ITTO Project :
"PROMOTION OF SUSTAINABLE DOMESTIC CONSUMPTION OF WOOD PRODUCTS IN THAILAND"
(PD 926/22 Rev.1 (I))

RUBBER
SUPPLY CHAINS IN THAILAND


YONGYUT TRISURAT
TETRA YANUARIADI

KASETSART UNIVERSITY
INTERNATIONAL TROPICAL TIMBER ORGANIZATION

JAPANGOV THE GOVERNMENT OF JAPAN
MAFF Ministry of Agriculture, Forestry and Fisheries
KASETSART UNIVERSITY SINCE 1943
ROYAL FOREST DEPARTMENT
ITTO

ITTO Project:
"PROMOTION OF SUSTAINABLE DOMESTIC CONSUMPTION OF WOOD PRODUCTS IN THAILAND"
(PD 926/22 Rev.1 (I))

RUBBER SUPPLY CHAINS IN THAILAND

2024

Yongyut Trisurat
Tetra Yanuariadi

KASETSART UNIVERSITY
INTERNATIONAL TROPICAL TIMBER ORGANIZATION

RUBBER
SUPPLY CHAINS IN THAILAND

Published by Kasetsart University and International Tropical Timber Organization

Printing June 2024

Citation KU and ITTO. 2024. Rubber Supply Chains in Thailand. Kasetsart University, Bangkok, Thailand and International Tropical Timber Organization, Yokohama, Japan. 63p.

ISBN (e-book) 978-616-278-843-7

Authors Yongyut TRISURAT and Tetra YANUARIADI

English editor P.K. THULASIDAS

Designed by Suchanart SUYARAT and Saichon MUTARAPAT

PREFACE

The impacts of the global COVID-19 pandemic will remain a significant problem in the tropical timber trade market in which international prices and demands are expected to decline. There have been disruptions in supply chains, leading to limited sales of tropical timber in the global market. The ITTO Market Information Service (MIS) and Thailand's Forest Statistics reported that exports of primary wood products to international markets (e.g., Japan and EU27) in 2021 declined more than 20% compared to 2019 before the pandemic.

In addition, the EU Regulation on deforestation-free products entered into force on 23 June 2023 becomes become an additional barrier for international trade of topical timber. In contrast, the consumption of wood and wood products in the domestic market is predicted to steadily increase due to residential properties development in big cities and the government's property stimulus package for buying new houses.
To this end, the Government of Thailand needs to develop its wood and wood products in domestic markets to reduce the country's economic dependency on export markets. In addition, this practice will support the government policy on green growth and sustainable development by increasing bio-based economy value in new market segments.

With the financial support from the Forestry Agency of Japan through ITTO, the Kasetsart University and the Royal Forest Department in Thailand jointly implement ITTO project entitled **"Promotion of sustainable domestic consumption of wood products in Thailand" (PD 926/22 Rev.1 (I)) or ITTO Sustainable Wood Use.**

Therefore, the development objective of the project aims at enhancing sustainable domestic wood consumption in Thailand. The specific objective is to promote sustainable domestic consumption of wood and wood products in Thailand through policy improvement on wood certification, stakeholder capacity building, and timber supply chains.

Sawed timber rubber in Thailand

PREFACE

This technical report on **"Rubber *(Hevea brasiliensis)* Supply Chains in Thailand"** is the outcome of the ITTO Sustainable Wood Use Project in Thailand during 2023-2025. The report comprises seven sections, namely: (1) Background, (2) Rubber Ecology, (3) Rubber Plantations, (4) Rubber Supply Chains, (5) Imports and Exports, (6) Challenges in Rubber Industry, and (7) Policy Recommendations. This report also provides guidance for future work in promoting sustainable management of natural and planted teak forests in the tropics.

It is of hope that this technical report will serve the national and global rubber community not only with the most up-to-date information on the status and distribution of natural rubber, but also on the sustainable management of rubber latex and rubber wood, and sustainable consumption of legally harvested rubber wood from sustainable sources.

It also intends to promote sustainable rubber wood use to strengthen capacity building of smallholder rubber plantation (78% of the total rubber farmers), actors along the legal and sustainable supply chains, and other relevant stakeholders in Thailand. The report contributes to the achievement of SDGs, especially SDG 1 (No poverty), SDG 12 (Sustainable production and consumption), SDG 13 (Climate action) and SDG 15 (Life on land) and the Global Forest Goals of the United Nations Strategic Plan for Forests 2030 (UNSPF), as well as ITTO Strategic Action Plan (SAP 2022 – 2026).

ACKNOWLEDGEMENTS

This technical report presents the outcome of the ITTO Sustainable Wood Use in Thailand during 2023-2025. Publication of this book was made possible by the financial support from the Forestry Agency of Japan, Ministry of Agriculture, Forestry and Fisheries (MAFF) through International Tropical Timber Organization (ITTO). The project has been jointly executed by the Kasetsart University (KU) and the Thailand's Royal Forest Department (RFD).

We gratefully acknowledge the technical cooperation and management provided by the Faculty of Forestry, Kasetsart University, the Royal Forest Department, Forest Industry Organization in Thailand, Thai Timber Association, several private forest plantations and smallholder plantations. We are thankful to the ITTO for the fruitful technical support and administrative assistance throughout the project period for implementation. Special thank is given to Mr. Gen Akahane, Director of Wood Products Trade Office of the Forestry Agency of Japan and his staff for providing excellent supports during the project implementation.

The authors would like to acknowledge the contribution of the Project Steering Committee, Project Technical Committee, Mr. Suchat Kalyawongsa (Senior Forestry Expert), Dr. Preecha Ongprasert (ITTO National Focal Point), Dr. Suwan Tangmitcharoen (Direct of Forestry Research and Development Office), Mr. Boonsuthee Jeravongpanich (Director of Forest Economics Office), and Dr. Wirongrong Duangchai (Project Coordinator) for untiring support and guidance proving guidance and technical supports throughout the project period. Our sincere thanks to the authors of all references and reports cited in this technical report. We are grateful to the project staff, Ms. Suchanart Suyarat and Ms. Saichon Mutarapat for their effective and efficient work to administer the project. Finally, we would like to thank Dr. P.K. Thulasidas for the proof-reading of the report.

Y. Trisurat

Yongyut Trisurat
(Ex-Project Coordinator, Kasetsart University)

Tetra Yanuariadi
(ITTO Projects Manager)

TABLE OF CONTENTS

1 BACKGROUND

Forest cover in Thailand had significantly declined from 53% of the country in 1961 to 25% in 1989 due to over-exploitation and encroachment for agriculture, illegal logging and unsustainable forest management. In addition, the rise of grassroots social movements on environmental awareness resulted in the Thai government imposing a nationwide logging ban in 1989 responding to environmental and social concerns. Deforestation rate in Thailand has been stabilized in the last few decades, and the extent of forest cover has even increased in some areas. The remaining area of forest cover is 32%, which is less than the national target of 40% of the country area, of which 25% for conservation forests and 15% for production forests. The extent of conservation forests or protected areas now is about 23% and most likely achieve the 25% target soon. The remaining forest cover outside protected areas (after expansion of protection areas) would be approximately 7.2%. Thus, additional plantation areas of 8% (3.5 million ha) are targeted to achieve the 15% target.

Thailand now has large areas for forestation, including teak, rubberwood, eucalyptus and other valuable species plantations. Rubberwood (mostly domestically sourced) alone contributes 87% of wood furniture production, while eucalyptus supplies a large part of Thailand’s domestic pulp and paper demand.

Teak mainly from the Forestry Industry of Thailand (FIO) contributes about 40,000-60,000 m³ per year (Royal Forest Department, 2023). Imported hardwoods are mostly used in the construction sector, although they also make up the balance of supply to the furniture industry. Almost all the 4 million cubic meters roundwood of sawn wood used in the construction industry in Thailand in 2016 were got imported. The Forestry Development Strategy (2017 – 2036) predicted an wood demand of 47 million tons. This huge demand can be met either by the additional forest plantations of 3.5 million ha in order to achieve the 15% of the country’s land area or a significant increase in imported logs and sawn wood for reprocessing for export. Of this, 1.4 million ha is targeted by 2036.

The characteristics of wood industry and the wood products in Thailand are as follows:

- Thailand is increasingly ambitious in seeking to become a regional manufacturing hub for wood-based products and it is a major supplier of furniture and other wood-based products to European, USA and Asian markets. However, access to international markets will require efforts to verify that all timber in its products (both imported and domestically produced) is legally sourced.

Recently, Japan and the Republic of Korea have also established requirements to promote the trade of legal timber products.

- Thailand started exploring an EU Forest Law Enforcement Governance and Trade (FLEGT), Voluntary Partnership Agreements (VPAs). Under the VPA process, Thailand is developing a Timber Legality Assurance System (THA-TLAS) to verify that wood products conform to national laws, whether they are domestically harvested or imported.
- Thailand’s voluntary certification scheme is a mean to provide Thai industry a method to show to the buyers the legal origin of wood they purchased. However, with the complexity of the industry, high cost (in particular smallholders), only a few big companies and FIO can afford the certification scheme and the.well-established enforcement modalities.
- Article 7 of the amended Forest Act 2019 permits landowners in private land and public land to cut tree species, which were earlier listed as restricted species. However, the operators who wish to transport the cut logs is required to register their private seal with the RFD.

In addition, the operators of wood processing plants (small- medium and large plants) must obtain a license from the government. Legality risks relate to the confusion, differing interpretations of regulations and uneven enforcement inevitably lead to barriers to utilize native tree species. ITTO and RFD had developed criteria and indications (C & I) for certification of wood from community forests and smallholder plantations, but it has not been officially adopted by the RFD.

- The design and styles of wooden furniture produced by woodworking villagers were not matched in quality standards with the market requirements. Therefore, the preference for imported wood furniture has increased steadily from 79 million USD in 2012 to USD 140 million in 2020, while the export of wood furniture remains stable at USD 539 million during this period.
- There is a wrong perception that wood is scarce and utilization of wood products either from legal or illegal sources lead to deforestation and climate change impact.

This wrong propaganda and understanding by environmental activists are stimulated by multi-media and social movements. This has lead to extremist attitude towards wood-use and exert pressure on the wood manufacturing and exporting industry. A certain portion of the urban population (52% of the total population in 2020 and 60% in 2030), especially the young generation living in big cities rush to use substituted materials, including wood composite, grass, concrete, etc.

ITTO reported that the global COVID-19 pandemic during 2018-2022 impacted the trade of tropical timber products;disruptions in supply chains leading to substantial decline of demand and sale of tropical timber in the global market and subsequent decline of international prices.of timber. The ITTO Market Information Service (MIS) and Thailand’s Forest Statistics reported that exports of primary wood products to international markets (e.g., Japan and EU27) in 2021 declined more than 20% compared to 2019 before the pandemic. In contrast, the domestic consumption of wood and wood products is predicted steadily increase due to residential properties development in big cities and the government’s stimulus package for buying new property and homes.

To this end, the Government of Thailand needs to develop wood and wood products in domestic markets to reduce the country’s economic dependency on export markets. In addition, this practice will support the government policy on green growth and sustainable development by increasing bio-based economy value in new market segments.

Therefore, the development objective of the project *“Promotion of Sustainable Domestic Consumption of Wood Products in Thailand (PD 926/22 Rev.1 (I))“* funded by the Forestry Agency of Japan through ITTO aims at enhancing sustainable domestic wood consumption in Thailand. The project duration covers 2 years starting from 1 February 2023. The specific objective is to promote sustainable domestic consumption of wood and wood products in Thailand through policy improvement on wood certification, stakeholder capacity building, and timber supply chains in pilot provinces.

The target areas selected for this project are in two provinces of Thailand: Nan and Trang. Nan province in northern Thailand was selected because it is recognized as important for Nan Basin that contributes over 40% volume of total water to Chaophya River. Natural forests decreased by nearly 25% during 1995-2012, but the agricultural lands rapidly increased by more than 50% (Trisurat *et al.*, 2018). In addition, local people mainly hill tribes have changed their land use practices from the traditional slash and burn agriculture system to permanent cultivation for commercial trading. Main crops cultivated are maize and cassava, which price incentive and the engagement of big agricultural companies.

Nevertheless, Nan province is recognized as an important area for teak and rubber plantations. Planation areas rapidly increased from 8,740 ha in 2007 to 35,000 ha in 2015. In addition, many communities gathered together and form smallholder teak plantations and community enterprises.

Trang province is located in the west coast of peninsular Thailand. Trang was the area where rubber trees were first planted, brought by governor Phraya Ratsadanupradit Mahison Phakdi from British Malaya in 1899.

