

Article

Risk Analysis of Regions with Suspicious Illegal Logging and Their Trade Flows

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Abstract: To eradicate illegally harvested wood sources in its domestic market, it is critical to conduct risk assessments on wood sourcing in regions with illegal loggings. It is not reliable to use a single indicator to analyze suspicious illegal logging. This study integrates three key global indicators: CPI (Corruption Perceptions Index), HDI (Human Development Indicator), and WGI (The Worldwide Governance Indicators) by applying the entropy weight method to establish a new risk indicator to rank suspicious illegal logging regions. This study aims to establish better risk indicators by considering more factors to assess the risks of illegal logging and its trade flow more reliably. By analyzing roundwood production, Myanmar, Congo, and Nigeria are rated high-risk. Countries such as the U.S., Germany, Canada, and Finland are rated low-risk.

Keywords: suspicious illegal logging; risk analysis; Human Development Indicator (HDI); The Worldwide Governance Indicators (WGI); Corruption Perceptions Index (CPI); entropy weight method



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1. Introduction

Generally, illegal logging includes a wide range of activities, such as logging without authorization, logging with illegally obtained permits, logging exceeding the area covered by the permit, and logging conserved tree species [1–4]. Violating related regulations and obtaining logging permits through bribes are also aspects of illegal logging [5–7].

Illegal logging and trade cause not only significant economic losses but also a lot of devastating environmental problems. For example, illegal logging further accelerates the emission of greenhouse gas. According to a report released in 2012 by Asia-Pacific Economic Cooperation (APEC), illegal logging and its trade severely affected the rights and interests of the APEC economies. It was estimated that it costs the global environment and society US\$60 billion annually [8]. In addition, a report from the World Bank [9] pointed out that illegal logging in the developing countries brought about a loss of more than US\$10 billion in assets and revenues. Illegal logging also causes a shortage of US\$5 billion in tax revenue around the world. An assessment by the UN Environment and Interpol showed that 10–30% of the global roundwood trade was illegal, resulting in potential losses of US\$5.1–152 billion [10].

The World Wide Fund for Nature (WWF) called attention to major issues in many developing countries that provide timber or wood products to Western countries and China: massive foreign debts, inefficiency of governance, severe poverty, failure in managing sustainable forests, and losses of woods of high values [11]. Illegal logging occurs easily due to poorly implemented laws on forest use, poor execution, possession of too many discretionary powers with insufficient information, disproportionate distribution of power among all parties in power relationships, and even weak punishments for non-

compliance [12]. Based on previous studies on factors that drive illegal logging and its associated trade, socio-economic and political-legal issues need to be addressed.

Socio-economic issues mainly involve poverty and international demands for timber which will prompt needs for timber or land. Poverty is a determinant cause of illegal logging for private use [13]. Poverty is not only a driving force of illegal logging but also a cause of poor education, which fails to raise environmental awareness and to enhance consumption knowledge [14]. In developing countries, forest-dependent communities are generally poor. All their essential necessities, from fuelwood, wood for sale, or wood products come from forests. Naturally, residents who rely on forest resources would not comply with forest laws once they believe that their livelihoods would be adversely affected by being law-abiding [15]. Furthermore, it is very likely to cause illegal logging once forests are not the most profitable land use, requiring conversion of forests into agriculture [14]. In a study seeking drivers of deforestation and forest degradation, the Global Forest Coalition [16] indicated that their strong profits are direct inducement to illegal logging. Potential underlying causes could be poor economy and lack of fuelwood or other sources of household livelihoods. In addition, Duncalfe and Watson [14] also considered that consumers' demands for cheap wood and wood products had caused illegal logging. Moreover, in most wood markets, a small price difference makes it hard to differentiate legal wood products from illegal ones. Consequently, low-cost illegal timber production is a strong incentive for illegal logging activities [13]. On top of that, after having studied illegal harvesting in Asia, Rosander [15] affirmed that the high demand for cheap timber is to be blamed as one of the major causes of illegal logging in Asian regions.

Political-legal issues generally involve the conditions of environments or regions for timber production. These conditions are concerned with the quality of personnel rather than natural factors. The causes include an unsound system, poor law enforcement, deficient management of woodland, and corruption.

For an unsound system, the government lacks sufficient staffing and funds to maintain the forests. With such inadequacy, the property rights cannot be clearly identified. Additionally, issuing of logging permits by an unsound system could also give rise to illegal wood harvesting. Palmer [17] deemed that illegal logging in Indonesia was mainly induced by the dysfunctional government. The ineffectiveness of the government was probably a result of poor taxation system or subsidy policy because a poor taxation system allowed forest rents to be deprived by private enterprises [18]. As proved by Scotland and Whiteman [19], private enterprises could gain super-profits because of the constraint set by the Indonesia government. In addition, the subsidy policy has an adverse effect and causes bribery. Once those who have profited from the subsidies, they are likely to exaggerate the effect of a subsidy policy [20]. Furthermore, the monopoly of logging permits is an example of market failure. The World Bank [21] accused Indonesia of issuing logging permits to only few corporations. Because the aforementioned reasons, nearly a half of the market was monopolized [22].

