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Making Timber Accessible to Forest Communities: A Study on Locally-Adapted, Motor-Manual Forest Management Schemes in the Eastern Lowlands of Bolivia

Benno Pokorny [1], Juan Carlos Montero Terrazas [2], James Johnson [3], Karen Mendoza Ortega [4], Walter Cano Cardona [5] and Wil de Jong [1] *

[1] Chair of Silviculture Freiburg University
[2] GOPA Worldwide Consultants
[3] Canavalia Verde
[4] Instituto Boliviana de Investigacion Forestal
[5] World Commision of Protected Areas
* Correspondiese: wilhelmus.de.jong@waldbau.uni-freiburg.de

Abstract: Forest communities around the world have great difficulties in utilizing the economic potential of their forests, especially timber, under current technical requirements and legal frameworks. The present study examines the feasibility of motor-manual forest management among indigenous Chiquitano communities in Bolivia's Eastern Lowlands. With a focus on sustainable timber harvesting, it evaluates local practices, tests technical optimization options, and assesses their technical, financial, and environmental impacts. Findings reveal that traditional motor-manual timber production is scarcely profitable, exacerbated by burdensome legal frameworks and limited market access. However, motor-manual forest management remains an essential source of income for communities, and it constitutes an important option for rural development. Field tests demonstrate that with the use of better equipment such as high quality chainsaws, and improved maintenance and workflows, productivity and profitability of local logging can be enhanced. Despite low environmental impact, optimized motor-manual forest management continues to be constrained by governance challenges, logistical limitations, and limitrfd markets for locally produced timber. The study recommends a holistic approach to optimize these aspects, including targeted technical support, market development, simplified legal frameworks, and the setting up of robust local governance structures instead of ineffective centralized command and control approaches. These improvements would enable communities to sustainably manage forests while addressing their socio-economic needs. The findings underscore the potential of logging by local communities as an alternative to large-scale mechanized logging.

Keywords: community forestry; social technologies; tropical forests; Chiquitania

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1. Introduction

Over the last three decades, customary rights of indigenous and traditional communities to land and associated natural resources became recognized, and land tenure and resource management rights were adjusted accordingly [3,4,53,58,59]. Many of these communities are forest users, and large natural forest areas became subject to communal collective use rights [29]. In South America alone, 20% of the land is designated as protected areas, most of them populated by indigenous and traditional communities [10,50]. The positive impact of resident communities on the conservation of forests has resulted in advocating community-based conservation [18,31]. Living conditions of forest communities, however, have in many cases remained precarious. Communities still face social marginalization and remain vulnerable to external threats like climate change, deforestation, land dispossession, and resettlement [21,33]. In addition to the allocation of land rights, sustainable income opportunities are necessary for poverty alleviation and to create long-term prospects, especially for young people [28,56].

Since the 1992 Rio Summit, the sustainable production of timber has been identified as an option to combat deforestation in the tropics [57]. Timber generates economic dynamics increases the value of forests and avoids other unsustainable forestland uses [5,15]. However, timber production was assumed as mechanized harvesting by timber companies with specialized personal and sufficient financial resources [46]. When the importance of forest communities for forest conservation was recognized, community forestry initiatives became prominent, financed by international donors, and implemented by NGOs. Community forestry became included in the legislation of many countries, especially in the tropics. Bolivia´s forestry legislation, [8] however, emphasized that communities follow technical and administrative requirements demanded of timber companies [34,46]. In practice these legal, administrative, and technological challenges turned out unachievable. Forest communities are dependent on timber companies when wanting to benefit from forest logging, or on NGOs, who offer only temporary support [7]. Once external support ceases local forest management usually collapses [46] and communities may be left with social conflicts [2,44].

These frustrations after two decades of investment in community forestry have led to a decline in support from international donors for sustainable logging by indigenous and traditional communities, and these options are ignored in new bioeconomy strategies [61]. On the other hand, some countries made an effort to better adapt forestry legislation to the realities of communities. In Bolivia, for example, in the last 15 years, Bolivia's forestry regulations have recognized and legalized previously illegal community forest management practices. The harvesting of small volumes without the design of forest management plans is one of the most innovative changes in Bolivia's forestry regulations that allowed the proliferation of small-scale timber extraction for the benefit of communities. Community members are no longer necessarily dependent on timber companies to use timber from their forests, but can also negotiate with chainsaw operators who are familiar with the legal and administrative procedures for harvesting smaller volumes [18]. Nevertheless, in practice, it remains very difficult for communities in Bolivia to capture the economic potential of their forests.

The sustainable use of timber from natural forests by communities requires exploitation options adapted to local capacities, needs, and interests; and a high degree of flexibility and autonomy, and avoiding complex bureaucracy and investments in costly machinery. This study analyses the feasibility of locally adapted low-input, motor-manual timber harvesting among indigenous communities in the Bolivian Chiquitania, a highly diverse forest region in Eastern Bolivia. The study will: (1) describe local timber extraction schemes; (2) test options to enhance motor-manual harvesting as the base for low-input forest management, and (3) assess the technical, and financial performance and environmental impact of such management.

2. The Case study

2.1. The Situation in Bolivia

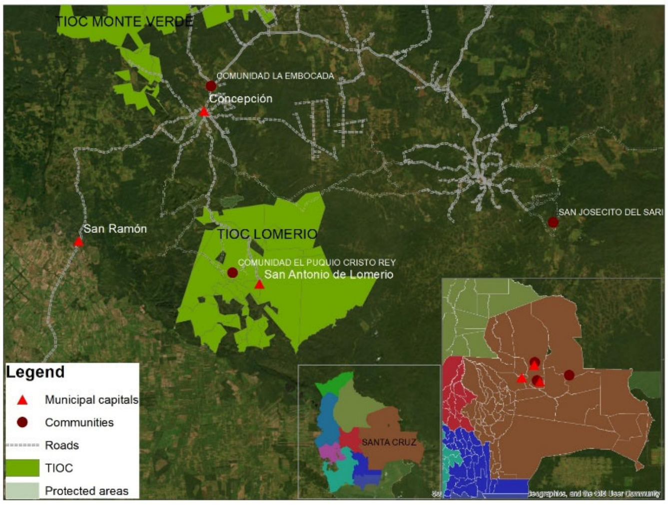
Over the past two decades, Bolivia has experienced notable growth in forest areas managed by indigenous and peasant communities, and local social groups [1]. They managed 2.2 million ha in 2009, and 6.6 million ha in 2023, or 63% of the 10.6 million ha under management. Forest companies managed 2.9 million ha, while private ownership accounted for 1.6 million ha. Bolivia’s forest legislation mandates reduced impact logging (RIL) with oversight and approval by the national government forestry agency ABT (*Autoridad de Fiscalización y Control Social de Bosques y Tierras*). Many efforts since Bolivia’s 1990s forestry reforms aimed at building technical and managerial capacities of indigenous communities to follow forestry regulations. Only a few success stories can be reported [27] and the harvesting and marketing of timber from indigenous and other community lands is carried out by logging companies, or community members negotiate individually with chainsaw operators to extract timber [19]. The results are low prices, and the conversion of logged-over forests to agricultural land, or negative social, economic, and environmental consequences [37].

