Big Data-Driven Risk Analysis of Environmental Grievances in the Southeast Asia Palm Oil Industry for Sustainable Decision-Making

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Abstract

The expansion of the palm oil industry affects environmental sustainability. This study aims to assess palm oil's environmental grievances reported pre- and post-Covid-19. A hybrid of data-driven and multicriteria decision-making analyses was used to analyze unstructured data from nine companies' grievance logs. A total of 884 cases with the trend peaking in 2019. Predominantly deforestation, a total of 564 cases affecting ~66,716.23 ha in Indonesia, 312 cases affecting ~49,704.97 ha in Malaysia, 6 cases affecting ~43,500 ha in Papua New Guinea, and 2 cases in the Philippines. Network analysis reveals that the environmental grievances affected multiple companies, with WILMAR suppliers at the center. On average, companies take ~100 days to resolve. Clustering analysis shows Sime Darby Oil, WILMAR, KLK, and Mewah Group have influences on addressing grievances in high-risk provinces. Quantile-quadrant analysis reveals that provinces in Kalimantan, Pahang, and Sarawak are in the high-risk quadrant and therefore require immediate mitigation plans. This finding points toward the need for the formation of a private consortium among identified key players and local government in the high-risk region as a new strategy to improve management of environmental sustainability issues that predominantly involve deforestation.

Keywords: *big data-driven risk analysis, deforestation, environmental sustainability, grievance reports, palm oil industry*

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Introduction

Palm oil emerged as one of the most valuable export agricultural commodities globally. Palm oil-derived oleochemicals can be used in manufactured goods, including edible and non-edible products. Palm oil contributes approximately 30% of global edible oil production, and the demand is expected to continue to rise (Otieno et al., 2016). While 90% of palm oil is used in the food industry, the remaining 10% produces non-edible products, such as soap, cosmetics, and biodiesel (Lai et al., 2020). In 2021, annual production of palm oil increased to ~80.58 million metric tonnes, which is 88.1% from the Southeast Asia region (Foreign Agricultural Service, 2021). This increase has had an impact on the environmental sustainability of the region, leading to the loss of forest ecosystems and biodiversity, as well as contributing to the global carbon footprint, which in turn is causing climate change. Fortunately, Malaysia and Indonesia in Southeast Asia (SEA) have suitable climate conditions for cultivating oil palm trees, dominating ~95.5% of regional palm oil production. Other countries in the SEA region are also expanding their oil palm plantations (Foreign Agricultural Service, 2021). The increasing demand for palm oil led to the ongoing expansion of oil palm plantations,

raising several environmental sustainability issues. Among the recurring environmental issues are rapid deforestation, peatland forest conversion to plantations, and biodiversity loss. Between 1990 and 2019, Southeast Asia has lost approximately 15% of forest cover (Turner & Snaddon, 2023). Malaysia and Indonesia saw 250% (~2.5 million ha; mHa) and 82% (~7.8 mHa) primary forest loss between the years 2000 and 2021 (Rahman et al., 2025). In 2018, the region had over million hectares of oil palm plantations in Indonesia, Malaysia, and Thailand (Danylo et al., 2021). Forest conversion to oil palm plantations and replanting also encourage pollution, such as open fire, which has a negative impact on the health of millions of people in that region. Addressing sustainability issues in the palm oil supply chain is crucial to achieving several United Nations Sustainable Development Goals (SDGs), which aim to provide a better and more sustainable future, particularly with sustainable consumption and production (SDG 12), climate action (SDG 13), and life on land (SDG 15).

The rising environmental sustainability issues have a severe impact on palm oil exports, as a global movement and awareness of sustainable products put pressure on countries to ban products derived from palm oil. For the past few years,

palm oil sourced from suppliers in Malaysia and Indonesia has been banned from entering the United States and the European Union. For example, the European Union's (EU) Parliament has voted to exclude Indonesia's palm oil from the biofuel market (Novelli, 2017). A sustainability assessment of palm oil-based bioenergy in Indonesia reveals that the average environmental score index is only 35.02% (less sustainable) (Papilo et al., 2018).

Many manufacturing companies started reassessing their supply chain due to international pressure, directing them towards more sustainable palm oil sources. These include sourcing from suppliers with sustainable certification and transparently publishing their grievance reports to the public. As a multi-million agro-industrial player, negative sentiment instilled by global movements adversely affects the corporation's business growth and profit. A big-data study conducted on the consumer perception of the overall palm oil industry shows a tremendous negative sentiment, mainly towards the issue of environmental destruction (Teng et al., 2020). At the same time, most of the environmental cases were pointed to large-scale palm oil companies, indirectly impacting smallholders (Ayompe et al., 2021).

As the most regulated agriculture industry, producers are obligated to comply with the regulations imposed by importing governments. The most recent is the European Deforestation Regulation (EUDR), which took effect in June 2023. The aim is to ensure that palm oil-based products are not sourced from land deforested after December 31, 2021. According to the regulations, palm producers are required to share geolocation information about oil palm plantations with manufacturers (European Commission, 2023). In the United States, the Renewable Fuels Standards (RFS) program, the End Palm Oil Deforestation Act, and the Withhold Release Order (WRO) are relevant to the industry. The list is not exhaustive. The most well-known case is in December 2020, when Sime Darby Plantation Berhad (rebranded to SD Guthrie Berhad since May 2024) was issued a WRO due to child labor concerns in their production process (U.S. Customs and Border Protection, 2020).

To improve environmental sustainability practices and address concerns among consumers in the industry. The implementation of sustainability certification and policies has been ongoing for the past decades. This includes the implementation of voluntary sustainability policies for the agriculture industry, such as No Deforestation, No Peat, No Exploitation (NDPE), Good Agricultural Practice (GAP), High Carbon Stocks Approach (HCS), Roundtable on Sustainable Biomaterials (RSB), and International Sustainability and Carbon Certification (ISCC) (McInnes, 2017; Mohd Suib et al., 2023). Palm oil certification by the Rainforest Alliance has been phased out by June 2023, but broader certification for agriculture and the network program, Sustainability Agriculture Network (SAN), remain active (Rainforest Alliance, 2021).

There are also sustainability certifications specific to the palm oil industry that have been introduced by a group of business conglomerates, non-governmental organizations (NGOs), and producing countries. The most prominent is Roundtable Sustainable Palm Oil (RSPO) certification, established in 2005 by the World Wildlife Fund, the Malaysian Palm Oil Association, Unilever, AAK, and Migros. The introduction of RSPO has pushed producing countries to establish their own certification programs. Indonesia's Ministry of Agriculture introduced Indonesian Sustainable Palm Oil (ISPO) in July 2009 and decreed it mandatory in 2011 (Harsono et al., 2012). In September 2013, the Malaysian standard MSPO was established and made mandatory for plantations, organized smallholders, and mills (McInnes, 2017; Sanath Kumaran et al., 2021).

Sustainability certifications cover almost all entities in the upstream palm oil supply chain, which include smallholders, plantations, suppliers, mills, and refineries. A comparative study of leading certification standards by the Forest People Programme, which assesses RSPO, RSB, SAN, ISCC, HCS, MSPO, and ISPO, shows that the strongest certification is RSPO. The national certifications, MSPO and ISPO, turn out to be the weakest certifications compared to others, with MSPO being stricter than ISPO (McInnes, 2017). Malaysian smallholders have high literacy on risk management (Abdullah et al., 2024) . RSPO has been criticized because of the lack of impact on the deforestation rate after the introduction of certification schemes (Cazzolla Gatti et al., 2019). For refineries, the bottleneck of the palm oil global supply chain, NDPE policies have covered 83% of refining capacity in Malaysia and Indonesia with 78% implementation (Kate et al., 2020). Fast-moving consumer goods (FMCG) companies have increasingly developed NDPE policies. However, leakage of palm oil sources from deforested land into the supply chain of various FMCGs continues, thus indicating weak NDPE monitoring and verification mechanisms (Rjik et al., 2020).

Grievance reporting is critical to sustainability certification standards and the palm oil industry's ESG framework. The RSPO initiated the complaint mechanism as part of the certification standard in 2004. As the industry evolves, grievance reporting mechanisms continue to advance, which increases transparency and accountability. NDPE policies are designed to address grievances related to deforestation, peatland clearance, and exploitation occurring in the supply chain. The procedure entails logging grievances that are accessible to the public, verifying and rectifying issues, and reporting outcomes. However, the downside of RSPO and NDPE voluntary reporting is limited transparency in their handling processes, grievance tracking, and public disclosure. Inadequate collaboration and engagement with the local and indigenous communities, insufficient monitoring and enforcement, and a lack of impactful resolution and whistleblower protection (Jonas, 2014; Rjik et al., 2020).