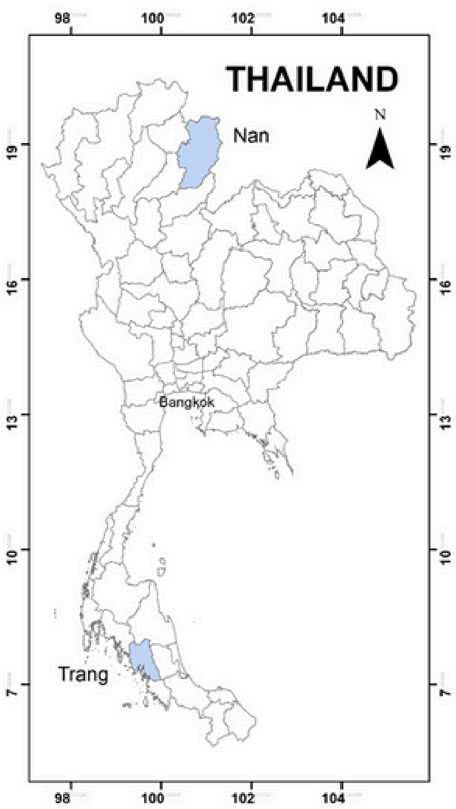
The current rubber plantation area covers about 1.34 million rai or 215.000 ha or 43% of the province area. Trang is ranked the fourth for rubber plantations (212,340 ha) and contributes 5.5% of the total plantations in Thailand. About 100,000 households are involved in rubber plantations. Agriculture contributes about 31% of the provincial GPP (2.08 billion USD in 2019) (Trisurat *et al.*, 2018). The GDP per capita of Trang is ranked as 8th in southern Thailand provinces and 34th in Thailand. Currently, there are 105 rubberwood industry factories (e.g., furniture, veneer, sawn wood, play toys, etc) with an investment of over 17 billion USD or 5 billion baht in Trang province.

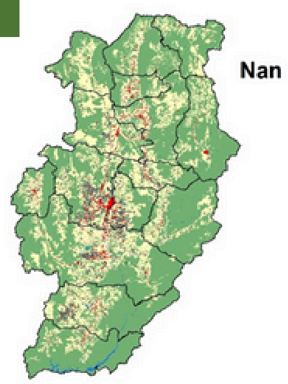
Theemphasis of this technical report is on rubber plantation and rubber wood supply chains, while another technical report is on the sustainable wood use project focusing on teak supply chains. The objectives of this report include:

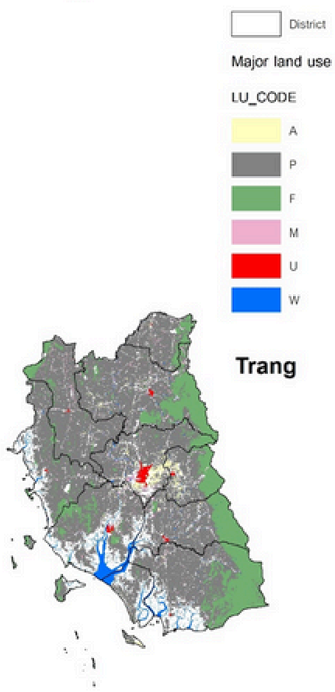
1)Gather information on rubber plantation and rubber wood in Thailand
2)Assess rubber legal supply chains from upstream, intermediate stream to downstream industries and uses
3)Determine challenges and opportunities on rubber supply chains
4)Provide recommendation for sustainable rubber wood industries and international trade

Figure 1

Location map on Nan and Trang Provinces







2 RUBBER ECOLOGY

Hevea brasiliensis (HBK.) Muell.Arg. (Pará rubber tree, sharinga tree, *seringueira*, or most commonly known as "rubber tree" belongs to the spurge Family Euphorbiaceae. The species is native to the rainforests of Amazon basin, encompassing Brazil, Venezuela, Ecuador, Colombia, Peru, and Bolivia (Schultes 1990; https://www. rainforest-alliance.org/species/rubber-tree). (Figure 2) but is now pantropical in distribution due to introductions.

There are nine species in this genus, but only the Para' rubber (*Hevea brasiliensis* Muell. Arg.) is grown commercially. Among the other nine species of rubber trees, only *H. benthamiana* produces a latex of decent quality, but this species has rarely been used in breeding programs. According to IUCN conservation status, Para rubber is categorized as Least Concern species (Fabriani and Hills, 2020). In addition, there are other plants that produce latex including the recent rubber crop of interest *(Russian dandelion)*, however, only the Para' rubber tree is widely cultivated, or tapped to produce natural rubber. In the rubber industry's infancy, natural rubber in the Amazon region was produced from tapped wild rubber trees.

In Brazil, before the name was changed to 'Seringueira' the initial name of the plant was 'pará rubber tree', derived from the name of the province of Grão-Pará.

In Peru, the tree was called 'árbol del caucho', and the latex extracted from it was called 'caucho'. The tree was used to obtain rubber by the natives who inhabited its geographical distribution. The Olmec people of Mesoamerica extracted and produced similar forms of primitive rubber from analogous latex-producing trees such as Castilla elastica as early as 3,600 years ago.

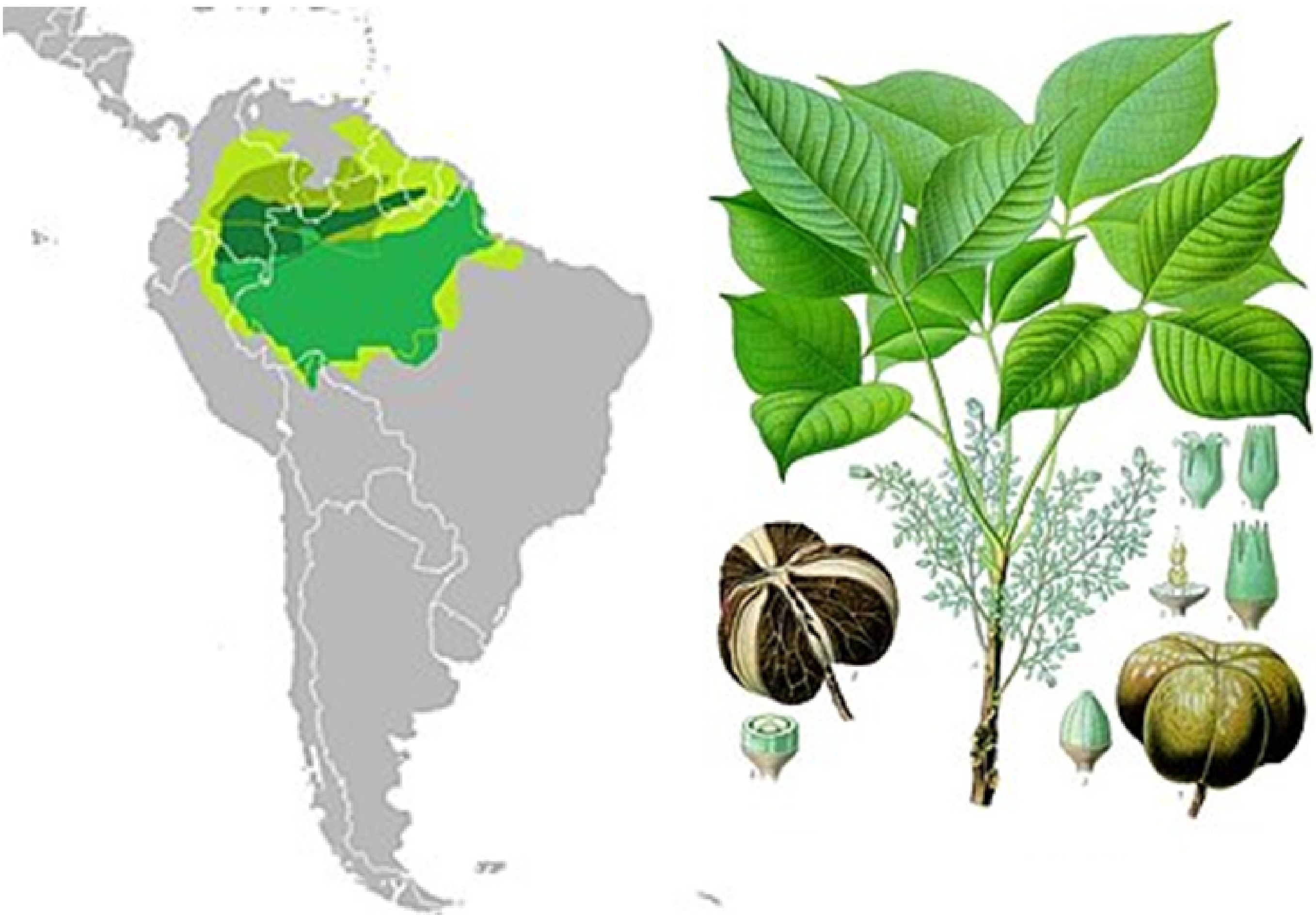
Hevea brasiliensis or rubber is a tall deciduous tree growing to a height of up to 43 m (141 ft) in the wild. Cultivated trees are usually much smaller in size because tapping for the latex restricts its growth. The trunk is smooth, cylindrical, erect and unbranched up to a considerable height with a leafy crown, but frequently and may have a swollen towards the base. The outer bark is fairly greyish and smooth, and the inner bark is extracted for latex when tapped. The leaves have three leaflets and are spirally arranged. The inflorescences include separate male and female flowers. The flowers are pungent, creamy-yellow and have no petals. The fruit is a capsule that contains three large seeds; it opens explosively when ripe (Müll.Arg, 2017). The native habitat of Para' rubber lies between the equator and 15° S which is relatively flat, with a wet equatorial climate (Strahler, 1969).

The mean monthly temperature is 25°C to 28°C. Annual rainfall exceeds 2,000 mm. Therefore, conditions ideal for rubber cultivation are: 2,000 to 4,000 mm annual rainfall distributed over 100 to 150 d, mean annual temperature around 28 ± 2°C with a diurnal variation of about 7°C, and sunshine hours of about 2,000 h year^{-1} (Ong *et al.*, 1998, Watson, 1990).

Para rubber tree is the most economically important member of the genus, Hevea because the milky latex extracted/harvested from the tree is the primary source of natural rubber. The rubber was used, among other things, to make the balls used in the Mesoamerican ballgame (Langenheim, 2010).

Figure 2

Native rubber tree distribution in Amazon Basin
Source: Hills (2020)



3 RUBBER PLANTATIONS

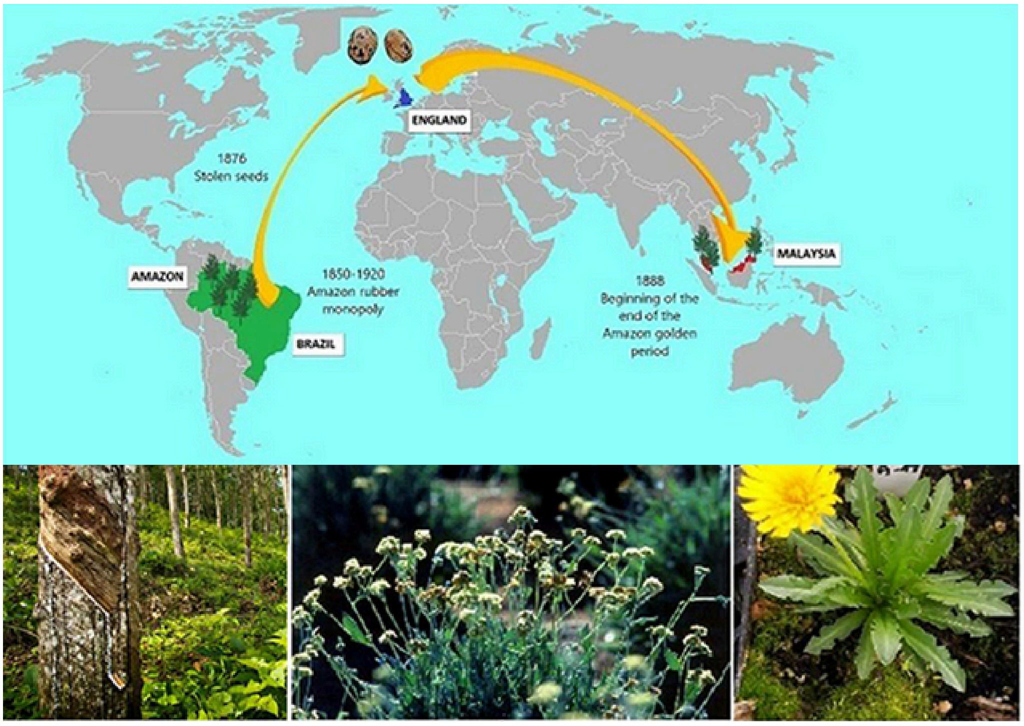
3.1 Global Plantation

Naturally, the South American rubber tree grew only in the Amazon rainforest, and increasing demand and the discovery of the vulcanization procedure in 1839 led to the rubber boom in that region, enriching the cities of Belém, Santarém, and Manaus in Brazil and Iquitos, Peru, from 1840 to 1913.

