ASSESSMENT OF HIGHER MECHANISATION POTENTIAL FOR VIETNAMESE PULPWOOD SUPPLY CHAINS USING SUSTAINABILITY INDICATORS

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TRAN VT, DUONG VT, PICCHI G & BECKER G. 2016. Assessment of higher mechanisation potential for Vietnamese pulpwood supply chains using sustainability indicators. In Vietnam, planted forests are the main source of timber, providing about 4.8 million m^3 of roundwood, which accounted for more than 70% of the domestic wood supply in 2009. However, most logging and extraction operations are still performed manually and by means of animal skidding, in rather poor working conditions. This study showed that the typical wood supply chain for pulpwood from planted forests on moderate slope (less than 30%) could be mechanised using suitable agricultural tractor–trailers to extract short logs from stump area to a landing accessible by large trucks to transport the logs to a mill for further processing. Higher level of mechanisation would lead to decrease of 15.3% in production costs, lower the directly involved employment from 13.90 to 4.26 hours m^{-3} as well as improve working and safety conditions for employees. However, mechanised system will create more heavily disturbed and impacted area in forest stands compared with manual and animal skidding methods if planning and supervision are not fully and carefully implemented.

Keywords: Logging, harvesting systems, plantations, Vietnam

INTRODUCTION

Vietnam has 13.12 mil ha of natural forests and plantations with total forest cover of 39.1% of land surface (VNFOREST 2010). The plantation area in Vietnam is about 2.81 million ha (VNFOREST 2010), of which 80% is located on steep terrain (slope ≥ 30%) while only about 20% on moderate slope (< 30%) (MARD 2005). Plantations are usually even-aged and single-species forest stands with harvesting age of less than 10 years. *Acacia* and *Eucalyptus* species dominate. In 2009, planted forests in the country provided around 4.8 mil m^3 of roundwood, of which 75% was small diameter log classified as pulpwood while the remaining 25% had larger diameter and were used as sawlog in furniture production (To & Canby 2011).

In the last decades, the operations of logging and transport have been highly mechanised in most developed countries and partly mechanised in many developing countries. However, in Vietnam, harvesting operations in planted forests are still carried out using labour-intensive manual methods. These are commonly regarded as less cost-efficient and, particularly, much more dangerous from the safety point of view (Axelsson 2013). While in countries with higher labour costs, the introduction of mechanisation leads to economic benefit, this is not necessarily true in the case of countries with lower manpower costs. A sustainability analysis is necessary to assess the environmental and social consequences related to the adoption of higher level of mechanisation in logging operations. The present study was aimed at assessing impacts of traditional logging and transport operations in Vietnam on economic, social and environmental aspects and to compare them with a higher mechanisation level, for immediate introduction in the country. For this purpose, a case study on pulpwood supply chains from plantation forest

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on moderate slope (less than 30%) was carried out in northern Vietnam, considering this as the easiest conditions for adoption of mechanised logging techniques and as potential starting point for the implementation of modern forest operations in the country.

According to Päivinen et al. (2010), the forest–wood supply chain (FWSC) is defined as a set of processes by which forest resources are converted into wood products and services. It deals with all processes within the chain, starting from the regeneration of a new forest to the recycling of the produced end-product (Vötter 2009). In this study, only wood procurement processes starting from pre-harvesting activities and ending with unloading the pulpwood at mill site were selected for assessment.

MATERIALS AND METHODS

In order to assess effects of the adoption of higher degree of mechanisation in the extraction of timber in plantations on a moderate slope, a set of sustainability indicators was applied. A current wood supply chain, which was considered to be typical for plantation logging and transport in Vietnam was chosen as a basic scenario. In contrast, an optimised wood supply chain with higher mechanisation level was developed by including a tractor and trailer unit to be applied under comparable conditions. The sustainability impacts of the current and mechanised supply chain were assessed and compared.

Sustainability indicators

The key criterion for the selection of indicators is their ability to capture the impacts of FWSC on three aspects of sustainability: economy, society and environment (EFORWOOD 2006). For the present analysis, four sustainability indicators were chosen for assessment (Table 1).

Production costs

Production costs of the whole chain were calculated by summing up the production costs of each process including all costs accrued from machine or animal costs, labour costs, administration costs and tax. The cost calculation was mainly based on the method of Miyata (1980) combined with that of Brinker et al. (2002). The total production costs (€ m^{-3}) of pulpwood FWSC were analysed and discussed. The exchange rate in 2010 of 1/28,000 between Euro and VND was used for calculation. The use of manpower and machines was measured in the field during time studies.