Similar to Indonesia, Cameroon also has a long wait for the issuance before the loggers can legally harvest wood. In order to avoid work delays, it is very likely that businesses opt to harvest wood illegally. This is an example where bureaucracy becomes one of the factors that fuel illegal logging [23]. Weak government mechanisms fail to sustain logging activities [24] and vague laws encourage corruption. A logging ban deteriorates illegal logging and such a policy would defeat its original target [15]. The logging ban has been proved effective only in the preliminary phase where the timber supplying replacements and forest conservation are still in the transition period [25].

As the incompetent laws fail to stop illegal operations and punishments are futile, the conflicts in a society will never cease and illegal logging practices thus proliferate. When Alemagi and Kozak [23] studied the main cause for local illegal logging in Cameroon, they observed a high frequency of conflicts coupled with an increase in the opportunities for illegal wood harvesting. For example, disputes between local departments allowed enterprises to use such divides to run illegal businesses. In addition to the disagreement

among departments and sectors, there exist conflicts among forest communities. A majority of those conflicts occur in remote areas where there is little public supervision, which therefore aggravates illegal logging practices. The incompetence of laws and regulations also directly affects economic incentives to maintain sustainable forests [13].

Likewise, the incursion of illegal logging behaviors also comes from unclear laws or laws that fail to address managing sustainable resources [14]. Similarly, as mentioned by Rosander [15], many governments are incapable of implementing forestry regulations effectively due to lack of manpower, funds, and managerial abilities. Once there is inept governance and weakened administration, illegal activities will occur. Developing countries hardly conduct enough forest surveys because most of their domestic forest resources are remote [14,26]. The officials in charge have only a very vague idea about the current condition and lack the knowledge of commercially important species. As a result, the changes in resources are hard to monitor without baseline data. An even worse scenario is that an inadequately equipped forest sector fails to monitor and to track illegal activities [27].

Corruption can be defined as the illegal exertion of authority by politicians or civil servants to pursue private interests. Forest logging that involves corruption can be deemed as illegal logging [26]. Most studies agree with what Transparency International [28] proposed, that the Corruption Perceptions Index (CPI) and the occurrence of local illegal logging are highly correlated. Such a correlation is particularly noticeable in the forest sectors of developing regions. According to the data from the CPI, of the top 20 most corrupt nations, 14 are in developing regions that are rich in forest resources. The study by Søreide [29] indicated that either a group or an individual involved in logging is likely to be in touch with corrupt activities. Rosander [15] also observed the prevalence of corruption in the whole forest sector while studying illegal logging in South-East Asia. Palmer [17] pointed out that a large part of Indonesian illegal logging came from corruption. In the report on related issues of global illegal logging and timber market, Seneca Creek Associates et al. [11] also mentioned that there existed positive correlation between suspicious log supplies and a nation's CPI. Because the convicted can access illegally harvested wood to make higher profits than legal operations, the corruption of the forest managing department still retains close ties with illegal logging practices [30]. High levels of corruption are signs of failures in both laws and administration. Apparently, a system lacking transparency can easily give rise to illegal logging [14].

One of the measures for countries to combat illegal logging is to enact laws and policies to control the import of timber, and to prevent illegally harvested wood from entering the domestic market. Currently, three of the most reputed ordinances with substantial impacts in the world are the Lacey Act Amendment, the European Union Timber Regulation (EUTR), and the Illegal Logging Prohibition Act (ILPA). These three ordinances make up the largest network that monitor timber legality, regulating timber and wood products in risk management via the Due Diligence System or the Due Care System to ensure the legality of harvested timber and of wood products traded in the domestic market. All manufacturers and importers of wood products are asked to obtain information about the origin, quantity, and suppliers of wood, and assess the possibility of any illegal timber in the supplying chain. If there is any risk, they are required to conduct risk management to lower risks. Collecting this information is the first and foremost step in the Due Care system, which is the basis for the succeeding risk assessments. That is, all suppliers of wood products must establish a secure chain of custody to track wood. Before delivering wood to these countries and their consumers, manufacturers must keep a record of all the sales and processing for tracking.

As a precautionary measure, the risks on importing products of illegally harvested wood can be greatly reduced by conducting Due Care or its risk assessment. In fact, it is difficult to assess the risks of illegal logging and its associated trade. Alternatively, it is widely accepted to use indicators to evaluate the levels of risks of suspicious illegally harvested wood and related trade. The most widely adopted indicator is the CPI developed

by Transparency International [11], but a single indicator is likely to be biased. Therefore, this study aims to establish a new risk indicator by considering more factors to assess the risks of illegal logging and its trade flow more reliably.

