Oil palm and rubber-driven deforestation in Indonesia and Malaysia (2000-2021) and efforts toward zero deforestation commitments

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Research Article

Keywords: Deforestation, Oil palm, Natural rubber, Palm oil, Supply chain, Zero deforestation

Posted Date: May 19th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2945587/v1

Abstract

This study evaluates the oil palm and rubber-driven deforestation in Indonesia and Malaysia between 2000–2021 through secondary data analysis from a rich data set by collecting and integrating secondary data from multiple sources. Results show a significant tree cover loss, including 82% and 250% of primary forest loss in Indonesia and Malaysia. Oil palm harvested area increased by 650% in Indonesia and 50% in Malaysia, while palm oil production rose by 566% in Indonesia and 65% in Malaysia over the same period. The study also find that rubber-harvested areas increased by 54% in Indonesia but decreased by 20% in Malaysia, with rubber production increasing by 108% in Indonesia but decreasing by 49% in Malaysia. Over the past two decades, Indonesia's palm oil export volume has risen by 619%, while Malaysia's has increased by 83%. Indonesia's natural rubber export volume also increased by 69%, but Malaysia's decreased by 33%. The study reveals that the impact of oil palm and rubber on deforestation varies by region and period. However, plantation expansion and associated forest conversion have slowed, which can be associated with the consumer demand for no deforestation oil palm and rubber products. Many of the world's largest traders and producers have pledged zero deforestation commitments, guaranteeing the elimination of deforestation from their supply chains in Indonesia and Malaysia. Such commitments can only be accomplished through government, private sector, farmers, and community collaboration. Finally, to ensure sustainability in these sectors, comprehensive policies and practical solutions that support farmers' livelihoods are also crucial.

Introduction

Generally, the term "deforestation" refers to the conversion of forests to other land uses, whether human-induced or not (FAO 2018). From 2001 to 2021, globally, 437 million hectares (hereafter "Mha") or 28% of tree cover loss (tree cover loss encompasses the loss of both natural and planted forests and can occur for reasons beyond human activity) occurred, where the dominant drivers of loss were the conversion of forest to commodity crops (GFW 2023). Commercial agriculture is estimated to be the proximate driver for around 50% or 86 Mha of deforestation in all regions in the world between 2000 and 2018; about 78% or 66 Mha of the forest area is converted to commercial cropland in Asia (79% or 28 Mha) and Africa (78% or 38 Mha) during the same period (FAO 2022). Dummet et al. (2021) assessed that illegal agro-conversion was responsible for the loss of at least 32 Mha of tropical forest loss between 2013 and 2019. These lands were encroached from indigenous and local communities, mainly due to the inadequate land tenure rights prevalent in countries such as Indonesia (Pacheco et al. 2021).

Over the past few decades, market influences, particularly from the European Union, the United States, and the United Kingdom, have played a vital role in determining the supply and demand of agricultural commodities linked to tropical deforestation and forest degradation (WWF and BCG 2021; DeValue et al. 2022). Tropical deforestation is primarily driven by land conversion to produce commodities like oil palm, rubber, cocoa, coffee, pulp and paper, soybean, and meat (Pendrill et al. 2022), which account for over 58% (71.6 Mha out of 123 Mha) of all agriculture-driven deforestation between 2001 and 2015 (Goldman et al. 2020). Meanwhile, a study by Curtis et al. (2018) found that 27% (5.8 Mha) of global forest loss during the same period was caused by permanent land use change for commodity production, with 95% (5.1 Mha) of this deforestation occurring in the tropics. In Asia, agricultural cropland expansion is responsible for 50% (18 Mha) of deforestation between 2010 and 2018 (FAO 2022). More specifically, the conversion of forests into oil palm plantations contributed to approximately 7% or 11.3 Mha of global deforestation, among 29% (10.3 Mha) in South and Southeast Asia and 11% (0.3 Mha) in Oceania during the same period (FAO 2022).

Existing literature and databases revealed that Indonesia and Malaysia are the world's leading producers and exporters of both oil palm and rubber. We identified the following nine studies conducted at a country level on oil palm and rubber production in Indonesia and Malaysia. Austin et al. (2019), Gaveau et al. (2022), and Busch et al. (2022) utilized satellite imagery data from 2000 to 2019 to investigate deforestation caused by oil palm plantations in Indonesia. They show that oil palm causes 11–23% of deforestation in Indonesia, with the highest rate between 2008 and 2012. However, the ban on oil palm in the European Union reduced deforestation from 2014 to 2019, resulting in a 1.6% reduction. Austin et al. (2017) and Cheng et al. (2017) used satellite imagery and land cover maps to study oil palm production in Indonesia from 1995 to 2015. They found that oil palm plantations expanded by 6–9 Mha during this period, causing the loss of 95% of secondary forests. Using satellite and plot survey data from 1974 to 2016, Li et al. (2020) and Tang and Qahtani (2020) studied oil palm in Malaysia and found that the plantation area increased by 5 Mha over the last 42 years, with a growth rate of 84%. Xu et al. (2020) used satellite imagery data from 2001 to 2016 to investigate oil palm in Indonesia and Malaysia. They assessed that oil palm plantations increased by 147% in Indonesia and 322% in Malaysia, with a higher growth rate observed in Indonesia. Ali et al. (2021) examined rubber production in Malaysia between 1990 and 2019 and found that the global economic recession of 2008–2009 caused smallholder rubber farmers to clear-fell their rubber trees for timber.

Above mentioned studies have shown that in Indonesia and Malaysia, the primary driver of deforestation is undoubtedly the conversion of forests to agricultural commodities specifically oil palm and rubber to meet global demand. These studies have concluded that the expansion of oil palm and rubber plantations in both countries is unsustainable and contributes to deforestation and peatland degradation. Furthermore, this expansion is destroying the habitats of endangered species like the orangutan (*Pongo* spp.), Borneo pygmy elephant (*Elephas maximus borneensis*), and Sumatran rhino (*Dicerorhinus sumatrensis*) (https://www.worldwildlife.org/industries/palm-oil). However, no studies have yet comprehensively evaluated the impact of both oil palm and rubber production on deforestation in Indonesia and Malaysia. This involves analyzing multiple data sources for assessing tree cover and primary forest losses in both countries as well as oil palm and rubber cultivation and harvesting, production, and export.

On the other hand, halting deforestation in commodity supply chains in Southeast Asia, particularly in Indonesia and Malaysia, is crucial to achieving the goals of both climate action and sustainable development. Recently, global interest in reducing deforestation has gained momentum; governments, civil society organizations, and corporate groups have pledged and set time-bound targets for achieving “zero deforestation” from the agriculture and forestry sector by 2030 (Austin et al. 2021). These pledges are known as *“zero deforestation commitments”*, initially signed in 2010 by the Consumer Goods Forum (CGF) to achieve zero net deforestation in key commodity sectors like oil palm and rubber in Southeast Asia by 2020 (Consumer Goods Forum 2017; Newton and Benzeev 2018; Pendrill et al. 2019). In the latest, around 500 companies have established sustainable commodity supply chain commitments, and more than 100 companies have pledged to announce zero deforestation commitments at the 26th UN Climate Change Conference (COP26) in Glasgow (Scotland) in 2021 to eliminate commodities produced at the expense of forests from their supply chains (Rothrock et al. 2019; Austin et al. 2021).

Based on the above discussion, in this paper, we evaluate the trend of oil palm and rubber-driven deforestation in Indonesia and Malaysia between 2000 and 2021 using secondary data from different sources. Furthermore, we will examine the progress of zero deforestation commitments implemented by both countries from oil palm and rubber supply chains. No data set is available for the purpose of this study, a comprehensive time-series assessment, so we created a rich data set by collecting and integrating secondary data from multiple sources. This is one of the main contributions of this paper. The specific objectives of this study are as follows:

1. to assess the rate of deforestation in Indonesia and Malaysia.
2. to assess the status of oil palm and rubber in both countries.
3. to identify the link between oil palm and rubber production with deforestation and efforts toward zero deforestation commitments from their supply chains.

An overview of oil palm and rubber

Oil palm

Oil palm tree (*Elaeis guineensis*) is one of the most important agricultural commodities globally, and its products are found in about half of all packaged products sold in supermarkets. The tree originated in the tropical rainforest region of West Africa. In Southeast Asia, it was introduced as an ornamental crop in 1848 in Bogor, Java Island of Indonesia. The first commercial oil palm plantation was established on the Sumatra Island of Indonesia in 1911, followed by Selangor State in Malaysia in 1917 (Robins 2020). Currently, large-scale production of this crop is primarily concentrated in Indonesia, Malaysia, Thailand, Latin America, and Africa and provides a livelihood for approximately four million smallholders worldwide (RSPO 2023). Palm oil-based industry creates job opportunities for around four million people in Indonesia and nearly a million in Malaysia, particularly in remote rural areas, where employment opportunities are limited (RSPO 2023). The tree is highly productive. After three to four years, it becomes mature to produce fruit. The palm fruit grows in bunches weighing over 10 kilograms and contains hundreds of small fruits similar to plums or apricots (Orangutan Foundation 2023). Additionally, the oil palm is normally replanted with a newer breed every 25–30 years due to economic reasons. Significantly, oil palm plantations in South and Southeast Asia cleared 10.3 Mha, which accounted for 29% of the deforested area (FAO 2022).

Its economic ability to efficiently produce vegetable oil led to its widespread cultivation and commercial development of large-scale plantations. Moreover, there is a growing global demand for a wide variety of oil palm-based food items, including cookies, biscuits, chocolates, ice cream, noodles, chips, baking items, cheese, margarine, and baby formulas (Stedman 2021; Orangutan Foundation 2023). In addition, oil palm is widely used in the production of cosmetics such as soap, shampoo, deodorant, lipstick, and other items, as well as cleaners like toothpaste, detergent, and dishwasher, and can be used as a source of biofuel or biodiesel (Stedman 2021). Oil palm is the cheapest vegetable oil to produce due to its higher yields and lower costs compared to other oil crops such as sunflower, soybean, or rapeseed (RSPO 2023). In addition, oil palm is considered a zero-waste crop because every part of the plant can be used. By-products of palm oil production, such as fiber and shells, can be used as fuel in the mills, while leaves and empty fruit bunches serve as organic fertilizers in plantations (Aziz 2023). The wood from felled trees can be repurposed as the primary material for furniture-making. This makes oil palm a sustainable option, as its by-products can be converted into energy or animal feed (Aziz 2023).

In 2022, the global production of edible palm oil called crude palm oil (CPO), an edible oil extracted from the outer part (flesh or pulp) of the oil palm fruit, was about 77.2 million tons, representing 36.3% and 36.5% of global vegetable oil production and consumption (USDA 2022). Indonesia, Malaysia, and Thailand were the leading producers of CPO. Indonesia accounted for 59% (45.5 mt) of the world's CPO production, while Malaysia and Thailand had a 24% (19 mt) and 4% (3.26 mt) share, respectively. Additionally, Indonesia (56% or 28.45 mt) and Malaysia (33% or 16.7 mt) are the primary exporters of CPO, accounting for 89.2% of the product that is bound for international markets (USDA 2022). The USDA (2022) also projects that demand for CPO will double by 2030 and triple by 2050. Furthermore, kernel palm oil (KPO) is extracted from the inner, softer part of the seed. It is commonly used for non-edible purposes such as manufacturing soaps, cosmetics, and detergents (Krungsri Research 2022).

Figure 1a illustrates the trends in global and Southeast Asian oil palm harvested areas from 2000 to 2021 using FAOSTAT data. Notably, the harvested area in Southeast Asia increased rapidly from 10.6 Mha in 2009 to 16.4 Mha in 2013 and continued to grow steadily to 21.2 Mha in 2021, as shown in the figure. This trend was also reflected globally, as Southeast Asia controls the global oil palm, and changes in production in this region tend to influence global production levels. Over the same period, the global oil palm harvested area increased by 178%, while the increase in Southeast Asia was even greater, at 274%.

Figure 1b displays the trends in global and Southeast Asian CPO production from 2000 to 2021 using FAOSTAT data. As shown in the figure, CPO production in Southeast Asia increased steadily from 18.5 million tonnes (mt) in 2000 to 53.3 mt in 2015. The production then decreased to 51 mt in 2016 before resuming a continuous increase to reach 67.6 mt in 2021. The trend in global CPO production followed a similar pattern, as Southeast Asia is the major producer of CPO, and changes in production in this region tend to influence global production levels. Between 2000 and 2021, global CPO production increased by 247%, while Southeast Asia increased by 266%.

