activities to promote circularity in the ACMA value chains in the fields of recycling and industrial symbiosis.
- Contacting relevant Dutch expertise and technologies in the identified opportunities to gather knowledge on the applicability and cost of their technology in Benin. In total, five Dutch technology providers were interviewed from the following organisations: EV Biotech, Rabobank, SkyNRG, Waste Transformers and TNO.[1]
- Stemming from the previous steps, business cases were developed.

A broad feasibility study has also been undertaken for the development of waste recovery pilots, including the evaluation of technical, economical as well as socio-economic conditions.

2.3 Structure of this report

This report is structured in two main sections: (1) the analysis of current waste streams and current uses of these streams in ACMA2-supported value chains; and (2) the identification of opportunities to promote circular practices in ACMA-supported value chains. This latter section also includes five business cases and recommendations on activities for ACMA3.

[1] However, Waste Transformers have not yet provided relevant financial information.

3 Analysis of current waste streams and current uses of these streams in ACMA supported value chains

3.1 Organic/agricultural waste streams and recovery options for ACMA intervention areas

3.1.1 Identification of key crops produced in the ACMA intervention zones

The national production dataset (Directorate of Agriculture Statistics of the Beninese Ministry of Agriculture, Livestock and Fisheries) provides information on crops production by department and by commune. The present study analysed results from 2015 to 2021 in the ACMA2 (Plateau, Ouémé) and ACMA 3 (Borgou, Donga, Collines) zones of intervention.

Cereals, tubers, pulses, vegetables, cashew, palm oil and pineapple have been considered in this study. The ACMA intervention zones (IZ) can be considered as the country attic for several crops like cereals, tubers and pulses. For instance, 48% of the national production of maize is harvested in those zones, with Borgou and Plateau combined representing 29%. In addition, ACMA IZ encompass 62% of groundnut production (mainly in Collines and Zou), 66% of Cassava (mainly in Collines and plateau), 65% of soya beans (mainly in Borgou) and 82% of the cashew nut production (with only 3 ACMA departments e.g., Borgou, Collines and Donga representing 75% of the national cashew nut production in these study areas). Cassava is the main crop harvested in the intervention zones (IZ) (2,6 million tons/year on average since 2015), followed by yam (2,4 millions tons/year), maize (712,000 tons/year), and soya beans (124,000 tons/year). The Plateau and Collines departments are the main cassava producers, with a combined production of 1,8 million t/year. Maize is produced in all 6 departments, Borgou and Plateau alone reaching 425,000 t/year (for a visual representation of the geographic spread of maize production, see Figure 3-1[2]). Yam, soya beans and sorghum are the Borgou flagship products with half or more of the IZ tonnage. Groundnuts production amounts to 43,000 t/year and 26,000 t/year in the Collines and Zou departments, respectively. Cashew nuts are mainly harvested in the north part of the IZ with Borgou, Donga and Collines totalizing 76,000 t/year. Over the ACMA region, rice is primarily produced in the Collines department with an average of 46,000 t/year. A visual representation of the geographic spread of tubers production is shown in Figure 3-2. The distribution of ground nuts, pulses (cowpea, bambara groundnut, pigeon peas) and rice production is presented in Figure 3-3 and Figure 3-4.

The country has a dynamic palm oil sector covering 710,000 hectares,[3] with a South to North gradient. Oueme-Plateau is a leader region for palm oil plantations. Due to the lack of reliable statistics, it is difficult to accurately evaluate palm oil production in Benin. A 2016 evaluation communicated by the Ministry of Agriculture, Livestock and Fisheries[4], stated that 319,500 tons had been produced in the country that year. The mean yield number published in 2013 was 5,95 tons/ha, but one should be cautious in extrapolation based on the national cultivated areas due to a non-Gaussian distribution of yields (different agricultural techniques, from natural plantations to industrial agriculture). In 2015, the National Institute of Statistics and Economical Analysis[5] published that Benin had produced only 75,000 tons of palm oil, a number that has to be taken with caution knowing that the national areas dedicated to palm tree production are evaluated at several hundred thousand hectares.

[2] National Directorate of Agricultural Statistics, General Secretariat of the Ministry, Ministry of Agriculture, Livestock and Fisheries
[3] Rapport de faisabilité de développement de la filière palmier à huile au Bénin. March 2020. MAEP
[4] Plan Stratégique de Relance du Secteur Agricole 2016 – DSA-MAEP
[5] https://instad.bj/

Figure 3-1 Maize production in ACMA regions, averages from 2015 to 2021 (in tons/year)

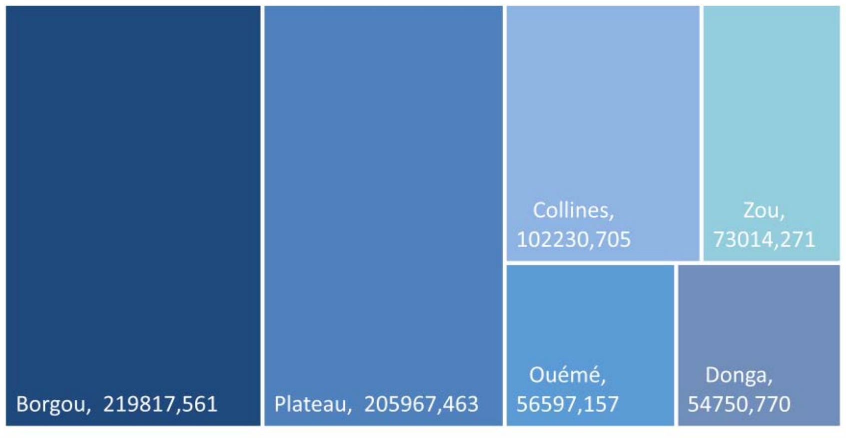


Figure 3-2 Tubers (cassava, yam and sweet potatoes) production in ACMA regions, averages from 2015 to 2021 (in tons/year)

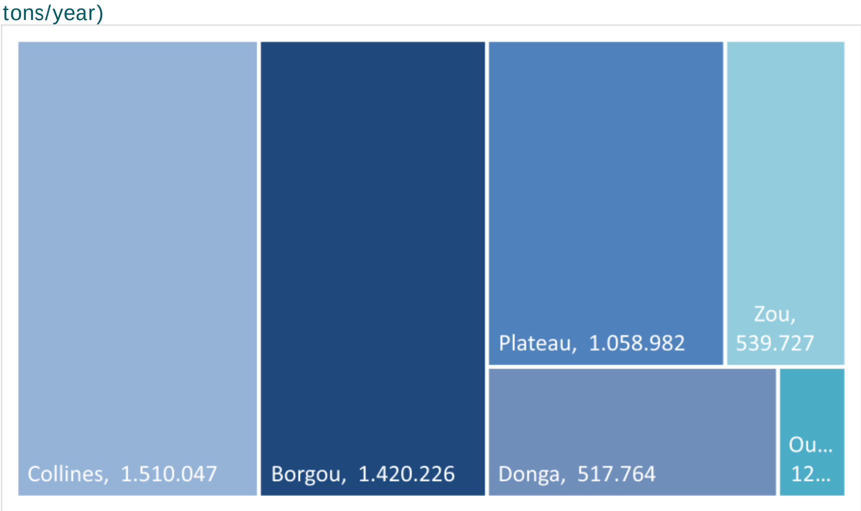


Figure 3-3 Distribution of ground nuts and pulses (cowpea, bambara groundnut, pigeon peas) in ACMA regions, averages from 2015 to 2021 (in tons/year)

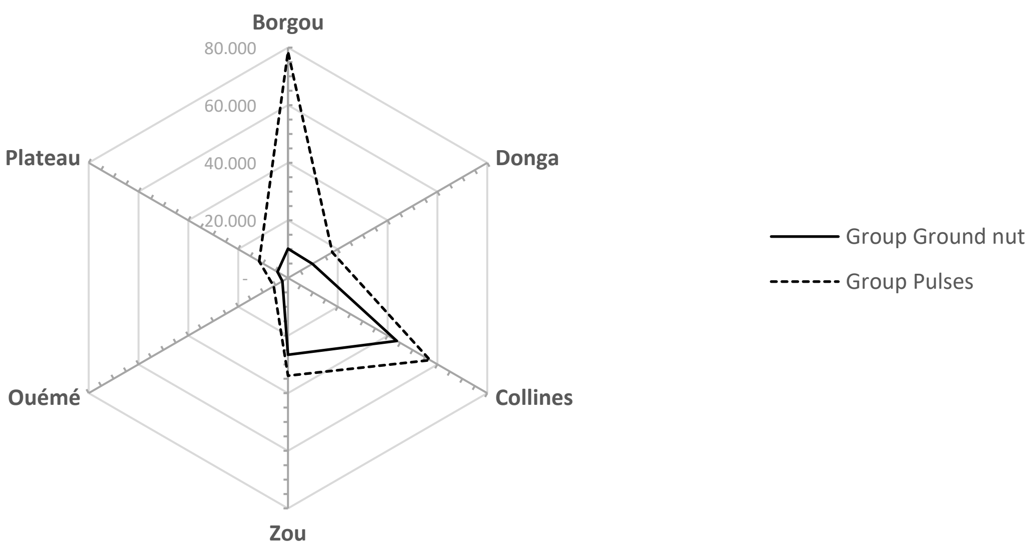


Figure 3-4 Distribution of rice production in ACMA regions, averages from 2015 to 2021 (in tons/year)

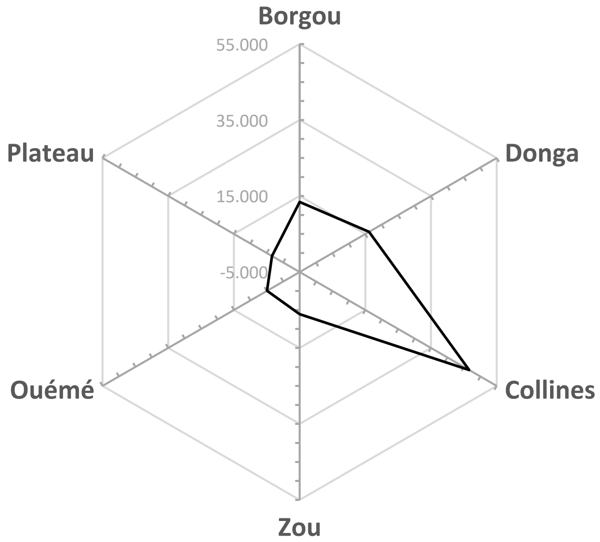


Table 3-1 The ten main crops in ACMA 2 and 3 regions[6], averages from 2015 to 2021 (in tons/year)

Crop	Borgou	Donga	Collines	Zou	Ouémé	Plateau	TOTAL
Cassava	231,191	1,329	793,662	40,001	111,657	1,007,713	2,677,134
Yam	1,184,575	380,519	713,974	134.439	45	50,008	2,463,558
Maize	219,818	54,751	102,231	73,014	56,597	205,967	712,378
Soya	66,708	10,391	31,083	13,903	-	2,533	124,618
Ground Nut	1,017	9,846	43,682	26,651	2,227	4,208	96,784
Rice	13,427	1,615	46,614	6,102	4,932	3,396	90,621
Cashew	28,151	16,301	31,691	5,502	52	1,549	83,246
Tomato	8,734	4,489	977	6,147	21,241	32,686	83,066
Cowpea	11,168	575	20,415	18,504	5,357	6,838	68,033
Chili	1,814	755	4,085	1,136	31,197	11,948	50,935
Sorghum	30,094	11,901	2,558	685	-	-	45,238

3.1.2 Livestock rearing

ACMA3 has identified livestock as targets for the project, including poultry farming and small ruminants. The National Agriculture census of 2021 provided the livestock data used in the analysis and highlights that livestock production in the ACMA areas is not diversified and is mainly orientated towards local chicken farming, bovine, goats, and sheep (Figure 3-5). Figure 3-6 gives a more in-depth analysis of the cattle distribution in the IZ.