2. Materials and Methods

2.1. Variables for Risk Indicators

Regarding the choice of variables for a risk indicator, the driving factors for illegal logging are international demand for timber, poverty, deficiency in law enforcement, poor forest management, and corruption. Although many factors are related to illegal logging, there is hardly one single indicator that can cover all the driving factors. Hence, the option of an indicator by this study has been made by a comprehensive evaluation of all the factors.

The Human Development Indicator (HDI), released by the United Nations Development Programme (UNDP) in 1990, was adopted to address the socio-economic issues. The HDI is estimated by considering the expected lifespan, the length of school education (including the average years of education and expected years of education), and estimation of per capita national income [31]. When there is a discrepancy in education levels coupled with a low national income per capita, illegal logging activities are very likely to happen in responding to the increases in the international timber demands [13,15]. In this study, regions were classified into four categories (extremely high, high, medium, and low) to assess the standard of growth of socio-economic development.

The Worldwide Governance Indicator (WGI) [32] is an indicator to assess if a system is unsound and if the law enforcement is weak by evaluating the following six factors: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness (GE), Regulatory Quality, Rule of Law (RL), and Control of Corruption in governments. The WGIs have been calculated for 215 regions since 1996, based on the data collected from questionnaires conducted by governments surveying on many enterprises, citizens, and experts.

The Corruption Perception Indicator (CPI) developed by Transparency International has been releasing annually as an indicator for assessing corruption since 1995. The CPI is evaluated by a survey that collects opinions from businesspersons and experts. Before the year 2011, the CPI was evaluated by the international business risks based on the previous two years. The scores of the assessment are between 0 and 10. The higher a score that a country achieves, the less corruption there is in a country. Since 2012, the ranking of CPI has been made based on the level of corruption perceptions compared to other regions. The scores of the assessment have been changed to a scale of 0 to 100 for ranking. What remains unchanged is that the higher a score a country achieves, the less corruption there is in the country.

2.2. Data Sources

To establish a risk indicator for assessing suspicious illegal logging regions, the data sources of this study coming from the three indicators were applied to 182 regions around the world: HDI of 2004–2014, WGI, and CPI. Data from developing regions are usually not sufficient despite the fact that those regions are severely affected by illegal logging. When there is missing data, an alternative is to estimate by the values of the year before and the year after. This study also adopted the data of the production and the export volume of roundwood of the period 2004–2014 from Forestry Production and Trade of FAO (Food and Agriculture Organization of the United Nations) for the succeeding risk ranking comparisons.

2.3. Developing Risk Indicator for Suspicious Illegal Logging Regions

To assess suspicious illegal logging, the entropy weights for the HDI, WGI, and CPI attributes were first evaluated. The entropy value in the entropy weight method can be interpreted as “uncertainty”. The larger the entropy value, the more random the data

is. The entropy value was used here to represent the relative weight of attributes. A risk indicator can then be obtained through the entropy weighted sum of HDI, WGI, and CPI.

Assume that the data matrix X_{ij} with m alternatives and n variables of indicators where $i \in \{1, 2, \dots, m\}$ and $j \in \{1, 2, \dots, n\}$. The steps of calculation are detailed as follows:

1. Because the scales of the variables are not the same, it is necessary to standardize the data. The standardized data matrix of X_{ij} is represented as the following notation d_{ij} :

$$d_{ij} = X_{ij}/X_{kj}, \quad (1)$$

where X_{ij} is the value of the j -th variable in the i -th alternative and X_{kj} is the observed value of the j -th variable in the k -th alternative.

2. Transform d_{ij} to the probability of occurrence P_{ij} as follows:

$$P_{ij} = d_{ij}/D_j, \text{ for } i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (2)$$

where $D_j = \sum_{i=1}^m d_{ij}$.

3. The weighted value e_j of all variables using P_{ij} is calculated as follows:

$$e_j = -k \sum_{i=1}^m P_{ij} \cdot \ln P_{ij}, \text{ for } j = 1, 2, \dots, n \quad (3)$$

where $k = 1/(n \cdot m)$ such that $0 \leq e_j \leq 1$.

4. Calculate the relative weighting λ_j between variables as follows:

$$\lambda_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)} = \frac{1 - e_j}{n - \sum_{j=1}^n e_j} = \frac{1 - e_j}{n - E}, \quad (4)$$

where $E = \sum_{j=1}^n e_j$; $(1 - e_j)$ represents the degree of certainty for the j -th variable and $(n - E)$ represents the overall degree of certainty for all variables.

5. Calculate the weights of all variables using normalization as follows:

$$B_j = \lambda_j / \sum_{j=1}^n \lambda_j \quad (5)$$

The weighted sum of HDI, WGI, and CPI leads to the Risk Index (RI) for a suspicious illegal logging region, which is demonstrated as follows:

$$RI = BHDI \times HDI + BWGI \times WGI + BCPI \times CPI \quad (6)$$

where BHDI, BWGI, and BCPI are the weighted value of the HDI, WGI and CPI variables, respectively, through normalization.

The RIs for suspicious illegal logging regions could be classified into five categories as Low (>0.8), Medium Low (0.6–0.8), Medium (0.4–0.6), Medium High (0.2–0.4), and High (<0.2).

