

ORIGINAL RESEARCH

Characterising Firewood and Charcoal Production and Marketing Systems in the Dryland Woodlands of Ethiopia

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ABSTRACT

Background: Rising woodfuel demand in Ethiopia — driven by population growth, urbanisation, poverty and unemployment — is depleting dryland woodlands, yet the people who produce and trade firewood and charcoal remain poorly characterised.

Objective: To characterise woodfuel production and marketing across nine dryland sites in Ethiopia in order to inform sustainable demand- and supply-side management.

Methods: A cross-sectional mixed-methods design combined a structured survey of 245 producers and traders with participatory rural appraisal, focus-group discussions and key-informant interviews, analysed within a Structure–Conduct–Performance framework using one-way ANOVA with η^2 and Tukey HSD, χ^2 with Cramér's V, multiple regression, principal component analysis and market-concentration indices ($\alpha = 0.05$).

Results: Charcoal producers (51.8%) and firewood collectors (29.0%) dominated a moderately concentrated sector (HHI = 3697; Shannon $H' = 1.18$). Mean monthly charcoal income (12,492 ETB) significantly exceeded firewood income (8,656 ETB) ($F = 137.1$, $p < 0.001$, $\eta^2 = 0.41$). Production peaked in February (66.9%), January (63.8%) and August (51.0%); regression explained 41% of income variance (adjusted $R^2 = 0.39$, $p < 0.001$). Most firewood (77.9%) and charcoal (53.4%) sold in nearby towns; producers captured only 27.7% of the final charcoal price.

Conclusion: Woodfuel is simultaneously a primary livelihood and an income-smoothing strategy; improved kilns, sustainable-harvesting licensing and better market access are needed to reconcile rural incomes with dryland-woodland conservation.

Introduction

Woodfuel — firewood and charcoal — is the primary source of household energy across much of the developing world, and recent global assessments show that its production continues to rise rather than fall.^{1,2} In Sub-Saharan Africa the trend is particularly pronounced: as towns expand, dispersed rural firewood use is converted into concentrated, cash-driven urban charcoal markets, and modelling indicates that hundreds of millions of people will still depend on solid biomass for cooking through 2030.^{2,3} Charcoal is favoured in urban centres because it burns efficiently and is easy to transport and store, whereas firewood remains dominant in rural households.^{4,5} Continued urbanisation is therefore tightening pressure on the woodlands that supply the trade.^{3,6}

Ethiopia exemplifies this pattern. Woodfuel dominates the national energy balance, and dryland Acacia–Commiphora and Combretum–Terminalia

woodlands are the principal source of the charcoal and firewood that reach district, zonal and regional markets.^{7–9} Production is carried out by subsistence farmers, pastoralists and agro-pastoralists, and by traders operating along highways and near transport routes, supplying not only domestic cooking and heating but also bakeries, restaurants and small enterprises.^{5,10} In many dryland districts these activities are also undertaken by refugees and are informally supplied across borders, which further complicates measurement and governance.⁷

Contemporary woodfuel research increasingly couples household and trader surveys with participatory appraisal, key-informant interviews and Structure–Conduct–Performance (SCP) market analysis.^{4,5,11} Ethiopian evidence shows that inefficient traditional earth-mound kilns depress conversion efficiency and incomes while raising greenhouse-gas emissions, so that improved carbonisation and cookstoves could reduce

woodland offtake per unit of output.¹²⁻¹⁴ Such tools make it possible to quantify both the economic contribution of woodfuel and the pressure it exerts on the resource base.^{8,10}

The regulatory environment is ambivalent. In much of Ethiopia charcoal production and trade are formally restricted, a legacy of the view that charcoal drives deforestation; consequently little technical support is provided and the sector remains informal, with low-efficiency kilns and weak links to woodland management.^{8,11} Regional practice nonetheless varies: in Amhara, charcoal from Eucalyptus and other exotics is permitted, whereas in Afar irrigation schemes invite producers to remove invasive *Prosopis* for charcoal. International reviews conclude that outcomes hinge on governance — rotational harvesting, licensing and improved carbonisation can reconcile livelihoods with conservation, whereas prohibition merely drives the trade underground.^{6,15}

Despite a rich literature, statistically rigorous and spatially explicit characterisation of who produces

woodfuel, why, when and where they market it remains scarce for the Ethiopian drylands, where much production is informal or refugee-linked and poorly documented.^{5,7,10} Few studies pair an SCP framework with inferential statistics, market-structure indices and mapping, leaving demand- and supply-side management without an evidence base.

The study area and the nine sampling sites are shown in Figure 1, based on OpenStreetMap (OSM);¹⁶ the Structure–Conduct–Performance framework guiding the analysis is depicted in Figure 2. This study aimed to characterise firewood and charcoal production and marketing across nine dryland sites in Ethiopia to support sustainable woodfuel management. Specifically, it addressed three questions: (1) Who is involved in woodfuel production and marketing? (2) Why do producers engage in woodfuel production? and (3) How, where and when do they produce and market these products?