The approach taken by investigating bodies and companies in sharing their grievance reports and logs with the public is usually paragraphs with limited figures and tables formatted in PDF or dedicated online pages with tabulated summaries of cases. This type of unstructured to semi-structured information sharing causes increased complexity and difficulty in conducting computational analysis by stakeholders or entities outside the supply chain. How impactful is the grievance information shared by companies, and to what extent can computational analysis be used for a more insightful perspective?

In late 2019, the rise of the deadly Covid-19 virus led to a global pandemic and lockdown, detrimentally halting the

global economy. While the demand for palm oil remains high, the industries and associated supply chains are severely affected. However, the impact of the pandemic on the management of environmental sustainability in the palm oil industry is still under investigation. Analyzing grievances between the pre- and post-Covid-19 periods allows for a comprehensive understanding of industry challenges so that more effective sustainability management can be developed by stakeholders. Thus, this study aims to elucidate the challenging nature of managing environmental grievances in the palm oil industry in Southeast Asia at a holistic level by using big-data approaches. Then, combined with multicriteria decision analysis (MCDA), it further strengthens the analytical foundation in assessing the level of risk and identifying key regions and key players. Ultimately, it improves sustainability decision-making for better environmental grievance management.

Methods

Data collection This study selects nine major oil palm companies (reporting entities) operating in Southeast Asia and actively publishing environmental grievances in their supply chain between 2019 and 2021, during the Covid-19 pandemic. The companies were APICAL Group, GAR, IFFCO, IOI, KLK, Mewah Group, Musim Mas, Sime Darby Oils, and WILMAR, which were also chosen due to their rank in the top 50 in SPOTT environmental, social, and governance (ESG) policy transparency (https://www.spott.org/palm-oil/). The reporting entities constructed the grievance log based on the non-governmental organization's investigation report (primary sources) (Figure 1). The grievance log and report include detailed information about the situation, including the supply chain, location, and action taken for cases. Because the grievance log published by the companies only provides summaries of the cases, referring to the primary sources for more detailed information, verification, and validation are crucial steps in database construction. A total of 884 cases from grievance logs and reports published by reporting entities and accused suppliers were curated into the database.

Dataset curation and database construction Unstructured information from the grievance reports and logs was extracted, transformed, categorized, and curated into a structured, computer-readable dataset (Table 1). The dataset recorded information from the grievance logs published by
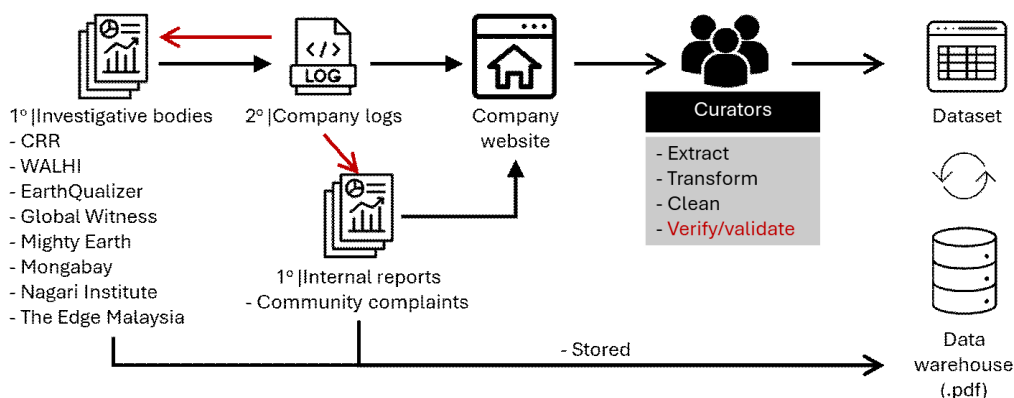

Figure 1 The framework of palm oil environmental grievance database for holistic level industry analysis and sustainability decision-making. 1° = primary information, 2° = secondary information, CRR = chain reaction research, WALHI = Wahana Lingkungan Hidup Indonesia, → = steps in constructing the database, → = verification/validation by our curators, → = steps taken by the reporting entity/company.

Table 1 Type of information that was extracted from grievance reports and logs and curated into the palm oil grievance dataset

Dataset structure (column)	
- Reporting entities	- Status
- Cases	- Close
- E: Environmental	- Ongoing
- Pollution	- Unknown
- Deforestation	- Land area (hectarage)
- Peat clearance	- Reported/logged date
- Land clearance	- Country
- Peat development	- Province /State
- Clearance prep/stacking line	- District
	- Latitude
	- Longitude
	- Address
	- Report hierarchy (1° / 2°)
	- Primary source
	- Company (plantation/supplier)
	- Attachment/source

the companies as secondary sources, as well as the origin of the grievance reports as primary sources. All primary sources were links to original websites or reports stored separately on the cloud, forming our in-house database. Only information on environmental issues such as deforestation and peatland clearing was extracted and analyzed (Figure 1).

Data cleaning and validation The grievance dataset was cleaned by identifying and fixing errors. Data cleaning involves error detection and reparation. General data fixing was conducted by removing any unwanted values and errors in the dataset (Figure 1). Specific formats were selected for each column to ensure that the data input was correct and consistent for computational analysis. The grievance report was used to make corrections; if no information is available, data associated with the error is removed. The subsequent validation process involved cross-checking the information from the reporting group grievance log with the primary sources of the grievance report to eliminate misinformation, data duplication, and data mismatches (Chu et al., 2016). Grievance cases on the same plantation, but reported by different reporting groups, were considered duplicates and filtered out using the generated ID code for analysis at the district and province levels.

Data analysis Several standard tools in descriptive statistical data analysis were used to numerically and graphically summarize the information curated in the constructed grievance database. For identifying high-risk states or provinces. All descriptive statistics summaries, explorative, and network analyses were coded using the R statistical programming language and a Microsoft Excel spreadsheet (R code in supplementary). For numerical data, errors were detected via outliers in the quartile analysis. The quantile-quadrant multicriteria decision risk analysis was designed to categorize the level of risk to environmental sustainability. It is based on the numerical summaries of two variables: the number of active cases (sum of cases that are ongoing and unknown status) and the total land area (ha). The quadrant threshold for land area and number of active cases are based on the 75th and 50th (median) percentiles, respectively.

Results
Covid-19 and the palm oil industry in Indonesia, Malaysia, Papua New Guinea, and Philippines Grievance publication shows a downward trend in Malaysia and Indonesia between 2019 and 2021, indicating the negative impact of the Covid-19 pandemic on sustainability efforts in the palm oil industry (Figure 2a). Between 2020 and 2021, the gap in grievance publication narrowed between Malaysia and Indonesia, which consequently affected the reported land size between the two countries. Consequently, inverse land area trends in Malaysia are orders of magnitude higher than in Indonesia (Figure 2b). The differences in the land area are contributed to by either no information being provided or affected land areas being smaller, even though there is a high grievance count. The Philippines has two fire grievances in Palawan logs filed by Mewah Group in March 2020; however, the affected land area is not mentioned in the report or log.

Further classification of environmental grievances into six categories reveals deforestation (primary forest) is the biggest cause, with 658 out of 884 grievances, followed by only 92 grievances on peat development (Table 2). The lowest grievance occurrences are pollution and land clearance, respectively. All grievances under the environmental pollution category are attributed to fires, with minimal information provided about the affected land area. Fire pollution is generally associated with open burning for land or forest clearance. According to the publication from 2019 and 2020, Indonesia and Malaysia accounted for the majority of deforestation and peat development grievances (Table 3).