The Bolivian Constitution of 2009 creates the possibility for forest communities to define their own rules, management, and governance systems, which should be supported and validated by ABT [43]. In practice, however, this legal opportunity has not yet been adopted widely. Instead, the Integrated Forest and Land Management Plan, which should incorporate indigenous and local communities' forest management traditions, follows the forest regulations defined for timber concessions managed by timber companies (Administrative Resolution ABT N° 250/2013). Several regulations allow small volumes of timber to be harvested on indigenous and local community lands in some Bolivian regions. These regulations increase decision-making power to communities but do not break dependence on other forestry actors for commercial timber extraction such as timber companies and non-local entrepreneurs [11,19].

2.2. Study Area

The study focuses on the Chiquitanía (Fig. 1) in the eastern lowlands of Bolivia, an area covered largely by natural forest constituting a transition from dry seasonal lowland forest, the Chiquitano forest, in the South (55% coverage) to humid Amazonian forest in the north (21% coverage). The remaining area is covered by seasonally flooded marshlands and dry endemic shrublands locally called *abayoy* [39]. Currently, the Chiquitanía is the source of 80% of Bolivia's timber from indigenous territories and community land [1,13]. The Chiquitano forest is threatened by predatory timber harvesting deforestation from agricultural and cattle ranching, and forest fires [37]. Over the past two decades, the national government has increasingly attempted to settle farmers from upland areas of Bolivia in the Chiquitanía [20]. The older Chiquitanía settlements are indigenous communities founded by Jesuits [51]. The principal indigenous nation in the region is the *Chiquitano*, of approximately 40,000 people, just under half of the region's population. Over four million ha have been allocated under different rights of tenure to indigenous communities, logging concessionaires, private landholders, farmer communities (*campesinos*), and local social groups [1].

The study reported here was implemented in the *Territorio Indígena Originario Campesino* – TIOC (indigenous native peasant territory) of Lomerio () covering an area of 259,189 ha and made up of a total of 29 communities with a population of 6,178 or around 1,200 families (CICOL, personal information, 2019). The TIOC Lomerio is legally affiliated with the Organization of Indigenous Communities of Lomerio, CICOL (*Central Indígena de las Comunidades Originarias de Lomerío*), which aims to establish autonomy over indigenous territories.



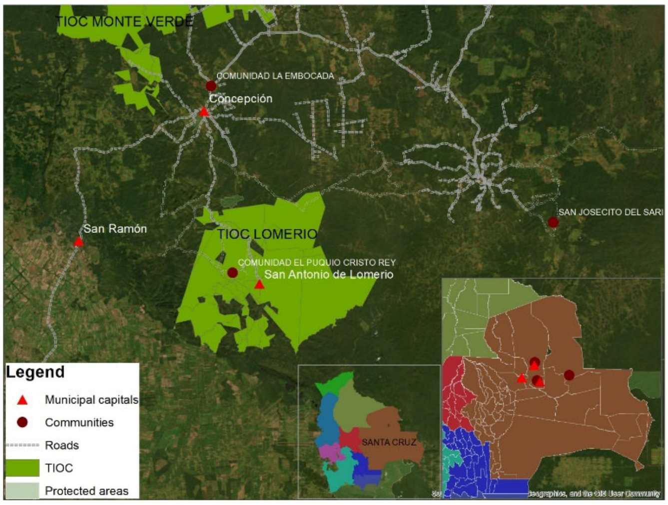


Figure 1. Map of the TIOC Lomeria in the Chiquitanía region in Bolivia.

The soil and terrain of the area are poorly suited for intensive farming. Traditionally, families cultivate less than one ha of swidden plots and collect fruits, nuts, medicinal plants, and wood from collectively owned forests. Beekeeping is gaining in importance. Many families, however, are switching to livestock farming. A recurring problem is forest fires caused by escaping fires when burning recently slashed agricultural fields or pastureland [12,37].

The communities of Monterito were selected in coordination with CICOL and community members for the analysis of informal timber harvesting schemes and options for the enhancement of local logging practices through improved motor-manual harvesting. Forest operators from Monterito, San Josecito del Sarí (Municipality of San Ignacio de Velasco), Villa Nueva - La Embocada (Municipality of Concepción), and Puquio (Municipality of Lomerío)near Puquio joined the testing. These communities are institutionally connected to indigenous organizations responsible for the implementation of the forest management plans in their respective communities.

2.3. Experiences from Formal Timber Harvesting In The Study Area

In the 1990s, with support from NGOs, government agencies, and international cooperation, a General Forest Management Plan (GFMP) was developed for the TIOC Lomerio under the responsibility of CICOL. This included the purchase of a stationary band saw mill located in the community of Puquio. Individual communities or groups of communities were allowed to

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implement their Annual Operation Plan (AOP). The AOP included the extraction of logs with machinery and their subsequent milling in the stationary sawmill in Puquio. The machinery was managed by a private company under the supervision of CICOL, with technical support provided by local NGOs. The sawmill was expected to generate financial returns that would initially cover CICOL's operating expenses to then distribute any surplus to the communities. In addition, communities benefited from temporary jobs as well as incomes from the timber harvested in their forests. Income from the sale of timber was used for school improvement, the purchase of medicines, and maintenance of a health care center. Challenges in generating expected cash flows arose, primarily due to the low productivity, high costs, and unfavorable market prices. Disagreements between the sawmill and local communities, particularly over delayed and perceived underpayments were frequent. Distant communities did not benefit from employment opportunities at the sawmill [32]. By 2000, significant losses led to the suspension of the GFMP under CICOL´s supervision, and the sale of the sawmill to a private company.

At this point, some members of the communities took the initiative to use their chainsaws to fell and saw timber on their own, without prior communal endorsement. They began cutting trees in the most remote parts of the forest, especially where they had previously fought against intruders together with CICOL. The timber was sold informally for little money to local buyers, who transported the timber to Santa Cruz. Discontent with this practice soon grew within communities because the income remained in the hands of a few unauthorized loggers, and it violated the GFMP, which covered the entire area managed by CICOL, jeopardizing forest activities of all the 28 communities involved. As a result, the community of Monterito decided to organize its logging and prepare a new AOP. After consultation, Monterito's plans were authorized by CICOL and the other communities.

To overcome the lack of operating capital, Monterito requested the support of a timber company, which provided the financial resources to implement their new AOP for 280 ha. The company appointed a professional forester as a collaborator and hired community members as temporary staff to carry out a forest census. After approval of the AOP logging operations were carried out under the supervision of the forester. The company was eventually caught undertaking illegal activities and collaboration was terminated. All communities included in the CICOL's GFMP were affected, and the plan was suspended for two years. Many communities as a result lost interest in collective forest management coordinated by CICOL. Informal logging operations, however, continued.