Rubber

The rubber tree (*Hevea brasiliensis*) is the commercially viable source of natural rubber, a native plant of the Amazon basin, introduced from there to tropical Asia and Africa during the late 19th century. In some regions, there are small-scale rubber plantations by the farmers; but mostly rubber plantations are increasingly large-scale, intensively managed, and have even-aged trees. Natural rubber is extracted as latex, white milky fluid from the bark's inner layers, through a process called "tapping" (Malaysian Rubber Council 2023).

Rubber is a hugely important commodity worldwide, used in thousands of everyday items. In 2021, the global production of natural rubber reached 13.8 mt, and consumption reached 14.1 mt (Malaysian Rubber Council 2023). Thailand and Indonesia are the top-producing countries, with an annual production of 4.8 mt and 3 mt, respectively (Statista, 2023). Moreover, Thailand (3.3 mt), Indonesia (1.7 mt), and Vietnam (1.4 mt) are the world's largest exporters of natural rubber in the same year, accounting for 51% of the global export (Malaysian Rubber Council 2023). China is the largest rubber consumer, with a consumption of 4.1 mt, followed by India with one mt, and the United States with 0.7 mt (Malaysian Rubber Council 2023).

Figure 2a depicts the global and Southeast Asia rubber harvested areas between 2000 and 2021 using FAOSTAT data. The data indicates that the rubber-harvested area in the region displayed a consistent trendline, increasing from 5.7 Mha in 2000 to 10 Mha in 2021. However, the rate of growth between 2015 (9 Mha) and 2021 (10 Mha) was slower, with only a one Mha increase. On the other hand, the global rubber harvested area gradually increased from 7.5 Mha in 2000 to 9.6 Mha in 2011. The growth rate picked up significantly after 2012 (10.3 Mha), and by 2021, the harvested area had risen to 12.9 Mha, indicating an increase of almost 3 Mha in only nine years. Overall, the global rubber harvested area increased by 73% between 2000 and 2021, while in Southeast Asia, the increase was 75%.

Figure 2b depicts the trend of natural rubber production in global and Southeast Asia between 2000 and 2021 using FAOSTAT data. The data indicates that Southeast Asia's rubber production steadily increased from 5.3 mt in 2000 to 8.2 mt in 2008 but declined to 7.6 mt in 2009. Subsequently, rubber production increased from 8 mt in 2010 to 11.3 mt in 2019 but decreased in 2020 and 2021 to 10.7 and 10.8 mt, respectively, possibly due to the impact of COVID-19. On the other hand, global natural rubber production showed a consistent increase from 7.1 mt in 2000 to 14.5 mt in 2019. However, as in the Southeast Asia, global rubber production declined in 2020 and 2021, with 14 mt each year. Overall, between 2000 and 2021, global natural rubber production increased by 98%, while in Southeast Asia, the increase was 104%.

Rubber is an essential commodity worldwide and finds uses in thousands of everyday items. The majority of rubber consumption, approximately 70%, is in industrial applications, with the automobile, tires, and tubes industries being the biggest consumers in the Asia-Pacific region (Research and Markets 2022). Other significant rubber products include disposable rubber gloves, footwear, sports balls, and rubber bands. Moreover, natural rubber is currently used in manufacturing rubber diaphragms that pump blood in artificial hearts, as well as high-damping rubber seismic bearings (https://www.myrubbercouncil.com/marketplace/).

Materials and method

Study countries

Indonesia and Malaysia are neighboring Southeast Asian countries. Indonesia is the largest archipelago in the world lies between latitudes 11°15'S and 6°8'N and longitudes 94°45'E and 141°05'E, consisting of more than 17,500 islands with an area of 1,916,906 sq km, where marine area occupies about 74.3% of the country's area. The total forest area in Indonesia is 120.5 Mha, which is about 63% of the total land area (Ministry of Environment and Forestry 2020). Indonesia is also home to the world's largest tropical peatlands with an area of 14.9 Mha. With a population of 273.8 million in 2021, Indonesia is the world's fourth most populous nation and the largest economy in Southeast Asia (World Bank Data 2023). The country's islands are home to highly varied geography, topography, and climate, ranging from sea and coastal systems to peat swamps and montane forests. The climate of Indonesia is tropical equatorial, hot and humid (average humidity 80%), and has abundant rainfall throughout the year mostly in low-lying areas (mean annual precipitation between 1991 and 2020 is 2,782 mm) and mountainous regions experiencing cooler temperatures. The temperature is stable, with the mean annual temperature between 1991 and 2020 is 26°C (Climate Change Knowledge Portal 2021). Indonesia is a large producer of rubber, oil palm, cocoa and coffee, tobacco, gas and coal, timber, bauxite, silver, and tin.

Malaysia is located between 2°30'N to 7°30'N and 100°E to 119°E with an area of 330,803 sq km. Malaysia consists of two primary land masses divided by water. Peninsular Malaysia, located on the Asian mainland, lies to the west, while the states of Sarawak and Sabah, collectively referred to as East Malaysia, are situated on the island of Borneo (available at: https://www.malaysia.gov.my/portal/index). Malaysia has 55% forest area, where 68% is production forest, and the rest 32% is protection and conservation forest (Ministry of Environment and Water 2020). Malaysia is a multi-racial country with a population of over 33.6 million in 2021 (World Bank Data 2023). The climate of Malaysia is tropical equatorial, quite humid (average humidity 84%), and rainy throughout the year (mean annual precipitation between 1991–2020 is 3,002 mm). Temperatures are high and stable, with the mean temperature between 1991 and 2020 at 26°C and relatively little seasonal variability in average monthly temperature (Climate Change Knowledge Portal 2021). Moreover, Malaysia is one of 17 megadiverse countries, home to numerous endemic species. Malaysia is a large producer of rubber, oil palm, cocoa, rice and pepper, petroleum and natural gas, tin, and timber.

Methods and data analysis

This study is based on secondary data sources from 2000 to 2021 from different sources. Data were collected from the following sources: FAOSTAT (available at: https://www.fao.org/faostat/en/) of the Food and Agriculture Organization of the United Nations (FAO) for the data of global status of oil palm and rubber, southeast Asia's status of oil palm and rubber, and Indonesia and Malaysia's status of oil palm and rubber; Global Forest Watch (available at: https://www.globalforestwatch.org/) for tree cover loss and primary forest loss data; International Production Assessment Division (available at: https://ipad.fas.usda.gov/cropexplorer/Default.aspx) of the United States Department of Agriculture (USDA) for regional and country-level data of oil palm and rubber in Indonesia and Malaysia; Direktorat Jenderal Perkebunan (available at: https://ditjenbun.pertanian.go.id/) and Badan Pusat Statistik (available at: https://www.bps.go.id/) for oil palm production and export volume and value in Indonesia; Malaysian Palm Oil Board (available at: https://www.mpob.gov.my/) and Department of Statistics, Malaysia (available at: https://www.dosm.gov.my/v1/) for oil palm export volume and value in Malaysia; and Malaysian Rubber Council (available at: https://www.myrubbercouncil.com/), Rubber Research Institute of Malaysia (available at:) and Malaysian Rubber Board (available at: https://www.lgm.gov.my/webv2/home) for rubber production area, production, and export volume and value in Malaysia. Moreover, data was also collected from peer-reviewed journal articles and books, as well as yearly statistics from several websites and government departments in Indonesia and Malaysia (mentioned in the previous sentences). Official export values for oil palm and rubber in Indonesia, as well as the export value for rubber in Malaysia, are readily available in USD. To facilitate comparison with Indonesia, the oil palm export value for Malaysia was adjusted for inflation, using the local currency unit per USD in 2010, and changes in Malaysia's consumer price index in 2010. These data were obtained from the World Bank Data (available at: https://data.worldbank.org/). The above data sources have contributed to ensuring that the data used in the study is trustworthy and reliable.

For this study, a comprehensive range of data, particularly on deforestation, such as tree cover loss and forest loss, drivers of deforestation, oil palm and rubber production, export volume and value, and zero deforestation activities in Indonesia and Malaysia were collected and compiled. The data was then analyzed using R software (version 3.6.1) mainly using descriptive statistics and regression scatter plots. This approach allowed for a deeper understanding of the relationship between the different variables and the current state of deforestation and oil palm and rubber in the two countries.

Results

Tree cover losses in Indonesia and Malaysia

The results presented in Fig. 3a using Global Forest Watch data indicate that between 2001 and 2021, Indonesia experienced a significant tree cover loss, with a total of 28.55 Mha lost. In contrast, Malaysia lost 8.67 Mha of tree cover during the same period. The annual tree cover loss in Indonesia was not consistent and higher in the years 2016 (2.42 Mha), 2012 (2.26 Mha), and 2009 (1.94 Mha). However, from 2017 to 2021, there was a decrease in tree cover loss, ranging from 1.30 to 0.84 Mha. In Malaysia, the annual higher tree cover losses showed in the years 2014 (0.65 Mha), 2012 (0.63 Mha), 2009 (0.62

Mha), and 2016 (0.57 Mha). Similarly, from 2017 to 2021, there was a decrease in tree cover loss in Malaysia, ranging from 0.48 to 0.28 Mha. The percentage of tree cover loss was higher in Malaysia (0.56–1.95% per year) than in Indonesia (0.29–1.27% per year) from 2001 to 2021. During the period, in total, Indonesia's tree cover loss increased by 13.5%, while it decreased by 15.2% in Malaysia.

Primary forest loss in Indonesia and Malaysia

Figure 3b illustrates the primary forest (primary forest refers to areas of forest having reached the final stage of succession and no significant disturbances in recent records due to human activity) loss in Indonesia and Malaysia between 2001 and 2021 using Global Forest Watch data. Over this period, Indonesia lost a significant amount of primary forest, with a total of 10.1 Mha lost, representing 35% of its total tree cover loss during the same period. The primary forest loss was higher in the years 2016 (0.93 Mha), 2012 (0.86 Mha), 2014 (0.74 Mha), and 2009 (0.68 Mha). However, from 2017 (0.37 Mha) to 2021 (0.20 Mha), the rate of primary forest loss decreased. On the other hand, Fig. 3b also shows that Malaysia lost 2.8 Mha of primary forest between 2001 and 2021, which represents 32% of its total tree cover loss during the same period using Global Forest Watch data. The primary forest loss was higher in the years 2009 and 2012 (0.24 Mha each), followed by 2014 (0.23 Mha), 2016 (0.19 Mha), 2011, and 2017 (0.16 Mha each). However, from 2017 (0.14 Mha) to 2021 (0.07 Mha), the primary forest loss rate decreased, similar to the trend observed in Indonesia. Overall, between 2001 and 2021, the amount of primary forest loss in Indonesia increased by 82%, while in Malaysia, it increased by a much greater magnitude of 250% during the same period, surpassing Indonesia in terms of the increase.

Status of oil palm in Indonesia and Malaysia

Figure 4 assessed the cultivated and harvested area for oil palm in Indonesia and Malaysia between 2000 and 2021 using data from FAOSTAT and government statistics. The data in Fig. 4a shows that Indonesia's oil palm cultivation area has increased from 4.2 Mha (2.2% of the total land area) in 2000 to 14.7 Mha (7.7% of the total land area) in 2021, representing a 250% increase over the last two decades. Additionally, in 2000, the oil palm harvested area was only 2 Mha (1% of the total land area). By 2021, this figure had increased to 15 Mha (7.9% of the total land area), representing an astounding 650% increase over the last two decades (Fig. 4a).

According to Fig. 4b, Malaysia's oil palm cultivation area has increased from 3.4 Mha (10.3% of the total land area) in 2000 to 5.7 Mha (17.2% of the total land area) in 2021. This increase represents a 68% growth over the last two decades. Moreover, Malaysia's harvested area of oil palm has also increased during the same period, from 3.4 Mha (10.21% of the total land area) in 2000 to 5.1 Mha (17.84% of its land area) in 2021. This expansion represents a 50% increase over the same period, according to Fig. 4b.

Status of rubber in Indonesia and Malaysia

Figure 5 evaluated the rubber cultivation and harvested area in Indonesia and Malaysia between 2000 and 2021 using data from FAOSTAT and government statistics. The data in Fig. 5a shows that Indonesia's rubber cultivation area has increased from 3.4 Mha (1.8% of the total land area) in 2000 to 3.8 Mha (2% of the total land area) in 2021, representing a 12% increase over the last two decades. Figure 5a also showed that in 2000, Indonesia had a rubber-harvested area of 2.4 Mha, representing 1.3% of its total land area. After two decades in 2021, the rubber harvested area in Indonesia had increased to 3.7 Mha, or 1.9% of its total land area. The study revealed that between 2000 and 2021, Indonesia's rubber-harvested area increased by 54%.