[6] Ministère de l'Agriculture, de l'élevage et de la pêche, Direction de la Statistique Agricole

Figure 3-5 Livestock heads in ACMA regions, per type of livestock (number of heads)[7] (2021)

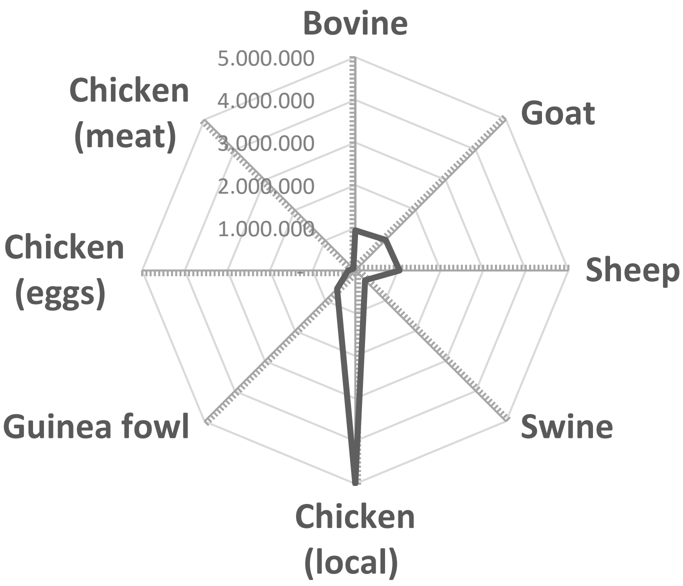
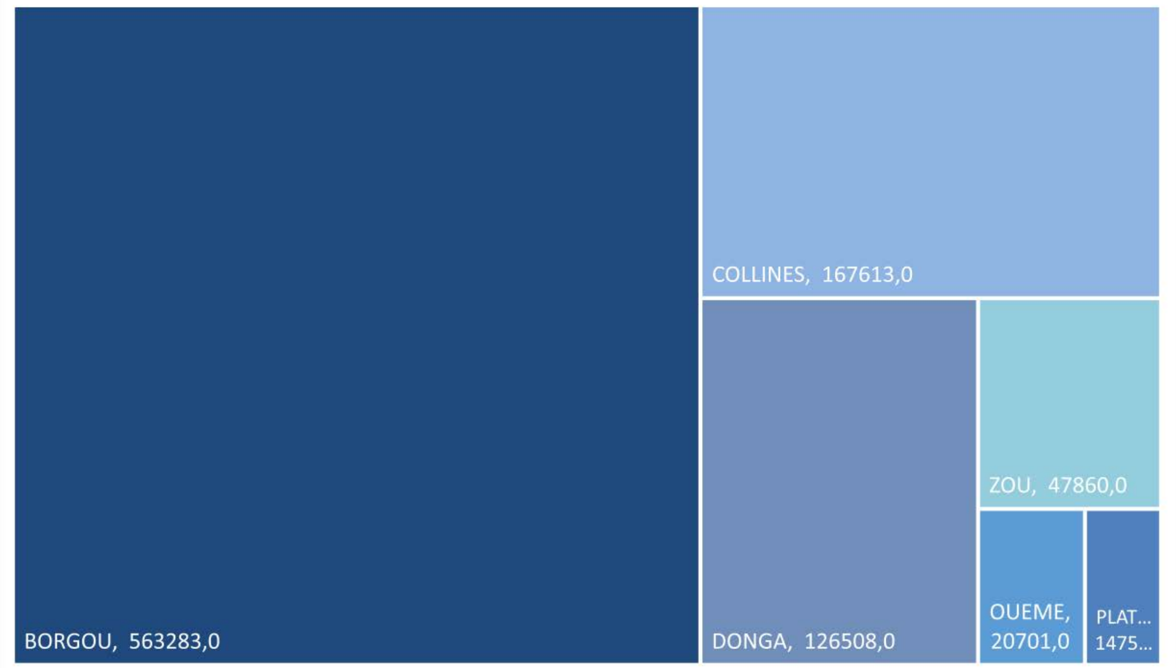


Figure 3-6 Bovine livestock in ACMA regions (number of heads)



Nevertheless, ACMA regions represent approximately half of the livestock of the country. Fifty-three percent of the bovine numbers are located in the ACMA areas of intervention, Borgou alone representing 32% of the national cattle livestock and more than half of livestock heads of ACMA regions (see figure 3-6). Over the 10 million national local chicken, more than 3 million are located in Borgou, Collines and Zou alone. This data is shown in Table 3-2.

[7] Ministère de l'Agriculture, de l'élevage et de la pêche, Direction de la Statistique Agricole

Table 3-2 Livestock heads in ACMA 2 and 3 regions[8] (in t/year)

Livestock	BORGOU	DONGA	COLLINES	ZOU	OUEME	PLATEAU	BENIN
Bovines	563,283	126,508	167,613	47,860	20,701	14,752	1,773,157
Goat	297,625	173,636	258,809	167,510	53,480	60,847	2,362,001
Sheep	349,514	160,925	151,662	192,402	96,538	87,562	2,295,522
Swine	23,002	19,178	42,651	122,936	81,405	35,833	681,885
Chicken (local)	1,018,029	682,752	1,025,685	1,258,541	532,851	477,774	10,250,541
Guinea fowl	262,253	159,353	87,895	65,253	18,499	10,662	1,348,029
Chicken (eggs)	19,714	5,184	29,887	40,746	54,298	16,139	356,098
Chicken (meat)	3,020	2,259	7,862	16,231	26,179	6,842	117,750

In Borgou, the livestock distribution is uneven, with Kalale representing 35% of the department bovine numbers, 36% of the ovine concentration and 22% of the guinea fowl. In Donga, local chickens are by far the main livestock, mainly bred in Djougou where the largest town is situated. In the department of Collines, Savalou and Glazoué are the most active communes for livestock with 48% of the chickens, and cattle is also mainly situated in Savalou with a little over 40,000 heads. For the Zou department chickens, goats and sheep are the most represented livestock with the farming activities located in Djidja and Za-kpota, two communes that also host a swine production of approximately 60,000 heads. Chicken are the main livestock in Ouémé and Plateau, all communes being active except Porto-Novo and Aguégués, respectively due to their urbanized or riparian situation.

The number of large or industrial-scale chicken farms in Benin is low, and even lower the more up north one goes. The largest farms identified during this study are producing between 500 to 10,000 chickens. Bovine is an even less industrialized activity, with the predominance of nomadic types of breeding cows which are grazing freely along the transhumance paths. The national strategies for livestock development in Benin support the enlargement of chicken farms and the settlement of bovine exploitation. This orientation, if implemented, could provide an easier access to livestock residues in the future. These can provide key nutrients to bio-organic fertilizer production.

3.1.3 Waste production analysis

Agricultural residues on the farm fields

Based on desk research and expert knowledge, a percentage of the crops which are not sold for transformation in the ACMA3 zone are used as inputs in the FAO Biomass Potential Assessment Tool (BEFS RA Tool).[9]

In this study, 32 crops were assessed in order to evaluate the crop characteristics of the IZ, and subsequently evaluate the residues generated and deliver actionable results for the transformation opportunities inside the frame of circular economy. Crops were divided into the following groups:

- Maize group (maize alone)
- Rice group (rice alone)
- Other cereals group (Sorghum, fonio and millet)
- Tubers group (cassava, yam and sweet potatoes)
- Groundnut group (groundnut alone)
- Pulses group (cowpea, soybean, goussi, Bambara groundnut and pigeon peas)
- Pineapple group (pineapple alone)
- Cashew group (cashew nuts alone)

[8] Ministère de l'Agriculture, de l'élevage et de la pêche, Direction de la Statistique Agricole
[9] https://www.fao.org/energy/bioenergy/bioenergy-and-food-security/assessment/befs-ra/natural-resources/es/

Vegetables were not included as little residues are generated by this type of crops. The groups' data agricultural results are presented in Table 3-3.

Table 3-3 Groups of crops for the residues calculation (ref) (in t/yr)

Groups	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Group Maize	219,818	54,751	102,231	73,014	56,597	205,967
Group Rice	13,427	16,150	46,614	6,102	4,932	3,396
Group Other cereals	30,298	12,834	2,574	685	-	-
Group Tubers	1,420,226	517,764	1,510,047	539,727	121,788	1,058,982
Group Groundnut	10,170	9,846	43,682	26,651	2,227	4,208
Group Pulses	78,613	17,771	57,062	33,928	5,741	11,549
Group Pineapple	-	-	3,050	731	526	1,135
Group Cashew	28,151	16,301	31,691	5,502	52	1,549

The residue analysis has been performed based on the FAO tool and on the literature reviews on residue calculation. The residue quantity evaluation is based on a range of percentage, and in this study a conservative method has been followed so as to not overestimate available quantities.

Maize group

There are 3 main types of residues from maize production. The stover is generally let on the field to dry and is then burnt locally. The husk and the cob are either produced next to the farm (for direct domestic use or pre-transformation before selling) or at the flower production units. The FAO tool used the residue to crop ratio for maize presented in Table 3-4.

Table 3-4 Maize residue to crop ratio[5]

MAIZE	Stover	Husk	Cob
Average	1.96	0.22	0.33
Minimum	1.00	0.20	0.20
Maximum	3.77	0.30	0.86
St. Dev.	0.67	0.04	0.16

The ratio 1, 0.2 and 0.2 have been chosen for residues calculation of stover, husk and cob respectively. A conservative approach was therefore adopted (use of minimum ratios) to determining residues for the purpose of proving viability of applications in downstream value-add operations. In this study, the hypothesis is that only 70% of the maize residue could be readily available. The results are presented in Table 3-5.

Table 3-5 Potential maize group residues (in t/yr)

MAIZE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Maize stover	153,872	38,326	71,561	51,110	39,618	144,177
Maize husk	33,852	8,432	15,744	11,244	8,716	31,719
Maize cob	50,778	12,647	23,615	16,866	13,074	47,578

Other cereals groups

There are 3 main types of residues from other cereals group production. The residue to crop ratio for sorghum in FAO tool does not provide husk or cob data but only for stalk (Average:2.44, min:1, max:0.46; stdev:0.97). This ratio is comparable to the maize ratio. Therefore, the maize ratio was used to calculate the other cereals group residues but only 50% of the crop residues are considered to be available. The results are shown in Table 3-6.

Table 3-6 Other cereals group residues (in t/yr)

OTHER CEREALS GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Other cereals stalk	15,149	6,417	1,287	342	-	-
Other cereals husk	3,333	1,412	283	75	-	-
Other cereals cob	4,999	2,118	425	113	-	-

Rice group

There are 2 main types of residues from rice production. The straw is generally let on the farm to dry, then can be burnt. The husk is produced at the rice transformation unit. The FAO tools used the residue to crop ratio for rice presented in Table 3-7.

Table 3-7 Rice residue to crop ratio [5]

RICE	Straw	Husk
Average	1.33	0.25
Minimum	0.42	0.15
Maximum	2.15	0.36
St. Dev.	0.68	0.06

The ratio 0.42 and 0.15 were chosen for residues calculation of straw and husk respectively, and calculations are based on the aforementioned hypothesis that only 70% of the residue could be readily available. The results are presented in Table 3-8.

Table 3-8 Rice group residues (in t/yr)

RICE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Rice straw	3,947	4,748	13,704	1,794	1,450	998
Rice husk	2,350	2,826	8,157	1,068	863	594

Tubers group

There are 2 main types of residues from tubers production: the stalk and the peels. The stalk is let on the farm to dry and can then be reused (e.g., for plantation), left to decompose or burnt. The peels are produced mainly at the transformation unit (production of "cossettes" or "gari" or starch). The FAO tool only provides stalk to crop ratio (Average: 0.13, min: 0.06, max: 0.20; stdev: 0.06).

The ratio 0,06 has been chosen for stalk residues calculation of cassava, yam and sweet potatoes. In this study, the hypothesis is that only 50% of the stalks could be readily available due to reuse for other purpose. For the peeling residues, only cassava and yam have been considered, as sweet potatoes are not transformed inside specific units (domestic use only). Cassava peeling residues are 19% of the wet weight of cassava with 67 % of moisture content[10]. The calculation of peeling residues is based on an estimated 30% of transformation rate, and results are presented in Table 3-9.

Table 3-9 Tubers group residues (in t/yr)

Tubers	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Stalk	42,607	15,533	45,301	16,192	3,654	31,769
Peelings (Dry matter)	54,068	19,607	57,577	20,411	4,266	40,394

[10] Sammy N. Aso, Arthur A. Teixeira and Simeon C. Achinewhu. Cassava Residues Could Provide Sustainable Bioenergy for Cassava Producing Nations. From the Edited Volume "Cassava"Edited by Viduranga Waisundara

Groundnut group

Husk is only one main type of residue from groundnut production. The minimal residue to crop ratio for ground nut husks has been used (Average: 0.47, min: 0.32, max: 0.67; stdev: 0.12). Husks are mainly produced at the transformation unit (peanuts, oil, peanut pasta), hence the residues originating from domestic use are not considered in this study (the transformation/domestic ratio is estimated at 0.7). Table 3-10 presents the results.

Table 3-10 Groundnut group residues (in t/year)

Groundnut	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Husk	2,278	2,206	9,785	5,970	499	943

Pulses group

There are 2 main types of residues from pulses production: the straw, which is generally let on the farm to dry and can then be burnt; and the pods, which are produced at the pulse's pre-transformation unit next to the farm. The FAO tools used the residue to crop ratio for soya beans presented in Table 3-11.

Table 3-11 Soya beans residue to crop ratio

Soya	Straw	Pod
average	1.53	1.09
Minimum	1.00	0.90
Maximum	2.50	1.36
St. Dev.	0.84	0.24

The ratio 1 and 0.9 were chosen to calculate the residue quantities of straw and pods respectively, considering that soya beans, cowpea, vouandzou, sesame and angole have approximatively the same ratio. In this study, the hypothesis is that only 70% of the residue could be readily available. The results are presented in Table 3-12 below. Soyabeans paste resulting from the transformation of beans is likely to increase by 2024 due to the government's planned ban on untransformed soyabeans exportation.

Table 3-12 Pulses group residues (in t/yr)

Pulses & soya	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Straw	55,029	12,440	39,943	23,749	4,018	8,084
Pods	49,526	11,196	35,949	21,375	3,617	7,276

Pineapple group

There are 3 main types of residues from pineapple production: the pineapple leaf residue left on the field to dry, be composted or burnt; the peels and the head taken off at the first stage of transformation; finally, the fibre paste left after juice extraction. Pineapple leaf residue is estimated to be equivalent to the fruit weight, the peels and head represents 44% of the fruit weight, and the fibre paste 34%.[11] Whereas the average percentage of transformation in the world amounts to 30% of the production, this study adopted a more conservative approach, considering that only 20% of the Beninese pineapples are actually transformed in juice. Table 3-13 shows the residues generated from pineapple production at the field level and at the transformation unit site.

Table 3-13 Residues from pineapple production (based on wet matter%, t/yr)

PINEAPPLE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Plant leaf residue	-	-	2,135	512	368	794
Peel	-	-	268	64	46	100
Fiber paste	-	-	726	174	125	270

[11] https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-018-1207-8

Cashew group

Cashew is one of the crops that proportionally produces the larger quantity of residues. There are 5 types of residues possible:

- Cashew apple (never exported), estimated to have 10 times the weight of the cashew nut[12]
- Cashew apple bagasse resulting from the juice extraction represents 30% of the fruit weight;
- Testa represents 1 to 3% of the nut shell weight[13];
- Cashew shell represents 67.7% of the nut weight, with an average moisture content of 6.47%[14];
- Cashew nut shell liquid resulting from the liquid extracted from the nuts, which represents 30 to 35% of the shell weight.

In this study, we considered that only 30% of the cashew production is transformed locally (data ranging from 5 to 30% [15,16]), with the remainder being exported (without the apple) towards India without transformation. Table 3-14 shows the residue quantities generated by cashew production in Benin. This calculation is likely to change in the near future due to a decision made by the Beninese government to forbid the exportation of untransformed cashew nuts by mid-2024.