2.4. Data Gathering

Structured interviews were conducted with 28 of the 56 families living in the Monterito community to record details of informal timber harvesting and to find out whether and to what extent families were involved in these activities. The survey was carried out by locals who had previously received intensive training. The questionnaire and the survey process were tested to ensure the suitability and comprehensibility of its application. In each household both spouses were interviewed. The interviews focused on timber harvesting (activities, logistics, tree selection criteria, harvesting volumes, products, sales markets, actors involved, and governance arrangements), but also discussed non-timber forest products, the economic importance of the different products, and the forest and the general land use dynamics. Questions were asked about the costs and benefits of timber harvesting and its environmental impact. Data was tabulated for subsequent analysis.

In addition, a group of community members was brought together to verify and complement information from the surveys. The group drew maps of logging sites and discussed selection criteria. For each site, the group recalled how many trees and of which species had been logged. Opportunities and risks associated with informal timber harvesting were discussed, as well as possibilities for optimization. Information on timber quantities was provided in the customary Bolivian unit of measurement "*pie tablar*" (pt), which corresponds to a board foot of one inch x one foot x one foot or 2.54 cm x 30.48 cm x 30.48 cm. Therefore, 424 board feet (bf) equals one cubic meter (m^3). The prices were expressed in local currency Bolivianos (Bs). At the time of the study (2019), the exchange rate was 6.96 Bs for one USD.

Three community members with experience in timber harvesting were asked to demonstrate how trees are selected, felled, processed, and transported off-site, to evaluate the technical, financial, and environmental performance of informal logging. The three members, each with one assistant felled a total of 16 trees, mainly cuchi (*Astronium urundeuva*), but also curupaú (*Anadenanthera colubrina*), and sirari (*Copaifera chodatiana*), with an average volume of 1.26 m³ per tree, as well as 3 tajibo (*Handroanthis serratifolius*) trees of significantly smaller dimensions (**Error! Reference source not found.**).

Table 3. Dasymetric parameters of the 16 trees felled for the study.

Species	N	Average			
		dbh (cm)	Commercial height (m)	Volume (m³)	Total height (m)
Cuchi (*Astronium urundeuva*)	9	56.1	7.88	1.26	20.33
Curupaú (*Anadenanthera colubrina*)	2	62.5	8.50	1.27	16.00
Sirari (*Copaifera chodatiana*)	2	73.5	5.80	1.25	21.00
Tajibo (Tabebuia sp)	3	48.3	5.90	0.51	17.33
Total	**16**	**57.6**	**7.33**	**1.12**	**19.31**

The group was given full autonomy in how to carry out the operations and was accompanied through all working steps. The following measurements were taken: work efficiency, yield of the timber processed, and damage to the remaining forest stand. The time the workers invested for each activity was measured, as were the volumes of the felled trees, sawn logs, and sawn products. To assess financial viability, both direct and indirect costs were considered. Direct costs include all input-related items such as equipment, materials, and services, including transportation costs and salaries. Direct costs were determined for each phase of work, while indirect costs, e.g. depreciation of equipment and materials, were estimated using standard values.

The damage caused by the felling and sawing was measured by classifying all trees with a diameter at breast height greater than 20 cm (dbh) into five classes of damage classes: 1. no damage, 2. damage to 25% of the crown but intact trunk, 3. damage to 50% of the crown and/or moderate damage to the trunk, 4. damage to 75% of the crown and/or severe damage to the trunk, 5. the tree had severe damage or died. No surveys along the skid trails were conducted since no roads are needed to transport sawn timber products without heavy machinery and therefore major damage was not expected.

The study of technical optimization options focused on two primary cost-relevant activities i.e., the sawing of logs into locally marketed end products such as long logs, short logs, and poles, and the transportation of these products to the collection points for further distribution. All operators underwent training on the proper use and maintenance of the tested equipment which included instruction on equipment assembly, chain sharpening, and lubrication.

For milling, we considered three options: 1) the traditional technique, freehand sawing of the trunk with the chainsaw, but with quality equipment in terms of the chainsaw (STIHL MS661), the latest generation model with high performance, low weight, and reduced vibration thanks to an all-electric management system, a specific milling chain (Rapid Duro), and professional maintenance including periodic sharpening; 2) The use of a portable mill Bristol guide bar for single-person use consisting of a frame adjusted by a bolt system adjustable in all its sections and used for mounting on the saw blade. The Bristol unit used in the test was made in Brazil and weighs 7 kilograms; and, 3) the use of a portable attachment Logosol timberjig and guide rail (further referred to as Logosol equipment) consisting of three main parts: the timberjig used as a stand, two steel guide rail supports

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that can be adjusted at 90° angles in four exact positions, and a 2.75-meter aluminum guide rail, adaptable for longer dimensions. The unit weighs 15 kg (5kg excluding the rails) and can be used with blades up to 90 cm in length for sawing logs up to 80 cm in diameter. The Logosol equipment is manufactured in Sweden.

The three technologies were evaluated based on three parameters: 1) yield, understood as the ratio between the volume of the log to the volume of the sawn products; 2) time, understood as the description and qualitative and quantitative documentation of the flow of operations to calculate the total time, productive time, non-productive time and efficiency percentage of each technology; and 3) input, required for the operations (i.e. gasoline, spare parts, logistics, transportation). The study used two hardwood species, tajibo amarillo (*Handroanthis serratifolius*) and cuchi (*Astronium urundeuva*), and three semi-hardwood species with commercial value: tarara colorada (*Platymiscium fragans*), tarara amarilla (*Centrolobium microchaete*) and roble (*Amburana cearensis*) to balance out the effects of different wood densities and wood qualities.

Three options for transporting the sawn products from the processing site to the storage yard were compared: 1) Manual transportation on shoulders which is common in the area. People between 30 and 50 years of age in good physical condition were selected for the study. The boards were transported by two people, the planks and poles by one person; 2) Transport on horseback, more specifically two experienced local people who handled two horses with their respective harnesses and accessories. The animals were used alternately to avoid excessive strain; and, 3) transport with a Chinese-made 250 cc three-wheeled cargo bike (Dayand-PUMA), very common in the area, with a trailer with a maximum load capacity of 300 kg.

For each option, times were measured for each step (i.e. loading and shipping, transporting, unloading and stacking, and packing), including preparing access routes for the horse and motorcycle. Non-productive times for refreshments, rest breaks, and equipment maintenance, as well as unforeseen events (mechanical breakdowns, rain, storms, etc.) were also recorded. The distance traveled on each trip was measured and, based on the measured volume, the total weight of the transported products was calculated. Necessary resources were recorded, including periodic feeding and watering of the horses.