3. Results

3.1. Entropy Weights for HDI, WGI, and CPI Indicators

According to [33,34], there are two stages to measure the index value of suspicious illegal logging risk in various regions. The first stage is the estimation of the index entropy weight value, and the second stage uses the entropy weight value to determine the suspected illegal logging risk index value of all regions in the world.

This study estimates the weights of indicators with the entropy weight method. By collecting the data (2004–2014) from 182 regions, we used the entropy weight method to

measure the weights of HDI, WGI, and CPI. The results indicate that the weight of CPI ranks the highest and WGI comes second (Table 1).

3.2. The Risk Indicators for Suspicious Illegal Logging Regions

Of all the 182 regions, there are 19–23 regions listed as low-risk. The lowest-risk (>0.95) regions include Switzerland, Sweden, Finland, Denmark, and New Zealand. There are 20–37 high-risk regions and among them, the highest-risk (<0.1) ones are Chad, Republic of South Sudan, the Democratic Republic of Congo, Sudan, Central African Republic, and Afghanistan. By region, Africa is relatively high-risk. Regions in Africa belong mainly to high and medium-high risk groups, while in Asia, a majority of the regions are medium high- and medium low-risk. Europe and the rest of the world are mainly listed as low-risk (Table 2).

Table 1. Entropy weights for Human Development Indicator (HDI), Worldwide Governance Indicators (WGI), and Corruption Perceptions Index (CPI) indicators.

Indicator	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CPI	0.453	0.455	0.431	0.436	0.433	0.457	0.453	0.457	0.451	0.307	0.311	0.361
HDI	0.211	0.218	0.227	0.224	0.228	0.210	0.226	0.209	0.208	0.267	0.256	0.258
WGI	0.337	0.327	0.341	0.340	0.339	0.333	0.321	0.334	0.341	0.426	0.433	0.381

Table 2. Comparison of the risk levels of suspicious illegally harvested timber in all continents.

Year	Risk Level	Africa	Asia	Oceania	Europe	North and Central America	South America	Total
2004	high-risk	21	8	1	0	1	1	32
	medium	24	20	2	9	6	7	68
	high-risk	6	8	4	9	8	2	37
	medium-risk	1	10	1	8	4	2	26
	low-risk	0	2	2	13	2	0	19
	Total	52	48	10	39	21	12	182
2006	high-risk	21	12	1	0	1	0	35
	medium	23	19	2	8	5	8	65
	high-risk	8	7	4	7	9	2	37
	medium-risk	0	7	1	10	4	2	24
	low-risk	0	3	2	14	2	0	21
	Total	52	48	10	39	21	12	182
2008	high-risk	24	11	1	0	1	0	37
	medium	20	18	5	6	5	7	61
	high-risk	6	9	2	8	8	3	36
	medium-risk	2	7	0	12	5	2	28
	low-risk	0	3	2	13	2	0	20
	Total	52	48	10	39	21	12	182

Table 2. Cont.

Year	Risk Level	Africa	Asia	Oceania	Europe	North and Central America	South America	Total
2010	high-risk	21	11	1	0	1	0	34
	medium	23	18	4	6	8	8	67
	high-risk	6	9	3	10	4	2	34
	medium-risk	2	7	0	10	5	2	26
	low-risk	0	3	2	13	3	0	21
	Total	52	48	10	39	21	12	182
2012	high-risk	15	4	0	0	1	0	20
	medium	27	19	2	3	3	5	59
	high-risk	8	15	6	9	8	5	51
	medium-risk	3	7	0	13	6	1	30
	low-risk	0	3	2	14	3	1	23
	Total	53	48	10	39	21	12	183
2014	high-risk	16	5	0	0	1	0	22
	medium	27	15	2	3	4	5	56
	high-risk	8	17	6	9	8	5	53
	medium-risk	2	8	0	13	6	2	31
	low-risk	0	3	2	14	2	0	21
	Total	53	48	10	39	21	12	183

These results show that the proportion of suspicious illegal logging and its trade is within 10% in low-risk countries like Canada and America. In medium low-risk regions like South Korea, Taiwan, Slovakia, and Estonia, the proportion for suspicious illegal logging and trade is 10–50%. In regions ranked as medium-risk such as Bulgaria, Columbia, Costa Rica, Thailand, Malaysia and Mexico, the proportion for suspicious illegal logging and trade is 25–70%. As for those ranked medium high-risk like China, Ecuador, Gabon, Nicaragua, Indonesia, Libya, Honduras, Benin, Albania, Russia, Bolivia, Ghana, Peru, Mozambique, the Philippines, and Laos, the proportion for suspicious illegal logging and trade is 20–90%. Finally, regions like Papua New Guinea, Cameroon, Myanmar, Niger, Equatorial Guinea and Congo belong to the high-risk group with a proportion of 50–90% for their suspicious illegal-logging and trade [7,11,13]. The ranking of risks calculated by this study is similar to the trend in suspicious illegal logging rates estimated by prior studies. Regarding regions of low and of medium low risks in the ranking, the proportion of their suspicious illegal logging and trade is within 50%. However, the proportion of suspicious illegal logging and trade of high-risk regions is greater than 50%. As for regions ranked medium and medium high-risk, the proportion for suspicious illegal logging and trade is 20–90%.