Structured grievances information provides a holistic perspective on supply chain sustainability issues in the palm oil industry Our study found that information on supplier locations and incidents is usually mentioned in
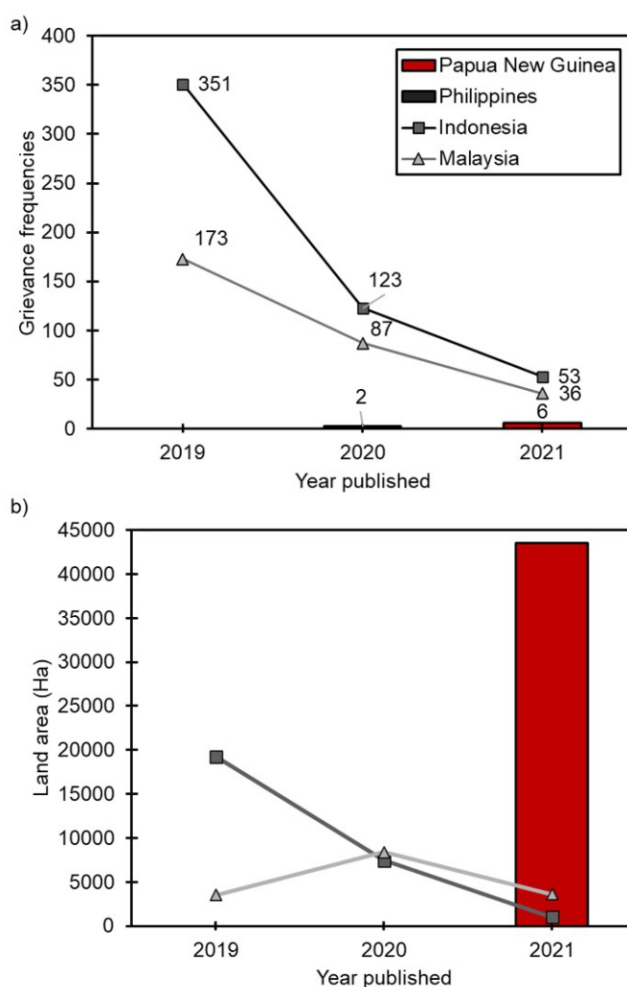

Figure 2 Trends of total palm oil environmental sustainability grievances published by nine companies that are operating in Indonesia, Malaysia, Papua New Guinea, and the Philippines between years 2019 and 2021. Note that (b) the total land affected by grievances is based on information available in reports/logs, i.e., no information on the affected land area was given for the Philippines.

Table 2   Categories of environmental grievances and counts (2019–2021)

Grievance categories	2019	2020	2021	Total
Clearanceprep/Stacking line	50	24	3	77
Deforestation	371	175	112	658
Land clearance	6	-	1	7
Peat clearance	9	-	27	36
Peat development	85	7	-	92
Pollution: Fires	9	2	3	14
Total	530	208	146	884

Table 3   Categories of environmental grievances and count by countries

Grievance categories	Indonesia	Malaysia	Papua New Guinea	Philippines
Clearance prep/Stacking line	42	35	-	-
Deforestation	439	214	5	-
Land clearance	3	4	-	-
Peat clearance	27	9	-	-
Peat development	42	50	-	-
Pollution: Fires	11	0	1	2
Total	564	312	6	2

Table 4   Counts of published environmental grievances caused by suppliers in the supply chain of reporting entities between 2019 and 2021

Reporting entities	2019	2020	2021	Total
APICAL GROUP	20	4	6	30
GAR	45	14	9	68
IFFCO	6	-	-	6
IOI	19	2	-	21
KLK	77	29	19	125
MEWAH GROUP	50	31	21	102
MUSIM MAS	27	13	4	44
Sime Darby Oils	102	40	68	210
WILMAR	184	75	19	278
TOTAL	530	208	146	884

primary reports. Reporting entities' logs typically summarize the incident and focus on the action being taken to address the complaint. All reports from Earthqualizer are in semi-structured data, while others are unstructured. Logs by reporting entities are in table format with paragraphs of a summary of action; as a result, they tend to be semi-structured. Among the nine reporting entities, WILMAR and Sime Darby Oils published the most grievances, respectively (Table 4).

The grievance analysis revealed that reporting entities' supplier networks extend to multiple countries. Mewah Group sources its palm oil from Indonesia, Malaysia, PNG, and the Philippines. Sime Darby Oils and KLK are sourced from Indonesia, Malaysia, and PNG. While others source from Indonesia and/or Malaysia (Table 5).

The dataset also categorized the status of the cases, which reflects the mitigation action taken by the reporting entities: "closed" indicates the cases are resolved, "ongoing" indicates that the cases are being monitored, and "unknown" indicates the mitigation approach to the cases is not mentioned in the

report. The "closed" status indicates that the reporting entities prove that the issues are not tied to their supply chain, suspending or terminating trade deals with the suppliers.

Managing grievances requires investigation, communication intra- and inter-company, and decision-making, which take a significant amount of time. The status of grievances, logging date, and report date allow for a descriptive analysis of the mitigation effort. Almost all nine reporting entities besides Mewah Group have higher 'closed' than 'ongoing' and 'unknown' statuses (Figure 3a). Only GAR, with 68 grievances, has ~89.7% closed status, while KLK, WILMAR, and Musim Mas have over 70% closed status. IOI, Sime Darby Oils, APICAL, and IFFCO have more than 50% closed status, and Mewah Group has the lowest percentages at ~24.5%, respectively (Figure 3b).

Network analysis elucidates the intricate connection between reporting entities and their troubled suppliers (Figure 3c). Degree centrality analysis on the network found that the supplier-reporting entity ratio is 4:6, 9:5, 21:4, 49:3, and 52:2. The remaining suppliers provided only one

Table 5   Counts of published palm oil environmental grievances caused by suppliers in the supply chain of reporting entities between 2019 and 2021

Reporting entities	Indonesia	Malaysia	Papua New Guinea	Philippines
APICAL GROUP	30	-	-	-
GAR	62	6	-	-
IFFCO	5	1	-	-
IOI	10	11	-	-
KLK	77	46	2	-
MEWAH GROUP	34	63	3	2
MUSIM MAS	32	12	-	-
Sime Darby Oils	119	90	1	-
WILMAR	195	83	-	-
Total	564	312	6	2
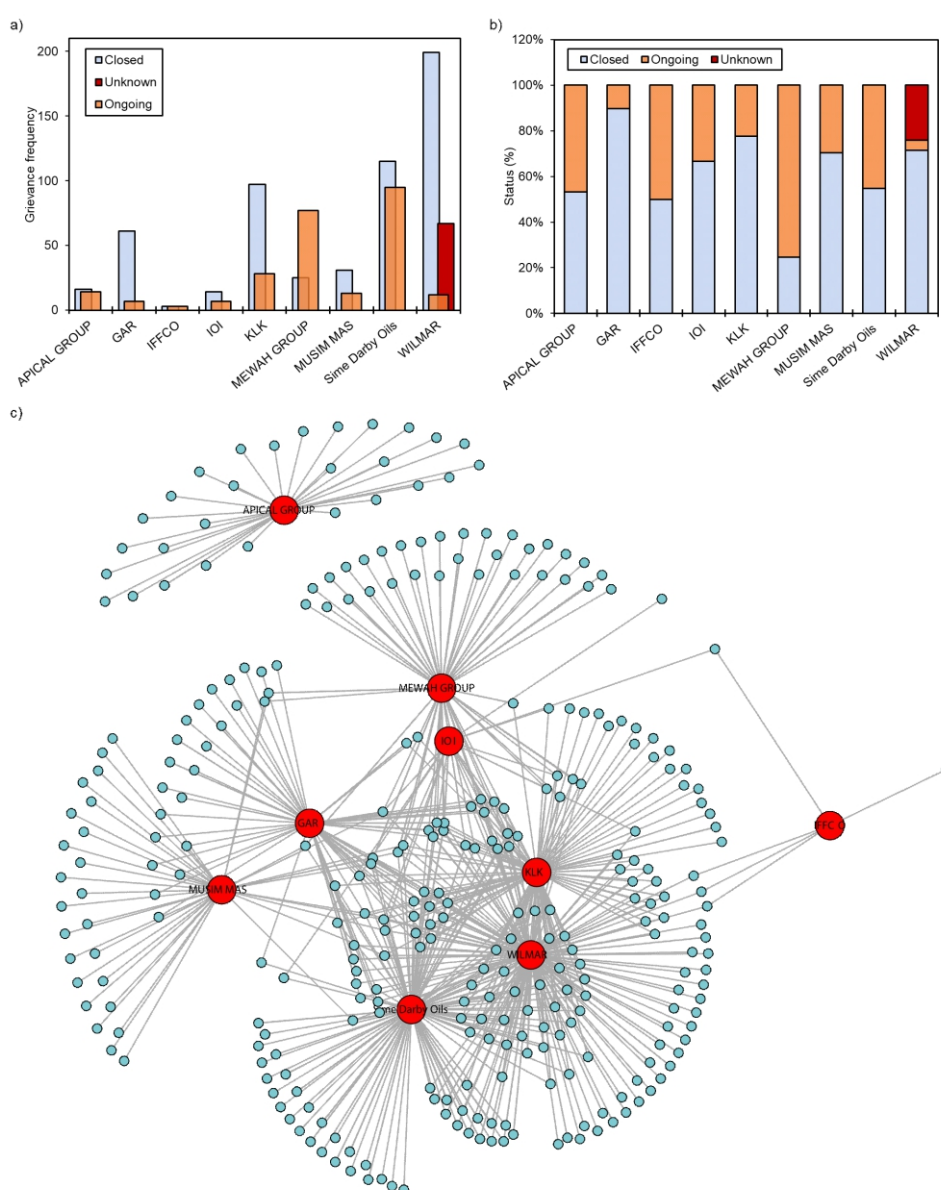
Figure 3   Curation of the dataset ended in October 2023; a) count of grievances, b) in percentages recorded by reporting entities between 2019 and 2021 published by reporting entities, c) network analysis reveals multiconnection between reporting entities (●) and the accused suppliers (●) for causing environmental grievances between 2019 and 2021.