Table 3-14 Residues from cashew production (dry matter when not specified, t/yr)

CASHEW GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Cashew apple (WM)	281,515	163,010	316,912	55,015	518	15,486
Cashew shell (%WM)	2,641	1,529	2,973	516	5	145
Cashew nut shell liquid	792	459	892	155	1	44
Testa (WM)	845	489	951	165	2	46

Residues from livestock farming

Livestock farming in Benin is dominated by a small, traditional farms with little concentration of cattle, making the manure collection impossible for any scaled opportunity in circular economy. Aside from local opportunities in biogas or composting, the potential of manure in the ACMA regions is nevertheless investigated in this study as national strategies promote larger chicken farms and intend to enforce the settling of nomadic cattle (feedlot development to increase production rates). This paradigm change, if followed by results, could create new opportunities for exploiting this neglected resource in the near future.

Residues from cattle have been calculated using the FAO algorithm dedicated to livestock.

Bovine residues

The calculation for bovine residues is based on several hypotheses:

- All bovine heads have been considered as cattle due to the lack of national statistics differentiating dairy cow from cattle. This choice does not have a substantial impact on results as there is little difference in manure production between the two uses;

[12] Trakul Prommajak, Noppol Leksawasdi and Nithiya Rattanapanone. Biotechnological Valorization of Cashew Apple: a Review.

[13] https://www.researchgate.net/publication/279949116_Thermal_properties_of_tannin_extracted_from_Anacardium_occidentale_L_using_TGA_and_FT-IR_spectroscopy

[14] Atul Mohod, Sudhir Jain, and Ashok Powar. Cashew Nut Shell Waste: Availability in Small-Scale Cashew Processing Industries and Its Fuel Properties for Gasification ; International Scholarly Research Network ISRN Renewable Energy volume 2011, Article ID 346191, 4 pages doi:10.5402/2011/346191

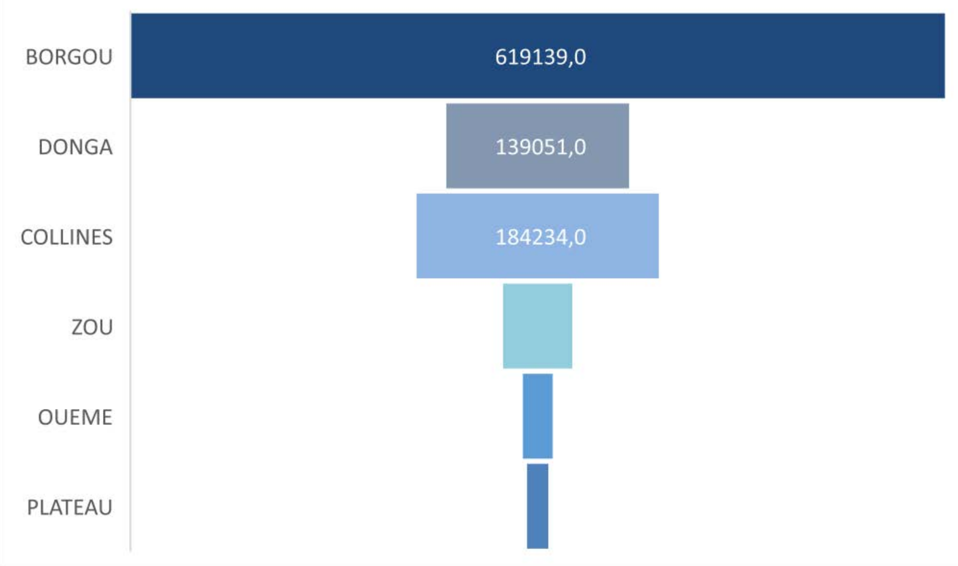
[15] TANDJIEKPON André Mahoutin. Analysis of the Benin Cashew Sector Value Chain. African Cashew initiative- GIZ. africancashewinitiative.org

[16] Mahloukou Kingnide ARINLOYE. Research on Benin Cashew Nut Exportation Trade. International Journal of Science and Research (IJSR). p76-79 Vol. 9 (2), February 2020 ISSN: 2319-7064

- The commercial production has been set to 30% of the head count, which represents an important improvement compared to the current situation. Collecting waste in households is not considered as an opportunity due to obvious logistics constraints;
- Manure production is 14.34/kg/head, with 13% of volatile solids[5];
- 60% of bovine were assumed to be fed via a mixed feeding system using grazing and stable feeding, the remaining 40% were considered as "grazing only"
- 30% of the manure obtained is assumed be used for other purposes (composting, fertilizing, firing, etc.) and would therefore not be available for other usage.

The results obtained are presented in Figure 3-7.

Figure 3-7 Hypothesis of potential bovine manure reservoir in ACMA regions (in tonnes / year)



Chicken manure calculation

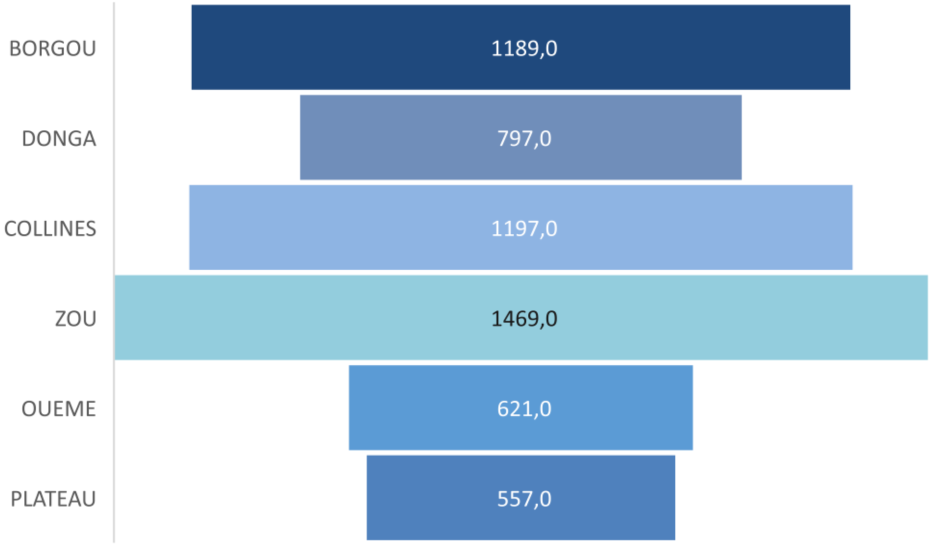
Calculating chicken manure quantities evaluation is more challenging than bovine due to major size difference across chicken species. In addition, local chickens are mainly bred in open spaces and commercial concentration is not likely to occur in the future due to a lack of zootechnics methodology of local industrial farms. In order to perform the calculation, the hypothesis of a progressive replacement of the local species by more standard species has been made, assuming that a portion of the needs in local chickens will be fulfilled by standard chicken in the near future.

The following hypotheses were made:

- Only 10% of the local chicken heads will be raised with standard chicken production;
- Manure production for a standard chicken is 0.04 kg/day/head and contains 49% of volatile solids;
- Uses of chicken manure that are likely to reduce its availability have been estimated to reach 20%.

The results in Figure 3-8 show that there is a large difference in chicken manure availability compared to bovine manure in ACMA regions.

Figure 3-8 Hypothesis of potential chicken manure reservoir in ACMA regions (in tonnes / year)



Residues from transformation of agricultural products

Apart from the waste produced on farm fields, waste is also generated after bulk purchase for industry transformation, for all 5 crops. For example, maize can be transformed into flower, soya bean into cheese, milk or oil, cashew into "nuts" or pasta, cassava into "Gari", and Yam into fermented chips. These different transformation processes produce specific residues (peels, starch, industrial water, husks, heat, ashes, etc.).

Twenty-two potential agricultural residue producers were contacted during the study to investigate the availability of their residues:

- 2 palm tree farms (Plateau) declared having fibres, nut shells, stalks and sludge residues. All residues are reused for fire, mulching or maggot production;
- 11 "multicrop" farms (soyabean, yam, maize, rice) declared partially using their residues for composting or direct soil fertilization;
- 9 livestock farms declared using most of their residues for direct fertilization or composting.

An assessment of local transformation units of palm nuts, dairy products, cassava, yam has been done, which yielded the following results:

- 2 palm oil producers declared using most of their residues for direct fertilization of palm trees or for fire;
- 1 "Gassiré" cheese producer declared selling part of the residue for direct livestock feed;
- 6 cassava transformers (the products are "Gari", "Cossettes", "tapioca" and starch) declared using some or all their residues for direct livestock feed.

Municipal waste

Agricultural products distributed in local markets for domestic consumption leads to the production of organic waste as part of municipal waste. In some cities, market and domestic waste are collected by the municipalities.

The domestic waste collection systems of municipalities lack a systematic and organized approach at the national level. Since 2018, the government has put in place a collection and landfill dumping system, carried out by a public company called SGDS-gn, but the service only concerns the south of the country (namely the cities of Abomey-Calavi, Ouidah, Cotonou, Sèmè and Porto-Novo). Unfortunately, in the ACMA region no such system has yet been put in place. Waste collection is often organized by the municipalities which delegate the task to several NGOs, the price being paid directly by households. This system encourages inadequate behaviour using unofficial dumping grounds all over the country. The strategy of the government is to extend the system developed in the south of Benin to the rest of the country, but this structured system in unlikely to be put in place in these regions in the next few years.

Up to now, the only wastewater treatment plant in operation is in Cotonou. The government has launched construction projects for several new plants over the country, with one in Sèmè Kpodji being well advanced. In Parakou, Omidelta Funds financed a sewage treatment area using on phytoremediation that gives an acceptable exit for the wastewater collected in the commune; a large water treatment plant construction has been planned by the government of Benin but the date of but the date of entry into office is still unknown. In the ACMA regions, sewage activities are carried out by private entities which can only unload the sludge unofficially, leaving no opportunities to consider this source of organic matter in the transformation of agricultural residues. An exception to this situation concerns the city of Parakou where a specific site has been dedicated to the sludge dumping with a natural plants treatment system.

3.2 Recycling practices and recovery options

The outcomes of ACMA2 have highlighted that the circularity approach was scarcely integrated into the agricultural sector, leaving potential for Circular Economy applications to use by-products and implement a regenerative transformation strategy. Nevertheless, some small-scale projects and programmes do already exist across the country, and these should be highlighted and further investigated as options for scaling up.

Like in many regions around the globe, circular economy approaches have been, to some extent, a traditional way of dealing with organic waste, such as the composting of organic waste or the use of production residues for mulching. Recuperation or use of residues considered as valuable is intensively practiced in Benin, but without taking full advantage of the opportunities offered by a circular economy. A circular economy approach in agriculture should not be limited to management and use of waste resources, but also engage a regenerative approach and unlock sustainable opportunities in energy, water, climate change, food security, manufacturing, health, education, and address impacts and outcomes with social and environmental benefits.

Benin follows some interesting initiatives in the agriculture-related sector, ranging from reuse of waste materials and fertilizer production to energy recovery and pellets production. Examples include:

- Green Keeper Africa is a Beninese company that collects and transforms water hyacinth in industrial absorbent for oil spills control in the industry sector, the used absorbent is then collected for complementary fuel in industry[17]. Since 2020, Green Keeper African transforms also water hyacinth in a fertilizer called Djèmimè sold in the south of the country;
- DEFIA is an ENABEL program targeting the pineapple sector. The management of waste has been highlighted among the challenges identified. Five companies (small enterprise stage) are coached by OVO (Entrepreneurs for entrepreneurs) and have been granted in 2022 with 38.000 Euros for the development of a concept proof (mushrooms, fertilizer, nutritive powder, animal feeding and equipment);
- The Swiss ReBin Foundation in Toffo which has performed composting and biogas production from market waste for several years;[18]

[17] https://greenkeeperafrica.com/fr/
[18] https://youtu.be/jAK6o4MV8KE

- A biodigester prototype was implemented to transform cassava waste into biogas in order to reduce the usage of charcoal in the production of gari (a flower made from cassava) in Zè, with the support of the NGO Afrique Espérance;[19]
- The transformation of waste into charcoal for households' consumption by the NGO GBOGBETO in Porto-Novo;[20]
- The reuse of coconut waste from the oil extraction for energy, rowing medium and ropes by the Beninese SME Royal Ted in Calavi;
- Oil extraction from neem seeds and reuse of the waste for fertilizer/biopesticide by two companies: Biophyto [21] and *Huiles Végétales des Collines*;
- Sale of draught waste to livestock producers by SOBEBRA, the Beninese brewery;
- Reuse of cotton seeds to make cooking oil by SHB (Societe des Huileries du Benin) in Bohicon.
- Feasibility study on cashew waste gasification conducted by CIRAD [22];
- Several artisanal entities manufacture different agri-food or cosmetic products based on cashew waste (juice-Sweet Benin, jam, ointment), however with mixed commercial success.
- SENS Benin supports the production of cashew honey with "Ruche des Collines".
- Fludor (C Corporation) transforms soya beans cake and cotton seed cake into pellets then sold to local livestock farmers and animal food producers, or are exported.[23]
- Fludor (C Corporation) extracted cashew nut balm from the cashew nut, but this activity was stopped[24]. Several research studies have been done in Benin on the transformation of cashew nuts into biochar[25] but so far, no industrial project exists. HRD Industries, an Indian corporation has a plan to invest $12 millions in an industrial (inside the industrial zone of Glo Dji Gbe) unit dedicated to the transformation of cashew nuts.
- Cashew shells have been used directly in the heating process needed for cashew nuts production with a negative environmental impact. The University of Abomey Calavi has developed a pyrolysis prototype to enhance the energetic efficiency of the process and reduce environmental consequences. A large Indian company (HRD Industries) is expected to install its factory in the new industrial zone of GLO DJIGBE (North of Calavi), but the foreseen process for waste reuse is still undisclosed.[26]
- A study focusing the potential use for solar energy supply across the maize value chain in Benin was performed in 2019.[27]
- The Association of African Entrepreneurs and the Association Defense Jeunesse et Solidarite (ADJS-NGO) are assessing a biochar energy plant for Benin.[28]
- "Eko-Sika" makes an ecological charcoal replacement from available biomass to reduce pressure on forest resources.[29]
- A UN Environment grant allocated through the Special Programme on Institutional Strengthening for Chemicals and Waste Management addresses the misuse of pesticides and other chemical contaminants in the cotton sector.[30]

