Journal of Research in Forestry, Wildlife & Environment Vol. 15(4) December, 2023
E-mail: *jrfwe2019@gmail.com*; *jfewr@yahoo.com*
http://www.ajol.info/index.php/jrfwe
jfewr ©2022 - jfewr Publications
ISBN: 2141 – 1778
Hagumigara et al., 2023

SOCIAL, ECONOMIC AND ECOLOGICAL CONTRIBUTIONS OF CHARCOAL PRODUCTION AND SALES TO PEOPLES' LIVELIHOOD OF KARONGI DISTRICT

Hagumigara E[1], Manirakiza G [2], Nzamukosha B[3], Nkamiyabanga T[4], and Iranzi H[5]

Forest Resource Management, Rwanda Polytechnic - Integrated Polytechnic Regional College (RP-IPRC) Kitabi

*Corresponding Author: *hagumigaraetienne123@gmail.com;* (+250)787582320

ABSTRACT

Biomass uses accounts for 98.5% of the country's primary energy needs. Of this, firewood accounts for 57.0%, charcoal for 23%, along with smaller amounts of crop residues, peat, and other materials totaling 60.0% and 14.0%, respectively **(Hakizimana E *et al*., 2020).** ***The study aimed at assessing the socio-economic, contributions of charcoal production and sales to peoples livelihood was conducted in three sectors Mutuntu, Twumba and Rwankuba of Karongi district. The study also was conducted under three specific objectives; i) Identify Tree species size and Charcoal production methods adopted in the study area ii) Examine Socio-economic, and Ecological impact of Charcoal Production and Selling Cooperatives, iii) Perform Benefit - Cost Analysis (BCA) between Charcoal Selling Price and Production Cost. A sample of 200 households was selected from the study area using Yemane formula, With SATATA, the Regression Analysis was made to determine the correlation among independent and dependent variables. The findings indicated that 64.5% of trees were harvested at diameter class ranging from 10 to 20 cm of DBH and Traditional Charcoal Production Method is applied at 95%. Casamance's BCR is greater than the one of Tradition Method with 2.7 and 1.5 respectively. It was also found that P – values obtained on both Social, Economic and Ecological aspects are less than 0.05. Charcoal Production and Selling makes positive significant improvement in Social and Economic impact on peoples' livelihood and ecologically to the sustainability of forests of Karongi District especially in the study areas.***

Keywords: Charcoal production, Charcoal Selling, Peoples' Livelihood, Forest Management, Benefit - Cost Analysis (CBA).

Correct Citation of this Publication
Hagumigara E, Manirakiza G, Nzamukosha B, Nkamiyabanga T., and Iranzi H. (2023). Social, economic and ecological contributions of charcoal production and sales to peoples' livelihood of Karongi District**.** *Journal of Research in Forestry, Wildlife & Environment,* 15(4): 17 - 29

INTRODUCTION

The Republic of Rwanda is a small landlocked country with an equatorial climate, experiencing temperatures between 16°C and 24°C and annual rainfall ranging from 700 mm to 2000 mm. The forestry sector in Rwanda covers 30.4% of the country's total land area, consisting of state forests, district forests, and private forests. Forests are classified based on ownership (state, district, private) and management style (natural and plantation forests). (Nduwamungu, 2011).

Natural forests cover 11.9% of the nation's land, including national parks and reserves, while plantation forests cover 18.5% and consist mainly of Eucalyptus species. The forestry sector plays a crucial role in Rwanda's social, economic, and ecological aspects, providing timber, poles, firewood, and charcoal, as well as non-timber forest products. Forests contribute to job creation, biodiversity conservation, soil erosion control, and water purification. The sector is vital for the country's economy, with the production of firewood and charcoal contributing 5% to the GDP. (MINAGRI, 2012).

Charcoal production in Rwanda involves traditional methods like earth mound and pit kilns, as well as improved methods such as the Casamance Kiln. About 86% of charcoal is produced using traditional methods, contributing to biomass being the primary energy source in Rwanda (Nogueira *et al*., 2021).
The consumption of charcoal is high, with 85% of the population relying on wood for cooking. The government aims to reduce biomass energy dependence by promoting clean and efficient cooking technologies. (Hakizimana *et al*., 2020).

Charcoal production involves the carbonization process, where wood is heated between 450°C and 600°C in the absence of air. Traditional kilns, such as earth mound and pit kilns, are commonly used in Rwanda, while improved methods like the Casamance Kiln offer higher efficiency. (Nogueira *et al*. 2021). The charcoal supply chain in Rwanda includes wood owners, producers, collectors, transporters, retailers, wholesalers, and consumers. The transportation cost significantly influences charcoal prices, accounting for 60-70% of the final price. Charcoal consumers include wholesalers, retailers, industries, institutions, restaurants, and individual users.

Rwanda's forestry sector is a vital component of its economy, providing various products and services. The high reliance on biomass energy, particularly charcoal, presents challenges, and efforts are underway to promote cleaner and more sustainable energy sources. (Tuyisingize et al., 2022). Charcoal production involves a mix of traditional and improved methods, and the sector plays a significant role in job creation and economic development. (Arakwiye E, Rogan K, and Eastman S, 2021).