Based on the data presented in Fig. 5b, the rubber cultivation area in Malaysia has decreased from 1.4 Mha (4.3% of the total land area) in 2000 to 1.1 Mha (3.4% of the total land area) in 2021. This indicates a 21% decline over the period. Figure 5b also reveals a similar pattern in Malaysia's rubber harvested area, which decreased from 1.4 Mha, representing 4.3% of the total land area in 2000, to 1.1 Mha, equivalent to 3.4% of its total land area in 2021. This decline represents a 21% reduction over the same period.

Palm oil production and export from Indonesia and Malaysia

In 2000, Indonesia's production of palm oil (including CPO and KPO) was only 7.7 mt, while Malaysia's production was 12.2 mt. By the end of the two decades, Indonesia's production had risen to 51.4 mt, while Malaysia's production had risen to 20.2 mt. This indicates that Indonesia's palm oil production increased by 565% over the last two decades, while Malaysia's production increased by 66%, as illustrated in Fig. 6a using FAOSTAT data.

The present study found that Indonesia exported a significant portion of its total palm oil production (CPO and KPO), ranging from 50 to 91% between 2000 and 2021. In contrast, Malaysia exported almost all of its total palm oil production, with 74–100% range during the same period (Fig. 6b). Specifically, Indonesia exported a higher amount of palm oil in 2021, with 33.7 mt, followed by years 2019 (30.23 mt), 2017 and 2018 (29 mt each), and 2015 (28.28 mt). On the other hand, Malaysia exported a higher amount of palm oil in 2011, 2013, and 2019 (with more than 19 mt each year), followed by 2012, 2014, 2015, and 2020, with more than 18 mt each year. Indonesia's palm oil export volume increased by 619% in the last two decades, and Malaysia's increased by 83%.

Natural rubber production and export from Indonesia and Malaysia

In 2000, Indonesia's natural rubber (both primary forms and other forms) production was 1.5 mt, while Malaysia's was 0.9 mt. By 2021, Indonesia's production had increased to 3.1 mt, a 107% increase over the last two decades. In contrast, Malaysia's production decreased by 44% over the same period, falling to 0.5 mt (Fig. 7a) using FAOSTAT data.

The export of natural rubber in Indonesia and Malaysia has been significant, with Indonesia exporting most of its production and Malaysia exporting almost all of its production between 2000 and 2021

(Fig. 7b). Specifically, Indonesia exported 74–93% of its total natural rubber production during this period, while Malaysia exported 82–139% of its total. Regarding the highest export amounts, Indonesia had the highest export in 2017 at 3.2 mt, followed by 2018 at 2.81 mt and 2017 at 2.7 mt. Malaysia had the highest export in 2004 at 1.43 mt, followed by 2005 at 1.15 mt, 2006 at 1.13 mt, and 2007 at 1.02 mt. Indonesia's natural rubber export volume has increased by 69% over the last two decades, and Malaysia's export volume decreased by 33%.

Export values of palm oil and natural rubber in Indonesia and Malaysia

The export value (in billion USD) of palm oil in Indonesia and Malaysia increased steadily between 2000 and 2021, as shown in Fig. 8a. In particular, Indonesia earned the highest revenue from exported palm oil in 2021 at 28.68 billion USD, followed by 2017 at 20.8 billion USD, and 2011, 2012, and 2014 at more than 19 billion USD each year. Similarly, Malaysia's highest earnings from exported palm oil occurred in 2021 at 27.25 billion USD, followed by 2011 at 21.33 billion USD, 2017 at 19.28 billion USD, and 2012 and 2020 at more than 18.6 billion USD each year.

The export value of natural rubber (in both primary and other forms) in Indonesia and Malaysia showed an upward trend between 2000 and 2021, as depicted in Fig. 8b. In particular, Indonesia earned the highest revenue from natural rubber exports in 2011, with a value of 11.76 billion USD, followed by 2012 and 2010, generating more than 7 billion USD. Additionally, in 2008 and 2013, Indonesia generated more than 6 billion USD from natural rubber exports. On the other hand, Malaysia's highest revenue from natural rubber exports was in 2011, with a value of 4.34 billion USD, and in the years following 2006, 2007, 2008, 2010, 2012, and 2013, Malaysia generated more than 2 billion USD each year.

Major regions of palm oil and rubber production in Indonesia and Malaysia

Figure 9a shows the geographical distribution of palm oil mills across Indonesia and Malaysia. This visualization provides an overview of the locations where oil palm is processed in the two countries and highlights the concentration of mills in certain regions. The distribution of mills can provide insights into patterns of production and supply chains, as well as potential deforestation associated with oil palm production in these countries.

Figure 9b illustrates the key regions for oil palm and rubber cultivation, as well as the levels of deforestation in those regions in Indonesia. The data shows that oil palm is grown in 33 regions across the country, with 11 of those regions being major producers of CPO, accounting for 79% of the country's total production. The Indonesian islands of Sumatra and Kalimantan, also known as Borneo in Indonesia, divided between Malaysia, and Brunei, are globally renowned as the most productive regions for oil palm cultivation. The Borneo Islands have a tropical climate and are home to a rich diversity of flora and fauna, including tropical rainforests that are considered biodiversity hotspots. The region's ideal climate and fertile soil make it a prime location for oil palm cultivation, which was introduced during the Dutch colonial period and has since become a major industry in the area (Shoumatoff 2017). Of these, the top palm oil-producing provinces are Riau, North Sumatra, and South Sumatra, with a share of 27%, 15%, and 10%, respectively.

Similarly, natural rubber production is concentrated in those eight regions of Indonesia (Fig. 9b), which account for 69% of the country's total production. Indonesia's top natural rubber-producing regions are South Sumatra, Riau, and Jambi, with a share of 32%, 10%, and 10%, respectively. Additionally, the table reveals that oil palm and rubber cultivation are linked to deforestation in Indonesia. Indonesia's major oil palm and rubber production regions are responsible for 66% of the country's total deforestation between 2001 and 2021. Of these regions, Riau, West Kalimantan, Central Kalimantan, and South Sumatra have the highest levels of deforestation contributing 14%, 13%, 12%, and 12%, respectively.

Figure 9c illustrates the major regions for oil palm cultivation and production, as well as the levels of deforestation in Malaysia. In Malaysia, oil palm is grown in 16 regions, with five regions being considered major regions for CPO production, accounting for 81% of the total country's production. The top regions for oil palm production are Sabah and Sarawak (Malaysian Borneo) and Johor with a share of 25%, 19%, and 16%, respectively. Additionally, five regions also account for 83.5% of the country's total deforestation, with Sarawak, Sabah, and Pahang having the highest levels of deforestation with a contribution of 35.9%, 20.1%, and 13.7%, respectively. The states of Johor, Pahang, and Perak in addition to Borneo are home to tropical forests, diverse peat swamp ecosystems, intricate river networks, and extensive mangrove forests. Due to their favorable climate and soil properties, these areas have become popular destinations for oil palm cultivation, which has become a major source of economic growth for these regions.

Correlation between the attributes of oil palm in Indonesia and Malaysia

Table 1 presents a correlation analysis of six attributes (log_{10} transformed data) related to oil palm in Indonesia and Malaysia over the last two decades. The attributes are cultivation area, harvested area, tree cover loss, primary forest loss, palm oil production, and price in USD. The table is organized in a matrix format, where each attribute is listed as a row and a column, and the intersection represents the correlation between them. The values in the table represent Pearson's correlation coefficient (r) between the attributes, which measures the strength and direction of the linear relationship between two variables. The asterisk indicates the significance level of the correlation.

Table 1 for Indonesia shows significant correlations between several attributes. Strong positive correlations exist between oil palm cultivation area and harvested area (r = 0.98***), oil palm production (r = 0.99***), and price of palm oil in USD (r = 0.60**). Harvested area strongly correlates with production (r = 0.98***) and price (r = 0.67**). Tree cover loss and primary forest loss have a strong positive correlation (r = 0.89***), while tree cover loss and palm oil price have a weak positive correlation (r = 0.45*). Primary forest loss and price have a weak correlation (0.49*), while production and price have a moderate positive correlation (r = 0.63**).

Table 1
Correlation between oil palm attributes in Indonesia and Malaysia between 2001–2021

Attribute	Cultivation area	Harvested area	Tree cover loss	Primary forest loss	Production	Price USD
Indonesia						
Cultivation area	1					
Harvested area	0.98***	1				
Tree cover loss	0.29	0.36	1			
Primary forest loss	0.16	0.27	0.89***	1		
Production	0.99***	0.98***	0.34	0.21	1	
Price USD	0.60**	0.67**	0.45*	0.49*	0.63**	1
Malaysia						
Cultivation area	1					
Harvested area	0.95***	1				
Tree cover loss	0.40•	0.42•	1			
Primary forest loss	0.51*	0.59**	0.76***	1		
Production	0.92***	0.94***	0.49*	0.68***	1	
Price USD	0.64**	0.77***	0.37	0.62**	0.73***	1

Note: Pearson correlation coefficients between each variable pair are displayed along with their significance level indicated by letter size and asterisk (***p < .001; **p < .01; *p < .05; •p < 0.1).

Table 1 for Malaysia shows significant correlations between several attributes. There is a strong positive correlation between oil palm cultivation area and harvested area (r = 0.95***), production of oil palm (r = 0.92***), and price of palm oil in USD (r = 0.64**). Harvested area shows a strong positive correlation with primary forest loss (r = 0.59**), production (r = 0.94***), and price (r = 0.77***). The table also shows a strong positive correlation between tree cover loss and primary forest loss (r = 0.76***). Furthermore, a strong positive correlation between primary forest loss and both production (r = 0.68***) and price of palm oil (r = 0.62**). Finally, palm oil production strongly correlates with the increase in palm oil price (r = 0.73***).

Correlation between the attributes of rubber in Indonesia and Malaysia

Table 2 presents a correlation analysis of six attributes (log_{10} transformed data) related to rubber in Indonesia and Malaysia over the last two decades. The attributes are cultivation area, harvested area, tree cover loss, primary forest loss, rubber production, and the price of natural rubber in USD. The significance level of the correlation is indicated by asterisk.

Table 2 for Indonesia displays a strong positive correlation between rubber cultivation area and harvested area (r = 0.83***) as well as rubber production (r = 0.82***). Harvested area positively correlates with tree cover loss (r = 0.45*), production (r = 0.86***), and the price of natural rubber (r = 0.54*). Tree cover loss and primary forest loss exhibit a strong positive correlation (r = 0.89***). Primary forest loss and rubber production are moderately correlated with the price of natural rubber, with correlation values of 0.61** and 0.64**, respectively.

Table 2
Correlation between rubber attributes in Indonesia and Malaysia between 2001–2021

Attribute	Cultivation area	Harvested area	Tree cover loss	Primary forest loss	Production	Price USD
Indonesia						
Cultivation area	1					
Harvested area	0.83***	1				
Tree cover loss	0.22	0.45*	1			
Primary forest loss	0.05	0.36	0.89***	1		
Production	0.82***	0.86***	0.54*	0.45*	1	
Price USD	0.28	0.54*	0.52*	0.61**	0.64**	1
Malaysia						
Cultivation area	1					
Harvested area	1.00***	1				
Tree cover loss	-0.65**	-0.65**	1			
Primary forest loss	-0.73***	-0.73***	0.76***	1		
Production	0.40˙	0.43˙	-0.05	0.04	1	
Price USD	-0.73***	-0.71***	0.40˙	0.69***	0.08	1

Note: Pearson correlation coefficients between each variable pair are displayed along with their significance level indicated by letter size and asterisk (***p < .001; **p < .01; *p < .05; ˙p < 0.1).

Table 2 presents several significant correlations in Malaysia's rubber industry. There is a strong positive correlation between rubber cultivation area and harvested area (r = 1.00***). On the other hand, cultivation area has strong negative correlations with tree cover loss (r=-0.65**), primary forest loss (r=-0.73***), and the price of natural rubber (r=-0.73***). Harvested area shows similarly strong negative correlation with tree cover loss (r=-0.65**), primary forest loss (r=-0.73***), and the price of natural rubber (r=-0.71***). Interestingly, tree cover loss strongly correlates with primary forest loss (r = 0.76***) and primary forest loss has a strong positive correlation with the price of natural rubber (r = 0.69***). Rubber production has a weak positive correlation with cultivation area (r = 0.40*) and harvested area and rubber production (r = 0.43*). However, there is no significant correlation between tree cover loss and rubber production, as well as primary forest loss and rubber production.