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[19] https://www.climate-chance.org/en/best-pratices/recovery-of-organic-waste-to-increase-the-income-of-womens-cassava-processing-groups-in-the-city-of-ze-in-southern-benin/
[20] https://www.urbanlimitrophe.com/2021/06/Gbobeto-Waste-Sustainable-Energy-Benin.html
[21] https://biophyto-benin.com/
[22] https://agritrop.cirad.fr/577649/1/th%C3%A8se%20finale%20MELZER%202013.pdf
[23] https://fludorbenin.com/english/produit/cotton-and-soya-bean-meal-doc/
[24] http://www.commodafrica.com/14-01-2020-lactivite-de-transformation-des-noix-de-cajou-de-fludor-benin-en-faillite
[25] https://www.nitidae.org/actions/beninut-etude-de-faisabilite-sur-la-valorisation-energetique-des-dechets-de-noix-de-cajou-au-benin
[26] https://gdiz-benin.com/hrd-industries/
[27] https://energypedia.info/wiki/Energy_input_in_the_Maize_value_chain_in_Benin
[28] https://www.globalgiving.org/pfil/15019/projdoc.pdf
[29] https://agribusinesstv.info/en/benin-ecological-charcoal-to-preserve-forests/
[30] https://www.unep.org/news-and-stories/story/waste-no-more-benin-confronts-long-history-chemical-waste-mismanagement

- The African Development Bank has a project to support food production and build resilience in the Alibori, Borgou and Collines Departments.[31]
- A study which focuses on achieving balanced plant nutrition to enhance groundnut production in Benin has been completed by several institutes in the country.[32]
- Research has been undertaken to enhance the sustainability of maize and soya beans production in the department of Borgou.[33]
- The French Facility for Global Environment (FFEM) has a programme on re-using agricultural and agro-industrial waste in West Africa (including Benin) to develop a solution to recycle the waste and produce electricity.[34]
- A study has been undertaken by UNSTIM (Benin) and CIRAD (France) which evaluated the energy potential of agricultural waste in West Africa from three biomasses of interest in Benin.[35]
- The International Atomic Agency (IAEA) is addressing enhanced production and export of soya bean using bio-fertilizers and isotopic technology.[36]
- In 2013, the Faculty of Agronomy at the University of Parakou did an inventory of innovation systems for agriculture and climate in Benin.[37]
- Father Godfrey Nzamujo is a farmer inspiring and agricultural movement in Benin with his “zero waste” agriculture system that increases food security, helps the environment and creates jobs.[38]
- The GIZ, through the Benin Ministry of Agriculture, Animal Husbandry and Fishery (MAEP), implemented the ProAgri Project (2017-2020), which addressed sustainable opportunities in environment and climate through selected value chains (cashews, rice, shea and soyabeans).[39]
- In June-July 2013, USAID through the Millennium Challenge Corporation (MCC) sponsored an Agribusiness Commercial Legal and Institutional Reform (AgCLIR) diagnostic in Benin as part of the first phase of due diligence in the evaluation and refinement of the proposed agribusiness enabling environment project under the second Compact for Benin (MCC Benin II Compact).
- In Kouandé, with the support of the NGO GERME, a cooperative of women is parboiling rice with bio-charcoal made from rice husks and reusing the water from the process for the vegetable garden of the cooperative. This project was financed by the PROCAD program in 2020.

Despite these initiatives, Benin has yet to grasp the full potential of circular economy. Most of the initiatives cited above are prototypes or may have an unstable economic model.
Circular Economy Principles also drive the collaborative nature of project development, and as can be seen from these many examples there is a disparate and disconnected link between them.

3.3 Relevant national regulations

The main law framing environmental regulation in Benin is Law No. 1998-030 of 12 Feb 1999 on the framework law on the environment in the Republic of Benin.[40] It introduces general aims related to environmental protection, in particular to prevent and anticipate actions likely to have immediate or future effects on the quality of the

[31] https://www.afdb.org/fileadmin/uploads/afdb/Documents/Boards-Documents/Benin-Rev_1-_Proj__to_sup__food_product_PAPVIRE-ABC.PDF
[32] https://academicjournals.org/journal/AJAR/article-full-text-pdf/8D5612E62409
[33] https://www.sciencedirect.com/science/article/pii/S2772390922000129
[34] https://www.ffem.fr/en/carte-des-projets/re-using-agricultural-and-agro-industrial-wastes-west-africa
[35] https://www.journalijar.com/uploads/105_IJAR-31285.pdf
[36] https://www.iaea.org/newscenter/news/benin-enhances-production-and-export-of-soybean-using-bio-fertilizers-and-isotopic-technology
[37] https://www.nri.org/images/documents/development-programmes/climate_change/publications/WorkingPaper3Benin.pdf
[38] https://edition.cnn.com/2020/06/24/africa/zero-waste-farming-godfrey-nzamujo-benin-spc-intl/index.html
[39] https://www.giz.de/en/worldwide/80045.html
[40] In French: Loi N° 1998-030 du 12 févr. 1999 portant loi cadre sur l'environnement en République du Bénin. Available at:http://extwprlegs1.fao.org/docs/pdf/ben16685.pdf

environment, to stop all pollution and degradation or at least to limit their negative effects on the environment, to promote sanitation with the aim of improving the living environment, and to closely and continuously monitor the quality of the environment. In addition, this law states the aim of ensuring a balance between the environment and development. With regards to environmental protection, this framework law contains provisions related to waste management, including on waste treatment and waste disposal. However, it does not mention any aspects related to circularity such as recycling. The design of a new Environmental law has been ongoing for the past two years, meaning that broader and/or more stringent environmental regulation may be introduced in the foreseeable future.

No circular economy strategy in Benin, and no such strategy will be published in the near future as it is not on the agendas of relevant Ministries. The only regulation which explicitly incorporates some elements related to circularity is Decree No. 2003-332 on solid waste management in the Republic of Benin.[41] The purpose of this decree is to protect the environment and human health from any harmful influence caused by waste, including agricultural waste. Its stated aims are: (1) to prevent or reduce the production of waste and its harmfulness; (2) to promote the recovery of waste, in particular by recycling, reuse, recuperation, use as a source of energy; (3) to organise the elimination of waste; (4) to limit, monitor and control the transfer of waste; and (5) to ensure the restoration of sites. Related to valorisation, article 30 of the decree states that waste elimination must be ensured during pre-collection, collection and treatment, and this must be done under conditions favourable to the recovery of reusable materials, elements or forms of energy which can be reused. However, this Decree has been little enforced. A new decree regarding solid waste management is currently being drafted to replace the current one, it includes a larger place for waste transformation opportunities and an enhanced actionability under the new Environmental Law to be enacted

Benin's National Long-term Vision - **"Benin Alafia 2025"**[42] (2000-2025) supports the agriculture sector by encouraging agricultural research and the development and dissemination of proven innovations and by giving agricultural development strategies priority in the realization of a strong and sustainable economy.[43] The circular use of agricultural residues could contribute to the achievement of some aspirations listed in this Vision, namely: a rationalised management of soil and environmentally friendly energy sources. One of the listed objectives is to promote spatial planning which ensures regional development and a rational management of the environment, including via the promotion of environmentally friendly production, processing and conservation techniques, and via the preservation, restoration and promotion of natural resources, including soils. Overall, this Vision recognises the need to develop further the agricultural sector to contribute to the economic development of the country, as well as the need to develop this sector more sustainably, but does not reflect on resource circularity. Moreover, no link is made between economic and environmental aspirations (e.g., it ignores how a more efficient use of resources can bring economic benefits).

The main agricultural policy documents currently in place in Benin are the Strategic Plan for the Development of the Agricultural Sector and the National Plan for Agricultural Investments and Food and Nutritional Security. The Strategic Plan for the Development of the Agricultural Sector [PSDSA] (2017-2025)[44] was adopted in 2017 and outlines the sector's strategic objectives, which aim at strengthening the growth of the agricultural sector, food sovereignty and the food and nutritional security of the population, through efficient production and sustainable management of farms. The plan has a strong orientation on the adaptation to climate change and takes into account the sustainable management of the resources and the resilience of the populations. The third strategic act of the plan on resilience contains a mention of sustainable land management, in which the need to protect and rehabilitate soils is stressed (via investment plans, regulation, and integration in agricultural planification at communal level, and information sharing). Although this is not

[41] In French: Décret nº 2003-332 portant gestion des déchets solides en République du Benin -- Decree on waste management
[42] https://www.cabri-sbo.org/en/documents/benin-alafia-2025-benin-long-term-strategic-vision-to-2025
[43] https://www.africaportal.org/publications/policy-and-institutional-landscape-ecological-organic-agriculture-benin/
[44] https://ecowap.ecowas.int/media/ecowap/naip/files/BENIN_SIM6akD.pdf

reflected in the plan, the circular use of agricultural residues could contribute to the achievement of this strategic act. However, considering that the first strategic act focuses on improving the productivity and production of key agricultural sectors and that there are no mentions of circularity or waste management in the sector, it is likely that the implementation of the plan will lead to increased waste production without systematically considering the use of residues as a resource.

The National Plan for Agricultural Investments and Food and Nutritional Security (PNIASAN) (2017-2021) brings together all sectoral projects and programmes underway and in the pipeline (both public and private). It takes into account the internal resources of the government, the financing of Technical and Financial Partners as well as the contributions of the private sector and civil society. The strategic axes of PNIASAN 2017-2021 are aligned with those of the PSDSA: i) improvement of productivity and production in priority agricultural sectors; ii) promotion and equitable structuring of value chains; iii) strengthening of resilience in the face of climate change and improvement of food and nutritional security of vulnerable populations; iv) improving governance and information systems in the agricultural sector, food and nutrition security; v) setting up financing and insurance mechanisms that are adapted and accessible to the different types of farms and categories of actors.

The PNIASAN is heavily focused on productivity and food security and does not contain a strategic axis related to improving circularity in agricultural value chains.

Law no. 2020-05 on electricity code in the Republic of Benin defines, amongst other elements: (1) the electricity sector's policy orientation and general organisation; (2) rules concerning production, transport, distribution, commerce, consumption, import and export; (3) the public governance structure (roles and responsibilities); and (4) the methods of participation of public and private companies or the electricity sector. Of particular relevance to the activities in the scope of this study, article 26 on independent production of electricity states that independent producers are allowed to sell their production under conditions set by the minister for electrical energy, and can be authorised to build lines to connect to the electricity transport and distribution network. In addition, article 30 on conditions for supplying the electricity sector with primary energy states that primary energy purchase contracts - including regarding agricultural residues - are subject to the approval of the Electricity Regulatory Authority, which must ensure the transparent nature of the acquisition process and the competitiveness of the purchase price of primary energy.

Following this law, Decree No. 2022 - 474 on off-grid electrification regulation in the Republic of Benin was enacted. This decree mandates the obtention of a license to produce off-grid electricity for commercial purposes, which relates to production, distribution and commercialisation. The decree lays out different procedures for facilities with less or more than a 500 kW cumulative installed capacity. The decree also states several obligations to which electricity producers must comply, control procedures, pricing requirements, etc.

Any applications in terms of driving a circular economy transition in the agricultural sector would need to take heed of existing legislation and regulation, specifically regarding any opportunities or barriers that they may pose. Specifically, key stakeholders in this sector (including the likes of ACMA) need to actively lobby for enabling legislation that helps to unlock new investments and developments in the sector. Some of the technology suggestions in Section 4.4 address energy generation either as a primary or secondary output and would need to be assessed in any future due diligence on feasibility through the laws and decrees addressing energy above. Laws typically have an inertia that drags slowly compared to rapid advances in technology development, and affected sectors need to lobby actively for change that embraces sustainable development and applications.

4 Identification of opportunities to promote circular practices in ACMA-supported value chains

4.1 The relevance of circular practices and solutions for ACMA

The Communal Approach to the Agricultural Market (ACMA) program aims to contribute to the improvement of food security and increase the agricultural incomes of Beninese economic stakeholders. To ensure a coherent and holistic approach, the project's implementation strategy is based on five integrated activity areas: access to inputs and agricultural innovations, market access and professionalization, agricultural finance access, information and communications technology (ICT) for agriculture, and public-private partnerships. Valorising agricultural residues using Circular Economy approaches can contribute to each of these strategies. To do so, circular practices/solutions that can be applied at the following value chain levels need to be identified: a) production (lower costs and risks in raw materials, better productivity, simplification of production processes, stimulation of innovation, b) use (better targeting of needs) and c) end-of-life (better uses of waste).

Key economic applications at the stages of production, processing and market are generally investigated, whereas they ignore the end-of-life issues, specifically agricultural residues, post-harvest losses, processing losses and food waste tends to be overlooked. In Circular Economy, this paradigm is changed, with a large focus being placed on investigating end-of-life options as key inputs to the remainder of the value- and supply-chains. The linear economy model of agriculture ignores key aspects in resource circularity, leading to: depleted soils; loss of productivity; increased chemical use in fertilizers, herbicides and pesticides; increased water usage; negative impact on biodiversity; negative environmental impacts; increased negative anthropogenic impacts and socio-economic pressure/stress; decline in nutrition and subsequent health; and negative impacts on the carbon cycle and climate change.