MATERIALS AND METHODS

Study Area – Karongi District

Karongi District is one of the seven Districts in the Western Province. It is bordered by Rutsiro to the north, Ngororero and Muhanga districts to the north-east, Nyamasheke and Nyamagabe districts to the south, Ruhango district to east and it borders with the Democratic Republic of Congo and Lake Kivu to the west. Karongi District stretches over an area of 993 km^2 with a population of 331,808 distributed into 77000 households. Karongi District is divided into 13 administrative sectors. It is subdivided into 88 cells and 538villages (Tuyisingize *et al*., 2022).

As reported in 2020, the Karongi district is among the districts of Rwanda which has high density of 334 persons/ km^2 and faces to the demographic growth with average annual growth rate of 1.7%. It was also indicated that the majority of the population from Karongi district is young with 80% of population aged less than 40 years old. About 54% of the population is aged 19 years or younger. People aged 65 years and above make up 5% of the population (Rudiarto *et al*., 2019).

Karongi district experienced tropical climate of altitude. It is one of Rwanda regions which have high rainfall. The amount in the district benefits the area and it is characterized by two dry seasons covering the period from December to January and from June to mid-September, and It is also characterized by two rainy seasons the long rains start in mid-September and end in December and from February to June with an annual average of temperature varying from 16oc to 21oc annual rain falls ranging from 1100 to 1500 mm, thus these features are favorable to agriculture and livestock development Emmanuel H, Isaac M (2021).
Concerning forest sector, the report of Ministry of Environment on Forest cover map in Rwanda 2019 indicated that 30.2% corresponding to 23,915 ha was covered by forest (REPUBLIC OF RWANDA Ministry of Environment Rwanda Forest Cover Mapping (2019). As reported by Ministry of Natural Resources (MINIRENA, 2017). Karongi is among the districts of Rwanda with high production of charcoal and the charcoal chain is a fundamental source of employment and revenue for close to 15% of rural households.

Study design and sampling

Using the Yemane, 1967 formula with a 95% confidence interval and a 5% precision level, the number of sampled respondents used in this study was calculated from three sectors Mutuntu, Rwankuba, and Twumba of Karongi districts. To choose a single household representative from the study area, random sampling was used. In total, a sample of 200 respondents were selected include 3 forest extensionists, 75 charcoal sellers, 48 charcoal producers, and 57 forest growers.

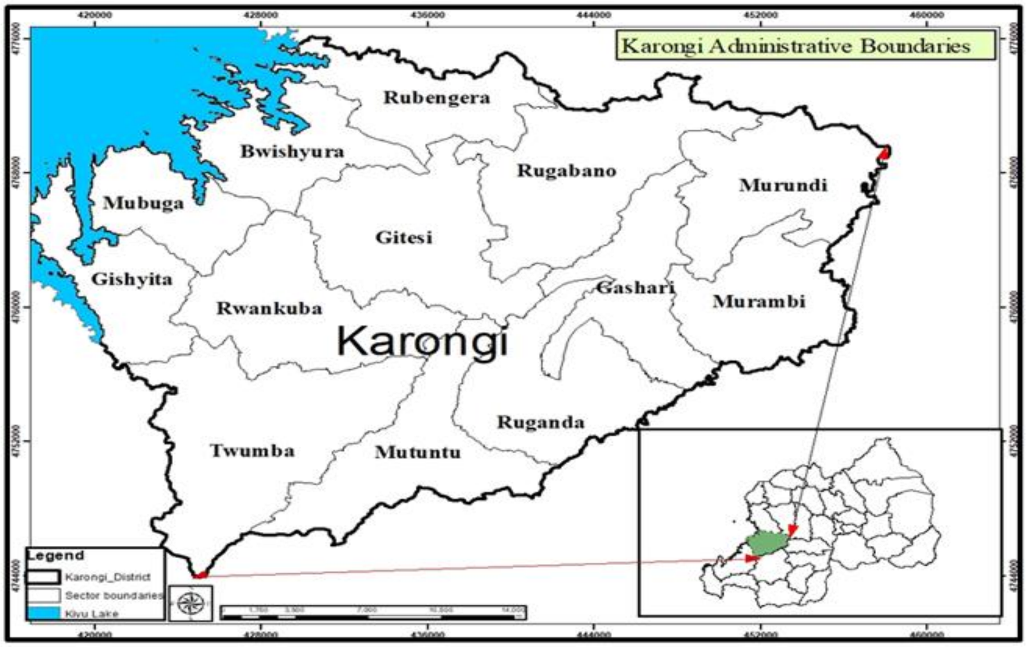

Figure 1: Administrative Map of Karongi district

Data collection

Sources of data were drawn from both primary and secondary sources.

The names of tree species, dimensions in terms of diameter, bole height, and length of logs used to make charcoal, charcoal production techniques, social, economic, and ecological functions of charcoal production and sale, various viewpoints on charcoal production and selling, challenges encountered in charcoal production and sale, estimated size of a charcoal kiln, estimated quantity of charcoal produced from one kiln, and price per on harvested charcoal were all included in the primary dada source. The secondary dada source assisted the research in determining the institutional and forestry policies that currently govern the production and use of charcoal.

Books, journals, government documents, national plans for the long and short terms of the country, and the internet were among the sources. To gather the necessary data, a well-structured questionnaire with both closed- and open-ended questions was developed. Quantitative information can be expressed as a quantity in terms of numbers, ranges, lengths, diameters, areas, costs, and volumes., among other things (Niyonkuru B, 2021).