3.3. Risk Ranking for Global Top 20 Regions of Roundwood Production and Exports

Regions ranked top 20 in global roundwood production and exports from 2004 to 2014 are taken as examples to examine their global risk rankings. In terms of the volume of roundwood production, Myanmar, Democratic Republic of the Congo, and Nigeria were ranked high-risk during this period of time while the U.S., Germany, Canada, Sweden, and Finland were ranked low-risk. The production volume of roundwood among the top 20 regions from 2004 to 2014 makes up more than 70% (71–73%) of the annual total (Table 3). In terms of quantity, those regions ranked medium high-risk are the highest in proportion.

Table 3. Risk ranking for global top 20 regions of roundwood production.

Risk Level\ Regions	2004	2006	2008	2010	2012	2014	2004~2014
high-risk	Myanmar, Democratic Republic of the Congo, Nigeria, Ethiopia	Myanmar, Democratic Republic of the Congo, Nigeria, Ethiopia	Myanmar, Democratic Republic of the Congo, Nigeria, Ethiopia	Myanmar, Democratic Republic of the Congo, Nigeria, Ethiopia	Myanmar, Democratic Republic of the Congo, Nigeria	Myanmar, Democratic Republic of the Congo, Nigeria	Myanmar, Democratic Republic of the Congo, Nigeria, Ethiopia
medium high-risk	Russia, Uganda, Indonesia, India, China, Ghana	Russia, Uganda, Indonesia, India, China, Ghana	Russia, Uganda, Indonesia, India, China	Russia, Uganda, Indonesia, India, China, Mexico	Ethiopia, Russia, Uganda, Indonesia, India	Ethiopia, Russia, Uganda, India	Russia, Uganda, India, Indonesia, China
medium-risk	Mexico, Brazil, Poland	Mexico, Brazil, Poland	Ghana, Mexico, Brazil, Poland	Ghana, Brazil	China, Mexico, Ghana, Brazil	Indonesia, China, Mexico, Ghana, Brazil	Mexico, Ghana, Brazil
medium low-risk	France, Chile	Chile	Chile, France	Poland, Chile, France	Poland	Poland, Chile	Poland, Chile
low-risk	United States, Germany, Canada, Sweden, Finland	France, United States, Germany, Canada, Sweden, Finland	United States, Germany, Canada, Sweden, Finland	United States, Germany, Canada, Sweden, Finland	Chile, France, United States, Germany, Canada, Sweden, Finland	France, United States, Germany, Canada, Sweden, Finland	France, United States, Germany, Canada, Sweden, Finland
high-risk (%)	7.95	8.14	8.52	8.52	5.54	5.57	8.36
medium high-risk (%)	29.06	29.12	28.87	30.74	22.69	19.44	28.75
medium-risk (%)	9.05	8.66	9.98	7.80	19.18	21.59	9.16
medium low-risk (%)	2.69	1.32	3.11	3.93	1.05	2.71	2.43
low-risk (%)	23.85	24.59	20.15	19.74	22.59	21.46	22.57
Proportion of roundwood production in the top 20 regions (%)	72.61	71.83	70.63	70.73	71.06	70.77	71.27
Total production (Million M ³)	3547	3545	3458	3526	3614	3680	21,371

As is seen from the export volume of roundwood, Myanmar was ranked high-risk while France, the U.S., Germany, Canada, Australia, Sweden and New Zealand were ranked low-risk (Table 4). From 2004 to 2014, the roundwood production of the top 20 regions makes up about 80% (78–84%) of the annual total.

Table 4. Risk ranking for global top 20 regions of roundwood exports.