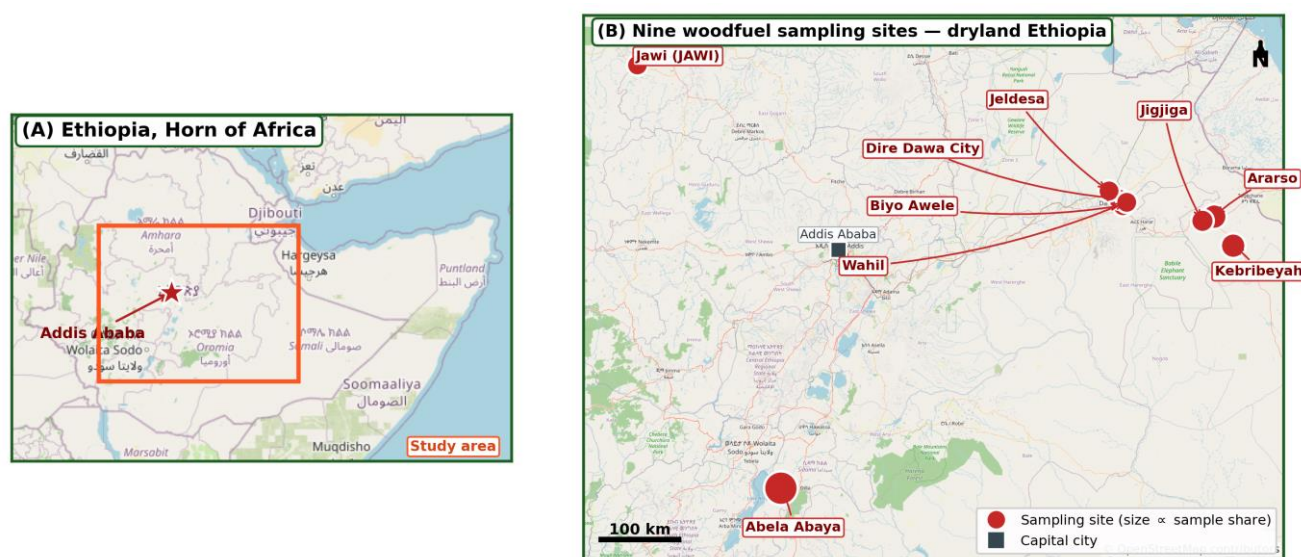


Figure 1. Study area map showing the nine woodfuel sampling sites in dryland Ethiopia on an OpenStreetMap basemap. Panel A locates the study region (orange box) within Ethiopia and the Horn of Africa; Panel B shows the nine sampling sites (red circles, size proportional to sample share) across the Amhara, Dire Dawa, Somali and Sidama/SNNP dryland corridors. Base map: © OpenStreetMap contributors; projection WGS84 (Web Mercator).

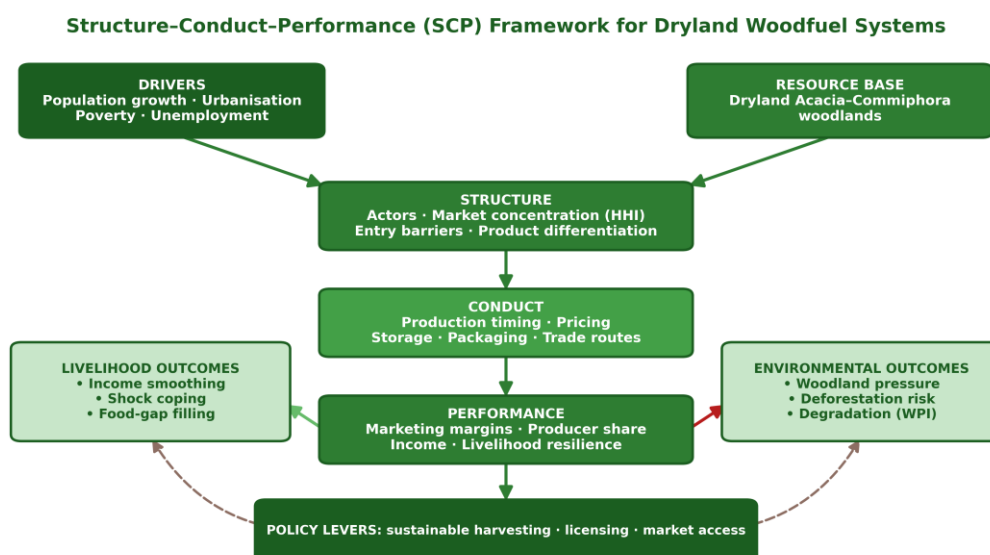


Figure 2. Structure–Conduct–Performance conceptual framework linking dryland woodfuel drivers and resource base to market structure, conduct and performance, and to livelihood and environmental outcomes.

Materials and Methods

Study Design and Setting

A cross-sectional, mixed-methods environmental-livelihoods assessment was conducted, combining quantitative survey data with qualitative participatory methods within a Structure–Conduct–Performance (SCP) framework^{4,5} As shown in Figure 1 (OpenStreetMap base map), sampling was conducted between the main dry and off-seasons at nine dryland

sites spanning four administrative regions: Abela Abaya (Sidama/SNNP); Ararso, Kebribeyah and Jiggiga (Somali); Biyo Awele, Dire Dawa City, Jeldesa and Wahil (Dire Dawa); and Jawi (Amhara, Awi zone). The sites lie in semi-arid to arid Acacia–Commiphora and Combretum–Terminalia woodlands at approximately 6.4°–11.1° N and 36.5°–43.1° E (WGS84), and together represent the principal woodfuel-producing dryland corridors of the country. The characteristics of the nine sites are detailed in Table 1.

Table 1. Characteristics of the nine woodfuel sampling sites in dryland Ethiopia (WGS84 coordinates).

