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The Potential Biomass Resources for a Sustainable Bioenergy Planning in West Africa: Insight from Niger

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Abstract
Sub-Sahara Africa main energy supply comes from forest and coal mining. Indeed, wood is largely the most energy source that has been using in Niger, leading several environmental and climate impact. Consequence of the limited power Supply; and the weak alternative for upgrading existing energy production resources and technologies. This study aimed at: estimating the biomass resources, characterizing Niger bioenergy technologies and, assessing the potential sustainable biopower capacity. The method had involved a literature review, a survey; processing of spatial data (Land Use Land Cover, Plant Dry Matter, GIS); and evaluating their expected thermal value. The results shown, a significant potential of biomass deposits of which respectively 651,788,458 tons/Ha/year, 6,935,764 tons/year, 20,876,240 tons/year, and 322,784,07 tons/year for forest resources, agricultural residues, livestock dung, and organic MSW. These resources ought to produce up to 5.71335001.〖10〗9 EJ through methanization and efficient clean combustion. the possibility from biomass resources in durable bioenergy can resolve many conservation challenges. Therefore, deep investigations in the designing program, projects are important for sustainable perspectives regarding green bioenergy resources. And energy policy strategies must be developed, adapted promoted in order to help sustainable bioenergy well integration especially in rural area, despite all the potential barriers.

Keywords: Dry Matter, Biomass, Bioenergy, Waste, Sustainable Energy, Niger, West Africa

Abbreviations

AGRHYMET : Centre Climatique Régional pour l'Afrique de l'Ouest et le Sahel (Regional Climate Center for West Africa and the Sahel).
AMU: Abdou Moumouni University.
BZ: Bioclimatic Zone
Cmd : Commander (Forest military)
CNSEE: Centre National de surveillance Ecologique et Environnementale (National Center of Ecological and Environmental Monitoring
DGEF: Direction Générale des Eaux et Forets (General Direction of Environment and Forest)
DM : Dry Matter
DS/ MAG/EL: Direction de Statistique/Ministère de l'Agriculture et de l'élevage (Statistic Direction/Ministry of Agriculture/Livestock.

GDP: Gross Domestic Product
GHG: Green House Gas
GIS: Geographical Information System
Hbts: inhabitant
IEA : International Energy Agency
INRAN : Institue Nationale de Recharche Agronomique du Niger (National Institute on Agronomic Research in Niger)
INS: Institue Nationale de la Statistique (National Institute of Statistic)
IRENA: International Renewable Energy Agency
IUCN: International Union for Nature Conservation
LULC: Land Use Land Cover
ME: Ministère de l'Energie (Ministry of Energy)
MSW: Municipal Solid Waste
MW: Megawatt
NGOs : No Governmental Organisation
OM: Organic Matter
OS: Occupant of Soil
PDM: Plant Dry Matter
RPR: Residue Production Rate
SEforALL : Sustainable Energy for All
t-test: Student Test
UN: United Nation
USD: United State Dollars
ZHA: Huper Aride Zone
ZA: Arid Zone
ZSA: Semi Arid Zone
ZH: Humid Zone
WAC-SRT: West African Center for Sustainable Rural Transformation
WASCAL: West African Science Center on Climate Change and Adapted Land Use

1. Introduction

Traditional biomass energy approach has led to an inefficient power production, various health issues and deplete natural forests [1]. This practice results several impacts on natural resources and still contributing to ecological imbalance, despite the reforestation efforts and the various forest management programs [2,3]. Consequently, around 200 km² of forest is lost worldwide to meet fundamentally Human needs [4-6]. Thus, the daily energy needs for household cooking in Sub-Sahara Africa are met by firewood and charcoal [5]. Thus, by 2050 combined effect of land degradation and climate change could cut crop yields till 10% and, increase the risk of diseases, population displacement and various disasters like acridoidea invasion, erosion, drought, flood etc [7]. In Niger, firewood is the more atractive energy source although the unsustainable use of this resources, leads to an overexploitation and loss of forest areas of about hundred thousand hectares per year [8]. As alternative to autonomous and sustainable energy system (SDG7) and, implementing the Paris Agreement on Climate Change biomass can play an important for development and improving efforts [9-11]. Thus, new alternatives with less negative outcomes from bioenergy will be very interesting. However, the potential future biomass resources for bioenergy could come from agricultural residues and invasive plant species [12]. That alternative sustainable bioenergy contributes in the achieving of positive development ambitions and, can be a reason to mitigate negative consequences of climate change and environmental hazards in the country [9]. This study aims to estimate biomass resources, and review the literature of the current bioenergy technologies and, assess the potential sustainable biopower generation in Niger.

2. Materials and Methods

2.1 Study Site

2.1.1 Geographical Location

Niger is a Sahelian and landlocked country, with a land mass area of 1 267 000 km² and, located in the Western part of Africa between the parallels 11°37 and 23°33 north latitude on the one hand and, the meridians 16° east longitude and 0°10 West longitude on the other hand. The Republic of Niger shares land borders with seven counties [8].

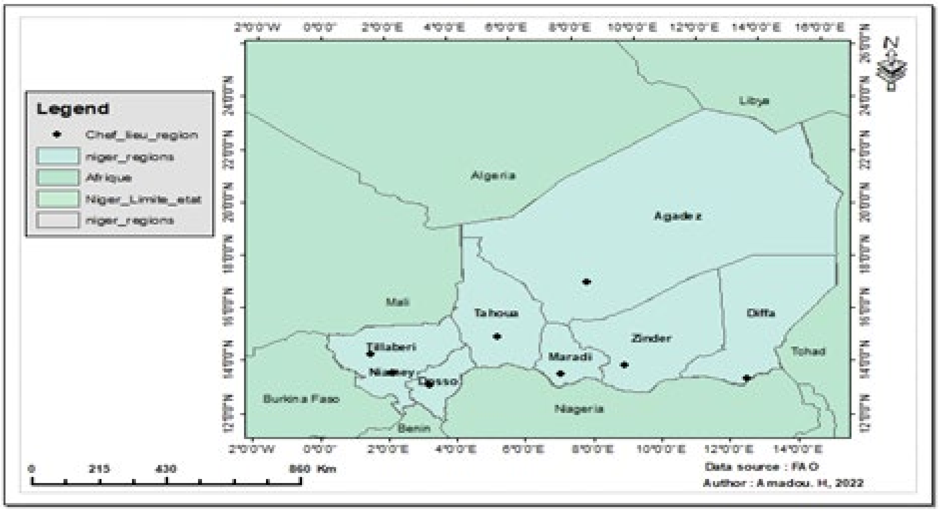

Figure 1: Niger Map With the Regions and the Limits Countries in West Africa

2.1.2 Demography

The country has a population estimated at 21.942.943 million of person such as 10 905 994 Men and 11 036 949 Women, with a population growth rate of 3.83 percent [13,14].

2.1.3 Climate Condition

The climate of Niger is dry tropical type, characterized by high temperature. Rainfall is linked to the seasonal swing of the intertropical front [15].

