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Estimating Global Forest-Based Employment

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Abstract: There has been an ongoing interest in how important forests are for employment and what measures need to be taken to reduce decent work deficits. This study aims to contribute to the existing debate on the extent of informal and subsistence employment globally, with a particular focus on the forestry and logging sub-sector. Estimates on employment numbers not captured in the official statistics are aggregated with the recent official reported data to demonstrate a partial overview of global forest-based employment. The previous estimation method is extended by incorporating clustering techniques in response to the paucity of available labour productivity rates. Related employment and production data compiled by FAO are used as a basis of analyses. Main findings reveal that at least two-thirds of the entire forestry and logging-based employment is informal or subsistence. Estimates are highly concentrated in developing countries where decent forestry work need to be strengthened most. Aggregating official employment statistics and our additional estimates, the global forest-related workforce amounts to at least 64 million persons FTE in 2015. The study can be considered a step towards a more profound assessment approach in estimating informal and subsistence employment in the global forest sector based on the officially reported statistics. Disaggregated data based on employment status and gender is essential for improving the indirect estimation of the forest sector's informal economy and thus requires more attention by policymakers in the near future.

Keywords: forest-based employment; informal employment; forest sector; global

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1. Introduction

Forests are indispensable for global and national development in several dimensions. They provide a wide range of environmental, social, and economic benefits and are an essential source for subsistence. The forest sector plays a further vital role in achieving several targets of the Sustainable Development Goals (SDGs), such as economic growth, full and productive employment, and decent work for all [1]. Employment provided by the forest sector contributes to rural economies enhancing the opportunity for livelihood improvement and poverty alleviation [2]. Information on the quantity of employment is a crucial indicator of the distribution of socio-economic benefits derived from labour activities of the forest sector [3]. Understanding the contribution of the forest sector for employment is also important in supporting decision and policy processes towards sustainable development.

As reported by FAO [3], global formal employment in the forest sector was at 13.2 million people in 2011, accounting for 0.4 per cent of the total labour force. For the same period, Li et al. [4] indicate however that the global forest sector employed over 18 million people directly and supported more than 45 million jobs through direct, indirect and induced impacts. The causes of reported discrepancies can be explained by the considered assessment unit in both studies and the number of countries included in the analyses. For example, annual average employment by Li et al. [4] was adjusted for seasonal jobs but was not converted to the unit of full-time equivalent (FTE). Often employment figures presented in literature and statistics can be merely treated as "formal" employment, as they are

generally underreported. Moreover, there is an invisible part that far surpasses the visible one as forests generate more jobs than apparently reported from the official statistics [5]. For example, Poschen and ILO [5,6] identified 30 million informal and subsistence employment FTE in the late 1990s, with the highest shares reported for the forestry and logging sub-sector. Estimates by FAO [3] revealed that at least 41 million people were employed in the informal forest sector between 2010–2011. The estimate covers wood fuel, charcoal production and forest products used for construction in less developed countries (ibid). These indicative numbers show that informal employment is in fact more extensive than the formal one. Particularly in developing countries, the forest sector is characterised by a high degree of informality and a substantial presence of microenterprises and family labour [7].

Informal and unpaid workers are generally considered vulnerable due to social and economic insecurity. Many forest workers do not have formal contract arrangements and suffer from inadequate personal protection and training; particularly logging operations are often associated with decent work deficits [8,9]. In addition, women are often involved in a wide range of informal forest-related activities including low-paid or unpaid conditions such as fuelwood collection [9]. Quantifying informal and subsistence employment can therefore positively impact decision and policy processes by enhancing decent work deficits where it is needed most [1]. Estimating the number of persons who are informally employed or engage in subsistence work in the forest sector has continued to be one of the remaining challenges in this research domain. The reported level of total forest-based employment globally and at the country level can substantially vary among sources. This is due to different assessment approaches and reference data, calling for a more efficient estimation procedure as the status quo.

The aim of our study is to provide improved and up-to-date estimates on the magnitude of the global informal and subsistence employment, focusing on the forestry and logging sub-sector. We extend the method employed by FAO [3] by incorporating cluster analysis in response to lacking of labour productivity rates. Our contribution builds on a global country-level assessment approach with countries being clustered based on similarity characteristics across variables affecting labour productivity of forestry and logging activities, respectively. Following the assumption from FAO [3], the informal and subsistence employment in the forestry sub-sector primarily includes employment in wood fuel production. In case of our study, however, we further include potential informal employment from industrial roundwood harvesting, too. Finally, we aggregate our estimates with the recent official information on employment compiled by Food and Agriculture Organization of the United Nations (FAO) and the United Nations Industrial Development Organization (UNIDO) presenting an updated partial overview of the global total forest-based employment.

The article is structured as follows. Section 2 presents an overview of forest sector and employment definitions which forms the basis of our analysis. Section 3 outlines the methodological approach and describes the steps of estimation procedure. Section 4 begins with a presentation of the current situation of global visible forest-based employment and continues with the main results of the estimated informal employment and subsistence workforce quantities. Section 5 discusses the main results of the study and highlights the limitation of our analysis, followed by the concluding remarks.

2. Definitions

2.1. Forest Sector

The analysis of forestry-based employment requires a clear and consistent definition of the forest sector, geographical classification and time reference [10]. The forest sector in our study corresponds to the International Standard Industrial Classification (ISIC) and encompasses forestry and logging, wood industry, paper industry, furniture and printing sub-sectors (Figure A1). The forestry and logging sub-sector (ISIC division A02) incorporate raw wood producing activities, extraction and gathering of non-wood forest

products (NWFP), and products that undergo marginal processing in the forest. Wood industry covers manufacturing of semi-finished wood and products of wood (ISIC division C16). Paper industry (ISIC division C17) refers to manufacture of pulp, paper and converted paper products. In case of furniture industry, we use ISIC division C31 as proxy in the absence of employment statistics for wooden-furniture production. This includes furniture manufacturing of any kind and any material, except stone, concrete or ceramic. The printing sub-sector refers to ISIC class C1811 that incorporates printing of products such as newspaper, books, labels etc. [11].

2.2. Formal vs. Informal Employment

Estimating informal and subsistence employment necessitates a clear understanding of its definitions and the implication to the forest sector. Our study considers formal and informal employment created directly by any sub-sector activity. The scope of formal and informal employment is described according to the coherence between enterprise-based and job-based concepts using the building block approach (Table 1), initiated by ILO [12]. The production units are categorized into formal and informal sector enterprises and households. The informal sector is defined on the basis of enterprise characteristics, i.e., micro-enterprise in term of number of employees, non-registered enterprise and non-registration of its employees [12]. By status, employment can be distinguished into two main categories namely employees (wage and salaries workers) and self-employed. Further disaggregation of self-employed comprises employers, own-account workers, members of producers' cooperatives, and contributing family workers [13]. The essential criteria to distinguish formal and informal jobs is that whether they are subject to labour legislation and income tax or entitled to social protection or not [14].

Table 1. Building block approach to describe formal and informal employment. Adapted from International Labour Organization, 2013 [12]. Copyright © International Labour Organization 2013.

Production Units	Employment Status								
	Own-Account Workers		Employers		Family Workers	Employees		Member of Producers' Cooperatives	
	Informal	Formal	Informal	Formal	Informal	Informal	Formal	Informal	Formal
Formal Sector enterprises		F 1		F 2	I 1	I 2	F 3		F 4
Informal sector enterprises	I 3		I 4		I 5	I 6	I 7	I 8	
Household	I 9					I 10	F 5		

Notes: F and I denote formal and informal employment, respectively. The grey backgroud colour indicates that these blocks refer to informal employment.

The building block leads to three main combinations. Formal employment (block F 1 to F 5) include employed and self-employed workers who work in formal sector enterprises and are legally protected by, e.g., access pension schemes or payment in absence for illness. Informal employment (block I 1 to I 6, block I 8 to I 10) is defined as employed person holding an informal job whether carried out in formal or informal enterprises or at the household-level. Notably, block I 7 describes a situation in which employees are formally employed in an enterprise that due to its small size is not accounted for in the statistics as formal. This case is included as employment in the informal sector but excluded from informal employment corresponding to international standards adopted by the 17th ICLS in 2003 [15]. The blocks without any codes refer to jobs that by definition do not exist in the type of production unit in question [12].

