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Original Article

Economic Analysis of Integrated Harvesting Relative to Conventional Harvesting on a *Pinus patula* Stand in Tanzania

Ntalikwa Scolastica Justin[1], Nordfjell Tomas[2], Shemwetta Dunstan Tahonna[1], Abeli Willbard Shoo[1]*

[1] Sokoine University of Agriculture, P. O. Box 3009, Morogoro, Tanzania.
[2] Swedish University of Agricultural Sciences, Umeå, Sweden.
[*] Author for Correspondence ORCID ID; https://orcid.org/0009-0006-7000-2791; Email: scolastica.ntalikwa@sua.ac.tz

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ABSTRACT

The conversion of a standing tree into a usable product is a very important activity and studies have shown that it is highly affected by the conversion costs which are associated with the whole plan (harvesting and processing). The economic aspects of forest harvesting are multifaceted and require careful consideration. Two harvesting systems were compared; first, Conventional Harvesting (CH) in this study means harvesting and processing of logs where only large diameter parts of the trees are utilized and mostly the small diameter parts are discarded causing loss of resources. Second, integrated harvesting (IH) in this study means the harvesting and processing of logs which are sorted according to end use allowing maximum utilization of the wood to the smallest diameter parts. This study aimed to determine the overall economics of forest conversion on tree felling and processing systems, specifically to determine the costs and revenue associated with IH and CH, with the factors influencing the choice of a felling and processing system. A study was done at FWITIC, a processing industry in the southern highlands, and data was collected through key informant interviews. The findings indicate higher total costs with IH ($2379) than CH ($1544), but also lower unit costs (84.37 US$/m3 for IH) and (100.3 US$/m3 for CH). The costs are topped by the revenue generated from each harvesting system of 177.222 US$/m3 for IH compared to 128.3 US$/m3 for CH, giving a benefit of 28.2 US$/m3 with CH and 92.84 US$/m3. The costs, benefits and time taken during the harvesting operations inform more on the influence on the selection of a harvesting and processing system.

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INTRODUCTION

Forest harvesting is a vital aspect of forestry management and plays a significant role in the economy (Canuel *et al.*, 2022). It involves the process of removing trees from forests and utilizing them for various purposes, such as timber production, fuelwood, pulp and paper, and non-timber forest products (Rullifank *et al.*, 2020). Timber harvesting is usually done by using basic technologies for tree felling, skidding, and forwarding. These include felling tools such as crosscut saws or chainsaws while skidding and forwarding is done by farm tractors or skidders (Silayo & Shemwetta, 2014), sometimes logging methods and machinery such as harvesters, feller bunchers, cable/grapple skidders, and forwarders can be used. In Tanzania, Timber harvesting operations is a very important activity and studies have shown that it is highly affected by the harvesting costs (Cho *et al.*, 2022) which are associated with the whole plan (Russell & Mortimer, 2005). The two most important costs that influence harvesting operations are explained as the purchasing costs of the machine and the fuel costs of operating the machines (Mauya *et al.*, 2011).

Two harvesting systems are discussed in this paper, first Conventional Harvesting whereby, the term conventional harvesting in this study means harvesting and processing of logs while not entirely considering the end products for the customer, as only large-diameter parts of the tree are utilized and mostly the small-diameter parts are discarded causing loss of resources. Second, The term Integrated harvesting in this study means the harvesting and processing of logs for desired products, as logs are sorted according to the required end use and involves removing in one cutting all usable timber in the forest, allowing also utilization of small diameter parts (Ntalikwa *et al.*, 2024). This harvesting practice is common in Europe and other developed countries (Magagnotti *et al.*, 2021: Pucher *et al.*, 2023). Integrated timber harvesting has proven to offer substantial cost reduction in the long run compared to other harvesting (Spinelli *et al.*, 2019). The economic aspects of forest harvesting are multifaceted and require careful consideration. Factors such as the cost of tree harvesting, extraction, transportation, processing, and market demand for wood products all play a role in determining the economic viability of forest harvesting (Lohri *et al.*, 2016; Dionisio *et al.*, 2021). Therefore, analyzing the economics of forest harvesting involves a comprehensive assessment of these factors to understand the costs, benefits, and overall impact on the economy. Timber industry business owners need to identify possible mechanization combinations they can adopt that can minimize costs and hopefully maximize profits. This can be achieved by comparing the productivity and production costs of both systems. Forest harvesting is not only essential for meeting the growing demand for wood products but also for sustaining economic growth and development. It is crucial to understand the economic implications of forest harvesting in order to make informed decisions regarding sustainable management practices and policy development (Harrill & Han, 2012).