reporting entity. Notably, APICAL Group suppliers are isolated from other reporting entities. This finding demonstrates the impact of problematic suppliers on the industry's overall supply chain sustainability. Since most of the reporting entities share their supply chains, it is highly recommended to form a consortium for supplier management with grievances.

Descriptive and relationship analysis of supplier grievance status Further analysis into status categories, specifically 'closed', provides a deeper perspective on reporting entities' mitigation efforts. Hypothetically, the number of grievances and suppliers would directly affect the

period to resolve and assign status as 'closed'. Correlation analysis reveals minimal to no effect between the count or percentages of 'closed' grievances and the overall median or mean of the resolving period in days (Figure 4a), despite the median and percentage forming a clad in hierarchical clustering (Figure 4b). Multivariate regression also shows no significant (p-value > 0.3) association between counts of grievances and variance, mean, or median resolving periods (result not shown). Overall, the median and average resolving periods for reporting entities to 'close' their grievances are 99 days and $161.3 \pm 40.79_{SE}$ days, respectively. IFFCO, with six grievances, has the shortest median resolving period of 33 days, with three (50%) 'closed' grievance counts. Sime Darby
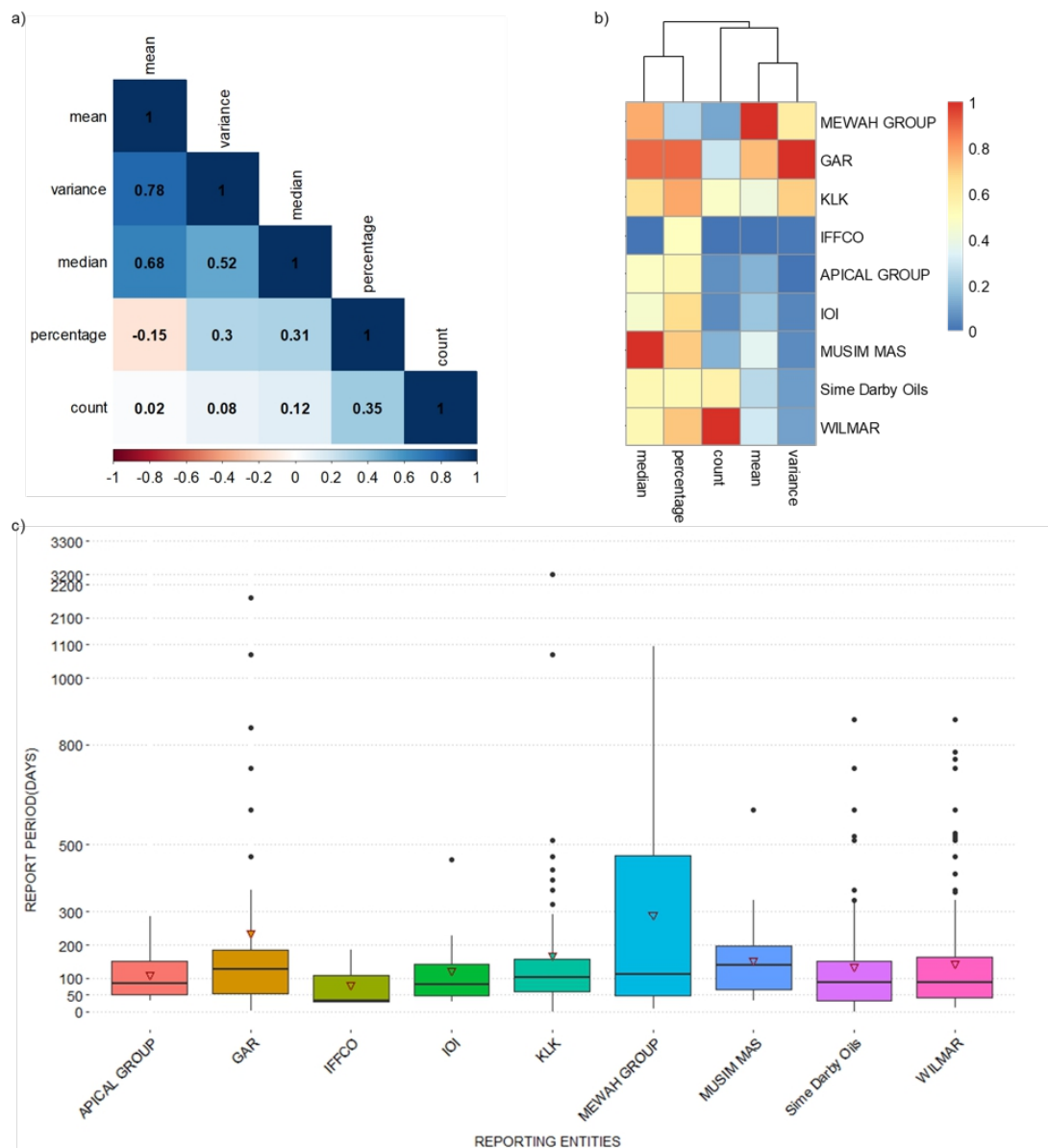

Figure 4 Association analysis of grievances with 'closed' status. a) Pearson correlation heatmap of numerical summary of 'closed' grievances, b) heatmap with hierarchical clustering of normalised numerical summary (0 to 1 range) for tendency analysis, c) boxplot shows the distribution of periods in days taken to resolve palm oil environmental grievances and assigned as 'closed' by reporting entities, ▼ = average, • = outlier. The count is the number of grievances that have 'closed' status. Percentages are calculated by the number of 'closed' grievances over total grievances. Mean, variance and median are numerical summaries of the period (days) for reporting entities to close the grievance.

Oils (53.8%) and WILMAR (71.6%) have two order magnitudes of 'closed' grievances, with a median of 89 days. GAR has the longest resolving period median, with 127 days and 61 (89.7%) closed grievances (Figure 4c).

A deeper analysis at the provincial level revealed the severity of grievances caused by suppliers of reporting entities to the region. Severity in this study is defined by case recurrence and affected land area in the region. All nine reporting entity suppliers with recurrence grievances are concentrated on Borneo Island: Kalimantan Tengah, Kalimantan Barat, and Kalimantan Timur of Indonesia, as well as Sarawak, Malaysia (Figure 5a). Analysis of cumulative affected land size (in hectarage; ha) shows Sabah

and Pahang, Malaysia and East New Britain, PNG were the most affected (Figure 5b). It is important to note that the cumulative land area values are not absolute due to the inadequacy of the affected land size information in some of the primary reports.