Early attempts to grow H. *brasiliensis* outside Brazil were made in 1873. After some effort, 12 seedlings were germinated at the Royal Botanic Gardens, Kew. These were sent to India for cultivation, but could not survive. A second attempt was then made, some 70,000 seeds from the Santarem area in Brazil were smuggled to the Royal Botanic Gardens (Kew Gardens) in London, England in 1875 by Henry Wickham, in the service of the British Empire. About four percent of these (280 seedlings) germinated. From there, the seeds were distributed to the British colonies such as Sri Lanka (1876), Singapore, Malaysia (1876), India (1878). In addition, it was introduced to the botanical gardens at Buitenzorg, Java, in 1883, Thailand in 1899, and parts of Africa. (Figure 3)

Figure 3

Para rubber tree introduced to other countries by British explorer, Henry Wickham
Source: Arias and Van Pijk (2019)



Source: commons, Wikimedia.org

Although, most of the historically suitable sites (60% ±5) are located in tropical South America where *H. brasiliensis* is native, but the cultivation of the natural Para rubber in South America (Amazon) ended early in the 20th century because of indigenous blights disease (the South American Leaf Blight or SALB), which has reduced the productivity of rubber in the Americas (Guyot and Le Guen, 2018). The South American leaf blight disease , is caused by the fungus Ascomycetes, *Pseudocercospora ulei* , also called *Microcyclus ulei* or *Dothidella ulei*, which is endemic to the Amazon basin. The blight was considered one of the five most aggressive diseases in commercial crops in South America. Nowadays, Brazil produces only about 1% of the world’s natural rubber.

The rubber plantations established by the British in other parts of the world, especially Asia and Southeast Asia where the tree is exotic is not being affected by local plant diseases. Hence, more productive than the predominantly wild rubber trees tapped for latex in the Amazon basin (Dean, 1987). In addition, large-scale production in Amazon basin is no longer commercially viable due to the occurrence of the fungal pathogen and high labour costs.

Currently, global rubber plantations occur in 28 countries along the equatorial zone (Figure 4), in wet tropical and sub-tropical regions of the world where the climate is favourable for its growth.

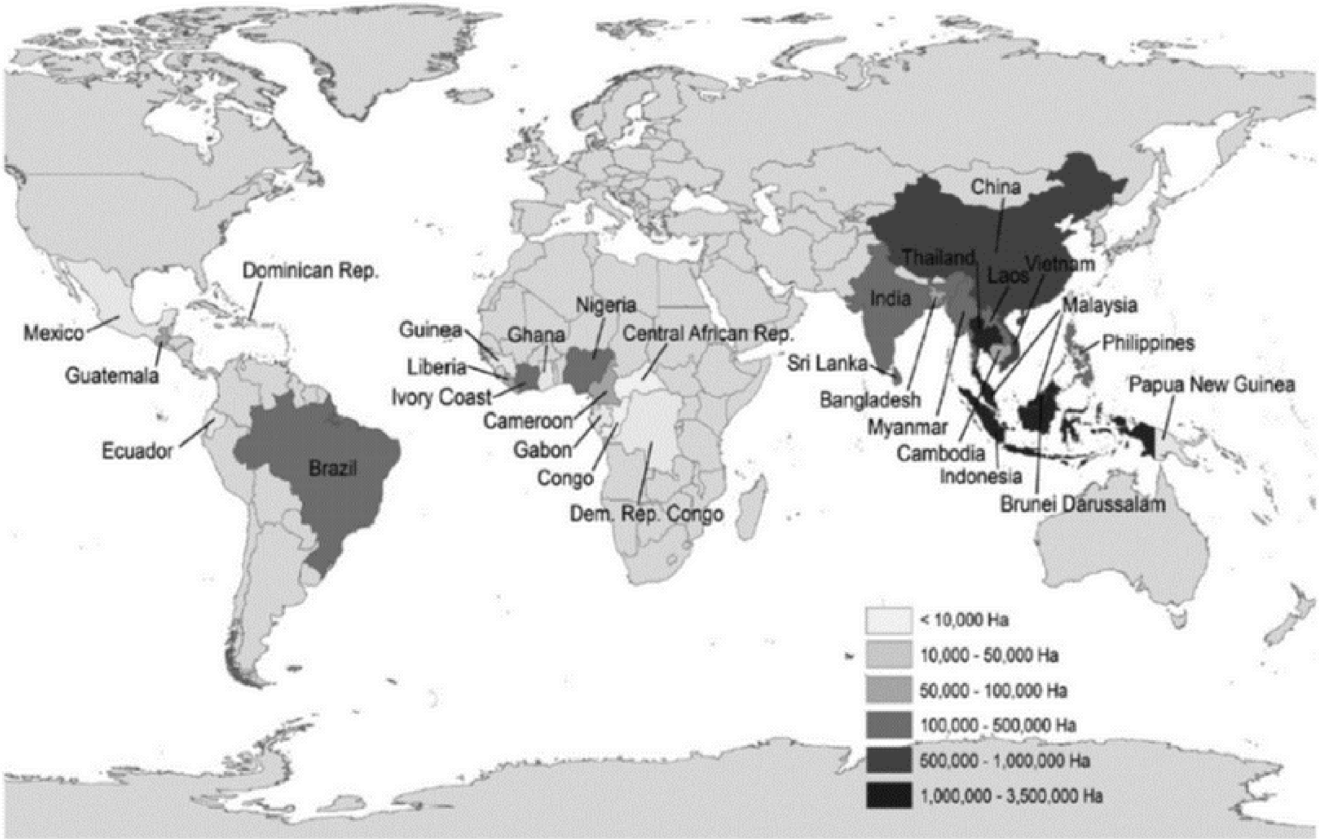
In recent decades, rubber plantations have been extended beyond these ideal locations, to colder and more hilly regions (Fox and Castella, 2013, Priyadarshan 2011), cater to the needs of the global demand for natural rubber and alleviate local economic benefits. Rubber plantations have been established as far away from the equatorial zone as 20°S in Brazil and 23°N in India, at altitudes of up to 671 m in China and in Vietnam where the mean temperature is 21°C (Priyadarshan, 2011).

Rubber eventually became an important perennial crop in this continent. Ecological niche model indicated that approximately 2 million km^2 suitable space is located in SE Asia, most of which occurs in Indonesia (65%), the Philippines (11%) and Malaysia (11%) (Ahrends *et al.*, 2015). However, the actual global rubber plantations cover about 12.7 million ha (79.2 million rai) in 2021. Almost 50% of the world’s rubber being produced in continental Southeast Asia or SEA (FAO, 2023). The top five rubber-producing countries in 2021 were Indonesia (3.7 million ha), Thailand (3.5 million ha), India (0.7 million ha), Vietnam (0.7 million ha), China (0.7 million ha), and (Figure 5). Although Thailand has plantation area slightly less than Indonesia, but the average yield (1,394 kg/ha or 223 kg/rai) and total latex production in Thailand (4.9 M tons) were higher than Indonesia.

Figure 4

Geographical distribution of Para' rubber *(Hevea brasiliensis* Muell. Arg.) plantations.

Credit: Warren-Thomas *et al*. (2015).



The global production of natural rubber has increased steadily, but slowly, in the last 20 years from 6.91 million tons in 2001 to 10.3 million tons in 2010, and 14.2 million tons in 2021. SEA countries produced about 78% of the world's natural rubber, with Thailand producing 34%. In 2022, the overall sales of globally exported natural rubber totaled US$16.1 billion in 2022, which increased about USD 13.2 billion from 2018. The five largest exporters are Thailand, Indonesia, Ivory Coast, Vietnam, and Malaysia which generated about four-fifths (80%) of the global natural rubber trade (http://www.worldstopexports.com/natural-rubber-exports-country/).

Among continents, providers in Asian countries exported $12.4 billion worth or 77.3% of international natural rubber sales.
African exporters supplied 14.9% worth of the global total trailed by European suppliers at another 5.6%.

The average annual expansion of rubber plantation during 2010-2021 was 2.65%. However, it increased rapidly in China from less than 600,000 ha in 2000 to 746,000 ha in 2021. With this rapid trend, Kou et al. (2015) indicated that China is going to become a consistent top player in the global rubber production and trade.

Figure 5

The top ten rubber-producing countries in the world, 2021.
Source: Food and Agriculture Organization of the United Nations
(Data as of 3 Jan 2023)

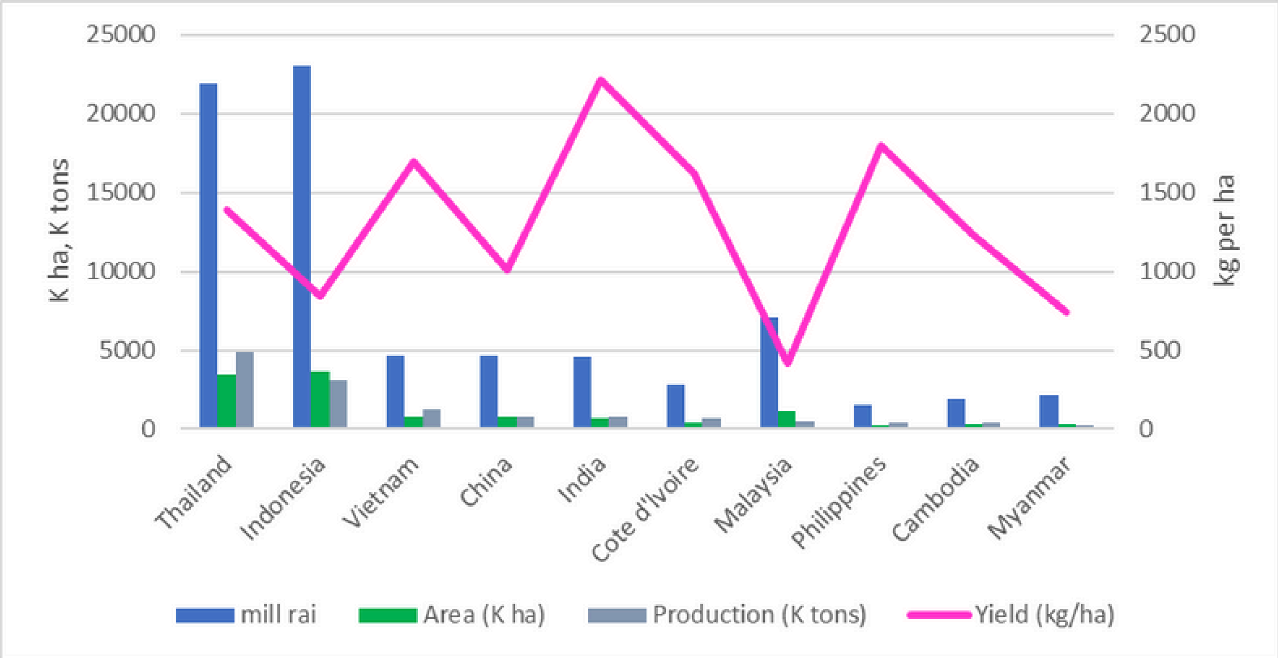
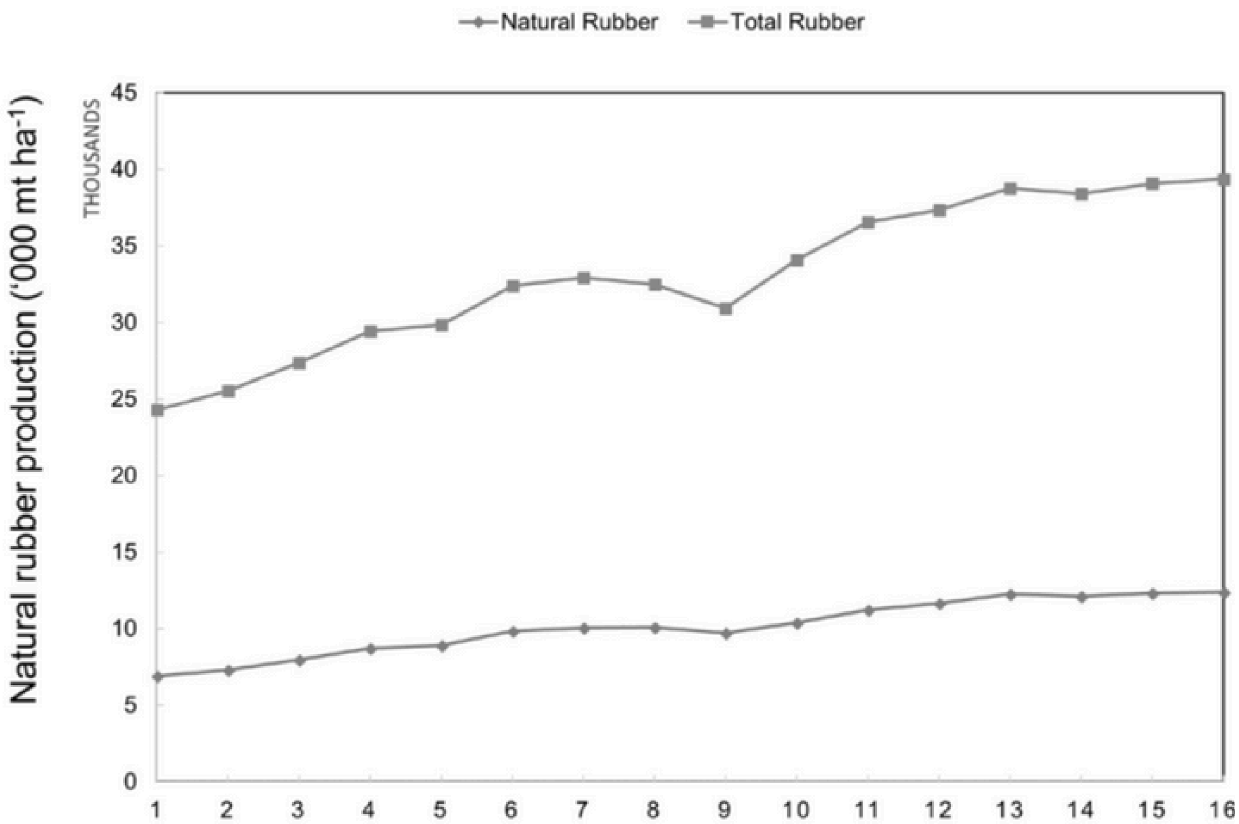


Figure 6

Global production of natural rubber, 2001–2016.
Source: IRSG 2017, Statista 2018



Ahrends *et al.* (2015) reported that rubber spreads by farmers copying a seemingly lucrative activity from their neighbors, and/ or taking advantage of existing rubber farming infrastructure in their vicinity. The recent spread of rubber has been largely uncoupled from environmental conditions: sub-optimal environments and unsustainability risks. Almost all mainland SE Asian countries intend to increase the monoculture rubber plantation area, subsequently cause negative impact on biodiversity.