For systematization and analysis, parameterized matrices were designed in Excel format to standardize the data recorded in the field. Based on the data collected on time and input, input costs, and sales value of final products were entered (**Error! Reference source not found.**). For all options, a net cash flow analysis was undertaken to calculate the net present values (NPV) and internal rates of return (IRR).

Table 1. Prices for relevant items used for calculation for the year 2019.

Item	Price
Chainsaw STIHL MS 661	1.015,00 USD
Attachment Big Mill Basic (Logosol)	1506.00 USD
Portable Mill Bristol Guide Bar (Marco guía)	330.00 USD
Cargo Bike Dayand-PUMA (Motochata)	1250.00 USD
Depreciation	15% per year
Materials and minor tools	93.50 USD per person
Oil	7.03 USD per liter
Fuel	0.54 USD per liter
Maintenance (Cleaning the devices, replacing worn parts, skid trail maintenance)	2.96 USD per m^3
Daily rate for a worker	14.40 USD per day
Personal Protective Equipment	109.00 USD per person
First aid kit	40.00 USD per person
Food	6.45 USD per person

Average price of boards and planks produced (as in the district capital Concepción)	5.52 per m³

For the analysis, the sale price of the lumber from the forest road was assumed at 105 USD/m³, regardless of the product and species. Accordingly, the timber trader´s costs of 58 USD/m³ for transporting the timber over 100 km to Concepción, the nearest city, were not taken into account. The analysis also did not take into account the costs of technical training and support for local operators.

3. Results

3.1. Local Timber Harvesting Practices

Three-quarters of the households surveyed had actively participated in logging in the past year. Tree felling locations were generally easily accessible but outside the area of the AOP. According to the municipality's land use plan, the selected areas were designated for agriculture or grazing land. In some communities, logging happens with the permission of local authorities while in others it does not, which may lead to conflicts within the community, with other communities, and with CICOL. In Monterito, only one person logged without permission, while 14 people obtained permits from the community head (*cacique*) and another nine from the community assembly. Two people had the approval of both the head and the assembly.

Households harvested an average of 13.5 trees the previous year. Two persons harvested more than 30 trees each. Households harvested trees for their consumption, particularly for the construction of fences, suggesting a close link between local forest use and the expansion of livestock farming. Others engaged in commercial logging. The timber was sold to third parties and a smaller proportion within the community. Species were selected that have durable wood, adequate dimensions, and a reasonably straight trunk. Within the two main categories, construction materials and fencing, seven products were locally manufactured using chainsaws (**Error! Reference source not found.**). All the products are sold in standard dimensions corresponding to volumes expressed in board feet. The volume of one piece varies between 0.0075 m³ for one strut, and up to 0.045 m³ for a cross beam. Prices vary from USD 244/m³ for roof beams to 169 USD/m³ for fence posts.

Table 2. Principle products obtained by local chainsaw milling.

Product		Description	Standard dimension	Volume	Price*	
				m³	USD/unit	USD/m³
Triangular fence posts		**A longitudinal portion of wood triangular shape, with a base typically of 13 cm and a height of 12 cm. The length is 2.20 m used for fence posts or for dividing paddocks in livestock activities. Its is**	10 cm x 10 cm x 12 cm x 220 cm	0.017	2.87	169
Straining or corner posts		Rectangular or round posts range from 4" to 8" and up to 3 m long used in cattle corrals. .	20 cm diámetro x 250 cm de largo	0.079	17.24	218

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Product		Description	Standard dimension	Volume	Price*	
				m³	USD/unit	USD/m³
Lintel		A wide solid structure, used to support the weight of a roof or concrete over doors or windows of a dwelling. The lintel is less than the length of the gables and its dimensions fit 4" high x 8" wide x 2 m long.	15 cm x 15 cm x 300 cm	0.067	17.24	257
Struts		Rectangular piece to aid in securing corrugated iron or tiles used for roofing. Dimensions vary according to need but are typically 2" x 2" inches.	5 cm x 5 cm x 300 cm	0.01	2.16	216
Roof beam		The rectangular wood is utilized for constructing roof supports, which are shaped as either triangles or rectangles. The dimensions of the wood are 4" in width and 2" in height for use with zinc roofing, or 6" in width and 2" in height for shingles. The length of the wood ranges from 2 meters to 5 meters, depending on the required roof size.	5 cm x 15 cm x 400 cm	0.03	7.33	244
Cross beam		Rafters are also rectangular timbers used for roof supports, but, unlike the scissors, they are self-supporting structures. When a roof is assembled, the rafters are placed parallel and perpendicular to the battens. Their most common dimensions are between 5"-7" wide and 2" high. The longer the better, but from 15' and up are acceptable, unless for smaller constructions.	15 cm x 10 cm x 300 cm	0.045	9.63	214
Planks		Planks are wider than other products and are used for different purposes, ranging from the manufacture of furniture to the production of flooring or wooden utensils. The width is variable but the thickness is generally between 1" and 2". The board is considered short if it is less than 8', and long, if greater than 8'.	10 cm x 2.5 cm x 300 cm	0.0075	1.58	211

*Average prices in Lomerio in May 2022.

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Nine tree species were named that were harvested last year. Cuchi (*Astronium urundeuva*) accounted for more than half of the harvested volume (57%). Cuchi wood is known for its durability, and accounted for 85% of fence posts production, but is also used as corner posts for houses. In the second place, although in significantly lower volumes, tajibo is used locally, including two species: *Tabebuia sp. and Handroanthis serratifolius.* Both are among the most commercially valuable species in the region and are used for furniture, house construction, and crafts. In addition to these species, some cases of harvesting of cedro (*Cedrela fissilis*) and roble (*Amburana cearensis*) were mentioned, both with great commercial importance in the region 20 years ago. Their reduced utilization suggests a decrease in availability as a result of past exploitation. Similarly, the lack of mention of Bolivian rosewood (*Machaerium scleroxylon,* morado) indicates a rapid decrease in availability. Interviews confirmed that households in the region also use a variety of non-timber forest products (NTFPs) such as nuts, medicinal plants, fibers, forest seeds, wild fruits, and honey. The sale of baru nuts (*Dipteryx alata*) and honey in particular can generate considerable income. In addition, families engage in hunting and fishing, often in combination with logging. Overall, forest uses play a key role in household subsistence and are an important element of cultural identity.

Chainsaws without any special accessories are the preferred equipment for felling trees and for sawing. All chainsaw operators in the community are self-taught. Experienced operators offer their services for a daily rate. There were 21 such operators in the community. All of them use Stihl chainsaws; 16 own their chainsaws, while five operators rent chainsaws for the equivalent of USD 7.20 per day. Most of the chainsaws were more than five years old, many even more than 10 years old. Only two chainsaws were purchased in the last two years.