The overall aim of this study is to compare the overall economics of IH and CH; that is to apply economic principles for an economic analysis of a mechanical tree felling and processing system and specifically to (i) determine the costs associated with IH and CH (ii) determine the revenue related to CH and IH and (iii) determine other factors influencing the choice of a harvesting and industrial processing system. The study has high relevance as its findings significantly advance understanding of the economic consequences of

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the systems and thus enhance the decision-making for a firm, and ultimately improve forest policies and practices which more effectively achieve desired goals.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in the Southern Highlands in Tanzania in the Iringa region at Mafinga Township. Harvesting data was collected from Sao Hill Forest Plantation (SHFP), the largest forest plantation in the country, which supplied raw materials to the Forestry and Wood Industries Training Centre- FWITC, located 20km from the plantation in Mafinga Township, Iringa. At FWITIC the raw materials were processed into different products and the centre was equipped with key forestry equipment and tools for harvesting and sawmilling.

Data Collection

Trees were harvested from a 28-year-old *Pinus patula* stand which according to SHFP management was due for harvesting. Trees were cut, de-limbed and extracted to landing as stems, bucked and sorted for loading on trucks and then transported to FWITIC. At FWITIC the logs were processed into desirable products. The time consumption for harvesting and skidding was determined with time studies (Ntalikwa et al., 2024). The time consumption for industrial processing was also determined with time studies (Ntalikwa *et al.*, 2024b).

The data for costs and sales were obtained from key informants from the industry, presented in Table 1, and informed consent of participation from the key informants was obtained verbally. Three workers were used during the felling activity and 5 during the sawing process. Salvage value (S), for the machines was 12% of the purchase price with an insurance rate of 5% and an expected life of 15 years for the chainsaw and truck, 20 years for the bell logger and 25 years for the Sawmill machine 1.

Table 1: Summary of Data Collected from Key Informants

S/N	Item	Cost Tzshs	Costs $
1.	Labourers	15 000/day	6
2.	Fuel	1 800/litre	0.72
3.	Electricity	3000/kWh	1.2
Equipment			
1.	Purchase price chainsaw	1 500 000	600
2.	Purchase price bell logger	15 000 000	6 000
3.	Purchase price tractor	18 000 000	7 200
4.	Purchase price saw machine 1	30 000 000	12 000
5.	Purchase price saw machine 2	18 000 000	7 200
6.	Purchase price briquette machine	5 000 000	2 000
Sales			
1.	Big size lumber	320 767/m^3	128.3
2.	Small size lumber	110 288/m^3	44.11
3.	Briqquettes	12 000/kg	4.8

Table 2: Recovery Rate and Volume Harvested

Item	CH	IH
The total standing stem volume in the compartment. (Harvested volume m^3)	40 m^3	40 m^3
Recovery rate (%) after harvesting	60%	75%
the total volume of logs delivered to the industry (Recovered volume)	24 m^3	30 m^3
Recovery rate (%) in industrial processing	41%	98% (50, 26,18)
Sold volume of industrial products m^3	Big logs 9.84 planks with waste 5.56	Big logs 15 Small logs 7.8 Briquettes 5.4