Employment rate

Employment rate is an important indicator that reflects the ability of job creation, the level of mechanisation as well as efficiency of human labour involved. In this study, employment was considered as the number of direct working hours needed to complete a unit of work (hour m^{-3}).

Green house gas emissions

Machines and equipment in wood harvesting systems consume fuel and mineral oil lubricants, which produce green house gases (GHG) that contribute to climate change. GHG primarily include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). In order to calculate the amount of GHG emitted from machines and equipment, the method of DEFRA (2009) was applied using the amount of used fuel and emission factors of fuel (e.g. petrol and electricity). The values for CH_4 and N_2O were presented as CO_2 equivalents (CO_2 eq). The unit calculation used for this indicator was kg CO_2 eq m^{-3}. Fuel consumption was directly measured in field investigations. The GHG

Table 1 Sustainability indicators used for the assessment

Indicator	Parameter	Unit	Data collection
Economy	Production cost	€ m^{-3}	Field investigation: - Time study - Observation and measurement - Interview Some from publications
Society	Employment	hour m^{-3}	
Environment	Green gas house emission	kg CO_2 eq m^{-3}	
	Disturbed area	%	

produced from lubricants were small, therefore, they were not accounted for in calculation.

Disturbed area

Logging in most cases leads to soil disturbance that may cause soil erosion or compaction (Rice et al. 1972). When soil is compacted, soil porosity decreases (Nyland et al. 1976), reducing water infiltration, soil moisture availability, aeration and rooting space (Greacen & Sands 1980). This increases resistance to root development (Murphy et al. 2004) and may have negative influence on tree growth. However, no significant effect on average tree volume was observed in plots where only litter had been removed, while a significant decrease in volume growth was recorded where topsoil had been removed (Murphy et al. 2004). This means that possible negative impacts can be estimated by assessing the disturbance level of vegetation cover, especially the litter layer (Rice et al. 1972). In this study, the following soil disturbance classification system suggested by Murphy (1982) was used to classify soil disturbance levels: (1) low disturbed area where forest floor is disrupted, litter or slash disturbed but topsoil is not exposed, (2) moderately disturbed area where mineral soil is exposed and removed up to a depth of 5 cm and (3) heavily disturbed area where mineral soil is removed to a depth greater than 5 cm. The data needed for the calculation of disturbed area indicator were collected in the field by observation and measurement of disturbed areas caused by logging activities. The unit of the indicator was calculated in percentage of disturbed areas in relation to the total logging area.

Study site

In Vietnam, felling and bucking are performed by chainsaw and the ensuing timber extraction is generally done by means of animal skidding (buffaloes) on moderate slope or manually on steeper slope. At roadside, logs are loaded on trucks and transported to the mill. Loading and unloading operations are carried out mostly manually. However, in some cases, a tractor and trailer or forwarder unit is used to transport logs from the roadside to a further landing or to a local sawmill. In those cases, loading and unloading activities are mechanised by means of an attached crane. In this study, the wood supply chain on moderate slope with felling and bucking by chainsaw, skidding by buffalo, transporting by truck, loading and unloading by manpower was analysed and assessed. It is called improved FWSC.

In 2009, a case study was carried out during harvesting operations conducted by Doan Hung Forestry Company, located in Phu Tho province (northern Vietnam). The company is state owned and operates under the management of the Vietnam Paper Corporation. The main mission of the company is to provide pulpwood for Bai Bang Paper Mill from 2064 ha of plantation, mainly *Acacia mangium*. The total clearly harvested area was 150 ha with a volume of 11,075 m^3, mostly pulpwood assortments.

Located in the tropics, the study site has high temperature and humidity with mean annual temperature of 23 °C and relative humidity of 85%. The annual rainfall in Doan Hung ranges from 1600 to 1800 mm, of which 80% typically falls between April and October. The main characteristics of the study site are shown in Table 2.

Processes of the wood supply chain

The details of the processes in the current FWSC in this study are described in Figure 1.

