Sustainability Impact Assessment (SIA) of alternative Forest-Wood Supply Chains (FWSCs) of Natural Forests in Vietnam

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Abstract:
In the north of Vietnam, steep slopes are dominating (above 47%). Harvesting there is carried out manually by using chainsaws for felling and sawing logs into small boards right at the felling site, the boards is then extracted by buffaloes to the lower landing and transported further by trucks to the industry (FWSC1). In the centre and the southern of Vietnam, the slopes are more gentle (less than 47%). Harvesting is partly mechanized by using chainsaw for felling and tractors equipped with cables or winches for extracting round wood to lower landing and then further with trucks to the industry (FWSC 2). The results of a sustainability impact assessment with a set of selected indicators show that FWSC 2 had more positive impacts in economic and social aspects as well as generated less waste, but emitted more GHG and caused more negative impact to soil than FWSC 1. However, as developing country, Vietnam focuses more on economic and social aspects than environmental aspects. Thus, FWSC 2 is assessed more sustainable as compared with FWSC 1 in the context of Vietnam.

Keywords: Sustainability Impact Assessment (SIA), harvesting systems, harvesting in natural forests, Vietnam

1 Introduction

Vietnam has a total of 13.258 million ha of forests which cover 39,1% of the land surface. 10.339 million ha are natural forests (VNFOREST, 2010), which provide annually more than 300.000 m³ of large dimension logs as supply for all kinds of wood industry in the country (MARD, 2005). The greatest part of these natural forests is located in hilly or steep terrain. In the north of the country steep slopes are dominating (above 47%) (MARD, 2005). Harvesting there is carried out manually. Trees are felled and sawn into small boards (0,2 – 0,35 m³) right at the felling site (pit sawing), the sawn timber is then extracted by buffaloes to the lower landing and transported further by small trucks to the wood processing industry (FWSC 1).

On the contrary, in the centre and the southern parts of Vietnam, the slopes are more gentle (less than 47%) (MARD, 2005) and the harvesting operations are partly mechanized by using chainsaw for felling and de-branching followed by extraction of the logs with tractors equipped with cables or winches to the lower landing and then further with bigger trucks to saw mills (FWSC 2).

Logging and transport are labor and cost intensive operations and have inevitable impacts on the natural environment and also on social issues as employment, health and safety of the labor force. Depending on the level of mechanization, these impacts are different. The aim of this study is to assess the sustainability impacts of activities in FWSC 1 and FWSC 2 for a selective set of indicator. Furthermore, suggestions to optimize the chains will be proposed to reduce the negative impacts and to enhance positive impacts.

2 Materials and methods

2.1 Study sites

In order to assess the overalls sustainability of FWSCs of natural forest in Vietnam, two case studies that are typical for two different level of mechanization were being chosen. The case study FWSC 1 was carried out in Van Ban, located in Lao Cai province, the other, FWSC 2, was conducted in Song Kon, located in Binh Dinh province (Figure 1 a). The characteristics of two sites are shown in Table 2.

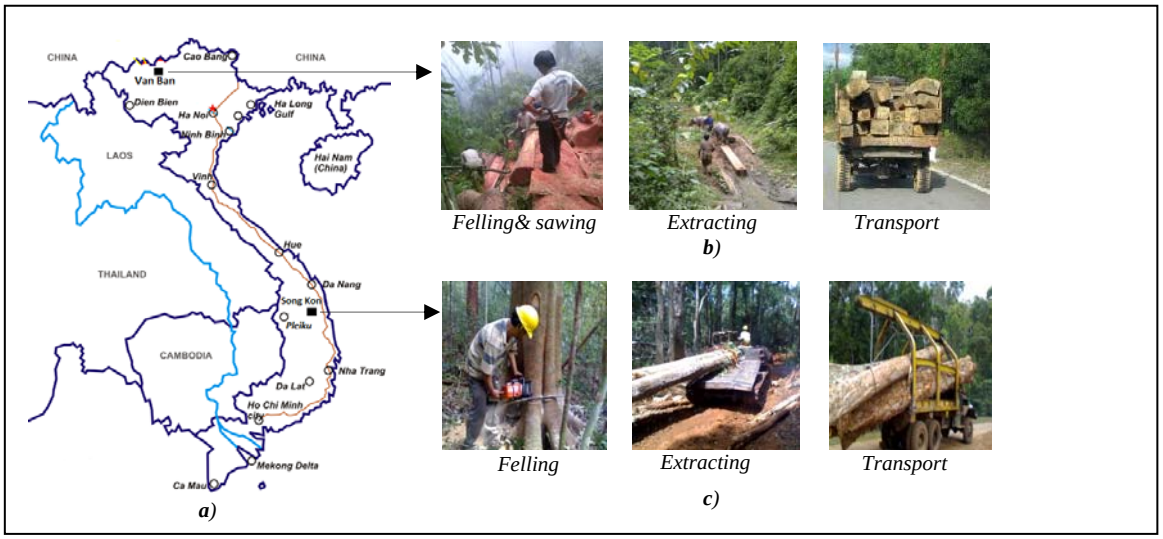

Figure 1: Selection of study sites for two case studies a) Selected sites; b) Some main processes of FWSC 1 in Van Ban; c) Some main processes of FWSC 2 in Song Kon