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Data Analysis

Analyses of the two systems were compared via a cost-and-benefit analysis and conducted through a break-even analysis. In this methodology, Operating costs refer to the sum of all costs resulting from the machine acquisition and operation, expressed in effective hours of work. Then, costs are classified into cost components, where equipment costs are composed of: fixed costs (including depreciation, insurance costs and taxes) and variable costs (consisting of operating labor costs, hourly machinery costs and repair and maintenance costs). The operational costs were estimated by the methodology of Machado and Malinovski (1988). Thus, the final cost is a sum of these components, obtained by the equation 1:

$$CT = CF + CV \quad \text{...} (1)$$

Where: CT = total costs; CF = fixed costs; and CV = variable costs.

i. Fixed costs

- Depreciation: is a way of recovering the original investment of equipment. Here, linear depreciation is used, estimated by using equation 2

$$D = \frac{P-S}{L} \quad \text{...} (2)$$

Where: D = depreciation; P = equipment purchase price; S = residual value and; L = economic life of the machine equipment

ii. Variable costs

- Labour costs: These are costs formed by the direct payment to all labourers involved, according to the time taken for the task (Equation 3).

$$CL = LP \times T \quad \text{...} (3)$$

Where: CL = cost for labourers; LP= task payment to a labourer; and T = time taken to finish provided task

- Fuel costs: This cost was calculated by multiplying the average hourly consumption of each machine, according to its average in the study of times, by the current market price of fuel (Equation 4). These were recorded on a daily basis

$$CC = Cb \text{ (measured)} \times P \quad \text{...} (4)$$

Where: CC = fuel cost; Cb = fuel consumption per effective hour of work (L) and; P = fuel market price.

- Maintenance costs: all costs involved in the maintenance of the machines

The total costs (summation of variable costs and fixed costs) were converted into unit cost of production by dividing with the harvested volume (table 2), obtained from Ntalikwa *et al.* (2024) calculated using equation (5)

$$\text{Unit cost (TZS/m3)} = \frac{\text{Total costs (TZS)}}{\text{Harvested volume (m3)}} \quad \text{.................................} (5)$$

Benefit analysis (break-even analysis): The benefits were determined by subtracting the total costs from the amount obtained from sales of the forest products, the unit benefit was identified by dividing the benefits by harvested volume. A break-even is considered if the benefits are higher than the associated costs of the harvesting system.

Multiple Criteria Analysis

The alternatives included in this study involve CH and IH. The criteria consisted of the total time taken for the harvesting system, the total operating cost (from stand to mill) and the benefits associated with each harvesting system obtained from the key informants of the industry these are the criteria of uttermost importance when considering a harvesting system.

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Figure 1: Multiple Criteria Analysis Framework for the Case Study.

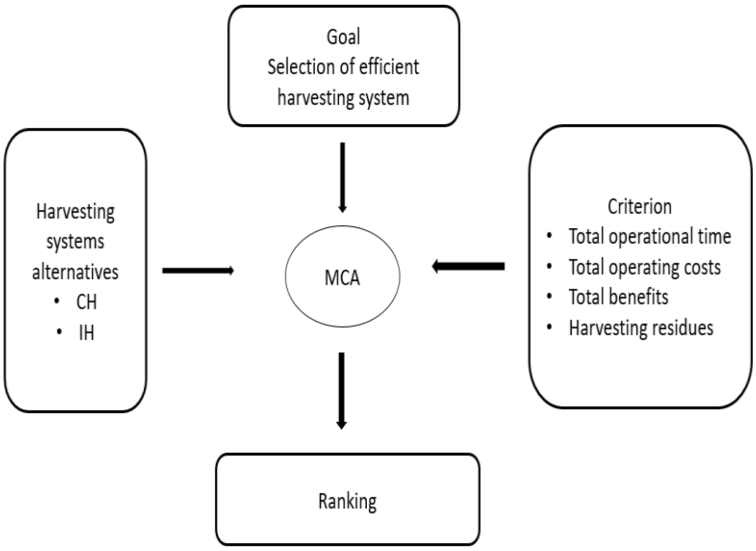

Figure 1 explains the multiple criteria analysis used in this study. The analysis calculates positive and negative preference flow for each criterion. The positive flow expresses how much an alternative is dominating (power) the other one, and the negative flow how much it is dominated (weakness) by the other one. Based on these flows the ranking is obtained.