In total, 13,310 km² classified as forest (ESA, 2010) and 8952 km² of land within Key Biodiversity Areas (KBAs) are now under imminent threat. Over half of these areas are in environmentally risky areas where rubber growth may be unsustainable. In the case of Vietnam even more land has already been converted and will affect socio-economic and ecologically important marginal habitats such as community managed forests in northern Vietnam (Phuc and Nghi, 2013)

3.2 Rubber Plantation in Thailand

As mentioned previously, Para rubber was introduced to Thailand by Phraya Ratsadanupradit and planted at Kantang District, Trang province in 1899. And rubber has later become Thailand's major export product (http://www.tourismthailand.org/See-and-Do/Sights-and-attractions-Detail/The-first-rubber-tree-in-Thailand--806).

Figure 7

Rubber plantation.
Credit: Yongyut Trisurat

Figure 8

Rubber latex tapping.
Credit: THAWISAK/stock.adobe.com

The rubber plantation covers extensively in southern Thailand where climatic conditions and land types are favorable for the rubber tree. The rubber plantation has been extended to Northeast Thailand since 1990 when the rubber plant was proved to successfully grow in the Northeast conditions. For the past two decades, the higher incentives of the rubber product and the government incentive program pushed forward the expansion of plantation areas by switching the field crops such as cassava and sugar cane to rubber tree. Currently, the rubber tree became one of the major economic crops in the Northeast. The marginal lands have been used for the rubber plantation, resulting degraded land and unproductive yield.

Land Development Department (2011) reported that about 1.32 million ha (8.26 million rai or 33% of the total plantion areas) were planted in unsuitable areas or steep slope, which are not accessible by roads. According to the Agricultural Statistic (Office of Agricultural Economics or OAE, 2022), the total rubber plantation in Thailand covered 3.9 million ha (24 million rai) and the harvested areas covered 3.5 million ha (22 million rai) in 70 provinces out of 77 provinces in Thailand (Figure 9). In addition, there were 1.28 million households (about 5.5 million population) involved in the rubber plantations or 6% of the total households in Thailand. The total latex production in 2022 was 4.89 million tons or 34% of the global production and it was ranked as the highest rubber producing country. The plantation areas in the south covers about 2 million ha (12.507 mill rai) or account 57% of the total plantations, followed by the northeast (0.94 million ha), the central (0.36 million ha), and the north (0.21 million ha) regions (Figure 10). In addition, smallholders holding land less than 15 rai (2.4 ha) account 78.5% of Thailand (Research and Rubber Development, 2023) and about 75% of the world's natural rubber production (Fox and Castella, 2013).

Previous data showed that rubber plantation in Thailand increased about 143,360 ha or 4% in the last decade.

The top 10 provinces with the highest plantation areas include Surat Thai, Songkhla, Nakhon Srithammarat, Trang, Yala, Pattalung, Loei, Narathiwat, Bueng Khan, and Chumphon provinces (Figure 9). Going by the previous trends, the total rubber plantation will be 4.81 million ha (30 million rai) by 2030. Due to the negative trend of rubber price and global competition, the Government of Thailand has a policy to reduce the plantation area to 2.95 million ha or 18.4 million rai by 2036 (OAE, 2022).

The highest rate of increase was reported in northeast, followed by central and north regions with the increase of area 816, 000 ha (5.10 million rai), 398,499 ha (2.49 million rai), and 203,200 ha (1.27 million rai), respectively (Figure 10). However, the plantation areas in the south showed a negative trend. Large areas were converted for durian and oil palm plantations due to lucrative market price. Moreover, they have been affected by leaf fall disease or leaf disease outbreak.

Other factors include extreme weather conditions (drought and floods) and availability of immigrant labors returned to their home countries during the COVID-19 pandemic.

Leaf fall disease is characterized by out-of-season leaf fall, beyond the normal 'wintering' which occurs annually in the dry season (Azizan et al., 2023). It is caused by a phytopathogenic fungal-like organism Phytophthora. Three species of Phytophthora are common in Thailand, viz., Phytophthora palmivora Butler (Tsao et al., 1976), P. botryosa Chee, and P. nicotinae var. parasitica (Figure 11); Rubber Research Institute of Thailand, 2010).

The canopy reduction as a result of leaf fall generally ranges from moderate (30%) to severe (>75%). In severely affected areas, the canopy density was seen reduced up to 90% (Ismail and Gohet, 2020). A 75% defoliation of para rubber tree may reduce latex yield by up to 30-50% (Chee, 1969). Azizan et al (2023) reported that there is a strong possibility of climate change responsible for the emergence of the new Rubber Leaf Fall disease. However, additional research is required for concrete explanations.

Figure 9

Natural rubber plantation areas in Thailand 2022
Source: Office of Agricultural Economics (2023)

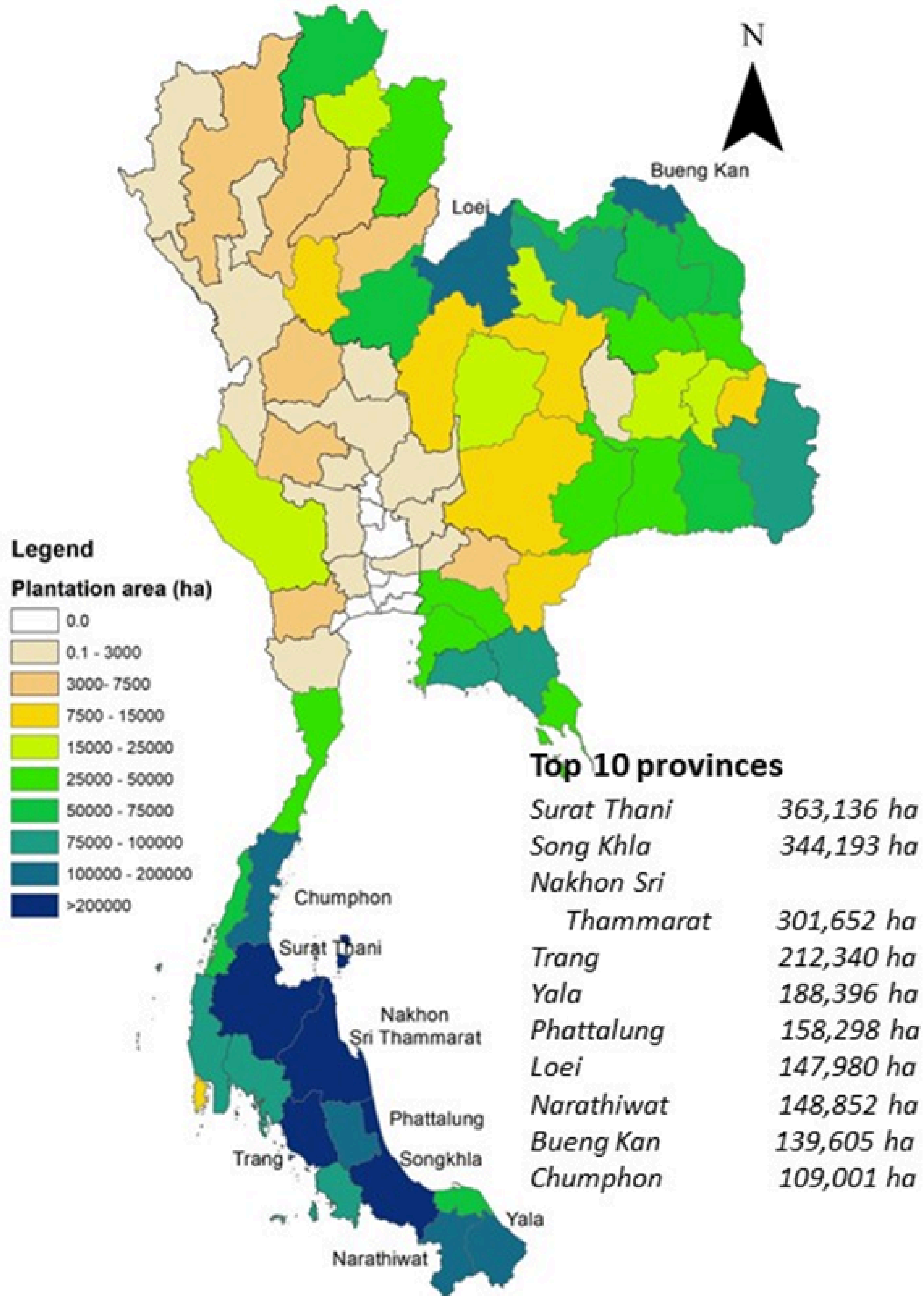


Figure 10

Rubber plantation in Thailand during 2011-2022
Source: Office of Agricultural Economics, (2022)