The core objective of ACMA is to increase the agricultural incomes of local-level economic actors. Focussing on waste will create opportunities to achieve this. To feed a growing population in Benin and capitalize on abundant natural resources to bolster a thriving export market will require embracing new farming methods that increase productivity, while reducing associated environmental impacts. Regenerative agriculture is embraced now as a disruptive circular economy approach based on the principals of designing waste and pollution out of the system, keeping products and materials in use and regenerating natural systems. Successful and sustainable implementation of this transformative approach requires a collective approach from all stakeholders and needs to focus on the outcomes at the base of the value chain.

One of the key opportunities in embracing this change is that the focus on regenerative principles in about getting carbon back into the soil. Opportunities for creating carbon sinks, offsets and sequestration are not just about increasing production and nutrition, but open additional possibilities for climate finance and drive local agendas regarding Nationally Determined Contributions (NDC's) and compliance with the global goal of Net-Zero by 2050. Activities and opportunities around the beneficiation of agricultural residues can play a strong part in achieving the Country's NDC goals.

4.2 Identification of opportunities and activities to promote circularity in the ACMA value chains

There is sufficient information available to provide a national and regional snapshot of the available agricultural residues, and to use this information to assess viable and sustainable economic opportunities in their beneficiation to the benefit of farmers. Understanding the scale and location of implementation will be essential in providing realistic opportunities in the final financial assessment for this report. It is also important to state that in Circular Economy, very little in terms of project implementation is limited to just one sector. Additional opportunities can be unpacked where agricultural residues may be just one component of the final solution. For example, the development of high-value bio-organic fertilizers can benefit from additional nutrient inputs from abattoir waste, fish waste, chicken litter, feedlot sludges and faecal matter, sewerage sludge and other nutrient sources. Digestion and composting operations can benefit from a diversified feedstock including post-harvest losses, market waste and green waste – this is required to ensure the correct Carbon/Nitrogen ratio to create the optimum microbial activity. Additional feedstock can be sources from other operations such as organic waste destined for landfill, or biomass derived from alien vegetation eradication programmes or mulched field clearing for new agriculture. While accurately identifying and quantifying all of the unique input materials at the front-end is beyond the scope of this study, creating applications on the ground will unlock markets for new materials that could have additional spin-off benefits for the country.

Circularity also addresses other needs in the value chain. When addressing post-harvest losses across Africa, it is quite evident that issues around cold storage and opportunities for agri-processing (sauces, jams, pickles, etc.) are limited by a lack of access to electricity, particularly in agricultural areas distant from urban centres. Agricultural residues can be used for both energy and carbon by-products. There are other opportunities for intensive agriculture operations closer to the markets in urban centres using controlled-environment container systems and hydroponics, but this is not a focus of this study.

Many different technical and innovative solutions exist for agricultural residues. These can be sustainably implemented at different scales dependant on the available volumes and material composition of the residues. Notably, 5 key opportunities for project implementation, backed up with a financial analysis and financial business plan,[45] are presented in section 4.4 of this report.

The possible options for viable and sustainable utilisation of agricultural residues are presented in Table 4-1 below.

Table 4-1 Options for viable and sustainable utilisation of agricultural residues along the value chain. Source: own elaboration

Application	Feedstock	Outputs	Scale	Benefits/Impacts	Viability
Composting: Windrow Composting, Aerobic	Agricultural residues, green market or garden waste	Compost. Low yield, low quality	Variable. 1 tpd upwards, but takes a lot of space as production is slow	Simple application. Viable product, but needs additional nutrients	Low-medium. Compost has low market value
Composting: Aerated Static Pile, Aerobic	Agricultural residues, green/garden waste, food waste, chicken litter and dung	Compost. Medium yield, medium quality	Variable. 5tpd upwards. Uses less space and quicker production	More efficient process, can manage additional nutrient feedstocks	Medium. Product value can be enhanced with biochar

[45] Note that this is a financial overview addressing economic viability and not a fully structured bankable business plan

Application	Feedstock	Outputs	Scale	Benefits/Impacts	Viability
Composting: In-Vessel, Aerobic	Agricultural residues, green/garden waste, food waste, chicken litter and dung	Compost. Medium yield, medium quality	Variable. 0.5tpd to about 20tpd per unit. Modular	Quicker processing needs less space. Better quality	Medium, expensive and smaller scale
Composting: Static Pile, Anaerobic & humic	Agricultural residues, green/garden waste, food waste, chicken litter and dung, fish and abattoir waste, Sewage sludge	Compost. High yield, high quality	Variable from 1 ton per day, better economics > 5tpd	High quality, nutrient load and carbon content	High. High value biofertilizer and reasonably low-tech
Anaerobic Digestion	Agricultural residues	Energy: electricity or gas, low yield	Small to large scale. 300kg/day upwards	Energy and residue can be further composted	Medium to high. Compressed gas can be transported, direct energy needs to be close to grid
Incineration	Agricultural residues	Electricity, low efficiency. Ash, Heat and steam	5-200 tons per hour	Easy installation, simple steam turbine technology	Medium-high, needs secure offtake
Pyrolysis	Agricultural residues	Energy, fuels and char	0.5 to 3 tons per hour	Sound technology, quality outputs	Medium to high if scaled
Gasification, energy	Agricultural residues	Electricity, heat, biochar	0.5 to 5 tons per hour	Efficient output, high quality biochar	High. Heat market a benefit, quality biochar
Gasification, fuels	Agricultural residues	Biodiesel, heat. Biochar	0.5 to 5 tons per hour	More dependent on feedstock, but plug and play clean energy	High. Heat market a benefit, quality biochar
Vermiculture	Agricultural residues, but more green waste and clippings	Quality fertilizer, liquid foliar spray and fertilizer	0.1 to 5 tons per day	Easy to deploy at local level and replicable	Medium. More local input than economic business model
Agri-Protein	Agricultural residues, green waste and food waste	Protein feeds, oils and compost	0.1 to 5 tons per day	Huge impact on local protein production and food security	Medium to High. Market needs developed
Biorefineries	Agricultural residues	Various – vinegars, oils, essence, fertilizer, fuel	Various	High value product development	Medium to high

There is some circularity in some of the applications listed: sludge from anaerobic digestion can be reused in composting applications, or biochar from thermal applications can have high value in final bio-organic fertilizer compositions. Biochar can also be further refined to higher grade products such as activated carbon or graphite. Food security is not just about the crops in the ground but needs to extend to sustainable protein production as well. Agricultural residues can contribute to this through agri-protein production and application of biochar in poultry and this creates additional nutritive residues that can be recirculated in the system. There is no shortage of technology applications that can be applied in the region to address agricultural residues What is required is an understanding of the complexity of their implementation, their scale, location and access to market. The limitations of specific areas have been taken into account by the project team when assessing the economic viability and impact of opportunities in subsequent sections. A recommendation suggested from this is to address training, skills and capacity development in the region to understand regenerative circular agricultural practices and the economic, social and environmental benefits this can bring to local stakeholders.

To do so, understanding the metrics of the outputs is key, i.e., to measure, report and showcase the results. In terms of implementation, and this also needs to be assessed in regard to understanding implementer vs. beneficiary. A larger-scale project run by external Technology Application Providers (TAPs) may have greater impact in terms of the number of beneficiaries. Smaller-scale projects can be assessed at the local level should the capacity, expertise and resources be available; otherwise, training should be budgeted as part of the implementation. Moreover, availability of residues for a project's output should take cognisance of existing circular project development to ensure that competition for resources is minimised. If this is not considered, supply and demand may increase the prices of residues to the point where this would render certain projects unviable. Considering commercial realities, however, competition is also good as it will ensure that the strongest applications survive and thrive - this just needs to be done in a manner that will not impact the positive benefit to those at the base of the value-chain.

Whilst extrapolations are available of the residues in the different regions from the production statistics of the different crops, information on available collection infrastructure is lacking. Residues are often burnt in the fields as costs of transportation are prohibitive and there are no markets currently available. As part of the future opportunity regarding benefit to the farmers on the ground, a suggestion to ACMA3 would be to address logistical operations for collection, this point is further discussed in the recommendations. This can add additional benefit to farmers by providing them payment for their residues, as long as those expectations are managed. An alternative to incentivisation could be, for example, selling high-grade bio-organic fertilizer to the farmer at a reduced rate per ton if that farmer is supplying their residues to the project. The real benefit would be in supporting value- and supply-chains that benefit the farmers directly as well as sales of more affordable organic fertilizers to replace expensive purchases of synthetic fertilizers. This, in turn would directly save them in water usage, herbicides and pesticides, whilst increasing yields and nutritive value. Diversification of the agricultural sector would also underpin economic benefits and food security and provide additional materials into the beneficiation cycle.

4.3 Identification of relevant Dutch expertise in the identified opportunities

The project team has created a database containing the contact information of relevant Dutch technology providers (Appendix 1) and communicated via email the envisaged available residues (Appendix 2) to this database, requesting technology providers' inputs and participation. It should also be noted that whilst engagement with Dutch expertise and technology providers is a key part of this assessment, they should also be competitive in any future consideration. Several meetings have already been held, informing the outcomes and possibilities detailed in the sections below.

4.4 Development of business cases

Using the available information collected on the agricultural residues, the information was shared with Dutch technology providers in the database as well as through our own technology teams to assess the potential opportunities. Some of these opportunities are unpacked in this section of the report using a brief description of the technology and a financial summary indicating the potential feasibility of each application Note that these are not directly representative of the exact location or availability of residues, but indicative of the opportunity in the ACMA region with the specific technology application. In other words, these are presented as a desktop feasibility using the knowledge and technology expertise of the team compiling this report and by no means a bankability assessment. Recommendations will be provided to potentially address future project implementation in the region that yields maximum benefit to the beneficiaries.

4.4.1 Biomass gasification for Carbon Neutral Energy Needs

In Benin, there is an abundance of biomass that can be transformed into energy and other important products, and which would reduce the need for fossil fuel fertilizers. In the following points backed by scientific knowledge we illustrate that biomass to energy is the cleanest form of creating energy for Africa focusing on biomass waste and growing biomass for energy. Note that in growing biomass for energy, this is focussed on land not zoned for food crops, where additional productivity can be brought to marginal, unsuitable, or unutilised lands.

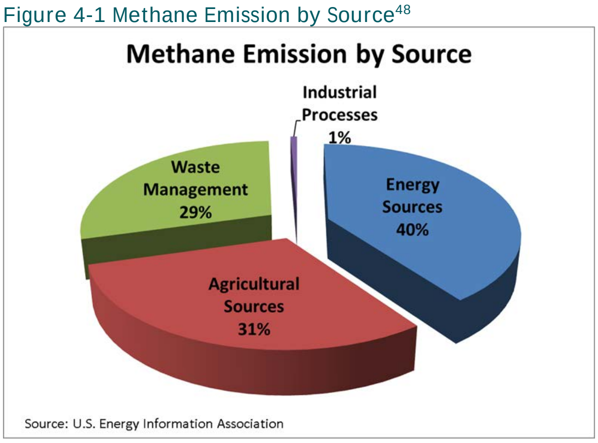
Introduction of waste biomass

Many countries have millions of tons of agricultural waste that is mostly burned, which damages the soils and can create runaway fires. When this biomass is burnt, you are releasing carbon dioxide and methane into the atmosphere and not getting any return from it. Present estimates indicate that biomass burning contributes between about 20 to about 60 Tera-grams per year of carbon in the form of methane to the atmosphere. This represents only 5 to 15% of the global annual emissions of methane.[46] Biomass burning like this also emits large quantities of ozone precursors to the lower atmosphere which are harmful.

In an anaerobic environment, biomass decays and produces methane, which is a valuable energy source. This methane can replace fossil fuels if harvested and not left to decay or be burnt in open fields. Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds.

The bioeconomy is one booming area for biomass, which is considered the largest renewable energy sector globally. "A core component to biomass and its benefits is how it plays a role in the bioeconomy".[47] Biomass fuels are a renewable resource because they can be replaced fairly quickly (times ranging from one growing season to perhaps one or two decades) without permanently depleting Earth's natural resources. By comparison, fossil fuels such as coal, petroleum, and natural gas require millions of years to be produced. Bioenergy, or energy derived from biomass, is a sustainable alternative to fossil fuels because it can be produced from renewable sources, such as plants and waste, that can be continuously replenished. And reduce our supply of gasoline – affecting national security. In addition, unlike other renewable energy sources, biomass can be converted directly into liquid fuels, called "biofuels" to help meet transportation fuel needs. The two most common types of biofuels in use today are ethanol and biodiesel, both of which represent the first generation of biofuel technology.

Figure 4-1 Methane Emission by Source[48]



[46] https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SUB1.PDF?Dockey=P100SUB1.PDF
[47] https://cnr.ncsu.edu/news/2021/01/biomass-a-sustainable-energy-source-for-the-future/
[48] http://theamericanenergynews.com/energy-politics/report-finds-declining-methane-emissions-natural-gas-development

When waste biomass is burnt or left to degrade, methane is released into the atmosphere, which could have been captured and used for energy and subsequently leaving high grade biochar. As methane is emitted into the air, it reacts in several hazardous ways. For one, methane primarily leaves the atmosphere through oxidization, forming water vapor and carbon dioxide. So not only does methane contribute to global warming directly but also, indirectly through the release of carbon dioxide. Methane (CH_4) is the second most important greenhouse gas. CH_4 is more potent than CO_2 because the radiative forcing produced per molecule is greater. In addition, the infrared window is less saturated in the range of wavelengths of radiation absorbed by CH_4, so more molecules may fill in the region. In the harsh sunlight of the upper atmosphere, methane can react with other gases to form water vapor, which then breaks down into other chemicals that destroy ozone. The largest source of anthropogenic methane emissions is agriculture, responsible for around a quarter of the total, closely followed by the energy sector, which includes emissions from coal, oil, natural gas and biofuels. In sufficient amounts of oxygen, methane burns to give off carbon dioxide (CO2) and water (H2O). When it undergoes combustion it produces a great amount of heat, which makes it very useful as a fuel source. Methane provides a great environmental benefit, producing more heat and light energy by mass than other hydrocarbon, or fossil fuel, including coal and gasoline refined from oil, while producing significantly less carbon dioxide and other pollutants that contribute to smog and unhealthy air.