Effect of regional regulation on grievances management
Environmental sustainability is directly tied to government policy, the size of a country's primary forest, and economic development. Being the biggest country in SEA with the largest primary forest, Indonesia has the highest grievance count, with 373 cases that have been closed, 134 that are still ongoing, and the remaining 57 that are unknown compared to
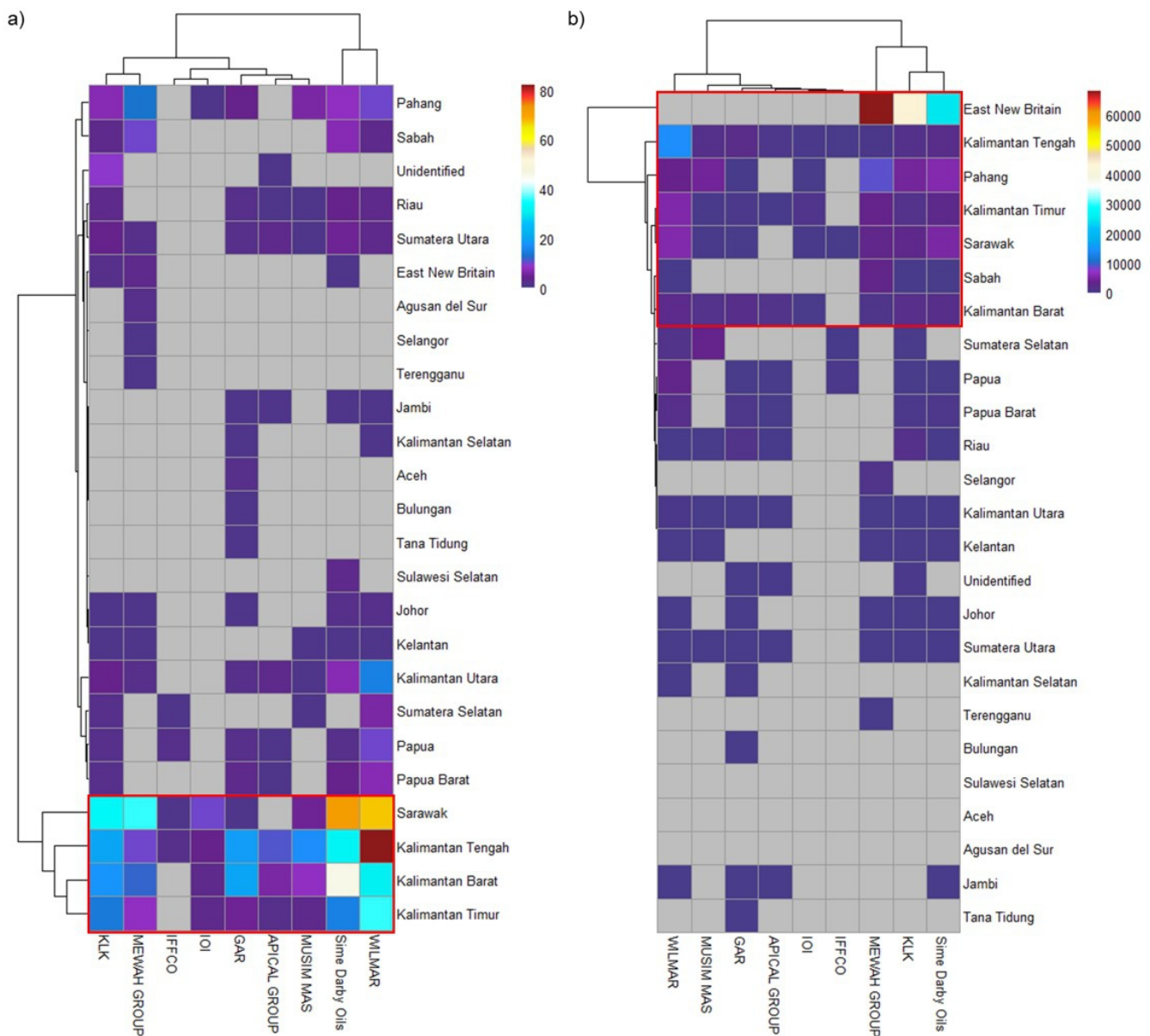

Figure 5 Heatmaps of a) frequency and b) total land area (ha) by provinces/states and reporting entities with 'closed' status. Dendrogram constructed using hierarchical clustering. Grey = no cases (Figure 5a and Figure 5b) or information not provided by reporting entities (Figure 5b).

the others (Figure 6a). However, the status ratio shows that Indonesia has more 'closed' grievances than the rest. Malaysia, being the second largest palm oil producer, has higher percentages of 'ongoing' grievances than Indonesia. PNG and the Philippines with single-digit grievances have an equal proportion of 'ongoing' and 'closed' grievances (Figure 6b). Resolving period analysis on grievances with 'closed' status shows that Indonesia has a shorter resolving period median (85 days) and averages (140.39 days) compared to Malaysia (median = 119 days; mean = 203.33 days) and the Philippines (Figure 6c). This suggests that reporting entities are more proactive in resolving sustainability issues in their Indonesian supply chain.

Identifying high-risk regions and associations with government policy Descriptive analysis at the provincial level shows that provinces in Kalimantan, Indonesia, which are located on Borneo Island, are the most affected by the recurrence of environmental grievances, mostly deforestation and peatland clearance. On the Malaysian side of Borneo, neighbouring Kalimantan borders, Sarawak and Sabah are on the top three highest grievance counts, except Pahang, which is located on the Malaysia Peninsula. Sarawak has the highest active ('ongoing' and 'unknown') grievance count (n = 90) compared to the other provinces (Figure 7a). However, the most affected land area is East New Britain, PNG, where ~43,500 ha of forest and peatland have been cleared. Followed by Pahang and Sarawak, Malaysia, with ~16,891 ha and ~10,239 ha, respectively. Then followed by four provinces in Kalimantan, Indonesia (Figure 7b). This indicates that Borneo Island has become the epicenter of environmental grievances, primarily deforestation in the SEA.
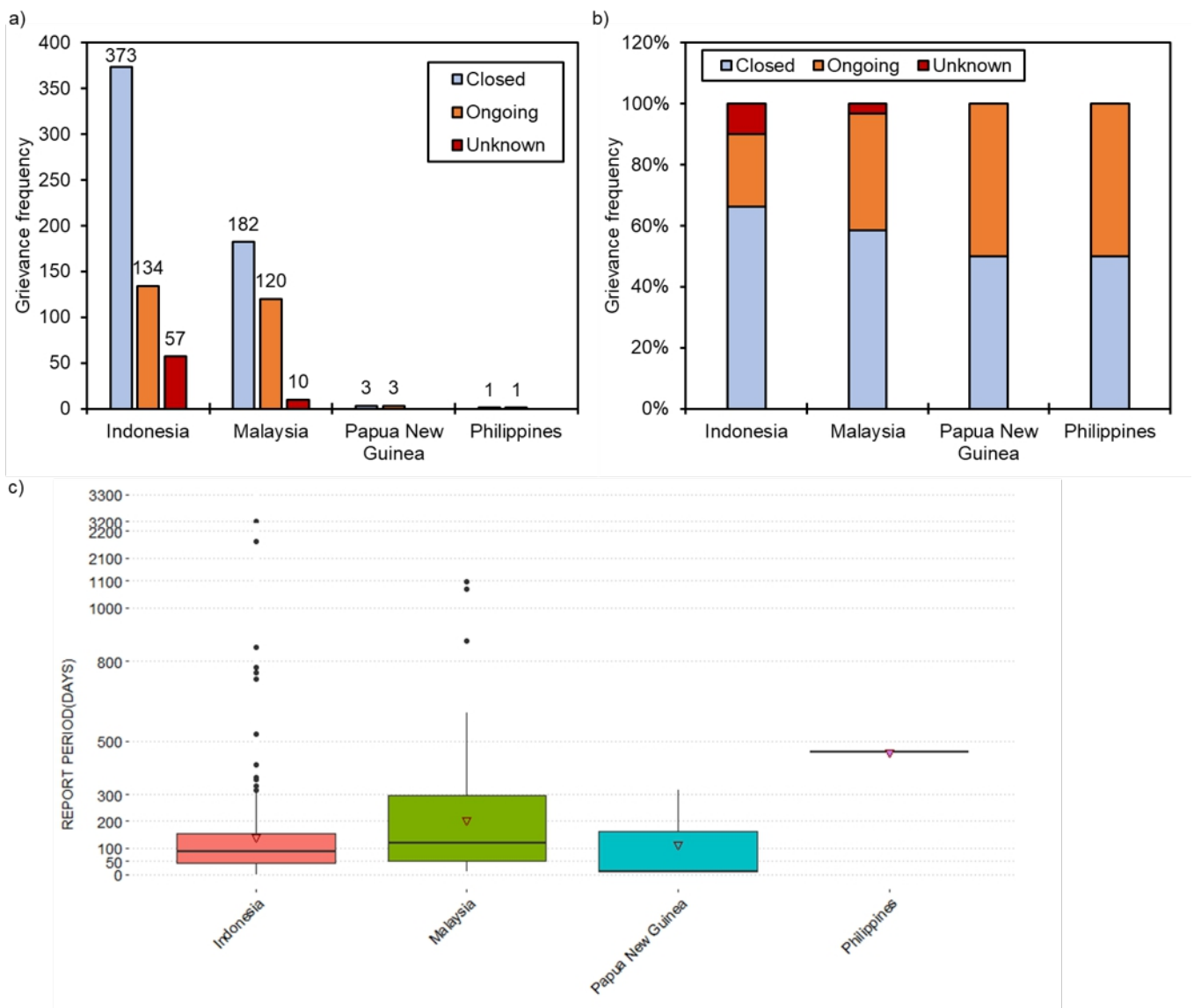