Pre-harvesting

Pre-harvesting included operational logging planning and the preparation of skid trails, roadsides and tents. The logging planning was carried out by three technicians. It included the demarcation of the compartments to be harvested, timber inventory of the harvesting area and decision on the harvesting method. In this case, the harvesting costs, needed manpower and equipment demand were pre-calculated. However, a comparison of alternative harvesting methods and an optimised planning of skid trails and landings as well as details of work organisation were not included in planning activities. The preparatory work included clearing the vegetation of 1.5 m wide corridors for skid trails, preparing roadside for cross-cutting, debarking, sorting and piling activities as well as building tents for employees.

Table 2 Main characteristics of the study site

Characteristic	Information
Logging area	1.4 ha
Forest owner	State owned
Species	*Acacia mangium*
Total of stand volume	126 m^3
Harvesting method	Clear felling
Log length in transport	4 m in pulpwood
Average harvested diameter at breast height	13.5 cm
Average slope of terrain	25%
Average slope of skid trail	16%
Average skidding distance	180 m

Figure 1 Main operations in the supply chain including felling, extracting, loading and transporting

Harvesting

This process included activities of felling, delimbing at the stump area, extracting, cross-cutting, debarking and sorting at the roadside. Felling was carried out by chainsaw operated by an operator and a helper. After felling of several trees (8 to 15), the chainsaw operator began debranching and topping. Subsequently, the full-length logs were skidded one by one to the roadside by a team of six to eight buffaloes plus six to eight men depending on the skidding distance. At the roadside, the full-length logs were debarked by four men using knives and cross-cut into standard length of 2 m for sawlogs (small head diameter, d ≥ 15 cm) and 4 m for pulpwood (d < 15 cm). After that, the logs were sorted and piled by the felling and extracting teams. All the workers were local people employed as temporary employees.

Post-harvesting hygiene

Post-harvesting activities were carried out by two workers after harvesting operations ended. The workers collected and burnt all remaining biomass left on the ground as preparation for the next cycle planting.

Transport

At the roadside, sawlogs were sold to a local sawmill while pulpwood was sold to Bai Bang Paper Company, with transport distance of 14 and 55 km respectively. A 4.5-tonne truck with one driver was used for delivering both products, loading up to 10.2 m^3 sawlogs and 9.8 m^3 pulpwood. Both operations of loading at the roadside and unloading at the sawmill were carried out manually by four to five men, while unloading at the paper mill was carried out by a timber loader.

RESULTS AND DISCUSSION

Production cost

The total costs to supply logs to the paper mill were 12.61 € m^{-3}, of which pre-harvesting, felling and processing costs were only 1.98 € m^{-3} while the operations of extracting, debarking and sorting accounted for the highest cost with 5.13 € m^{-3} (Figure 2).The costs for post-harvesting hygiene were lowest with 0.04 € m^{-3}, the loading costs using manpower were 0.89 € m^{-3}, while the unloading costs using loader were much lower with 0.32 € m^{-3}. The transport costs to the paper mill by 4.5-tonne truck (loaded with 9.8 m^3) over a distance of 55 km was calculated as 3.85 € m^{-3}. The delivery price of wood at landing I in December 2010 provided by Doan Hung Forestry Company was 39.28 € m^{-3} (d < 15 cm). Thus, the total production costs of pulpwood to the roadside including costs of pre-harvesting, felling, cross-cutting, delimbing, extracting and post-harvesting accounted for 18.2% of the delivered wood value.

According to Wald-Prinz (2013), the price of industry wood (pulpwood, short and normal quality) in 2010 in Germany was around 43.0 € m^{-3} while the harvesting costs of industrial wood with an average diameter at breast height (dbh) of 15 cm was 21.4 € m^{-3} (Uwe-Bornschein 2008). This meant that logging costs of industrial wood accounted for 49.8% of delivered wood value at roadside, while in this study, the ratio was much lower at only 16.9%.

Employment

The total labour input needed for all work processes to deliver the timber to roadside was 10.68 hours m^{-3}, whereby 8.36 hours m^{-3} (78.3%) accounted for activities of extracting, debarking and sorting (Figure 3). Felling, delimbing and cross-cutting accounted for 1.47 hours m^{-3} (13.8%), while pre-harvesting and post-harvesting activities, 0.85 hours m^{-3} (7.9%).

The labour input related to loading manually at the roadside was 2.18 hours m^{-3}, while unloading by means of a loader at the paper mill accounted for only 0.07 hours m^{-3}, 31 times lower. The pulpwood transport to the paper mill over a distance of 55 km accounted for employment rate of 1.82 hours m^{-3}.