In summary, methane emitted from Agricultural waste, bush encroachment, garden waste and alien invasion waste, if burnt or left to degrade, is twenty-eight times worse than using it in gasification to create energy. The waste from the gasification process is a high-grade biochar that if mixed with say chicken manure waste can replace the need for synthetic fertilizers entirely. The biochar has a slow release of the nutrients ensuring the plants get what they need when they need it. The biochar also acts as a carbon sink that helps to draw further carbon out the atmosphere for the plants to grow.

Figure 4-2 Growing Biomass for Energy Production

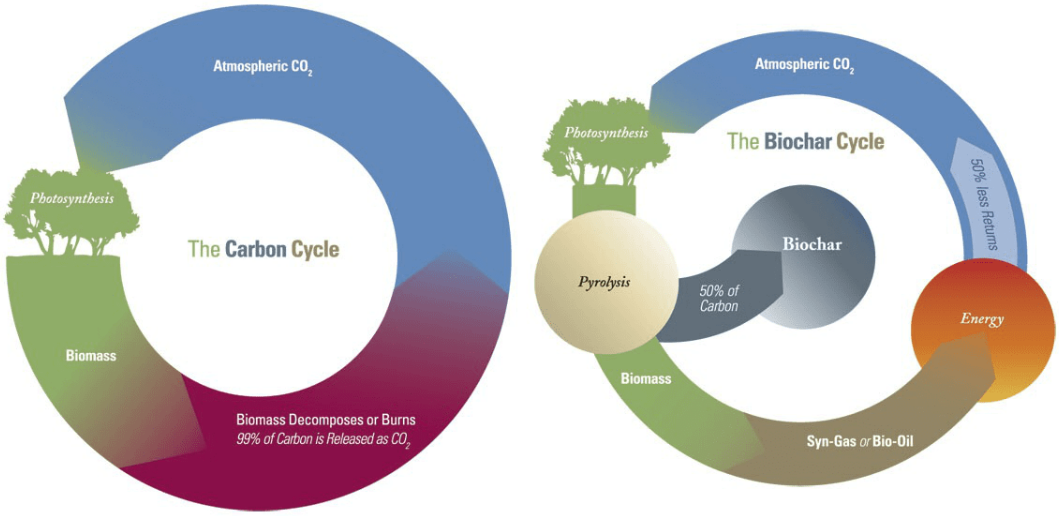
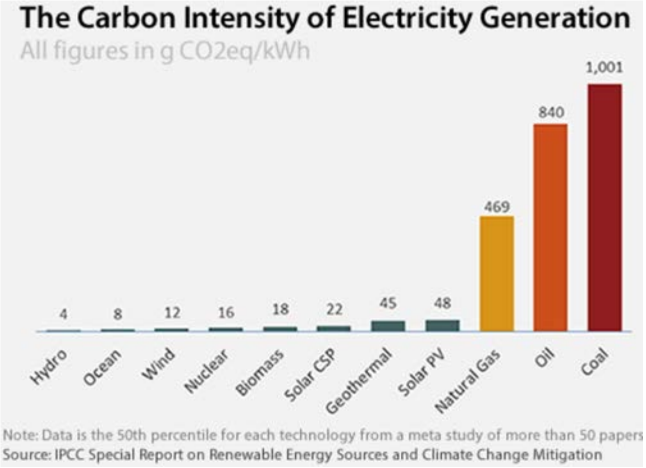


Figure 4-3 Carbon Intensity of Electricity Generation[49]



Growing biomass for energy production allows the grower to obtain carbon credits which can be as valuable as the harvest of the crop. Also, when you harvest the biomass, the roots are left in the ground to assist the carbon build up for the next crop cycles.

Many argue with the scientists regarding biomass been placed 5th on the scale of clean energy as in 99% of these claimed studies the carbon footprint to manufacture the plants, transport and erect them were not factored in. From our studies and assumptions, we believe that biomass should be ranked number 2 on the scale due to the waste from nuclear being so toxic and the fact the wind farms kill bird life and once they are at end of life both systems cost a fortune to remove. A gasification plant can be totally recycled and as the waste is a highly sought-after component of creating carbon sinks to grow additional crops, we believe these facts alone should place the technology as the second-best alternative energy source in the world. Benefits of biomass and growing biomass for energy are indicated below:

- Biomass mostly derived from plants, that means that as long as plants are going to be on this planet, biomass will be available as renewable energy source. Biomass helps reduce the amount of GHG that give more impact to global warming and climate change. The biomass emissions level is far smaller compared to fossil fuels.
- Biomass energy offers substantial economic benefits to the local community, by creating new jobs for the local community, improving economic growth, and creating a green environment through the reduction of emissions and air pollution.
- Biomass has many benefits, the primary one being that it cannot be depleted like fossil fuels. With an abundance of plants on Earth, biomass could be a primary source of renewable energy that's used as a sustainable alternative to fossil fuels.
- Growing your own biomass for energy production allows for power plants to be scalable based on the land size available.
- Biomass Sorghum trials in South Africa illustrate that 21 tons of dry biomass can be harvested twice per year to secure consistent supply to biomass power plants.
- Biomass Sorghum grows in arid conditions and therefore does not consume lots of water.
- Biomass Sorghum has a very high calorific value of 19 MJ per kilogram so using gasification technology one would use one ton to create 1 MWh of electricity.
- For every dry ton of biomass harvested, one can receive half a ton of carbon credits that can be used to add to the value of the crop or used to assist the funding process due to banks looking for carbon offset projects.

In summary, growing biomass is a very lucrative opportunity that can create thousands of sustainable employment opportunities for local communities. Growing your own biomass gives more stability for scaling up a power plant and represents a secondary earning opportunity by selling the carbon credits from the plantation.

[49] https://shrinkthatfootprint.com/greenest-electricity-source/

Table 4-2 Comparison of biomass potential with other renewable energy resources[50]

Resources	Technical potential [PJ / year]
Biomass	755
Sunlight	445
Wind	281
Geothermal Energy	220
Water	49

Growing biomass can replace fossil fuels reducing the carbon footprint of producing energy. Using this biomass in a gasifier can produce electricity, crude bio-oil, wood vinegar and biochar that can be converted into activated carbon. So, growing a biomass crop one can ensure that a plant has sufficient biomass to produce the power required.

Opportunity in Benin for using agricultural residues

Two main benefits could be derived from using agricultural residues:

- Reducing Electricity Shortage using Agriculture Residues; and
- Reducing Imports large volumes of fossil fertilizers using Agriculture Residues.

Thirty-two percent of Benin's population has access to electric power[51], with 1.1 TWh of total annual consumption, and an average peak daily load of 180 MW.

Benin is a relatively small country with very little base load electricity production and procures most of its electricity from Nigeria making the energy costs high and reducing the independence of Benin. With poor energy supply, it is difficult for Benin to plan and grow industry, agriculture, tourism and even the SMME sectors. Without a reasonable priced stable electricity supply Benin will struggle to grow and resolve poverty and so this is a key sector that needs to be addressed.

Benin has large volumes of agricultural residues with the largest volume coming from the Borgou province equalling 619,139 tons per year. The second largest volume is from Collines province with 184,234 tons and then Donga province with 139,051 tons per year. If these volumes can be collected to a central point in each province, these volumes combined can produce 79MW of clean sustainable carbon neutral base load electricity. (625,680MWhrs per year).

It would not make financial sense to transport the large volumes of the biomass to one central place but to build smaller systems in each of the provinces. One of the key reasons for this is that you can build micro grids and not have to build massive infrastructure across Benin at a very high cost. Energy Transition includes the challenge of centralised generation and then the one tied to distribution. Biomass offers additional solutions on base load and the solutions presented in this study are scaled energy generation at point-source that can deliver directly to remote areas on a micro-grid. These are relatively immediate solutions as opposed to centralised generation and distribution that can take decades. Therefore, with the biomass volumes Borgou could support a 52MW power plant, Collines a 15MW and Donga a 11MW. This is in a perfect world, so it would a recommendation that the approach to follow would be to design, supply and build smaller systems around the 8MW to 20MW size. This could target the residual agricultural waste in each area building up the processes effectively and also provide redundancy for when one plant needs to be serviced. Each plant is designed around to run 330 days of the year so one can see the logic in spreading the risk and load across multiple plants. Research[52] showed that Benin accepted a 4 MW biomass gasification plant to be built in 2017[53] - there is no proof

[50] https://www.researchgate.net/figure/Comparison-of-biomass-potential-with-other-renewable-energy-resources-in-Poland-5_tbl1_330781937
[51] https://www.usaid.gov/powerafrica/benin#Energy%20Sector
[52] https://www.thegef.org/projects-operations/projects/5752
[53] https://www.thegef.org/news/building-sustainable-energy-future-benin

we can find that this plant was every commissioned, but it illustrates that the desire is there for this type of clean energy.

Table 4-3 Capital investment Model for an 8MW Biomass to Electricity Plant

	CFA	USD
Revenue Electricity	3 238 931 520.00	$4 922 388.33
Tech Costs	360 175 500.00	$ 547 379.18
Payroll	392 796 300.00	$ 596 954.86
Admin	24 812 400.00	$ 37 708.81
Repayment of Capex	91 429 409.47	$ 138 950.47
Profit	2 369 717 910.53	$ 3 552 800.47
Capital Investment	7 874 514 200.00	$11 805 868.37
IRR	45%	
Payback	3.2 Years	

This model is based on project assumptions in neighbouring Togo and would be similar to conditions in Benin. This illustrates that the agricultural residues can really assist Benin in a viable, sustainable, profitable way. The numbers above are based on a financial model that was created for agricultural waste in Togo as we are not sure on the distances to collect the biomass and what the farmer will charge to stockpile their agricultural waste the numbers are not finalised. This would take a more in-depth review with visiting the farmers securing the biomass and understanding the distances and road conditions so we can fully understand the logistics costs. We would also need to negotiate with the local energy supplier who looks after the grid on obtaining a Purchase Power Agreement for the electricity produced. At this time, we would need to look at the interconnection structure and what will be required to tap into the existing grid. Here it is important to note that we would need to take into consideration the national policies on electricity production and distribution in Section 2.3.

Small-scale Containerised Biomass Gasification to Electricity

In Benin there is a lack of electricity infrastructure and building large scale power plants would mean that the power lines will also need to be upgraded. However, one can also change this approach with small-scale systems building a decentralised grid. Containerised power plants can be positioned where the biomass is collected and only need a shed to keep the biomass dry and to convert it into pellets. A plant will require 12 tons per day of pelletised biomass and will produce 480kW's of electricity. 60kW's of this energy is used in the process allowing 420kW's for usage. The real benefit of these plants is that they are easy to use and will give the user 333 days of uninterrupted supply. The plants are also stackable so one can add additional units as and when there is enough biomass and power requirements. These plants can be moved very easily to other areas offering the easy of mobility. So, if a mine, farm, Agri hub or even shopping centre changes their power requirements these units can be loaded and moved to other rural areas while the infrastructure is being built.

The by-product from the gasification process is a high-grade biochar that is highly sought after for the fertilizer sectors and the other by-product from these plants is the waste heat. This waste heat from the process should be used for drying food products, lumber from a sawmill, chicken farms, abattoirs to produce steam, etc. These small-scale plants really compare against diesel generators in size but produce the electricity at 25% of the cost per kW hour.

Table 4-4 Capital investment Model for the 480kW Containerised Gasification Plant

	CFA	USD
Revenue Electricity	352 098 432.00	$ 535 104.00
Revenue Biochar and Waste heat	303 204 400.00	$ 460 800.00
Tech Costs	30 004 800.00	$ 45 600.00
Payroll	79 552 200.00	$ 120 900.00
Admin	7 106 400.00	$ 10 800.00
Repayment of Capex	209 236 867.28	$ 317 989.16
Profit	329 404 565.06	$ 500 614.84
Capital Investment	1 501 740 240.00	$ 2 282 280.00
IRR	34%	
Payback	4.5 Years	

Note: For this financial model, we used the end users price point for electricity as this unit is too small to sell to the grid.

These projected financials are based on a generic application to Africa and not specific to Benin. These power plants are the solution for Africa as they can be deployed in real rural areas or mines that would have to use generators due to no electricity infrastructure close by. The numbers above illustrate they are financially viable and even profitable for the user.

Agricultural Biomass Residue to Pellets for Cooking and Heating Requirements

97% of the energy used in Benin is from biomass[54] mainly charcoal production[55] for cooking and heating purposes and even for the export market. When one zooms in on Google maps and analyse the energy situation[56] one can see that there are very little trees left and in the coming years this could be a major factor for Benin. The second option for the agricultural residue is to install small biomass pellet plants near where the residues are produced and pelletize the biomass. These pellets can replace charcoal for cooking using small rocket stoves that are better at combusting the fuel, thus use less fuel and produce less smoke, carbon monoxide and soot. This sector could take a while to educate the population on the benefits and savings using this format so we would recommend a slow set up and to build the offtake as the demand grows. These pellet plants can be as small as a ton per day through to 10 ton per hour dependant on feed stock and offtake. There is also an opportunity to export these pellets into the international market and they are fetching very high prices now with the energy shortage. However, better to build a local market and to keep the resource local of the peoples benefit.

Financial Model for a Biomass Pellet Plant

The financial model below is based on the current cost of biomass from the growers through to the current selling price of the pellets. These numbers are based on projections in South Africa because there is no pellet market in Benin so far. Assessing the pellet market in Benin would require a dedicated market study based on the prices of the different types of energy by location and type of client (domestic and industrial) and to evaluate the willingness to pay of final users (change of habits, cost of process modification to incorporate pellets). As we do not have all the costings and details for Benin these numbers may change but over all this is an amazing opportunity to stop the destruction of the forests and natural vegetation in Benin.