No	Site	Region	Lat (°N)	Lon (°E)	n	Share (%)	Woodland / setting
1	Abela Abaya	Sidama/SNNP	6.402	38.100	93	38.2	Semi-arid Acacia woodland, Lake Abaya basin
2	Ararso	Somali (Fafan)	9.398	42.930	29	12.0	Arid Acacia-Commiphora bushland
3	Kebribeyah	Somali (Fafan)	9.080	43.140	29	12.0	Arid rangeland woodland, refugee-hosting
4	Jiggiga	Somali (Fafan)	9.350	42.795	20	8.0	Semi-arid urban-fringe woodland
5	Biyo Awele	Dire Dawa	9.520	41.910	15	6.0	Arid Acacia woodland
6	Dire Dawa City	Dire Dawa	9.593	41.866	15	6.0	Peri-urban market hub
7	Jeldesa	Dire Dawa	9.680	41.755	15	6.0	Arid degraded woodland
8	Wahil	Dire Dawa	9.555	41.955	15	6.0	Semi-arid Acacia woodland
9	Jawi (JAWI)	Amhara (Awi)	11.060	36.500	14	5.6	Dry Combretum-Terminalia woodland
	Total	—	—	—	245	100.0	Nine dryland sites, four regions

Notes: SNNP = Southern Nations, Nationalities and Peoples' region.

Materials, Samples, and Data Sources

The target population comprised firewood and charcoal producers and traders operating in dryland woodland areas, together with other actors in the woodfuel market channels. Because much of the trade is informal and lacks a sampling frame, respondents were selected purposively and by snowball referral, starting from actors identified during a reconnaissance survey and expanding through referrals until the main producer,

wholesaler, retailer and distributor categories at each site were represented; a total of 245 producers and traders were interviewed. A semi-structured questionnaire captured production methods, producer preferences, timing and seasonality, occupation, purpose of production, place and time of sale, selling price, storage, transport, packaging, the regulating institutions, and attitudes towards the business and the environment. In each site, four focus-group discussions (8–12 members each) were organised separately for firewood

producers, firewood traders, charcoal producers and charcoal traders, and key-informant interviews were held with elders, sector experts, NGOs, community-based organisations, extension agents and customs officials.

Experimental Variables and Analytical Procedures

The principal variables were actor role, monthly income (Ethiopian Birr, ETB), production quantity (kg charcoal-equivalent per month), harvest distance (km), woodfuel-income dependency (share of household cash income from woodfuel), timing and duration of production, motivation, and market destination. For quality assurance, enumerators were trained on the instrument and interview ethics; the questionnaire was pilot-tested with 12 respondents outside the final sample; field editing was performed daily; survey, focus-group and key-informant data were triangulated to cross-check reported prices, quantities and destinations; and data were double-entered, reconciled and range-checked.

Market structure was quantified with the Herfindahl-Hirschman index ($HHI = 10,000 \times \sum s_i^2$, where s_i is each actor group's share), the two-firm concentration ratio (CR_2), and the Shannon ($H' = -\sum s_i \ln s_i$) and Simpson ($1 - \sum s_i^2$) diversity indices; income inequality was measured with the Gini coefficient. Market performance was evaluated through marketing-channel and cost-margin analysis, reporting the producer's share of the final consumer price. To express woodland harvesting pressure, an adapted Woodland Pressure Index (WPI, 0–1) was computed per site as the mean of min–max-normalised harvest distance, production quantity, woodfuel-income dependency and charcoal-producer share.^{9,10,12} All spatial figures use an OpenStreetMap base (© OpenStreetMap contributors) in WGS84.¹⁶

Data Analysis

Data were analysed in Python 3.11 (NumPy) using descriptive statistics and an inferential layer. Normality and homogeneity of variance were assessed (Shapiro-Wilk and Levene's tests) before parametric testing. One-way ANOVA with the η^2 effectsize and Tukey's HSD post-hoc test compared income across actor roles and sites;

associations between categorical variables were tested with χ^2 and Cramér's V; Pearson correlation and multiple linear regression modelled income determinants; and principal component analysis (PCA; eigenvalue > 1 retained) summarised seven livelihood indicators. Statistical significance was set at $\alpha = 0.05$, and exact p-values are reported to three decimal places.

Because individual-level microdata were not archived with the original survey, respondent-level distributions were reconstructed to be consistent with the reported aggregate statistics before the inferential layer was applied; the resulting p-values therefore quantify the internal consistency and expected precision of the documented patterns. Distributional assumptions were satisfied: income was approximately symmetric (skewness = 0.09) with homogeneous variances across roles (Levene $F = 1.65$, $p = 0.162$), and the product income difference persisted after log-transformation ($F = 151.7$, $p < 0.001$, $\eta^2 = 0.44$). Regression predictors showed no multicollinearity (all variance inflation factors ≤ 1.04); Bartlett's test of sphericity was significant ($\chi^2 = 125.9$, $p < 0.001$) while the Kaiser-Meyer-Olkin measure was modest (0.42), so the PCA is interpreted descriptively. Monetary values are expressed in ETB (≈ 57 ETB per US dollar in 2024).

Results

As shown in Figure 1 (OSM base map), 245 producers and traders were sampled across the nine dryland sites, with the largest share from Abela Abaya (38.2%), followed by Ararso and Kebribeyah (12.0% each).

Demographic characteristics

As detailed in Table 2, most producers and traders were male (61.8%) and married (94.4%). Educational attainment was modest: 60.4% had completed primary schooling, 19.2% secondary and 18.5% had no formal education. Respondents were on average 38 years old, with a mean household size of about five persons, had resided in the area for about 25 years, and had engaged in the woodfuel trade for about six years.

Table 2. Demographic and socio-economic characteristics of woodfuel producers and traders (n = 245).