Our study follows the concept of informal employment described above. Concisely, informal employment comprises "(i) own-account workers and employers employed in their own informal sector enterprise, (ii) all contributing family workers, (iii) employees who are not subjected to legal protection or social security, (iv) members of informal producers' cooperatives, and (v) own-account workers producing goods exclusively for their own-final use, if their production significantly contributes to the total household consumption" [12]. This broad definition is sufficient to capture all possible informal work

in the forestry and logging sub-sector, such as seasonal loggers who are not bound by any written contract or wood fuel collectors for household subsistence.

2.3. Visible vs. Invisible Employment

It is important to note that the ISIC does not distinguish between formal and informal, as well as legal and illegal production [11]. As employment statistics compiled by FAO and UNIDO are defined corresponding to ISIC, official figures in some countries may not be only referred to as formal employment. Accordingly, we treat the employment numbers reported in official statistics under the term "visible employment", referring to the number of people who are visibly captured in the official employment database. Informality rates in emerging and developing countries are substantially higher than in developed countries [16]. Thus, it can be expected that most forest-based visible employment figures from developed countries are likely referred to as formal employment.

The primary purpose of our study is to estimate the unknown number of forestry workers who are not captured in the official statistics on the basis of reported employment and production statistics. Subsequently, results based on a methodology for countries with no reported employment data have to be interpreted with caution. In fact, it remains unclear whether sectoral employment statistics of these countries are either not well documented, inaccurate or their forest-based employment is highly characterized by informality and subsistence activities. Consequently, the term "invisible employment" will be used in this article for employment estimates that is not covered by FAO statistics. For countries with available employment statistics, invisible employment estimates hypothetically refers to informal employment's broad definition, cover workers with informal jobs in the formal and informal sector enterprises, and further include household subsistence employment. The respective term may thus also include formal employment for countries with missing employment statistics which particularly holds true for developed countries.

3. Methodological Approach

Our methodological approach is based on five consecutive steps (i) to quantify visible employment in the forest sector, and (ii) to estimate invisible employment in the forestry and logging sub-sector (Figure 1). The aggregation of official visible employment figures together with the invisible employment estimates provides an overview of the quantity of people are globally employed in the forest sector. In the following sections, we describe the data sources and estimation processes corresponding to step 1 to 5 of the analytical framework.

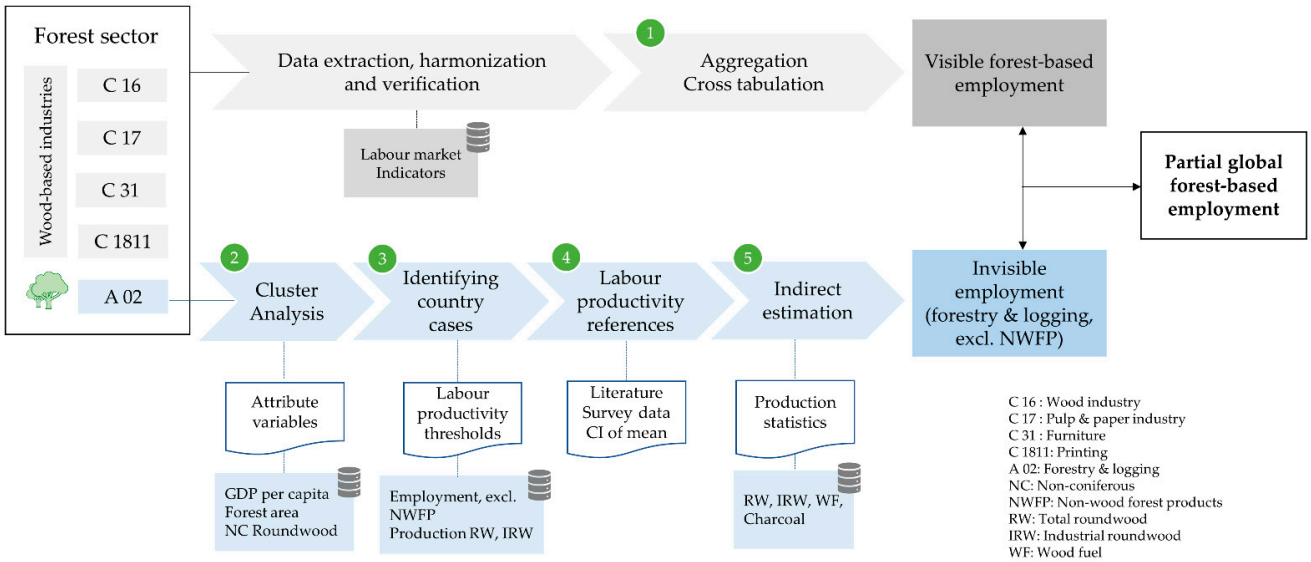

Figure 1. Analytical framework.

3.1. Visible Employment (Step 1)

Official employment statistics from five sub-sectors are extracted and harmonized to obtain the current overview of how many people are visibly employed in the forest sector. As the focus of this study is on the global scale, the analysis requires information using comparable definitions and measurement units. The interchangeable form of employment as discussed above can occur depending on several factors such as seasonality and individual living conditions. For instance, a person's primary occupation is a daily wage logger, and at the same time, this person also harvests wood fuel for home consumption [5]. In that sense, employment in the unit of FTE can diminish, for example, the number of people who only spend part-time on collecting firewood. Moreover, employment quantity in the unit of a person in FTE allows us to produce labour productivity rates at the same ratio, enabling an accurate country comparison. In this respect, FRA 2020 and INDSTAT compiled by FAO [17] and UNIDO [18] are currently the most comprehensive database on the country level. The most recent comparable year of employment data across the forest sector is 2015, and subsequently is used as reference period for this study.

Employment figures from FRA 2020 are reported in the unit of person FTE and in case available, data are further disaggregated by gender and forestry economic activities at the 4 digit-level. A first verification was performed checking whether the sum of employment reported under gender and per group of economic activity is equal to total employment as reported in ISIC division A02. Forestry and logging employment data compiled by FAO covers employment activities in the forest, i.e., silviculture, timber logging, extracting and gathering NWFP, and support services to forestry and transportation within the forest. Reported numbers are based on an average value of a three years period. For instance, data from 2015 are derived from the years 2014–2015–2016 [19]. Altogether, forestry and logging related employment data in 2015 cover 137 countries (For the case of Kenya, Zimbabwe, Mali, Mongolia, Korea, Viet Nam, Turkmenistan, New Caledonia, Peru and Venezuela, data of FAO refer to 2010), representing 91 per cent of the global forest areas in the considered study period.

In the case of wood-based industrial sub-sectors, we extracted information on the number of employment at the 4 digit-level of ISIC from the INDSTAT4 database which is compiled by UNIDO [18] and summed-up to its respective division. For countries with missing data at the 4 digit-level, we use employment data at the 2-digit level of ISIC Revision 3 from INDSTAT2 instead. To be consistent with the forestry and logging sub-sector, the average value of employment is computed using the same year periods. Approximately more than 100 countries report employment statistics for the manufacturing of wood, pulp and paper. For the furniture and printing sub-sector, the number of reporting countries are 90 and 66, respectively. Aggregated employment statistics comprising the five mentioned sub-sectors provide the current overview of visible forest-based employment and its contribution to the global labour force. We further present the distribution of visible forest-based workforce among sub-sectors and gender, as well as the pattern of sectoral employment by income classification.

3.2. Invisible Employment Estimation

FAO assumed that informal forestry employment includes employment in wood-based production which is not captured by the officially reported data. Estimated informal employment is based on average labour productivity rates on the regional level and production statistics of wood fuel and charcoal [3]. We extend the method of FAO by integrating cluster analysis and an additional step to identify country cases based on labour productivity thresholds. In general, labour productivity measures how efficiently labour inputs are used in economic activity to produce a given output level. In our case, labour productivity related to forestry activities refers to the correlation of the volume of output and inputs. We apply this concept twice. Firstly, we use labour productivity as a mean of verification to identify country cases in which invisible employment can be expected. Secondly, labour productivity is employed to produce employment estimates that are

not captured in the official statistics. A further critical indicator in producing invisible employment estimates is the volume of output from the forestry sub-sector. In the absence of aggregated NWFP production data on the global scale, estimated invisible employment in our study covers wood-based economic activities in the forest until the forest gate. The roundwood removals reported by FAO will be used as a proxy for output derived from the forestry sub-sector. Further details of the analytical framework steps 2 to 5 are described in the following sub-sections.