[54] https://www.usaid.gov/powerafrica/benin#Energy%20Sector
[55] https://au-afrec.org/benin
[56] https://energypedia.info/wiki/Benin_Energy_Situation#:~:text=Communaute%20Electrique%20du%20Benin(CEB,85%25%20of%20generation%20capacity).

Table 4-5 Capital investment Model for a Biomass Pellet Plant (10 ton per hour)

	CFA	USD
Pellet Revenue	3 425 113 720	5 205 340
Travel and Training	7 896 000	12 000
Tech Costs	130 284 000	198 000
Payroll	127 112 440	193 180
Marketing	14 739 200	22 400
Admin	28 812 504	43 788
Repayment of Capex	702 345 252	1 067 394
Profit	2 421 820 324	3 680 578
Capital Investment	5 518 185 400	8 386 300
IRR	84%	
Payback	1.8 Years	

Chicken Manure Opportunity

Another key factor noted is that fossil fuel fertilizers are in the top ten of Benin's imports[57] and costs to the fiscus. With the advancement and understanding of soils and how to give them the best nutrients it is now proven that fossil fuel fertilizers cause damage to the soils as they kill the microbial balance of the soils. There are two very simple systems to create an organic fertilizer system that is proven to increase the yields of the plants grown.

Currently Benin has 5,500 tons of chicken litter and manure per year which is 458.3 tons per month. A static pile microbial humisoil system[58] will convert this resource into a high-quality fertilizer that is better for the soils at a fraction of the costs of fossil fuel fertilizers. As there is chicken litter in multiple provinces with the largest being Zou with 1,469 tons then Collines with 1,197 tons and Borgou with 1,189 down to the smallest being Plateau prince with 557 tons per year one can produce this organic fertilizer at each site where it is produced. This approach will assist the farmers in the area and reduce the costs of logistics while increasing their food production capabilities. Another advantage is that you are only using one ton per hectare so with the volumes produced you will have a 5500-hectares fertilized and after year three you can reduce the volumes used per hectare and can focus on additional areas. One can even add in sewerage, animal waste, other biomass to ensure that we have the volumes required for the agricultural sector.

Chicken Manure makes a great fertilizer once processed and the process is not smelly, and it also does not attract flies. If there are dead birds or offal from the abattoirs available this can be added to increase the nutrients. From all the trials completed this process illustrates massive gains in both yield and quality. This is potentially the holy grail for farmers as they will halve their costs, rebuild the soils, decrease costs and increase profits on a long-term sustainable basis.

Financial Model for Microbial Organic Fertilizer

The financial model below was based on a client need in Mauritius and shows that even a smaller set up is financially rewarding. With the volumes available in Benin, we would need to design the entire process with the manufacturing of the microbes required through to all the equipment required for each and every department.

This process will require a team to visit all the sites and assess what will be required to get the plants set up and running by first identifying potential local actors and partners.

[57] https://globaledge.msu.edu/countries/benin/tradestats

[58] https://www.vrm.science/success-stories

Table 4-6 Capital investment Model for Microbial Organic Fertilizer Operation (17,000 tons per annum input)

	CFA	USD
Total Revenue	421 196 160.00	$ 640 115.74
Tech Costs	21 978 000.00	$ 33 401.22
Payroll	111 296 000.00	$ 169 142.86
Marketing	3 385 500.00	$ 5 145.14
Admin	39 471 600.00	$ 59 987.23
Repayment of Capex	74 870 446.45	$ 113 784,87
Profit	170 194 613.55	$ 258 654.43
Capital Investment	537 362 100.00	$ 816 659.73
IRR	65%	
Payback	2.2 Years	

This option is a winner for Benin as most of the farmers have over-worked their farms and the soils are currently in need of restoration. This application will substantially increase yields and quality while reducing their costs inputs on unsustainable synthetic products. Fossil fuel fertilizers have killed the microbial balance in the soils and the only way to fix this is to direct regenerative technologies to achieve long-term sustainability. When considering an output on saleable organic fertilizer of 12,000 tons a year at $100 per ton, current synthetic fertilizer costs of above $600 per ton, this would save local farmers $6 million a year in costs, so the capital required for this is almost irrelevant.

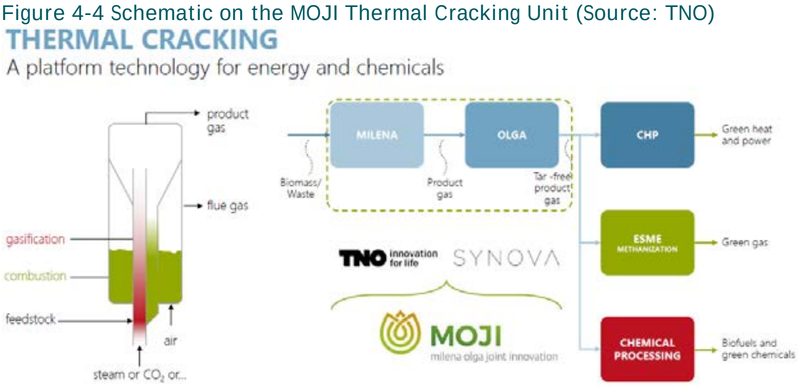
4.4.2 TNO Biomass Conversion Technologies

Through the Innovation for Development programme, the Dutch organisation TNO has collaborated on several smart application technologies for beneficiating biomass.

Thermal Cracking

TNO and SYNOVA have developed a system combining Milena and Olga technologies to create the Milena Olga Joint Innovation (MOJI) thermal cracking process to convert agricultural residues to biofuels and green chemicals.[59]

Figure 4-4 Schematic on the MOJI Thermal Cracking Unit (Source: TNO)



TORWASH

The Dutch Water Authorities produce 1.3 million tons sewage sludge per year and the sludge disposal/treatment cost are between 115 – 250 M€ per year. A technology called Torwash[60] reduces the amount of sewage sludge (or optionally manure) with 85 % and has as a product a dry hydrophobic and brittle pellet that can be combusted. The remaining liquid can be efficiently fermented to biogas. Process applied is hydrothermal without additives (high pressure 25 bar and

[59] https://www.tno.nl/en/newsroom/insights/2022/07-0/forming-new-value-chains-circular/
[60] https://www.tno.nl/en/sustainable/co2-neutral-industry/biobased-fuels-chemicals/torwash-technology-succesful-waste-water/

temperature 150-250ºC). Water and salt are pressed out of the sludge. Torwash performs better than centrifuges or decanter methods. Point of attention is the phosphorous content of the pellets. Pilot facility (50 kg/hr) available in transportable container. Next generation aims for min. 1 ton/hr and is under development. TNO spin-off: https://www.torwash.com/ has the license for sewage and industrial sludge.

Figure 4-5 Torwash system (Source: TNO)

Figure 4-6 Torwash feedstock issues (Source: TNO)

Use of agro waste is challenging because of:

- Too high a salt content (K, Cl)
- Too high a water content
- Low energy density
- Difficult to grind, homogenous blend with coal not possible
- Bio-degradability

Torwash combines advantages and eliminate disadvantages in the following ways:

- Washes out harmful salts
- Makes pellets water repellent
- Prevents pellet degradation and water adsorption
- Bulk density and energy density closer to coal
- Brittle and easy to pulverize to blend with powder coal
- Flexible in feedstock
- Homogeneous final composition
- TORWASH Black Pellets show even tighter specs than wood pellets and can be processed within a coal feed stream

Figure 4-7 Biomass pellets with Torwash (Source TNO)

Figure 4-8 Torwash Feedstock Examples (Source: TNO)

Black pellets have the following market advantages:

- Minimum boiler efficiency loss (low VOC's, high grindability);
- Minimum boiler corrosion risk (chlorine removal);
- Optimal boiler bed stability, no slagging (potassium removal);
- Lower feedstock price;
- Co-firing in coal fired power plants possible.

A real commodity fuel: easy trade, transport and storage

- Not affected by moisture;
- Not affected by fungi or bacteria;
- Lower transport costs by higher energy density.

Figure 4-9 Comparison of Torwash black pellets Vs coal and wood pellets (Source TNO)

BLACK PELLETS VS. COAL VS. WOOD

	Torwash pellets	Coal	Wood pellets
LHV (MJ/kg)	18 - 22	23 - 28	17 - 18
Bulk Density (kg/m³)	700 – 1000	800 - 850	600 - 620
Cl-content	0,02	N/A	0,02
K-content	0,03	N/A	0,03
Grindability	Easy to grind	Easy to grind	Difficult to grind
Shelf life time	One year	Infinite	30 days

Figure 4-10 Torwash Financial Investment

DEMONSTRATION

Specifications:

- Input: 400 ktons FFB
- Output: 27 ktons black pellets
- Integrated in a CPO mill
- Project duration 12-24 months

Utility requirements:

- Water 15,000 m3 industrial quality
- Electricity 950 MWh
- Heat 50.000 GJ

Preliminary calculation for feasibility study: no rights can be attached

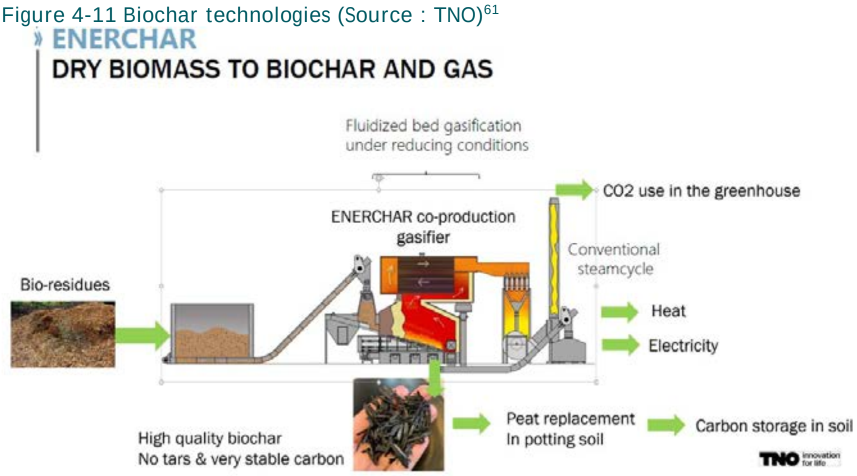
Financial Key Numbers Torwash Investment

Technical details			
FFB in	400000	ton/yr	
Black Pellets out	27932	ton/yr	
CAPEX			
Total CAPEX	$5.097.555		
P&L			
Revenues of black pellet sales	$2.793.244	$100	$/ton
Revenues of non food oil sales	$0	$350	$/ton
Operational Expenditures	$573.921		
Depreciation	$509.755		10 yrs depr period
Profit per year	$1.709.568		
Pay back time	2,98	years	
IRR	18,3%		
Return of Investment	34%		

EnerChar

An additional component to the TORWASH options is then the gasification of materials to biochar and gas using the EnerChar system also facilitated through TNO.

Figure 4-11 Biochar technologies (Source : TNO)[61]



BIOCHAR

Why biochar plus bio-energy and why large scale:

- You can make biochar by pyrolysis (only heating of the feedstock) and by gasification (lean oxygen).
- At the elevated temperature, the biomass feedstock degasses and produces a combustible gas.
- It can replace fossil fuels; biochar captures CO2 and fertilizer ingredients. Has no nitrogen, but this could be added. Char has extremely low tar concentration.
- Prevents problems with slacking/agglomeration and corrosion due to problematic components in biomass.
- Economically attractive: two products with economic value.
- Scaling helps economics; presently 0,5 MWth pilot in Petten; next step 5 MWth prototype.

Regarding Horti-BlueC, for a greenhouse location 15 MWth input (20.000 ton) and 4500 h of heat requirement are aimed for, whereas for an industrial location, 25 MWth and 8000 h could still be realized with local sources of bio-residues.

[61] https://ilvo.vlaanderen.be/uploads/documents/Horti-BlueC-Webinar-1-TNO-Rian-Visser.pdf

4.4.3 Advanced Biorefinery Application in the value-chain

EV biotech is a Dutch company using agricultural residues through fermentation to develop products in the field of biorefinery, which are of higher value than composting. The process begins with a feasibility study which tests whether the project is worth investing R&D costs into (biological pathway search, patent search, technical feasibility, financial feasibility, and identification of business opportunities).[62] Such reuse of agricultural residues into biorefinery applications in value chains present opportunities that require more R&D but can be profitable to farmers that could sell their agricultural residues to companies commercialising derived products.

Biorefinery industry development offers unique opportunities in creating much higher values from waste, but in more advanced technological applications that may not yet be practical in Benin. However, these should be considered in future assessments for the country in developing advanced value chains for its agricultural residues. High lignosic wastes can be processed to create products such as wood vinegar or more advanced applications such as hydrolysis to extract biofuels from cellulose and hemicellulose. Other products include ethanol, hydrogen, carbon char, bio-oils, flavourings, industrial glues, and other industrial chemicals.

4.5 Funding options for project developments in Agri-residues

The Dutch Rabobank partnership provides expertise and funding opportunities in the fields of financial system transformation and food system transformation in developing countries. Impact is created around the four following pillars:

- Advisory: conducting advisory projects and structuring fee-driven digital ecosystem solutions.
- Investments: investments in emerging markets.
- Impact finance: structuring and blending public and concessional funding with commercial finance to trigger food system change in emerging markets.
- Smallholder ecosystems: developing a digital, scalable and profitable Rabobank proposition towards food and agriculture clients and (smallholder) farmers in emerging markets.[63]

This partnership could contribute to financing projects that aim to recycle agricultural residues in Benin. The AGRI 3 Fund, which was created as part of the Partnership for Forest Protection and Sustainable Agriculture, is an example of initiative that could be used by stakeholders in the agricultural sector of Benin to finance the development or deployment of circular technologies. The AGRI 3 Fund provides guarantees to commercial banks and other financial institutions and subordinated loans to customers of these institutions to mobilise financing by de-risking and catalysing transactions that actively prevent deforestation, stimulate reforestation, contribute to efficient sustainable agricultural production and improve rural livelihoods.[64]

Another Rabobank initiative is Acorn: Agroforestry Carbon Removal Units (CRUs) for the Organic Restoration of Nature. The rationale underlying this initiative is to support the livelihood of smallholder farmers while combatting climate change, land degradation and food insecurity, as well as to provide clients with high integrity carbon removal units and build new capabilities for the bank. As such, this initiative provides opportunities for farmers to sell carbon sequestration units internationally. In addition to this financial benefit, carbon farming contributes to achieving a more diverse diet (shift away from monoculture), healthy soil and improved climate resilience. This transition can be supported by the partnership via grants, loans, blended finance funding, impact bonds, or a technical assistance facility. Currently, Acorn has projects in seven African countries.[65] While opportunities under Acorn specifically relate to agroforestry,

[62] EV Biotech (2022) Introduction slides
[63] Rabo Partnerhips: Spreading your wings
[64] https://agri3.com/#TheAgri3Fund
[65] Rabobank. Acorn: Agroforestry Carbon Removal Units (CRUs) for the Organic Restoration of Nature

participation by farmers in Benin switching to an agroforestry system could contribute to enhance their financial capabilities and enable them to invest in the circular use of agricultural residues.

