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Fulvio Di Fulvio , Dalia Abbas, Raffaele Spinelli, Mauricio Acuna, Pierre Ackerman & Ola Lindroos

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Benchmarking technical and cost factors in forest felling and processing operations in different global regions during the period 2013–2014

Fulvio Di Fulvio [a,b], Dalia Abbas[c], Raffaele Spinelli[d], Mauricio Acuna[e], Pierre Ackerman[f] and Ola Lindroos [b]

[a]Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; [b]Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Umeå, Sweden; [c]Warnell School of Forestry and Natural Resources, Savannah River Ecology Lab, University of Georgia, Athens, GA, USA; [d]Trees and Timber Institute CNR-IVALSA, Sesto Fiorentino, Italy; [e]Australian Forest Operations Research Alliance (AFORA), University of the Sunshine Coast, Sippy Downs, QLD, Australia; [f]Department of Forest and Wood Science, Stellenbosch University, Stellenbosch, South Africa

ABSTRACT

In a global bioeconomy, benchmarking costs is essential in the evaluation of current forest harvesting systems and addressing decisions on the most efficient supply chains for available forest resources. Benchmarking cost rates in forestry is challenging, due to a lack of harmonized terminology and difficulties in collecting information on comparable forest technologies. This study provides a first-time series of cost factors to be used when modeling and evaluating the cost competitiveness of forest felling and processing operations on a global scale. It is based on an expert survey using a standardized method of data collection. This benchmarking identifies and updates the knowledge of technical and socio-economic factors capable of influencing the cost rates of forest felling and processing operations across different regions. This study is expected to act as a reference for larger investigations, and for regular updates, with the aim to provide current data that can be used by forest practitioners and decision makers for improving their cost efficiency and for designing future supply systems more effectively.

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International benchmarking; cost rating; forest harvesting; cost database; competitiveness

Introduction

The global competition for wood supply is increasingly intense, and it is expected to further intensify in the future, due to the need of meeting the growing demand for wood fiber (Fricko et al. 2016). The different labor, harvesting and transportation systems' costs, coupled with the fluctuation of exchange rates, have led to different levels of supply costs in different countries over time (Siry et al. 2006). Hence both technical and socio-economic factors need to be considered when evaluating the cost competitiveness of forest supply chains from different regions of the world (Nordfjell et al. 2004).

Estimating production costs in forestry has always been one of the core areas of forest engineering (Mathews 1942; Stridsberg & Algvere 1967; Miyata & Steinhilb 1981; Nurminen et al. 2009). Wood supply costs can be assessed by detailed calculations of the time-unit costs for machinery, labor, fuel and other consumables (e.g. Miyata 1980; Butler & Dykstra 1981; Tufts & Mills 1982; Brinker et al. 2002; Bilek 2009; Ackerman et al. 2014) and of their respective production rates. Forest harvesting is mostly conducted in rough and unstructured environmental conditions, which strongly affects work performance and the impacts from operations should be minimized. At the same time, the resources (i.e. trees) are highly variable, in both size and shape. Thus, the prediction of production rates is challenging and has resulted in a substantial body of research, where different production systems have been investigated (e.g. Olsen & Kellog 1983; McNeel & Dodd 1997; Eliasson et al. 1999; Purfürst & Lindroos 2011; Eriksson & Lindroos 2014; Tolan & Visser 2015; Lindroos & Cavalli 2016).

The rationale of this study is based on the understanding that although production rates are very susceptible to work conditions, they are not strongly influenced by country borders. Thus, under similar conditions regarding, for instance, tree and terrain features, labor skills, and harvesting technology, the production rates will be more or less similar across countries. Therefore, models to predict production rates under various work conditions are rather straightforward to be used in international comparisons.

In contrast, international benchmarking of costs are less straightforward because of the strong influence of national economies. For instance, time-unit costs derived in one country cannot directly be applied to another country with different costs of living, and would need to be corrected for possible differences capital, labor and fuel costs, and taxation levels, as well as exchange rates. Thus, even if the production system and the production rates are similar, the production cost may differ between countries.

Benchmarking is a means of discovering the best achievable performance, in this case in the forest industry sector. Benchmarking approaches are also useful tools for acquiring

CONTACT Fulvio Di Fulvio difulvi@iiasa.ac.at Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

Supplemental data for this article can be accessed here information on factors leading to cost differences between countries, and for addressing decisions on the most convenient supply from available forest resources. Hence, benchmarking can be used to implement best practices and to identify industry leadership performance targets. A series of benchmarking studies on factors influencing the contract rates for forest operations in different regions have been recently completed through long-term monitoring (Holzleitner et al. 2011). Also interviews with forest contractors (Baker et al. 2013; Abbas et al. 2014; Dodson et al. 2015; Spinelli et al. 2015) and analyses of web databases (Spinelli et al. 2011; Malinen et al. 2016) have been conducted. These studies point out that benchmarking of cost rates is extremely challenging, due to the difficulties in harmonizing the technical terminology and collecting information on comparable technologies.

The objective of this benchmarking study is to explore the variable technical and socio-economic factors capable of influencing the cost rates of forest harvesting operations across different regions of the world. The study is based on an expert survey using standard data collection methods. The study aims to integrate and update the existing information to build an expert's validated reference database. The database provides a first time series of cost factors to help model and evaluate the cost competitiveness of forest felling and processing operations on a global scale. Results from the study could aid in the development of market studies targeting wood supply and demand factors globally.

Materials and methods

Data collection and harmonization

An expert-based data collection process was initiated in September 2014. Experts in timber harvesting operations through the authors' professional networks, and experts' recommendations, from different regions of the world were contacted by e-mail, face-to-face meetings, and telephone calls. These experts were asked to provide an itemized and detailed description of hourly costs for the most representative technologies used for felling trees in their region and/or country. Experts were asked to select the most common felling operations in their region/country from the following three options:

(A) Medium-sized wheeled harvester: cut-to-length (CTL) harvester equipped with single grip harvesting head, 6–8 wheels, weight 15–20 tonnes, engine power 140–180 kW (e.g. Komatsu 911, John Deere 1170).
(B) Medium-sized tracked harvester or feller-buncher: CTL or full tree-tracked harvester equipped with single grip harvesting head or with a feller-buncher head, weight 25–35 tonnes, engine power 200–250 kW (e.g. Tigercat 830, 845, CAT 522, 541).
(C) Motor-manual felling with chainsaw: a specialized operator with heavy chainsaw, chainsaw weight 6–8 kg and engine power 4–5 kW (e.g. Stihl 461, Husqvarna 395).