Logs are usually processed directly at the felling site as there is no equipment available to move them in one piece. Sawn products are transported manually on shoulders if they are not too heavy and the distance is not too large, usually less than 200 m. Eight of the interviewees stated that they shouldered products over a distance of up to 1 km, and three even mentioned distances of more than 1 km. For heavier products, horses and sometimes cargo bikes are used. More than a third of respondents stated that they work almost exclusively manually, but combine manual transportation with the use of horses and cargo bikes. More than 80% of the operators do not market the timber products they produce. One-third used the products for their purposes, such as building houses and fencing pastures. One-tenth supplied their community for community projects or to meet a specific demand. A single operator supplies its products to another community.

Less than 20% of the people engaged in logging sold their sawn products almost exclusively tajibo and, less frequently cedro, roble, and curupaú. The prices obtained for the products fluctuated widely: In Lomerio between USD 2.90 per post and USD 17.25 per straining or corner post. Eight households were more intensively engaged in external marketing. In one year they produced a total of 1,895 posts (46.46m^3). One businessperson reported having sold 15.51 m^3 of tajibo as flitches to Santa Cruz. A few people have specialized in these more lucrative urban markets, although selling without the required permit is risky.

3.2. Technical and Financial Assessment

3.2.1. Technical Aspects

Felling and processing of the 16 trees selected by the teams that were requested to test low-input, motor-manual timber harvesting required an average of 6.5 hours per tree, which essentially corresponds to one tree per day per team (). Of these 6.5 hours, about 35% was dedicated to productive work, and 19% to logistics. Almost half of the time (46%) was recorded as waiting time, which included waiting, hunting, and resting. It took a total of one hour to get to and from the forest each day. Half an hour was spent searching for trees. The felling, including preparations, took less than 20 minutes while sawing of the felled tree took about one hour and a half. Less than one hour was spent on sharpening the chain, troubleshooting the chainsaw and other interruptions, and 30 minutes on a lunch break.

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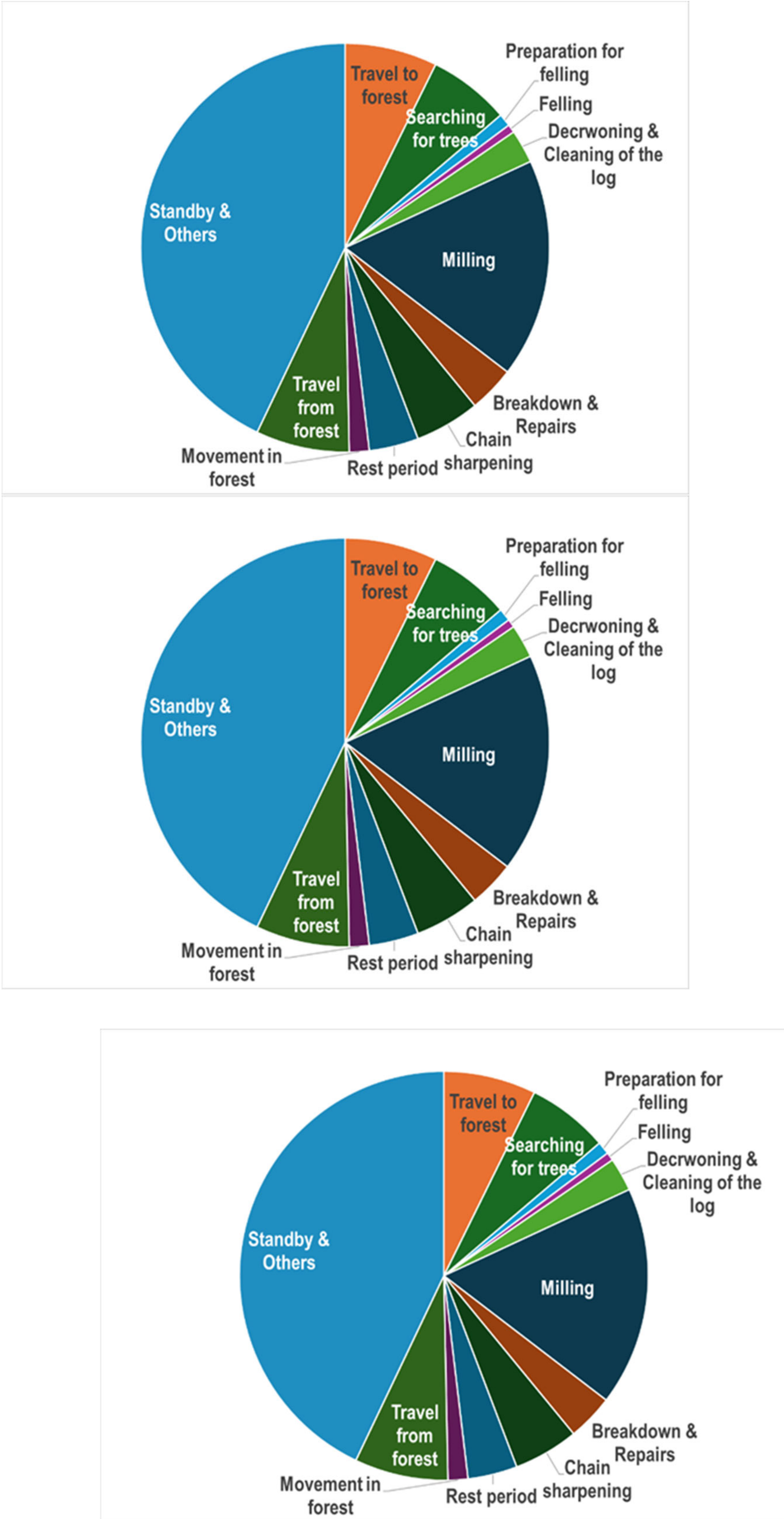

Figure 2. Average times to harvest and process a tree with the chainsaw per activity (N=16).

A total of 5.5 m³ of final products were obtained from the 16 trees (**Error! Not a valid bookmark self-reference.**). Almost 60% of this volume consisted of fence posts and 30% of roof beams for housing construction.

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Table 4. Total production volume of the 16 sample trees by product category.

Category	Volume (m³)	Proportion (%)
Triangular fence posts	3.182	57.7
Roof beams	1.584	28.7
Straining pots	0.418	7.6
Beams	0.146	2.6
Lintel	0.083	1.5
Planks	0.058	1.1
Struts	0.048	0.9
Total	**5.520**	**100,0**

Around 30% of the log volume was transformed into products (**Error! Reference source not found.**). Posts showed yields of over 30%, but also the yields for construction timber reached almost 30%, both yields being lower than expected as trees with low-quality stems were sawn. The differences in yields per species was sirari (33,4%), cuchi (32,0%), and curupaú (30,3%). Cuchi and curupaú trunks were on average longer than those of the other species and varied between 28 cm and 78 cm in diameter. Tajibo trunks had smaller diameters and were of poorer quality, compared to those of the other species.

Table 6. Yields per product category.