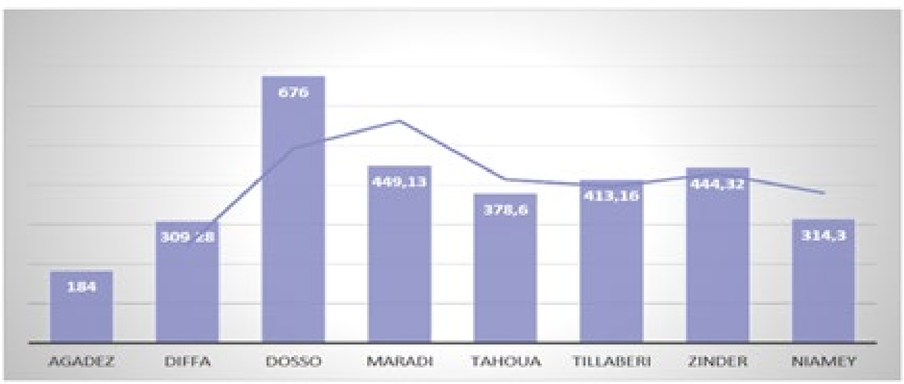

Figure 2: Cumulative Rainfall in 2019 [16]

With normal rainfall (1981-2010) varying between 150 and 300 mm and, based on the 1961-1990 climate series, the duration of the rainy season varies on average between 60 and 120 days for the central and western Sahel. In the northern and eastern Sahel, an average of 40 days of rainfall is observed Generally, there is a dry and cold season from November to February, during which temperatures drop significantly below 10°C [14]. A dry and hot season from March to June, with hot and dry wind. The maximum temperatures easily exceed 40°C in the shade [15].

2.1.4 Relief and Soil

Niger is characterized by low altitudes (200 to 500 m) with a relief marked by mountainous massifs in the northwest (Aïr massif), plains and plateaus in the south [17]. It is composed of five (5) geomorphological units: the Plateau (mostly made up of ferruginous soils), the slopes, the glacis, the sandy skirts, the lowlands (alluvial plains, they consist of the main valley) [18].

2.1.5 Natural Resources

The country is one of the largest producers of uranium, being ranked 4th in the world. Other important natural resources are gold, iron, and coal. It also has gas and oil deposits [8]. Niger has one river and a lot of pond (permanent and semi-permanent).

2.1.6 Biodiversity

The flora of Niger comprises about 2217 species including 1575 Phanerogams, 14 Pteridophytes, 10 Bryophytes, 71 fungi and 547 Algae [19]. In addition, 478 newly known for Niger raises the flora to 2695 plant species. The bioclimatic layering of Niger allows the country to have a rich and varied fauna composed of at least 3200 animal species including 168 species of mammals, 512 species of birds, 150 species of reptiles and amphibians, 112 species of fish and many invertebrates (molluscs, insects, etc.) [20].

2.1.7 Economy

The main economic activities of the country are basically agriculture, livestock, trading and fishing. These primary sector contribute about 44% of GDP (SE/CNEDD, 2016). The overall GDP hovers around USD 8.12 billion (including a per capita value of 378) with a growth of 5.2% [8].

2.2 Data Collection

2.2.1 Phytomass Data Collection

The methods based on GIS are widely applied to assess biomass potentials ; or to the analysis of forest biomass [21-23]. Also for assessing the suitable power plant location based on biomass potential [23]. They typically over lay various layers of data (such as forest, agriculture, urban, slope…) to define suitable areas with biomass potentials [10]. Three main data sets were used, including Land Use Land Cover data, dry matter data (both in raster format) from FAO 2020 data Base https://land.copernicus.vgt.vito.be/PDFportal/Application.html#Home" and, data on bioclimatic zones (in image format) dating from the year 2020. Collected and processed at the National Center for Ecological and Environmental Monitoring (CNSEE).

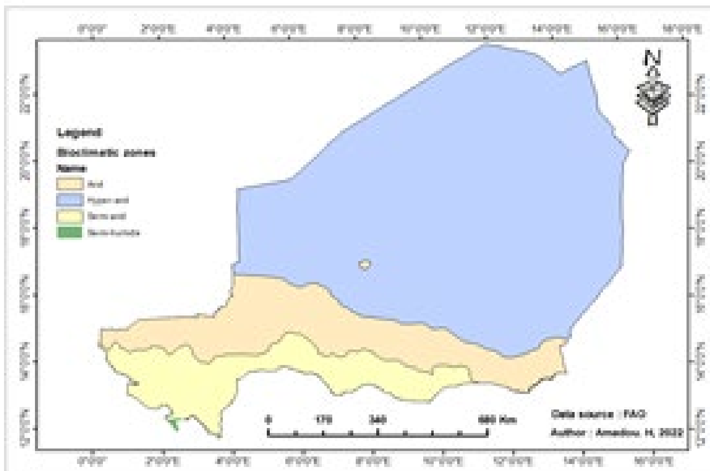

Figure 3: Presentation of Niger Bioclimatic Zones(stages) from 2001 to 2020

2.2.2 Data Collection of: Agriculture Residue Potential, Zoomass and Urban Organic Waste (Organic MSW).

Two principal ways were followed to get data upon agriculture waste. One was the literature review of National papers of Ministry of Food staff and agro-industry in Niger, National Institute of Statistic survey results. Also a survey at the national company of Niger rice implies an interview at the general direction of the company with the technical manager. So the animal organic matter or waste estimation is done by analysis of the Niger's livestock population by region. The organic MSW (Municipal Solide Waste) data are collected from the sub-direction of the waste management of the Ministry Environment, especially at the General Direction of Forest and Water management. Indeed, urban waste is thus composed of two main streams according to their origin, importance and composition (table 1 below).

Flow	Constituent	Nature and importance
Household and similar waste	- waste from households - waste from economic activities	Majority flow with extremely heterogeneous composition
Waste produced by the municipalities (Ben Ammar, 2018)	- waste from green spaces - market waste -sewage waste	Flow composed of totally organic waste, but with a very variable moisture content depending on the type of waste

Table 1: Characterization of the Urban Waste

2.2.3 Data Collection of Bioenergy Technologies

It finds its source in literature review of credible institutions in sustainable energy research and promotion (IRENA, IEA, IUCN, FAO, ME …). The types of data expected in this part consist mainly of a detailed inventory of potential bioenergy production prospects. But also, the basic information characterizing the technologies, methods, techniques and fundamental parameters that govern the functioning of biomass energy.

2.3 Data Analysis

2.3.1 Data Analysis Phytomass

It has implied to estimate the dry plant matter in Kg/Ha by

Bioclimatic zones according to various unit of plant formation (savanna, forest, water body, riparian…). Thus, the main commands and sequences of manipulations after obtaining the Raster data were executed in several actions such as:
Command 1: conversion of the Raster into Shape file forma;
Command 2: Overlay, the land use data with a specific bioclimatic zone;
Command 3: DM Estimation by forest formation unit or type and by bioclimatic stage;
Command 4: Linking of the absolute dry matter to the specifically selected Dry Matter;
Command 5: And to determine the area of biomass or dry matter of each formation unit by bioclimatic stage, the applied manipulation is.;
Command 6: Import the data to the Excel spreadsheet so that it can be analyzed and processed by the following manipulations.
The test, Student's t-test of two independent samples comparison is performed between the variation of biomass classes and the spaces of bioclimatic zones.