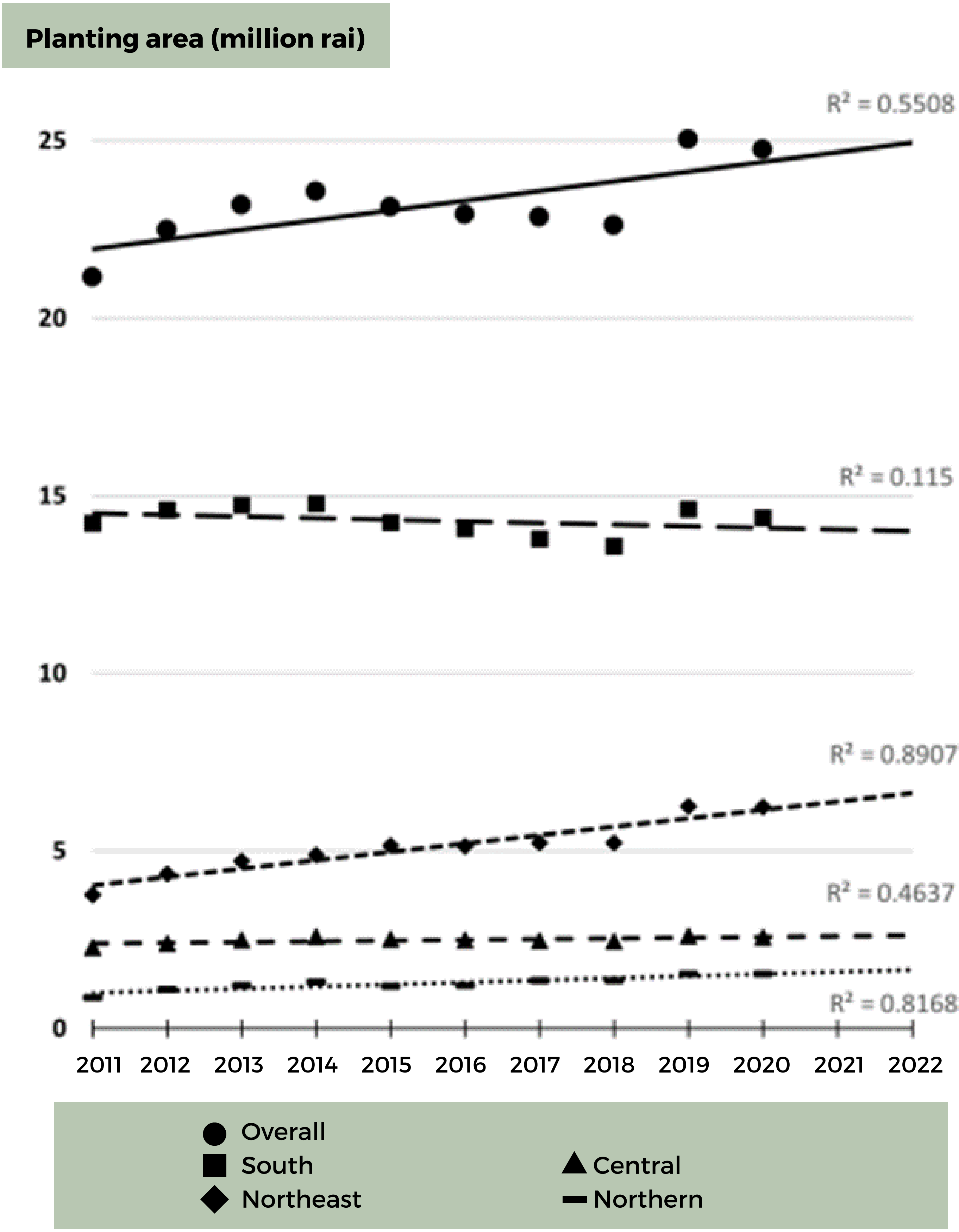


Figure 11

Global Natural Rubber Prices and Ending Stock

Source: DOA, OAF, DIT, World Bank, Krungsri Research

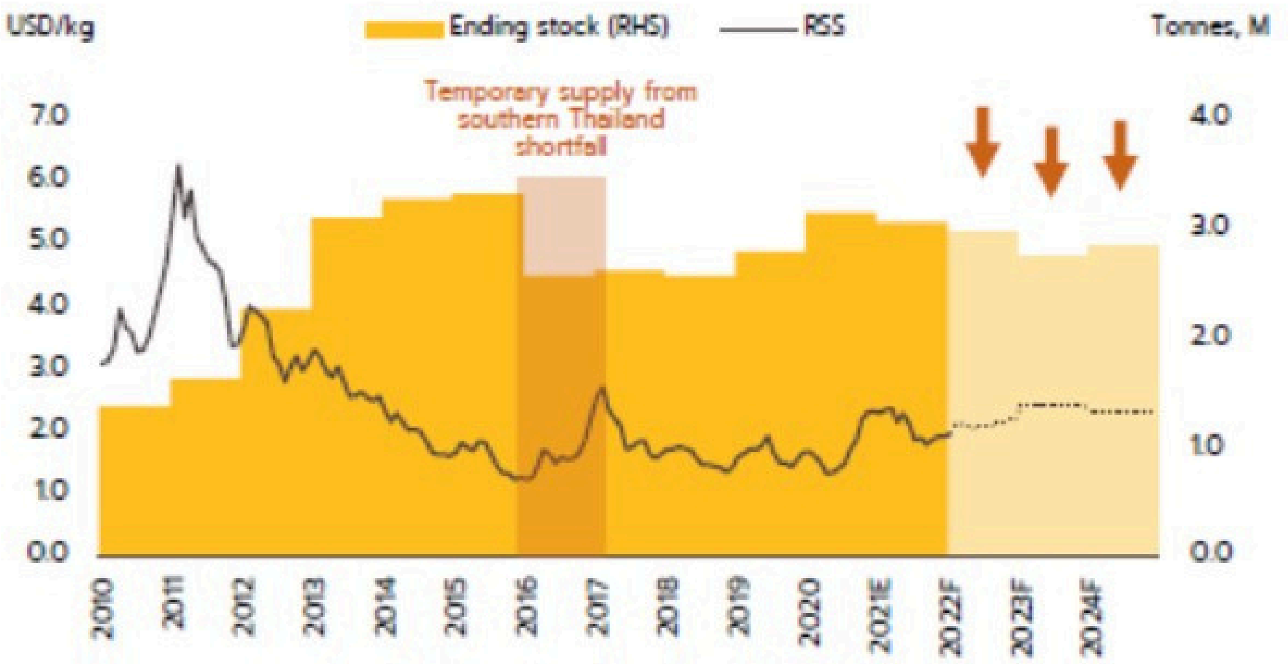
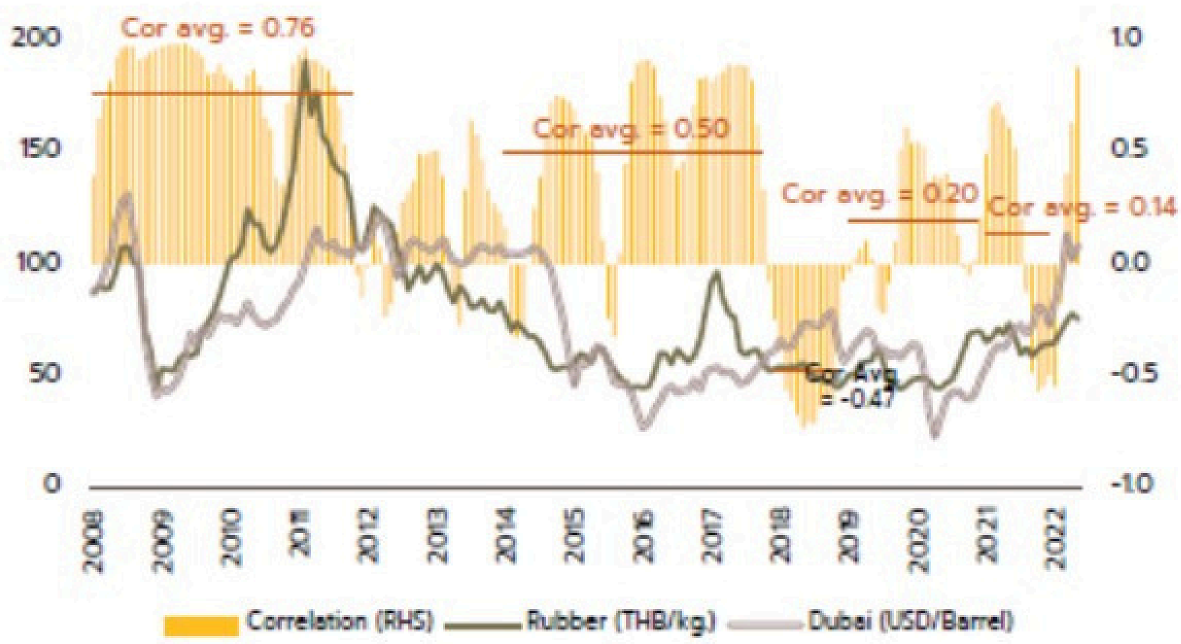


Figure 12

Global Natural Rubber Prices

Source: DOA, OAF, DIT, World Bank, Krungsri Research



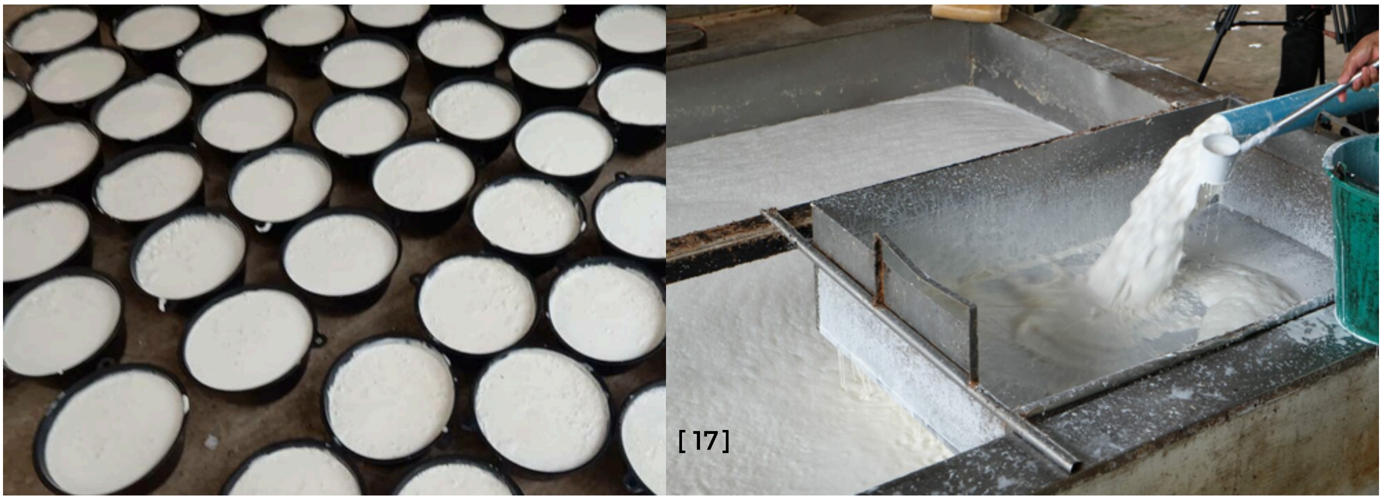
4 RUBBER SUPPLY CHAINS

4.1 Natural Rubber Latex Supply Chains

The natural rubber supply chain in Thailand involves several layers of smallholder farmers, field latex collection and preliminary products made of field latex (Figure 13) to sophisticated industrial raw material for the manufacture of about 50,000 products. They are broadly divided into three major components (Figure 14). **1) *Upstream industries*** are involved in the cultivation of rubber and harvesting of latex on plantations by growers and tappers, but to add value to primary production, some producers are now begin to engage in basic processing of their rubber to produce dried rubber products, such as rubber cup lump, rubber scraps, sheet rubber and crepe rubber. Almost all upstream production in Thailand is consumed as inputs into domestic midstream industries. ***2) Midstream industries***, or natural rubber processors, take rubber produced from plantations and convert this into semi-finished products, such as ribbed smoked sheets (RSS), technically specified rubber (TSR), concentrated latex, compound rubber and skim rubber, which have the qualities and properties required as inputs to downstream producers in both domestic and international markets. ***3) Downstream producers***, or producers of rubber products, that requires more processing or combined with synthetic rubber or other materials such as automobile tyres, latex gloves, condoms, elastics, rubber shoes, and so on. In some cases, synthetic rubber (SR), which has been developed by the petrochemical sector or for mixing with NR to become more suitable properties for each application (Figure 14).

Figure 13

Upstream rubber products.
Credit: https://www.technologychaoban.com/bullet-news-today/article_220332



As mentioned previously, the total rubber plantation in Thailand covered 3.9 million ha (24 million rai) with the harvested areas of 3.5 million ha (22 million rai) found in 70 provinces out of 77 provinces in Thailand (OEA, 2022). Rubber plantations contribute about 15% of the agricultural area in Thailand. It is estimated that 1.6 million households are involved, which is ranked as the second after rice cultivation (37 million households).

1) *Upstream industries*

Although the total plantation areas in Thailand (3.9 million ha) are slightly less than Indonesia (3.69 million ha), but latex production in Thailand in the last 10 years has been ranked as the highest. Thailand contributed 4.89 million tones (34%) of the global latex production of 14.26 million tons in 2022. This is due to the average latex yield in Thailand is about 223 kg/rai or 1,394 kg/ha, while it is 843 kg/ha in Indonesia. The highest yield is observed in India (2,200 kg/ha), followed by the Philippines (1,800 kg/ha), and Vietnam (1,694 kg/ha) (FAO, 2023). The 20-year long-term Rubber Strategy of Thailand (2017-2036) aims at increasing double the yield (360 kg/rai or 2,250 kg/ha) from the current productivity.

The average yields in the south and the central are 250.7 and 215.3 kg/rai, respectively, however, the yield is gradually declining due to climate variation and leaf fall disease.

While, the yield in the northeast and the north are increasing with the average of 204.0 kg/rai and 166.2 kg/rai, respectively.