The order of priority for providing information was A to C, meaning that if they could not provide a good estimate of costs for A, they could provide estimations for B, or C, in that order. If other forest felling and processing technologies were also relevant in their region, they should provide a short description and their cost rate estimation.

The aim of establishing the categories mentioned above was to create groups of equipment which are as comparable as possible, in terms of size, brand, and manufacturers.

The experts were asked to provide estimations of the most current cost rates, preferably from the years 2013 and 2014. The estimated costs reflect average operating conditions of their country or region and all costs provided in Local Currency Units (LCU).

The experts completed a standard MS Excel-based spreadsheet for accounting costs of forest harvesting operations (Ackerman et al. 2014). A guide on the approaches for assessing single cost components was provided, according to the recommendation given by Ackerman et al. (2014). The experts' input the cost parameters using the fields (c.f. Table 1) to the costing model and checked the output obtained from the cost model (as costs per hour, cost per month and cost per year). However, experts could not modify the model equations or calculations.

Experts' contacts provided all relevant inputs needed for calculation of machine cost rates per Productive Machine Hour (PMH).[1] VAT (Value Added Taxes) were excluded from cost accounting, as well as the profit margins for forest companies. Complementary information was also collected,

Table 1. Parameters collected with the standardized cost accounting template.

Input	Unit
Machine type	Description
Country specific currency (Local currency unit)	LCU
Machine fixed cost inputs	
Purchase price or replacement cost	LCU
Salvage value	LCU or % (Purchase Price)
Expected economic life (EEL)	PMH
Interest rate	%
Machine tax/registration	LCU/Year
Machine insurance	LCU/Year
Machine transfers	LCU/Year
Garaging for machine	LCU/Year
Machine variable cost inputs	
Fuel cost per liter	LCU/liter
Fuel consumption	liter/PMH
Oil and lubricant cost	% (Fuel Cost/PMH)
Maintenance and repair cost	LCU/Year or % (Purchase Price)
Running gears	LCU/PMH
Consumables	LCU/PMH
Operator costs	
Number of operators/shift	No.
Average net wage	LCU/SMH
Subsistence allowance	LCU/SMH
Other operator costs	LCU/SMH
Social charges	LCU/SMH or % net wage
Personal protective equipment	LCU/SMH
Training	LCU/SMH
Phone charges	LCU/SMH
Insurance	LCU/SMH
Operator transportation	LCU/SMH
General input	
Number of working days per year	No.
Number of shifts per day	No.
Scheduled hours per shift	No.
Machine utilization rate	% (PMH/SMH)
Other	
Machine overhead + operator/s	LCU/Year or % (fixed and variable cost/PMH)

such as short descriptions of the most representative operational environment types in the region/country, and notes on the approaches used for estimating single parameters if required.

A total of 32 responses (each representing one observation) were completed by the technical expert and returned by January 2016. The database was based on input records from 19 experts, or groups of experts, each representing one region/country (Table 2). The response rate was 46% based on initially contacting 41 experts.

The data for the US states of Minnesota and Michigan were collected in 2007 and 2009, respectively but updated to 2013 for comparability. The "production price index for construction machinery" was used as a multiplier for updating the purchase price of machinery from 2007/09 to 2013 (Bureau of Labor Statistics; BLS 2016). Wages for tree fallers and logging equipment operators were updated to that of the United States according to their growth reported in BLS (2016), whereas the fuel prices were updated according to GIZ (2013).

Based on the descriptions of machinery provided by the experts, the equipment was categorized according to: wheeled harvesters (WH), tracked harvesters (TH), tracked feller-bunchers (TFB), wheeled feller bunchers (WFB), tracked excavators (TE), and chainsaws (CH).

Based on the experts and manufacturers' specifications, an operating machine weight was assigned to each of the machines. The harvesters (WH, TH, TFB, WFB, TE) were also divided into two groups: wheeled (W) and tracked (T) according to their mobility.

Conversion of monetary values

All costs collected as LCU were converted into US dollars ($) by applying an Official Exchange Rate (OER) for traded goods (i.e. purchase price of machinery, price of fuels) (Eq. 1) and the Purchasing Power Parity exchange rate (PPP) for un-traded ones (i.e. labor cost) (Eq. 2).

The OER were sourced from the The World Bank (2014a) and the International Monetary Fund (IMF; 2014). OER is affected by short-time fluctuations, for this reason a 5-year (2009–2013) average exchange rate was used to account for the long-term trends (Supplemental data).

The PPP exchange rate expresses the number of units of a country's currency required to buy the same amount of goods and services in the domestic market as one US dollar would buy in the USA. The PPP conversion factor was obtained from the World Bank International Comparison Program database (The World Bank 2014b http://data.worldbank.org) and the average of 5 available years (2009–2013) was used (Supplemental data). A PPP conversion factor was available for 199 countries (Supplemental data).

The conversions to US dollars ($) were according to (Eq. 1) and (Eq. 2):

$$\mathrm{Cost}(\$) = \frac{C(LCU)}{OER} \tag{1}$$

$$\mathrm{Cost}(\$) = \frac{C(LCU)}{PPP} \tag{2}$$

Where:

C (LCU) = cost in local currency in the Reference Country; OER = official exchange rate in the Country; PPP = Purchase Power Parity conversion factor in the Country.

Benchmarking to official economic indicators

Labor costs observed (i.e. net wages and social charges reported by the experts) were benchmarked against official economic indicators. The correlation with "minimum statutory wages" and "PPP ratios" was tested for the net wages.

Minimum statutory wages are the statutory nominal gross monthly minimum wage (LCU) collected from theInternational Labour Organization (ILO) (2013) and converted to international dollars ($) by using the PPP conversion factor (Supplemental data).

The PPP level ratio (PPP ratio), also referred to as the national price level (price level ratio of PPP conversion factor to market exchange rate), makes it possible to compare the cost of the bundle of goods that make up the gross domestic product (GDP) across countries. It indicates how many dollars are needed to buy a dollar's worth of goods in the country as compared to the United States. The price level ratio of PPP was obtained from the World Bank International Comparison Program database (The World Bank 2014c, http://data.worldbank.org), the average of the last 5 available years (2009–2013) was available for 182 countries (Supplemental data).

Social charges in this study are intended as the social security contributions paid to general government that confer entitlement to receive social benefits. They include: unemployment insurance benefits and supplements, accident, injury and sickness benefits, disability and pensions, family allowances, reimbursements for medical and hospital expenses or provision of hospital or medical services.

The correlation with "official social charges" from a statistical database of global labor policies (The World Bank Group 2014, http://www.doingbusiness.org) was tested for observed social charges (Supplemental data).