GHG emission

Total GHG emission calculated at the roadside was 0.64 kg CO_2 eq m^{-3}, mostly generated from the operations of felling and debranching at the stump areas and cross-cutting at the roadside (Figure 4).

GHG emission from the pulpwood transport by 4.5-tonne truck to the paper mill with distance of 55 km was 4.46 kg CO_2 eq m^{-3}. Between loading and unloading operations, the activities performed manually were considered as not contributing to the GHG emissions, thus only the pulpwood unloading at the paper mill using loader produced GHG of 0.72 kg CO_2 eq m^{-3}. Total GHG emission from the whole supply chain to the paper mill was 5.82 kg CO_2 eq m^{-3}.

Disturbed area

Totally disturbed area caused by logging activities was 22.3%, with different degrees of disturbances: heavy (4.2%), moderate (6.4%) and negligibly low (11.7%). Of the heavily disturbed area, skid trails accounted for 53.3%, while the roadside contributed to 39.5%. In this study, moderate and low disturbance areas were mostly caused by skid trails, with 67.9 and 80.3% respectively. The remaining was accounted for by roadsides, tents and other areas.

A study conducted by Ruth (1967) found that using skyline for clear-cut harvesting affected only 6.4% of the harvesting area. Wooldridge (1960) showed that disturbed area caused by using tractor after clear-cut felling was 29.9%. Compared with the above studies, the totally disturbed area caused by logging in this study was 3.48 times higher than that using skyline but 25.4% lower than that using tractor skidding.

IMPROVEMENT OF THE SUPPLY CHAIN

Due to the typically small area of the logging units (less than 5 ha), the low average dbh of felled trees (13.5 cm) and low costs of human labour, the current supply chain shows typical attributes of small-scale harvesting. Thus, if introducing higher degree of mechanisation is envisaged, forest machinery suitable for small-scale plantations should be chosen. Such equipment should have low investment and capital cost, low transportation cost, flexibility to deal with different material sizes and being technically compatible with locally available agricultural machines. In this study, the extraction and loading operations are the most labour intensive operations (Figure 3), therefore, they are considered with priority for higher mechanisation. According to Russell and