Discussion

Our study findings indicate that tree cover loss and primary forest loss in Indonesia and Malaysia for oil palm and rubber cultivation have significantly decreased from 2017 to 2021. During the specified period, Indonesia reduced its area loss from 1.67 Mha to 1.04 Mha, while Malaysia reduced its area loss from 0.64 Mha to 0.35 Mha. One possible factor for tree cover loss reduction is the nationwide implementation of a moratorium on developing new oil palm concessions on peatlands and in primary forests (Busch et al. 2015; Gaveau et al. 2018, 2022). The moratorium was extended indefinitely in 2019 and emphasized regulation and certification, which has resulted in reduced investments in developing new oil palm plantations (Busch et al. 2015). Moreover, there are other factors that have likely contributed to this reduction. Firstly, the improved legal framework for community-based land claims in Indonesia has made it more difficult for companies to access land (Astuti and McGregor 2017). Secondly, sourcing and sustaining land and labor has become increasingly challenging (Gaveau et al. 2022). Thirdly, the focus on reducing deforestation has received both national and international attention, with consumers pressuring for products that are free of deforestation, and governments increasing their oversight and enforcement of zero deforestation commitments (Gaveau et al. 2018, 2022). Yet, the oil palm harvested area has increased in both countries for the last two decades. On the other hand, rubber harvested area has also increased in Indonesia and Malaysia. The present study demonstrates that the impacts of oil palm and rubber on deforestation vary by region and period in both countries. Gaveau et al. (2018) assessed that Borneo Islands lost 6 million hectares (3.7 Mha and 2.3 Mha lost in Indonesian and Malaysian Borneo, respectively) of forest cover between 2000 and 2017 for oil palm and pulpwood plantations. Similar to the present study's findings, previous research has pointed to industrial oil palm and rubber plantations as being responsible for widespread deforestation in both countries until 2016 (Gatto et al. 2015; Varkkey et al. 2018; Austin et al. 2019; Xu et al. 2022; Hanafiah et al. 2022).

Recent studies indicate a slowdown in industrial oil palm plantation expansion and associated forest conversion in Indonesia (Gaveau et al. 2018; Austin et al. 2019). One reason for the slowdown might be that expansion of plantations is linked to the price of CPO, which has declined in recent years (Gaveau et al. 2018). The high stock of CPO in Southeast Asia, which reached a record high of 3 mt in 2018, coupled with low demand for CPO from consumer countries such as China, the European Union, Pakistan, and the Philippines (resulting in a 12.9% month-on-month drop in exports in December 2018), has contributed to the decline in CPO prices (Shamsudin 2019). In addition to these factors, price fluctuations in other edible oils like soybean oil, the availability of oil palm feedstock for biodiesel production, labor shortages, and changes in policies have also had a negative impact on CPO prices in both countries (Yusof 2022). Isa et al. (2020) found that in Malaysia, the strengthening of the Malaysian currency against the USD has resulted in an increase in the cost to import CPO for importing countries. This increase in cost has led to a decrease in the demand for CPO in the global market. The decline in demand has subsequently caused a decrease in the price of CPO. Gaveau et al. (2022) assessed that a 1% decrease in price was associated with a 1.1% reduction in the establishment of new industrial plantations and a 0.7% reduction in forest loss in Indonesia. The study also noted that lower CPO prices discouraged investors from expanding oil palm cultivation in Indonesian Borneo, and this trend is expected to impact Malaysian plantation expansion as well. Subsequently, many of the major plantation companies are now expanding their concessions in Papua, Central and Western Africa, and the Americas (Austin et al. 2017; Furumo and Aide 2017).

Furthermore, the price drop of CPO can also be attributed to the economic growth of China and India from 2000 to 2011, which led to a quadrupling of the CPO price (from an annual mean of USD 261 to USD 1,077), led to a surge in investment in new plantings. However, as the economies of China and India slowed around 2011–2012, the market was unable to absorb the increased supply, leading to a decline in prices. As a result, between 2011 and 2019, the annual price of CPO was halved, reaching USD 523 by 2019 (Gaveau et al. 2022). However, it is worth noting that CPO prices have begun to rise once again. In 2019, the annual mean was USD 524, which increased to USD 666 in 2020 and further to USD 1,039 in 2021 (Gaveau et al. 2022). Moreover, the demand for palm oil is expected to increase due to Indonesia's biodiesel program, which may act as a further stimulus for expansion. Effective from 1 February 2023, Indonesia implemented the B35 (35% blend of palm oil) biodiesel program in its transport sector, which increases the required palm oil mix from B30 (Listiyorini and Harsono 2023). As a result, domestic consumption of palm oil is expected to increase, around a 19% increase compared to 2022 (Biofuel Central 2022). Conversely, as Indonesia tightens its palm oil export policy to prioritize domestic supply, demand for Malaysian palm oil is expected to increase. This shift is predictable to assist in reducing higher domestic palm oil stocks in Malaysia (Jalil 2023).

Since 2014, the world's largest palm oil producers, traders, consumer goods companies, and financial institutions have had comprehensive commitments to "No Deforestation, No Peat, No Exploitation (NDPE)" policies, considered one of the most effective private instruments to cut the direct link between deforestation and palm oil (Proforest 2020). As of June 2020, NDPE policies covered 83% of the palm oil refining capacity in Indonesia and Malaysia, with 78% of companies implementing these policies (Chain Reaction Research 2020). In Malaysia, stricter adherence to NDPE policies by palm oil refineries has resulted in reduced palm oil production supplied from deforested or peat lands, slowing the expansion of oil palm cultivation (Aidenvironment 2021). Out of the 21 largest oil palm growers in Indonesia, 16 of them comply with NDPE policies regarding the clearance of forests and peatlands (Chain Reaction Research 2020). However, the Indonesian government also offered local leakage refiners an escape from NDPE market requirements through the palm oil diesel market. This has led to a situation where some growers are still engaging in deforestation for oil palm, despite the fact that eight out of the twenty-five largest refiners in Indonesia and Malaysia are involved in the leakage market. China, India, Indonesia, Pakistan, and Bangladesh are major leakage markets for palm oil, collectively accounting for approximately 43% of the exports from Indonesia and Malaysia (Chain Reaction Research 2020).

Currently, NDPE policies are still applied to only the palm oil supply chain rather than the entire corporate entity of suppliers, such as timber and mining (Chain Reaction Research 2023).

Additionally, the tightening of sustainable certification requirements by the 16th Annual Conference of Roundtable on Sustainable Palm Oil (RSPO) 2018, which prohibits deforestation and peatland clearing, has also contributed to this trend. Moreover, 86.39% of Malaysia's oil palm plantations and 96.04% of refiners have been certified sustainable under the Malaysian Sustainable Palm Oil (MSPO) certification scheme established in 2015 to mitigate social and environmental impacts from oil palm supply chain (Law and Wong 2021).

The relationship between plantation expansion and deforestation remains a subject of debate even in research (Gaveau et al. 2016, Mosnier et al. 2017, Gaveau et al. 2018). In contrast, a recent study found that rubber plantations were converted to oil palm plantations at an average rate of 1.9% and 2.6% annually in Indonesia and Malaysia (Jayathilake et al. 2023). Starting in 2016 or so, rubber prices were down in Malaysia, so smallholder farmers abandoned their rubber plantations, and many farmers converted to oil palm, who generally prefer crops that offer high and quick returns on investment (Shevade and Loboda 2019). Many farmers also obtain an immediate income by cutting down rubber trees to be sold for timber (Ali et al. 2021). Similarly in Indonesia, traditionally managed rubber agroforestry cannot compete with oil palm in terms of profitability (Feintrenie et al. 2010). Additionally, the labor-intensive nature of rubber and its low returns from land prices have rendered rubber less appealing to smallholders in both countries (Jayathilake et al. 2023).

Meanwhile, consumers in the European Union, for example, demand palm oil products from Indonesia and Malaysia that are free from deforestation (Gaveau et al. 2018), which burden these countries to ensure deforestation-free export commodities. However, recent research has suggested that banning imports from the European Union of deforestation-free commodities may have a much less significant impact on preventing forest loss than was originally expected (Busch et al. 2022). Following that, Indonesian palm oil companies began exporting palm oil to China without NDPE commitments. Between 2019 and 2021, Indonesia exported 1.4 mt of palm oil to China, which was twice the amount exported between 2016 and 2018 (see details at https://www.tradeatlas.com/en). More importantly, one ton of palm oil can be produced on as little as one-eighth of the land (0.26 ha) needed for producing other major oil crops such as soybean (2 ha), sunflower (1.43 ha) and rapeseed (1.25 ha) oils. Given that demand for palm oil is expected to nearly double by 2050, substituting oil palm for other crops may exacerbate the problem of banning palm oil products (IUCN 2018).

Nevertheless, environmental NGOs and activists are also working to eliminate all palm oil or deforestation-linked palm oil from consumer goods. Many of the world's largest traders and producers of palm oil have made zero deforestation commitments "No Deforestation, Clear Peatland, Or Exploit Workers," in which they guarantee to eliminate deforestation from their supply chain by a stated date (Lambin et al. 2018). Studies found that these commitments can potentially make substantial long-term contributions to supply chain transparency and public-private engagement (Hoang and Kanemoto 2021) and increase direct sourcing and traceability (zu Ermgassen et al. 2022). Commitments can also help improve territorial governance (Pendrill et al. 2022) and influence government policies (Dermawan et al. 2022). However, traders and producers commitments are somehow fragile, and even this low accomplishment is being threatened by rising product prices and the increasing influence of traders with limited transparency. Only 28 of 350 companies, the most influential ones, have published new commitments to address deforestation. Only 11 of these companies have deforestation commitments for all commodities they deal with. Furthermore, only 23 of 150 financial institutions have a deforestation policy and reported on its implementation progress (Burley and Thomson 2021). Moreover, at the 2021 UN Climate Change Conference more than 100 leaders committed to working collectively to halt and reverse forest loss and land degradation by 2030 while delivering sustainable development and promoting an inclusive rural transformation. In the “Declaration on Forests and Land Use,” countries outlined their strategy, which focuses on supporting trade and development policies that promote sustainable production and consumption (see details at https://ukcop26.org/).

Governments and other stakeholders are concerned with identifying ways to increase productivity and eliminate deforestation from the supply chains. Ensuring the sustainability of these sectors demands comprehensive policy measures and practical solutions for farmers that enhance their livelihoods. This can only be accomplished through government, private sector, farmers, and community collaboration. Conversely, after the COVID-19 pandemic situation, palm oil prices are likely to increase as demand increases for its use in food and biofuels (liquids or gases made from plant products including oil palm), boosting the profitability of palm oil again and programs such as biodiesel expansion, which could drive further plantation expansion. Since 2015, the Indonesian government has provided significant subsidies to producers of biodiesel blends that use palm oil in order to keep the prices of these biofuels competitive. Biodiesel blends derived entirely from palm oil, known as B100, are used as a replacement for conventional diesel. As of 2021, Indonesia was the third largest producer of biofuels, generating 312 petajoules annually, and the largest producer of biodiesel from different feedstocks, including oil palm, after the United States and Brazil (www.statista.com). Both countries are striving to boost exports to India and China, two growing biodiesel importers. This is part of their efforts to promote biodiesel as an eco-friendly substitute for conventional aviation and shipping fuels (Coca 2020). However, in order to meet the demand for B100, an additional 15 Mha of oil palm plantation would need to be established, which is more than double the current area of oil palm plantation in the country. This represents a significant challenge for the industry and the government (www.statista.com).

Conclusion

This study’s findings indicate that oil palm and rubber production-related deforestation in Indonesia and Malaysia has decreased over the last few years. Corporate zero deforestation commitments and policies cannot halt tropical deforestation alone. Smaller companies and smallholder farmers run out of forest to clear without such commitments and can still sell their products in the leakage market, like in China. Therefore, to prevent deforestation, efforts are being made to protect forestland, increase engage community participation in forest management, improve forest monitoring using technology, provide open access to real-time deforestation data, enhance transparency and sustainability in the forestry products supply chain, and improve planning and management for oil palm and rubber in Indonesia and Malaysia. Further, the two countries may increase deforestation pressure due to the increasing use of oil palm as biodiesel in local and international markets. Here required public and private governance arrangements and robust government monitoring to implement the zero deforestation commitments.