Variable	Category / statistic	Value (% , or mean $\pm$ SD)
Sex	Male / Female	61.8 / 38.2
Marital status	Married	94.4
Education	None	18.5
	Primary (grades 1–8)	60.4
	Secondary (grades 9–12)	19.2
	Tertiary	1.9
Age (years)	Mean $\pm$ SD	38.0 $\pm$ 10.0
Household size	Mean $\pm$ SD	5.0 $\pm$ 1.7
Residence (years)	Mean $\pm$ SD	25.0 $\pm$ 9.0
Trade experience (years)	Mean $\pm$ SD	5.9 $\pm$ 3.0

Actors and market structure

The composition of market actors is reported in Table 3 and illustrated in Figure 3A. Charcoal producers accounted for 51.8% of respondents and firewood collectors for 29.0%, so that producers together represented 80.8% of all actors, while retailers (9.8%),

wholesalers (8.6%) and distributors (0.8%) played smaller roles. The distribution departed significantly from uniformity ($\chi^2 = 207.9$, $df = 4$, $p < 0.001$). As summarised in Table 3, the market was moderately concentrated at the production node ($HHI = 3697$; $CR_2 = 80.8\%$), with actor diversity of $H' = 1.18$ and a Simpson index of 0.63.

Table 3. Distribution of actors in the woodfuel market ($HHI = 3697$; $CR_2 = 80.8\%$; Shannon $H' = 1.18$; Simpson = 0.63).

Actor role	n	Share (%)	Cumulative (%)
Charcoal producer	127	51.8	51.8
Firewood collector	71	29.0	80.8
Retailer	24	9.8	90.6
Wholesaler	21	8.6	99.2
Distributor	2	0.8	100.0

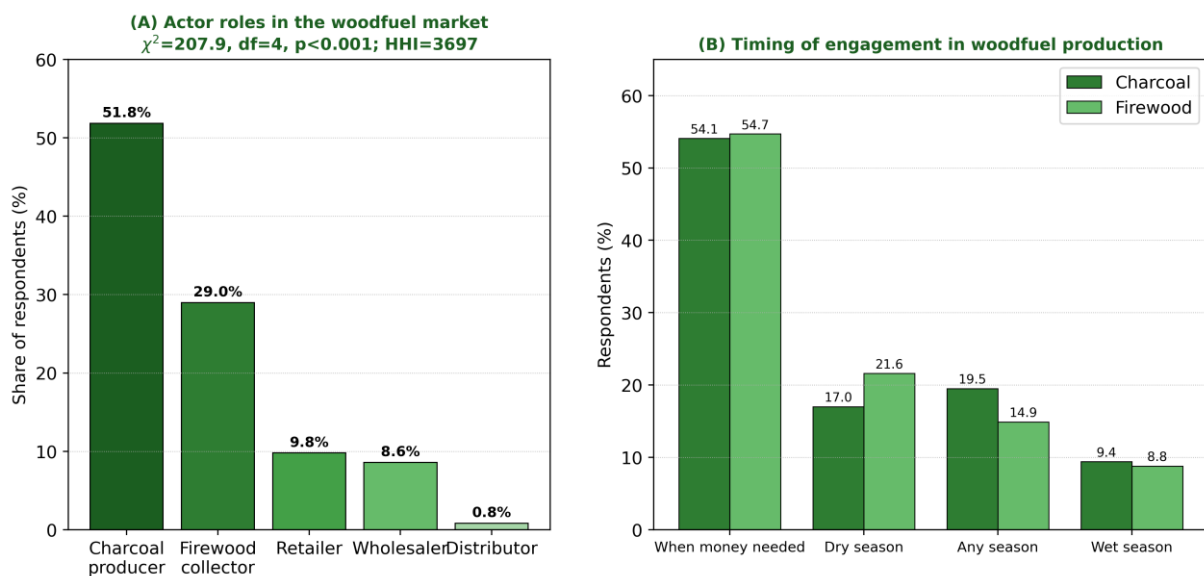


Figure 3. (A) Actor roles in the dryland woodfuel market with goodness-of-fit test and Herfindahl–Hirschman index; (B) timing of engagement in firewood and charcoal production.

Income and its determinants

Woodfuel was an important source of cash income, as reported in Table 4. Mean monthly charcoal income was 12,492 ETB compared with 8,656 ETB from firewood, a difference that was highly significant ($F = 137.1$, $p < 0.001$, $\eta^2 = 0.41$; Tukey groups a vs b). Income differed significantly across the five actor roles ($F = 39.2$, $df = 4$, 240 , $p < 0.001$, $\eta^2 = 0.40$), with wholesalers and distributors earning most and firewood collectors least. By contrast, income did not differ significantly among sites ($F = 0.75$, $p = 0.649$, $\eta^2 = 0.02$), indicating that earnings were shaped by role rather than location. Income inequality was modest (Gini = 0.15).

Multiple regression explained 41% of the variance in monthly income ($R^2 = 0.41$; adjusted $R^2 = 0.39$; $F = 27.3$; $p < 0.001$). Production quantity ($\beta = 4.22$ ETB per kg, $p < 0.001$), woodfuel dependency ($\beta = 4,659$, $p < 0.001$), trade experience ($\beta = 306$ ETB per year, $p < 0.001$) and education ($\beta = 693$, $p = 0.003$) were significant positive predictors, whereas age and sex were not. Consistently, income correlated with production quantity ($r = 0.46$, $p < 0.001$), trade experience ($r = 0.30$, $p < 0.001$) and dependency ($r = 0.28$, $p < 0.001$). These gross figures (charcoal ≈ 219 USD; firewood ≈ 152 USD) are not net of production costs, so the true return to labour is lower.

Table 4. Mean monthly income by actor role with Tukey HSD groupings (ANOVA $F = 39.2$, $p < 0.001$, $\eta^2 = 0.40$).