RESULTS

Costs Associated with CH and IH

From the harvested trees, the major costs associated were broken down into ownership and operational costs. The benefit analysis will involve both cost calculations with the number of days it took to accomplish the targeted task. Table 3 summarises the total estimation of the costs involved in harvesting and processing of the compartment.

Table 3: Costs Associated with CH and IH

S/n	Item	CH		IH	
		Total costs	US $	Total costs	US $
Felling costs					
1.	Chainsaw purchasing costs	1 500 000	600	1 500 000	600
	Depreciation	88 000	35.2	88 000	35.2
2	Fuel costs	18 000	7.2	22 000	8.8
3.	Lubricant costs	50 000	20	50 000	20
4.	Labour costs	45 000	18	45 000	18
	Total	201 000	80.4	205 000	82
Skidding costs					
1	Bell loader purchasing costs	20 000 000	8 000	20 000 000	8000
	Depreciation	880 000	352	880 000	352
2	Fuel costs	93 600	37.44	122 400	48.96
3	Operator costs	30 000	12	30 000	12
	Total	1 003 600	401.44	1 032 400	412.96
Transportation costs					
	Truck costs	18 000 000	7 200	18 000 000	7200
	Depreciation	1 056 000	422.4	1 056 000	422.4
	Fuel costs	220 000	88	220 000	88
	Driver costs	30 000	12	30 000	12
	Total	1 306 000	522.4	1 306 000	522.4
Sawmill Processing costs					

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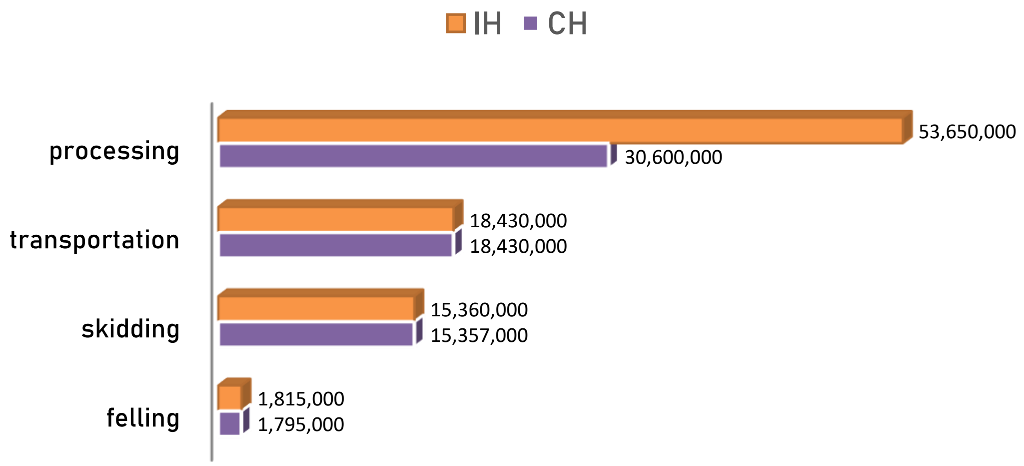
S/n	Item	CH		IH	
		Total costs	**US $**	**Total costs**	**US $**
	Sawmilling machine 1	30 000 000	12 000	30 000 000	12 000
	Depreciation	1 760 000	422.4	1 760 000	422.4
	Sawmilling machine 2	-		18 000 000	7200
	Depreciation			1 056 000	422.4
3.	Briquetting machine	-		5 000 000	2000
	Depreciation			293 333	117.3332
4.	Labor costs	225 000	90	840 000	336
5	Electricity cots	100 000	40	160 000	64
	Total	1 381 000	552.4	3 405 333	1 362.1332
	Total fixed costs	3 080 000	1232	4 429 333	1 771.7332
	Total variable costs	781 600	312.64	1 519 400	607.76
	Total costs	3 861 600	1 544.64	5 948 733	2 379.4932
	Costs per m3	**250 753.25**	**100.3013**	**210 947.98**	**84.37919**

Figure 2: Costs Involved for Each System.