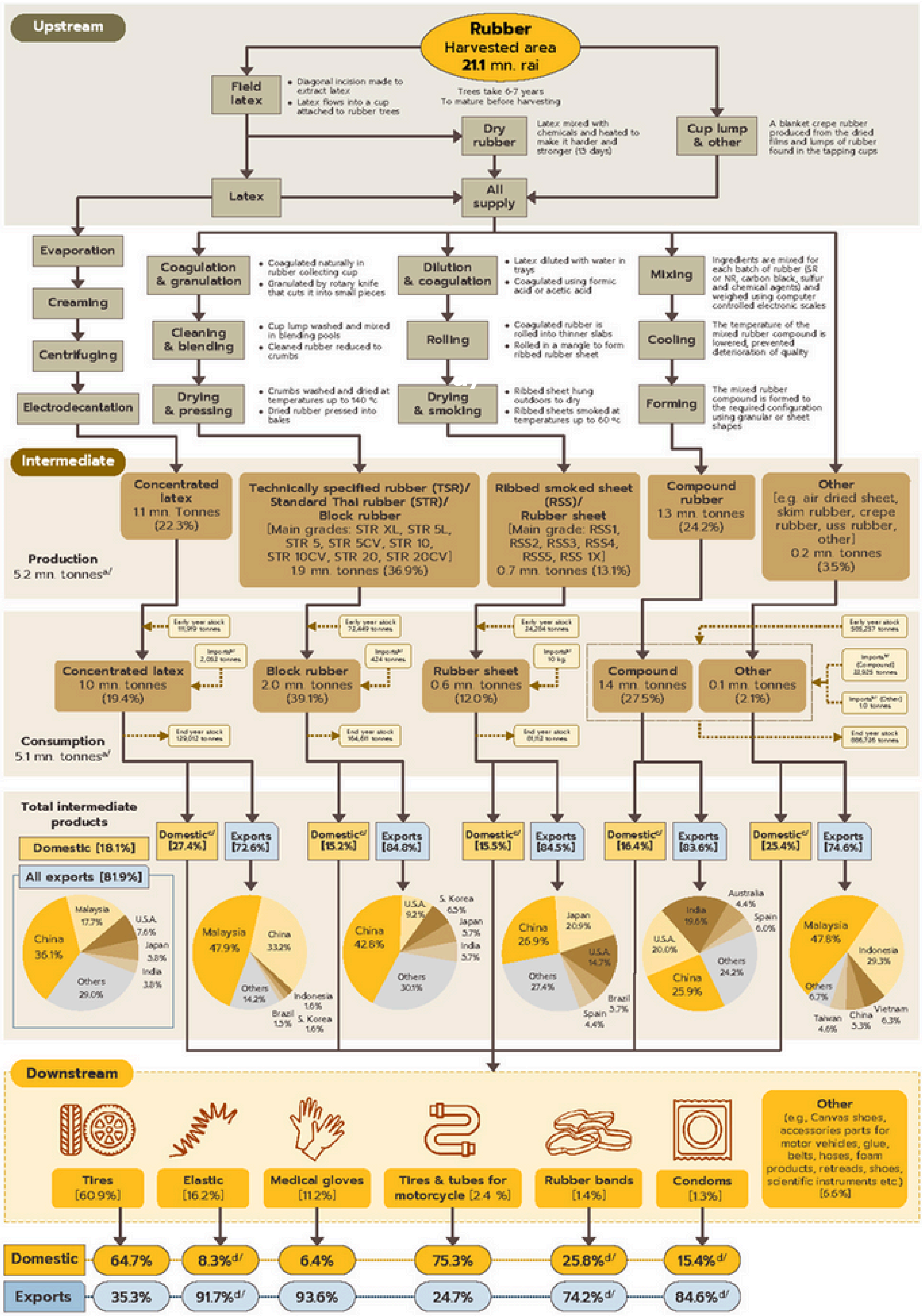
Most of the raw products of the upstream industry (latex, dry rubber and cup lump) are initially processed through evaporation, coagulation & granulation, mixing with other substances to produce ***intermediate rubber products*** such as concentrated latex, technically specified rubber (TSR), standard Thai rubber (TRS), block rubber, ribbed smoke sheet (RSS)/rubber sheet, compound rubber and others. The estimated total productions of intermediate products were 5.2 million tons in 2021, Note that high proportion of raw products are used to produce technically specified rubber, standard Thai rubber (36.9%) followed by compound rubber (24.2%) and concentrated latex (22.3%) (Figure 14). Small proportions were imported from other countries.

About 82% of intermediate rubber products were exported to international markets in 2021, especially to China, which contributed 36.1% of the total immediate products, followed by Malaysia (17.7%, USA (7.6%), and Japan (5.8%). And the remaining 18% were used to produce the downstream products such as tyres (60.9% of the intermediate products), followed by elastic (16.2%), medical gloves (11.2%), and others such as rubber tube, condom, rubber band.

Figure 14

Natural rubber supply chains in Thailand.

Source: Economic Intelligence Center of Krung Sri Ayudhya Bank (2022)



Source: OIE, MOC, RIU, DOA, Krungsri Research,
All icons come from https://thenounproject.com/

Note : a/ Includes only the dry rubber content (DRC).
b/ As per weight at customs check points (this does not distinguish between hard and dried rubber products).
c/ Excludes stocks and imports.
d/ As of 2020, the latest data available from the Rubber Intelligence Unit.

Thailand produces various intermediate rubber products with the total value of 340 billion baht (9.7 billion USD) in 2021. This is due to the fact that latex product in Thailand accounts approximately 92% of the field latex that is feasible to reprocess and produce various intermediate products. In contrast, Malaysia and Indonesia produce cup lump of 90% and 40%, respectively which is later used to produce block rubber.

2) The intermediate rubber products include ribbed smoked sheet (RSS), block rubber, concentrated latex compound rubber, and crepe rubber. Block rubber accounts 39.1% of the total latex and is ranked the highest, followed by compound rubber (27.5%), concentrated latex (19.4%), and rubber sheet (12.0%) (Figure 14).

Ribbed Smoked Sheet (RSS) is classified into 6 grades: RSS 1X, RSS1, RSS2, RSS3, RSS4, and RSS5. In Thailand, about 95% of ribbed smoked sheet product is categorized as RSS2 or grade 3, which is equivalent to block rubber and used to produce tyres, rubber tubes and shoes. The value of Ribbed Smoked Sheet for domestic use and internal trading in 2021 was 1.17 billion USD (41 billion baht) compared to , 3.71 billion USD (130 billion baht) in 2011 or a decrease of 11% per year due to competition from other ASEAN countries such as Cambodia, the Philippines, Myanmar, Vietnam and Lao PDR. Nevertheless, Thailand was ranked as the first and contributed 29.3% of international trading or 84.5% of the total production in Thailand. Main importing countries include China (26.9%), Japan (20.9%), USA (14.9%) and the remaining 15.5% were used internally in the country.

Figure 15

Intermediate rubber products.

Ribbed smoked sheet (RSS)
Credit: https://www.thairath.co.th/news/local/2185828

Block rubber (TSR)
Credit: https://www.sritranggroup.com/en/business/natural-rubber/overview

Technically Specified Rubber (TSR) includes 2 products: TRS made from latex and TRS made from dry rubber. The TRS products manufactured from latex have better quality and are later to produce vehicle tires and airplane tires, while the latter product is used to produce lower quality products. The total TSR value in 2021 was 2.85 billion USD (100 billion baht). Of this figure, 84.8% was from international trade and 15.2% for domestic consumption. Main markets include China (42.8%, USA (9.2%) and South Korea (6.5%). Thailand was ranked as the second after Indonesia and contributes 25% of the global trade.

Concentrated latex accounted 0.23 billion UDS (8 billion baht) in 2021, which constitutes internal trade of 72.6% and domestic consumption of 27.4%. Thailand contributes about 71% of global concentrated latex. It is anticipated that the export volume will continue to decline after the COVID-19, but domestic consumption, especially for medical gloves and condoms will increase 170-180 billion tons per year to 280-360 billion tons. Main importing countries include Malaysia (47.9% of the total export volume) followed by China (33.2%) and Indonesia (1.6%).

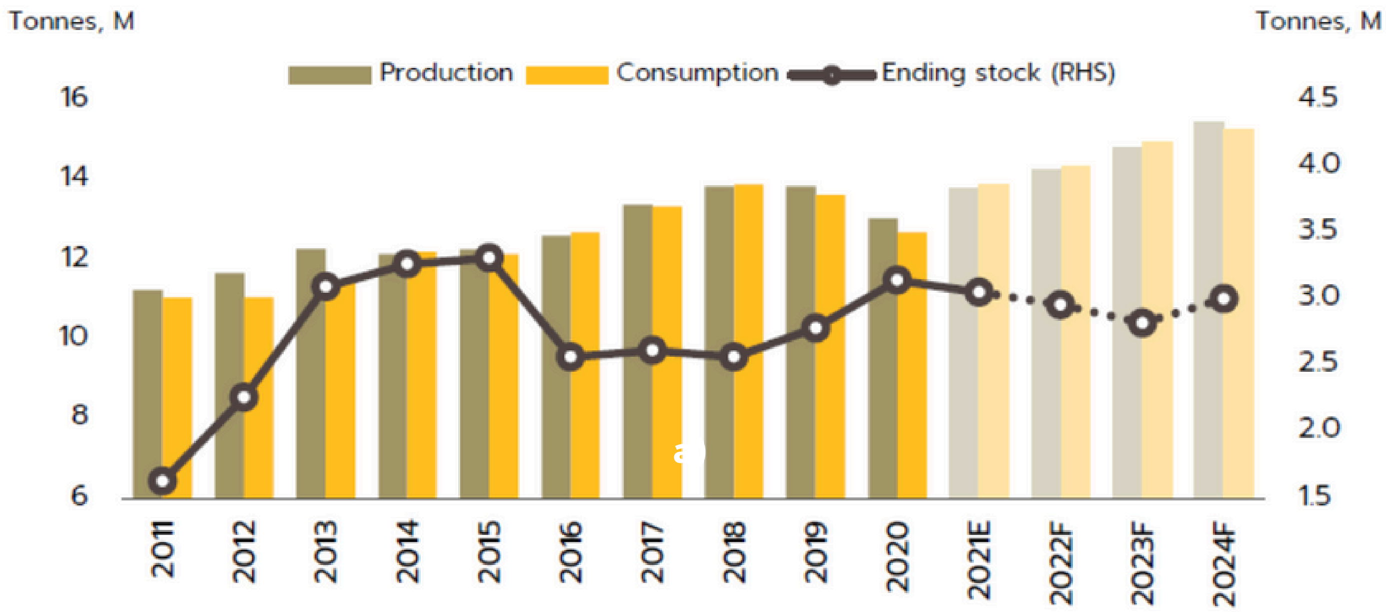
Other products, in particular compound rubber is the combination of natural rubber, synthetic rubber and chemical substances to produce specific products such as tires, tubes, rubber band etc.

The value of compound rubber in Thailand is about 3.71 billion UDS (130 billion baht), including 83.6% for export and 16.4% for domestic uses. Thailand is ranked fifth, after Germany, USA, Italy and Poland, respectively. China is the major importing country, which accounts about 25.9% of the total compound rubber. About 80-95% of compound rubber is used in vehicle tires.

In the light of the above information, it is clear that intermediate rubber industries of Thailand significantly rely on international markets, which are influenced by world economic situation and downstream supply chains of importing countries, as well as the competition among natural rubber producing countries. In recent years (2006-2012), the CLMV countries (Cambodia, Laos, Myanmar and Vietnam) produced more natural rubber that exceeds domestic demands, and exported surplus products to international markets. Moreover, China significantly expands rubber plantation areas in Yunnan province and, has more negotiating power and manipulates rubber price in international markets (Figure 16). Nevertheless, Thailand remains the first exporter of concentrated rubber and Ribbed Smoked Sheet and the second for block rubber.

Figure 15

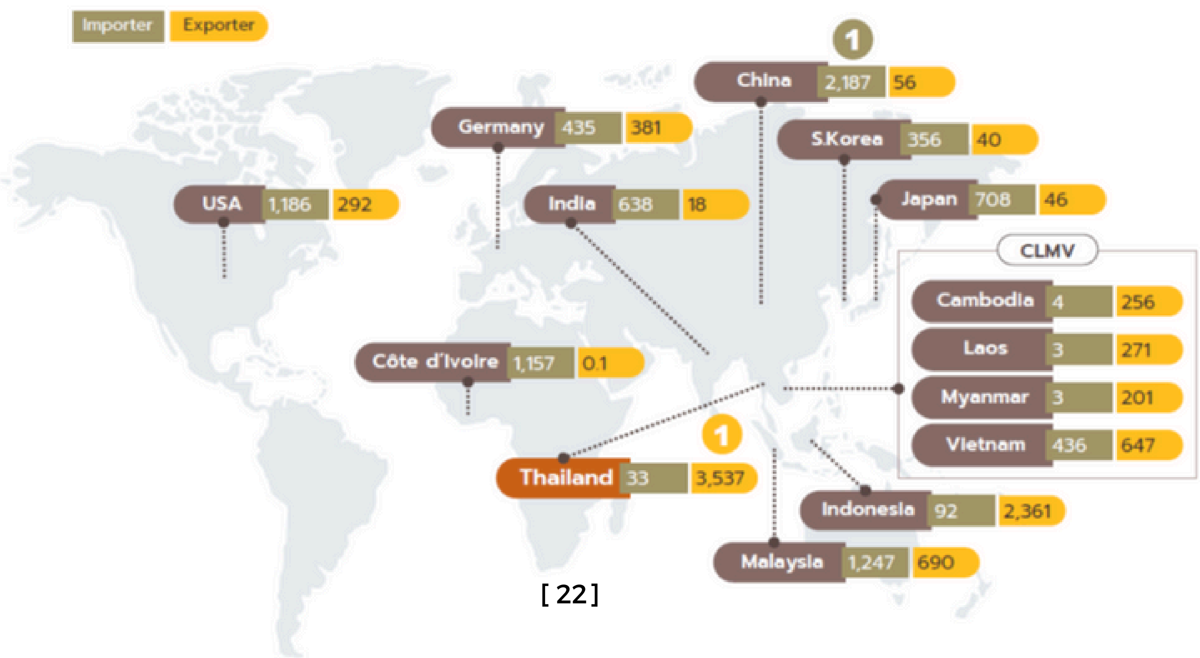
Major natural rubber exporters and importers (2021) (unit: 1,000 tons).
Source: Economic Intelligence Center of Krung Sri Ayudhya Bank (2022)



Share of World NR Production and Consumption (2021)

Production	
Thailand*	**37.5%**
Indonesia	22.6%
Vietnam	8.9%
China	6.3%
India	5.0%
Malaysia	3.8%
Others	15.9%

Consumption (**)	
China	42.9%
India	8.6%
Europe	8.3%
U.S.A.	7.0%
Japan	4.8%
Thailand*	**4.2%**
Others	24.2%



Krungsri Research Center (2021) reported that the global consumption of intermediate rubber products in 2021 was 13.9 million ton. of which 81.9% were used internally in the country. China was ranked as the top world consumer and importer of intermediate rubber products, followed by India, EU, USA and Japan. Importing countries of Thailand's intermediate rubber products are not diverse but are dominant in a few countries like China (36.1% of the total rubber products) and Malaysia (17.7% of the total rubber products). Meanwhile, China imported 42.8% of the total block rubber product, while Malaysia imported 47.9% of concentrated rubber, followed by China (32%). Thus, rubber industry is always quite risky and largely depend on international trade.