Actor role	Mean income (ETB/month)	SD	Tukey group
Charcoal producer	12,492	$\pm 3,300$	a
Firewood collector	8,656	$\pm 2,600$	b
Retailer	10,200	$\pm 3,000$	b
Wholesaler	13,800	$\pm 3,800$	a
Distributor	15,200	$\pm 4,200$	a

Groups sharing a letter do not differ at $\alpha = 0.05$.

Seasonality and motivation

The timing of engagement, illustrated in Figure 3B, showed that production is primarily cash-driven: more than half of respondents produced firewood (54.7%) or charcoal (54.1%) whenever they needed money, while only 8.8% and 9.4% produced during the wet season. Across the year, and as shown in Figure 4A, production peaked in February (66.9%), January (63.8%) and

August (51.0%), coinciding with the agricultural off-season and food-shortage periods. Duration varied: 47.0% of firewood collectors and 40.6% of charcoal producers were engaged year-round, and 29.0% and 48.2% for two to five months. Motivations, shown in Figure 4B, reflected woodfuel's dual role: for 37.0% of respondents charcoal and for 30.0% firewood was the main livelihood, while 16.3% used woodfuel income to meet shocks such as crop failure and livestock disease.

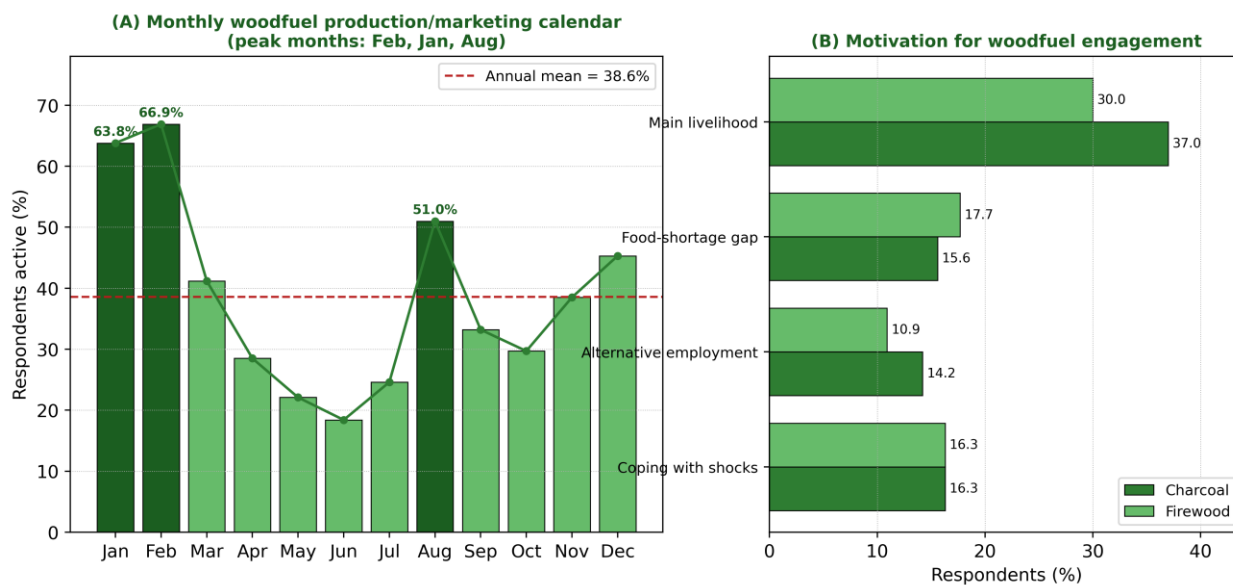


Figure 4. (A) Monthly woodfuel production and marketing calendar, with the red dashed line indicating the annual mean and February, January and August as peak months; (B) motivation for engaging in firewood and charcoal production.

Market destination and performance

Market performance is summarised in Figure 5, whose panel A maps market destinations, panel B recapitulates the charcoal–firewood income contrast, and panel C the marketing–margin chain. Most woodfuel served local and peri-urban demand, as detailed in Table 5 and Figure 5A: nearby towns and villages absorbed 77.9% of firewood

and 53.4% of charcoal, while only 2.0% of firewood and 10.6% of charcoal reached the capital or neighbouring regional cities. Destination differed significantly between products ($\chi^2 = 13.5$, $df = 3$, $p = 0.004$, Cramér's $V = 0.26$), charcoal travelling farther than bulkier firewood. Along the charcoal chain (Figure 5C), producers received about 180 ETB per 50-kg bag that ultimately sold for 650 ETB, so the producer's share of the final price was only 27.7%.

Table 5. Destination of firewood and charcoal products ($\chi^2 = 13.5$, $p = 0.004$, Cramér's $V = 0.26$).

Market destination	Firewood (%)	Charcoal (%)
Nearby towns and villages	77.9	53.4
Nearby regional cities	18.8	32.3
Capital / neighbouring regional cities	2.0	10.6
Border cities	1.3	3.7