Figure 6 Grievance status was reported between 2019 and 2021 caused by palm oil suppliers in Indonesia, Malaysia, Papua New Guinea, and the Philippines. Grievance frequency (a) and percentages (b) are categorized according to status, (c) boxplot of period taken to resolve grievances and classify as 'closed'.
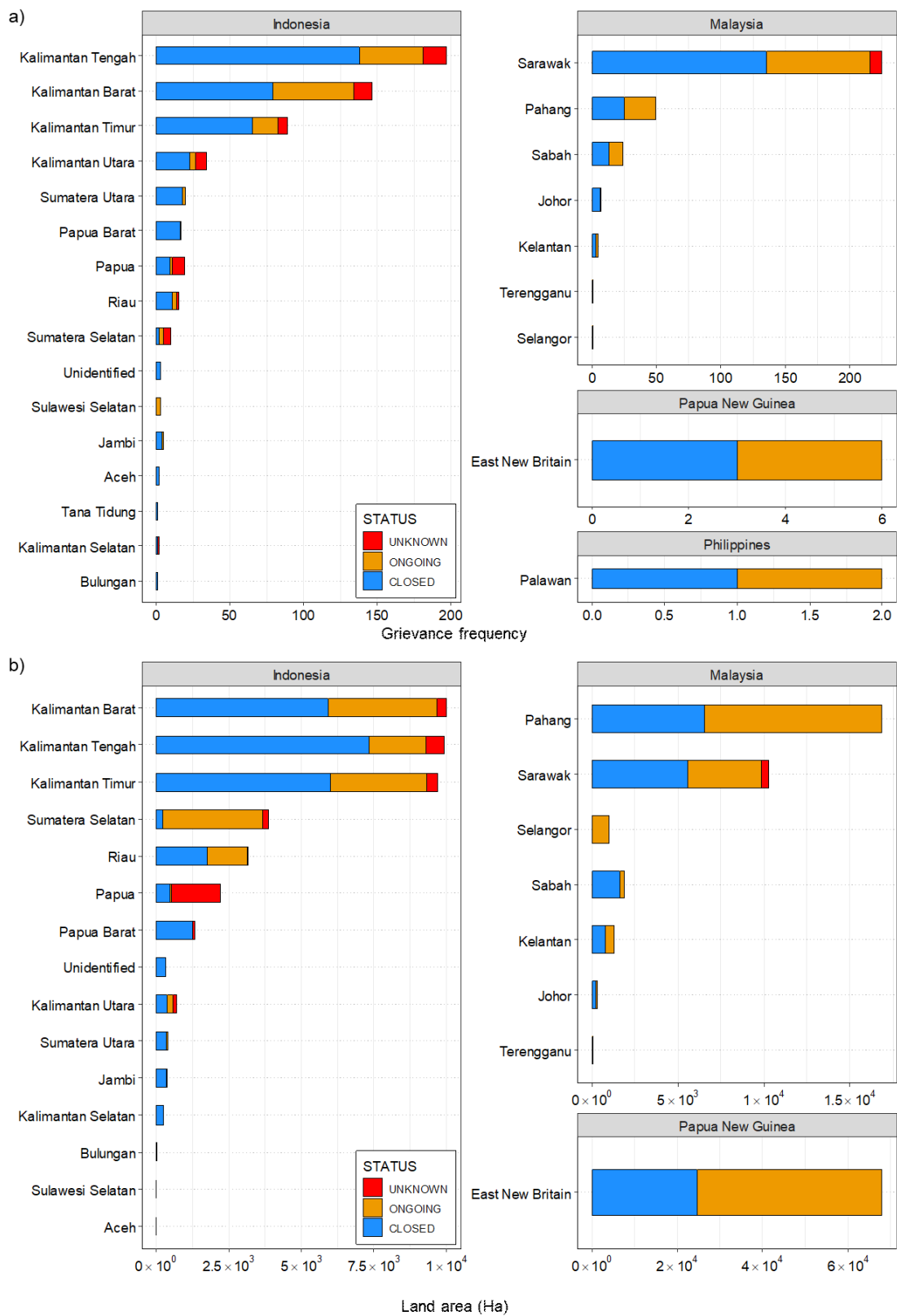
Figure 7 Environmental grievance a) frequency and b) total affected land area (ha) by country and states between 2019 and 2021. The total affected land area (ha) includes closed, ongoing, and unknown status. In several instances, grievances were reported without affected land area (Figure 7b) data; therefore, they were removed before plotting.

Identifying high-risk regions is essential for companies and local governments to prioritize their mitigation efforts in managing palm oil's sustainability issues. In this study, quantile-quadrant multicriteria decision risk analysis was designed to categorize the level of risk based on the numerical summaries of two variables: the number of active cases and the total land area (ha) of active grievances ('ongoing' and 'unknown' status). The quadrants were divided based on the 75th percentile of grievance frequency and the median of the land area. The second quartile (Q2) was considered a high-risk quadrant that requires immediate and high priorities for mitigation (Figure 8). The quantile-quadrant analysis only measures active grievances (ongoing and unknown) because the presence of risks posed to environmental sustainability is not being addressed. The closed status was excluded because the reporting companies have taken appropriate measures to resolve the issues. The decision to set quadrant thresholds is relative and entirely depends on the decision-maker.

The analysis shows that three provinces in Kalimantan,

Indonesia, and two states in Malaysia are in the high-risk quadrant (Figure 8: Q2). States/provinces in high-risk quadrants are high-priority regions to be mitigated and require immediate remediation, either by the local government or a consortium that operates there. In Malaysia, most of the new oil palm plantations were opened in East Malaysia (Sabah and Sarawak) due to the vast land area available for agricultural activities compared to West Malaysia. In Sabah, in the low-risk quadrant (Figure 8: Q3).