Statistical analyses

Statistical indicators were used for analyzing the variability in the dataset, identifying significant differences between group mean values and correlations between variables. Specifically, Pearson's correlation tests, t-tests and General Linear Models were used in the analyses of significant differences and correlations. The significance was tested at three different levels ($p < 0.10$, $p < 0.05$, $p < 0.01$). Due to the relatively small sample size, the 10% residual error was also included as an option for investigating possible differences which did not appear at the 5%.

Comparisons of standardized cost rates

Based on the results of statistical analyses, the hourly cost rates (sum of fixed, operational and labor costs, but excluding overhead) for each of the observations were re-calculated after the standardization of the major technical parameters

Table 2. Summary of collected information: Country/Region, Item description, Machine category, Mobility group, Operational environment, Power, Machine weight, Reference Expert Group and data sources.

Obs. no.	Country/ region	Machine description reported	Machine category[a]	Mobility[b]	Operational environment	Engine power (kW)	Machine weight (kg)	Reference: Name(s) and organization	Source[c]
1	Australia (AUS)	Tracked harvester medium	TH	T	Eucalyptus plantation	220	27,000	Mauricio Acuna, Mohammad Ghaffariyan, AFORA	Own cost model
2	Brazil (BRA)	Tracked harvester, weight 22.7 tonnes, engine 119 kW	TH	T	Eucalyptus plantation	119	22,700	Saulo Guerra, Guilherme Oguri, UNESP	Forest contractors
3	Brazil (BRA)	Feller-buncher tracked weight 30 tonnes, engine 205–219 kW	TFB	T	Eucalyptus plantation	212	30,000	Saulo Guerra, Guilherme Oguri, UNESP	Forest contractors
4	Canada (CAN)	Medium wheeled harvester Komatsu model 931.1	WH	W	Boreal forest	185	19,000	Luc LeBel, Shuva Hari Gautam, Pierre-Serge Tremblay, University of Laval	-
5	France (FRA)	Wheel Harvester Medium JD 1270 D	WH	W	Temperate forest	160	17,500	Paul Magaud, Philippe Ruch, FCBA	-
6	Germany (DEU)	Wheel Harvester Medium-large JD 1270–1470	WH	W	Temperate forest	170	18,600	Jörg Hittenbeck, University of Göttingen	Own teaching cost model
7	Italy (ITA)	Thinning Harvester 4 wheels, weight 15 tonnes, engine 100 kW	WH	W	Thinning pine forest	100	15,000	Raffaele Spinelli, Natascia Magagnotti, CNR-IVALSA	Forest contractors and field studies
8	Japan (JPN)	Chainsaw operation medium size Husqvarna 550 XP	CH	-	Thinning forest	2.8	4.9	Kazuhiro Aruga, Utsunomiya University	-
9	Latvia (LVA)	Medium harvester JD 1070	WH	W	Early thinning forest	136	14,100	Andis Lazdiņš, SILAVA	Forest contractors
10	Norway (NOR)	Medium wheeled harvester	WH	W	Forest	160	17,500	Bruce Talbot, Skogoglandskap Institute	-
11	Portugal (PRT)	Medium wheeled harvester JD 1270D	WH	W	Pine forest and eucalyptus plantation	160	17,500	Helder Viana, Polytechnic Institute of Viseu	Forest contractors and machine dealers
12	Slovenia (SVN)	Chainsaw medium	CH	-	Forest	4.9	7.0	Nike Krajnc, SFI	Own cost model
13	South Africa (ZAF)	Tracked harvester Timberpro TL725B	TH	T	Eucalyptus plantation	225	25,000	Pierre Ackerman, Simon Ackerman Stellenbosch University	Forest contractors
14	South Africa (ZAF)	Tracked excavator with Hitachi Zaxis 200Lc with harvester head	TE	T	Eucalyptus pulpwood plantation	118	21,300	Pierre Ackerman, Simon Ackerman Stellenbosch University	Forest contractors
15	South Africa (ZAF)	Tracked excavator Volvo EC210bf with harvester head	TE	T	Eucalyptus pulpwood plantation	115	23,000	Pierre Ackerman, Simon Ackerman Stellenbosch University	Forest contractors
16	Spain (ESP)	Medium wheeled harvester 160 kW, 18 tonnes	WH	W	Forest	160	18,000	Sandra Sanchez, Elena Canga, CETEMAS	Forest contractors and field studies
17	Sweden North (SWE_NO)	Harvester JD 1170	WH	W	Forest	145	16,700	Ola Lindroos, SLU	Forest contractor
18	Sweden (SWE)	Harvester medium sized	WH	W	Forest	160	17,500	Lars Eliasson, Skogforsk	Forest contractors
19	US Maine (USA_ME)	Tracked harvester medium-large	TH	T	Forest	220	27,000	Steve Bick, Northeast Forests, LLC	Forest contractors
20	US Maine (USA_ME)	Tracked feller-buncher	TFB	T	Forest	212	30,000	Steve Bick, Northeast Forests, LLC	Forest contractors
21	US Michigan (USA_MI)	Feller-buncher tracked 179 kW	TFB	T	Partial cut forest	179	24,700	Dalia Abbas, Michigan State University	Forest contractors and cost models
22	US Michigan (USA_MI)	Harvester medium 149 kW	WH	W	Partial cut forest	149	16,700	Dalia Abbas, Michigan State University	Forest contractors and cost models
23	US Minnesota (USA_MN)	Feller-buncher tracked Timbco 425 160 kW	TFB	T	Partial cut forest	127	22,600	Dalia Abbas, University of Minnesota	Forest contractors and cost models
24	US Minnesota (USA_MN)	Feller-buncher tracked Fabtek 153 123 kW	TFB	T	Partial cut forest	123	20,400	Dalia Abbas, University of Minnesota	Forest contractors and cost models

(*Continued*)

Table 2. (Continued).