Table 1: Characteristics of two chosen sites for SIA of FWSCs

Features	Measurement units	In Van Ban	In Song Kon
Altitude	m.s.l.m	880 - 1260	695 - 753
Area of study sites	ha	10.2	8.2
Kind of forest	-	Natural production forest	Natural production forest
Forest owner	-	State owned	State owned
Species	-	Mixed	Mixed
Total of stand volume	m^3/ha	272	278
Harvesting method	-	Selective felling	Selective felling
Harvesting intensity	% (of stand volume)	14.7	32.5
Number of harvested trees	trees	80	153
Dimension of extracted wood	m^3	0.2-0.35	1.2 – 6.8 *(aver. 2.6)*
Average harvested BDH	cm	71	65
Max slope of terrain	%	57.7	38.4
Min slope of terrain	%	46.6	8.75
Average slope of terrain	%	52.2	23.1
Max skid trail distance	m	1666	742
Min skid trail distance	m	1490	652
Average skid trail distance	m	1578	697
Max slope of skid trail	%	36.4	20.0
Min slope of skid trail	%	17.6	8.75
Average slope of skid trail	%	27.0	14.4

2.2 Processes (activities) of natural forest FWSCs at the selected site in Van Ban and Song Kon

The first process of pre-harvesting activities is harvesting planning. This activity was conducted by technicians one year before felling. The aim of planning is to find out where and how the harvesting activities are carried out and make a plan for harvesting cost and employment needed for harvesting and transporting the wood to landing II. The second step of pre-harvesting activities is field preparation. The purpose of this activity is to make the later felling activity safer. The work of this activity is to prepare routes accessing to selected trees and area around those trees as well to cut off all climbing plant on the harvested trees. However, the work of field preparation was not done in Van Ban case because harvesting contractor did not want to pay for that. The last step of pre-harvesting activities is skid trails, landings and tents preparation. In case study in Van Ban, most of old skid trails with 1.5 m width as well as landings were used again for extracting by buffaloes. Only small reparation work is done to improve them. In Song Kon, most of skid trails were newly built by using bulldozer and manpower to create trails with width of 3-3.5 m for extracting by tractor.

After finishing pre-harvesting processes, the harvesting activities were carried out. In Van Ban, the activities of felling, de-branching, cross-cutting and sawing into board wood were done by chainsaw at a stump area. After that, all board wood was skidded by buffaloes to landing I. In Song Kon, harvesting process was carried out in a more mechanized way with felling and de-branching by chainsaw at the

stumps. The round wood then was extracted by tractor TDT 55 to landing I where long logs were cross-cut into shorter logs.

Post-harvest hygiene activity was done after all wood had been extracted to landing I. The aim of this work is to reduce to minimum negative impacts of harvesting activity to the remaining tree and the soil as well as to avoid potential accidents for people in the future.

Transport to landing II: The distance of road between landing I and landing II in Van Ban is 14 km. This is a steep and rough road, and therefore not accessible for a big truck. At landing I of FWSC 1, the logs were loaded by manpower into 3 tons trucks and then transported by that truck to landing II. After that the logs were unloaded as well by manpower. In Song Kon, the distance of the transport road from landing I to landing II is 15 km. Due to the asphalted road, the permitted load transported is up to 20 tons. Therefore a 9 tons truck was used for transporting logs to landing II. At landing I logs were loaded by winch equipped on truck, then the logs were transported to landing II where they were unloaded by the same winch.

Transport to mill: In Van Ban, most of the wood boards at landing II were sold to a customer in Hai Phong located 400 km away from Van Ban. The boards were transported to mill by 15 tons truck. In Song Kon, logs were sold at landing II to a regional customer. Logs were loaded by crane truck, and then transported by 8.5 tons truck to the mill at 120 km of transport distance. At the mill, logs then were also unloaded by crane truck.

Sawing at regional mill: The woods transported to the customer in Van Ban were sawn board woods. In Song Kon the product for the mill was logs. In order to be able to compare the already FWSCs under equal condition, the chain FWSC 2 included the sawing process at the mill where the logs were converted into boards.

Table 2: Processes and used method description of two selected FWSCs

Processes	**FWSC I in Van Ban**	**FWSC II in Song Kon**
	Description	**Description**
Planning	05 technicians	05 technicians
Field preparation	no	08 workers
Skid trail, landing and tent preparation	09 workers	01 crawler+02 operators+12 workers
Felling, cross-cutting, sawing into boards	02 chainsaws Husq 365 + 04 operators (sawing into boards)	01 chainsaw Husq-365+ 02operations (no sawing into boards)
Extracting	08 buffaloes + 05 drivers	01 tractor TDT55+ 03 operators
Post harvest hygiene	no	01 chainsaw Husq-365+ 02 operations+15 workers
Loading at landing I	05 workers	01 9 tons truck REO with winch+03 drivers
Transport to landing II	02 3 tons trucks+02 drivers;14 km	01 9 tons truck REO with winch +03 drivers; 15 km
Unloading at landing II	04 workers	01 truck REO 9 tons +03 drivers

Loading at landing II	08 workers	01 crane truck+02 drivers
Transport to mill	01 15 tons truck+02 drivers; 400 km	03 8.5 tons truck + 02 drivers; 120 km
Unloading at mill	06 workers	01 crane truck + 02 drivers
Sawing at mill	no	01 saw + 03 workers

2.3 Sustainability indicators

In order to assess and compare sustainability impact of whole chains, a set of sustainability indicators have to be chosen (Table 3). Sustainability indicators need to cover economic, social and environmental dimensions (EFORWOOD, 2006). The key criterion for selecting indicators is their ability to capture the impacts of the FWSCs on sustainability (EFORWOOD, 2006). After being chosen, the set of sustainability indicators were linked to each process of the chains, from planning to unloading activities at regional mill.