Discussion

Covid-19 and the palm oil industry in Indonesia, Malaysia, and Papua New Guinea The Covid-19 pandemic that swept across the globe in late 2019 has significantly impacted the livelihood of many people. By March 2020, the World Health Organization (WHO) had declared pandemic status; consequently, countries across the globe immediately imposed movement-controlled orders for their populations (World Health Organization, 2020). The movement restriction has severely disrupted the agriculture industry's
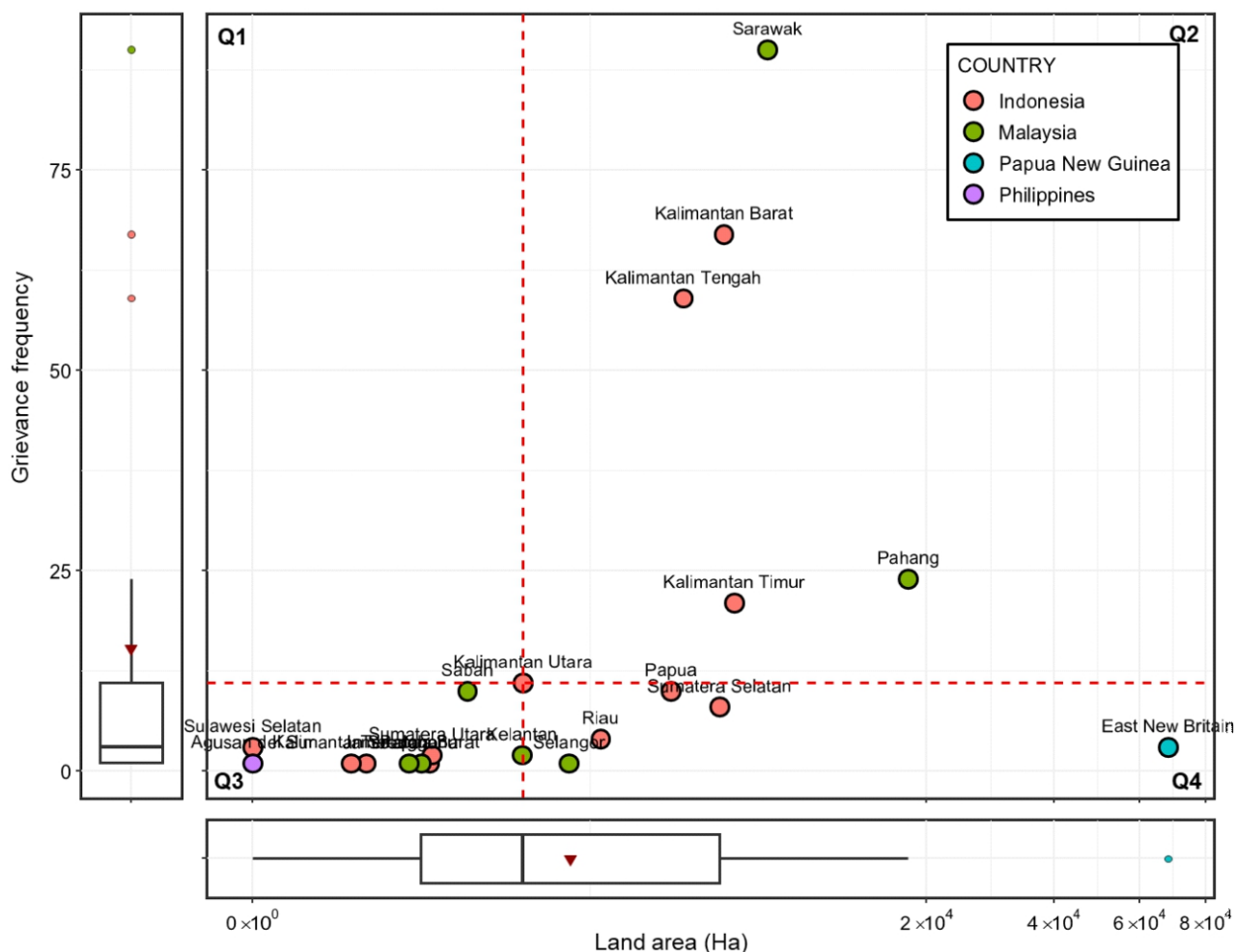

Figure 8 Risk level categorization using quantile-quadrant analysis for the province based on the median of affected land area (hectarage$^{1/4}$) and the 75th percentile of the number of active (ongoing and unknown) cases in the grievance reports published between 2019 and 2021. The quadrant threshold for land area and number of active cases are set at median and average values, respectively. (Q2 = high risk, Q3 = low risk).

supply chain and services, including palm oil. This includes any effort to report grievances that occur in the industry, which is an integral practice in the environmental, social, and governance (ESG) framework. Focusing on environmental grievances shared by nine reporting entities between 2019 and 2021, Indonesia has 564 cases, Malaysia has 312 cases, Papua New Guinea has 6 cases, and the Philippines has 2 cases (Figure 2a). All of these cases affect at least ~86,743.6 ha of forest and peatland (Figure 2b). According to Chain Reaction Research (CRR), between 2019 and 2021, a total of 147,000 ha of forest and peat were cleared in Indonesia, Malaysia, and Papua New Guinea (PNG) (Chain Reaction Research, 2022; Jong, 2022).

Our finding and CRR report are not comparable owing to our analysis perspective of the affected land size, which is based on the year of reports and logs being published, while grievances may or may not happen in the same publication year or the total land that happened over a period of several years. For example, the reported 43,500 ha in PNG is based on a report by Global Witness, which was published in 2021 (Global Witness, 2021). It represents the total amount of deforestation that occurred between 2007 and 2019.

The dwindling number of reports published during this period is linked to the Covid-19 pandemic, which causes activity and movement constraints across the country (Figure 2a). When Malaysia first implemented a national lockdown named the Movement Control Order (MCO) on March 18, 2020, nearly all sectors were closed, and only essential services were allowed to operate. For Indonesia, the government decided to apply large-scale social restrictions, which were later modified to Community Activities Restrictions Enforcement instead of implementing a nationwide lockdown. Even though Indonesia enforced a less stringent policy, the presence of numerous active Covid-19 cases negatively impacted many industry sectors. With Covid-19 restrictions and ongoing active cases, on-site and off-site palm oil supply chains, environmental sustainability assessment activities were limited. This put a hold on the sustainability assessment done on the oil palm plantations, resulting in a low number of reported grievances. Moreover, the Covid-19 pandemic reduced the number of environmental violations committed at plantations due to restricted palm oil industry activities. The fear sentiment of contracting the virus among communities and the limited industrial activities imposed by the government to control the outbreak eventually decreased environmental cases as the farmers did not open new land for oil palm plantations. Even though Covid-19 has a detrimental effect on human health, it is beneficial to nature and the environment due to the decreased overall pollution cases reported worldwide (Muhammad et al., 2020). Notably, the Covid-19 pandemic affects the energy-based market prices worldwide, including palm oil biodiesel industry exports. A study shows that the uncertainty in market price was driven by a crisis such as the oil market downturn in 2014–2015 and the Covid-19 pandemic, resulting in a negative impact on the palm oil market price (Dutta et al., 2021). Moreover, the global movement restriction affected the market price of fuel oil in general, including palm oil-derived biodiesel (Veza et al., 2021). As a result, the decreased demand for palm oil-derived biodiesel will eventually reduce the need to open new oil palm plantations.

Most of Indonesia and Malaysia's peatlands were classified as protected areas because the peat forests have higher carbon stock reserves than the primary forests. As seen in Indonesia, the government aims to protect 24 Mha of peatland and restore a minimum of 2 Mha that are degraded to their initial condition. Among the actions taken by Indonesian authorities is the deployment of surveillance technologies and legal systems to engage with large-scale peatland users, including the palm oil industries (Astuti, 2021). In Malaysia, the state authorities enforce a clear land usage policy so that the opening of new oil palm plantations can only be expanded through designated agricultural land, reducing the expansion of the peatland forest (Wan Mohd Jaafar et al., 2020). In addition, the RSPO certification plays a significant role in decreasing peatland conversion to oil palm plantations. In 2018, all RSPO members were prohibited from sourcing palm oil originating from plantations that used to be peatland forests to secure sustainability certification (Astuti, 2021).

Structured grievances information provides a holistic perspective on supply chain sustainability issues in the palm oil industry Oil palm farming faces significant regulation compared to other agricultural industries in the world (McInnes, 2017). Voluntary implementation of no deforestation, no peat, and no exploitation (NDPE) policies is a commitment by palm oil companies to environmental sustainability (Kate et al., 2020). Although not mandatory, the publication of detailed grievance procedures is part of the commitment to NDPE. Having grievance-handling mechanisms in place also aligns with the RSPO certification scheme (Jonas, 2014). More information included in the grievance logs and reports, such as oil palm plantations and suppliers, reflects the company's transparency and traceability, which are indicators of commitment to the ESG sustainability framework. All reporting entities–APICAL Group, GAR, IFFCO, IOI, Mewah Group, Musim Mas, Sime Darby Oils, and WILMAR–have adopted NDPE policies (Table 4 and Table 5).

According to CRR, the top palm oil refineries in Malaysia and Indonesia as of 2020, which are WILMAR, Sime Darby, KLK, Mewah Group, and GAR, all employ NDPE policies, have supply chain transparency, and have operational grievance systems in which the companies collect information on the grievance lodged on their website (Kate et al., 2020).

Government policies during the Covid-19 pandemic have influenced the resolving period. With the stricter policy, especially MCO, implemented in Malaysia, suppliers and reporting entities require more time and resources to solve active cases (Figure 4c). For example, in MUSIM MAS's grievance log for the deforestation issues in Pahang, the plantation planned to terminate the management associated with the deforestation cases in March 2022 and remediate the situation, but the process has been put on hold because of the pandemic situation in Malaysia. Another factor that may have contributed to the higher closed status in Indonesia is primarily because the global palm oil group (reporting

entities) focused more on solving the plantation issues in that country. With profit and vast opportunities in Indonesia, palm oil groups began to focus on expanding their plantations in Indonesia, including Malaysia-owned palm oil groups. Approximately 30% of Indonesian oil palm plantations are owned by Malaysian capital owners (Eco-Business, 2011). Even with the same starting point in the palm oil industry, Indonesia slowly climbed the export trade ladder to become the world's number one source of an export commodity for palm oil, with a 46% share of the global market compared to Malaysia's 41% (Varkkey et al., 2018). With a vast market and opportunity ahead in Indonesia, companies invest more effort to close the active cases in return for more profit, directly reflecting their commitment towards achieving sustainable practices.