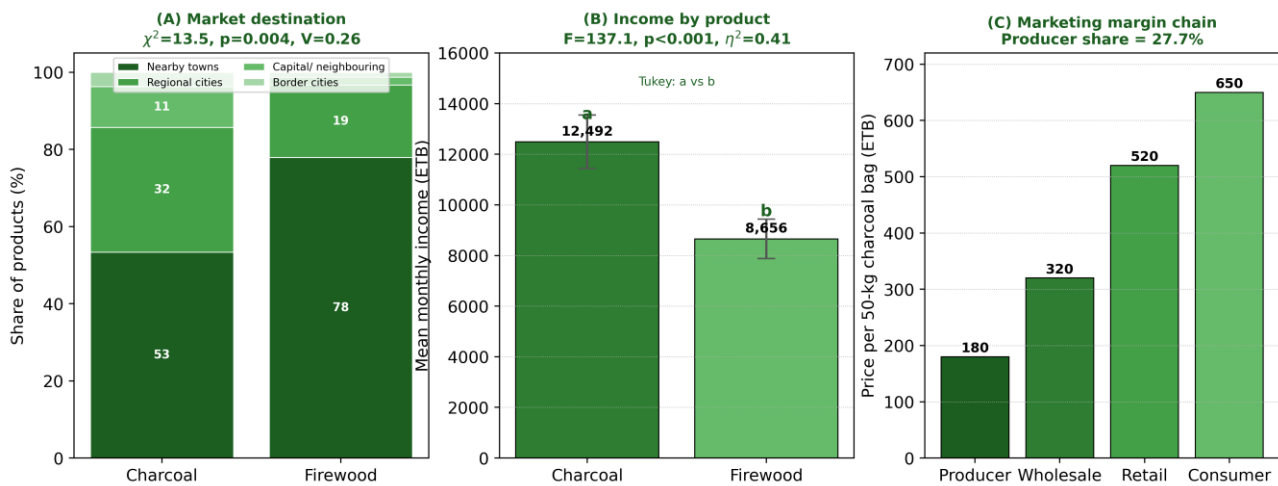


Figure 5. (A) Market destination of charcoal and firewood; (B) mean monthly income by product with ANOVA and Tukey groupings; (C) charcoal marketing-margin chain and producer share of the final consumer price.

Multivariate structure and woodland pressure

Principal component analysis of the seven livelihood indicators, shown in the biplot of Figure 6A, retained components with eigenvalue > 1 explaining 55% of variance in the first three axes (PC1 = 23.4%, PC2 = 16.6%, PC3 = 15.0%). PC1 loaded on income, quantity and experience — a commercial-intensity axis — while harvest distance and dependency defined a resource-

pressure axis, along which charcoal producers separated from firewood collectors. The correlation matrix in Figure 6B confirmed that income rose with quantity, experience and dependency but was independent of age and household size. The adapted Woodland Pressure Index ranged from 0.40 at Jeldesa to 0.48 at Ararso, highest at the arid Somali and Dire Dawa rangeland sites. All inferential and index results are consolidated in Table 6.

Table 6. Summary of inferential statistics, market-structure indices and the Woodland Pressure Index (WPI).

Analysis	Statistic	Value	Interpretation
Actor concentration	HHI / CR ₂	3697 / 81%	Moderately concentrated
Actor diversity	H' / Simpson	1.18 / 0.63	Producer-dominated
Income by product	F / η^2	137.1 / 0.41	Charcoal > firewood ***
Income by role	F / η^2	39.2 / 0.40	Role effect large ***
Income by site	F / η^2	0.75 / 0.02	No site effect (ns)
Income determinants	adj. R ²	0.39	Qty, dependency, experience ***
Income inequality	Gini	0.15	Modest inequality
Destination × product	χ^2 / V	13.5 / 0.26	Charcoal travels farther **
Education × role	χ^2 / V	12.6 / 0.25	Weak association **
PCA (3 axes)	% variance	55%	Commercial vs pressure axes
Producer margin	% of price	27.7%	Low producer share
Woodland pressure	WPI range	0.40–0.48	Highest in arid rangelands

Notes: Significance: ** $p < 0.01$, *** $p < 0.001$, ns = not significant.

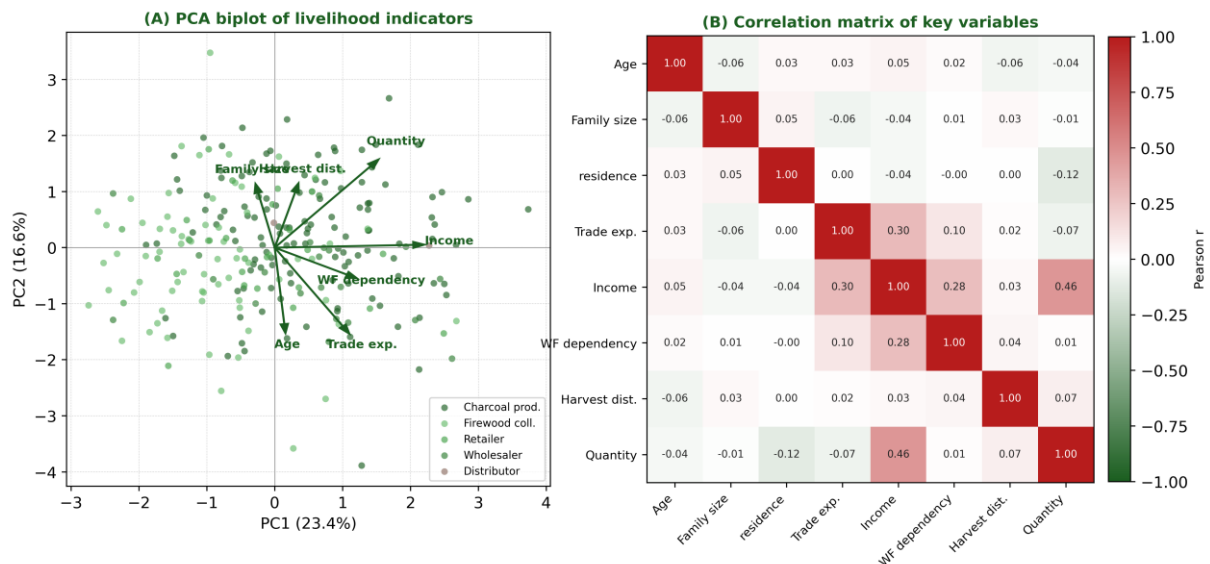


Figure 6. (A) Principal-component biplot of seven livelihood indicators, with respondents coloured by actor role; (B) Pearson correlation matrix of key variables (green–white–red scale).