Table 3: The set of sustainability indicators

Indicators		**Unit**	**Data collection**	**Data calculation**
Economy	Productivity	m^3_{bw}/PUH	Time study	Excel
	Production cost	€/m^3_{bw}	Investigation in field	Excel and Umberto(1)
Society	Employment	shift/m^3_{bw}	Investigation in field	Excel and Umberto
	Wage	€/shift	Investigation in field	Excel
	Occupation accident	cases from 2008 to 2011	Interview in field	Excel
Environment	GHG emission	Kg CO2eq/m^3_{bw}	Investigation in field	Excel and Umberto
	Waste generation	kg/m^3_{bw}	Investigation in field	Excel and Umberto
	Disturbed area	m^2/ha	Investigation in field	Excel

2.4 Methods of data collection and calculation

Productivity: Due to time limitation for data collection, data for calculating the productivity of planning, field, skid trails, landing and tent preparation as well as post-harvest hygiene were collected by interviewing directly technicians, workers and supervisors who had been involved in to these activities. Data for the other processes were collected by time studies. Time study is defined as the analysis of the methods, material, tools and equipment used in the production process (Barnes, 1968). Time study not only measure time and production but also identifies time categories according to the action (Mousavi, 2009). Time concept used for time studies is below (Figure 2). A series of five times studies (equal to five whole working days) for felling, crosscutting and extracting activities were carried out. For loading, transport and unloading activities, one cycle of time study was conducted for each activity.

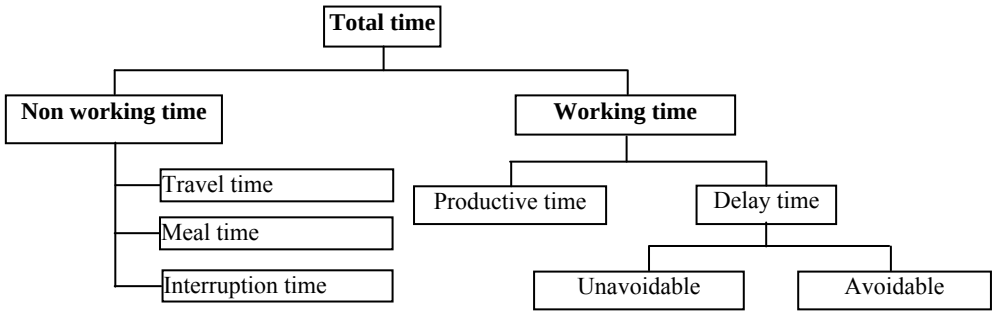

Figure 2: Time concept used for time studies

Production cost: The production cost of each process of FWSCs were calculated in unit cost (€/m^3_{bw}) based on system cost (€/shift) that consist of machine cost, labor cost, administration cost and tax. The machine cost includes fixed cost (interest, depreciation, insurance) and variable cost (fuel and lubricant oil cost, maintenance and repair cost, short life parts cost). The unit cost is calculated from system cost as follow:

$$\text{Unit cost} = [\text{System cost}]/\text{Productivity} \qquad €/m^3_{bw}$$

Employment: The creation of sufficient decent work opportunities, especially for youth, is an important issue in Viet Nam (MOLISA, 2010). This is an important and significant indicator for Vietnam. In order to assess exactly the employment creation of FWSCs the demand of employment for one m^3_{sw} is calculated basing on the number of actors involved directly in each activity and productivity of each process as follows:

$$\text{Employment} = [\text{Number of men}]/\text{Productivity } (\textit{of one shift}) \qquad \text{shift}/m^3_{bw}$$

Wage: In both FWSCs, most of employers were paid by the amount of work they had done (piece wage). The amount of money that employers received (overturn) included machine cost, labor cost, administration cost and tax. The wage depended on productivity and was calculated as follows:

$$\text{Wage} = (\text{Overturn} - [\text{Machine cost} + \text{Administration cost} + \text{Tax}]) \times (\text{Productivity per shift}) \quad €/\text{shift}$$

Some were paid by shift (08 working hours) that did not depend on productivity (or the amount of work they have done). This income was considered as wage per shift (€/shift).

Note: 1. Umberto is a software for modeling, evaluation and optimization the processes and the flow of materials, energy and work.

Occupational accident: The number of accident cases in forestry activities is not recorded by any agency in Vietnam. Therefore no data are available at the moment. In order to get this information, interview method was used. The actors of each activity were directly interviewed about the information of accidents happening in the time period between 2008 and 2010. In this study, occupational accident was divided into two kinds of accident: fatal accident and non fatal accident. Fatal accidents are cases that had to be taken to hospitals while non fatal cases were treated at working place or at home.

Green house gas emission (GHG emission): GHG can be measured by estimating the amount emitted using activity data (such as amount of fuel used) and applying relevant conversion factor (e.g calorific values, emission factors, oxidation factors) (DEFRA, 2009). GHG emission was calculated based on the amount of fuel consumption and emission factors of fuel. In this study, emission factor was used for calculating as follows:

$$\text{GHG emission} = \text{fuel consumption} \times \text{emission factors} \qquad (\text{kg } CO2eq/m^3_{bw})$$

The amount of fuel consumption was collected by field investigation. Emission factors were given on table 4.

Table 4: Emission factors with different kinds of fuel (DEFRA, 2009).

Fuel type	units	CO_2 *(Kg CO_2 per unit)*	CH_4 *(Kg CO_2 per unit)*	N_2O *(Kg CO_2 per unit)*	Total GHG *(Kg CO_2eq per unit)*
Diesel	liters	2.6391	0.0019	0.0283	2.6694
Petrol	liters	2.3035	0.0047	0.0226	2.3307
Electricity	kWh	-	-	-	0.5266

Waste generation: There are two kinds of waste being collected data and calculated in this study: hazardous waste that cause danger, or are likely to cause danger to health or the environment because of their chemical reactivity, toxic, explosive, radioactive or other characteristics; non-hazardous waste that do not have any properties of danger for health or the environment (AFOCEL, 2005). However, logging residues such as slash, crowns, bark, etc are traditionally left at the site in forests and are of prime importance for the restitution of minerals to the soil. They will not therefore be considered as waste here.