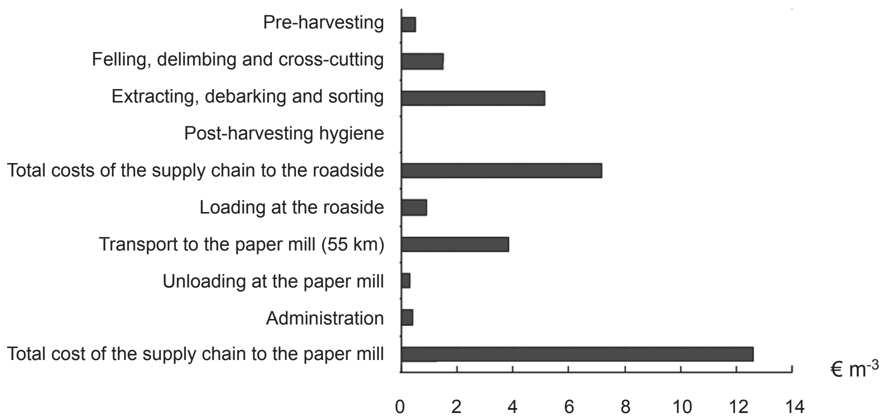

Figure 2 Production costs of activities in the current wood supply chain

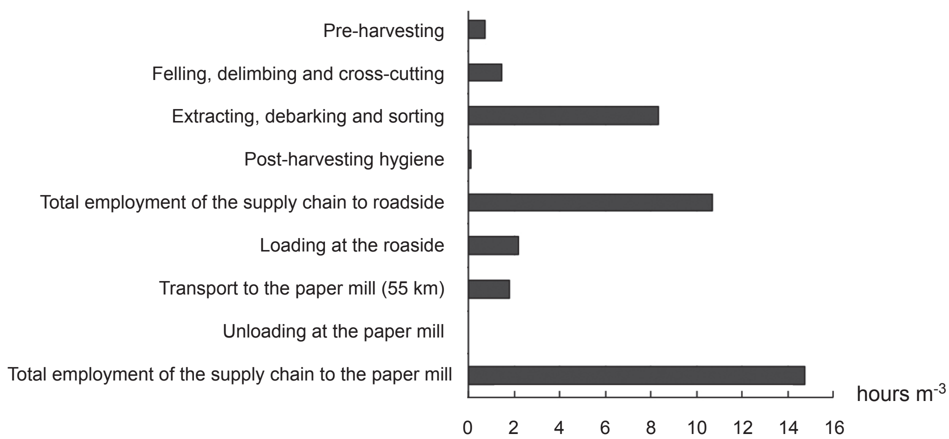

Figure 3 Employment rate of activities in the current wood supply chain

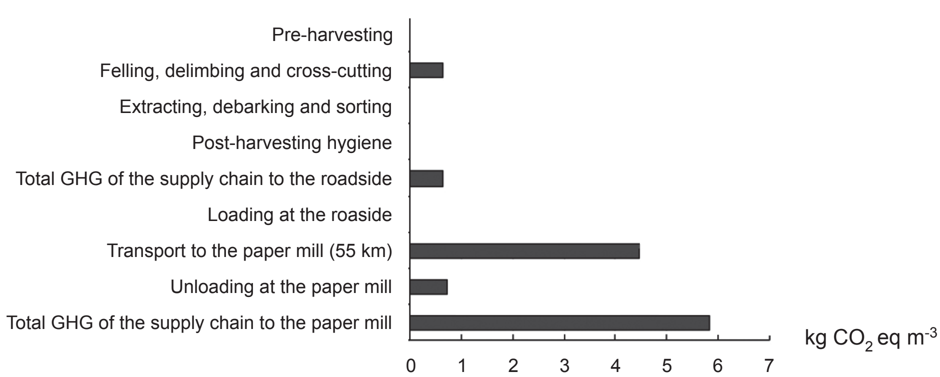

Figure 4 Green house gas (GHG) emissions from the activities in the wood supply chain

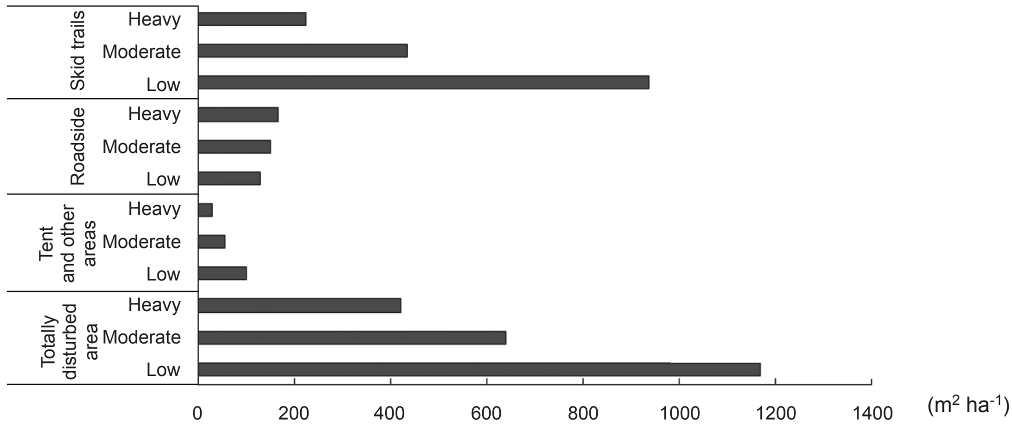

Figure 5 Disturbed areas caused by activities in the current wood supply chain

Mortimer (2005), a tractor with horsepower of less than 37 kW coupled to a trailer with timber crane is suitable for the extraction of logs with small dbh on moderate slope of less than 30%. Such tractor–trailer has loading capacity in the range of 3 to 8 m^3 with average payload of 5 tonnes. Due to unfavourable forest conditions and forest road systems in Vietnam, a tractor with higher driving power of about 45 kW and a 5-tonne trailer equipped with timber grapple was selected for the following calculations.

In the optimised supply chain, trees are felled, delimbed and cross-cut with standard length of 2 m by chainsaw at the stump area, where they are also debarked and classified before being forwarded to the landing by tractor–trailer. The loading at stump area and unloading at landing II are carried out by the grapple crane mounted on the trailer. In order to make the pulpwood transport from landing II to the paper mill more effective, an 11-tonne truck, equal to two trips of the tractor–trailer, is selected to replace the currently used 4.5-tonne truck. However, in contrast to the current pulpwood supply chain, the transport capacity of the improved pulpwood supply chain is based on legal payload restrictions for the truck. This means that two round trips of the tractor–trailer supply enough load for one round trip of the truck. The subsequently optimised pulpwood supply chain to the paper mill is shown in Figure 6.