In addition to Dutch applications, there are a plethora of global financing initiatives addressing regenerative agriculture and food security. Conservation international has a Regenerative Fund for Nature that seeks to transform agricultural practices. Regeneration International has a list of 37 funding organisations looking at regenerative agriculture. Restore Africa Fund is specific to Africa investing in climate-smart conservation and regenerative agriculture. These represent just a few of the international options available for funding in this sector.

4.6 Recommendations on activities for ACMA3

Through reporting methodology, we have already identified several recommendations for ACMA3 to consider for their future operations. Recommendations identified thus far include, but are not limited to:

- to form some level of structure to enhance communication and collaboration between the many actors in this field to drive the circular economy agenda in agriculture
- to address training, skills and capacity development in the region and also look at education across the value-chain to understand and ultimately accept and embrace the opportunities for implementation. Specifically, skills and capacity in understanding the benefits and opportunities of transitioning to a circular economy, as well as the impacts and outcomes.
- to address logistical operations for collection and payment/benefit to farmers for their residues identified in Section 4.2 as an opportunity to add additional benefit to farmers and secure feedstock for further processing and potentially supply affordable organic fertilizers or energy as an outcome.
- Section 3.2 illustrates some local applications in Benin following circular approaches to agricultural residue applications. However, detail on these is scant and these all work in isolation somewhat limiting their efficacy. The formation of a Circular Economy Platform could bring these initiatives together and share information and resources to meet the country's needs in this respect and could also bring some level of structure to enhance communication and collaboration between the many actors in this sector. This could in turn increase the chances of success of projects by enabling more learning and collaboration.

The results of the calculations on agricultural residues carried out in this study should not be considered as precise. Indeed, they are based both on agricultural production results from 2015 to 2021, which are themselves affected by a certain approximation, and on the FAO calculation module, which is by definition an estimate. However, the objective was to provide initial figures to identify residue deposits, to have an order of magnitude to base circular business models on. It will be important, prior to the implementation of any models, to carry out a more circumscribed availability study for targeted residues. Similarly, no matter how good the feasibility study is, it is impossible to identify all the supply challenges, as the success of a circular economy project depends greatly on its ability to adapt and innovate in the face of raw material input challenges.

This study did not address in detail the supply logistical aspects due to the impossibility of a general logistical approach (all agricultural sectors, all locations, all technical proposals, etc.). Indeed, the logistical aspects are strongly modified according to the type of residue, the intrinsic value of the residue (its calorific value, its sugar content, etc.), the accessibility of large producing farms taken individually, the need for pre-collection by small producers, the competition for the acquisition of residue, etc. We recommend, when setting up a specific circular economy project, that a particular focus should be put to assess the logistical costs of acquiring the residues (several routes hypothesis to consider). This analysis can strongly modulate both the geographical positioning of the industrial unit and the mode of acquisition/collection of the residues.

4.7 Recommendations from the findings

There are undoubtedly substantial volumes of agricultural residues in Benin as estimated within this report and several broad financial analyses have been presented indicating the potential application and opportunities for Benin. Benin may not yet be adequately positioned to address Biorefinery applications, but in the interim should at least look to some of the simpler packaged solutions around energy and bio-organic fertilizer production. These do not have huge capital expenditure requirements and indicate profitable paybacks within 1.8 to 4.5 years. The research in this report clearly indicated that access to electricity is a key issue in the country and that a significant spend for the country is in imported synthetic fertilizers. Both issues could be addressed to a significant extent making use of the available agricultural residues in the country.

Taking a Circular Economy approach affords us the opportunity to extend our views to future options in complementary organic waste feedstocks in chicken litter, feedlot waste, fish waste, abattoir waste, municipal solid waste, and sewerage sludge waste. Although not the focus of this report, we have tried to assess some of this information as this needs to remain on the radar for ACMA as additional feedstocks that could supplement technology development in this field. Some of these applications are simply no-brainers. The microbial organic fertilizer option, although the cheapest, appears expensive at $820,000 investment and 2-year return on investment. However, if we consider that this would offset 12,000 tons a year of imported synthetic fertilizers at a saving of $6 million a year to the farmers, it really contextualises the value of this investment. The summary financial assessments provided are extracted from complex financial models developed by the project team for commercial applications across Africa. These can be unpacked to illustrate all the input and Capex costs, operational costs and jobs created for each, but can then also be expanded to understand the indirect impacts such as job creation and skills development, as well as cost savings from water savings and reduced needs for chemical herbicides and pesticides; then further developed to address potential Carbon Offset returns that could accrue.

The energy options are similarly impactful as energy is the base of all future development in the sector to add value through cold-chain storage and agri-processing facilities that could add substantially to the value of crops and farmers in the region, as well as contribute to sustainability in human health and education in the region with the advantages that electrification bring.

A recommendation from this report would be to unpack at least two of these investment opportunities for the country and implement them. This will require additional resources as these broad feasibility assessments need to then be populated with exact information based on their inputs, location and outputs to get this to an acceptable bankability stage for investors. However, the options to address this are also discussed in this report with the likes of the Dutch Rabobank and other global investment options where assistance can come in project development assistance to financial investment in the application.

Opportunities in circular economy in the agricultural sector should maximise benefit to local stakeholders – the farmers and their communes. Basic applications should be practiced on-site that require little to no additional capital investment or simply more effort on the part of the farmer. These include simple composting, mulching, vermiculture, permaculture applications such as bioswales, and these should be presented as per the recommendations in developing a CE platform and skills development programme to teach these simple methods. These are basic skills that could be provided through the likes of INRAB or ACMA using available free online methods[66]. Courses could also cover simple agri-processing methods to add value to crops and reduce post-harvest losses like drying or manufacture of pickles, and

[66] https://www.freepermaculture.com/ https://www.permaculturewomen.com/courses/

juices[67]. Slightly more expensive options such as home biogas systems and Black Soldier Fly applications would need more training. However – to get real solutions to scale would provide maximum benefit to a greater number of beneficiaries and substantially change the dynamic through the likes of electricity production and bio-organic fertilizer production where these would greatly enhance production, reduce post-harvest losses (cold chain and processing), massively reduce costs to farmers offsetting costs in water, fertilizers, herbicides, and pesticides and reducing impact on environment and biodiversity.

If we are looking at scaled applications there would need to be an agglomeration of residues, else we are limited to permaculture activities at the farm level, and this would need to be incentivised. Put into perspective, the details on the residues are aggregated at a level in this study that suggests relative availability and distribution. Second stage implementation would require a guarantee of supply and site-specific details to address any due diligence requirements for investment. This is a key aspect where ACMA could support the ignition of large residue collection systems, the intention would not necessarily be for ACMA to undertake this, but facilitate a process identifying a private sector investor who could cease the opportunity and engage with the farmers.

Through additional engagements with Dutch agencies, there is also a willingness to take some of these recommendations further to project implementation with Rabobank and TNO where additional resources can be allocated to specific project identification, stakeholder analysis, project partner identification, material sourcing and project development to create bankable options through the above suggestions.

The main recommendation from this study is that Benin should not be asking if they should be investing in these opportunities, but when.

67 http://www.freeonlinecoursesforall.com/2022/02/27/10-free-online-agro-food-processing-courses/

APPENDIX 1: Database of Dutch Technology Providers:

Names and emails in original database, not provided here for privacy reasons

Name of organisation	Website
The Waste Transformers	https://www.thewastetransformers.com/
EV Biotech	EV Biotech
Eneco Group	Climate Neutral Faster | Eneco
Blackwood Technology	http://www.blackwood-technology.com/
BTG Bioliquids and BTG Biomass Technology Group	https://www.btg-bioliquids.com/
BTG Bioliquids and BTG Biomass Technology Group	BTG Biolifides | Nous remplaçons les combustibles fossiles (btg-bioliquids.com)
Twence	Home - Twence
Loop	_https://www.loop-of-life.com/
Parenco Hout	https://www.parencohout.com
NewFoss	Home - Newfoss
Van der Wiel	Van der Wiel - Infrastructures, environnement et transports : Van der Wiel
Feedtuber	https://feedtuber.com/
Bio Energy Netherlands	FR - Bio Energy Pays-Bas (bioenergynetherlands.nl)
Holland Biomass	Home - Holland Biomass 4 Energy Solutions
Avantium Technologies BV	https://www.avantium.com/
BFP International BV	BFP International BV (bfp-international.com)
Delft University of Technology	Université de technologie de Delft (tudelft.nl)
DNV-GL-KEMA	KEMA Laboratories va changer de propriétaire de DNV GL à CESI
DSM	Royal DSM N.V. - Bright Science. Une vie plus lumineuse. ™
Ecofys	_https://guidehouse.com/capabilities/industries/energy-sustainability-infrastructure
Energy REsraech Centre of Netherlands	ECN: Recherche sur l'énergie
FeyeCon D&I BV	FeyeCon - Supercritical CO2 Technology
LyondellBasell Industries	LyondellBasell Industries | LyondellBasell
Petroquantum	www.petroquantum.com
Rabobank International	The Netherlands (rabobank.com)
Shell Global Solutions BV	Shell Catalysts & Technologies | Shell Global
SkyNRG	SkyNRG - Carburant d'aviation durable
TNO	L'innovation pour la vie | TNO
Wageningen University & Research Centre	https://www.wur.nl/en.htm

APPENDIX 2: Summary of Agricultural Residues shared with Tech groups

Maize group residues (in t/year)

MAIZE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Maize stover	153,872	38,326	71,561	51,110	39,618	144,177
Maize husk	33,852	8,432	15,744	11,244	8,716	31,719
Maize cob	50,778	12,647	23,615	16,866	13,074	47,578

Other cereal group residues (in t/year)

GROUPE DES AUTRES CÉRÉALES	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Other cereals stalk	15,149	6,417	1,287	342	-	-
Other cereals husk	3,333	1,412	283	75	-	-
Other cereals cob	4,999	2,118	425	113	-	-

Rice group residues (in t/year)

RICE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Rice straw	3,947	4,748	13,704	1,794	1,450	998
Rice husk	2,350	2,826	8,157	1,068	863	594

Tubers group residues (in t/year)

TUBERS GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Stalk	42,607	15,533	45,301	16,192	3,654	31,769
Peelings (dry matter)	54,068	19,607	57,577	20,411	4,266	40,394

Groundnut group residues (in t/year)

GROUNDNUT GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Husk	2,278	2,206	9,785	5,970	499	943

Pulses and soy group residues (in t/year)

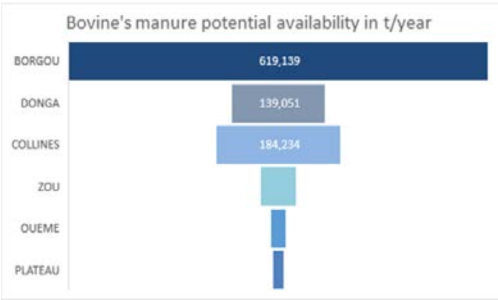
PULSES AND SOY GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Straw	55,029	12,440	39,943	23,749	4,018	8,084
Pods	49,526	11,196	35,949	21,375	3,617	7,276

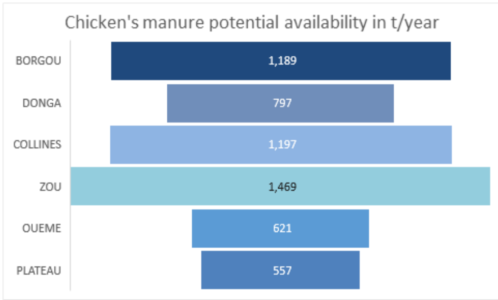
Pineapple group residues (based on wet matter percentage, t/year)

PINEAPPLE GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Plant leaf residue	-	-	2,135	512	368	794
Peel	-	-	268	64	46	100
Fiber paste	-	-	726	174	125	270

Cashew group residues (dry matter if not specified, t/year)

CASHEW GROUP	Borgou	Donga	Collines	Zou	Ouémé	Plateau
Cashew apple (WM)	281,515	163,010	316,912	55,015	518	15,486
Cashew shell (%WM)	2,641	1,529	2,973	516	5	145
Cashew nutshell liquid	792	459	892	155	1	44
Testa (WM)	845	489	951	165	2	46


Bovine's manure potential availability in t/year
BORGOU
619,139
DONGA
139,051
COLLINES
184,234
ZOU
OUEME
PLATEAU


Chicken's manure potential availability in t/year
BORGOU
1,189
DONGA
797
COLLINES
1,197
ZOU
1,469
OUEME
621
PLATEAU
557

Trinomics B.V.
Westersingel 34
3014 GS Rotterdam
The Netherlands

T +31 (0) 10 3414 592
www.trinomics.eu

KvK n°: 56028016
VAT n°: NL8519.48.662.B01

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Prinses Beatrixlaan 2
PO Box 93144 | 2509 AC The Hague
T +31 (0) 88 042 42 42
Contact
www.rvo.nl

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