Table 5: The main categories of wastes generated by logging work (AFOCEL, 2005)

Hazardous wastes	Unit	Non-hazardous waste	Unit
Aerosols	kg/m^3_{bw}	Unsoiled packaging	kg/m^3_{bw}
Electrical parts/electronic components (WEEE)	kg/m^3_{bw}	Waste metal	kg/m^3_{bw}
Soiled packaging	kg/m^3_{bw}	Used tyres	kg/m^3_{bw}
Used oil	kg/m^3_{bw}	Glass	kg/m^3_{bw}
Miscellaneous fluids	kg/m^3_{bw}	Miscellaneous non-hazardous wastes	kg/m^3_{bw}
Soiled items	kg/m^3_{bw}		kg/m^3_{bw}
Batteries and accumulators	kg/m^3_{bw}		kg/m^3_{bw}
Solvents/detergents	kg/m^3_{bw}		kg/m^3_{bw}
Miscellaneous hazardous wastes	kg/m^3_{bw}		kg/m^3_{bw}

All data for waste calculation in this study were collected in Vietnam basing on categories of wastes in table 5.

Disturbed area: Logging often leads to disturbed area that may causes soil erosion (Megahan; Rice and Rothacher, 1972). The rate of this type of erosion is closely correlated with vegetative cover, especially litter on the soil surface that depends on level of disturbance (Rice; Rothacher and Megahan, 1972). In this study, the disturbance was divided into three levels: low disturbed area (where forest floor, litter or slash removed, top soil exposed) (Figure 2.a); moderate disturbed area (where top soil removed and subsoil exposed) (Figure 2.b) and heavy disturbed area (where subsoil removed to a depth greater than 5 cm and mineral soil exposed) (Figure 2.c). The data were collected by directly measuring in the field. Measurement unit is m^2/ha.

a) Low disturbed *b) Moderate disturbed* *c) Heavy disturbed*

Figure 3: Disturbed area caused by harvesting activities

3 Result

3.1 Volume flow

The table 5 shows the volume flow of two FWSCs. In Van Ban, all of firewood (23.8% of standing volume) including branches and wood tops and residues (42% of round wood) including slabs and sawdust are left in forest. Only board wood (58% of round wood) after being sawn are extracted to landing I, and transported by trucks to landing II and regional mill. In Song Kon, all of firewood is also left in forest but round wood is transported to regional mill, then being sawn into board wood (68% of round wood) and residues (32% of round wood) at regional mill. The residues at mill are mostly used as firewood. That means the proportion of board wood in Song Kon is 10% higher than that of Van Ban, and most of residues in Song Kon are being utilized as firewood while residues in Van Ban are being left in forest.

Table 5: Results of volume flow calculation of FWSC 1 and FWSC 2

Parameter			Unit	FWSC 1	Data source	FWSC 2	Data source
1			2	3	4	5	6
Total of standing tree volume			m^3	2,774	Harvest plan	2,280	Harvest plan
Harvest intensity			%	14.7	Harvest plan	32.5	Harvest plan
Standing tree volume planned for harvesting			m^3	407 (100%)	Harvest plan	742 (100%)	Harvest plan
Products	1. Round-wood		m^3_{rw}	250 (61.4%)	Investigated	494 (66.6%)	Investigated
	After sawing into board-wood	Board-wood	m^3_{bw}	145 (58.0%) (sawn at forest)	Investigated in field	336 (68.0%) (sawn at mill)	Investigated in field
		Sawing residues	m^3	105 (42.0%) (left in forest)	Investigated in field	158 (32.0%) (at mill)	Investigated in field
	2. Firewood left in forest		m^3	97 (23.8%)	Harvest plan	137 (18.5%)	Harvest plan

3.2 Sustainability indicators

Productivity

Time consumption: The time study of felling and extracting shows that there is a difference of time consumption between two places and among processes in one chain (Figure 4). In Van Ban total time per day is 8.1 hours in extracting and 8.9 hours/day in felling while in Song Kon total time consumption is

7.9 hours/day in felling and 8.5 hours/day in extracting. The time consumption for felling and extracting for each activity in Van Ban is almost the same with about 69% of productive time, 26% of non working time and 5% accounting for delay time while in Song Kon there is big difference between felling and extracting processes with about 48% and 71% of productive time, 36% and 21% of non working time and 16% and 8% of delay time. In felling process time consumption of sawing activity in Van Ban is the greatest; accounting for 85% of productive time while in Song Kon delimbing activity occupied the greatest time with 48% of productive time. In extracting process, time for loaded travel in Van Ban accounts for largest proportion with 50% of productive time, while in Song Kon loading activities occupied most of time consumption with 42% of productive time.

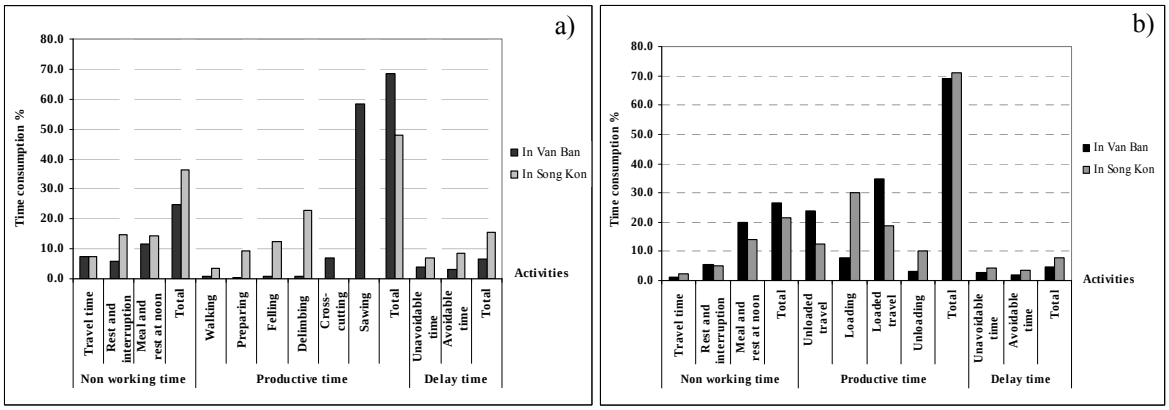

Figure 4: Time consumption of felling (a) and extracting (b) activities of natural forest FWSC 1 and FWSC 2