3.2.1. Cluster Analysis (Step 2)

A comprehensive literature search on labour productivity identified a limited number of available information. Thus, we conducted a cluster analysis to explore similarities between countries in respect of attributes related to labour productivity of logging and wood fuel harvesting. The primary concept of cluster analysis is to form groups of similar objects (here: countries) in a way that objects are more homogenous within a group and more heterogeneous between clusters. This allows us to precisely apply available labour productivity references to each country cluster, enabling more accurate estimates.

Cluster technique corresponding to distance-based algorithms are referred to as hierarchical and non-hierarchical clustering methods. A combination of hierarchical and non-hierarchical approaches is commonly advisable for choosing the optimal number of clusters and to construct cluster memberships [20]. For the purpose of our analysis, we firstly use the Ward methods which is a hierarchical technique to obtain an overview of the possible numbers of country clusters. We then use non-hierarchical procedures, i.e., Partitioning Around Medoids (PAM) or k-medoids developed by Rousseeuw [21], to select the final cluster solution. Compared to k-means, k-medoids is more robust in the presence of noise and outliers [22].

Determining a specific set of attribute variables is also an important step when applying cluster analysis. Labour productivity in the forestry and logging sub-sector generally varies between countries and regions, depending on factors such as timber characteristics, machinery used, terrain and climatic conditions and the physical work capacity and level of training received [23]. Per capita GDP is included as a proxy of country economic performance. High-income and developed countries are more likely to have a higher level of mechanization of forestry work where automation has replaced manual operations such as several countries in the UNECE region [24]. Share of boreal, temperate, sub-tropical and tropical forests in total forest areas represent forest type by climatic conditions. We employ the share of non-coniferous roundwood in total roundwood removals as a proxy for the type of timber. Other attribute variables, i.e., value added of agriculture, forestry and fishing as percent of GDP, share of rural population and share of forest areas under slope classes were also tested in the cluster analysis but resulted in lower average silhouette statistics and country coverage. The final cluster variable set amounted to a total of 172 countries based on three sets of attribute variables as presented in Table 2. Countries with missing information for at least one variable were excluded.

Table 2. Attribute variables used in the cluster analysis.

Attribute	Proxy Variable	Unit	Year [1]	Data Source
Country economic performance	Per capita GDP	constant 2010 US$	2014–2016	World Bank
Climatic conditions	Share of boreal forest area	0 to 1	2015	FRA2020
	Share of temperate forest area	0 to 1	2015	FRA2020
	Share of sub-tropical forest area	0 to 1	2015	FRA2020
	Share of tropical forest area	0 to 1	2015	FRA2020
Type of wood	Share of non-coniferous roundwood production	0 to 1	2014–2016	FAOSTAT

Note: [1] Whenever possible, average value are generated based on data from 2014 to 2016 to keep consistency with the employment and production statistics and also to smooth the fluctuations in the cross-sectional data used for the cluster analysis.

A low level of multicollinearity among clustering variables are advisable in the cluster analysis [25]. Vázquez et al. [26] and Everitt et al. [27] suggest that a correlation coefficient above 0.9 causes a problem because the final clustering solutions will be overrepresented by highly correlated variables. Due to high multicollinearity between share of average coniferous and non-coniferous roundwood production, only the latter variable was included in the cluster analysis. The correlation coefficients of the other variables at a significance level of 0.1 (Table A1) and confirm that the remaining variables provide a sound basis for grouping countries into an optimal number of clusters. Because of different scale dimensions, standardization as a function of z-scores is applied. This allows attribute variables to equally contribute on how country groups are clustered [22] using:

$$Z_i = \frac{x_i - \overline{x}}{MeAD} \quad (1)$$

x_i denotes variables used in the cluster analysis in the original units, where their means represented by $\overline{x}$. *MeAD* refers to Mean Absolute Deviation and is used to disperse the impact of outliers, as an alternative to standard deviation.

The optimal number of clusters is chosen based on the maximal average silhouette width for the entire dataset, which can range from -1 to 1. Further information on construction of silhouette statistics can be found in Appendix B. A silhouette width of 0.71 to 1 implies a strong clustering structure, whereas an average silhouette lower than 0.25 indicates no substantial structure [20]. Once receiving the final cluster solution, one-way ANOVA is performed, to test whether clusters significantly differ in the means of the attribute variables. Multiple comparisons of means are carried out to further check the differences in each pair of clusters on an individual attribute variable. In our case, every cluster has six dimensions of attribute variables. A good cluster solution is expected to differ in at least one attribute variable of any two clusters. Detail results of the cluster analysis (Figures S1–S3) and ANOVA tests (Tables S1 and S2) can be found in the supplementary materials.

3.2.2. Identifying Countries with Invisible Employment (Step 3)

Official employment statistics in some countries may already cover informal employment estimates as mentioned above. We use the relationship between production volume and labour input (labour productivity) as a means of verification to ensure that our additional invisible employment estimates are correct. Production statistics from FAOSTAT provide data for production volume of the forestry and logging sub-sector, particularly for roundwood, industrial roundwood and woodfuel. Hence, we divide the reported production volume by the total number of visible employment in the forestry sub-sector. If data are available, number of employed persons engaged in NWFP gathering activities are subtracted too.

Figure 2 presents the approach in how to identify countries with invisible employment in the forestry and logging sub-sector. We computed weighted and unweighted average labour productivity of total roundwood removals at the cluster level in the unit of cubic metre per person in FTE. The weighted average of labour productivity of each cluster is then calculated by using aggregate roundwood removals in the cluster, divided by the total number of people visibly employed in forestry and logging in the respective cluster. Unweighted average labour productivity, on the other hand, is the mean of labour productivity of countries in each cluster. Weighted and unweighted labour productivities (Table S3) provide the first overview whether the employment numbers reported in official statistics are realistic at the cluster level (Figure 2, step a). The cluster that represents the majority of developing countries, especially with on an average the highest share of woodfuel removals, is expected to have a lower average labour productivity rate compared to countries with a high proportion of industrial roundwood production. Using industrial roundwood production instead of total roundwood removals divided by the visible

employment numbers, is performed to test whether official employment statistics do not cover employment in woodfuel production.

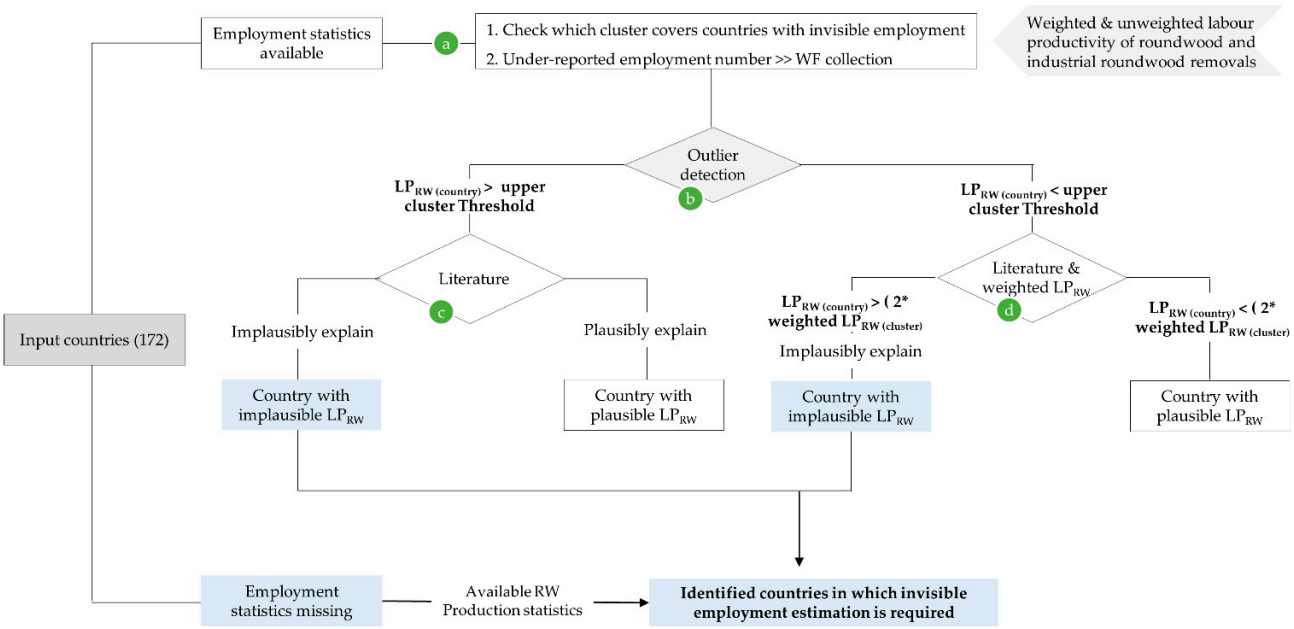

Figure 2. Decision process of identifying countries for invisible employment estimation. Note: $LP_{RW\ (country)}$ and weighted $LP_{RW\ (cluster)}$ denote labour productivity of roundwood removals of individual country and weighted labour productivity of roundwood at the cluster level, respectively. Letter a, b, c and d indicate the consecutive step of identifying country cases. * denotes multiplication.