The total fixed cost for the CH and IH system was estimated as TZS 3,080,000 and 4,429,333 with variable costs of 781 600 and 1 519 400 respectively which explains IH had higher total costs compared to CH. In the entire system, the processing activity at the Sawmill after transportation had higher costs compared to the other cost items as shown in Figure 2. Felling having the least costs followed with the skidding. The unit cost of production estimated from equation 5 was higher for CH (250,753.25 TZS, 100.3013 US\$/m^3) compared to that of IH (210,947.98 TZS, 84.37919 US\$/m^3)

Revenue Generated from CH and IH

The revenues are associated with the products obtained after processing the logs. The industry products obtained involve big-size lumber, small-size lumber and the briquettes for IH and only the big-size lumber for CH.

Table 4: Revenue Generated with CH and IH

S/N	ITEM	CH		IH	
		Total income	**Income/ m^3**	**Total income**	**Income/ m^3**
1	Big size lumber	3 156 347.28	320 767	4 811 505	320 767
2	Small size lumber	-		860 246.4	110 288
3	Briqquettes	-		64 800	12 000
	Total	**3 156 347.28**	**320 767**	**5 736 551.4**	**443 055**

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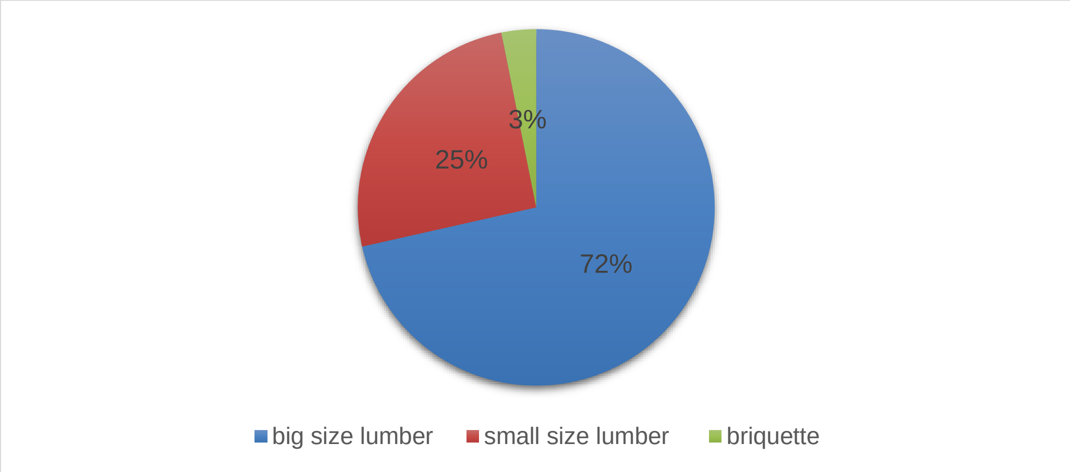
Figure 3: Income Generated from IH