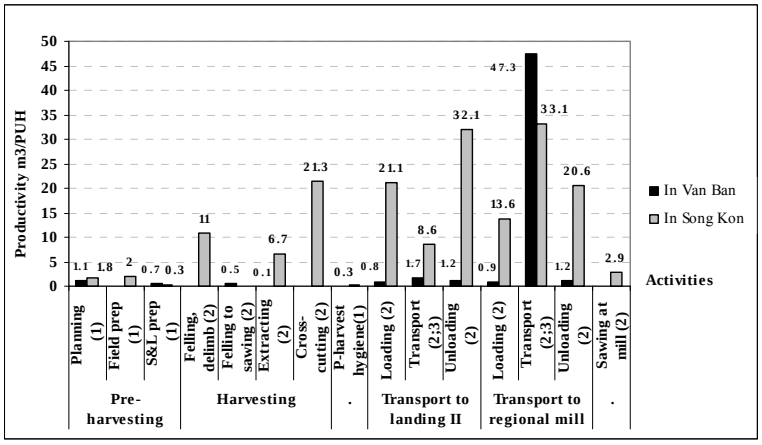

Figure 5: Productivity of each activity of natural forest FWSC 1 and FWSC 2

Productivity: Figure 5 shows the productivity of each process. With two hours of felling and delibing and one hour of crosscutting, the productivity of chainsaw in FWSC 2 used for felling, delimbing and crosscutting was 7.3 m^3_{rw}/PUH while that of chainsaw in FWSC 1 used for felling, delimbing, crosscutting and sawing was 0.5 m^3_{bw}/PUH, much lower than that in FWSC 2. In extracting, productivity of one buffaloes with trail slope 20 - 35% and average skidding distance 1660 m of FWSC 1 was 0.1 m^3_{bw}/PUH while that of one tractor TDT 55 with trail slope 10 – 15% and average skidding distance 650 m was 6.7 m^3_{rw}/PUH, 67 times higher than in FWSC 1. In loading and unloading, productivity of 9 tons truck REO with winch in Song Kon was 26.3 – 26.7 times higher than that of one man in Van Ban while productivity of one 7 tons crane truck in Song Kon was 15.1-17.1 times higher than that of one man in Van ban. In transport, the bigger truck had higher productivity. Most of trucks are overloaded from 1.5 – 2.0 times of the permitted weight.

3.3 Production cost

It can be observed from figure 06 that the total cost to regional mill of FWSC 1 in Van Ban is 50.83€/m^3_{bw} while total cost of FWSC 2 to regional mill in Song Kon is 35.73 €/m^3_{bw}, lower 15.10 €/m^3_{bw} (or 29.7% of total cost in Van Ban) than in Van Ban. Most of cost in Van Ban is spent for harvesting (from felling to extracting activities) with 35.13 €/m^3_{bw} (or 69.1% of total cost) while the cost of FWSC 2 in Song Kon is mostly spent for pre-harvesting and post – harvesting activities with 17.32 €/m^3_{bw} (or 48.5% of total cost). The cost of harvesting activity in Song Kon is only 6.09 €/m^3_{bw}, accounting for 17.0% of total cost. In transport, the biggest truck loaded with 40 m^3_{bw} (while 15 tons permitted) transporting board wood to regional mill in Van Ban has lowest cost of 0.60 €/m^3_{bw}.10 km while the smallest truck 5.1 m^3_{bw} (3 tons permitted) in Van Ban transporting board wood to landing II has highest cost of 3.9 €/m^3_{bw}.10 km. Two trucks in Song Kon with 15.4 m^3_{rw} loaded (9 tons permitted) and 22 m^3_{rw} loaded (8.5 tons permitted) has cost of 0.89 €/m^3_{rw}.10 km and 0.12 €/m^3_{rw}.10 km.

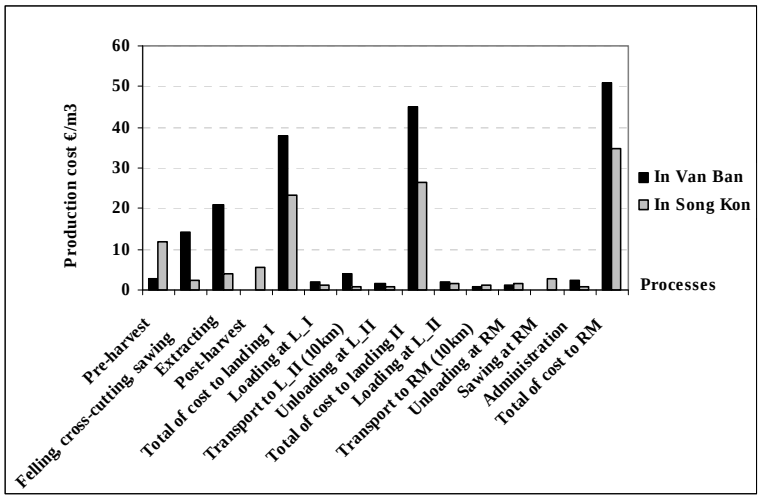

Figure 6: Production cost of natural forest FWSC 1

Note:

1. The value of productivity is calculated per man.

2. The value of productivity is calculated per one chainsaw (if felling, crosscutting, sawing at stump site); per one tractor or animal (if extracting); per one truck (if loading, transport or unloading).