2.3.2 Data Analysis of Agriculture Residue

The possible agricultural residue by crop type C_{ai} in a given area during a year y consider was evaluated through the formuler below.

$$C_{aiy} = \sum_{i=1}^{n} R_{rate\ i} * C_{yield\ i} \quad (1)$$

$$C_{aty}\ (\text{tones/year}) = \sum_{i=1}^{n} C_{aiy}\ (\text{tones/year}) \quad (2)\ [26];$$

With: C_{aiy} : Crop i residue potential for the year y, $R_{rate\ i}$: Residue rate by crop type i, $C_{yield\ i}$: Crop i yield per year, C_{aty} : Total potential of agriculture residue.

2.3.3 Data Analysis Zoomass

To determine the amount of excreta (W_{aiy}) produced by a given animal population (ai), during the reference year(y). [15]. These expressions are translated into the following relationships:

Equation 2: the total amount of dung by all livestock in the year

$$W_{aty}\ (\text{tones/year}) = \sum_{i=1}^{n} W_{aiy}\ (\text{tones/year})\ ; (3)$$

$$W_{aiy}\ (\text{tones/year}) = W_{aid}\ (\text{tones/head/days}) * 365 * A_{iy}$$

(number of heads/year) [24]. (4)

2.3.4 Data Analysis of Urban Organic Waste

The specific target for municipal waste has focused on waste generated by households, and in particular material with organic composition. Therefore, the waste produced at the level of a city (W_{uy}), during the reference year (y), is expressed in equation 3.

Equation 3: The Waste Produced by the cities

$$W_{uy}\ (\text{tones/city/year}) = W_{ud}\ (\text{tones/inhabitants/days}) * 365 * N_{uy}\ (\text{inhabitant/city}) (5)$$

In fact, the mass of organic waste produced at the level of the city, during the year of reference is estimated by equation 4.

Equation 4: The Share of the Organic Waste from the MSW

$$W_{omuy}\ (\text{tones/cities/year}) = W_{ui}\ (\text{tones/cities/year}) * OM\ (\%).\ (6)$$

$$W_{tomuy}(\text{tonnes/an}) = \sum_{i=1}^{n} W_{omuy}\ (\text{tones/cities/year})\ [15].\ (7)$$

2.3.5 Data Analysis of Bioenergy Technologies and Sustainable Biomass Energy Potential Bioenergy Technologies Identification and Sustainable Biomass Energy Potential

The energy potential of biomass resources was established by theirs heating value, multiplied by the dry mass production yield and the water content percentage [10]. The formula and workflow presented below are to evaluate bioenergy potentials for any region with good accuracy.

Biomass sources	Main biomass Nature	Average Energy content (GJ/t)
Forest	woods	0.005
Savana	woods	0.120
Steppe	stalks	0.002
Riparian cordon	straw	0.000 310
Humid land	stalks	0.000 002
Water body	straw	0.00 610
Farm land	straw	0.00 610

Table 2: Forest Unites Formation Affected by Potential the Energy Content

Equation 1: Energy Potential from Forest DMResources Assessed.

- $$P_{theoretical} = \sum A_{vegetation,i} \cdot Y_{vegetation,i} \cdot H_{u,i} \qquad (7)\ [17].$$

P_theoretical : is the theoretical energy potential of a specific land field in GJ/ha·a; i:is the crop type; $A_{vegetationi}$: is the area in ha of the vegetation type; $Y_{vegetationi}$: is the dry matter production yield of a specific vegetation type in t/(ha·a); $H_{u,i}$: is the calorific value in gigajoules per tons (GJ/t). Zoomass energy potential is the biogas production from the animal waste resource, and it energy content ranging between 15.7 and 29.5 MJ/m3. An average of the range of values, estimated to be 22.6 MJ/m3 [25].

Species	Average daily dung generation (kg)	Biogas yield (m3/Kg)
Asses	5	0,24
Camels	10	0,17
Cattle or buffalo	29	0,22
Chickens	0,1	0,34
Goats	2,5	0,31
Horses	14	0,31
Cheep	2,5	0,31

Table 3: Animal Average Daily Excreta Production and the Potential Biogas Yield

- $P_{zoo} = \sum N_{animal i} \cdot ad_i \cdot by_i$, then conversion the biogas quantity by its energy efficiency (8)

P_{zoo} : total biogas production potential, $N_{animal i}$: quantity in number of livestock i population, ad_i : average daily dung by livestock specie I (Kg/day), by_i : biogas yield of livestock i excreta (m3).

Agricultural residue energy potential is based on the production rate of the related crop, the average of the range of the RPR Residue Production Rate, and the average energy content [3].

Crops types	Residue types	RPR	Energy content (KJ/Kg)
Milet	Straws Empty bunches	2.44 1.48	15.400 16.730
Rice	Husks straws	0.26 2.18	15,205 12.440
Sorghum	straws	4.13	15.40
Potato	pells	1.14	21,100
Cassava	Pells stalks	0.64 0.60	16.433 17.000
Corn	Hasks stalks	0.25 2.44	18.135 17.740
Groundnut	Hasks/shells cobs	0.79 1	15.958 25.330
Sugar canne	bagasse	0.61	7850
Beans	shells	1.55	17,900

Table 4: Characterization of Agricultural Residue Types Affected by the their Energy Content

- $P_{crop} = \sum CY_i \cdot RPR_i \cdot EC_i$ (9)

P_{crop} : crops energy potential; CY_i : Production Yield of Crop i (tones/year); RPR_i : residue production rate by crop I; EC_i : Energy content of crop residue type i.

The municipal solid waste energy potential (heating value of mixed MSW) is ranging between 8 and 12MJ/Kg by potential resource [10].

3. Results

3.1 Biomass Resources Potential

3.1.1 Biomass Resources

The informations on plant dry matter potential of several types of ground occupation units on the extent of Niger at 300m of resolution. Thus, according to the Niger bioclimatic zones, the potential plant biomass is estimated by classes (intervals) of biomass (Kg/ha), as well as the value of the area they occupy (table 5).

Classes of biomass (Kg/Ha)	Area (ha)				
	Hyper arid	Arid	Semi-arid	Humid	Total area by Class of DM
]0; 3,01[	241 672,913	175 257,867	312 322,496	2 670,87355	731 924,149
[3,01; 8,32[	1 532 029,69	1 862 707,42	917 898,677	1 092,15535	4 313 727,95
[8,32; 14,2[	56 659,3166	4 420 121,89	744 250,354	847,130042	5 221 878,69
[14,2; 21,75[	12 070,8494	3 836 165,09	468 116,972	543,67536	4 316 896,58
[21,75; 29,34[	1 365,88704	3 694 227,39	664 932,135	1 374,48119	4 361 899,9
[29,34; 36,38[	251,546809	3 094 402,97	1 138 691,58	1 844,24843	4 235 190,34
[36,38; 44,78[	15,5500108	1 163 412,27	1 396 052,3	1 810,333	2 561 290,45
[44,78; 57,21[	0,71628881	429 423,335	1 013 526,42	2 314,10277	1 445 264,58
[57,21; 104,25[	0	84 459,7414	599 140,613	79 728,6723	763 329,027
Total	1 844 066,47	18 760 177,97	7 254 931,55	92 225,67	27 951 401,67

Table 5: Variation in Dry Mass Potential of Niger's Vegetation Cover (Kg/Ha) by Bioclimatic Stage and Cover

Throughout the national territory, it is the class of biomass ranging from 8.32 Kg / Ha to 14.2 Kg / Ha that occupies more surface with a value of 5 221 878.69 Ha. Likewise, about the potential coverage of biomass according to bioclimatic stages, it is found that the Arid zone (with 18,760,177.97 Ha) has a large coverage of biomass production. Followed by the Semi-arid zone (7, 254, 931.544 Ha); then the Hyper arid zone (1, 844, 066.472 Ha) and finally the Humid zone with an area of (92, 225.67201 Ha).