Risk Level \ Regions	2004	2006	2008	2010	2012	2014	2004~2014
high-risk	Myanmar, Papua New Guinea	Myanmar, Papua New Guinea	Myanmar, Papua New Guinea	Myanmar, Papua New Guinea	Myanmar,	Myanmar,	Myanmar,
medium high-risk	Belarus, Ukraine, Russia, Solomon Islands	Belarus, Ukraine, Russia, Solomon Islands	Belarus, Ukraine, Russia, Solomon Islands	Belarus, Ukraine, Russia, Solomon Islands	Papua New Guinea, Belarus, Ukraine, Russia, Solomon Islands	Papua New Guinea, Belarus, Ukraine, Russia, Solomon Islands	Papua New Guinea, Belarus, Ukraine, Russia, Solomon Islands
medium-risk	Malaysia, Latvia, Slovakia, Poland, Lithuania, Czech Republic	Malaysia, Latvia, Poland	Malaysia, Poland, Lithuania	Malaysia, Latvia, Slovakia	Malaysia		Malaysia
medium low-risk	Estonia, France	Slovakia, Lithuania, Czech Republic, Estonia	Latvia, Slovakia, Czech Republic, Estonia, France	Poland, Lithuania, Czech Republic, Estonia, France	Latvia, Slovakia, Poland, Lithuania, Czech Republic, Estonia	Latvia, Malaysia, Slovakia, Poland, Lithuania, Czech Republic, Estonia	Latvia, Slovakia, Poland, Lithuania, Czech Republic, Estonia
low-risk	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand	France, United States, Germany, Canada, Australia, Sweden, New Zealand
high-risk (%)	2.90	3.24	3.50	4.15	1.79	1.66	1.54
medium high-risk (%)	39.08	41.86	36.65	25.57	24.98	24.69	33.48
medium-risk (%)	13.51	6.83	5.10	11.22	2.53	0.00	3.38
medium low-risk (%)	5.53	5.19	11.39	13.33	14.26	16.60	11.89
low-risk (%)	23.13	26.88	25.78	27.90	36.70	34.84	31.43
Proportion of roundwood production in the top 20 regions (%)	84.16	84.00	82.41	82.17	80.27	77.80	81.73
Total exports (Million M ³)	121	135	119	112	119	142	748

3.4. Trade-Flow of Roundwood Exported by the High-Risk Rank Regions

Concerning the high-risk rank like Myanmar and Papua New Guinea, the proportion of exports to China is the highest, and it has been increasing. The proportion of the export

of roundwood from Myanmar to China increased from 68% in 2004 to 80% in 2014 of the industry total. The average rate was 79% (Table 5). As for Papua New Guinea, the proportion of its export of roundwood to China increased from 67% in 2004 to 88% in 2014 of the industry total. The average rate was 86% (Table 6).

Table 5. Trade-flow of industrial roundwood exported by Myanmar (M³).

Year	China	India	Japan	South Korea	Thailand	Philippines	Vietnam	Malaysia	Other Regions	Total
2004	4,055,794	478,086	404,871	321,228	126,156				584,829	5,970,964
2006	8,294,023	321,855	547,685	198,638	189,212	112,733		3425	458,817	10,126,388
2008	8,960,453	691,747	552,884	125,000	210,461	67,114	13,000	150,416	1,018,176	11,789,251
2010	11,289,276	781,083	239,245	251,759	47,934	35,299		21,474	387,414	13,053,484
2012	11,498,366	2,148,538	245,981	354,898	58,838	258,970	256,492	62,549	312,137	15,196,769
2014	16,633,750	3,103,785	121,485	240,238	58,344	33,053	219,852	78,743	208,146	20,697,396
Total	60,731,662	7,525,094	2,112,151	1,491,761	690,945	507,169	489,344	316,607	2,969,519	76,834,252

Table 6. Trade-flow of industrial roundwood exported by Papua New Guinea (M³).

Year	China	India	Japan	South Korea	Philippines	Vietnam	Thailand	Malaysia	Other Regions	Total
2004	2,264,023	133,282	302,684	310,273					363,254	3,373,516
2006	7,256,753	112,000	512,371	196,240	112,711		77,969		87,630	8,355,674
2008	8,741,972	540,429	378,285		66,700		111,416	1211	75,498	9,915,511
2010	9,954,471	570,907	232,804	248,899	35,244			37	145,299	11,187,661
2012	10,391,825	695,301	241,076	350,213	258,761	256,017	58,805	43,619	297,894	12,593,511
2014	15,341,647	1,279,304	117,135	239,531	33,053	216,637		55,660	192,844	17,475,811
Total	53,950,691	3,331,223	1,784,355	1,345,156	506,469	472,654	248,190	100,527	1,162,419	62,901,684

4. Discussion and Conclusions

This study seeks to improve the risk indicators of illegal logging in various regions. In addition to the CPI, the formulation of risk indicators also considers the driving factors of illegal logging behavior to estimate the national risk indicators of suspected illegal logging. There are two reasons for illegal logging. The first is economic issues. The increasing demand for cheap timber or international timber demand results in illegal logging. In addition, poverty causes insufficient education, further leading to a lack of environmental awareness. In developing countries, communities that mostly rely on forests are generally poor. When compliance with forest laws will endanger people's livelihoods, they are no longer willing to comply. The high demand for cheap timber is the main cause of illegal logging in some Asian countries.

The second reason is the lack of public power. When law enforcement is not effective in a region and punishment is ineffective, there are bound to be many conflicts in society. Under the ineffectiveness of legal restraint, conflicts continue to appear in society, and these conflicts are likely to lead to illegal logging. Countries with a high frequency of conflicts have jointly increased the opportunities for illegal logging of timber. Most of the domestic forest resources of developing countries are located in remote areas. They are usually large areas of vegetation, vast and rich in a variety of complex ecosystems. There are few sufficient forest surveys, and the basic information is not fully grasped, so the probability of illegal logging is increased. Actually, economic and political-legal issues are not individually independent, but are related to each other. Similarly, illegal activities are

induced by a series of dimensions, and these dimensions may also interact with each other or be causal to each other.