Declaration

Competing interests: The authors declare no competing interests.

References

1. AidEnvironment (2021) The need for cross-commodity no-deforestation policies by the world's palm oil buyers. Amsterdam, The Netherlands.
2. Ali MF, Akber MA, Smith C, Aziz AA (2021) The dynamics of rubber production in Malaysia: Potential impacts, challenges and proposed interventions. For Policy Econ 127:102449. https://doi.org/10.1016/j.forpol.2021.102449.
3. Austin KG, Heilmayr R, Benedict JJ, Burns DN, Eggen M, Grantham H, Greenbury A, Hill JK, Jenkins CN, Luskin MS, Manurung T, Rasmussen LV, Rosoman G, Rudorff B, Satar M, Smith C, Carlson KM (2021) Mapping and monitoring zero-Deforestation commitments. BioScience 71(10):1079-1090. https://doi.org/10.1093/biosci/biab082.
4. Austin KG, Schwantes A, Gu Y, Kasibhatla PS (2019) What causes deforestation in Indonesia? Environ Res Lett14(2):024007. https://doi.org/10.1088/1748-9326/aaf6db.
5. Aziz A (2023) Oil palm – A zero waste crop. Malaysian Palm Oil Certification Council, Selangor. https://www.mpocc.org.my/mspo-blogs/oil-palm-a-zero-waste-crop. Accessed 10 January 2023.
6. Badan Pusat Statistik (2023) https://www.bps.go.id/. Accessed 10 January 2023.
7. Biofuel Central (2022) Indonesia to Implement Mandatory 35% Biodiesel Blending Starting Jan 1, 2023. Posted on 17 December 2022. https://biofuelscentral.com/indonesia-implement-mandatory-35-biodiesel-blending-starting-jan-1-2023/. Accessed 22 December 2022.
8. Burley H, Thomson E (2021) A climate wake-up: But business failing to hear the alarm on deforestation. Global Canopy, Oxford, UK.
9. Busch J, Amarjargal O, Taheripour F, Austin KG, Siregar RN, Koenig K, Hertel TW (2022) Effects of demand-side restrictions on high-deforestation palm oil in Europe on deforestation and emissions in Indonesia. Environ Res Lett 17(1):014035. https://doi.org/10.1088/1748-9326/ac435e.
10. Busch J, Ferretti-Gallon K, Engelmann J, Wright M, Austin KG, Stolle F, Turubanova S, Potapov PV, Margono B, Hansen MC, Baccini A (2015) Reductions in emissions from deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions. Proc Natl Acad Sci USA 112(5):1328-1333. https://doi.org/10.1073/pnas.1412514112.

11. Chain Reaction Research (2020) NDPE policies cover 83% of palm oil refineries; implementation at 78%. https://chainreactionresearch.com/report/ndpe-policies-cover-83-of-palm-oil-refineries-implementation-at-75/. Accessed 19 March 2023.
12. Chain Reaction Research (2023) Lack of cross-commodity NDPE implementation allows deforestation. https://chainreactionresearch.com/report/lack-of-cross-commodity-ndpe-implementation-allows-deforestation/. Accessed 19 March 2023
13. Climate Change Knowledge Portal (2021) https://climateknowledgeportal.worldbank.org/overview. Accessed 13 January 2023.
14. Coca N (2020) As palm oil for biofuel rises in Southeast Asia, tropical ecosystems shrink. China Dialogue on 15 April 2020. https://chinadialogue.net/en/energy/11957-as-palm-oil-for-biofuel-rises-in-southeast-asia-tropical-ecosystems-shrink/. Accessed 16 February 2023.
15. Consumer Goods Forum (2017) Implementing and scaling up the CGF zero net deforestation commitment. https://www.theconsumergoodsforum.com/blog/2017/04/12/implementing-and-scaling-up-the-cgf-zero-net-deforestation-commitment/. Accessed 16 February 2023.
16. Curtis PG, Slay CM, Harris NL, Tyukavina A, Hansen MC (2018) Classifying drivers of global forest loss. Science 361(6407):1108-1111. DOI: 10.1126/science.aau3445.
17. Department of Statistics, Malaysia (2023) https://www.dosm.gov.my/v1/. Accessed 16 February 2023.
18. Dermawan A, Hospes O, Termeer CJAM (2022) Between zero-deforestation and zero-tolerance from the state: Navigating strategies of palm oil companies of Indonesia. For Policy Econ 136:102690. https://doi.org/10.1016/j.forpol.2022.102690.
19. DeValue K, Takahashi N, Woolnough T, Merle C, Fortuna S, Agostini A (2022) Halting deforestation from agricultural value chains: The role of governments. Food and Agriculture Organization of the United Nations, Rome.
20. Direktorat Jenderal Perkebunan (2021) Statistik Perkebunan Unggulan Nasional 2020-2022. Kementerian Pertanian, Jakarta.
21. Dummet C, Blundell A, Wolosin M, Canby K, Bodnar E (2021) Illicit harvest, complicit goods: The state of illegal deforestation for agriculture. Forest Trends, Washington, DC.
22. FAO (2018) Terms and definitions – FRA 2020. Forest Resources Assessment Working Paper 188. Food and Agriculture Organization of the United Nations, Rome.
23. FAO (2022) FRA 2020 Remote Sensing Survey. FAO Forestry Paper No. 186. Food and Agriculture Organization of the United Nations, Rome.
24. FAOSTAT (2023) Data. https://www.fao.org/faostat/en/#data. Accessed 16 February 2023.
25. Feintrenie L, Chong WK, Levang P (2010) Why do farmers prefer oil palm? Lessons learnt from Bungo District, Indonesia. Small-Scale For 9(3):379-396. https://doi.org/10.1007/s11842-010-9122-2.

26. Gatto M, Wollni M, Qaim M (2015) Oil palm boom and land-use dynamics in Indonesia: The role of policies and socioeconomic factors. Land Use Policy 46:292-303. https://doi.org/10.1016/j.landusepol.2015.03.001.
27. Gaveau DLA, Locatelli B, Salim MA, Husnayaen, Manurung T, Descals A, Angelsen A, Meijaard E, Sheil D (2022) Slowing deforestation in Indonesia follows declining oil palm expansion and lower oil prices. PLoS ONE 17(3):e0266178. https://doi.org/10.1371/journal.pone.0266178.
28. Gaveau DLA, Locatelli B, Salim MA, Yaen H, Pacheco P, Sheil D (2018) Rise and fall of forest loss and industrial plantations in Borneo (2000-2017). Conserv Lett 12(3):e12622. https://doi.org/10.1111/conl.12622.
29. Gaveau DLA, Sheil D, Husnayaen, Salim MA, Arjasakusuma S, Ancrenaz M, Pacheco P, Meijaard E (2016) Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. Sci Rep 6:32017. https://doi.org/10.1038/srep32017.
30. Global Forest Watch (2023) www.globalforestwatch.org. Accessed 13 January 2023.
31. Goldman E, Weisse MJ, Harris N, Schneider M (2020) Estimating the role of seven commodities in agriculture-linked deforestation: Oil palm, soy, cattle, wood fiber, cocoa, coffee, and rubber. World Resources Institute, Washington, DC.
32. Grow Asia Partnership Ltd. (2020) Case study: Rubber in Indonesia. Grow Asia, Singapore.
33. Hanafiah KM, Mutalib AHA, Miard P, Goh CS, Sah SAM, Ruppert N (2022) Impact of Malaysian palm oil on sustainable development goals: Co-benefits and trade-offs across mitigation strategies. Sustainability Sci 17:1639-1661. https://doi.org/10.1007/s11625-021-01052-4.
34. Hoang NT, Kanemoto K (2021) Mapping the deforestation footprint of nations reveals growing threat to tropical forests. Nat Ecol Evol 5:845-853. https://doi.org/10.1038/s41559-021-01417-z.
35. Isa MAM, Baharim AT, Mohamed S, Noh MKA, Nasrul F, Ibrahim WMFW, Hassan SS (2020) Crude palm oil price fluctuation in Malaysia. Int J Acad Res Bus Soc Sci 10(5):879-892. http://dx.doi.org/10.6007/IJARBSS/v10-i5/7319.
36. IUCN (2018) Palm oil and biodiversity. Issues Brief June 2018. International Union for Conservation of Nature, Gland.
37. Jalil A (2023) CPO prince to hover between RM4,000-RM4,200 this year, says MPOB. New Straits Times on 13 January 2023. https://www.nst.com.my/business/2023/01/869797/cpo-prince-hover-between-rm4000-rm4200-year-says-mpob. Accessed 10 March 2023.
38. Jayathilake HM, Jamaludin J, Alban JDTD, Webb EL, Carrasco LR (2023) The conversion of rubber to oil palm and other landcover types in Southeast Asia. Appl Geogr 150:102838. https://doi.org/10.1016/j.apgeog.2022.102838.
39. Krungsri Research (2022) Thailand industry outlook 2022-24: Palm oil industry. Bank of Ayudhya Public Company Limited, Bangkok.
40. Lambin EF, Gibbs HK, Heilmayr R, Carlson KM, Fleck LC, Garrett RD, de Waroux YleP, McDermott CL, McLaughlin D, Newton P, Nolte C, Pacheco P, Rausch LL, Streck C, Thorlakson T, Walker NF (2018)

The role of supply-chain initiatives in reducing deforestation. Nat Clim Change 8:109-116. https://doi.org/10.1038/s41558-017-0061-1.

41. Law Y-H, Wong SL (2021) Can oil palm explain the lower forest loss here? Pulitzer Center, Washington DC.
42. Listiyorini E, Harsono N (2023) Indonesia maintains biodiesel target despite slow start to B35. 30 March 2023. https://www.theedgemarkets.com/node/661507. Accessed 10 March 2023.
43. Malaysian Palm Oil Board (2023) https://www.mpob.gov.my/. Accessed 10 March 2023.
44. Malaysian Rubber Board (2023) https://www.lgm.gov.my/webv2/home. Accessed 10 March 2023.
45. Malaysian Rubber Council (2023) World rubber production, consumption and trade. https://www.myrubbercouncil.com/industry/world_production.php. Accessed 10 March 2023.
46. Malode SJ, Prabhu K, Mascarenhas RJ, Shetti NP, Aminabhavi TM (2021) Recent advances and viability in biofuel production. Energy Convers Manage: X 10:100070. https://doi.org/10.1016/j.ecmx.2020.100070.
47. Ministry of Environment and Forestry (2020) The state of Indonesian's forests 2020. Republic of Indonesia, Jakarta.
48. Ministry of Environment and Water (2020) Malaysia: Third biennial update report to the UNFCCC. Putrajaya, Malaysia.
49. Mosnier A, Boere E, Reumann A, Yowargana P, Pirker J, Havlík P, Pacheco P (2017) Palm oil and likely futures. Assessing the potential impacts of zero deforestation commitments and a moratorium on large-scale oil palm plantations in Indonesia. CIFOR infobrief 177:1-8. https://doi.org/10.17528/cifor/006468.
50. Newton P, Benzeev R (2018) The role of zero-deforestation commitments in protecting and enhancing rural livelihoods. Curr Opi Environ Sustainability 32:126-133. https://doi.org/10.1016/j.cosust.2018.05.023.
51. Orangutan Foundation (2023) Palm oil. https://orangutanfoundation.org.au/palm-oil/. Accessed 17 February 2023.
52. Pacheco P, Mo K, Dudley N, Shapiro A, Aguilar-Amuchastegui N, Ling PY, Anderson C, Marx A (2021) Deforestation fronts: Drivers and responses in a changing world. World Wildlife Fund, Gland.
53. Pendrill F, Gardner TA, Meyfroidt P, Persson UM, Adams J, Azevedo T, Lima MGB, Baumann M, Curtis PG, de Sy V, Garrett R, Godar J, Goldman ED, Hansen MC, Heilmayr R, Herold M, Kuemmerle T, Lathuillière MJ, Ribeiro V, Tyukavina A, Weisse MJ, West C (2022) Disentangling the numbers behind agriculture-driven tropical deforestation. Science 377(6611):1168. DOI: 10.1126/science.abm9267.
54. Pendrill F, Persson UM, Godar J, Kastner T, Moran D, Schmidt S, Wood R (2019) Agricultural and forestry trade drives large share of tropical deforestation emissions. Global Environ Change 56:1-10. https://doi.org/10.1016/j.gloenvcha.2019.03.002.
55. Proforest (2020) Understanding commitments to no deforestation, no peat and no exploitation (NDPE). Oxford, United Kingdom.