Hence, by averaging the different biomass classes, we can roughly estimate the total amount of biomass value produced in 2020. Table 6 shows this estimate according to the bioclimatic stages; the biomass cover.

Average DM (Kg/HA)	DM value (Kg)				
	HAZ	AZ	SAZ	HZ	Total DM
1,505	363 717,734	263 763,09	470 045,356	4 019,66469	1 101 545,84
5,665	8 678 948,19	10 552 237,5	5 199 896,01	6 187,06006	24 437 268,8
11,26	637 983,905	49 770 572,5	8 380 258,99	9 538,68427	58 798 354
17,975	216 973,518	68 955 067,5	8 414 402,57	9 772,5646	77 596 216
25,545	34 891,5844	94 369 038,7	16 985 691,4	35 111,122	111 424 733
32,86	8 265,82814	101 682 082	37 417 405,3	60 602,0034	139 168 355
40,58	631,019438	47 211 269,9	56 651 802,3	73 463,3131	103 937 166
50,995	36,5271479	21 898 443	51 684 779,8	118 007,671	73 701 267,3
80,73	0	6 818 434,92	48 368 621,7	6 436 495,71	61 623 552,3
Total by BZ (Kg)	9 941 448,31	401 520 909	233 572 903	6 753 197,8	
General total (tones)	**651 788,458**				

Table 6: Analysis of the Dry Mass of Plant Vegetation by Bioclimatic Zones

Notably, the potential of total biomass production (forest base by space borne remote sensing) amount of dry mass is 9,941,448.31 Kg, 401,520,909 Kg, 233,572,903 Kg, and 6,753,197.8 Kg respectively for the Hyper Arid, Arid, Semi-Arid, and Humid zone.

3.1.2 Forest

The production of forest dry matter concerns only the three bioclimatic zones: The Arid Zone, the Semi-arid, and the Humid zone; because the Hyper arid zone presents no forest (Figure 18).

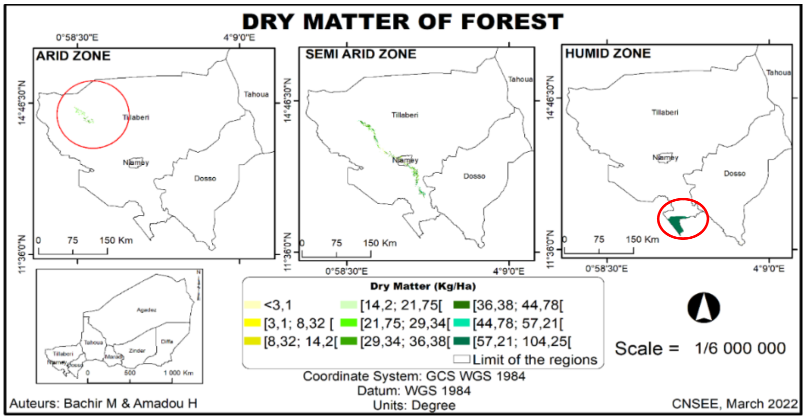

Figure 4: Classes of Forest Biomass Production by Bioclimatic Areas

The dry matter produced by the class ranging from 57.21Kg/Ha to 104.25Kg/Ha presents the largest area of coverage with about 81,234.8292 Ha, located only in the Semi-arid and humid zones.

Biomass (Kg/Ha)	Forest areas (Ha)			
	Arid zone	Semi-arid zone	Humid zone	Total (Ha)
]0; 3,01[	79.73326065	4, 303.76292	20.2121751	4, 403.70
[3,01; 8,32[	85.76002166	2, 094.53885	63.7319264	2, 244.03
[8,32; 14,2[	380.3103583	2, 929.66762	23.998647	3, 333.97
[14,2; 21,75[	1 808.559187	6, 006.3236	14.5884391	7, 829.47
21,75; 29,34[	5 186.638947	9, 790.79874	0.12112344	14, 977.55
[29,34; 36,38[	2 877.293203	15, 615.3723	20.6966422	18, 513.36
[36,38; 44,78[	879.6157424	13, 961.6243	65.9638099	14, 907.20
[44,78; 57,21[	63.62566062	8, 601.31114	1, 857.23562	10, 522.17
[57,21; 104,25[	0	1, 544.65209	79, 690.1771	81, 234.82
Total (Ha)	11, 361.53638	64, 848.05156	81, 756.72548	157, 966.27

Table 7: Forest Biomass Variation Among Bioclimatic Zones and their Recovery Area

3.1.3 • Farmland

The total area values with a significant potential for plant dry mass from farm formation units are presented in figure 5 below.

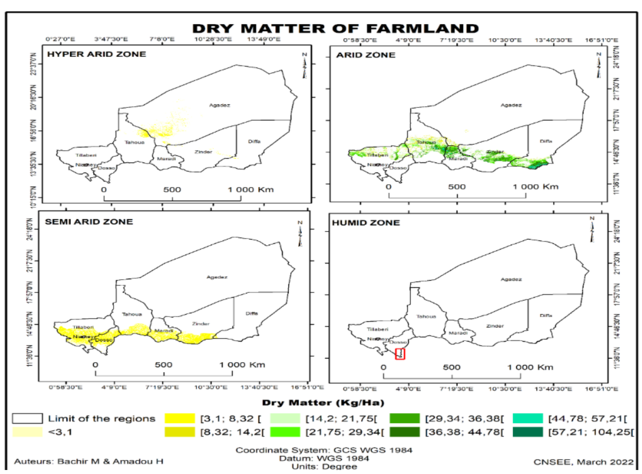

Figure 5: View of the Farm Land Zones of Biomass Production in Niger by Dry Matter Classes and by Bioclimatic Areas

Thus, we can see that the classes of [3.01; 8.32[, [8.32; 14.2[, [14.2; 21.75[, [21.75; 29.34[and [29.34; 36.38[(Kg/Ha) are majoring in terms of coverage; with the smallest surface value estimated at 1,696,339.23 Ha.

And the minorities are the intervals of]0; 3.01[, [36,38; 44,78[, [44,78; 57,21[, and [57,21; 104,25[(Kg/Ha) whose smallest value of area is evaluated at 33 166,15Ha.