3. The productivity of transport is calculated for 10 km (m^3.10km/PUH).

4. The productivity unit of activities from planning to unloading at mill in FWSC 2 is shown as m^3_{rw}/PUH; sawing activity at mill is m^3_{bw}/PUH. In FWSC 1, productivity unit of activities from planning to field, skid trails, landing preparation is shown as m^3_{rw}/PUH; activities from felling to unloading at mill is m^3_{bw}/PUH.

3.4 Employment

Figure 07 shows employment of natural FWSC 1 in Van Ban and natural FWSC 2 in Song Kon. The total of employment per m^3_{sw} of FWSC 1 is 57% higher than of FWSC 2. In FWSC 1 felling, cross-cutting and sawing activities take the highest employment with 30% of total employment in FWSC 1, then the second is extracting activity with 29% of total while in FWSC 2 the highest employment is taken by pre-harvesting activities with 39% of total employment in FWSC 2, and the second is post-harvesting activity with 32% of total.

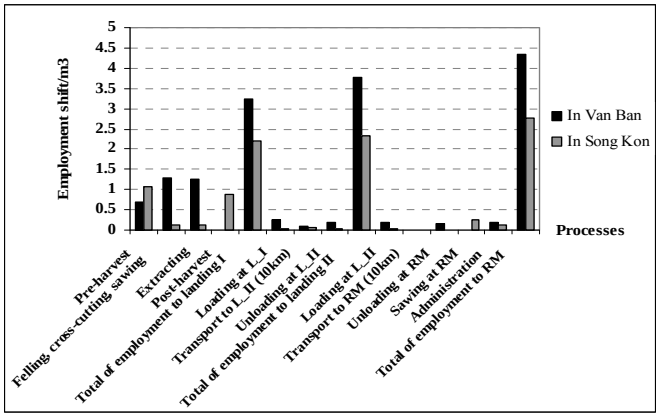

Figure 7: Employment of natural forest FWSC 1 and FWSC 2

3.5 Wage

Figure 08 shows average wage per shift (day) of direct actors in FWSC 1. The wage of truck operators is highest with 30.38 and 40.4 €/shift of transport to landing II and regional mill, respectively while the wage of workers preparing skid trail and landing is lowest with 3.57 €/shift, equal to 9% wage of truck operator of transport to regional mill.

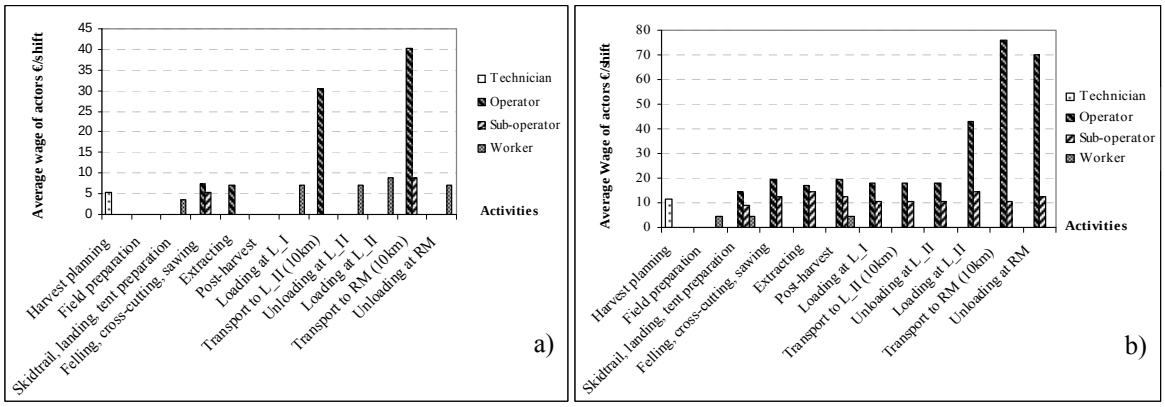

Figure 8: Average wage of direct actors involving in natural forest FWSC 1 (a) and FWSC 2 (b)

In Song Kon the truck operator of transport to regional mill has highest wage with 76.08 €/shift while workers of skid trail and landing preparation, field preparation and post-harvesting have lowest wage with 4.29 €/shift, equal to 5.6 % of above highest wage. Wage of chainsaw and tractor operators in Song Kon is much higher than chainsaw and animal operators in Van Ban with 165% and 139%, respectively.

3.6 Occupation safety

Figure 09 shows that from 2008 to 2010 the non fatal accident (NFA) happened frequently in most of activities of both FWSCs and sometime happened in preparation work and transport while the fatal accident (FA) happened fewer with one case in felling and one case in extracting of both study places. According to the report from 2008 to 2010 of two companies, total harvested volume in three years was 6,400 m^3_{rw} in Van Ban and 8,100m^3_{rw} in Song Kon.

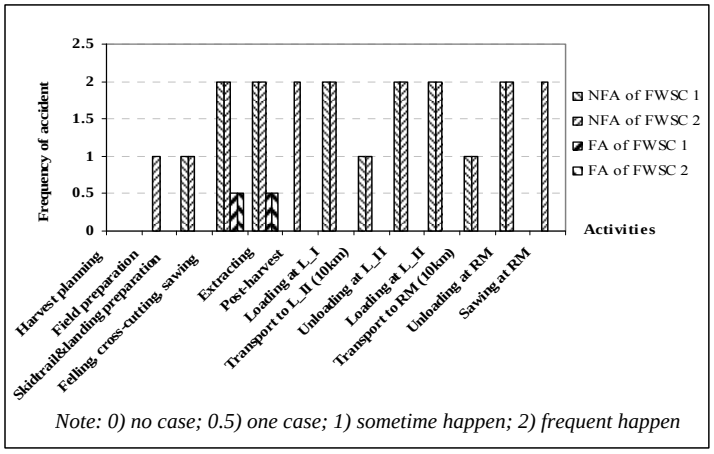

Figure 9: Occupational safety of natural forest FWSC 1 and FWSC 2

Therefore, the fatal accident rate of FWSC 1 and FWSC 2 was 3.125×10^{-4} cases/m^3_{rw} and 2.469×10^{-4} case/m^3_{rw}, respectively.