After the identification of clusters with potential underreported employment figures, we identify country cases where an invisible employment estimation needs to be estimated (Figure 2, step b). Based on the assumption that production volume statistics covers all roundwood removals, under-reported official employment figures would result in an implausible high labour productivity rate. To confirm whether this assumption holds true, we computed the first upper labour productivity threshold of roundwood production per cluster. This is to detect countries whose labour productivities for felling and harvesting of roundwood strongly deviates from the majority of countries in the same cluster. The first upper threshold value is determined based on the productivity rate of the cluster country members, applying the median plus 2.5 times of the absolute deviation around the median [28]. The absolute deviation around the median (MAD) is defined as:

$$MAD = b \times Median_i \left(\left| x_i - Median_j(x_j) \right| \right) \quad (2)$$

x_j is the n original countries in the cluster. $Median_j$ is the median of the series of labour productivity in the respective cluster. $Median_i$ is the median of the absolute difference. b is equal to 1.4286, assuming normal distribution and disregarding the abnormality induced by implausible cases [28].

We further investigate country labour productivity based on published information on labour productivity for logging activities and wood fuel collection (Figure 2, step c). Subsequently, countries are marked as outliers if labour productivities are higher than the first upper threshold, and if high productivity rates are not supported by empirical references. We further recheck countries whose labour productivity rates are lower than the first upper threshold. This is particularly relevant for countries with a high share of fuelwood and wood for charcoal production (Figure 2, step d). For this purpose, we recalculate weighted labour productivity for each cluster, excluding countries detected in Figure 2, step c. The recalculated weighted cluster average is applied as the second upper threshold to filter countries with implausibly high labour productivity. All labour

productivity thresholds applied to each cluster are shown in Table S4. Accordingly, invisible employment is estimated for two types of countries: (i) countries whose labour productivity is either higher than the first or the second upper threshold and not plausibly explained by published studies, and (ii) countries without officially reported employment figures, but available roundwood production information. Table S5 presents number of identified country cases and countries with plausible labour productivity rates by cluster.

3.2.3. Labour Productivity References (Step 4)

The present study aims to provide, as accurate as possible, invisible employment estimates in the forestry and logging sub-sector. Ideally, this requires well-estimated labour productivity rates, disaggregated by logging-related and wood fuel collection activities. For each cluster, available labour productivities at the country level derived from literature or empirical survey data are used as lower- and upper-bound productivity references. When information is unavailable, we apply labour productivity of plausible country cases in the respective cluster as a reference. Selected plausible country references of the same cluster should be similar to the identified country cases in terms of wood fuel production and geographical region. Moreover, labour productivity of total roundwood removals is used in absence of disaggregated information on industrial roundwood harvesting and wood fuel. The extracted labour productivity references are converted to the unit of cubic metre per person FTE. 1 FTE refers to approximately 2080 working hours annually. Labour productivity references by cluster can be found in Table S6.

3.2.4. Indirect Estimation (Step 5)

Based on the identified countries and available labour productivity references, we can derive the estimation procedure of number of persons in invisible employment for each cluster, and disaggregated by country groups with and without officially reported employment statistics (Table S7). The reported production level of roundwood, industrial roundwood and wood fuel, divided by labour productivity references from the step 4 produces a range of invisible employment estimates in the identified country cases. For identified countries with employment data, the invisible employment estimates already exclude the officially reported figure.

4. Results

4.1. Visible Forest-Based Employment

In 2015, the visible forest-based employment reached 28 million persons in FTE, accounting for 0.9 per cent of the global labour force. Approximately 12 million persons FTE are visibly employed in the forestry and logging sub-sector (Table 3). Compared to 2010, the global visible employment in forestry and logging has declined slightly. The low- and lower middle-income nations hold the largest absolute number of employed persons, accounting for 70 per cent of the global forestry employment. India reported the highest number with 6 million persons employed in this sub-sector which remained unchanged since 2010, followed by Sudan and Viet Nam. In the upper middle-income group, the number of forestry workforce dropped by around 9 per cent from 2010 to 2015. This was strongly influenced by China, as the country's second phase of national Forest Protection Programme resulted in massive job losses in state-owned logging and transportation companies since 2011 [29].

Table 3. Distribution of visible forest-based employment (million-person FTE), by income classification and sub-sector in 2010 and 2015.

Income Classification/Sub-Sector	N	Low Income		Lower Middle Income		Upper Middle Income		High Income		Global	
		2010	2015	2010	2015	2010	2015	2010	2015	2010	2015
Forestry (A02)	99	1.5	1.6	7.0	7.1	2.8	2.5	1.0	1.1	12.4	12.2
Wood (C16)	97	0.01	0.02	0.3	0.4	2.7	2.7	1.6	1.6	4.6	4.7
Paper (C17)	93	0.004	0.01	0.5	0.5	2.4	2.2	1.4	1.3	4.2	4.1
Furniture (C31)	69			0.4	0.5	0.8	0.9	1.6	1.5	2.8	2.9
Printing (C1811)	51			0.3	0.3	0.2	0.2	1.1	1.0	1.6	1.5
Forest Cluster	128	1.5	1.6	8.5	8.8	8.9	10.8	6.9	6.4	25.9	27.7

Notes: N denotes the number of countries in the calculation. World Bank defined income classification with a GNI per capita, calculated using the World Bank Atlas Method [30]. Cells with missing number indicates no countries reported the respective data. Listwise deletion is applied in each sub-sector to exclude countries with missing information at least one year.

Total visible employment in the wood-based manufactures amounts to 16 million people FTE in 2015 (The reported number is higher than the total number of visible employment in the wood-based manufactures as presented in Table 3 as only countries with entries for both years, 2010 and 2015, were accounted for). Similar levels of forest related industrial workforce can be observed between 2010 to 2015. A high employment number in wood-based industrial sub-sectors is attributed to upper middle- and high-income nations and about 6 and 5 million persons in 2015, respectively. In the upper middle-income class, China holds the largest share of workforce accounting for 5 million persons FTE employed in the wood-based industrial sub-sectors. Approximately more than half of the total Chinese wood-based workforce is found in the manufacturing of wood, pulp and paper. In case of these main sub-sectors, the number of Chinese workforces has decreased only marginally during the five-year period due to the strong influence of the pulp and paper sub-sector. The overall visible employment in the Chinese forest related industries has increased by 64 per cent when aggregating the number of employment in the furniture and printing sub-sectors in 2015. For the high-income group, USA contributes the largest workforce in the wood-based manufacturing sub-sectors totaling to 1.4 million people, followed by Germany and Japan. In case of USA, total employment in the wood-based industrial sub-sectors has decreased by 5 per cent from 2010 to 2015. However, the production of wood-based panel, wood pulp and paper and paper board in USA were stagnant during the same time period. Meanwhile sawn wood production rapidly inclined after the global financial crisis in 2008. The main driver of the declining forest workforce in USA stands in contrast to the reported production level explained by the ongoing mechanization development. Sawn-wood and veneer grading are nowadays operated with scanners [24].

Approximately 4 million (FTE) female are visibly employed in the forest sector globally. This is equivalent to 16 per cent of the total forest-based employment in 2015. Similar patterns can be observed across levels of per capita GDP (Figure 3). Overall, the rate of female participation is relatively low, even in countries with high per capita GDP. Thiscan be partly explained by the nature of forest sector work. Several tasks in logging, and wood-based industries typically require intensive physical labour which usually hinders female participation. The hazardous working nature of the forest sector make it more challenging for women to formally involve in forestry activities. Female workers are often preferred for tedious tasks such as planting of saplings [31], or in some cases become formally employed in administrative departments [24].