Sub category	Product category	Principle species	Log volume (m³)	Product volume (m³)	Yield (%)
Struts, roof beams, lintels, & cross beams	Constructio n	Tajibo	8.45	2.28	26.95
Simple milled planks	Boards	Tajibo	1.49	0.06	3.91
Triangular fence posts & straining posts	Posts	Cuchi, Sirarí, Curupaú	9.45	3.18	33.68
Total			**17.90**	**5.52**	**NA**
Average			**1.12**	**0.34**	**29.34**

The time required for processing varied greatly depending on factors like the species (wood density), type of product, dimension, quality of the log, the condition of the chainsaw and chain, the skill of the operator, and of the assistant. Processing of cuchi was more difficult than that of lower-density species such as sirari. Rough-sawn fence posts were produced more quickly than higher-quality products such as roof beams. Processing logs with depressions or other natural physical defects also took longer, especially if a good quality of the final product was to be achieved.

As for the transport distance of the sawn products, we measured an average distance of 160 m that operators carried on their shoulders. Typically, the operator carried two posts per trip corresponding to 0.034m³ or 34 kg. Consequently, 30 trips with 60 posts were needed to transport 1m³ of cuchi fence posts, corresponding to approximately 2.35 hours of working time.

3.2.2. Costs of Operations

Based on the time estimates, equipment used, and material costs described above, the cost of producing posts and boards and placing them at the roadside was estimated. According to this, the average cost of producing a fence post from cuchi was USD 2.86 per post, or USD 168.53 per m³. The production costs for sawn timber from tajibo amounted to USD 246.04 per m³. **Error! Reference source not found.** shows the breakdown by cost category. Almost 60% of the total costs were labor costs, together with the costs of transporting the operator and assistants to and from the forest, personal costs accounted for more than two-thirds of the total costs. A further 16% was accounted for by the chainsaw, which was rented daily. The costs for the transportation of wood and products, and for fuel and lubricants accounted for around 7-8% each. Other costs were negligible. In actual logging operations by community member payments may have to be made to officials to avoid the confiscation of timber when no valid transportation permit was obtained. Neither the costs for legalization nor compensation payments to the community for the use of communal forests were taken into account.

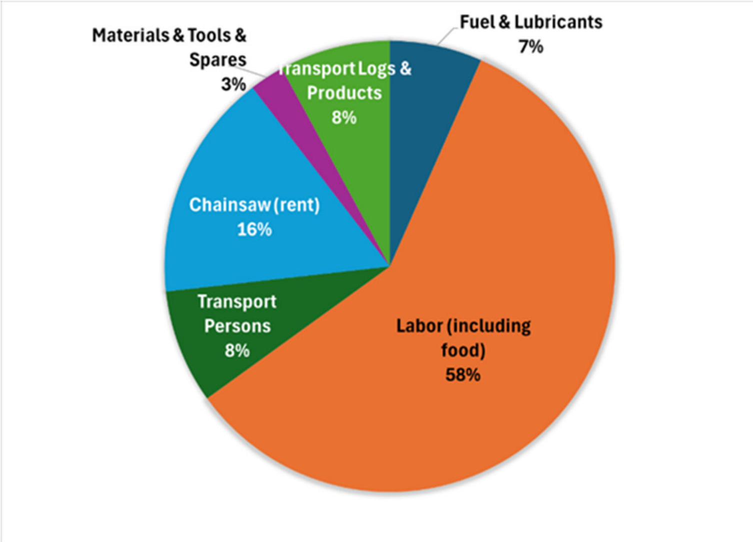

Figure 1. Proportion of cost categories for the processing of timber using low-input motor-manual harvesting.

If the products were to be sold following required legal procedures, the costs would increase significantly (**Error! Reference source not found.**). Many of the fees are fixed payments that disregard the low production volumes. However, there are also costs involved in organizing these payments, for example for filling out forms, for obtaining advice and information, for trips to the city, and for long waiting times at government offices.

Table 7. Cost related to the legality of forest production in Bolivia.

Item	Explanation	Cost estimates (USD)
Taxes	Flat-rate taxation of 8% on the final price	e.g. 13.52 USD / m^3 (posts) and 19.52 USD / m^3 (boards)
Forestry engineer (provided and charged by the responsible governmental agency	Sign and endorse both the information and documentation coming from the community	either 720 USD per month or 1-5 USD/m^3 in the case of larger volumes
Forestry Regulation Fee	Calculated on a daily updated index (35 Housing Development Units (Unidad de Fomento de la Vivienda-UFV) per ha)	12.95 USD/ha
Forestry Patent	Fixed value to be paid to the governmental forest authority to realize the yearly management plan	1 USD/ha
Yearly Harvesting Plan (POAF)	Mapping of trees for traceability and monitoring purposes	20 USD/ ha
Registration of the processing center	whether fixed or mobile.	~ 120 USD per year
Transport permits (Certificat of Origin- CFO	To be presented to the forestry authority for transport of the harvest regardless of volume	5.10 USD / 20m^3

3.2.3. Financial Return

There are four possible sale locations for Monterito timber products: Lomerío itself (Monterito, Puquio, or San Antonio), the small town of San Ramón (71 km), the district capital of Concepción (77 km), and the department capital Santa Cruz de la Sierra (268 km). The prices (as of May 2022) for a fence post ranged from USD 2.87/post in Lomerio to USD 3.59/post in Santa Cruz. The price difference for sawn timber was even greater at USD 243.68/m³ in Lomerio and USD 487.36/m³ in Santa Cruz. These prices were paid by traders. Although end users usually pay 10%-15 % more, communities tend to sell to traders to avoid having to find customers and rent storage facilities. When selling to traders, communities usually deduct the costs of transport, loading, and unloading, from the above prices. In response, traders offer to take over all forest work, including the risk of being caught for lack of permits, in exchange for lower prices paid for the products.

3.3. Environmental Impact

The damage of the logging operations described above was limited to the area around the felled trees. No tracks, skid trails, or stacking areas were created in the forest. A total of 18 trees were damaged during the felling and processing of the 16 trees. Almost 61% of the damage occurred to trees with a dbh less than 30 cm, but there were also three trees with a dbh greater than 60 cm that were damaged. In two-thirds of the cases the damage was minor and mainly affected the crown. Six trees were severely damaged.

An additional environmental impact is the possible link to forest fires. Tree felling and processing with chainsaws leave wood residues and flammable material on the ground. In combination with the possible construction and use of trails, this creates favorable conditions for the spread of forest fires, especially in the dry season. However, forest fire risk is much lower when using motor-manual logging than in the case of mechanized large-scale timber logging, as mechanized logging leaves a much higher fuel load. In addition, as forests close to villages are prioritized for chainsaw logging, firewood collection will reduce the fuel load in the harvested area.