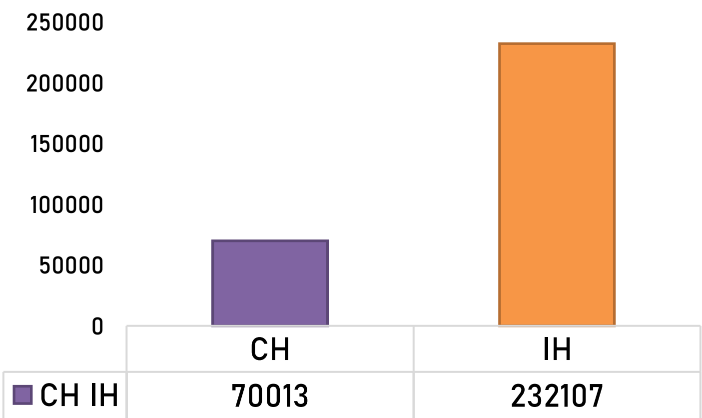
The income generated from IH involves different products represented in Figure 3, while those from CH only have one product of big-sized timber. Although big-size timber has the highest return compared to the other products, this study indicates only 72% of the value is gained with one kind of product and 28 % of the value is left for a loss. The lost value however can be gained with IH.

Table 5: Benefits Generated with Each Harvesting System

s/n	Description	CH		IH	
		tzshs	US$	tzshs	US$
1	Total Costs/ m3	250 753.25	100.3013	210 947.98	84.37919
2	Total revenue/ m3	320 767	128.30	443 055	177.222
	Total benefits/ m3	**70 013.75**	**28.2**	**232 107.02**	**92.84**

IH brings more profitability compared to the other used systems. The total income generated from selling logs depends on the 2020 selling price for each system. The profit was obtained by deducting the total harvesting and processing costs used for each system. The profit obtained was greater than the previous earnings with CH. The unit benefits/m3 is TZS 70,013.75/m3 with CH and TZS 232,107.02/m3 with IH indicating an increase in revenue for IH. The increase is associated with the added products for IH. When selecting a harvesting system to use in a forest, although IH has higher operating costs compared to CH, these costs are associated with the added activities from felling, skidding and processing. Eventually, the costs are subsided by the higher revenue gained after the various products are generated compared to CH as shown in Figure 4.

Figure 4: Profitability Comparison Between IH and CH



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Factors Influencing the Choice of a Felling and Processing System

The results show a positive flow for the time taken for operational time for CH and a positive flow for cost and benefit with IH (Table 6). Depicting power for the IH system, compared to the CH system which had a negative flow with costs and benefits showing weakness of the system.

Table 6: Multiple Criteria Flowchart

Factor	CH		IH	
	Description	Rank	Description	Rank
Time: felling	*3.73 min/tree*	+	*3.99 min/tree*	-
Skidding	*2.59 min/tree*		*3.95 min/tree*	
Costs	25 0753.25 Tshs/m^3	-	210 947.98 Tshs/m^3	+
Benefit	70 013.75 Tshs/m^3	-	232 107.02 Tshs/m^3	+

Time: This is mentioned here as the harvesting and processing time differs between the two systems. IH has a high harvesting and processing time compared to CH. Long hours will be spent while processing products for IH than the time that would be spent with CH.

Costs: The underlying costs associated with IH are higher compared to CH, this is because further processing of the unutilized part adds more processing costs compared to CH.

Benefits: The benefits are higher with IH compared to CH this is because of the sold-added products with IH, the added benefits are influencing the choice of a harvesting system, as most companies seek to have higher benefits.

DISCUSSION

The paper presents an economic analysis comparing integrated harvesting (IH) to conventional harvesting (CH) on a *Pinus patula* stand in Tanzania. The key findings from the study highlight the financial advantages of IH over CH. The results of the analysis indicate that IH incurs lower costs per cubic meter of timber harvested compared to CH, whereby; excluding the machinery purchase price, other major costs in harvesting are the operational costs (like fuel and labourers costs). The daily payment system was used for labourers, and other costs like Fuel and lubricant costs were recorded on a daily basis. The total costs involved the summation of fixed costs and variable costs, fixed costs constitute purchasing price, depreciation, and labour costs (Lusambo *et al.,* 2021). While variable costs consist of fuel, lubricant and other spare parts costs. The total estimation of the costs involved in harvesting and processing between the two systems differed (Table 2). This cost efficiency can be attributed to the reduced operational costs, as IH optimizes the use of machinery and labour, reducing the overall operational costs. By integrating multiple stages of the harvesting process, such as cutting and processing, the need for repeated use of machinery and labour is minimized.