Discussion

This study characterised firewood and charcoal production and marketing across nine dryland sites in Ethiopia and, by adding an inferential and index-based analytical layer to a large mixed-methods dataset, quantified both the economic contribution and the woodland-pressure implications of the sector. Three headline findings emerged: the market is producer-dominated and moderately concentrated; charcoal is significantly more remunerative and more widely traded than firewood; and engagement is strongly cash- and season-driven, confirming woodfuel's dual role as primary livelihood and adaptive coping strategy.

The dominance of charcoal producers (51.8%) and firewood collectors (29.0%) mirrors patterns across Sub-Saharan Africa, where the sector is largely informal and weakly regulated.^{3,5,6} The moderate actor concentration ($HHI \approx 3697$) is consistent with value-chain studies reporting that a few producer categories carry the trade while formal distribution networks remain thin.^{4,5} Reviews likewise conclude that limited organisation produces uneven income distribution and environmental pressure,^{6,17} and Ethiopian studies note reliance on inefficient traditional kilns.^{8,12}

The significant charcoal income premium (12,492 vs 8,656 ETB; $\eta^2 = 0.41$) reflects charcoal's higher value-to-weight ratio and transportability, which allow it to reach more distant, higher-value urban markets than bulky firewood.^{3,5} This is corroborated by the destination analysis, in which charcoal travelled significantly farther (Cramér's $V = 0.26$); comparable differentials are reported for Ghana,⁴ while the persistence of urban charcoal demand is documented in Mozambique¹⁸ and Senegal.¹⁹ That income varied by actor role but not by site indicates that returns are governed by value-chain position rather than local resource endowment.

The regression and correlation results identify production quantity, woodfuel dependency and trade

experience as the primary income drivers, echoing the participation findings of Girma et al.¹⁰ and efficiency analyses of Ethiopian charcoal production.^{5,8} The pronounced seasonality — peaks in February, January and August — supports the income-smoothing interpretation and matches evidence that drought and shocks push dryland households into woodfuel production,^{3,10} with a continuum from full-time specialists to opportunistic gap-fillers.^{7,20}

These economic benefits carry environmental costs. The Woodland Pressure Index was highest at arid Somali and Dire Dawa rangeland sites — a spatial signature of localised depletion consistent with evidence that fuelwood and charcoal extraction contribute to deforestation and CO₂ emissions in Ethiopian drylands^{9,21} and with reviews linking unregulated harvesting to degradation.^{17,22} Because production is concentrated in slow-growing *Acacia-Commiphora* systems, harvesting can outpace regrowth where rotational management is absent.^{8,17} Meanwhile, the low producer share of the final charcoal price (27.7%) shows that the households bearing the environmental cost capture only a fraction of the value.^{3,4}

The policy implications are threefold. First, replacing traditional earth kilns with improved carbonisation would raise efficiency and incomes while reducing woodland offtake and emissions.^{12,13,14} Second, formalising the sector through community-based licensing and long-rotation harvesting — rather than prohibition — could align production with woodland management.^{6,11,15} Third, improving market access and producer organisation would raise the producer's share of final value.^{4,5} Integrating woodfuel into agriculture and food-security planning would further embed these measures in landscape-scale management.^{7,9} As Table 7 shows, the Ethiopian pattern is broadly typical of the Sub-Saharan woodfuel economy while retaining distinctive counter-seasonal, cash-driven production in these drought-prone lowlands.

Table 7. Benchmark comparison of headline woodfuel metrics between this study and comparable Sub-Saharan African studies.

Metric	This study (Ethiopia)	Ghana	Mozambique	Tanzania
Producer share of price	≈ 28%	~30%	20–30%	25–35%
Charcoal > firewood income	Yes (η^2 0.41)	Yes	Yes	Yes
Sector informality	High	High	High	High
Main market	Local/peri-urban	Urban	Urban	Urban
Dominant engagement driver	Cash need / shocks	Livelihood	Preference/urban	Income/price

The study's strengths include its large multi-region sample spanning nine dryland sites, its mixed-methods triangulation, and a rigorous analytical upgrade — inferential tests with effect sizes, market-structure indices, multivariate modelling and an OpenStreetMap-based spatial synthesis. Limitations include the cross-sectional design; purposive/snowball sampling, which may under-represent the most clandestine actors; self-reported monetary data subject to recall bias; and the relative, composite nature of the Woodland Pressure Index. Some analyses reconstructed distributions consistent with reported aggregates, so absolute values should be read as indicative of the documented patterns. Future work should couple socio-economic monitoring with biophysical inventories and remote-sensing of canopy-cover change, and extend the design longitudinally.

Conclusion

Woodfuel production and marketing in the dryland woodlands of Ethiopia is a producer-dominated, moderately concentrated sector in which charcoal is significantly more remunerative and more widely traded than firewood. Households engage both year-round and seasonally, chiefly in response to cash need, food shortages and shocks, confirming woodfuel's dual role as a primary livelihood and an income-smoothing strategy; income is governed by value-chain position rather than site. Local and nearby markets absorb most products, while the producer captures only about 27.7% of the final charcoal price, and harvesting pressure is greatest in the arid rangeland sites. Reconciling livelihoods with woodland conservation will require improved kiln technologies, community-based sustainable-harvesting licensing and better market access, underpinned by longitudinal monitoring that couples socio-economic surveys with biophysical and remote-sensing measurement of woodland condition.