To analyse the effect of varying investment costs on economic efficiency of mechanisation, three possible purchase prices for the tractor–trailer (50,000, 80,000 and 110,000 €) were alternatively used for calculation. A wide cost range helps to define the break-even point, below which new or secondhand forest machinery could be considered, according to specific cases. Data for cost calculation of the tractor–trailer are shown in Table 3. Logging operations should be considered as heavy work. According to MOLISA (2012), the standard work time should not exceed 6 hours a day including at least 30 min for rest break for hard and heavy jobs.

The production costs of 1 m^3 pulpwood calculated for each process in the optimised supply chain are shown in Table 4. The production costs for extracting and loading by the tractor–trailer were 5.13, 6.09 and 7.53 € m^{-3} resulting from a purchase price of the tractor–trailer of 50,000, 80,000 and 110,000 € respectively.

The production costs of the improved supply chain with different purchase prices of the tractor–trailer were compared with the current supply chain in Figure 7. For the optimised supply chain, the break-even for the production costs was 17.49 € m^{-3}. In order to be competitive and realistic, the production costs of the optimised supply chain should not be higher than the production costs of the current supply chain. This means that the purchase price of the tractor and trailer crane should not exceed 90,000 €.

According to John Deere (2013), the purchase price of a new tractor John Deer 4-wheel drive 5075E (57–61 hp) would be around 24,850 €. A trailer crane made in China matching