Obs. no.	Country/ region	Machine description reported	Machine category[a]	Mobility[b]	Operational environment	Engine power (kW)	Machine weight (kg)	Reference: Name(s) and organization	Source[c]
25	US Minnesota (USA_MN)	Medium chainsaw	CH	-	Partial cut forest	4.0	6.0	Dalia Abbas, University of Minnesota	Forest contractors and cost models
26	US Minnesota (USA_MN)	Wheeled Feller Buncher Valmet 97 kW	WFB	W	Partial cut forest	97	8657	Dalia Abbas, University of Minnesota	Forest contractors and cost models
27	US North-West (USA_NW)	Feller-buncher, medium-large tracked, 30 tonnes, 220 kW	TFB	T	Partial cut forest	220	30,000	Beth Dodson, University of Montana	Forest machine dealers
28	US North-West (USA_NW)	Medium chainsaw STIHL MS461 4.4 kW 7 kg	CH	-	Partial cut forest	4.4	7.0	Beth Dodson, University of Montana	Forest machine dealers
29	US Tennessee (USA_TN)	Wheeled Feller Buncher JD 643 K 130 kW	WFB	W	Partial cut forest	130	15,700	Dalia Abbas, Tennessee State University	Forest contractors and cost models
30	US Tennessee (USA_TN)	Wheeled Feller Buncher CAT 563 C 152 kW	WFB	W	Partial cut forest	152	14,900	Dalia Abbas, Tennessee State University	Forest contractors and cost models
31	US Tennessee (USA_TN)	Medium chainsaw	CH	-	Partial cut forest	4.0	6.0	Dalia Abbas, Tennessee State University	Forest contractors and cost models
32	US West Virginia (USA_WV)	Harvester medium sized JD 1170 E	WH	W	Hardwood forests	145	16,700	Jingxin Wang, West Virginia University	Literature studies and sectorial surveys

[a]Machine category: TH, tracked harvester; WH, wheeled harvester; TFB, tracked feller-buncher; WFB, wheeled feller-buncher; TE, tracked harvester; CH, chainsaw. [b]Mobility: T, tracked, W, wheeled. [c]Source of collected information, if declared.

(salvage value, economic life and utilization). This enabled the removal of possible effects due to the specific condition of use (e.g. size of the forest company) and isolate the main country borders' effects.

Results

The benchmarking exercise consisted of 32 observations in total: 12 WH, 6 TFB, 4 TH, 3 WFB, 2 TE and 5 CH operations (see details in the Supplemental data).

Fixed costs

In the case of harvesters (WH, TH, TFB, WFB, TE) there were large variations in the reported purchase price, which ranged from 200,000 to 700,000 $ (Figure 1). The same was true for chainsaws, with a purchase price varying from 800 to 2,223 $.

A positive correlation (r = 0.36, p = 0.06) was observed between the weight of harvesters and their purchase price (Figure 1). Once weight was introduced in the comparison as a covariate, the price of highly sophisticated CTL machines (WH, TH) was significantly higher (p < 0.001) than the price of less sophisticated full-tree harvesting machines (TFB, TE, WFB), often based on multipurpose base machines. Machine weight and category (CTL vs. WT machine type) together explained 72% of the variability in the purchase prices of harvesters. The weight of the machines was also significantly correlated with their engine power rating (kW) (r = 0.49, p < 0.001).

The reported average salvage value was significantly lower for tracked harvesters (TH, TE, TFB = 12.2% of purchase value, SD = 5.1% units) than for wheeled harvesters (WH, WFB = 20.3%, SD = 7.8) (p = 0.001). The average salvage value for chainsaws was 9% (SD = 9%). The service life (years) and annual utilization (PMH/year) of harvesters did not show any significant correlation with salvage value.

The EEL was 13,561 PMH (SD = 5177) for harvesters (WH, TH, TFB, TE, WFB) and 1976 PMH (SD = 881) for chainsaws (CH). EEL was significantly (p = 0.03) shorter for wheeled feller bunchers (8667 PMH) compared with other harvesters (14,173 PMH). When reported in years, the EEL of harvesters averaged 6.8 years (SD = 3.1), with a tendency (p = 0.1) to a shorter life for tracked excavators. However, only two machines were observed in this category. The average EEL of chainsaws was 2.0 years (SD = 0.9).

In the case of harvesters, there was a large variation in reported annual productive work time (min = 960, max = 5376 PMH/year), which averaged 2332 PMH/year (SD = 1339), with a median of 1980 PMH/year. The annual productive worktime was higher when the machines were deployed in industrial plantations with short rotation cycles, where it reached 3634 PMH/year. This figure was significantly (p = 0.001) higher than for machines deployed on natural forests (1876 PMH/year). The annual productive worktime of chainsaws averaged 1058 PMH/year (SD = 298) and it was significantly (p < 0.001) lower than the values recorded for harvesters.

Average utilization rates were 72.5% (SD = 13.2), 73.5% (SD = 9.2), 73.8% (SD = 4.8), 78.5% (SD = 7.7) and 81.7% (SD = 11.5) for TFB, TE, TH, WH, WFB, respectively. There were no significant differences between machines types, although the data suggested that wheeled (WH, WFB) machines had a higher utilization rate than tracked machines (TH, TFB, TE) (p = 0.10). The average utilization rate for chainsaws was 73.6% (SD = 10.1) and did not significantly differ from the other categories (Figure 2).

Insurance cost was generally provided for harvesters (96% of observations), but not for chainsaws. The average yearly cost was 0.85% of the purchase price (SD = 0.30, min = 0.4% in Australia, max = 1.6% in South Africa).

Average interest rate figures as supplied by the experts ranged between 3% (France, Portugal) and 12% (South Africa). It is noticeable that a large variation (3% interest rate difference) was observed within the same country (e.g. Sweden), even when evaluating the same machine size and length of investment.

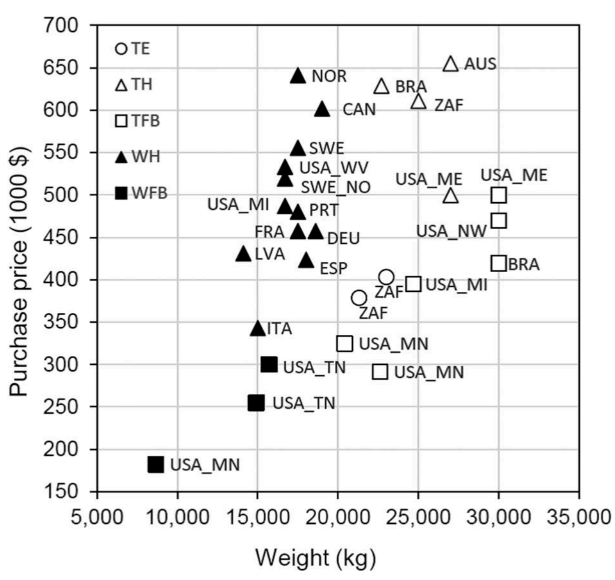

Figure 1. Purchase price by harvester category as a function of their weights.