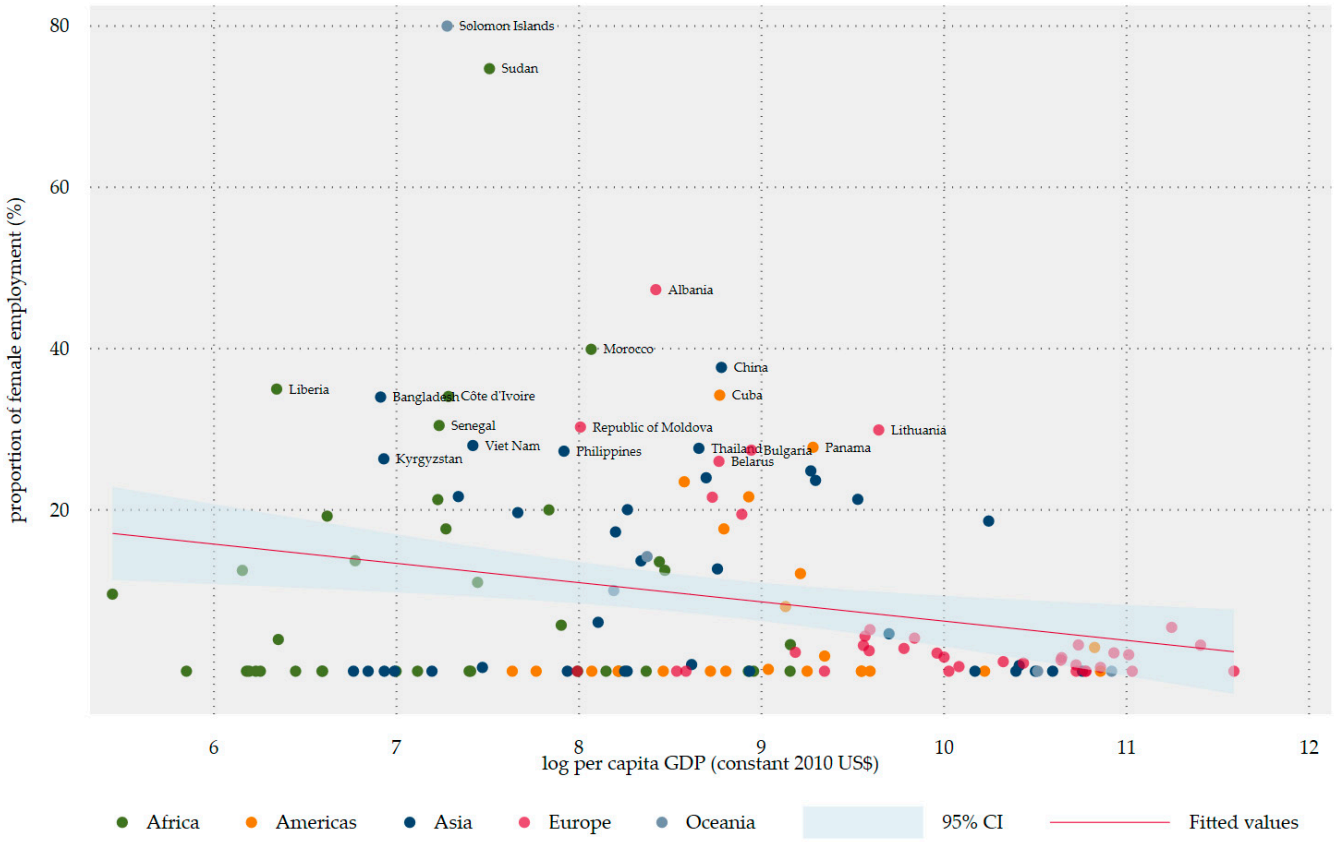

Figure 3. Distribution of female employment participation in the forest cluster in 2015.

A high proportion of forest-based female employment in some countries indicate gradual involvement of women in forestry-related economic activities. Countries with the largest proportion of women in national total forest-based employment are Solomon Island with 80 per cent, Sudan with 75 per cent and Albania with 47 per cent. According to the latest FRA country report, most of forestry employment in Solomon Island refers to logging with 7.4 thousand persons FTE being female. In Solomon Island, forest and logging is the second largest contributor to GDP after agriculture. However, the logging industry in the Solomon Islands employs mainly men for logging operations, and women are more represented in the provision of services for camp workers, administrative jobs, collecting foods, medicinal plants and firewood [32]. In Sudan, approximately 1.2 million persons are predominantly employed in the gathering of NWFP activities, accounting for 11 per cent of the national labour force. A study in Central Darfur State, Sudan revealed that the contribution of NWFP to total household income is about 54 per cent and to a large extend dominated by women [33]. According to the FRA 2020 country report, the most common NWFP in Sudan include Dom fruits, Hegglig fruits and Gum Arabic. In Albania, manufacturing of pulp and paper employed the highest share of women, with a proportion of 81 per cent of the total employment in this sub-sector.

Overall, our female employment estimates are still comparably low. FAO [3] revealed that women account for a quarter of employment in the forest sector. The significant lower female employment number could be explained by two reasons. Firstly, the number of countries with existing gender-disaggregated data used in our analysis is likely to be lower than the referred FAO report. For forestry sub-sector, 57 countries reported gender-disaggregated employment data to FRA. In the same period, the number of reported countries ranges from 25 to 38 for the case of wood-based manufactures. Secondly, the FAO study is built on the ILO database and supplemented with employment statistics from country sources. The reported employment number in the unit of head-count could also include part-time employment, which results in a higher number of female participants.

Women are likely more represented in the informal and subsistence activities due to inadequacy of options [2]. This phenomenon occurs particularly in many rural areas of emerging and developing nations, where people attempt to eradicate hunger and improve livelihood in general. FAO [3] reviewed that women collect approximately 60 per cent of wood fuel worldwide, with even higher shares evident in Africa. The same study also indicates that men tend to focus more on collecting wood fuel for sale, whereas wood fuel collected by women is mostly for subsistence use.

4.2. Size of Invisible Employment in Forestry and Logging Sub-Sector

The invisible employment is estimated for countries with implausible labour productivity rates or missing employment statistics. In total, 85 countries are part of the estimation, accounting for 40 per cent of the global forest area. Details of how we identified countries cases and calculated invisible employment figures can be found in the supplementary material. Building on upper- and lower-bound labour productivity references and the level of roundwood removals, the estimated size of invisible employment for wood-based economic activities ranges from 36 to 66 million persons FTE globally. The results refer to employment inside the forest until the forest gate and is further presented by countries with and with missing employment data.

Countries with available employment data: For the identified 26 countries with available employment data, we estimate that at least 20 million people are not captured in the official employment statistics. Results at the upper bound indicate that the size can be up to 38 million persons FTE. Within this category, the African region accounts for almost half of the total invisible employment, followed by America and Asia. In most cases, the proportion of wood fuel removals is relatively high and range from 70 to 90 per cent of total roundwood production. Countries with more than 1 million persons FTE in invisible employment at the minimum level include Brazil, Indonesia, Nigeria, Ghana, Bangladesh and Kenya, in descending order (Figure 4a).