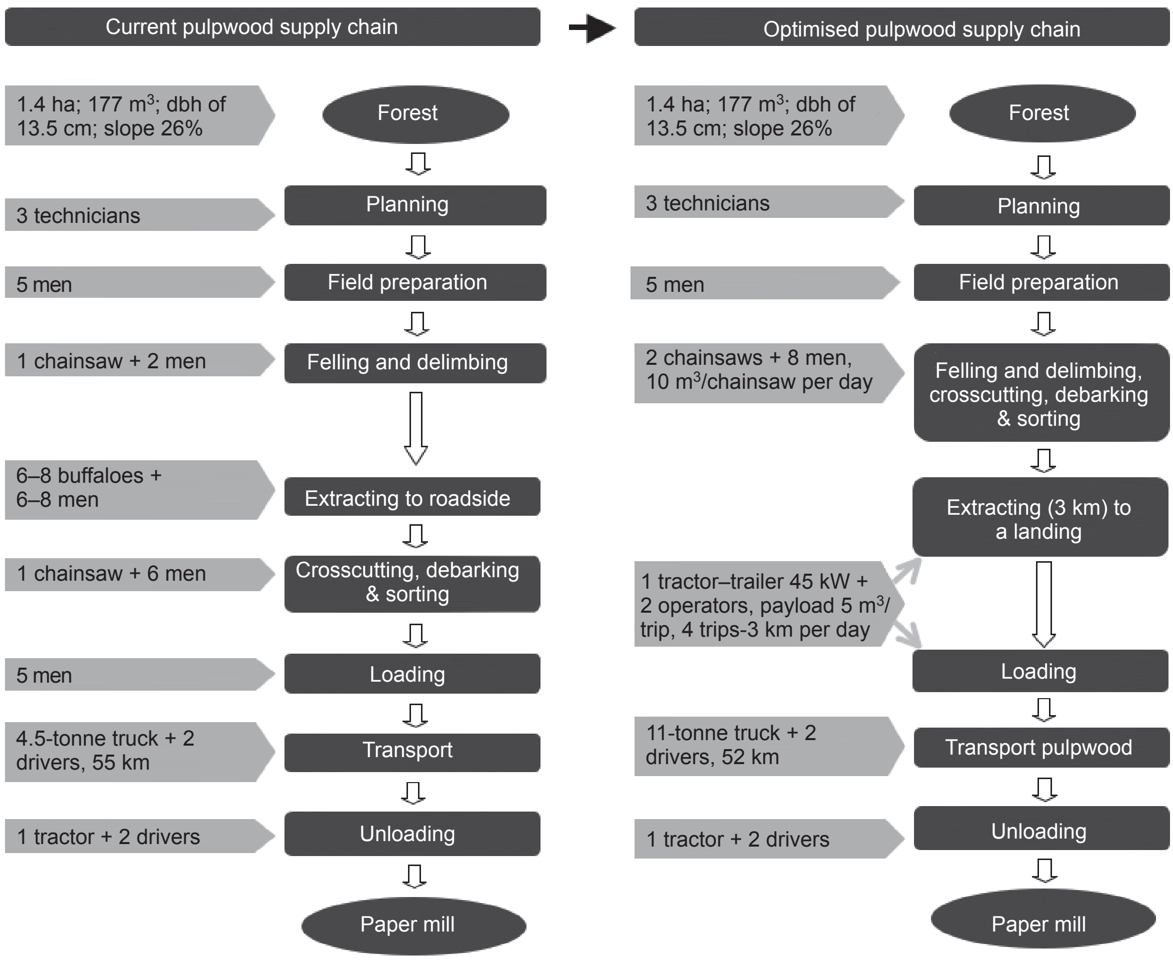

Figure 6 Improvement of the pulpwood supply chain to the paper mill

the tractor should be less than 7710 € (Bizrice 2013). A tax-free import to Vietnam is currently applied for agricultural tractors only with an engine power of more than 1100 cc. The trailer would be imported to Vietnam with a tax of 20% (MoF 2009). This means that the total purchase price of the recommended tractor and trailer crane plus grapple would be less than 34,100 €. At this mechanisation level, the production costs of the optimised supply chain would be 14.81 € m^{-3} which is 15.3% lower than the current supply chain.

As social aspects are concerned, the use of the tractor–trailer would reduce the employment rate from 13.90 to 4.26 hours m^{-3}, which decreases the number of workers directly involved in the hard work of skidding, loading and unloading. According to ECOWOOD (2002), mechanisation will improve working conditions in harvesting operations and eliminate most of the heavy physical labour associated with harvesting. Thus, it will help to reduce the number of occupational accidents and other occupational risks for employees. A case study conducted in Vietnam by Tran and Becker (2013) showed that an accident rate caused by natural forest logging on a moderate slope using tractor for skidding was 3.53×10^{-4} cases m^{-3} sawlogs while using buffalo on a steep slope caused a higher accident rate with 7.34×10^{-4} cases m^{-3} sawlogs. This has also been proven in other countries such as Austria where a decrease in the number of accidents at forest work from 8000 cases in 1955 to 1941 cases in 1999 was reached along by higher mechanisation level (BMLFUW 2008). In Germany, statistics of forestry accidents from 1999 by the German Board of Forestry Work and Technology also showed a decrease in number from 2111 to 1019 cases between 1999 and 2009 (KWF 2011). Mechanisation in

Table 3 Technical data for production cost calculation of the tractor–trailer

Characteristic		Value
Power		45 kW
Productiviy		20 m^3 day^{-1} (4 trips–3 km)
Salvage		20%
Economic life time of tractor		10 years
Interest rate		15%
Number of working days per year		250 days
Number of working hours per day		6 hours day^{-1}
Fuel use rate		5.5 L $hour^{-1}$ (0.029 gal/hp-hour)
Price of fuel		0.61 € L^{-1}
Maintenance and repair rate		0.8
Number of tyres		6 tyres
Average price of one tyre		143 € $tyre^{-1}$
Economic life of tyres		125 days
Labour cost	Operator	17.85 € $shift^{-1}$
	Sub-operator	7.14 € $shift^{-1}$

Table 4 Production costs of the optimised supply chain

Current wood supply chain		Improved wood supply chain		Assumption price of the tractor–trailer (€)
Activities	Costs (€ m^{-3})	Activities	Costs (€ m^{-3})	
Pre-harvesting	0.49	Pre-harvesting	0.49	
Felling and bucking	1.49	Felling and bucking	1.49	
		Debarking and sorting	0.85	
Extracting, debarking and sorting	5.13	Extracting and loading onto truck	5.13	50,000
			6.09	80,000
			7.53	110,000
Loading	0.89			
Transport to the paper mill	8.73	Transport to the paper mill	7.74	
Unloading	0.32	Unloading	0.32	
Administration	0.40	Administration	0.40	
Total costs	17.49	Total costs	15.39	50,000
			16.82	80,000
			18.28	110,000

harvesting and transport will lead to qualification of employment, thus leading to higher wages (Gläser 1956). In addition, according to Vietnam Forest Development Strategy 2006–2020, the domestic wood will gradually replace the imported wood and it is expected that by 2020, about 80% of the raw material for the wood industry in Vietnam instead of 20–25% in 2010 will come from domestic forests. This means that the plantation area will be increased substantially (To & Canby 2011). By this, new high quality jobs could compensate the reduction of employment rate per m^3 due to mechanisation.