In this study, various quantitative data were collected including; the height and diameter of the tree species used to produce charcoal, the age of the respondents, the number of charcoal kilns used, and the cost and price of the charcoal in terms of money. Status, education level, tree species names, forest plantation end products, cooperative names involved, and charcoal production techniques were among the qualitative data gathered.

Data and analysis

Data were sorted, recorded, and processed using Microsoft Word and Microsoft Excel after being collected from forest growers, charcoal producers and sellers, and other beneficiaries of charcoal production in the study area (Islam H. (2020). After that, data were summarized using Ms. Excel, and descriptive analysis with the Statistical

Package for the Social Sciences (RBM SPSS 22). Therefore, Regression Analysis with STATA were used. In addition, to justify the outcome from cooperatives initiation, an econometric model

$Y= f(x) \equiv Y = \beta_0+ \beta_1x_1+ \beta_2x_2+ \beta_3x_3\ldots+ \beta_nx_n+u$ ……….. (1) were used.

The following formula were used:

BCR = $\sum R_{t\&i}: \sum C_{t\&I}$ ……………….. (2)

Where:

BCR: Benefit Cost Ratio

$\sum R_{t\&i}$: Total revenue of charcoal produced under traditional and modern methods

$\sum C_{t\&i}$: Total cost of charcoal produced under traditional and modern method

$YS= -3.499 + 0.627X_1 + 0.893X_2 + 0.774X_3 + 0.862X_4 + 0.631 X_5+ 0.633X_6 +u$ …. (3)

$YC = -0.424 + 0.291X_1 + 0.184X_2 + 0.174X_3 + 0.219X_4 +u$ .. (4)

$YE= -1.1863 + 0.725X_1 + 0.692X_2 + 0.803X_3 + 0.589X_4 +u$ … (5)

Thus;

Social Contribution = -0.3499 + 0.627 Job creation + 0.893 Improved of charcoal production +0.774 Life Insurance Access + 0.862 Food Security + 0.632 Reduction of Forest + 0.633 Infrastructure Development

Economic Contribution = **-** 0.421 + 0.291 Access to Salary and Wage + 0.184 Access to Savings and Loans + 0.174 (Private Sector Investments + 0.219 GDP Improvement.

Ecological Contribution = -1.1862 + 0.725 Sustainable Forest Management + 0.692 Effective Forest Harvesting + 0.803 Afforestation Improvement + 0.589 Reforestation Improvement

RESULTS

All 200 (100%) sampled respondents participated in the study. Respondents from this study was made by 148 (74%) male and 52 (26%) female; 192 (96%) are married and 8 (4%) are single; 143 (71.5%) are adults, 35 (17.5%) are experienced, 22 (11%); 116 (58%) have primary school, 47 (25%) are illiterates, 32 (16%) finished secondary school, and 5 (2.5%) have attended tertiary studies.

Tree species names, size and charcoal production methods

Like other parts of the country *Eucalyptus* species is mostly used as charcoal. The results from the study indicated that most forests plantation in the study area is *Eucalyptus grandis* and 59% of charcoal produced come from the same species. The class of trees with the highest usage rate (67.0%) falls into the 10 cm to 20 cm Diameter at Breast Height (DBH) range. 80.0% of the height range for harvesting is between 10 m and 20 m, corresponds to the volume of 0.065 m^3 per tree with harvesting beginning at less than 10m. Both traditional and modern charcoal production techniques are reportedly employed. Both the Earth Mound Kiln and the Peat Kiln are still used in traditional techniques, though at differing rates, while the Casamance Kiln is an improved charcoal production technique that is being used, though at a much slower rate 84.6% of all kilns utilized are traditional mound kilns, 10.8% are peat kiln and 4.6% are improved kiln with Casamance.

Social, Economic, and ecological benefits of charcoal production and selling

Peoples that produce and sell charcoal assist society, the economy, and the environment by creating jobs, improvement of quality of charcoal, access to life insurance, forests violation reduction, access to development infrastructures, generating revenue in terms of salaries and wages, access to bank loans, adoption of improved charcoal production methods / technics, ensuring family food security, access to other sources of cooking energy, and meeting other requirements.

Table 1: Summary of respondents identifications in terms of Sex, Martal Status, Education and Occupation

Sex	Nber (sex)	% (S)	Marital Status	Nber (M.S)	% (M)	Education	Number (E)	% (ED)	Occupation	Nber (occ)	% (oc.)
Male	148	74	Single	8	4	Illiterates	47	24	Forest Grower	57	28.5
Female	52	26	Married	192	96	Primary	116	58	Charcoal Producers	65	32.5
						Secondary	32	16	Charcoal Sellers	75	37.5
						Tertiary	5	2.5	Forest Extensionists	3	1.5

Table 2: Tree species names, Sizes, and carbonization method/ technics

Tree species Name			Tree sizes used				Charcoal Production		
Name	**Number**	**Rate (%)**	**Diameter classes (cm)**	**Number**	**Rate (%)**	**Volume (m3)**	**Method**	**Number**	**Rate (%)**
E. saligna	118	59	Small (<= 10)	0	0	< 0.065	Earth Mound Kiln	55	84.6
E. camaldulensis	16	8	Medium (> 10 - <= 20)	129	65	0.065	Peat Kiln	7	10.8
E. macurata	20	10	Mature (> 20 - <= 30)	67	34	0.278	Casamance Kiln	3	4.6
E. microcorys	32	16	Over (mature) > 30 - <= 40	4	2	0.639	Brick Kiln	0	0
Other Species	14	7	Old > 40	0	0	> 1.149	Steel Kiln	0	0