According to the results of this study, the risks of trading illegal logging can be greatly reduced if high-risk regions with suspicious illegal logging are known. However, there are plenty of factors for illegal logging, and there is no way to accurately obtain the data regarding the actual illegal logging practice and its associated trade. Additionally, the whole supply chain from logs to products is complicated, which further fuels illegal logging and its related trade. Therefore, a representative indicator is valuable for assessing illegal logging and its associated trade. Conventionally, CPI is the most widely used indicator. However, a single indicator is less reliable. This study applies three indicators HDI, WGI, and CPI to assess illegal logging and associated trade in a more comprehensive manner. The three indicators of HDI, WGI, and CPI are considered to establish a better risk indicator by the entropy weight method.

The results of this study show that, by studying the global roundwood production from 2004 to 2014, the regions of Myanmar, the Democratic Republic of the Congo, and Nigeria are all ranked high-risk. By contrast, the U.S., Germany, Canada, Sweden, and Finland are all ranked low-risk. Moreover, analyzing roundwood exports, Myanmar is ranked high-risk while France, the U.S., Germany, Canada, Australia, Sweden, and New Zealand are ranked low-risk. Risk ranks are not absolute indicators, but rather relative compared results among regions all over the world, which can be references for a Due Diligence System. With the assessment results of the risk ranking, the demand for roundwood from high-risk regions can be reduced. When it is inevitable to import from those high-risk regions, some measures to mitigate the risks are suggested to take in order to ensure the legality of wood products.

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References

1. Brack, D.; Gray, K.; Hayman, G. *Controlling the International Trade in Illegally Logged Timber and Wood Products*; Royal Institute of International Affairs: London, UK, 2002.
2. Brack, D. Illegal logging and the illegal trade in forest and timber products. *Int. For. Rev.* **2003**, *5*, 195–198. [\[CrossRef\]](#)
3. Watson, A. *The Proposed New Zealand Approach Towards Addressing Illegal Logging and Associated Trade Activities*; Ministry of Foreign Affairs: Wellington, New Zealand, 2006.
4. Dieter, M. Analysis of trade in illegally harvested timber: Accounting for trade via third party countries. *For. Policy Econ.* **2009**, *11*, 600–607. [\[CrossRef\]](#)
5. Report for the MCPFE Workshop 2005. In Proceedings of the Ministerial Conference on the Protection of Forests in Europe (MCPFE) Combating Illegal Harvesting and Related Trade of Forest Products in Europe, Madrid, Spain, 3–4 November 2005.
6. Ottitsch, A.; Kaczmarek, K.; Kazusa, L.; Raae, K. Study on the Issues of Illegal Logging and Related Trade of Timber and Other Forest Products Issues in Europe. Available online: <https://foresteurope.org/wp-content/uploads/2016/08/Study-on-the-issues-in-Europe.pdf> (accessed on 20 January 2021).
7. World Wildlife Fund (WWF). *Illegal Wood for the European Market—An Analysis of the EU Import and Export of Illegal Wood and Related Products*; WWF European Policy Office: Bruxelles, Belgium, 2008.
8. Asia-Pacific Economic Cooperation (APEC). 2012 Work Plan—Experts Group on Illegal Logging and Associated Trade 2012. Available online: <https://www.apec.org/Groups/SOM-Steering-Committee-on-Economic-and-Technical-Cooperation/Working-Groups/Illegal-Logging-and-Associated-Trade> (accessed on 20 January 2021).
9. World Bank. *Strengthening Forest Law Enforcement and Governance—Addressing a Systemic Constraint to Sustainable Development*; World Bank: Washington, DC, USA, 2006.