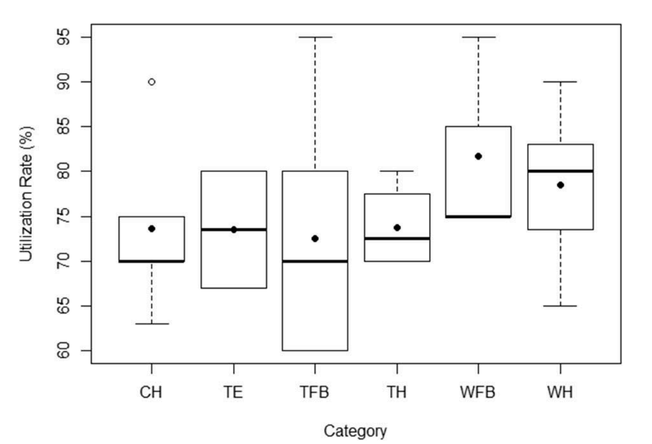

Figure 2. Box-and-whisker plots of utilization rates (%) by machine category. The black dots denote the mean, whereas the horizontal lines denote the median. The box edges are the first and third quartiles and the whiskers are extended to ± 1.5×Interquartile Range from the box edges, white circles are observations exceeding the whiskers.

Taxes and registration fees were observed for harvesters only in five cases (19% of observations). The amount paid per year was highly variable (min = 50$ for a WH in Latvia, max = 1241 $ for a TFB in US Minnesota), with a median of 216$/year.

Other fixed costs were collected for 52% of observations (transfer/relocation costs = 14 cases, garaging = 3 cases), and these figure showed a very large variability (min = 3200 $/year in US Michigan and max = 50,514 $/year in Sweden). The median of these costs was 5057 $/year. However, the sample was too limited to explore the encountered variability further.

Variable costs

Average reported fuel consumption for the different categories of harvesters was 15.9, 22.5, 23.9, 24.9 and 25.0 l/PMH, respectively, for WH, TE, TFB, TH, and WFB. Fuel consumption was positively and significantly correlated with engine power (p = 0.01), which explained 45% of the variability in the observations (Figure 3). When the engine power (kW) was included as a covariate, the hourly fuel consumption of wheeled harvesters (WH) was significantly lower than for all other categories (p < 0. 05). Fuel consumption for chainsaws averaged out at 0.9 l/PMH (SD = 0.23).

Average hourly (PMH) fuel consumption per unit of power was 0.10 l/kWh for wheeled harvesters, 0.15 l/kWh for other harvester types, and 0.23 l/kWh for chainsaws.

Fuel prices varied with the country, and ranged between a minimum of 0.67 $/l (US Maine) and a maximum of 1.71 $/l (South Africa).

Estimated as a percent of fuel cost, average lubricant costs reached the average values of 19.3% (SD = 10.8) and 24.0% (SD = 14.7) for harvesters and chainsaws, respectively. The mean value reported for harvesters did not vary with the power of the machine.

In 72% of the cases (n = 23), the experts assessed maintenance cost as a percent of purchase price, whereas for the remainder they provided an explicit monetary cost. Additional costs for running gears and consumables were specified in 40% of the cases (n = 13). Thus, to make all observations comparable, the maintenance and repair costs (including also the costs of running gears and consumables) was recalculated as a percentage of the purchase price (Supplemental data), defined as Repair and Maintenance Rate (RMR). The estimated RMR of harvesters averaged 73% (SD = 34) and showed a large general variation (min = 13% for a WH in Latvia and max = 182% for a WH in Norway). However, harvester RMR did not differ significantly across machine categories and it was not dependent on machine weight, EEL, annual productive worktime and working environment (industrial plantation/natural forest). The average RMR of chainsaw was 95%, with a median of 100% (SD = 9%). The variation in maintenance costs was large, even if considering the same machine category in the same country and working environment (e.g. TEs in South Africa working in plantations).

Labor costs

Net operator wages were collected for 30 observations (missing for obs. 19 and 20, where only the total labor cost was provided). Net wages did not appear to be different between harvester and chainsaw operators (p = 0.631).

The reported wage data were positively correlated with the minimum statutory wages in the country (r = 0.329, p = 0.002), though the minimum statutory wage as reported by ILO was available for 26 observations only. The net wage figures reported by the expert were between 1.3 and 5.8 times greater than the minimum wages, depending on the Country (Figure 4).

The reported wage was positively correlated also with the PPP ratio (r = 0.384, p < 0.001), if used as a proxy for the cost of life in the different countries. The ratio was available for all observations (Figure 5).

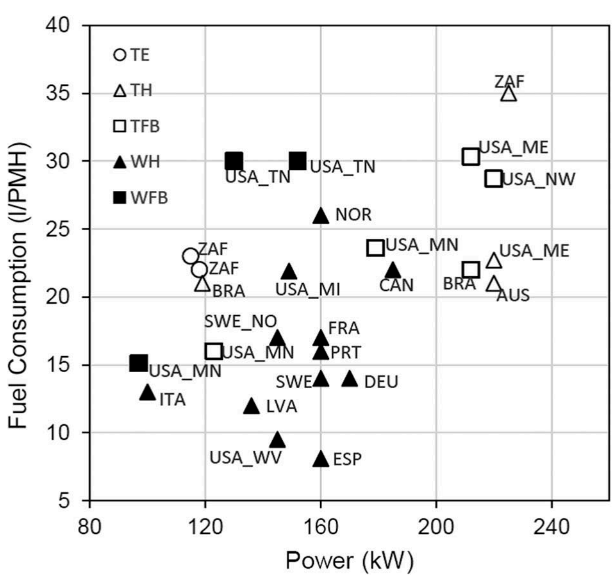

Figure 3. Fuel consumption by harvester category as a function of engine power.

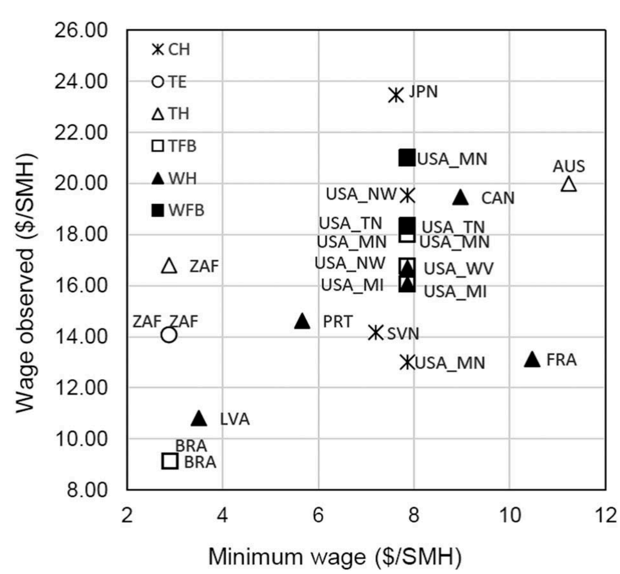

Figure 4. Reported hourly operator wages as a function of minimum statutory wages (ILO).