56. Research and Markets (2022) Natural rubber market - growth, trends, COVID-19 impact, and forecasts (2022-2027). Dublin, Ireland.
57. Robins J (2020) Shallow roots: The early oil palm industry in Southeast Asia, 1848-1940. J Southeast Asian Stud 51(4):538-560. https://doi.org/10.1017/S0022463420000697.
58. Rothrock P, Weatherer L, Zwick S (2019) Corporate commitments to zero deforestation: Company progress on commitments that count, 2019. Forest Trends, Washington, DC.
59. RSPO (2023) Roundtable on Sustainable Palm Oil. https://rspo.org/why-sustainable-palm-oil/. Accessed 17 February 2023.
60. Shamsudin MN (2019) Prospect of palm oil prices. Faculty of Agriculture, Universiti Putra Malaysia. https://agri.upm.edu.my/artikel/prospect_of_palm_oil_prices-53457. Accessed 17 February 2023.
61. Shevade VS, Loboda TV (2019) Oil palm plantations in Peninsular Malaysia: Determinants and constraints on expansion. PLoS ONE 14(2):e0210628. https://doi.org/10.1371/journal.pone.0210628.
62. Shoumatoff A (2017) Vanishing Borneo: Saving one of the world's last great places. Yale Environment 360, Yale School of the Environment, Yale University, New Haven.
63. Statista (2023) Rubber-Statistics & facts. https://www.statista.com/topics/3268/rubber/#topicOverview. Accessed 17 February 2023.
64. Stedman E (2021) Palm oil products - and why palm oil is bad for the environment. GoodToKnow, London. https://www.goodto.com/food/food-news/palm-oil-products-to-avoid-460304. Accessed 17 February 2023.
65. USDA (2022) Palm oil explorer. International Production Assessment Division of the United States Department of Agriculture (USDA). https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=4243000. Accessed 12 January 2023.
66. Varkkey H, Tyson A, Choiruzza SAB (2018) Palm oil intensification and expansion in Indonesia and Malaysia: Environmental and socio-political factors influencing policy. For Policy Econ 92:148-159. https://doi.org/10.1016/j.forpol.2018.05.002.
67. World Bank Data (2023) https://data.worldbank.org/indicator/SP.POP.TOTL. Accessed Retrieved 12 January 2023.
68. WWF and BCG (2021) Deforestation- and conversion-free supply chains: A guide for action. World Wide Fund for Nature, Gland and BCG, Boston.
69. Xu Y, Yu L, Ciais P, Li W, Santoro M, Yang H, Gong P (2022) Recent expansion of oil palm plantations into carbon-rich forests. Nat Sustainability 5:574-577. https://doi.org/10.1038/s41893-022-00872-1.
70. Yousof A (2022) CPO price to soften as vegetable oils pick up? New Straits Times on 21 February 2022 https://www.nst.com.my/business/2022/02/773178/cpo-price-soften-vegetable-oils-pick. Accessed 19 March 2023.

71. zu Ermgassen EKH, Lima MGB, Bellfield H, Dontenville A, Gardner T, Godar J, Heilmayr R, Indenbaum R, dos Reis TNP, Ribeiro V, Abu I, Szantoi Z, Meyfroidt P (2022) Addressing indirect sourcing in zero deforestation commodity supply chains. Sci Adv 8(17):eabn3132. DOI: 10.1126/sciadv.abn3132.

Figures

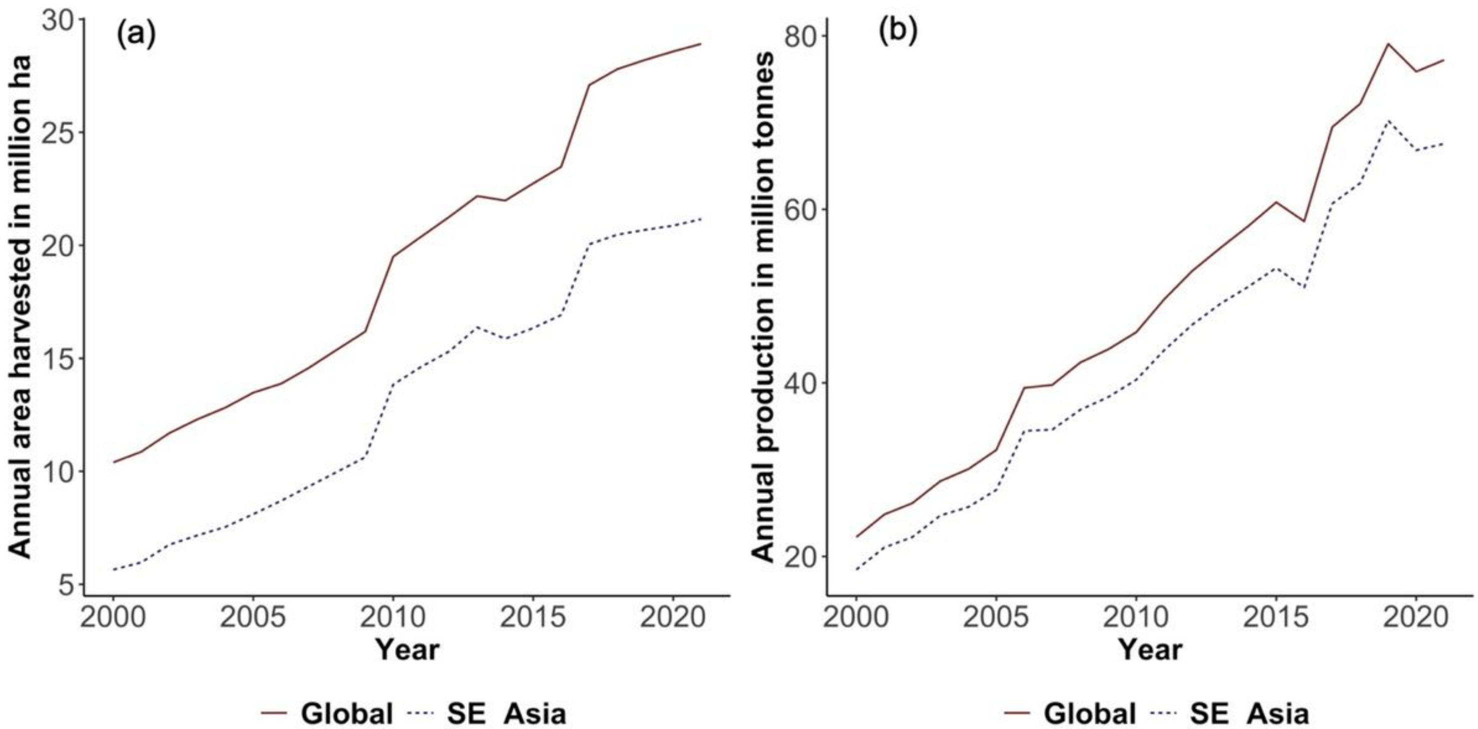

Figure 1

Global and Southeast Asia’s status of annual oil palm harvested area (a) and crude palm oil production (b) between 2000 and 2021 (data source: FAOSTAT, 2023).

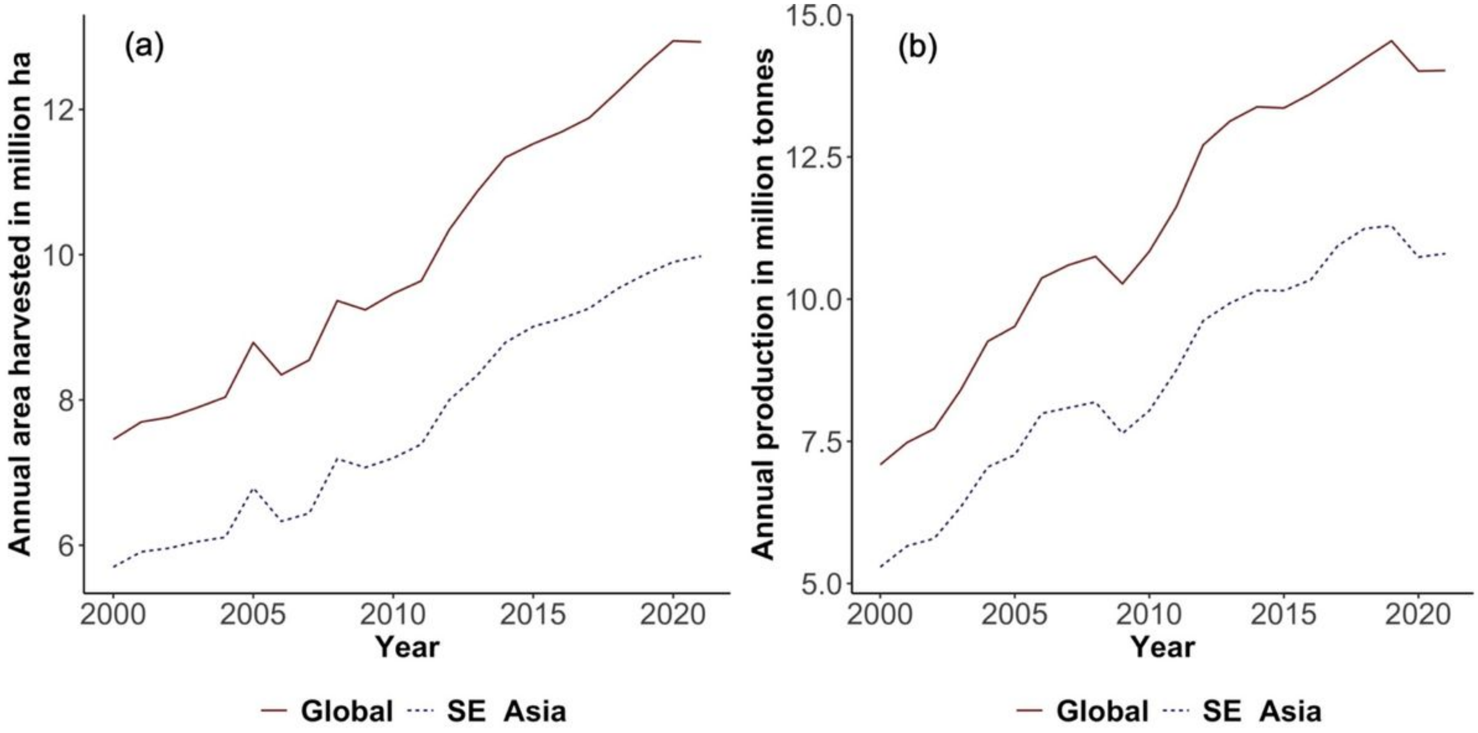

Figure 2

Global and Southeast Asia's status of annual rubber harvested area (a) and natural rubber production (b) between 2000 and 2021 (data source: FAOSTAT, 2023).