Recently, the EU decided to phase out using palm oil-derived biodiesel due to concerns about environmental issues (Rum et al., 2022). This severely impacts Indonesia's economic activities, as the EU is one of the biggest consumers of renewable energy biodiesel, with 30% of the sources coming from palm oil (Grinsven et al., 2020). Indonesia took the initiative to restore the trade deal by addressing the issues of the palm oil biofuel market ban at the international diplomatic level. However, environmental issues keep appearing, tainting the image of Indonesia's palm oil exports. Thus, the country decided to suspend trade activities, focus on developing a sustainable palm oil system based on international regulations, and align with sustainable development goals (SDGs) (Rifin et al., 2020). To promote the use of palm oil as a biodiesel source, the companies focused on proving that palm oil production is indeed sustainable by reducing active cases and solving rising environmental issues (Figure 3).

High-risk regions and association with government policy A sudden increase in PNG is driven by the government pushing for rapid growth in palm oil production (Figure 7 & Figure 8). The PNG government is planning to double the national plantation area, hence including the deforestation of primary forests (Global Witness, 2021). A similar situation occurs in Kalimantan provinces, Indonesia; however, the main factor is the decentralization of forest management between central and regional levels, leading to regulation loopholes that increase the complexity of reinforcement (Suwarno et al., 2015). The expansion of oil palm plantations in Pahang and other peninsular states of Malaysia is driven by a lack of transparency and non-NDPE actors that received over USD2.4 billion in business funds (Chain Reaction Research, 2021). While the Sarawak government has halted issuing new licenses for oil palm plantation expansion since 2018 (Malaysian Palm Oil Board, 2018).

In Indonesia, the decentralization of forest management contributed to a high deforestation rate (Suwarno et al., 2015). A case study in the province of Kalimantan Barat shows that decentralization has created loopholes in regulation, causing conflicting policies between central and local governments. Consequently, this increases the complexity of enforcement, thus facilitating deforestation (Prabowo et al., 2017). Another case study in Kalimantan Barat shows how conflicting regulations caused by decentralization create loopholes for the conversion of forests to oil palm plantations (Setiawan et al., 2016). Compared to minor smallholders, most large-scale industrial plantation companies opened new oil palm plantations illegally, without approval from the authorities. The large-scale companies employed machinery and were able to invest more money in opening new oil palm plantations. They also had the power to influence the region's policymakers to cater to their needs in opening new oil palm plantations (Astuti et al., 2022).

The primary cause is that Malaysia focused more on converting other commodities, such as rubber, to oil palm plantations than opening new palm plantations from virgin forests. In the 1930s, Malaysia was the world's largest rubber producer, with an estimated production covering 50% of global demand. However, because of the invention of synthetic rubber, the rubber market decreased. Since then, Malaysia has converted the rubber plantation into a highly demanded palm oil commodity. The second factor influencing the low number of deforestation cases is Malaysia's willingness to keep 50% of the total forest cover intact (BERNAMA, 2023). With the pledges in place, palm oil companies have limited access to open new plantations in Malaysia, resulting in a lower number of deforestation cases. However, the restrictions forced the oil palm company to open new palm plantations in Indonesia instead.

High deforestation cases in Indonesia are linked to governance policies decentralizing forest management at the national and district levels (Suwarno et al., 2015). Moreover, Indonesia practices decentralized forest management policies by giving control to local district authorities in managing forests. The deforestation cases of oil palm plantations were influenced by politics at the district level, as the deforestation cases related to oil palm plantations increased after the introduction of the direct mayoral election. Decentralization policies, which split the power among districts Have led to an increase in deforestation, primarily due to weaker enforcement than national forest regulations (Alesina et al., 2019). With less stringent policies on national forest regulations, policymakers at the district level exploit the available resources to get short-term electoral benefits, including increasing palm oil production without concern about sustainability (Cisneros et al., 2021).

The environmental cases are lower because the Sabah state focused on agricultural conversion from rubber plantations to oil palm plantations instead of opening forest areas (Varkkey, 2020). Meanwhile, Sarawak cases are higher because of their legislative power and development goals, which eventually disregard environmental sustainability. Sarawak negotiated special provisions regulating and holding land-related use, giving the state greater control over land policy (Colding, 2003). The ideology of Sarawak leaders towards developmentalism, aimed at keeping pace with West Malaysia's growth, further stimulated the expansion of oil palm plantations, driven by the belief that "Sarawak should not be left behind" (Ling, 2016). Pahang recorded the highest environmental cases in West Malaysia (Figure 6). From 2000 to 2018, the expansion of new oil palm plantations in West Malaysia was shifted towards the state of Pahang (Li et al., 2020). In 2020, TH Plantation's plan to open three new plantations in Yong Forest Reserve in Pahang breached the signed NDPE commitment (Chain Reaction

Research, 2020). However, the grievance recorded in our dataset is caused by the Pahang state-owned plantations (Mighty Earth, 2020).

Implementation of ESG frameworks is the way forward
Public disclosure of environmental grievances by reporting entities indicates their commitment to transparency and accountability, integral elements in the ESG framework. For the palm oil industry, this practice is embedded into NDPE, RSPO, and Global Reporting Initiative policies (Global Reporting Initiative, 2021; Wielga & Harrison, 2021). Our study found that reporting entities have different approaches in implementing ESG frameworks, causing variability in disclosing grievance information on their websites. This variability indicates a lack of standardization in metrics and guidelines at the industry level, another key element in the ESG framework. Integration of the Environmental Sustainability Index in RSPO would promote consistency of information in the industry (Abdul Murad et al., 2021). These nine reporting entities were chosen not just due to high ESG transparency scores in SPOTT but also for regularly updating their grievances, indicating commitment to the ESG framework (SPOTT, 2024). However, our study found that missing information on the land size is persistent in all reporting entities, affecting the outcome of our analysis (Figure 4 and Figure 5).

Conclusion

The palm oil industry poses a significant threat to environmental sustainability in Malaysia and Indonesia. To remediate this issue, many palm oil companies that operated in these countries pledged commitment to NDPE policies and acquired RSPO and national sustainability certification. One of the commitment's requirements is to share grievances filed against the company with the public. However, grievance reports and logs that are being published are either unstructured or semi-structured information, hence limiting the analytical approach. In this study, we demonstrate the efficacy of big data combined with MCDA in tapping into potential information hidden in the reports and logs to improve sustainable decision-making for environmental grievance management. Focuses on the environmental grievances published between 2019 and 2021, pre- and post-Covid-19. Our result indicates a decrease in environmental cases reported during the pandemic and this can be associated with a nationwide lockdown imposed by the government. This finding provides valuable insight on the effect of the Covid-19 pandemic on the reporting and management of grievances. Deforestation is the main risk/threat to environmental sustainability. A comparison between Indonesia and Malaysia shows that Indonesia has more recorded cases and total land area affected but has more closed cases, and vice versa for Malaysia. Network analysis reveals the effect of problematic suppliers (plantations) on multiple reporting entities, necessitating consortium effort for impactful remediation. Our novel quantile-quadrant analysis identified five provinces/states that are high risk to environmental sustainability: Pahang, Sarawak, Kalimantan Barat, Kalimantan Tengah, and Kalimantan Timur. The MCDA at the provincial level provides critical information

on the effect of environmental sustainability management due to differences in policy and governance. Overall, our analysis indicates that the private consortium and provincial/state governments need to work more closely together to tackle deforestation and other environmental sustainability issues. This big-data-driven risk analysis provides a systematic approach to identifying regions that need urgent attention and resources. Further able to identify key companies that have substantial presence and ESG effort in the targeted regions. This novel approach can also be implemented in other regions and industries that face similar challenges. However, the key limitation of this study is that it is solely based on the shared information published by the reporting entities. Therefore, we encourage more companies in the agricultural industries to be more transparent, standardize their grievance metrics and sharing guidelines, thus easing third-party organizations to compare their ESG efforts across industries and regions.

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Conflict of Interest

All authors declare no competing interest.

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