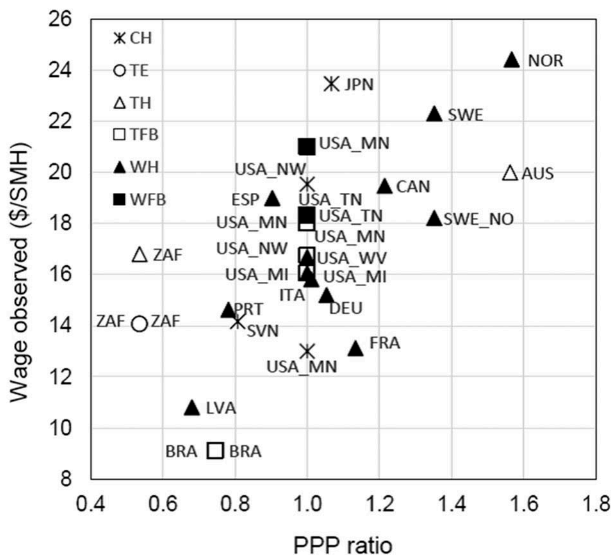

Figure 5. Reported hourly operator wages as a function of PPP ratios.

Social charges were collected for 27 observations (84% of cases). The average percentage of social charges was 37% of the net wages (SD = 25%) with a median value of 24%. The minimum value was observed in South Africa (8%) and the maximum in Brazil (104%). Official social charges explained 72% of the variability in the original observations of reported ones ($p < 0.001$). On average, reported social charges were 1.6 times greater than the official ones indicated in the country labor policies' statistics.

Other operator costs were collected in 53% of the cases (17 observations), and varied between 0.02 $/SMH in South Africa and 20.7 $/SMH in Portugal, with an average of 4.7 $/SMH (SD = 5.3 $/SMH) and a median 3.4 $/SMH. Subsistence allowances were reported in nine cases (28%), protective personal equipment (PPE) contribution in nine cases (28%), transportation of operators to workplace in nine cases (28%), insurances in nine cases (28%), training cost in eight cases (25%) and phone charges in six cases (19%). The largest cost components covered in other operator costs were subsistence allowances and operator transportation.

Overhead

Overhead was reported in 16 cases (50% of observation) and showed a broad variation (min = 2% and max = 55% of fixed and operational costs). The median value of fixed and operational costs was 8%, with an average of 18%.

Comparisons of standardized cost rates

In the standardization, the average salvage value (S, as a percentage of purchase price), was assumed as the average for each machine category, and separated on the basis of the significant differences found:

$$S_{CH} = 9.0\%\ \text{Purchase},$$
$$S_{WH,WFB} = 20.3\%\ \text{Purchase}, S_{TH,TFB,TE} = 12.2\%\ \text{Purchase}$$

The average economic life (N, years) was based on the differences found between annual productive work time (PMH/year) for different machine categories and in the different working environment, as follows:

$$N_{CH} = 1.849, N_{WHF} = 7.454,$$
$$N_{THF} = 7.929, N_{TFBF} = 8.071,$$
$$N_{WFBF} = 4.379, (F = \text{Natural Forest})$$

$$N_{WHP} = 3.696, N_{THP} = 3.931,$$
$$N_{TFBP} = 4.001, N_{TEP} = 3.947, (P = \text{Industrial Plantation})$$

The average EEL (PMH) was based on the differences found for each machine category:

$$EEL_{CH} = 1,976,$$

$$EEL_{WH,TH,TFB,TE} = 14,173,$$

$$EEL_{WFB} = 8,667.$$

The average utilization rates were based on the difference between machine type groups described earlier on:

$$\text{Utilization rate}\ (\%) = 73.6(\text{CH}),$$
$$74.8(\text{TH, TFB, TE}), 79.1(\text{WH, WFB}).$$

The calculated total cost rate for harvesters (i.e. after standardization of technical parameters) varied between 80.0 and 222.5 $/PMH, with an average of 125.9 $/PMH (SD = 29.6) (Figure 6).

The lowest total cost rates for harvesters were observed for: a WH used in Latvia for thinning (80.0 $/PMH), a WFB unit used in Minnesota (90.4 $/PMH), a WH used in Italy for thinning (91.4 $/PMH) and a TFB used in Minnesota (92.5 $/PMH) (Figure 6).

The highest total cost rates for harvesters were calculated for wheeled harvesters used in Norway (222.5 $/PMH), Sweden (164.5 $/SMH) and Canada (162.0 $/PMH), and a tracked harvester used in Australia (160.7 $/PMH) (Figure 6).

The lowest and highest fixed cost rates for harvesters were calculated for a WFB in Minnesota (21.8 $/PMH) and a WH in Sweden (72.9 $/PMH), respectively. The lowest variable cost rate was observed for a WH in Latvia (19.5), and the highest for a WH in Norway (126.8) (Figure 6).

The total cost for chainsaw operations, after standardization, varied between 23.4 and 52.5 $/PMH, respectively, in Minnesota and Japan. The averaged standardized cost rates for a chainsaw operation was 37.6 $/PMH (SD = 11.40) (Figure 6).

The lowest labor cost (i.e. when considering both harvesters and chainsaw operations) was observed for TE in South Africa (18.8 $/PMH), whereas the highest was observed for a TH in Maine (53.5 $/PMH) (Figure 6).

The fixed, variable and labor costs of harvesters accounted for 24–50%, 23–57% and 16–43% of total hourly cost rate respectively. In the case of chainsaws, the ranges were 1–3%, 4–9% and 88–95% (Figure 7).

The main share of fixed costs for harvesters corresponded to depreciation (43–88%) and interest (9–31%). Depreciation took the main share (91–93%) of the fixed costs incurred by chainsaws, while interest represented a minor component (7–9%).