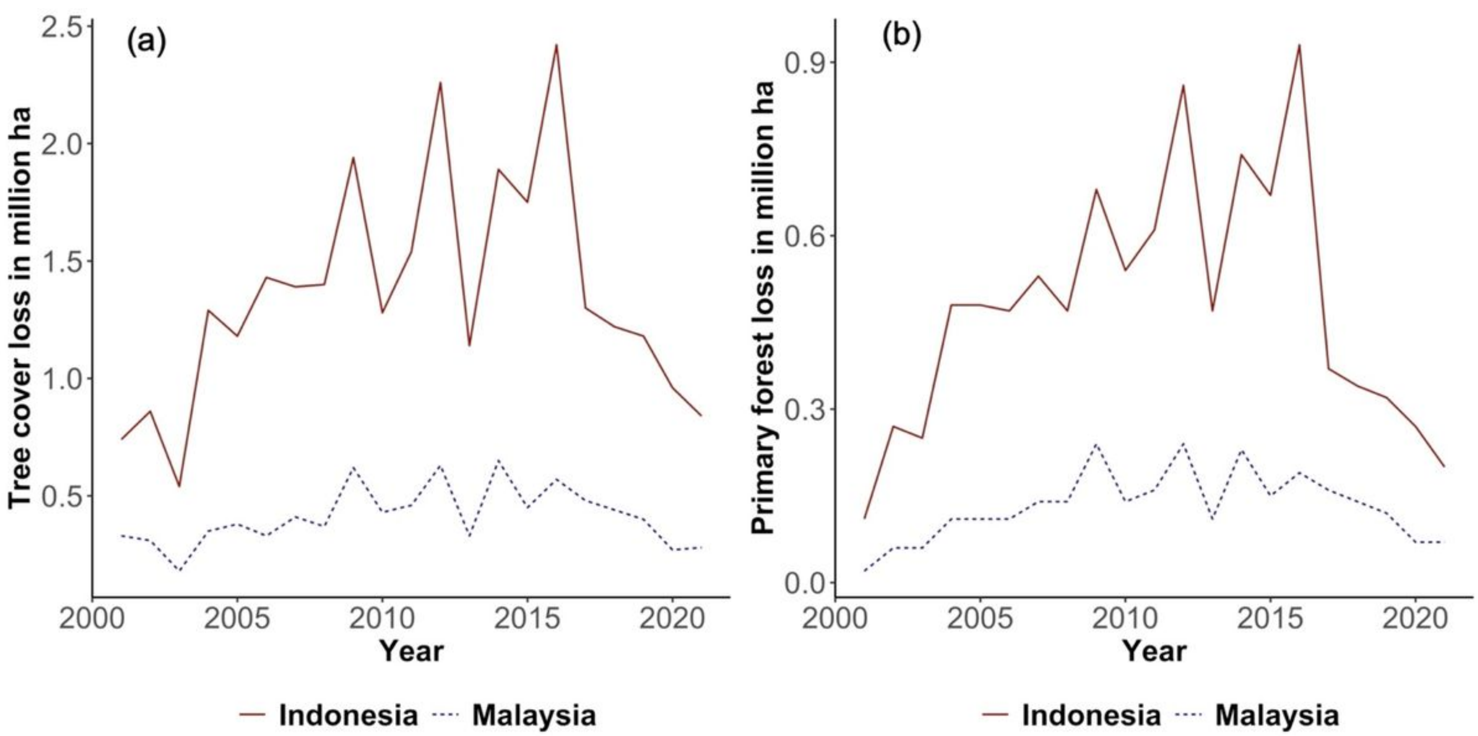

Figure 3

Annual tree cover loss (a) and primary forest loss (b) in Indonesia and Malaysia between 2001 and 2021 (data source: Global Forest Watch, 2023).

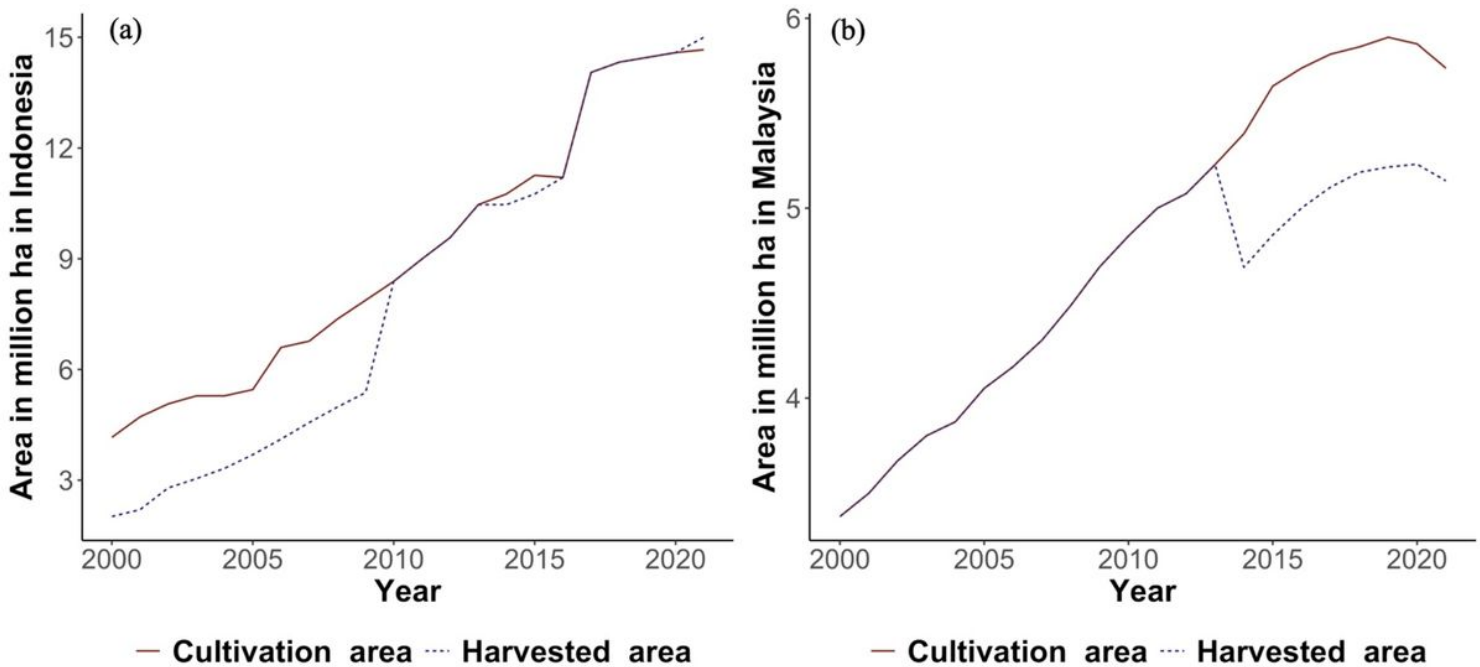

Figure 4

Annual area cultivated and harvested for oil palm in Indonesia (a) and Malaysia (a) between 2000 and 2021 (data sources: Malaysian Palm Oil Board, 2020; Department of Statistics, Malaysia, 2020; Direktorat Jenderal Perkebunan, 2021; Badan Pusat Statistik, 2022; FAOSTAT, 2023).

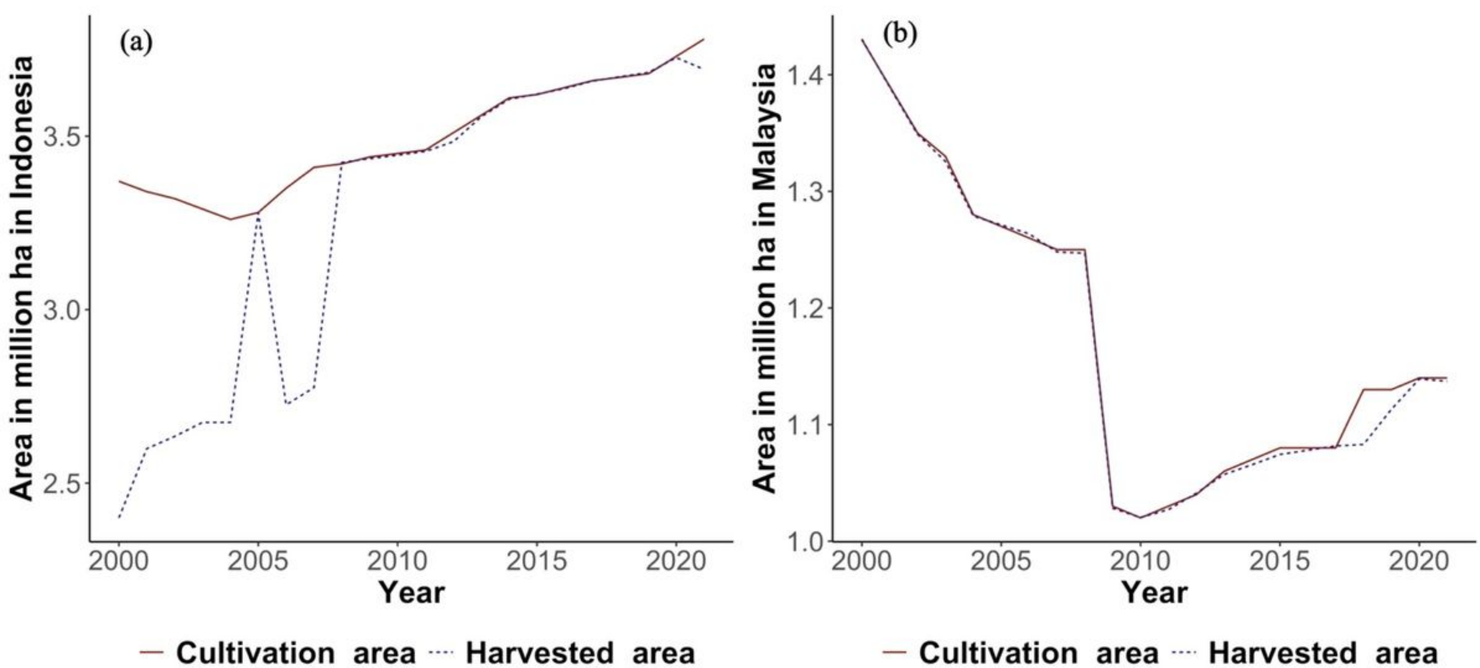

Figure 5

Annual area cultivated and harvested for rubber in Indonesia (a) and Malaysia (b) between 2000 and 2021 (data sources: Badan Pusat Statistik, 2022; FAOSTAT, 2023; Malaysian Rubber Council, 2023; Malaysian Rubber Board, 2023).

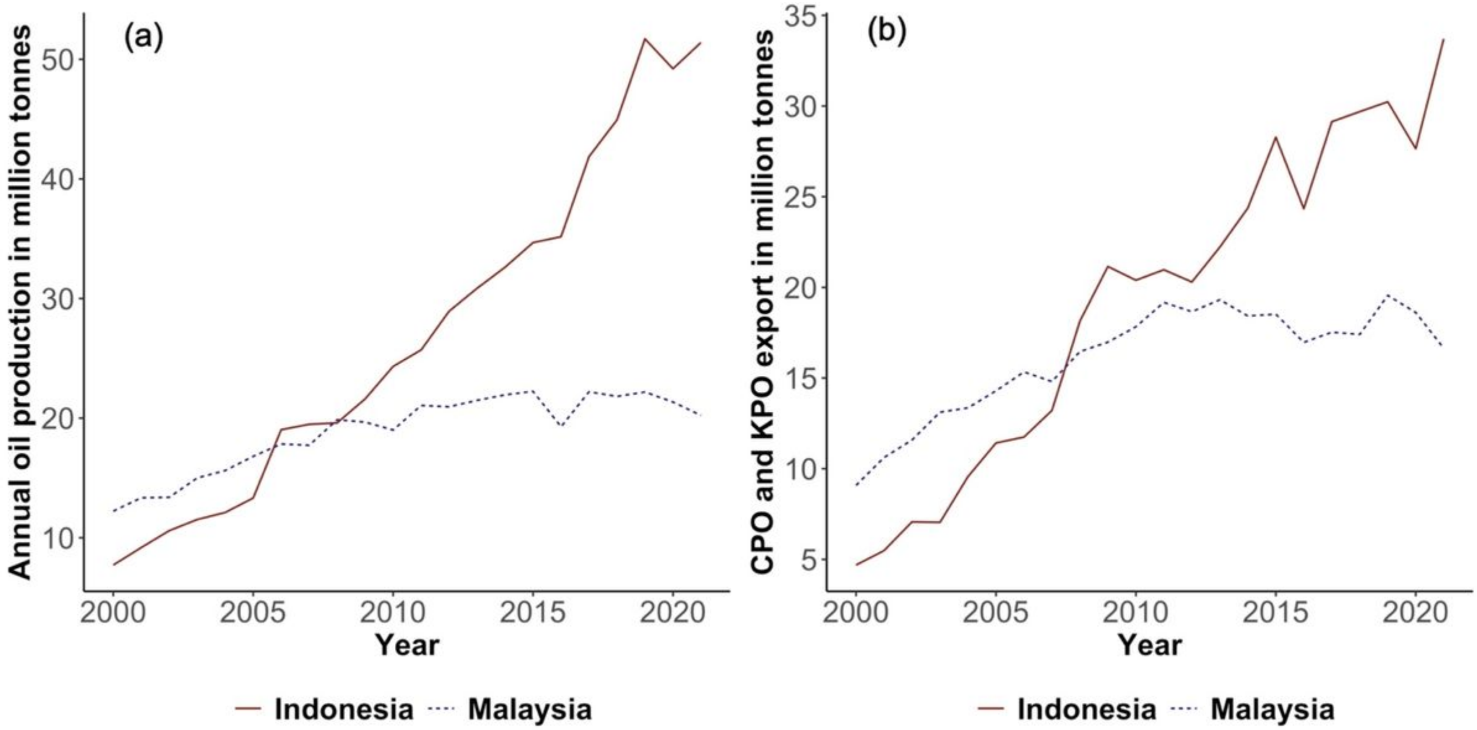

Figure 6

Annual palm oil production (a) and export volume (b) in Indonesia and Malaysia between 2000 and 2021 (data sources: Malaysian Palm Oil Board, 2020; Department of Statistics, Malaysia, 2020; Direktorat Jenderal Perkebunan, 2021; Badan Pusat Statistik, 2022; FAOSTAT, 2023).