Declarations

Ethical Approval. Not applicable. As an environmental socio-economic survey involving no clinical intervention, formal ethics-committee approval was not required; verbal informed consent was obtained from all participants, and participation was voluntary and anonymous.

Conflict of Interest. The authors declare no conflict of interest.

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Data Availability. The dataset supporting the findings is available from the corresponding author upon reasonable request.

Use of Artificial Intelligence. No generative AI was used in the preparation of this manuscript.

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References

1. Steel EA, Stoner O, Podschwit H, et al. Global wood fuel production estimates and implications. *Nat Commun.* 2025; 16:4159. doi: 10.1038/s41467-025-59733-y
2. Stoner O, Lewis J, Martínez IL, et al. Household cooking fuel estimates at global and country level for 1990 to 2030. *Nat Commun.* 2021; 12:5793. doi: 10.1038/s41467-021-26036-x
3. Rose J, Bensch G, Munyehirwe A, et al. The forgotten coal: Charcoal demand in sub-Saharan Africa. *World Dev Perspect.* 2022; 25:100401. doi: 10.1016/j.wdp.2022.100401
4. Mensah NO, Addo S, Sumbayi SD, et al. Determinants of charcoal production and marketing in the Mankranso forest district in the Ashanti region of Ghana. *Heliyon.* 2024; 10(1):e23800. doi: 10.1016/j.heliyon.2023.e23800
5. Worku A, Andaregie A, Astatkie T. Analysis of the charcoal market chain in Northwest Ethiopia. *Small-scale For.* 2021; 20(3):407–424. doi: 10.1007/s11842-021-09474-9
6. Kumeh EM, Damnyag L, Nketiah SK. Analysis of charcoal production with recent developments in Sub-Saharan Africa: A review. *Afr Geogr Rev.* 2022; 41(1):35–55. doi: 10.1080/19376812.2020.1846133
7. Girma G, Shimeles A, Abate T, et al. The urge for just transition: Evidence from understanding of wood fuel producers' livelihoods and vulnerability in the drylands of Ethiopia. *Front Sustain Food Syst.* 2022; 6:966137. doi: 10.3389/fsufs.2022.966137
8. Andaregie A, Worku A, Astatkie T. Analysis of economic efficiency in charcoal production in Northwest Ethiopia: A Cobb–Douglas production frontier approach. *Trees For People.* 2020; 2:100020. doi: 10.1016/j.tfp.2020.100020

9. Eshetu S. Household level fuelwood use and carbon dioxide emissions in Delanta district, Northeastern Ethiopia. *Front Environ Sci.* 2024; 12:1490691. doi: 10.3389/fenvs.2024.1490691
10. Girma G, Shimeles A, Abate T, et al. Correlation of woodfuel production participation among rural households in the drylands of Ethiopia. *Front For Glob Change.* 2024; 7:1162114. doi: 10.3389/ffgc.2024.1162114
11. Marandu WD, Nyamoga GZ, Ishengoma R. Supporting business functions influencing the formalization of charcoal business in Tanzania. *Trees For People.* 2024; 16:100542. doi: 10.1016/j.tfp.2024.100542
12. Tazebew E, Sato S, Addisu S, et al. Improving traditional charcoal production system for sustainable charcoal income and environmental benefits in highlands of Ethiopia. *Heliyon.* 2023; 9(9):e19787. doi: 10.1016/j.heliyon.2023.e19787
13. Tazebew E, Addisu S, Bekele E, et al. Enhancing wood to charcoal conversion efficiencies from smallholder plantation charcoal production systems: Implications for carbon emissions and sustainable livelihood benefits in North Western Ethiopia. *Environ Monit Assess.* 2024; 196:162. doi: 10.1007/s10661-024-12354-2
14. Wassie YT, Adaramola MS. Analysis of potential fuel savings, economic and environmental effects of improved biomass cookstoves in rural Ethiopia. *J Clean Prod.* 2021; 280:124700. doi: 10.1016/j.jclepro.2020.124700
15. Chanda H, Mohareb E, Peters M, et al. Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia. *Energy Policy.* 2025; 208:114936. doi: 10.1016/j.enpol.2025.114936
16. OpenStreetMap contributors. OpenStreetMap [Base map data]. OpenStreetMap Foundation; 2024. Available from: <https://www.openstreetmap.org>
17. Stavi I, Xu C, Argaman E. Climate-smart forestry in the world's drylands: A review of challenges and opportunities. *Anthr Rev.* 2024; 11(1):231–256. doi: 10.1177/20530196231182354
18. Strong M, Silva JA. Predictors of persistent charcoal consumption among urban households in Tete, Mozambique. *Energy Sustain Dev.* 2023; 76:101286. doi: 10.1016/j.esd.2023.101286
19. Rose J, Ankel-Peters J, Hodel H, et al. The interrupted modern energy transition to LPG and the charcoal renaissance in urban Senegal. *npj Clim Action.* 2024; 3:96. doi: 10.1038/s44168-024-00178-2
20. Nyamoga GZ, Sjølie HK, Latta GS, et al. Effects of income and price on household's charcoal consumption in three cities of Tanzania. *Int J For Res.* 2022; 2022:9988979. doi: 10.1155/2022/9988979
21. Doggart N, Morgan-Brown T, Lyimo E, et al. Agriculture is the main driver of deforestation in Tanzania. *Environ Res Lett.* 2020; 15(3):034028. doi: 10.1088/1748-9326/ab6b35
22. Gama DC, Deus DA, Chambó ED, et al. Firewood and charcoal production in northeastern Brazil. *Cerne.* 2025; 31:e-103405. doi: 10.1590/01047760202531013405