Excellent natural regeneration especially of cuchi was observed during fieldwork in the areas where chainsaws were used. Natural regeneration of trees also occurred in adjacent meadows and former agricultural areas. This indicates the considerable regenerative capacity of forests after motor-manual logging. Unfortunately, however, we also found that many families intended to use the harvested areas as pastureland afterward.

4. Options for Technical Optimization

4.1. Processing

To test the three sawing techniques used, i.e., free hand, using a guide bar, and using the Logosol equipment, a total volume of 47.68 m³of logs was processed into 7.62 m³ of short wood and 13.09 m³ of long wood. The total yield was 43.53%. For all three options, the yields were better than 40%, which meets the legally established minimum requirement [38], but there were clear differences in efficiency between the three technologies tested (**Error! Reference source not found.**).

Table 8. Comparative performance of technologies by board size.

		Log	Product Category			Yields		
	N	(m³)	short (m³)	long (m³)	Total (m³)	short (%)	long (%)	Total (%)
Free hand	46	15.33	1.45	4.85	6.30	9.49	31.62	41.11
Guide bar	36	12.72	3.70	1.84	5.54	29.07	14.44	43.88
Logosol	53	19.63	2.47	6.40	8.87	12.60	32.59	45.20

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Total	135	47.68	7.62	13.09	20.71

The use of Logosol equipment achieved the highest overall yield of more than 45%, followed by the guide bar (44%) and freehand use of the chainsaw (41%). These differences between the techniques were even more pronounced in the case of semi-hardwood timber. Logosol equipment use achieved a yield of nearly 46.94%, while freehand milling only produced a yield of 38.8%. However, if one looks only at hardwood species, which are the most commonly harvested in the region, freehand milling achieved the highest yield of 43.9%, followed by Logosol equipment (42.77%) and the guide bar (40.94%). The subjective quality assessment indicated that Logosol equipment achieves visibly better results than the other two techniques in terms of product surface smoothness and angular precision.

In terms of production times, it took an average of 4.4 productive hours to process one cubic meter of wood. However, at 5 hours per cubic meter, Logosol equipment and the guide bar required significantly more time than the 4 hours of free-hand milling due to additional time requirements for transport, assembly, and disassembly. In all three technologies, sawing required more than 70% of the total time, followed by positioning (8%-10%), de-logging (2%-17%), and rounding (2%-5%). In addition, time was spent on operational control activities. Working with Logosol equipment and the guide bar consumed more time per cubic meter compared to freehand milling, mainly due to the need to check the pusher rail, adjust the timberjig and square, necessary to correctly size the log, and ensure the quality of the cut. If productive and non-productive activities are considered together, the differences between the technologies are even greater, from Logosol equipment (6:38 hours per m^3), the guide bar (6:05 hours per m^3), and freehand milling with less than 5 hours per m^3 (4:63 hours). These differences are also reflected in the productivity levels: Logosol equipment 0.16 m^3/hour, the guide bar 0.17 m^3/hour, and freehand milling 0.22 m^3/hour.

The above-mentioned differences were also reflected in the consumption of the chainsaw's fuel mixture (approx. 95% gasoline and 5% engine oil). For example, freehand sawing consumed 6.22 liters per m^3 of sawn timber, while Logosol equipment 6.79 liters/m^3 and the guide bar 7.80 liters per m^3 respectively.

4.2. Transport

The three tested transport options (human power, by horse, with cargo bike) differed significantly in terms of productivity (**Error! Reference source not found.**).

Table 9. Performance of the three tested transport options.

	Cargo Bike			**Horse**			**Human power**		
	time (h)	**%**	**h/m³**	**time (h)**	**%**	**h/m³**	**time (h)**	**%**	**h/m³**
Loading & Dispatch	2.70	16	0.26	2.50	19	0.50	0.50	1.0	0.10
Transport	4.60	27	0.45	5.90	44	1.18	40.50	81.7	8.32
Unloading & Stacking	2.45	15	0.24	1.50	11	0.30	1.20	2.4	0.25
Cubing	1.55	9	0.15	0.50	4	0.10	0.90	1.8	0.18
Total productive time	**11.30**	**67**	**1.10**	**10.40**	**78**	**2.08**	**43.10**	**86.9**	**8.85**
non-productive time	5.50	33	0.54	2.90	22	0.58	6.50	13.1	1.33
Total Time	**16.80**	**100**	**1.64**	**13.30**	**100**	**2.66**	**49.60**	**100.0**	**10.18**

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Based on the measured transport distances of 379 to 689 meters, the cargo bike took 1.10 hours to transport one cubic meter of timber, while the horse took 2 hours per m³. Shoulder transportation took much longer, almost 9 hours per m³.

4.3. Financial Assessment

The financial results vary considerably for the three sawing technologies compared if the same transportation means are considered (Table 10). Because of the equipment costs, the costs for the Logosol equipment variant are much higher, while the additional investment for the guide bar is moderate.

Table 10. Financial results of the three processing options combined with Cargo Bike transport.

	Initial Investment* (USD)	Internal Rate of Return (%)	Net Present Value	Benefits/Cost	Net Financial Result (USD/m³)
Logosol equipment	3771	74.59	322.291	2.81	28.02
Guide Bar	2595	118.62	404.623	4.28	30.32
Freehand	2265	188.31	667.348	6.68	37.93

*for details see **Error! Reference source not found.**.

All three variants were cost-effective, with a positive net present value (NPV) and a benefit-cost ratio greater than 1. However, the benefit-cost ratio of 6.68 for freehand processing in combination with cargo bike transport was significantly higher than for the guide bar (4,24) or even for the Logosol equipment option (2.81).

All three techniques tested gave a positive net financial result above the local selling price of standing trees of 15.09 USD/m³. However, due to differences in productivity, inputs, investments, and operating costs, the financial results of the tested technologies were very different. The use of Logosol equipment yielded a net result of 28.02 USD/m³, the use of the guide bar resulted in 30.32 USD/m³, but the freehand processing of the logs in combination with the use of a cargo bike for transport generated a net income of 37.93 USD/m³.

5. Discussion

Like many forest communities around the world, the indigenous communities of the Chiquitania use timber from their forests to obtain material for domestic uses but also to generate income. The local form of logging, with freehand sawing of the trunk with a chainsaw to produce fence posts, beams, and other wood products, has modest profit margins. An acceptable income, i.e. an equivalent income that is no less than USD 15 daily wages that are remunerated in the region for unskilled labor, can only be obtained by avoiding the costs of permits and taxes. The communities where local loggers operate receive no payments for the use of collectively held forests. This informality results in a major barrier to reaching the more attractive markets of cities, which can only be achieved by taking significant risks. Only a few specialized households serve these markets.