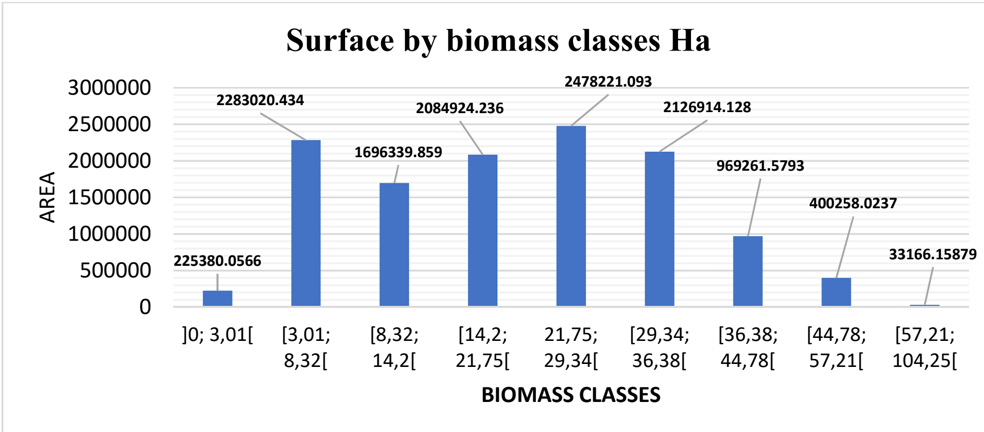

Figure 6: Distribution of Biomass Variations in Function of Land Farm Surface

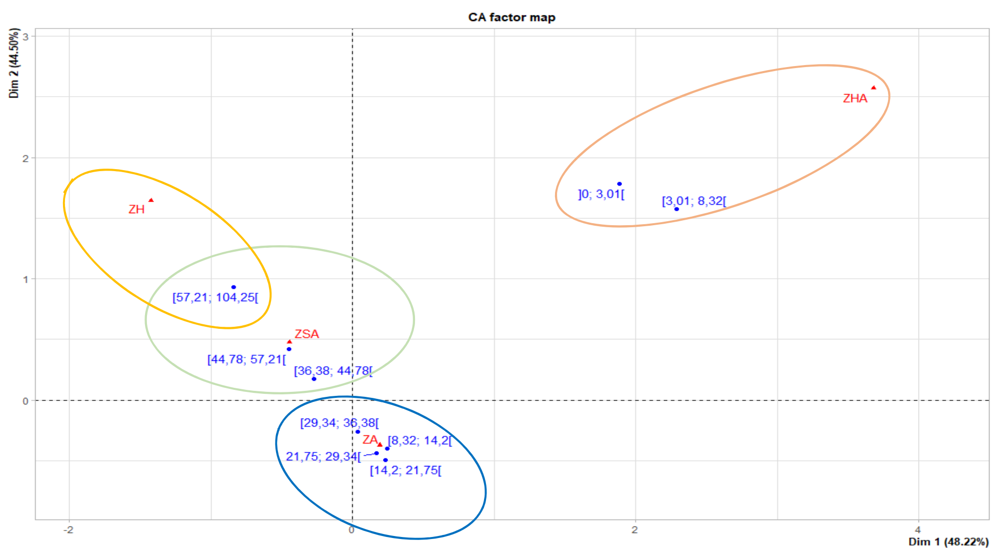

Figure 7: Identification of the Dependence Among the Variables of Biomass Classes and the Bioclimatic Zones

These results clearly show that the classes]0 ;3.01[and [3.01 ;8.32[are significantly related to the HAZ. As well as the AZ to the classes: [8.32 ;14.2[, [14.2 ;21.75[, [21.75 ;29.34[and [29.34 ;36.38[in a very strong way. Also we notice that for the SAZ, it is the classes of [36.38 ;44.78[[44.78 ;57.21[that are linked strongly to this zone, but weakly with [57.21; 104.25[. Finally, only the class of [57.21 ;104.25[is slightly linked to the HZ (Figure 7).

3.1.4 Wood

National demand for domestic energy (specially wood) is estimated at 4,899,213 tons in 2012, of which 4,000,028 tons were in rural areas, 558,226 tons for the regional capitals, and 340,959 tons for the other cities. However, the examination of the forestry balance sheet would result in a withdrawal from that resource 2.9 million tons of wood in 2013.

• Agriculture, Agroforestry production and Agriculture waste resources potential.

Agricultural activities in Niger are divided into winter cultivation with a main production of food products (millet, cowpeas, corn, etc.). Cash crops intended for marketing during the winter season and or by irrigation (groundnuts, onions, sesame...). Finally, the natural or artificial forest products (fruits, wood, leaves, flowers) likely to be used as feedstock potential for biofuel purposes in Niger are: *Vitellaria Paradoxa* (shea), *Balanites aegyptiaca* (balanites) and *Azadirachta Indica* L (neem).

Crops types	Production zone	Surface Cultiveted (Ha)	Residue types	Crops yield (tones)	Residues (tones)
Milet	Everywhere without Agadez	3 270 486	Straws Emptybunches	3 508 903	8,421,367.2 12,463,623.5
Rice	Tillabri, Dosso, Zinder, Maradi, Diffa, Niamey	133 700	Husks straws	115 093	29,924.18 250,902.74
Sorghum	Tillabri, Dosso, Zinder, Maradi, Diffa, Niamey, Tahoua	1 897 240	straws	2 132 295	8,806,378.35
Potato			pells	236 000	269,040
Cassava	Niamey, Diffa, Dosso, Maradi, Tillabéry, Zinder	648 320	Pells stalks	658 000	394,800 394,800
Corn	Everywhere in Niger	47 240	Hasks stalks	6 419	1,604.75 15,662.36
Groundnut	Dosso, Maradi, Tahoua	587 170	Hasks/shells Cobs	593 669	468,998.51 593 669
Sugar canne	Tahoua,Zinder, Dosso, Tillabéry	422 780	bagasse	186 000	113,460
Beans	Everywhere without Agadez	2 407 840	shells	2 629 772	4,076,146.6

Table 8: Potential biofuel production resources in Niger for the year 2019

In Niger, the Shea tree is found in the regions of Dosso and south of the Tillabéri region (mainly in the wooded savannah of West Africa). This tree only reaches adulthood at around 30 years of age when it can produce 20 kg of fruit, in example: 5 kg of dry almonds for less than 1 kg of shea butter.

However, the population of Balanites was around 100,000,000 feet in 1983 according to FAO in 2000. It can produce annually about 130 Kg of fruits (by mature tree) which are drupes weighing 5 to 6 g. The kernels of *Balanites aegyptiaca* contain a significant proportion of oil. From its stand in Niger, a biofuel production potential of 30,000 tons/year can be expected.

More, according to the Inventory of neem trees of the National Directorate of the Environment in 1990; 2,200,000 neem trees is estimated in Niger.

Thus, the average weight of fruits per tree is 20 kg corresponding to 14 kg of seeds. The pressing of the 14 kg of seeds gives on average 3 to 4 liters of oil. Indeed, if only 10% of the seeds are collected and pressed, the production of this biofuel would be 1000 tons/year.

Further, much of agricultural residues are widely used by rural households for livestock feed and, sometimes for cooking energy at the expense of soil fertilization. Nevertheless, some agricultural residues are still not useful by the population or their livestock feeding. These include the first residue from rice processing, groundnut (their husk) as example and, even sometimes constitute a challenge to be manage in the environment.

Figure 8: Niger Rice Production Company and the Waste Produced

The rice husk represents about 22 percent of the total quantity of rice to be processed, so with an annual production of 35,000 tons of rice. This result 7,700 tons per year (husk). With no consideration of husk from traditional processing.