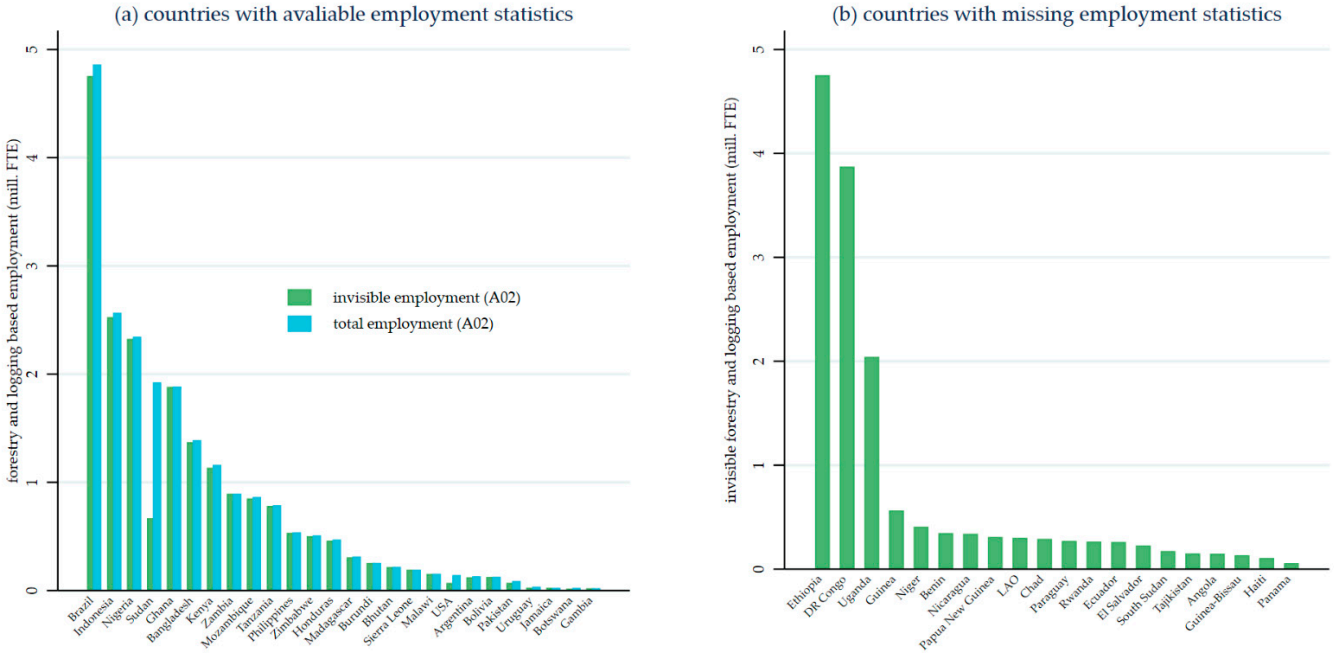

Figure 4. Visible and invisible employment in the forestry and logging sub-sector of selected countries with (**a**) for countries with available employment statistics, (**b**) for countries without employment statistics. Notes: Total employment in (**a**) is the aggregation of visible employment in the forestry and logging sub-sector compiled by FRA 2020 and our invisible employment estimates at the lower-bound. The invisible employment number in (**b**) is the lower-bound estimates.

The highest numbers of invisible employment are estimated for Brazil, ranging from about 4.8 to 9.3 million persons FTE. Thereof, 0.1 to 0.7 million persons FTE are invisibly employed in harvesting of industrial roundwood. Our appraisal is reasonable considering that [34] revealed over 0.5 million FTE workers were directly employed in the harvesting and processing of forest products in 2005 in the Brazilian Amazon only. Approximately 0.1 million persons were involved in timber logging activities, charcoal from extraction, timber forestry and charcoal from forestry (ibid). In 2015, employment in the Brazilian forestry sub-sector reported in FRA 2020 was at 0.1 million persons FTE for the whole country. In this respect, the officially reported employment figure appears to be unrealistic when comparing this with the reported amount of industrial roundwood and wood fuel production for the same year, and the amount of employment only in the Amazon region. Brazil belongs to the global top five producers of industrial roundwood, amounting to an average of 139.7 million m^3 during 2014 to 2016. For the same period, Brazil was the third largest wood fuel producer globally, after China and India, with a total production volume of about 118 million m^3 wood fuel. Although liquefied petroleum gas (LPG) is a major source of fuel in Brazil, a significant proportion of the Brazilian population still use firewood for domestic purposes [35]. Our study confirms the likelihood of high prevalence of informal employment and household subsistence workforce in the Brazilian forestry sub-sector and provides further quantitative evidence on the level of invisible employment.

It is worth noting that our approach also pointed to the USA as a country of having invisible employment. We used the number of employed persons reported in FRA 2020 at 73 thousand FTE for the basis of our estimation that resulted in an additional 70 thousand persons FTE in invisible employment at the lower bound level. Accordingly, total forestry and logging-based employment in USA is about 143 thousand persons FTE. This total number is in line with the U.S. Bureau of labour statistics illustrated in [24] which reported 159 thousand FTE employed in 2016 for this sub-sector. The definition of the forestry sub-sector from the U.S. Bureau of Labour Statistics used in UNECE and FAO [24] is corresponding to ISIC Revision 4 (Division 02) which is equivalent to data compiled by FRA 2020. Due to the discrepancy of official data in FRA 2020 and the U.S. Bureau of Labour Statistics, we cannot conclude at this stage that our additional estimates would entirely refer to informal employment. However, the same study [24] reviewed that migrant labour is significant in the Southwest of USA, where plantation forestry predominates.

Countries with missing employment data: As indicated above, estimates for countries with missing employment data need to be interpreted with caution as it may include employment with formal arrangements. The size of invisible employment based on the identified 59 countries ranges from 15 to 28 million persons FTE. Approximately 86 per cent of the estimated total invisible employment cluster in low- and lower middle-income countries in Africa. Ethiopia, the Democratic Republic of the Congo (DR Congo) and Uganda are the top three countries in this list, with high amount of estimated invisible employment of 4.8, 3.9 and 2 million persons FTE, respectively (Figure 4b). In these countries, about 90 per cent of total roundwood removals is characterized by wood fuel production. Generally, countries in Sub-Saharan Africa are still excessively depending on biomass fuels, covering 60 per cent of its total energy demand [36]. This is influenced by an increasing dependency on informal economic activities such as collection and trade of fuelwood and charcoal caused by poor performance of the formal economy for many African countries [37]. This supports the notion that our invisible employment estimates may refer to informal and subsistence workforce in most of the mentioned African countries. Noteworthy, for Greece, Albania and Bosnia and Herzegovina, invisible employment is also estimated due to missing information on reported employment in FRA 2020. Referring to a recent study from [24], employment statistics in the forestry and logging sub-sector from these countries are available. For instance, about 7 thousand persons are employed in the Greece forestry and logging sub-sector in 2015 as reported by Eurostat, whereas our estimate ranges 4 to 20 thousand persons FTE.

For developed nation particularly those with missing officially reported employment statistics in the FRA2020, our invisible employment estimates do not entirely refer to informal and subsistence employment. It is further worth mentioning that the total workforce in the forestry and logging sub-sector based on the aggregation of FRA 2020 employment figures and our additional estimates amounts to at least 48 million persons FTE globally. India holds the largest share of approximately 13 per cent of the global forestry and logging sub-sector workforce, followed by Brazil and Ethiopia. Adding the number of 100 million people, who are informally involved in commercial production of NWFP as estimated by FAO [3], the total forestry and logging-based employment extends to 148 million people FTE in 2015.

4.3. Global Forest-Based Employment

Figure 5 provides an overview of the global forest-based employment, based on official employment statistics of all sub-sectors and our invisible employment estimates. Altogether, the global forest-related workforce amounts to at least 64 million persons FTE in 2015, and can be up to 94 million persons FTE. Countries with the highest number of forest-based employment are India, China, Brazil, Ethiopia, Democratic Republic of the Congo and Indonesia, in descending order.

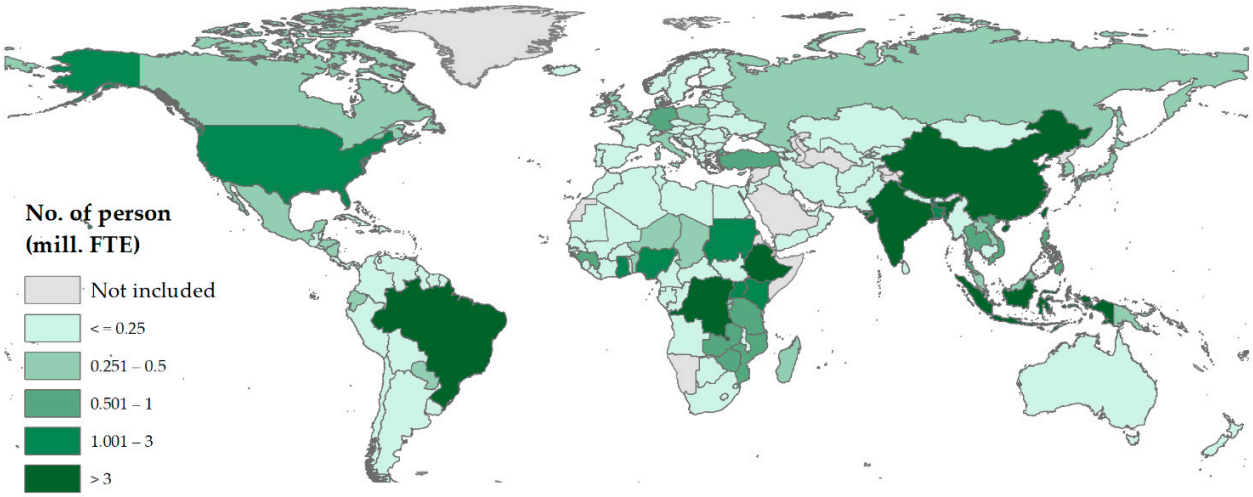

Figure 5. Global view of total forest-based employment. Source: own illustration. Notes: Global employment in this map encompasses visible employment in the forest sector and the lower-bound invisible employment estimates in the forestry and logging sub-sector; NWFP not included.