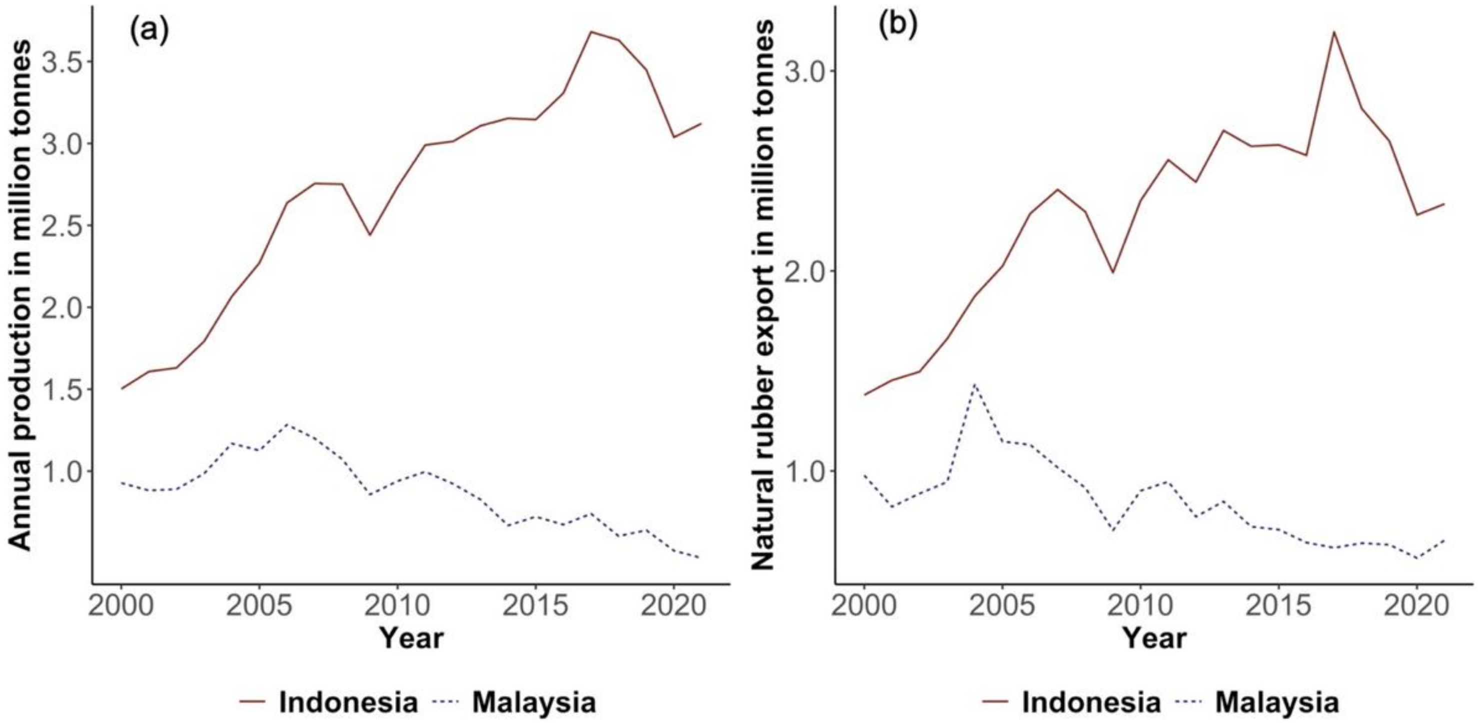

Figure 7

Annual natural rubber production (a) and export volume (b) in Indonesia and Malaysia between 2000 and 2021 (data sources: Direktorat Jenderal Perkebunan, 2021; Badan Pusat Statistik, 2022; Malaysian Rubber Board, 2023; FAOSTAT, 2023).

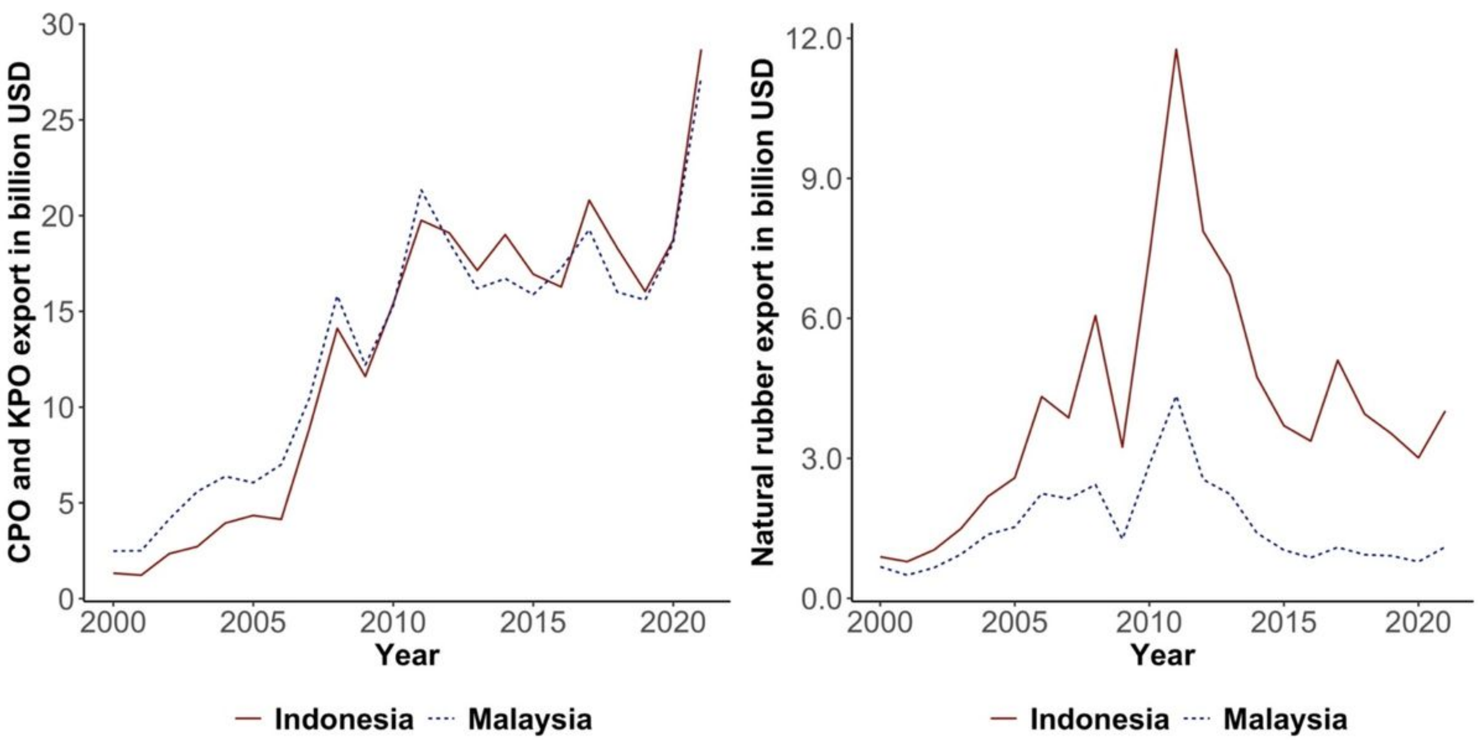

Figure 8

Export values of CPO and KPO (a) and natural rubber (b) in Indonesia and Malaysia between 2000 and 2021 (data sources: Malaysian Palm Oil Board, 2020; Department of Statistics, Malaysia, 2020; Direktorat Jenderal Perkebunan, 2021; Badan Pusat Statistik, 2022; FAOSTAT, 2023; Malaysian Rubber Board, 2023).

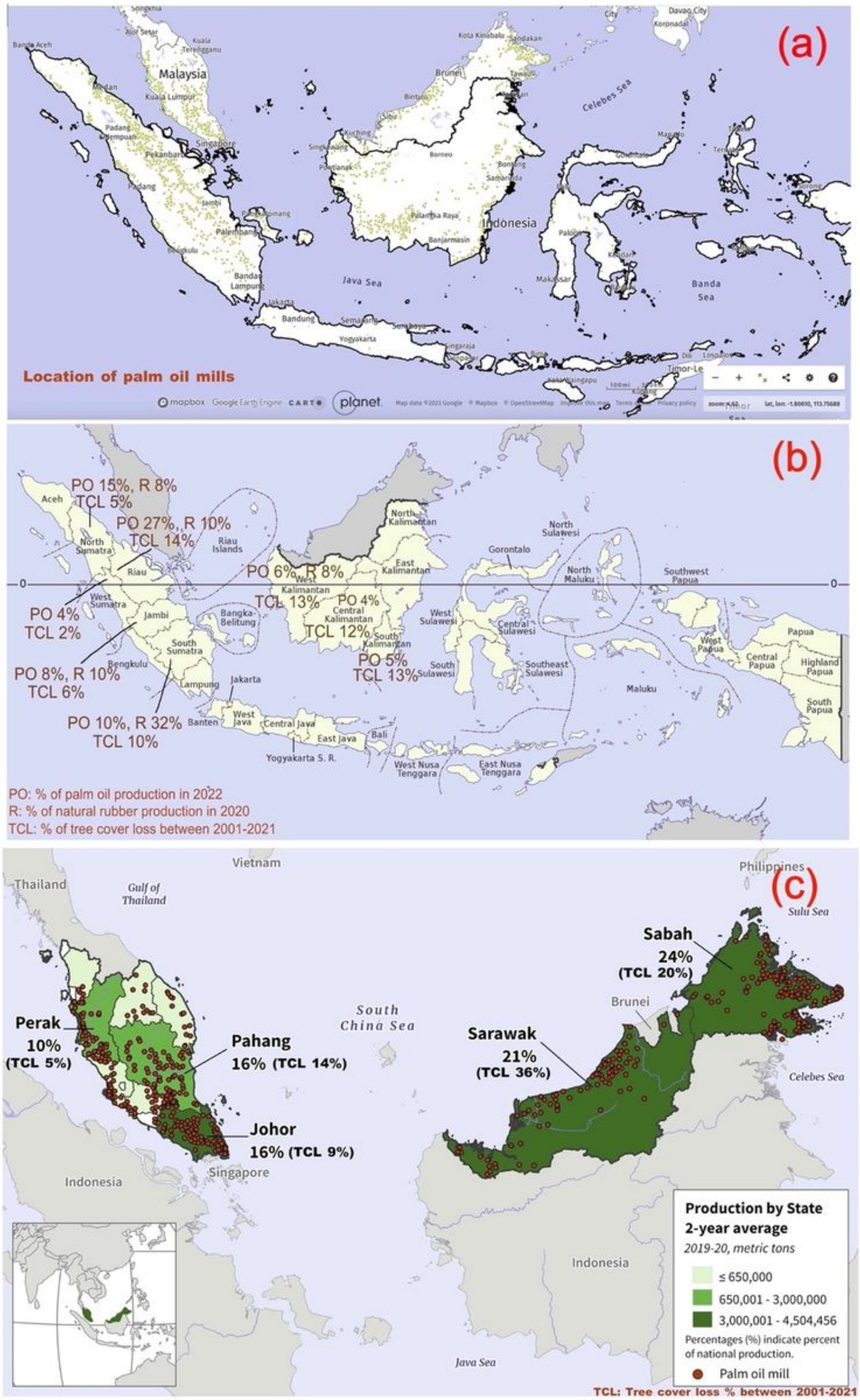

Figure 9

(a) Distribution of palm oil mills across Indonesia and Malaysia; (b) major regions of palm oil and natural rubber production and the extent of tree cover loss in those areas of Indonesia; and (c) major regions of palm oil production and the extent of tree cover loss in those areas of Malaysia (Data and maps sources: Grow Asia Partnership Ltd., 2020; USDA, 2023; FAOSTAT, 2023; Global Forest Watch, 2023).