Table 3: Social, Economic, and ecological benefits of charcoal production and selling cooperatives initiation

Social benefits			Economic benefits			Ecological Benefits		
Role	**Number**	**Rate (%)**	**Role**	**Number**	**Rate (%)**	**Role**	**Number**	**Rate (%)**
Jobs creation	195	17.7	Increase of salaries	170	18.4	Harvesting of mature trees	181	16.2
Charcoal quality improvement	184	16.7	Increase of savings	168	18.2	Forest harvesting pressure reduction	176	15.8
Access to life insurance	169	15.3	Access to wages	180	19.5	Afforestation	190	17.1
Family Food security	190	17.2	Access to loan	150	16.3	Reforestation	190	17.1
Security of forests violation	178	16.1	Private sector investment	145	15.7	Adoption of improved charcoal production methods	197	17.7
Access to infrastructures development	188	17	Improvement GDP	109	11.8	Access to other sources of cooking energy	180	16.2

Benefit – Cost analysis of charcoal production and selling

There was a benefit cost analysis between revenue from sales and the cost of production as well as other social-economic and ecological benefits in this study to make sure that charcoal manufacture and selling is a profitable job and enhances peoples' livelihoods. The cost of charcoal production under traditional method was assessed at the same time the revenue from this method. Also, the cost under improved charcoal production method was assessed at the same time modern method.

Regression Analysis with Stata

With STATA software, both Social, Economic and Ecological aspects were analyzed and the findings are presented as follow:

Table 4: Charcoaling cost / 1m^3 on both tradition and improved carbonization methods

Cost of 1m^3 wood			Charcoaling cost / 1bag			Transport cost / 1 m^3		
Cost	**Nber**	**T. cost/ frw**	**Cost/ fw**	**Nber**	**T. Cost/fw**	**Cost**	**Nber**	**T. cost/fw**
2500	11	27500	2500	2	5000	100	0	0
3000	2	6000	3000	4	12000	200	1	200
3500	2	7000	3200	5	16000	300	10	3000
4000	4	16000	4000	11	44000	400	15	6000
4500	3	13500	3500	35	122500	500	14	7000
5000	4	20000	4200	6	25200	600	16	9600
5500	4	22000	4500	2	9000	700	5	3500
6000	3	18000	5000	0	0	800	2	1600
6500	2	13000	5500	0	0	900	0	0
7000	5	35000	6000	0	0	1000	2	2000
7500	10	75000	6500	0	0	1100	0	0
8000	5	40000	7000	0	0	1200	0	0
8500	1	8500	7500	0	0	1300	0	0
9000	1	9000	8000	0	0	1400	0	0
9500	0	0	9000	0	0	1500	0	0
10000	0	0	9500	0	0	1600	0	0
-	57	**310500**	-	**65**	**233700**		65	32900
-	-	**5447.368**	-	-	**3595.385**		-	**506.1538**

Table 5: Price of charcoal on both traditional and modern carbonization methods

Bags	Traditional Kiln		Improved with Casamance		Price / frw	Traditional Kiln		M. with Casamance	
	Nber	**T. nber**	**Nber**	**T. nber**		**nber**	**Price/ frw**	**nber**	**price / frw**
10	3	30	0	0	2500	0	0	0	0
15	10	150	0	0	5000	0	0	0	0
20	13	260	0	0	7500	2	15000	0	0
25	13	325	0	0	10000	10	100000	4	40000
30	17	510	0	0	12500	21	262500	6	75000
35	6	210	1	35	15000	34	510000	10	150000
40	0	0	2	80	17500	8	140000	40	700000
45	0	0	0	0	20000	0	0	15	300000
	62	**1485**	**3**	**115**	**22500**	**0**	**1027500**	**0**	**1265000**
	-	**24**	**-**	**38.3**	**-**	**75**	**13700**	**75**	**16866.7**

Social contribution

Table 6: Linear regression (Source - STATA analysis)

Social contribution	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
	0.627	0.09	6.84	0	0.447	0.808	***
Charcoal improvement	0.893	0.05	16.71	0	0.788	0.998	***
Life insurance	0.774	0.04	19.61	0	0.696	0.852	***
Food security	0.862	0.07	12.45	0	0.726	0.999	***
Forest security	0.631	0.05	13.77	0	0.541	0.721	***
Infrastructure dpt.	0.633	0.06	10.51	0	0.515	0.752	***
Constant	-3.489	0.15	-22.89	0	-3.79	-3.188	***
Mean dependent var		0.575		SD dependent var		0.496	
R-squared		0.841		Number of obs		200	
F-test		169.505		Prob > F		0	
Akaike crit. (AIC)		-67.377		Bayesian crit. (BIC)		-44.29	

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Economical contribution

Table 7: Linear regression (Source: STATA analysis)

Economic contribution	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Wage & salary	0.29	0.068	4.27	0	0.156	0.425	***
Savings & loans	0.18	0.052	3.53	0.001	0.081	0.287	***
Private investments	0.17	0.047	3.68	0	0.081	0.267	***
GDP improvement	0.22	0.034	6.53	0	0.153	0.285	***
Constant	-0.42	0.082	-5.14	0	-0.586	-0.261	***
Mean dependent var	0.22			SD dependent var		0.415	
R-squared	0.312			Number of obs		200	
F-test	22.058			Prob > F		0	
Akaike crit. (AIC)	150.403			Bayesian crit. (BIC)		166.895	