The remaining of immediate products (18.1%) were used in the country to produce various products such as vehicle tires (60.9%), elastic (16.2%), medical gloves (11.2%), tubes (2.4%), rubber bands (1.4%), and condoms (1.3%). It is noted that high proportion of tires (64.7%) and tube (75.3%) were domestically used, while other products were exported overseas.

3) Downstream producers, or producers of rubber products, which require more processing or combined with synthetic rubber or other materials such as automobile tires, latex gloves, condoms, elastics, rubber shoes, and so on. Most of elastics, rubber bands and condoms are exported (Figure 17). In contrast, in some cases, automobile tires and medical gloves are used domestically.

Figure 17

Downstream rubber products.

Source: http://otop.dss.go.th/index.php/en/knowledge/interesting-articles/257-2018-11-30-02-25-50

car tires

rubber band

rubber pillow

rubber gloves

rubber teat

rubber material

4.2 Rubber Wood Supply Chains

Rubberwood is an important raw material for wood industry in Thailand. In 2022, rubberwood contributed about 30% of all wood production in Thailand after eucalyptus. However, eucalyptus is the main raw material for pulp and paper. If eucalyptus is excluded, the contribution of rubberwood for construction and other uses will be 96% (RFD, 2022). Rubber wood industry supply chain is complex and often fragmented, consisting of rubber plantation, raw material dealers (several layers), processing plants, traders and rubber product manufacturers.

Rubber wood industry comprises of 3 layers, including: i) upstream industry (smallholder plantation, cutting and transportation); ii) intermediate industry (processing such as sawmill, drying, lumber, plywood, wood pellets, etc); and iii) downstream industry (furniture, wood toys, wood utilities) (Figure 17).

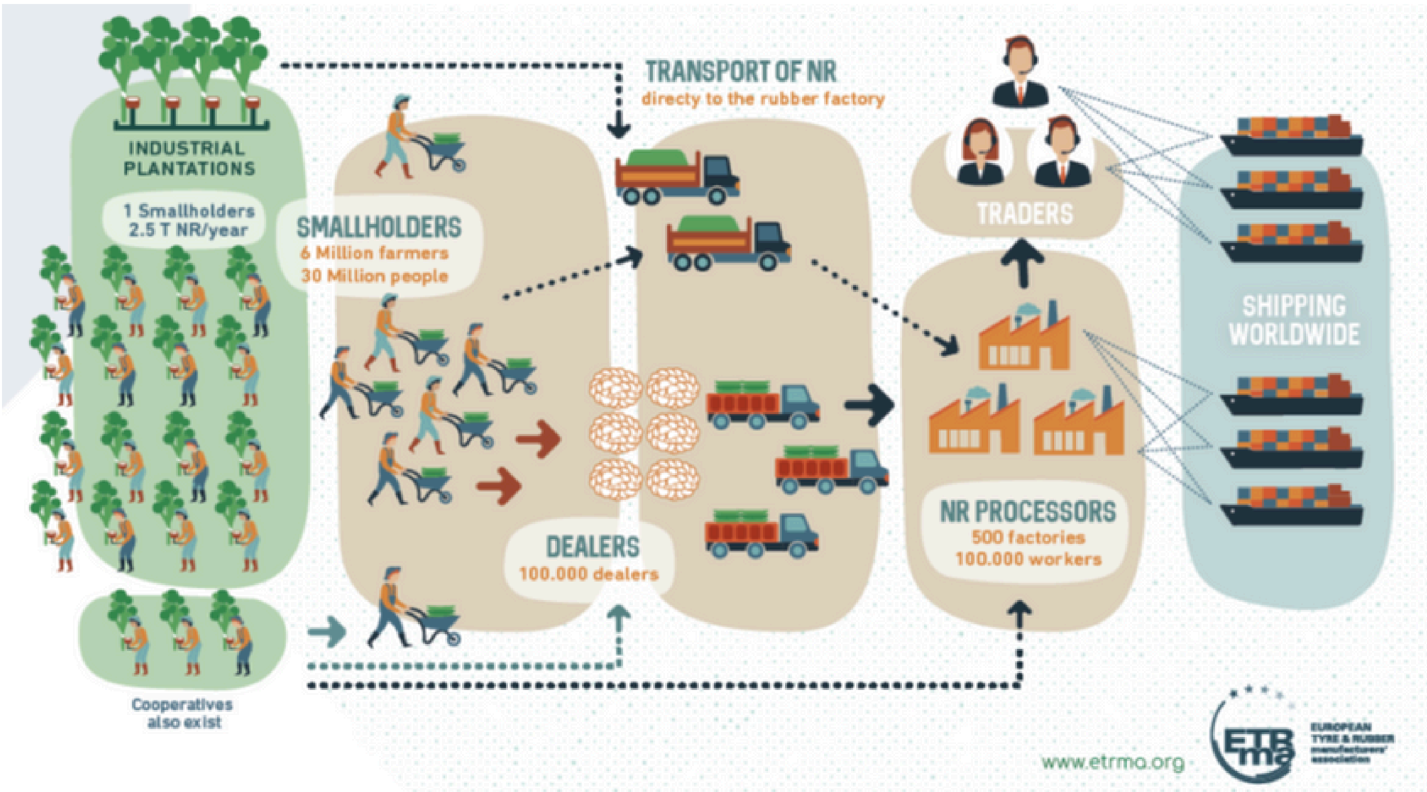
1) Upstream: Rubber plantation and rubberwood stock

According to Research and Rubber Development (2023), 78.5% of Thailand's rubber production is owned by smallholder with the land less than 15 rai or 2.4 ha.

Figure 18

Rubberwood supply chains.

Source: www.emrto.org



In addition, about 4.5 million rai or 20% of the total plantations are located in marginal land with low latex production (150-160 kg/rai), and 5.9 million rai or 27% are located in non-legitimate land. Para rubber is mainly planted for latex production. Latex harvest will be initiated by the 7th year when the tree attains a girth of 50 cm at a height of 150 cm. However, the period varies depending upon the soil and environmental conditions. Latex harvesting is done every day, except rainy days unless the latex prices are less than the investment cost (55-60 baht per kg. or 10.7 USD/ha). In high yielding rubber plantations, latex tapping is done on every alternate day as is being practiced in India. This is due to the fact that latex continue to zoom out throughout the day and do not coagulate.

The economic production of latex is for about 20-30 years, after which the old rubber trees are felled and become a source of timber (Figure 19).

A mature rubber tree is usually in the range of 20 to 30 m tall and its girth can reach up to 100 cm. or more. The trunk or clear bole is generally free of branches until the height of 3 to 10 m. Each tree can provide 0.5 m^3 of wood. Wood is white to creamy white when freshly cut, sometimes with a pinkish tinge, turns to light brown of creamy white on exposure. Sapwood and heartwood is not distinct in rubber wood. The wood is light to moderately heavy (air-dry specific gravity 0.46 – 0.65) and moderately a strong timber. Rubberwood is prone to insect and borer attack and is a perishable timber unless and otherwise the wood is treated with chemical preservatives. Rubberwood's favourable woodworking properties make it suitable for a wide array of applications in furniture industry, parquet and strip flooring, panelling, wood-based panels, packing cases, match splints and boxes etc.

Figure 19

Mature plantation and felling (Trang Provice, Thailand).

Credit: Yongyut Trisurat

Rubber trees are usually planted in rows and columns spacing 3-5 m. x 7-8 m. in wet zones (south and east) and 3-5 m x 6-7 m in dry zones (north and northeast). Thus, the density of stand vary from 50-70 trees/rai or 300-420 trees/ha. Forest Research Division of the RFD (1984) investigated growth performance of rubber plantation from 3-year-old to 23-year-old (Table 1). and found that the average growth of diameter was 1.21 cm/year or the girth of 3.79 cm/year ($2\pi r = 2 \times 3.14 \times 0.605 = 3.79$ cm.).

Table 1

Rubber wood volume by age

Source: Planning Division, Royal Forest Department (1984)

Age	Girth (cm)	Volume per tree (m3)	Volume per rai (70 trees)	Volume per ha (437 trees)
3	11.37	0.028	1.96	13.216
7	26.53	0.066	4.62	31.152
9	30.32	0.075	5.25	35.4
10	34.11	0.082	5.74	38.704
11	37.9	0.094	6.58	44.368
12	41.69	0.105	7.35	49.56
13	45.48	0.114	7.98	53.808
14	49.27	0.152	10.64	71.744
15	53.06	0.179	12.53	84.488
16	56.85	0.208	14.56	98.176
17	60.64	0.232	16.24	109.504
18	64.43	0.265	18.55	125.08
19	68.22	0.301	21.07	142.072
20	72.01	0.339	23.73	160.008
21	75.80	0.379	26.53	178.888
22	79.59	0.422	29.54	199.184
23	87.17	0.503	35.21	237.416

Phukaoluan (1988) and Sungsingh and Prommee (2010) indicated that 1 rai (6.25 rai = 1 ha) of rubber stand with the ages between 19-24 year-old planted at spacing 3 m x 8 m can produce total wood volume of approximately 45 m^3, including rubberwood log>6 inches of 30 m^3, and other components such as branches and root of 15 m^3. These components are reprocessed and can provide several components such as slap, shaving, saw dust and residues as shown in Table 2. Thus, 1 ha of rubber plantation would provide rubberwood log or the wood derived from the trunks about 153 m^3/ha (27-30 m^3/rai) after being felled. If branches and other residues are included, the average volume of rubber will be 281 m^3/h (45 m^3/rai). Ratnasingam *et al* (2012) indicated that rubberwood log for commercial purpose in Malaysia was 180 m^3/ha.

However, not all fallen trees are transported and processed in the wood sawmill. This is due to 5.9 million rai (0.94 million ha) were planted in natural forest reserves without legitimate land titles. In addition, about 4.5 million rai (0.7 million ha) were planted in unsuitable areas or steep slopes, which are not accessible by roads. Hytonen et al. (2019) reported that about 90,000 to 120,000 hectares of mature rubber plantations over 25-year-old are cut annually and rubberwood logs are transported to the sawmill. This is similar to the report of the Economic Intelligence Center (EIC) of Krung Sri Research, Bank of Ayudhya (2019).

EIC forecasted that the local production of rubberwood in 2016 was 20 million tons (30 million m^3) and increased to around 23 million tons in 2020 (Figure 20). This increase is due to new plantings of 3% per year during 1991-1995 following the typical rubberwood plantation cycle. In the long-term, Thailand's rubberwood production is expected to expand by approximately 4-5% per year, reaching 35 million tons by 2030.