The available forage production from agricultural residues is 6,935,764 tons of DM in 2019.

3.1.5 Zoomass or Livestock Waste

The Niger livestock is composed of cattle, sheep, goats, mules (donkeys), camels and horses. These animal species are distributed throughout the national territory, but with varied specific richness, linked to the adaptability of the species to the conditions of the environments.

Zones	Types of livestock
Hyper arid	camels, capric basically
Arid	buffalo, ovine, capric, and camels
Semi-Arid	All Niger livestock animals
Humide	All Niger livestock animals (without camels)

Table 9: Distribution of livestock richness by climatic zones

The average value of the of animal resource excreta as a function of species diversity and per day has led to the results below dealing with the potential of animal excreta from livestock in Niger. Then, the total value of livestock waste production from Niger's livestock population.

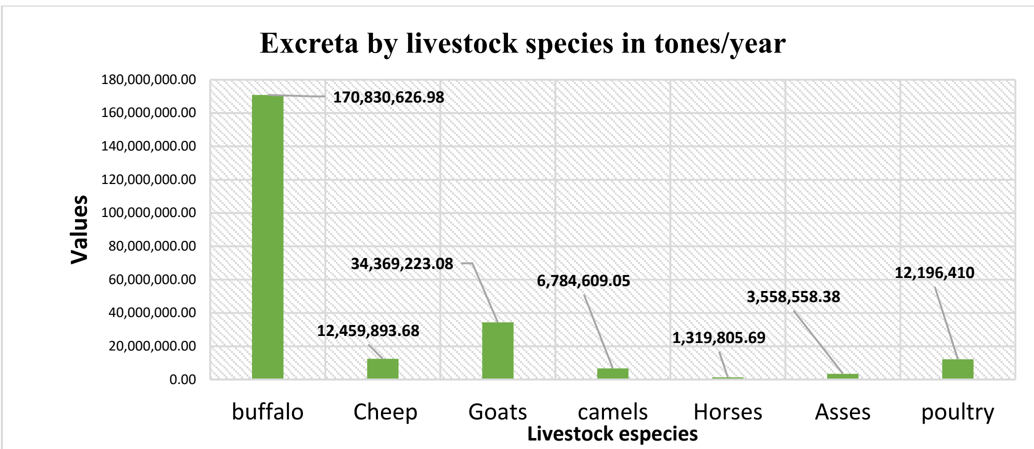

Figure 9: Theoretical Estimation of the Potential Zoo-Mass from Livestock Niger by Species (in tones/year)

Figure 9 shows that the quantity of bovine excreta is the most significant among all the production of Nigerien livestock, with a value of 170,830,626.98 tons per year. Then, goats, sheep, and poultry resources follow respectively with 34 369 223.08; 12 459 893.68 and 12 196 410 tons per year.

Definitely, the results show the total potential of animal residue for all species concerned amounts to 241 515 126.8 tons by the year 2020 (from the integral livestock herd 20,876,240).

3.1.6 Mineral Coal

Niger has a great potential for mineral coal in the desert or arid zone. This has made possible the installation of a thermal power plant using mineral coal for more than 40 years and which is still operational. So, the exploitation of mineral coal for the operation of these plant consumes on average (from 2010 to 2021) a quantity of about 235,000 tons of coal per year and with a cumulative consumed from since 1980 to 2022 around 7,557,569 tons.

3.1.7 Urban Biodegradable Organic Waste

The evaluation of organic waste deposits of urban origin is elaborated from an approach of crossing demographic data (Figure 10) and the results of recent studies carried out on the urban waste produced in Niger.

Moreover, in the case of the Urban Community of Niamey, its amount is 0.65 kg/day and 1.031 liters/day with organic matter fraction rat to 27%.

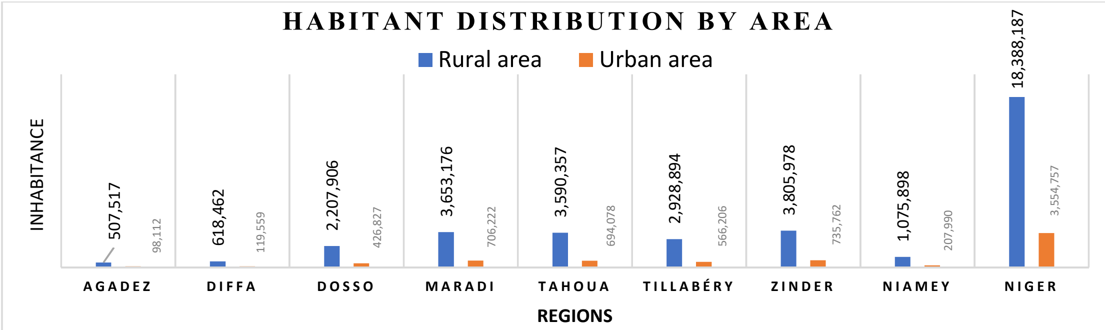

Figure 10: Niger Population Distribution Per Regions and Per Type of Area

Household waste in the city of Niamey is dominated by inert matter (57%). Again, organic matter accounts for nearly a quarter (24%) of the waste generated by households, and plastic accounts for 6%.

Urbain waste	Niger Regions								
	Agadez	Diffa	Tahoua	Maradi	Zinder	Dosso	Tillabéry	Niamey	W_{tomuy} (t/yr)
W_{uy} (t/city/yr)	14,324.35	17,455.61	101,335.38	103,108.41	107,421.25	62,316.74	82,666.07	49,345.62	537,973.46
W_{omuy} (t/city/yr)	8,594.61	10,473.36	60,801.23	61,865.04	64,452.75	37,390.04	49,599.64	29,607.37	**322,784.07**

Table10: Estimation of urban waste production from all the Niger Regions

Figure 11 shows the variation in the productive capacity of dry matter by different sources of plant and animal origin throughout the nation. It is the biomass of animal waste nature that is the most dominant with more than 20,000,000 t/year of animal excreta. Followed by the biomass from agricultural residues, then the biomass of wood energy, with respectively more than 6 900 000 t/year, 4 800 000 t/year.

Elsewhere, the other sources whose quantities of biomass are low: more than 174 t/year; 8,800 t/year, 22,100 t/year; respectively for wetlands, forests, and rocky cordon.