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Ecological Contribution

Table 8: Linear regression (Source : STATA Analysis)

Ecological contribution	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Sustainable Forest Management	0.725	0.053	13.59	0	0.62	0.83	***
Effective Forests harvesting	0.692	0.045	15.35	0	0.603	0.78	***
Afforestation improvement	0.803	0.069	11.62	0	0.666	0.939	***
Reforestation improvement	0.589	0.07	8.38	0	0.45	0.727	***
Constant	-1.863	0.109	-17.03	0	-2.079	-1.648	***
Mean dependent var		0.73		SD dependent var		0.445	
R-squared		0.776		Number of obs		200	
F-test		169.144		Prob > F		0	
Akaike crit. (AIC)		-46.694		Bayesian crit. (BIC)		-30.202	

**** p<0.01, ** p<0.05, * p<0.1*

DISCUSSION

Tree species names, size and charcoal production methods

The study's results indicated *Eucalyptus* are planted in the study area as trees for producing charcoal. *Eucalyptus* species are planted in Kigali rural areas at different rates with; 59.0% of *Eucalyptus saligna*, 16.0% of *Eucalyptus microcorys*, *Eucalyptus macurata* at 10.0%, *Eucalyptus camaldulensis* at 8.0%, and others such as *Eucalyptus tereticornis*, *acacia*, and *Pinus patula* but a very small rate. The similar findings indicated that Eucalyptus species dominates up 78% of all planted forests and other species with 6% of pines, 1.4% of native tree species, 3% of mixed exotic forests. (Rwibasira et al. 2021).

In addition to this, *E. saligna* and *E. teriticornis* are the two most prevalent eucalyptus species. *E. maculata*, *E. maidenii*, *E. mycrocoris*, and *E. citriodoris* are further common species. (Rwibasira et al. 2021). To assess if the time of harvesting used in the study area is done for mature forest or not, data on the volume of trees cut for charcoal production as well as their diameter at breast height and bole height were also collected. The length of the log needed to produce charcoal is therefore 2 meters, according to the study's findings.

As per reports, forests are cut down to make charcoal, and some of the trees involved have bole heights ranging from 12 to 28 meters. When the tree's DBH is less than 20 cm and its volume is less than 0.0055 m^3, harvesting is also carried out; however, the highest harvesting is done when the tree's DBH ranges from >10 cm to =20 cm and its volume is 0.639 m^3. The similar findings were indicated by Stelstra and showed that, Eucalyptus tree species such *E. grandis*, *E. microcorys*, *E. macurata*, and *E. camaldulensis*, among others, reach at 2.5 meters, while *Pinus patula* at maturity can grow up to 35 meters high and reaches a Mean Annual Increament of 15 to 30 m^3 / ha / year. (Stelstra, 2021).

Young plantings and coppice, which primarily consists of Acacia and Eucalyptus species, are increased at rates of 10.3 m^3/ha and 6 m^3/ha per year, respectively. Additionally, while woodlots and non-woody trees like *Eucalyptus*, *Grevillea*, *Pinus*, and *Cupressus* species have 10.8 m3/ha/year of MAI, softwood plantations like *Pinus spp*., *Cupressus spp*., and *Callitris spp*. have 8.6 m3/ha/year. (Nduwamungu 2011).

The study's findings revealed that 94.4% of the applied charcoal processing methods used in the study area are traditional techniques. They include; 84.6% of traditional earth with mound, 10.8% of traditional with Peat Kin and 4.6% of improved method with Casamance Kiln. (Nogueira *et al*., 2021)

In these kilns, earth is used to keep the carbonizing wood away from oxygen and to limit excessive heat loss. These kilns' main advantage is that they are inexpensive. In accordance with a study conducted by Kumar 2020 to assess the production of charcoal using conventional earth-mound kilns, the majority of earth kilns or mound kilns produce lump charcoal, which is a cheap and effective source of energy for both domestic and industrial uses. (Kumar et al. 2020). If the soil is rocky, hard, or shallow, or if the water table is close to the surface, the earth mound is recommended over the pit. However, the pit functions best in deep, loamy soil with good drainage. The size results of the study showed that a mound kiln's typical volume is 14 m^3. The results of this study also indicate that an average of 23 to 28 bags of charcoal are produced in one mound kiln. The efficiency varies from 8 to 15% (Richter 2012).

The Casamance is an additional charcoal production method that can be used in the area of study. This method, it was found, uses an Earth Mound Kiln with a Chimney. Better air flow control is made possible by this oil drum-constructed chimney. Additionally, pyrolysis is encouraged because the hot flues are only partially directed outside of the kiln. Because of this, reverse draft carbonization is more uniform and quicker than traditional kilns, producing charcoal with higher quality and up to 30% more efficiency. (Richter 2012).

Trials comparing the Casamance kiln to traditional mound kilns evidenced that the Casamance kiln has an advantage in terms of efficiency and faster carbonization times due to the improved hot flue circulation. Because it is more difficult to construct and costs more up front for the chimney, this type of kiln has disadvantages. Once the fire is started and up until the point at which carbonization is complete, the burners must continuously monitor the fire. To ignite the mound, live coals are placed in its center hole. 15 to 20 minutes after the fire starts, it is necessary to close the central hole, according to research. (Nahayo, Ekise, and Mukarugwiza 2013).