It is estimated that at least 10–12 per cent of the population in India depend on forests and forest-based industries for their livelihood [38]. According to official statistics, the forestry sub-sector workforce accounts for about 1.3 per cent of the total Indian labour force. In China, the wood-based industrial sub-sectors employs a large proportion of the total forestry workforce, particularly the manufacturing of wood and wood products. China is the largest furniture and wooden floor producer and exporter globally [29], registering an average of 1.2 million persons FTE employed in the furniture sub-sector between 2014–2016 (Table 4).

Informal and subsistence employment are likely to be prevalent in the Brazilian forest sector and accounts for 89 per cent of the total sectoral employment (Table 4). A similar situation can be observed for the case of Ethiopia, the Democratic Republic of the Congo and Indonesia. FAO [39] revealed that approximately 93 per cent of Ethiopian households use biomass fuel as a source of energy. Fuelwood business remains an important contribution to the livelihoods of poor and vulnerable local people. This particularly holds true for women as fuelwood collection can be their only source of income. In the Congo Basin, the majority of firewood and wood for charcoal collecting activities are within the informal

economy [40]. In case of Indonesia, income levels are generally high for the forest sector, but the prevalence of poverty due to unpaid labour remains at a high level, too [41].

Table 4. Number of visible and invisible employment from selected countries.

Sub-Sector by Employment Status	Number of Employment (Million Persons FTE)					
	India	China	Brazil	Ethiopia	DR Congo	Indonesia
Visible employment						
Forestry	6.24	1.15	0.11			0.04
Wood industry	0.09	1.51	0.17	0.01		0.24
Paper industry	0.25	1.39	0.19	0.00		0.15
Furniture	0.06	1.20	0.24			0.17
Printing	0.15	0.92				
Invisible employment						
Forestry, excl. NWFP						
minimum			4.76	4.75	3.87	2.53
maximum			9.27	8.63	7.02	4.87
Total employment						
minimum	6.78	6.16	5.46	4.76	3.87	3.13
maximum	6.78	6.16	9.97	8.65	7.02	5.47

Notes: For the forestry sub-sector excluding NWFP, minimum and maximum values refer to invisible employment estimates based on upper- and lower-bound labour productivity references in relation to roundwood removals, respectively. The minimum and maximum total employment are the aggregation of visible employment from all sub-sectors with the invisible employment estimates at the minimum and maximum level, respectively.

5. Discussion

Looking at the forestry sub-sector's situation of emerging and developing countries where invisible employment has been estimated, we can reasonably conclude that our invisible employment estimates cover the majority of informal employment and subsistence. In general, the high prevalence of informal employment can also limit improving working conditions, growing labour productivity and increasing economic development [42]. In particular, for the forest sector, the expansion of subsistence activities and high demand for charcoal and firewood are also key factors of forest degradation and deforestation [40,43,44].

Furthermore, we would like to address the reliability of our estimates through prior studies and in regards of our extended methodological approach. To our knowledge, there are two relevant past studies which seek to estimate the magnitude of total direct employment in the forest sector on a global level (Table 5). When comparing our estimates with the previously reported information, certainly, different input data, estimation procedures and time reference result in a discrepancy to our estimates.

Table 5. Comparison our employment estimates (person FTE) with the prior studies.

Source	Year	Forestry and Logging		Wood-Based Industries		Total
		Formal	Informal	Formal	Informal	
Poschen; ILO [5,6]	Late 1990s	4.7	13.6	12.7	16	47
FAO [3]	2010–2011	3.5	9.2	9.7	31.8	54
		Visible	Invisible			
Our estimates	2015	12.4	36	15.5	-	64

Notes: Visible employment refers to officially reported employment statistics compiled by FAO covering formal and informal employment estimates. Invisible employment is estimated applying our procedure and could cover some formal employment, particularly for developed countries, which are part of our estimation.

Our invisible employment estimates for the forestry and logging sub-sector, excluding gathering of NWFP, at the lower bound are about three to four times higher than the estimations from FAO; Poschen and ILO [3,5,6]. The discrepancies between our estimates

and the previous studies can be explained as follows: Firstly, the estimates from FAO [3] account only for income-generating activities as employment, i.e., charcoal production and firewood for urban use. Similar to Poschen and ILO [5,6], our invisible employment is defined following the broad definition of informal employment from ILO covering informal jobs and household subsistence. Secondly, our invisible employment includes estimates for 59 countries with missing employment statistics that cannot be entirely considered as informal and subsistence employment, particularly for developed country cases. Lastly, all three studies calculated informal employment primarily using statistics of wood fuel production, where removal quantity demonstrated an increasing trend from the year 2000 onwards. Higher informal employment estimates can be expected from the late 1990s to 2015 given that labour productivity and working conditions remain unchanged. Overall our study attributes the extend of informal employment and subsistence workforce and confirms that the numbers of persons to whom forests are the primary sources of livelihood are still underreported in the official statistics.

Based on our assumption, the majority of invisible employment estimates are derived from activities related to firewood and wood for charcoal collection. Nevertheless, four countries are also identified for reporting implausible employment figures for industrial roundwood harvesting, among them, Brazil and Indonesia. Using the officially reported production statistics and the lower-bound labour productivity rate, approximately 15 per cent of the total invisible employment estimates in both countries are from industrial roundwood harvesting. Small and medium-size forest enterprises (SMFE) are prominent in the forest industries in Indonesia [45] and to some extent also for the case of Brazil [46]. Albeit these two countries produce large volumes of legal timber, it is evident that they are also the main source of illegal wood supply [47]. Small-scale informal logging producers are not automatically and necessarily illegal; however, an apparent increase in illegal timber production by the informal small-scale producer has been identified [48]. From this perspective, illegal logging can be one crucial factor explaining the invisible workforce detected in our analysis. Nevertheless, further in-depth studies are required to address and identify causations of the informal forest economy. Moreover, our calculations are based on officially reported industrial roundwood statistics, which may primarily refer to the formal forest sector and may not capture some domestic illegal timber activities [47].

Not every country is identified having invisible employment applying our procedure, inter alia, India and China. Having not identified invisible employment, however, does not imply that there are no persons engaged in informal jobs and household subsistence activities in those countries. Generally, India is one of the countries with a high number of informal employment, with approximately 321 million people in 2019 [49]. Agriculture including forestry accounts for 47 percent of the total informal employment. It is therefore expected that also informal employment exists in the Indian forest sector. Considering the official employment statistics used in our calculation, India reported the highest amount of employment in the forestry sub-sector, with about 6 million persons FTE in 2015. The number has remained stagnant since 1990. Whiteman et al. [2] pointed out that this high number already includes some estimates of informal or unpaid workforce for activities such as firewood and fodder collection. This might be one reason why we could not identify invisible employment in our analysis. However, the forest related industry in India is strongly diverse, covering a wide range of services and entrepreneurs from individuals working informally to SMFE [50]. Agrawal et al. [51] reviewed that the Indian SMFE sector underreports the number of employees to avoid compliance with national labour laws. In that sense, it can be expected that the true number of persons employed in the forestry sub-sector and the overall forest sector in India is higher than the ones reported in the official statistics.

China is one of the countries with a high number of formal employment, representing 29 per cent of global formal forest-based employment [29,52]. However, Liu et al. [52] indicated that the proportion of formal employment in the Chinese state-owned forestry system is less than 3 per cent of the total Chinese workforce during 2006–2010, excluding

collective enterprises and self-employed practitioners. Due to its flexibility, informal employment is estimated as the main form of the Chinese forest-based employment (ibid). However, for the case of China there is no further evidence whether the numbers reported in FRA 2020 also includes any informal employment. One reason why we could not quantify invisible employment might be related to the underreported volume of total roundwood removals in production statistics.