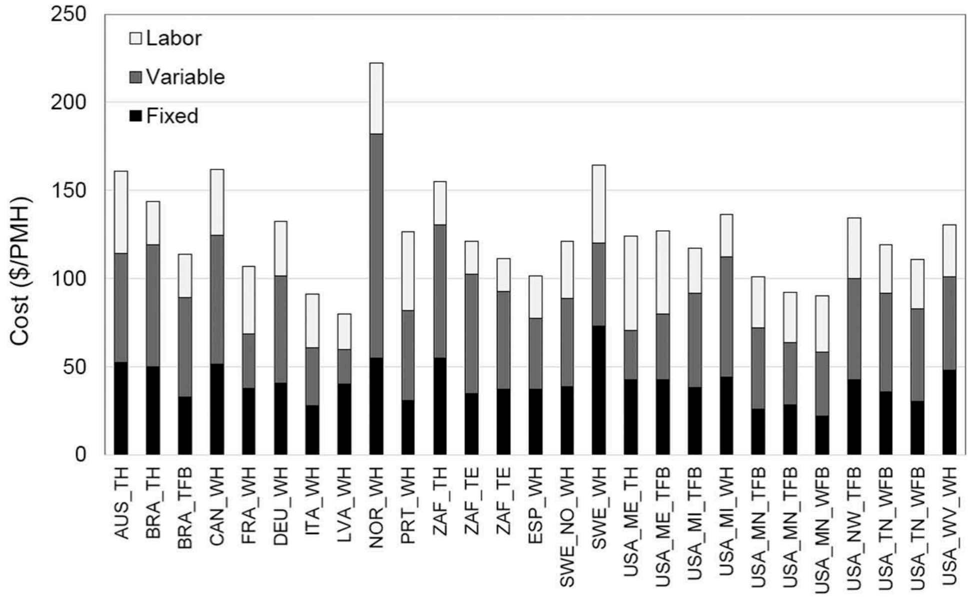

Figure 6. Distribution of total cost rates (sum of fixed, variable and labor costs), after standardization of salvage value, economic life and utilization rates by harvester category.

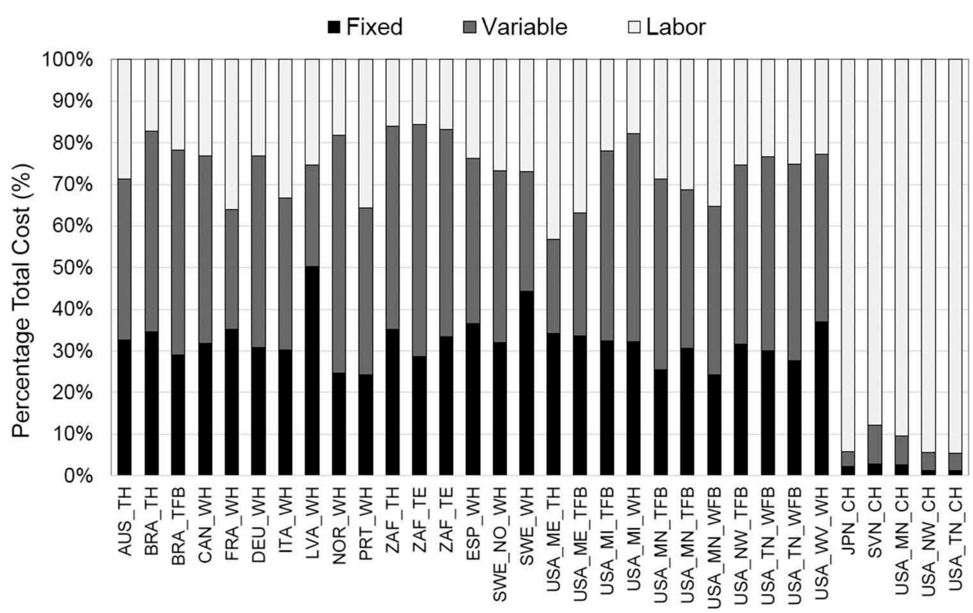

Figure 7. Percentage distribution of total cost rates (sum of fixed, variable and labor costs), after standardization of salvage value, economic life and utilization rates by harvester category (left) and chainsaws (right).

Maintenance (20–79%) and fuel (18–79%) accounted for the largest share of operational costs for harvesters. In the case of chainsaws, fuel (40–65%) was dominant over maintenance (25–52%).

Net wages represented the major share (41–100%) of labor costs. However social charges (7–51%) and other costs (0–46%) could represent a significant share of labor cost.

Discussion

Experts from 15 countries, 12 of which were OECD-based, were involved in this benchmarking exercise, with representatives from all five continents. The study constitutes the first cost benchmarking exercise on a global scale in the forest operations' domain. Similar benchmarking studies have been undertaken in the past but they were essentially limited to single regions in the US or Europe (e.g. Baker et al. 2013; Spinelli et al. 2015). The use of a standardized collection methodology and the involvement of academic researches from different regions globally, has potentially improved the reliability of results obtained in this study. Thus, this example is expected to act as a reference for larger investigations, and for regular updates. These results are considered preliminary and it is expected that the data set is regularly updated so that they can form the basis for improved forest operations' benchmarking practices.

Most of the observations were collected from Europe and the United States (23 observations). Other regions of the world were only represented though nine observations due to language and accessibility barriers.

An additional 22 experts or Institutions were contacted over the expert groups, but in most of the cases they declined to collaborate due to the lack of resources (i.e. time and money) or possible conflict of interests with the policies of their institution. This confirmed that the sharing of information regarding costs is a critical issue.

Tree felling and processing operations were selected for this first benchmarking exercise with the intention to identify a starting point along the supply chain. Tree felling and processing operations allows a better comparability than other harvesting operations (e.g. wood extraction), due to the relatively limited number of systems, which allows the isolation of the difference due to specific cost factors rather than the difference due to the systems' configurations. Contributors to this study were required to provide average costs in their region/country for a single piece of tree felling machinery. However, hourly costs are likely to differ between companies due to economies of scale: this factor was not considered in our analysis because a more standardized equipment-based costing method approach was used. Business size could have an impact on the way maintenance and repair or fuels are sourced from the market (Baker et al. 2013). At the same time, workman compensation (i.e. social charges) could be influenced by different regional regulations, depending on the size of the forest enterprise (Abbas and Clatterbuck 2015).

Even if a standardized data collection spreadsheet was used, there were still difficulties in the interpretation of how PMH and SMH were calculated between the different regions and countries. The machine and labor costs are also dependent on the contractual forms adopted in the individual countries, and therefore some approximations were needed.

Specific operational conditions could influence cost factors such as machine utilization and maintenance factors (Brinker et al. 2002; Dodson et al. 2015). In this study, we tried to gather additional information about work conditions (such as differentiating natural forests and industrial plantations). However, more observations and more detailed descriptions are needed for a deeper analysis of the effects of the environmental conditions on the machine operating costs.

The source used to assess the cost rates were different (forest contractors, machine dealers, cost models and literature), and in four observations the references were not disclosed (see Table 2). The experts could have applied estimations based on rule of thumb (i.e. salvage, economic lives, utilizations and maintenance rates), if they had not better data in their possession. The use of the rule of thumb instead of collected values could interfere in the comparability of costs. A guide for assessment of all cost factors was provided to the experts following Ackerman et al. (2014). However, the selection of the most appropriate factor or rule relied on the knowledge of operational and business conditions in the possession of each expert. Therefore, given the type of study (i.e. expert's interview), all observations were considered to have the same relevance in our analyses.