Social, Economic, and ecological benefits of charcoal production and selling

1. Initiation of charcoal production and selling cooperatives may contribute within three pillars of sustainable development.
Social Contribution; 62.7% Job creation, 89.3% Improved of charcoal production, 77.4% Life Insurance Access, 86.2%, Food Security, 63.2%, Reduction of Forest, and 63.3% Infrastructure Development. Economic Contribution; 29.1% Access to Salary and Wage, 18.4% Access to Savings and Loans, 17.4% Private Sector Investments, and 21.9% GDP Improvement.

Ecological Contribution

72.5% Sustainable Forest Management, 69.2% Effective Forest Harvesting, 80.3% Afforestation Improvement, and 58.9% Reforestation Improvement. Restaurants, wholesale markets, public and private institutions, and households are the primary consumers of charcoal, according to the study's findings. The aim of sustainable development, according to Niyonkuru and Barrett, is to meet present needs without compromising the ability of future generations to meet their own needs. The book on the introduction to sustainable development was published in 2015. However, the three main spheres of influence that must be taken into account in order to perceive sustainability are the so-called Three Pillars of Sustainability and their corresponding social, economic, and environmental aspects (Niyonkuru and Barrett 2021).

According to Miyuki Liyamna's 2017 study Understanding the Socio-Ecological Contexts Underlying Variable Sustainability Outcomes in African Landscapes using the Charcoal-Agriculture Nexus, the production of charcoal is a significant socioeconomic activity in Sub-Saharan Africa (SSA). Although the severity of effects on the multifunctionality of the landscape varies greatly, charcoal production is one of the main drivers of changes in rural land use in SSA (Iiyama et al., 2017). Although it is now more frequently acknowledged as a component of livelihood diversification strategies, selling and producing charcoal is still viewed as a last resort type of livelihood activity for those with few other options (Bernhard et al. 2021).

The fuel could possibly be produced using a better kiln, like Casamance, and limited to a sustainable supply, in accordance with the ecological aspect of producing and selling charcoal, to enable the restoration of tree biomass through plantation or natural regeneration (Iiyama et al. 2017). All parties involved in the forestry industry in the study area, including forest growers, charcoal producers, charcoal sellers, and forest extensionists, were aware of the problem (Dessie and Erkossa 2011). Even though land clearing for agriculture, habitation, and urbanization were the main drivers of natural resource bases, recent charcoal production in Rwanda was one of the factors that contributed to deforestation. (P. E., and D. U., 2022). According to the World Bank's report on socio-economic and ecological outcomes. Thus, it was suggested that there should be decentralized regulations, a specialized value chain with low transaction costs, and high margins at the production site (Niyonsenga, 2013).

Benefit – Cost analysis of charcoal production and selling

The relationship between revenues and costs for a given project at a specific interest rate constitutes the benefit-cost ratio. (Schettini *et al.,* 2021). In this conducted study, was stated that the costs associated with producing charcoal included wood, charcoaling, and transportation. The value of a forest in terms of wood is influenced by a number of variables, including tree species, size, and maturity, plantation location, charcoal production site near a road, and market or selling point. (Arakwiye, Rogan, and Eastman, 2021).

The findings of this study showed that the forest planted far away from markets or selling sites influences charcoal production, leading to small price. According to the prices in Rwandan francs (frw) per cubic meter (m^3) given by forest growers, they were divided into four classes based on how far a forest is planted from a road: = 2500, >2500 to = 5000, >5000 to = 7500, and >7500 to = 10000. However, charcoal production and selling contributes to people's livelihood and forest management. As stated, the cost of charcoaling includes all expenses related to performing all tasks, including tree cutting, drying, setting up a charcoal kiln, carbonizing, keeping track of, and harvesting and packaging charcoal.

The price can change depending on a number of variables, including the size of the kiln, the carbonization techniques to be used, the type and size of packaging, and the labor costs. As a result, the costs for producing 1 bag or 33 kg, as provided by all charcoal producers, are divided into 4 classes in this study: = 2500, >2500 to = 3000, >3500 to =4000, and >4500 to = 5000. According to research, 78.5% of people spend between 3000 and 3500 Rwf on charcoal for one bag. While 1 bag or 33 kg of charcoal costs, on average, 3595.385 Rwf. Transporting charcoal from the production site to the market or other selling locations adds to the cost of getting it into use. The price can vary depending on a number of variables, including transportation methods, where charcoal is produced in relation to its selling price, how much charcoal is transported, topographic factors, etc.

The study's findings showed that a bag of charcoal can cost anywhere between 200 and 1000 Rwf to transport. All transportation costs offered by charcoal vendors were divided into 5 categories: = 200, >200 to 400, >400 to 600, >600 to 800, and >800 to 1000. Therefore, it appears that 46.2% of consumers spend between 400 and 600 Rwf. The amount of charcoal produced varies depending on a variety of factors, including the types of trees used to make charcoal, the method of carbonization, the moisture content of the wood, how quickly the wood dries, and monitoring, among others. The findings of the study showed that using improved methods that also use the Casamance kiln causes a difference in the amount of charcoal produced compared to using traditional methods that use earth mound kilns or pit kilns. The results show that, using the traditional method, 47.6% of charcoal producers achieve very high production between 20 and 30 bags, 36.5% achieve medium production between 10 and 20 bags, 9.0% achieve low or subpar production between 30 and 40 bags, and 4.8% achieve less than 10 bags.