3.7 GHG emission

GHG emission of FWSC 1 and FWSC 2 is presented in Figure 10. The total of GHG emission of FWSC 2 was 2.7 times higher than that of FWSC 1. Most of GHG of FWSC 2 was emitted from pre-harvesting, extracting and sawing at mill, took 22% , 17% and 18% of total GHG of FWCS 2 while in FWSC 1 most of GHG was emitted from felling, crosscutting and sawing activity with 85 % of total GHG of FWSC 1. GHG emitted from felling, crosscutting and sawing at mill of FWSC 2 was 4.85 kg CO_{2eq}/m^3_{bw} while that from FWSC 1 was 6.85 kg CO_{2eq}/m^3_{bw}, 41% higher than FWSC 2.

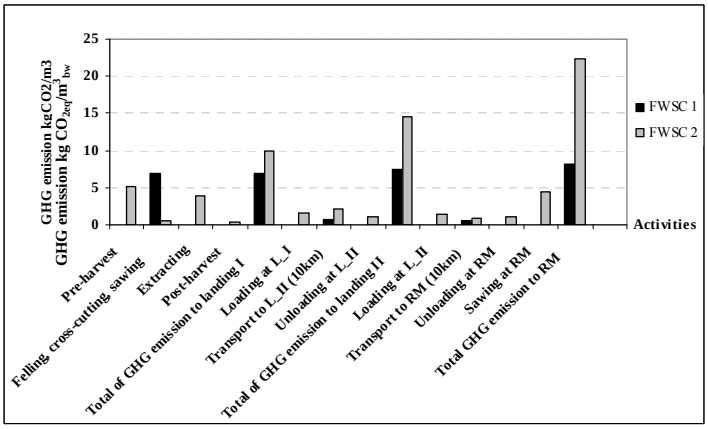

Figure 10: GHG emission of natural forest FWSC 1 and FWSC 2

3.8 Waste generation

Figure 11 shows waste generation from two FWSCs. It is surprised that the hazardous waste (HW) from FWSC 1 is 2.5 times higher than from FWSC 2 while mechanization level of FWSC 1 is lower than FWSC 2. The non hazardous waste (NHW) from FWSC 1 is also 14% higher than from FWSC 2. Most of HW from FWSC 1 was generated from chainsaws used for felling, crosscutting and sawing activities, took 97% of total HW while 57% of NHW from FWSC 1 was generated from animals using for extracting. Felling and extracting activities of FWSC 2 generated 33% of total HW from FWSC 2.

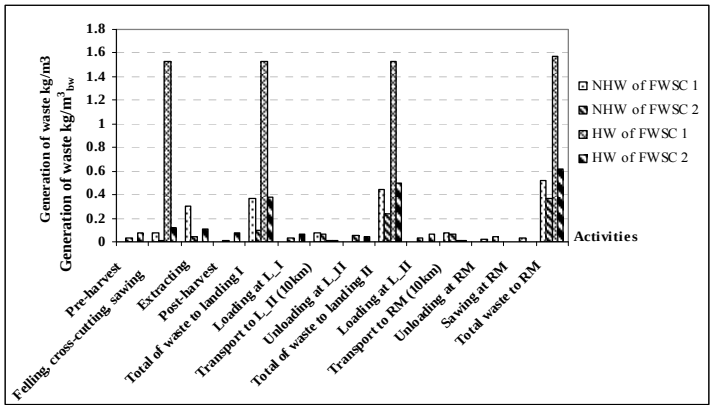

Figure 11: Waste generation of natural forest FWSC 1 and FWSC 2

3.9 Disturbed area

Figure 12 shows that in FWSC 1 low disturbed area, moderate disturbed area and heavy disturbed area took 3.7%, 3.4% and 3.4% of total area, respectively while in FWSC 2 low disturbed area, moderate disturbed area and heavy disturbed area took 3.8%, 2.7% and 6.2% of total area, respectively. The heavy disturbed area caused by FWSC 2 is 80% bigger than FWSC 1 while moderate disturbed area is 20% smaller and low disturbed area is nearly the same as compared to FWSC 1. The most of disturbed area is caused by skid trail.

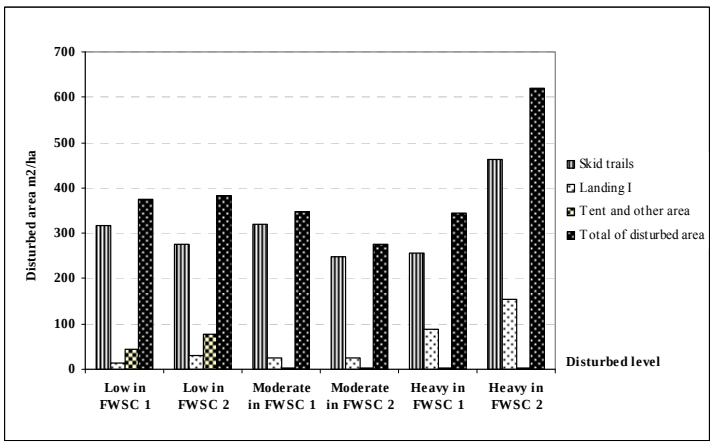

Figure 12. Disturbed area caused by natural forest FWSC 1 and FWSC 2

4 Discussion

4.1 Economic aspect

Due to sawing round wood into boards at stump areas in unfavorable condition by chainsaws, FWSC 1 in Van Ban had 10% lower of the utilization proportion as compared with FWSC 2 in Song Kon where logs were transported to mill and sawn into boards while average BDH of trees in FWSC 2 were 8% smaller than that in FWSC 1. In addition, all the tops, branches, stumps and residues (in Van Ban) were left in forests in both FWSCs. Thus, there were a decrease of the economic efficiency in forest production and a lower rate of forest recovery.