The activities consisted of felling, skidding, transportation and processing at the mill. IH had high total costs when engaged in the activities. But when transporting the logs from the stand to the industry the cost of production was the same for CH and IH. Even though IH had a high total cost the unit cost of production for CH was higher compared to IH (Table 2). Cost-benefit analysis involves determining the effectiveness of a system with respect to profits. It requires determining the benefits associated with selling IH logs. A study done by PFP (2016) had selling prices for logs of IH. From the market scenario of 2015 and 2016, the large saw logs were sold for 273,767 TZS/m^3, small pulp -logs were sold for 97,288 TZS/m^3 and the waste was sold as fuel wood the price was 81 060/m^3. Table 4 shows the current prices of logs, of which their value was obtained from the market of 2020 and 2021.

Table 5 computes the total benefits obtained if IH was to be adopted, for every system the benefit per unit of production differed mainly attributed to the volume which was sorted as large-size lumber, small-size lumber and briquettes. Compared to the previous system with a profit of 70,013 TZS/m^3

there is an increase of 162 094 TZS/m^3 up to 232,107 TZS/m^3 which is equal to 3 times the profit increase with IL systems (Table 5). These results concur with those obtained by (Held *et al.*, 2017), a study within Tanzania where the projected benefits with IH increased by 43% from the previous gains. The proper use of the logs will ensure maximum profitability in the timber market. This is by using IH to allow the waste to be used for other productive uses (diversifying products) which would also generate income.

The benefits associated with the IH take into consideration the requirements of the industries for defined dimensional wants to fit the end use. With IH, in the current market there will be added benefits as the sorting of logs according to needs will benefit the industries enabling the owners to sell waste for profit, also supported by (Kizha R & Han, 2015). Enhanced resource utilization is seen with the IH system as it involves better planning and coordination (Spinelli *et al.,* 2022), leading to more efficient use of resources. This includes better scheduling of equipment and personnel. With this IH has shown benefits with higher revenue generation: as it yields higher revenues due to the more efficient processing and higher volume recovered for timber and other products (Buchholz *et al.,* 2019). Policymakers can use the findings to support and promote IH practices through regulatory frameworks that encourage sustainable and efficient forest management. The adoption of integrated harvesting may require initial investments in new technologies and equipment. However, the long-term economic benefits highlighted by the study justify these investments.

CONCLUSION

The economic analysis presented in the paper demonstrates that IH offers clear financial advantages over CH methods on a *Pinus patula* stand in Tanzania. The costs per cubic meter and increased benefits underscore the potential for IH to enhance the profitability and sustainability of forest management practices. The final financial result shows higher total costs with IH ($2379) than CH ($1544), but also IH had lower costs per cubic meter (\$84.37/m^3) than CH (\$100.3/m^3) of final produced volume. The costs were topped by higher revenues generated by IH (\$177.222/m^3) compared to CH (\$128.3/m^3), resulting in greater benefits for IH (\$92.84/m^3) than CH (\$28.2/m^3). IH was shown to be more profitable due to better resource utilization and the ability to generate more products which equates to more volume.

The proper use of the logs will ensure maximum profitability in the timber market. This is by using IH to allow the waste to be used for other productive uses which would also generate income. This system is more beneficial as the client gets to choose the end product that they desire. The factors influencing the choice of a felling and processing system are explained as the total processing time, costs and benefits associated with each system. These findings support the broader adoption of IH as a viable strategy for maximizing economic returns while promoting sustainable forest use. Future studies could seek to test the mentioned factors in different scales and seek to expand the range of samples included to explore the scalability and transferability of the systems.

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Declaration of Interest

The authors declare to have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data supporting the findings of this study are available upon request from the corresponding author.

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