When using the improved Casamance kiln for producing charcoal, 33.3% and 66.7%, respectively, produce high outputs of 20 to 30 bags and 30 to 40 bags, respectively. A kiln with a volume of 16.0 m3 (4 m x 2.5 x 1.6) can typically produce 24.0 bags of charcoal on average using traditional methods, whereas 38.3 bags can be produced using the improved method using

Casamance. In order to calculate the typical number of bags of charcoal from 1 m^3 of wood. Therefore, while 2.4 bags of charcoal are typically produced from 1 m3 of wood in a Casamance kiln, 1.5 bags are typically produced from 1 m3 of wood in a traditional kiln. The price of charcoal can also change depending on a number of variables, including tree species, carbonization methods, quantity.

It is reported that charcoal produced under traditional method is sold between 7,500 and 12,500 Rwf, whereas between 10,000 Rwf and 12,500 Rwf for charcoal produced under improved method using Casamance. The study indicated that 1.5 gags are the average number of bags of charcoal from traditional kiln and costed 6365.3 while 2.4 are harvested from improved kilns and costing 5020 Rwf. The Benefit Cost Ratio on Tradition, BCR(t) Kiln is therefore 1.5 while Benefit Cost Ratio on Casamance, BCR(c) Kiln, which is 2.7. Additionally, the improved Casamance Kiln produces more charcoal than the Traditional Earth or Pith mound kiln. With the aid of STATA, it was also found that P – values obtained on both Social, Economic and Ecological aspects are less than 0.05 which leads to a rejection of H0 and H1 to be accepted. Therefore, this implies that Charcoal Production and Selling makes positive significant improvement in Social and Economic impact to Peoples' Livelihood and Ecologically to the Sustainability of Forests. in Karongi district especially in Mutuntu, Twumba and Rwankuba sectors.

The similar findings were obtained by different researchers, like for example indicated by Nahayo in 2013, the carbonization efficiency of conventional kilns in Rwanda were between 12% and 14%, similar to that of the majority of African countries. (Nahayo, Ekise, and Mukarugwiza, 2013). Typically, a traditional kiln produces 1.5 bags per stere or meter cube. The majority of charcoal burners are unskilled and untrained. As a result, they are compelled to learn the trade by copying others, which impedes industry innovation and growth. These modern kilns have efficiencies between 20% and 28%. Usually, 2.5 to 3 bags per stere, or one-meter cube, can be produced. (Nahayo, Ekise, and Mukarugwiza, 2013). Usually, 25 to 35 regular bags of charcoal are produced by these kilns. Each kiln can produce 825 kg to 1,155 kg of charcoal to the typical sac weight of 33 kg. (Richter, 2012). However, larger sacs that hold 50 kg to 60 kg of charcoal are also available. The quality of charcoal produced by the traditional earth mound kiln and the improved earth kiln (Casamance) differs noticeably in terms of carbonization and weight of charcoal.

As a result, the improved method of making charcoal requires less wood than the conventional method does to produce the same amount of charcoal (Richter 2012). The standard wage for laborers is 100 Rwf per bag loaded. Bags are occasionally delivered to a charcoal depot in between, where the charcoal is stored for use locally or regionally. (Niyonsenga 2013). This implies that through the adoption of improved charcoal making techniques with Casamance due to the initiation of charcoal production and selling cooperatives contribute significantly in improvement of sustainable development of people's livelihood through social, economic and ecological aspects in Rwanda especially in Karongi district.

CONCLUSION

The goal of the study was to assess the social, economic and ecological contribution of charcoal production and selling was conducted in tree sectors Mutuntu, Twumba, and Rwankuba of Karongi districts. However, the study's findings showed that *Eucalyptus saligna* make up 59.0% of the trees planted in the study area designated for the production of charcoal. Approximately 64.5% of trees used to make charcoal have a DBH between 10 and 20 cm, which equates to 0.0065m^3 of volume. Additionally, more than 95.6% produce charcoal using the traditional and 4.6% of improved method with Casamance. The production and sale of charcoal benefits people's livelihoods, the economy, the environment, and forest management. The study's findings showed that these activities completely satisfy the needs of families and help to provide them with a source of income. Both conventional kilns and Casamance are profitable, but at different rates, according to analysis of the Benefit Cost Ratio of charcoal production methods. The Benefit Cos Ratio for improved charcoal production using Casamance was 2.7 while the traditional method which are 1.5 respectively indicates how to motivate improved charcoal production. As a result, H_0 was rejected and H_1 was accepted because the P-value obtained was 0.000, which is less than 0.05. Therefore, this implies that Charcoal Production and Selling makes positive significant improvement in social and economic impact to peoples' livelihood and ecologically to the sustainability of forests in Karongi District.