The testing of milling and skidding variants demonstrated that the financial attractiveness of the customary system could be improved by simple means. The use of suitable chainsaws and chains, training in their operation and maintenance, and better organization of the work process significantly increase productivity and financial results. The test of three technologies for sawing and skidding showed that the freehan use of a chainsaw is financially more attractive than the use of Logosol equipment or a guide bar. The slightly higher yield and product quality of the latter two techniques does not justify the significantly higher investment and operating costs. The study also shows that the use of a cargo bike to transport sawn products to a collection point where truck transportation is

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possible makes sense compared to horse or shoulder transport. The administrative, financial, and technical incompatibility of indigenous communities' capacities with the scheme based on GFMPs and the use of heavy machinery, suggests that optimized motor-manual logging could be a viable and affordable option for these communities to generate income sustainably from their forests. However, this assumes that the cost of complying with regulations and administrative procedures can be reduced to an affordable level.

Some methodological shortcomings of the study should be considered. The study to describe customary practices and the one on optimization options were carried out with different actors from different municipalities. The originally planned coherent sequence of the two studies could not be carried out due to the COVID-19 pandemic and obtaining the necessary authorizations. In addition, there were differences in the methods used in the two aspects of the study. As a result, the estimates of productivity and financial results are not fully comparable. The limited sample size of motor-manual logging and processing reduces the accuracy of the reported values. Some parameters of relevance for the calculations could only be approximated, but not systematically measured, like, for instance, the quality of the sawn timber or its marketing options. Due to the sensitive nature of the informal wood-use system described, it can also be assumed that not all of the information provided in the interviews is entirely correct. Nevertheless, it can be assumed that even if not all values are equally reliable, the results provide a plausible overall impression of realities and potentials, also because a large number of local people and experts were interviewed.

According to our findings, motor-manual logging and processing is an attractive way for local communities to use the wood from their forests, even despite low-profit margins. This is also demonstrated by the fact that over 75% of the surveyed families reported that they were involved in this type of harvesting. It makes sense for many families as it is simple and flexible, does not require large investments, and avoids erroneous bureaucracy. In addition, logging can often be combined with hunting and gathering forest products, and products are made for personal use that could not otherwise be purchased, like for instance fence posts to expand livestock farming. Finally, this form of wood use is one of only a few opportunities to generate cash income. Improving the productivity and financial results of motor-manual logging can improve local livelihoods while resulting in low environmental impact.

NGOs and government agencies have, with financial support from international donors, attempted to get forest communities to use their forests sustainably following reduced-impact logging principles, with little success. Most initiatives were abandoned by communities after external support was withdrawn because of high costs, erroneous bureaucracy, and uncertain markets [46]. This also applies to attempts to use fixed and mobile sawmills in community settings [34], principally because of problems with maintenance and supply of spare parts by foreign manufacturers. Even the use of a device as simple as the guide bar is commonly too costly and too complicated.

Despite the positive financial assessment of motor-manual logging, its relevance is in practice constrained by a lack of the technical skills necessary to operate and maintain chainsaws properly and a lack of means of traveling people and equipment to logging locations. The greater the distance, the lower the financial viability due to the related transportation costs. The exploitation of more remote forest areas inevitably requires investment in road infrastructure which in turn increases the complexity and costs of operations. For this reason, harvesting will at least initially be limited to the easily accessible parts of the forest, until communities can undertake investments in roads [44].

A further challenge arises from the limited number of species that are logged, causing their overexploitation. This may even have consequences for the ecological stability of the forests, whose sustainable management depends on the widest possible range of species used to reduce pressure on a few tree species [48,55]. Communities would need to make sure that seed-providing trees of species that are exploited are preserved, which reduces profits, and requires ecological understanding and a functioning local self-regulation. Weak or non-existent governance increases the risk that some community members will enrich themselves from forests without a fair return to the community [11].

Ultimately, the benefits of the approach also depend on the existence and accessibility of stable and attractive local markets that accept products from motor-manual logging. At present, this is not the case, mainly due to the operation of these practices at the fringes of legality. When local motor-manual logging complies with regulations, the costs of management plans, transport permits, taxes, and other expenses would render this type of logging unprofitable. Legalizing wood products from moto-manual logging would make them much more compatible in domestic and even international markets, but it could lead to conflicts with the timber industry and economic actors interested in using forest land for agricultural purposes.

The gradual optimization of traditional forest management methods is a viable strategy, as it ensures compatibility with local capacities and interests and allows for direct and sustainable improvements. However, to make local motor-manual timber management much wider viable the following measures are required: First, relevant government agencies, NGOs, and other support organizations must develop expertise to engage rural, especially indigenous, communities effectively. This expertise should include knowledge of community dynamics, and methods for meaningful interaction, as well as technical skills such as chainsaw operation, silvicultural practices, timber harvesting, transport techniques, and support for local governance arrangements. Second, sufficient funds must be allocated to procure essential equipment, chainsaws, saw chains, cargo bikes, and spare parts. Finally, short-term expert visits should be combined with long-term, trust-based collaborations, which require sustained financial and human resources to support organizations effectively and optimize available resources.

A significant challenge lies in developing attractive and stable markets for locally produced wood. A key focus should be on developing local markets that allow the use of a wide range of tree species and short timber, typically sawn timber shorter than 2.50 m. In the present studies, short timber represented over 85% of the production. Important local customers include wood processors such as carpenters and builders, as well as farmers, who would use fence posts. However, there is potential in tapping into the markets of larger urban centers like Santa Cruz. Public procurement programs, which represent a significant market in Bolivia, could also play a crucial role, particularly if local products are explicitly prioritized. Collaboration with large sawmills may be beneficial, as they could market local products internationally. Independent export market development, however, seems feasible only for niche markets in the medium term due to the high formal requirements and high costs, despite higher prices.

In tropical countries, sustainable forest management is often perceived as requiring centralized state control. However, authorities typically struggle to effectively monitor large forest concessions and economic activities that convert forests into other land uses [42,45]. A more viable solution would involve local communities organizing to manage their forests through agreements and clearly defined mechanisms with established responsibilities. Such local governance schemes have to recognize that forest management at the local level is deeply interconnected with agricultural practices. For example, fence posts are a major local product, and easily accessible forest areas may also be converted into pastures. Consideration must also be given to the natural regeneration of both pastureland and forest as well as changes in the fire regime. The expansion of pasture management often leads to the privatization of collective forest areas. If local governance systems were successfully established, the state´s role would shift to monitoring the systems´ existence, quality, and performance, or even supporting them proactively. Authorities would thus become partners rather than controllers. The Bolivian constitution provides for such local governance systems.

It is imperative to adapt the legal framework to ensure the informal local motor-manual logging and processing can be fully realized, including as an alternative to mechanized forest operations by timber companies. Achieving this goal necessitates a comprehensive revision of national forest legislation. Key reforms should include reducing bureaucratic and technical barriers such as requiring inventories, management plans, annual harvesting plans, and transport permits. Additionally, tax procedures must be simplified to alleviate administrative burdens. A shift away from centralized control toward empowering local governance systems is crucial to fostering sustainable and inclusive forest management practices.

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