Two significant methodological limitations of this study must be acknowledged. Firstly, the officially reported employment statistics compiled by FAO already included informal estimates in some countries. However, the distinction is not clear on how many of the reported numbers refer to as formal and informal ones, which could lead to an overestimate of formal employment number. Furthermore, if we assume that the official employment statistics are formal and estimate the informal employment based on this reported number, we may also overestimate total employment in the forestry sub-sector. However, our analytical approach to firstly identify countries whose labour productivity rates are implausible (analytical framework step 3) is one way to overcome this uncertainty. Secondly, our invisible employment estimation hinges on labour productivity rates and production statistics of roundwood, industrial roundwood and wood fuel. Theoretically, labour productivity is one critical measurement for the efficiency of the production process and to capture the use of labour inputs. Time spent on collecting wood fuel can vary depending on several factors such as the prevailing forest conditions, distance, forest access etc. There is also a difference between collecting wood fuel for household subsistence or commercial purposes. Under the assumption that households collect firewood for subsistence demand, the computed labour productivity is likely to have not reached the maximum level yet. A low productivity rate used in the estimation can thus inflate the size of invisible employment.

Another key indicator involved in our estimation is the amount of roundwood removals, i.e., industrial roundwood and wood fuel, as reported by FAOSTAT. Amount of roundwood removals stem from all sources within each country including public, private and informal sources. The comparable definitions and measurement units make the FAOSTAT forest products database still the most suitable source for the purpose of our analysis. Despite these facts, we acknowledge that the data are still not perfect. For example, Buongiorno [53] revealed that the main source of under-reported consumption of industrial roundwood in some nations refers to the production statistics rather than trade data. The study also reviewed that some of the underestimated production of industrial roundwood could be attributed to illegal logging, such as China, Thailand and Viet Nam (ibid). Hence, under-reported industrial roundwood and wood fuel removals may lead to an underestimation of invisible employment in those cases.

6. Conclusions

The present study provides new estimations of the possible range of invisible employment in the forestry sub-sector using official statistics from various global sources. Our study extends the current knowledge on labour employment in the forest sector by integrating cluster analysis and identifying country cases using computed labour productivity threshold. Given the complexity of the forestry and logging sub-sector in different countries and limited information on labour productivity references, our study can be considered a step forward towards a more profound technique in estimating invisible employment based on official statistics on a global level. We can conclude that at least two-thirds of the entire forestry and logging-based employment is likely to be informal including subsistence activities and with a high concentration in developing nations. The size is expected to be more prominent when adding informal and subsistence workforce from the gathering of NWFP and wood-based industrial sub-sectors. Increasing the availability of decent forestry work is still needed for various developing countries. We concede that it is challenging to closely estimate how many people are informally employed in the forest sector based on the incoherence of official production and employment statistics. Quality and consistency

of employment statistics among countries are crucial issues to enhance the understanding of socio-economic benefits derived from the forests and its related economic activities. Disaggregated-data based on employment status and gender is essential for improving the indirect estimation of the forest sector's informal economy. High estimates of invisible employment in the identified country cases point to the need for further in-depth studies at the country level to assess causes and effects of the forest-based informal workforce and decent employment in the forest sector.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/f12091219/s1, Figure S1. Hierarchical dendrogram. Figure S2. Silhouette width for all possible cluster solutions. Figure S3. Country groups and attribute variables. Table S1. One-way ANOVA test of each cluster variable. Table S2. Pairwise comparisons of means (unequal variances): Games and Howell adjusted P value. Table S3. Unweighted and weighted labour productivity (m^3 per person in FTE), by cluster. Table S4. Identified country cases and labour productivity thresholds. Table S5. Number of country cases by cluster. Table S6. Labour productivity references (m^3 per person in FTE), by cluster. Table S7. Category of countries by cluster and estimation procedure.

Author Contributions: Conceptualization, R.S.L. and J.S.; methodology, R.S.L. and J.S.; validation, R.S.L. and J.S.; formal analysis, R.S.L.; resources, J.S.; data curation, R.S.L.; writing—original draft preparation, R.S.L.; writing—review and editing, R.S.L., S.C. and J.S.; visualization, R.S.L.; supervision, J.S.; project administration, J.S.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The harmonized data employed in this study are available from the authors upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

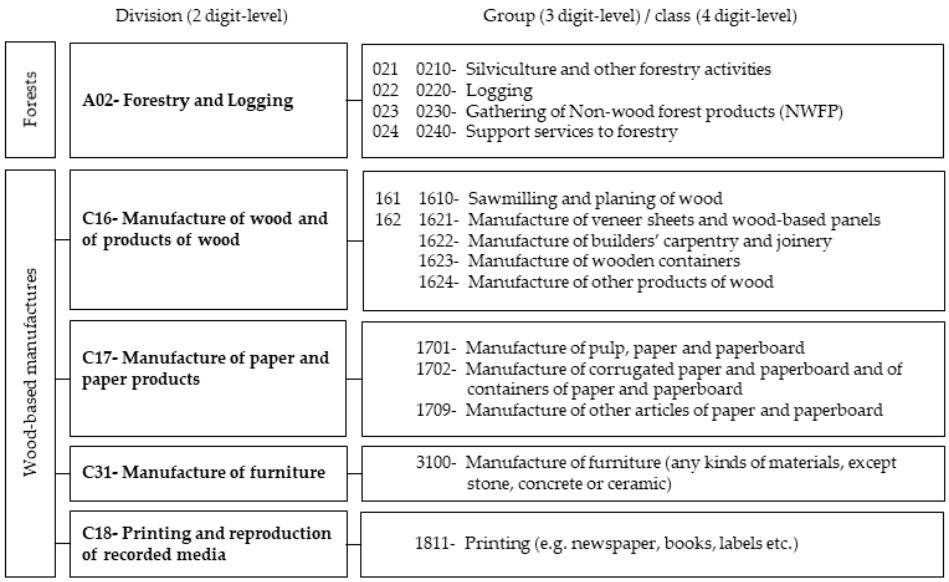

Figure A1. Forest sector definition corresponding to ISIC Revision 4. Source: constructed based on [11].

Table A1. Pairwise correlation coefficients for cluster attribute variables.

		Forest Area by Climatic Domain				
	GDP per Capita	**Boreal**	**Tropical**	**Sub-Tropical**	**Temperate**	**Non-Coniferous Roundwood**
GDP per capita	1					
Boreal forest area	0.3853 *	1				
Tropical forest area	−0.4627 *	−0.2585 *	1			
Sub-tropical forest area	0.0131	−0.0947	−0.5179 *	1		
Temperate forest area	0.3993 *	−0.0271	−0.7056 *	−0.1377 *	1	
Non-coniferous roundwood	−0.6114 *	−0.4445 *	0.6338 *	−0.0721	−0.5380 *	1

Note: * correlation significant at the 5% level.

Appendix B. Silhouette Statistics

Silhouette statistic is one of the powerful measures to index how well countries are located within the respective cluster [21,22]. The silhouette width is derived from the obtained partition and all proximities between objects (countries: c). The following explanation how to compute the silhouette width is intensively based on [21]. Supposing country c is assigned in the cluster A. If cluster A contains other countries apart from c, we can compute the average dissimilarity of country c to all other countries in the cluster A, denoted by $a(c)$. Assuming that there is Cluster C which is different from A, the average dissimilarity of country c to all countries of cluster C is d (c, C). After having all computed d (c, C), we choose the smallest number of dissimilarities which can be denoted by $b(c)$ = *minimum* d (c, C), given that C is not equal to A. We can derive cluster B for which this minimum dissimilarity is attained, referred as the neighbour of the country c. This implies that if country c is not in the cluster A, B would be the second-best option. It is assumed that dissimilarities are on a ratio scale, the value of silhouette can be thus defined into three following combinations.

- If within dissimilarity in Cluster A is smaller than the between dissimilarity to the neighbour cluster (B), the silhouette number is equal to $1 - \frac{a(c)}{b(c)}$.
- Reversely, the silhouette width is equal to $\frac{b(c)}{a(c)} - 1$, when $a(c)$ is greater than $b(c)$.
- The silhouette width is at zero when the dissimilarity of country c being in cluster A is equal to being in cluster B. Hence, it is unclear to which cluster the country c shall be assigned to.

In conclusion, all silhouette width values can be defined as $S(c) = \frac{b(c)-a(c)}{\max\{a(c)\ ,\ b(c)\}}$.

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