The database was populated with up-to-date technologies, the oldest being from 2007 and the most recent from 2014. Ideally, all cost information should be collected for the same year, which is difficult to achieve. Thus we used the period from the years 2009 to 2013 as a reference. All cost figures were updated to the same period. They were compared by using the average exchange rates during that period. Technological advances, for example in machine design, could have occurred between 2007 to 2014, which could have improved performances as well as costs and increased purchase prices (Nordfjell et al. 2010; Dodson et al. 2015). However, in an observation period shorter than 10 years these changes are expected to be relatively limited.

The study identified correlations between machine weight and purchase price, which is logical and expected. Similar correlations were identified when analyzing the resale values of harvesters in Europe (Malinen et al. 2016). Purchase price was also correlated with the level of specialization of machinery, indicating that CTL harvesting machines are more expensive capital investments than other machine types (e.g. feller-bunchers). However, there was a large unexplained variability in purchase price. This can be attributed to inherent differences in machine configuration, but also to different trade tariffs and demand for machinery in different countries.

Salvage value for tracked machines and chainsaws was close to the figures (10%) reported by Ackerman et al. (2014), whereas the higher figures observed for wheeled machines (20%) confirm the differences suggested by Brinker et al. (2002).

The expected economic life for wheeled harvesters was below the technical life expected for similar machines (i.e. 18,000 PMH, c.f. Spinelli et al. 2011), indicating that the observed machinery was sold when one third of their technical life was left.

Actual annual productive work time (PMH/year) of machines was lower in natural forests than in industrial plantations, where up to three shifts per day are often scheduled (i.e. in Brazil and South Africa). In other studies, it was noticed that the annual work time of wheeled harvesters increased when moving from Central Europe to the Nordic Countries (Holzleitner et al. 2011; Spinelli et al. 2011). Other local factors such as the weather conditions, type of business and contract arrangements could also impact annual work time (cf. Dodson et al. 2015).

The utilization rate figures found for wheeled harvesters (79%) were similar to those reported in a recent follow-up study performed in Sweden (i.e. 78% in Eriksson & Lindroos 2014). Our study, confirmed a general increase of utilization rate with the introduction of newer technologies, compared to the values from older follow-up studies (c.f. Kuitto et al. 1994). Tracked machinery tended to achieve lower utilization rates than wheeled machinery, as also noted by Brinker et al. (2002) for feller-bunchers.

The average hourly fuel consumption per unit of power (l/kW h) for wheeled harvesters was close to the value found by Holzleitner et al. (2011) (0.10 l/kW h) for the same machine type. The higher fuel consumption recorded for tracked harvesters and feller-bunchers is likely due to different operational conditions, as well as to differences in machine design (i.e. engine, transmission and power management). It is known that traction is higher for tracked machines than for wheeled ones, which is likely to explain the difference at least partly.

From this study, it is evident that cross-border comparisons of production costs need to take into account the effect of differences in the price of commodities. Indeed, if using the average fuel consumption for a wheeled harvester (15.9 l/PMH) and applying the observed minimum and maximum fuel prices (0.67–1.71 $/l), we obtain fuel costs ranging between 10.6 and 27.1 $/PMH. Thus, even when standardizing the technology and the operational environment, country effects can increase costs by almost three times.

The large variation in maintenance and repair costs confirmed that this is the most unpredictable cost component (c. f. Brinker et al. 2002; Dodson et al. 2015). That is because operating conditions, operator skills, repair and maintenance strategies, and machine qualities influence this cost (Werblow & Cubbage 1986). Furthermore, the procedures used so far to estimate maintenance cost are based on rule of thumb and seldom describe how the coefficients were obtained. In most cases, the coefficients are expert estimates derived from general practice, and they are inherently inaccurate as such. Some of the experts stated that a possible reason for the large variation was the different maintenance service options (i.e. internally executed vs. outsourced to an independent professional), but this could not be tested in the study. Thus, future research should aim at producing better estimates of machine maintenance cost, and of the factors affecting their variability. At any rate, the estimates obtained with this study are informative enough for the general goal of the study, and they are in line with the figures reported in the current literature. The net wages for operators were correlated to the living costs in the different countries, and their differences can be approximated by minimum statutory wages. We observed that social charges and other worker compensation costs have substantial impacts on total labor cost, and they need to be adjusted to the country border, in addition to wages.

There were no observable significant differences found between the wages of motor-manual operators and those of harvester operators, even if official statistics report different remuneration levels for the two different professional figures (BLS 2016). It is possible that the number of observations available for motor-manual operations was too small for finding the expected differences and draw more general conclusions.

The large variation observed in other labor costs (e.g. allowances, transportation of operators) was due to the fact that these costs were recorded separately or included in the overhead, depending on the book-keeping rules in each individual company. Similarly, for machine relocation, which occurs over variable distances, the cost spread over variable stand sizes and is conducted at different kilometric rates, depending on truck ownership (own or rented truck – see Spinelli et al. 2010). Therefore, a more detailed investigation is needed for a better characterization of overhead (e.g. by considering the size of forest enterprises, as well as their structural organization and production methods), which is not covered within the scope of this study and for this reason, overhead were not included in the calculation of the total cost rates.

The benchmarking of cost rates, after standardization of technical parameters, provided logical results and the range of variation for total cost rates was classified as reasonable. The differences in total cost rates reported in this study could be explained by country-specific differences in living cost, fuel prices and costs associated with the capital investment. Also, differences in technology and operational environment may have played their role in determining different outcomes.

In conclusion, this study provided an update on relevant cost factors for forest felling and processing technologies, and identified some aspects that need to be considered in a global scale benchmarking study of production costs in forestry. In an increasingly competitive global forest products industries environment, more extensive exercises, based on similar approaches, are to be performed on a regular basis. The purpose is to help develop and identify up-to-date data that can be used by forest operators, practitioners, and decision makers to improve the cost efficiencies of forest supply operations in a growing global bioeconomy.

Note

1. In its simplest definition, productive time is the part of the scheduled time during which a machine is performing productive work. The sum of productive time and non-productive delay time equals the scheduled operating time. The ratio of the productive time to the scheduled time for a machine is known as the utilization rate of the machine.

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ORCID

Fulvio Di Fulvio http://orcid.org/0000-0002-7317-6360
Ola Lindroos http://orcid.org/0000-0002-7112-4460

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