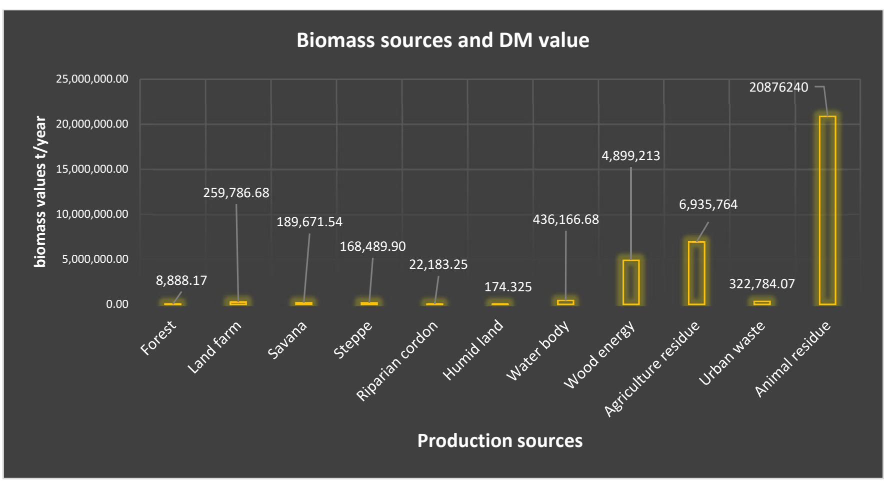

Figure 11: The General Potential of Biomass Production from Different Sources in Niger for the year 2020

Briefly, the identification of the recovery land by the potential biomass of each Bioclimatic Zone in consideration of the mean of the all land source by BZ (saw table 11), reveal that, for the Hyper arid, Arid, Semi-arid, and Humid zones; the potential rate went respectively 2%, 91%, 52%, 97% hectares.

Area in Ha	HAZ (Ha)	AZ (Ha)	SAZ (Ha)	HZ (Ha)	Total (Ha)
Total DM area by BZ	1 844 066,47	18 760 177,97	7 254 931,54	92 225,67	27 951 401,66
Total Area of the BZ	92 093 403,82	20 538 589,02	13 973 242,75	94 764,42	126 700 000
Rate of biomass land recovery	2%	91%	52%	97%	22%

Table 11: Comparison of Recovery Biomass Areas to the Total Area of the BZ

3.2 Bioenergy Technologies used in Niger and the Expected Biopower Potential

In Niger, more than 90% of households use wood as their main source of cooking energy and demand is still growing. Several types of improved stoves have been introduced in Niger and since 1980, the choices concerning production and dissemination have focused on boiler furnace or improved metal stoves characterized with various efficiency and life time such as: "Mai Sauki" (15% to 25% for 3 years), Banco stoves called "Albarka" (20% to 25% for 1 to 4 years), “Malgache furnace” ,(15% to 20% for 1 to 2 years), gas furnace(30 % to 60% for 6years), “Madi Sewa funace (20% to 30% for 3 to 5 years), rice husk furnace (25% to 30%, for 3 to 5 years), waste fuel furnace (15% to 25% for 2 to 5 years), wire furnace (10% to 20% for 1 to 3 years), etc.

Figure 12: Some Household Bioenergy Technologies in Niger

However, in the sustainable bioenergy framework, a promotion of the experimental production of biogas has been initiated since the 1980s, when a dozen digesters were installed, and which are unfortunately no longer operational. In fact, Niger is a member of an alliance for biodigester in West and Central Africa. Furthermore, in collaboration with the Direction of household energies Promotion (Ministry of Energy), many international and national organizations participate in the implementation and development of regional and international cooperation for sustainable domestic energy. Thus, a number of projects have carried out testing and extension of the biogas production system through international development organizations (NGOs) .It have been have installed (recently, in 2021) 20 out of 30 biodigesters of the dome fixed type in the Zinder Region. Again, 10 biodigesters in the Dosso Region (in Gaya department).

3.3 Potential Bioenergy Power Generation in Niger

The bioenergy power is assessed as feedstock from the potential biomass resources including the Agricultural residue and Forest resources, livestock excreta, urban organic waste. It is noticed that, the first tree Forest sources characterized with a good accuracy are the Steppe, the forest formation and the Savana stock. They account respectively **10,344,470.39 GJ; 9,046,132.275 GJ; 3,834,339.286 GJ.** Unlike, the other sources such as Humid land, Water body, Farm Land and riparian Cordon have no very important biopower potential. Indeed, this is the fact of the respective area size of each Forest sources which result in a big difference of biomass power potential. However, the Farm Land is not in this case, despite the important area occupied, its power potential is low.

Biomass sources	Area (Ha)	DM yield or X_{it} (t/Ha)	Potential energy (GJ)
forest	157, 966.27	8, 888.166	9,046,132.275
Savana	3,644,667.63	189, 671.536	3,834,339.286
Steppe	10,175,980.49	168, 489.898	10,344,470.39
Riparian cordon	923,376.459	22, 183.2515	945,559.7105
Humid land	174,325.377	174.325	174,499.702
Water body	38,845.3988	436, 166.684	475,012.0828
Farm land	12,297,485.6	259,786,681	272,084,166.6

Table 12: Power Potential of DM Biomass from Forest Resources in Niger in 2020

The integral power potential from Forest biomass resources is equals to **296,904,180 GJ/year.** The energy potential derived from animal waste converted to biogas is presented in Table 13.

Species	Population size	Biogas yield (m3/Kg)	Biogas quantity (m3)	Energy potential (PJ/yr)
Asses or donkey	1 912 000	24%	2294400	0.051853440
Camels	1 835 000	17%	3119500	0.070500700
Cattle	15 225 000	22%	97135500	2 195 262 300
Chickens	12 196 410	34%	414677,94	9 371 721,444
Goats	18 108 000	31%	14808700	334 676 620
Horses	256 000	31%	1111040	25 109 504
Cheap	13 193 000	31%	10224575	231 075 395
total	12452410		129108393	2 917 849 680

Table 13: Biogas Potential from Livestock Waste

The energy potential in form of biogas from livestock excreta shows the power capacity by species are such as: Catt le, Goat, Cheep, Horse, Chicken, Camel and then Asses. Indeed, an integral power potential from livestock excreta goes to 5,713,345,220 PJ/year or 5,713,345.220 EJ/year.

Crops types	Residue types	Energy potential (GJ/year)
Milet	Straws Emptybunches	129.689 208.516
Rice	Husks straws	0.454 3.121
Sorghum	straws	22%
Potato	pells	5.676
Cassava	Pells stalks	6.487 6.711
Corn	Hasks stalks	0.029 0.277
Groundnut	Hasks/shells Cobs	7.484 15.037
Sugar canne	bagasse	890.661
Beans	shells	72.963

Table 14: Agricultural Waste Energy Potential

The energy potential of agricultural residue available in Niger is presented in Table 14. This estimation means the sum of all single agriculture waste energy potential from the agriculture. The capacity of the potential energy through the conversion of the agricultural residue in its diverse form and energy heating value is estimated to **1,482.269 GJ/year.**

The waste from municipal solid is generated by households, the commercial and industrial sectors. The waste takes many forms, but including especially organic fraction. So, the energy potential of municipal solid waste from 537,973,460 Kg/year of MSW is **6,455,681,520 MJ/year.**

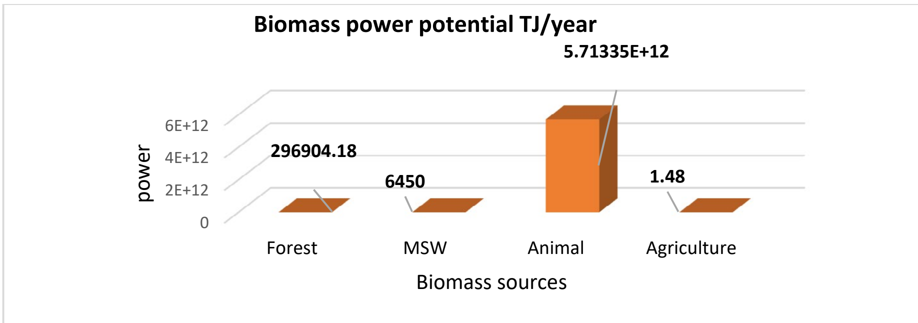

Figure 12: Bioenergy Power Potential from Assessed Biomass Resources

According to the results in Figure 12, the evident important biomass sustainable power potential comes from animal excretal with more than 5,71335. 10^{12} TJ/year.