The productivity of harvesting (from felling to extracting logs to landing I) calculated for one chainsaw and tractor in FWSC 2 (6.7 m^3_{rw}/PUH) was much higher than that in FWSC 1 calculated for one chainsaw and 4 buffaloes (0.4 m^3_{bw}/PUH). The reason is that sawing activity at stump areas occupied a lot of time (58.3% total consumption time), this leads chainsaw productivity there was low. In addition, the productivity of buffaloes was also low because of low loading capacity (0.25-0.35 m^3_{bw}) and long skidding distance with high slope.

Total production cost per m^3_{bw} of the FWSC 2 lower 30% than that of the FWSC 1. In the FWSC 1, harvesting activities (from felling to extracting) occupied most of cost (69% of total cost) while in FWSC 2 took only 17% of total cost. The result of calculation also shows that the bigger trucks that have bigger load capacity had the lower transport cost. However, big trucks are limited by investing ability and road condition.

4.2 Social aspect

Due to sawing logs into boards at the stump areas and using buffaloes to extract timbers to the landing I, the FWSC 1 had employment per m^3_{bw} higher than that of the FWSC 2, that means the FWSC 1 created more jobs than FWSC 2. However, most of jobs were very hard and dangerous on the difficult terrain, especially in extracting, loading and unloading activities of the FWSC 1. Thus, the creation of more jobs in those activities should not be encouraged but should be mechanized to reduce hard jobs as well as improve work condition.

The average wage of FWSC 1 was 12.13 €/shift while that of FWSC 2 was 19.32 €/shift, 59% higher than that of FWSC 1. In both FWSCs, the difference between lowest and highest wage of employers was remarkably high, those who have lowest wage (from 3.57 to 4.29 €/shift) are workers who prepared field, skid trail, landing and loaded and unloaded while those who have highest wage (from 30.38 to 76.08 €/shift) are operators who mostly own trucks and crane trucks.

There were two cases of FA happened from 2008 to 2010 in both FWSCs. Thus, the FA rate of FWSC 1 was 3.125×10^{-4} cases/$m^3_{rw,}$ and of FWSC 2 was 2.469×10^{-4} case/m^3_{rw}. That means the rate of FA in FWSC 2 was 21% lower that of FWSC 1. The result of study also shows that NFA happened frequently in almost all activities. The main reason is that most of the employers involved were not trained about occupational safety. Work clothing and personal protective equipment was almost not provided.

4.3 Environmental aspect

The total GHG per m^3_{bw} of FWSC 2 was 2.7 times higher than FWSC 1. In FWSC 2 pre-harvesting, extracting and sawing at mill took most of GHG with 57% of total GHG while felling and crosscutting took only 2% of total. Conversely, felling, crosscutting and sawing at stump area in FWSC 1 took most of GHG with 85% of total, and 46% higher than that of felling, crosscutting and sawing at mill of FWSC 2.

The HW and NHW per m^3_{bw} from FWSC 1 are 2.5 times and 14% higher than FWSC 2, respectively. That seems surprising because the mechanization level of FWSC 2 was lower than FWSC 1. The reason is that most of HW (97%) and NHW of FWSC 1 were emitted from chainsaw and buffaloes while the productivity of those was much lower than chainsaw and tractor of FWSC 2.

The total disturbed area of FWSC 1 took 10.4% total of harvested area while that of FWSC 2 took 12.7%. The heavy disturbed area caused by FWSC 2 is 80% higher than by FWSC1. The reason is that most of heavy disturbed area was skid trail and landing, the FWSC 2 used TDT 55 for skidding and needed more area for skid trail and landing than skidding by buffaloes.

5 Conclusion and suggestion

In Song Kon, the use of tractor TDT 55 for extracting large logs on terrain with slope ≤ 47% had more positive impacts in term of economy and society as well as generated less waste than using buffaloes in extracting small board wood on terrain with slope > 47% in Van Ban. However, FWSC 2 emitted more GHG and caused more negative impact to soil (both erosion and compact aspect). As a developing country, economic and social aspects are considered more important in Vietnam. Thus, FWSC 2 in Song Kon is assessed more sustainable than FWSC 1.

There are some following suggestions given to gain more sustainability in logging natural forest in Vietnam:

Trees harvested in natural forest usually have large DBH, chainsaws are still most suitable tools for felling. But extracting logs to landings should be mechanized with more appropriate machines and equipments for each particular condition, especially on high slope terrains. This would also minimize the need to cut boards with the chainsaws in the forest which causes low productivity and increases the proportion waste wood in the forest. This issue still needs to be studied.

The unutilized parts of harvested trees (Table 5) containing tops, branches, and stumps left in natural forests should be used as an energy source, and some could be used for the production of panels. However, the utilization of this waste wood also needs to be studied to assess sustainability impacts as well as nutrient issue for soil.

Training courses about occupational safety as well as the obligatory use of labor safety equipments for employers should be enforced to make sure that the number of occupational accidents is limited to a minimum.

Skid trails and landings should be carefully pre-planned to reduce disturbed areas as low as possible. Before and after harvesting, disturbed areas must be planted and covered by small wood waste to prevent soil erosion.

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