10. Nellemann, C.; Henriksen, R.; Kreilhuber, A.; Stewart, D.; Kotsovou, M.; Raxter, P.; Mrema, E.; Barrat, S. (Eds.) *The Rise of Environmental Crime—A Growing Threat to Natural Resources, Peace, Development and Security. A UNEP-INTERPOL Rapid Response Assessment 2016*; United Nations Environment Programme and RHIPTO Rapid Response–Norwegian Center for Global Analyses: Nairobi, KY, USA, 2016.
11. Seneca Creek Associates. *LLC and Wood Resources International. Illegal Logging and Global Wood Markets: The Competitive Impacts on the U.S. Wood Products Industry*; Seneca Creek Associates: Montgomery County, MD, USA, 2004.
12. Koyuncu, C.; Yilmaz, R. The Impact of Corruption on Deforestation: A Cross-Country Evidence. *J. Dev. Areas* **2008**, *42*, 213–222. [CrossRef]
13. Contreras-Hermosilla, A.; Doornbosch, R.; Lodge, M. The Economics of Illegal Logging and Associated Trade. Round Table on Sustainable Development 2007, SG/SD/RT(2007)1/REV For Official Use. Available online: <https://www.oecd.org/sd-roundtable/papersandpublications/39348796.pdf> (accessed on 20 January 2021).
14. Duncalfe, A.; Watson, A. *Illegal Logging: New Zealand Perspectives on a Global Problem. RM Update*; Ministry of Agriculture and Forestry: Thimphu, Bhutan, 2005.
15. Rosander, M.N. Illegal Logging: Current Issues and Opportunities for Sida/SENSA Engagement in Southeast Asia. Available online: <https://www.recoftc.org/publications/0000160C> (accessed on 20 January 2021).
16. Global Forest Coalition Getting to the Roots: Underlying Causes of Deforestation and Forest Degradation, and Drivers of Forest Restoration. Available online: <https://www.globalforestcoalition.org/wp-content/uploads/2010/11/Report-Getting-to-the-roots1.pdf> (accessed on 20 January 2021).
17. Palmer, C.E. The Extent and Causes of Illegal Logging: An Analysis of a Major Cause of Tropical Deforestation in Indonesia. Available online: <https://discovery.ucl.ac.uk/id/eprint/17588/1/17588.pdf> (accessed on 20 January 2021).
18. Day, B. Who's Collecting the Rent? Taxation and Super Profits in the Forest Sector. Environment Department Working Paper 1998. 123p. Available online: https://www.ucl.ac.uk/cserge/Forest_Rents.pdf (accessed on 20 January 2021).
19. Scotland, N.; Whiteman, A. Economic Rent in the Indonesian Forest Sector Volume 5: Financial and Management Considerations 1997. Available online: <http://documents1.worldbank.org/curated/en/939711468268800796/pdf/117580WP0Box385411B00PUBLIC0.pdf> (accessed on 20 January 2021).
20. Pearce, D.W.; von Finckenstein, D. Advancing Subsidy Reforms: Towards a Viable Policy Package. Paper prepared for Fifth Expert Group Meeting. In *The Greening of Financial Markets 1999*; Springer: Berlin/Heidelberg, Germany, 1999; pp. 181–302.
21. World Bank. *The Challenges of World Bank Involvement in Forests: An Evaluation of Indonesia's Forests and World Bank Assistance 2000*; World Bank: Washington, DC, USA, 2000.
22. Brown, D.W. Addicted to Rent: Corporate and Spatial Distribution of Forest Resources in Indonesia: Implications for Forest Sustainability and Government Policy. Available online: <https://studylib.net/doc/11937794/addicted-to-rent---corporate-and-spatial-distribution-of-> (accessed on 20 January 2021).
23. Alemagi, D.; Kozak, R.A. Illegal logging in Cameroon: Causes and the path forward. *For. Policy Econ.* **2010**, *12*, 554–561. [CrossRef]
24. Repetto, R.; Gillis, M. *Public Policies and the Misuse of Forest Resources. A World Resources Institute Book*; University of Cambridge Press: New York, NY, USA, 1998.
25. FAO and International Tropical Timber Organization (ITTO). *Best Practice for Improving Law Compliance in the Forestry Sector 2005*; FAO and International Tropical Timber Organization (ITTO): Rome, Italy, 2005.
26. Contreras-Hermosilla, A. The Underlying Causes of Forest Decline. Available online: https://www.cifor.org/publications/pdf_files/OccPapers/OP-030.pdf (accessed on 20 January 2021).
27. McGrath, W.; Grandalski, R. *Forest Law Enforcement-Policies, Strategies and Technologies*; World Bank: Washington, DC, USA, 2004.
28. Transparency International. Corruption Perceptions Index 2017. Available online: http://www.transparency.org/news/feature/corruption_perceptions_index_2016 (accessed on 20 January 2021).
29. Søreide, T. *Forest Concessions and Corruption*; U4 Anti-Corruption Resource Centre: Bergen, Norway, 2007.
30. Tangmar, M. Corruption in the Forestry Sector and Illegal Logging-the Problem, Its implications and Approaches to Combating It. Available online: <http://forestindustries.eu/sites/default/files/userfiles/1file/Corruption%20in%20the%20forestry%20sector%20and%20illegal%20logging%20-%20GTZ-%20June%202009.pdf> (accessed on 20 January 2021).
31. United Nations Development Programme (UNDP) Human Development Index (HDI), 2017. Available online: <http://hdr.undp.org/en/content/human-development-index-hdi> (accessed on 20 January 2021).
32. World Bank. Worldwide Governance Indicators (WGI) 2017. Available online: <http://info.worldbank.org/governance/wgi/index.aspx#home> (accessed on 20 January 2021).
33. Rahmati, O.; Pourghasemi, H.R.; Melesse, A.M. Application of GIS-based data driven random forest and maximum entropy models for groundwater potential mapping: A case study at Mehran Region, Iran. *Catena* **2016**, *137*, 360–372. [CrossRef]
34. Li, X. TOPSIS model with entropy weight for eco geological environmental carrying capacity assessment. *Microprocess. Microsyst.* **2021**, *82*, 103805. [CrossRef]