Then, comes the sources from Forest, MSW and Agricultural waste with respectively 296904,18 TJ/year; 6450 TJ/year and 1,48 TJ/year and as integral power potential of: **28,908.7075** Tkep/ year.

In the evidence of the result, where all the major kinds of national bioenergy technologies are explored, it is a fact that they are various but not sufficiently efficient. Because the highest efficient technologies level is around 30%, despite the large possibility of improved technics and technologies in a sustainable way.

Also, the huge value of biopower revealed that, the availability of the biomass resources is able to produce a very important bioenergy potential.

Label	Name of data file/data set	File types (file extension)	Data repository and identifier (DOI or accession number)
LULC	Land Use Land Cover (Soil occupation)	Raster file	Data set 1
PDM	Plant Dry Matter	Raster file	Data set 2
BZ	Bioclimatic Zone	Image format	Data file 1
INS (demography)	National demographic Information	MS Excel & MS PDF	Data file 2
DS/ MAG/EL	National Livestock herd information	MS Excel & MS PDF	Data file 3
DS/ MAG/EL	National Agriculture information	MS Excel & MS PDF	Data file 4
DEGEF	National Agroecology informations	MS Excel & MS PDF	Data file 5

Table 1 of data files/data sets

4. Discussion

Niger, energy supply is more provided by the biomass sources especial wood and coal (Salifou, 2015). This study confirms this fact, with the result of the energy consumption where the sector with high level of power use is fundamentally household. Indeed, the results on the national potential in terms of plant biomass production had shown that the coverage of dry matter occupies an area of 27 951 401,66 Ha in a general way all units of floristic formation are confused. More than 66% of this area is found in the Arid Zone with a specific cover rate of about 91%, compared to 97% for the Humid Zone, although it is the smallest of the three other zones (ZHY, ZA, ZSA). The Humid Zone, although being the most favorable from the climatic point of view for the development of the vegetal matter, it occupies the last position concerning the covering (because of its small representation in the country). As well as for the Hyper Arid Zone, although it represents more than ¾ of the country's surface, occupies third place in terms of dry matter coverage (because it is a desert part and the climatic parameters are very precarious). Thus from Dry Matter (DM) and land use data, coupled with their correspondence to Niger bioclimatic stages; some classes of biomass have been resulted. In fact, it is [8,32; 14,2] Kg/Ha that has more representation in the AZ, approximately up to 4 420 121,89 Ha; then the class [36,38; 44,78] in the SAZ with 1 396 052,3 and finally the class [57,21; 104,25[in the HZ with 79 728,6723 Ha.

However, for the study conducted by [14] [27], according to bioclimatic stages and by the method of MODIS AND NDVI of SPOT VEGETATION vary around 207 kg/Ha in the Saharan zone (HAZ); 360 kg/Ha in the Nord-Sahelian zone (SAZ) and 583 kg/Ha in the Sahelian zone (HZ), that is to say, respective average errors of 51%, 47% and 57% [27]. Thus, from the possible biomass resources assessed in this study including respectively forest, animals, urban waste, agricultural residue resources; it has resulted in fact that the main sources presenting a huge power potential are Animal and forest respectively 5,71335E+12 TJ/year and 296904,18 TJ/year. While the other sources like agricultural residue, urban waste have their power potential are slightly less significant compared to the first two source cited presciently. In spit the exclusion of the fact that to a social extent, the feedstocks used are generally also used for food, leading to increased competition as both biofuel and food demands continue to rise [9].

Moreover, the potential of bioenergy production from the organic dry matter potential of animal residues, urban waste, forest residue, wood and coal are respectively: 5.7E12 TJ/year, 6450TJ/year, 296904.1 TJ/year. Although in Nigeria, it is revealed that the energy potential derivable from animal wastes was estimated as 0.65 EJ and municipal solid waste could produce about 0.11 EJ. Also, the share from forest residues was estimated at 0.05 EJ. Currently, there is a huge dependence on wood fuel and charcoal, with potentials of 0.38 and 0.05 EJ [3].

In fact, this important difference of sustainable bioenergy potential from the various sources is explained by the fact that, the Niger assessment did not take in account any limitation of access to the biomass resources unlikely the Nigeria's study has integrated many barriers and constraint of accessibility (environment, economic, social…) of these biomass resource, because the potential bioenergy power is directly related to potentialities of biomass dry matter qualitative as well as quantitative manner. The local production and use of biomass resources as a substitute for fossil-based fuels offers many attractive benefits for Niger. This benefits include job creation, rural development, and poverty reduction. At the environment side, it includes offsetting the GHG emissions from fossil fuels burning, waste utilization, and erosion control. However, if not managed properly, this biomass resource development could have negative environmental impacts such as deforestation, increased GHG emissions, loss of biodiversity, and soil erosion [28].

5. Conclusion

In Niger, the most consumed source of primary energy in the country remains the biomass (about 79.4%) and, has been using in unsustainable way. Remarkably, this consumption comes fundamentally from woodfire and charcoal. This action engages in forest destruction, enhancing desertification, underpinning the afforestation efforts. Then, it impacts negatively population health (especially those in rural area) through air increasing pollution and associated related diseases development. However, the revealed diversity of biomass potential such as about 208.7 thousand tones/year from animal residue, 69.3 thousand tones/year from agriculture residue, 3.3 thousand tones/year from municipal organic waste and 59 thousand tones/year from woods and forest residue with an integral sustainable biopower potential around 28908.7075 Tkep/ year. That could significantly play a role in the achievement of the Nigerien Sustainable Energy Goal for 2030.

The use of domestic bioenergy resources would generally contribute to the diversification of the energy mix. Surely in Niger, bioenergy will continue to be most effective for GHG mitigation when it is adopted in association with other products. Particularly, by utilizing biomass wastes of primary product chains or biomass that has already served one or more functions. In fact, the use of this waste as an energy source provides an environmentally safe waste management and disposal, as well as the generation of clean electric power. Brief, biomass is the highest popularity energy source despite its several effect on environment, land, women health…, so in consideration of possible improving ways and the real potential of biopower. Thus, the remaining interest is to assess the key parameters and identify the principal challenges, to make this significant biopower potential in an operation condition, with an integrated socioeconomic and environment consideration [29-31].

Limitations

This is research was conducted in the interest to let understand very clearly the real potential of upgrading biomass energy including the related component such as biomass resources, bioenergy technics, technologies and also the possible efficient biopower production in a sustainable manner. However, the first limitation in this study is the fact that the biomass assess is purely theoretical. That mean it does not include social and socioeconomic challenges of resources accesses, although all the information come from credible and ethical science application. Second, as sustainable bioenergy, only the process of biomass conversion into biogas and combustion are considered instead of all the rest of sustainable bioenergy like pyrolysis, gasification, biofuels production…

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