With regard to environmental aspects, because of fossil fuel consumption by tractor–trailer, more GHG would be emitted from a higher mechanised supply chain with 11.69 kg CO_2 eq m^{-3} instead of 5.82 kg CO_2 eq m^{-3} in the current chain using buffalo. This result is consistent with other research (Engler 2011),

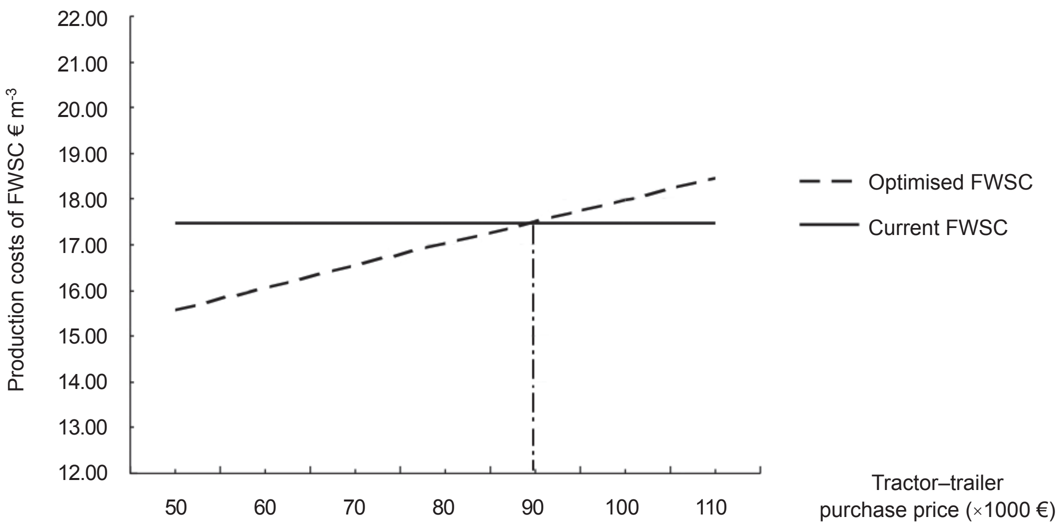

Figure 7 Comparison of the production costs between the current and optimised supply chain

but the study does not take into consideration all possible aspects of environmental impacts such as landuse or emissions of GHG directly related to buffaloes, which for instance produce about 50 kg of CH_4 year^{-1} due to poligastric digestion, corresponding to about 1050 kg CO_2 eq (Lerner & Matthews 1988). There are a number of studies such as Woolridge (1960), Malmer and Grip (1989), FAO (1998) and Wang (2000) concluding that using tractor for log extraction causes more heavily disturbed area compared with manual and animal skidding. However, this negative impact can be minimised to an acceptable level if operational harvesting is fully and carefully planned, the training of employees is fully carried out and the work in the field is well organised with full supervision.

CONCLUSIONS

A higher level of mechanisation using tractor–trailer in the optimised supply chain would reduce production costs and the number of employees involved in hard, physically demanding and dangerous work of extracting, loading and unloading while increasing productivity to expand production and create other better and more specialised jobs in related sectors. However, the higher level of mechanisation would cause larger disturbed stand areas than the use of buffalo and increase GHG emissions.

In order to improve pulpwood supply chain from plantations located on moderate slopes in Vietnam, a higher level of mechanisation should start with agriculture tractors and other simple equipment that is suitable for various types of plantations and terrains under small-scale operational conditions. Mechanisation should be implemented parallel to complete and careful planning, implementation and supervision of logging and transport operations to limit possible negative impacts.

There should be suitable policies to encourage forest owners and harvesting contractors to invest more in wood supply chains such as application of tax-free import of appropriate forest and agriculture machines and equipment. In addition, the average operating area of one single harvesting unit should be enlarged to increase productivity by reducing the moving and set-up costs of machines and equipment. A project for developing a model of timber harvesting mechanisation for specific cases including the selection of appropriate machines and equipment regarding all three aspects of sustainability should be considered. The results of the project after that could be applied to other comparable situations.

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