RECOMMENDATIONS

Based on the findings from the study suggests the following in light of its findings and conclusion to improve the effectiveness of charcoal production and selling towards livelihood improvement and forest management:

1. Because the dominance of one tree species in all plantation forests across the nation has a negative impact on the productivity of the forests, interventions should be directed toward diversification of new tree species that can also produce charcoal in addition to Eucalyptus species. To make forest owners, charcoal producers, and other charcoal users aware of the need to plan the harvesting of mature forests in order to improve the production outcome.
2. The country needs training in forestry production in order to meet its needs for social, economic, and ecological benefits. For instance, producing charcoal with the intention of increasing production while preserving biodiversity during effective forest harvesting. Use of alternative cooking energy sources, including solar panels, gas, and electricity.
3. To increase production in terms of both quality and quantity, use improved charcoal production methods like Casamance kin. Cooperatives can be used to accomplish this, lowering costs for all parties.
4. It is advised to strengthen the policy related to the use forest resources, that make, sell, or plant logs, in to adopt better technologies throughout the entire value chain associated with forestry.

REFERENCES

Arakwiye E, Bernadette M, John R, and Ronald E. (2021). "Thirty Years of Forest-Cover Change in Western Rwanda during Periods of Wars and Environmental Policy Shifts." Regional Environmental Change 21(2).

Bernhard F, Katie P. et al. (2021). "Effects of Integrated Conservation-Development Projects on Unauthorized Resource Use in Volcanoes National Park, Rwanda: A Mixed-Methods Spatio-Temporal Approach." *ORYX* 55(4): 613–24.

Dessie G, and Teklu E. (2011). Forestry Department Food and Agriculture Organization of the United Nations Planted Forests and Trees Working Papers Eucalyptus in East Africa Socio-Economic and Environmental Issues. http://www.fao.org/forestry.

Emmanuel H, Niyonshuti E, Mushinzimana I (2021). "Socio-Economic Aspects Influencing Rural Household Adoption of Improved Clean Cook Stoves Case Study: Rwanda." American Journal of Modern Energy 7(4).

Hakizimana E, Eustache U. G. ,Wali T, Diego S, and Kayibanda V (2020). "Environmental Impacts of Biomass Energy Sources in Rwanda." Energy and Environmental Engineering 7(3): 62–71.

Miyuki et al., (2017). "Conceptual Analysis: The Charcoal-Agriculture Nexus to Understand the Socio-Ecological Contexts Underlying Varied Sustainability Outcomes in African Landscapes." Frontiers in Environmental Science 5(JUN).

Islam W, Mohaiminul E. 2020. "Data Analysis: Types, Process, Methods, Techniques and Tools." International Journal on Data Science and Technology 6(1): 10.

Kiyani P, Jewel A, Yohan L, and Don K. L. (2017). "Benefits and Challenges of Agroforestry Adoption: A Case of Musebeya Sector, Nyamagabe District in Southern Province of Rwanda." Forest Science and Technology 13(4): 174–80.

Kumar W, Gulshan A. K , Mishra A, and Smita C (2020). Charcoal Production through Traditional Earth-Mound Kiln: A Case Study in Northern India.

MINAGRI (2012) "The Business Case for Investing in the Import and Distribution of Fertilizer in Rwanda." (May). www.rdb.rw/.../user.../Rwanda_ Fertilizer Import and Dist.

Nahayo A, Isaac E, and Alphonsine M. (2013). "Comparative Study on Charcoal Yield Produced by Traditional and Improved Kilns: A Case Study of Nyaruguru and Nyamagabe Districts in Southern Province of Rwanda." Energy and Environment Research 3(1).

Nduwamungu J. (2011). "Forest Plantations and Woodlots in Rwanda." https://www.researchgate.net/publication/301695197.

Niyonkuru E, Pascal R, and Hazel B. (2021). "Gender and Intergenerational Challenges to Women's Economic Empowerment Initiatives in Rwanda." *World Development Perspectives* 23.

Niyonsenga S, David M. (2013). "Urban Planning and Social Inclusion: A Study of Kigali City, Rwanda." In *Annual World Bank Conference on Land and Poverty,*.

Nogueira E, Marta C. J (2021). "Evaluation of Eucalyptus Microcorys Wood Properties." *Advances in Forestry Science* 7(4): 1197–1202.

Oko P. E, Odey, D. U (2022). "Impact of Population Growth on Biodiversity Loss in Boki Agro-Ecological Rainforests, Cross River State, Nigeria." *Global Journal of Pure and Applied Sciences* 28(1).

REPUBLIC OF RWANDA Ministry of Environment Rwanda Forest Cover Mapping (2019).

Richter A, Frank R (2012). Establishing a GrEEn CharCoal ValuE Chain in Rwanda. www.whalerockstudio.com.

Rudiarto F, Iwan W. H, Holi B. W, and Tia D. I. (2019). "Rural Livelihood Resilience: An Assessment of Social, Economic, Environment, and Physical Dimensions." MATEC Web of Conferences 280: 01002.

Rwibasira P, Francois X. N, Nsabimana D, and Monique C. (2021). "Long-Term Effects of Forest Plantation Species on Chemical Soil Properties in Southern Rwanda." Soil Systems 5(4).

Schettini et al., (2021). "Wood and Charcoal Production in the Kiln-Furnace System: How Do the Costs and Revenues Variation Affect Economic Feasibility?" Revista Arvore 45.

Stelstra A, Roberto M (2021). "Implementation of Native Tree Species in Rwandan Forest Plantations-Recommendations for a Sustainable Sector." https://www.slu.se/en/subweb/library/publish-.

Tuyisingize, D. et al., (2022). "Forest Landscape Restoration Contributes to the Conservation of Primates in the Gishwati-Mukura Landscape, Rwanda." International Journal of Primatology 43(5).