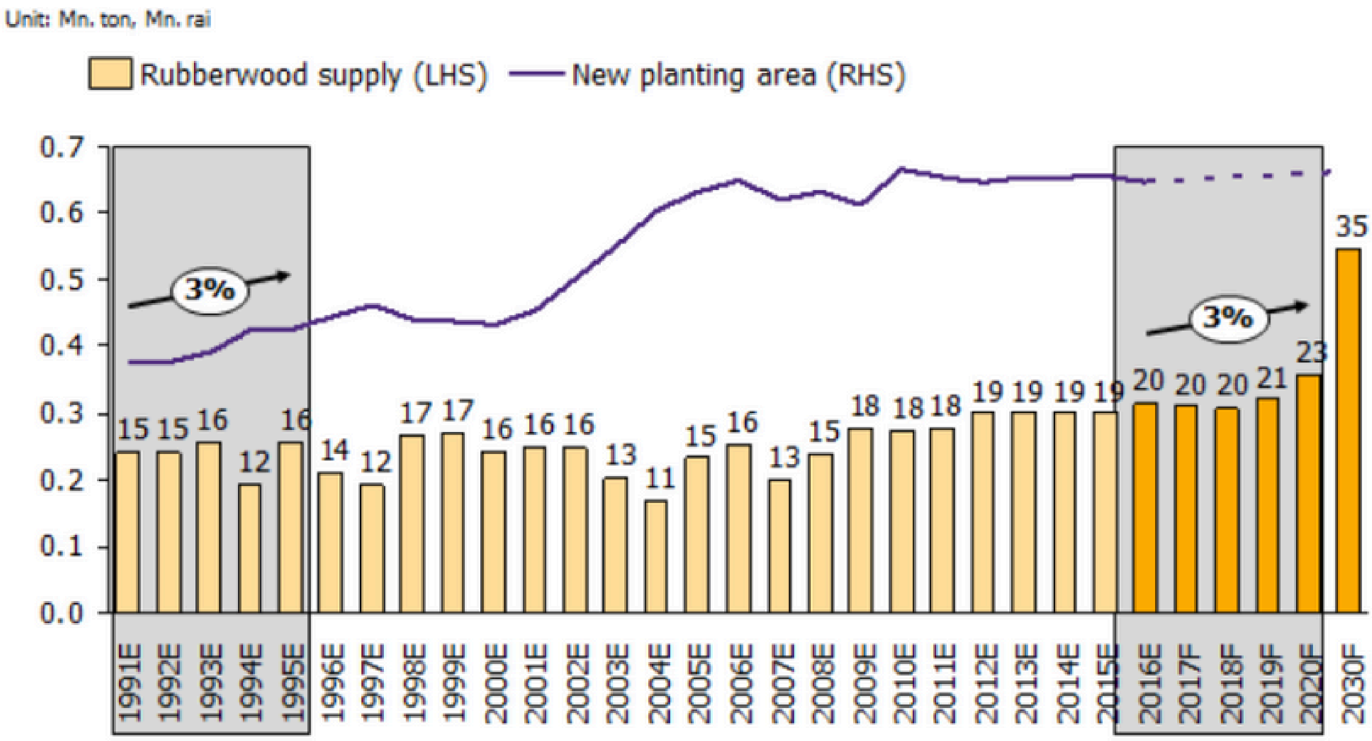
This projection is calculated based on the number of new plantings from 2000-2005, which increased significantly due to the high price of rubber latex (120-150 baht/kg). Although the price of rubber latex has dropped since 2011, new plantings have continued at a stable rate, except in southern Thailand since rubberwood remains as a relatively profitable cash crop.

However, the actual cutting and the amount of rubberwood may be less than the available stock due to the fact that the Government of Thailand through the Office of the Rubber Replanting Aid Fund (ORRAF) has provided a replanting subsidy of 16,000 baht/rai or USD 2,850 per ha (US$ 2,750 per ha in Malaysia) to rubber farmers to cut mature trees over 25-year-old on legitimate land and replant with high yielding rubber clones or good quality materials. The subsidy is released in 7 installments within 6 years.
The annual target area under this aid program ranks from 200,000 rai (32,000 ha) to 400,000 rai (64,000 ha) depending on available budgets.

Figure 20

Rubber plantation in Thailand and rubberwood production

Source: EIC analysis based on data from FAO



Thus, many rubber farmers with and without legitimate land titles are unable to apply for the replanting subsidy. As a result, large areas of mature rubber plantations are left over or converted to other economic crops or fruit trees or burned off after they are economically unviable for tapping latex.

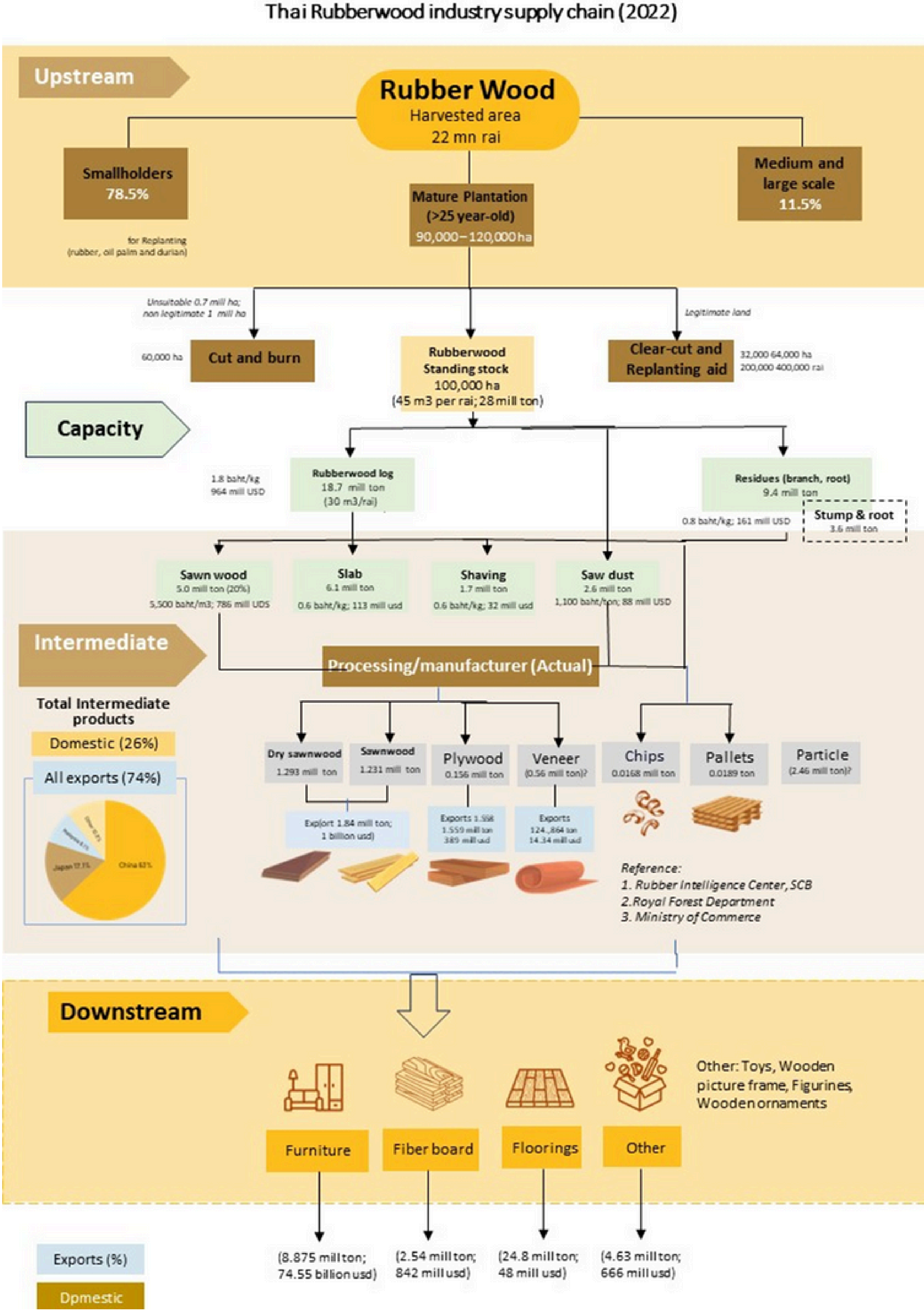
Sungsing and Prommee (2010) reported that the mature rubber plantation of 1 rai can provide the wood volume of 45 m³, including round wood log of 30 m³ and residues of 15 m³.

If all round rubberwood fallen from the target area of 200,000 rai (32,000 ha) under the replanting aid transported to the sawmills for processing, they can produce 1.6 mill m³ of sawnwood, slap of 2.1 m³, and saw dust of 0.9 m³, branches of 3.0 m³, and shavings of 0.6 m³ (Table 4).

The present price of rubberwood log are 1.7-1.8 baht/kg for rubber log with diameter >4 inches and 2.0-2.4 baht/kg for log with diameter >8 inches. In addition, the price for wood residues is 0.6 baht/kg. Thus, the total value of rubberwood log and residues are 964 million USD and 161 million USD, respectively (Figure 21).

Figure 21

Rubberwood supply chains in Thailand



Note: 1 ton = 650 kg (density = 0.65)

Table 2

Prices for rubberwood products (Thai baht).
Source: Bigger Wood Ltd, Trang Province

Thick (inch)	Thick (mm)	Width (inch)	Length (m)	Price per cubic feet (ft3)	Price per cubic meter (m3)
	AB				
0.5	23	1.5	1.00-1.30	360	4,000
0.5	23	2, 2.5. 3	1.00-1.30	420	4,666
0.625	32	1.5	1.00-1.10	420	4,666
0.625	32	2, 2.5. 3	1.00-1.10	500	5,555
0.75	34	1.5	1.3	470	5,220
0.75	34	2, 2.5, 3	1.3	520	5,777
0.75	34	4, 5	1.3	540	6,000
branches					0.8 baht per kg
Saw dust					1,100 baht per ton

Note: Thai baht 36 = USD 1

Intermediate steam industry

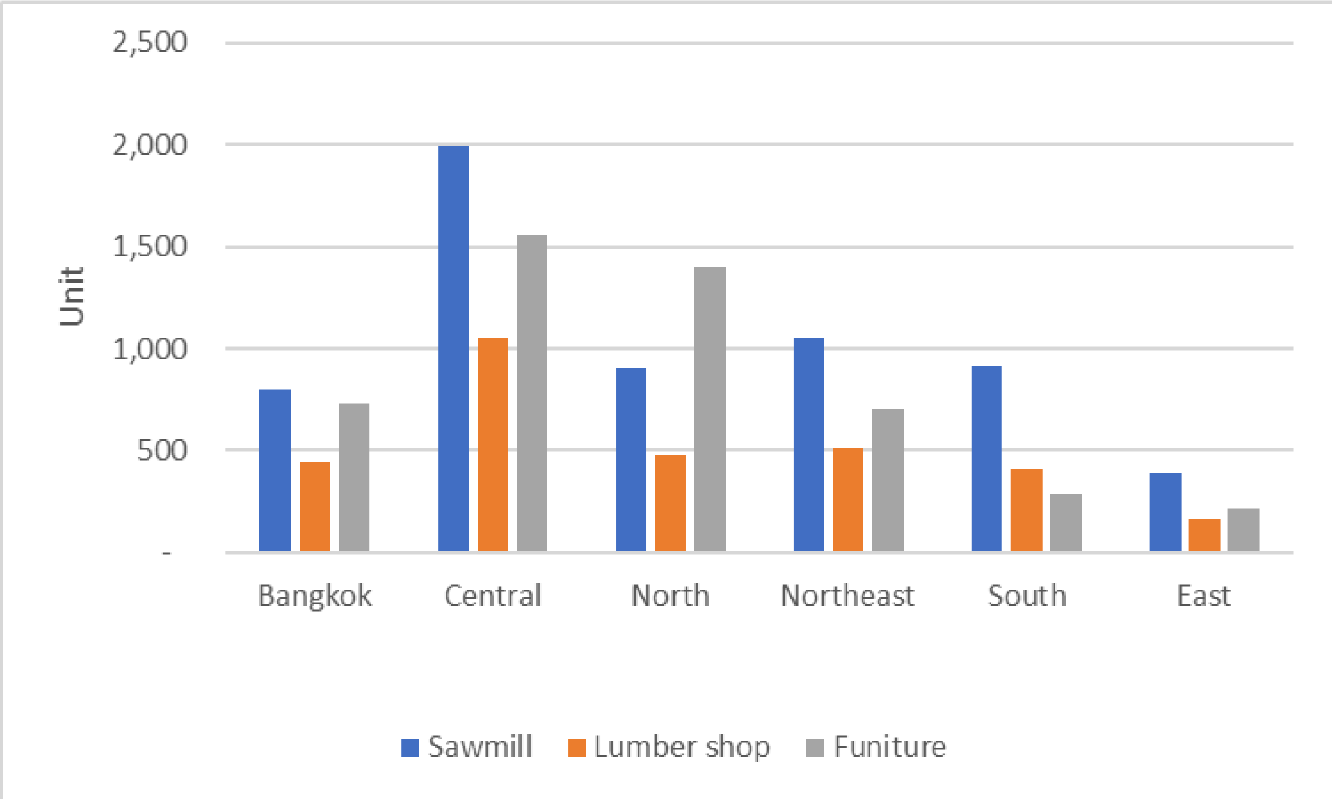
i) Sawing

After the rubber farmers cut and transported rubberwood logs and residues to the sawmill factories, they will be processed.
The intermediate rubber industry includes various processing through the supply chains such as sawing, drying, and wood products manufacturing. It is to be noted that rubberwood is a perishable timber, susceptible to biodegrading organisms like stain fungi and insect infestations soon after felling. Hence, the rubberwood logs must be transported to sawmills and sawn into sizes as soon as possible (within 7 days) and treated with wood preservatives.

The RFD (2023) reported that there were 6,062 sawmills, 3,053 lumber shops, and 4,885 furniture manufactures across the country in 2022 (Figure 22). Sawmills and lumber shops were dominant in the central region, while furniture manufactures are dominant in central and northern regions.
However, this is not the case for the rubber industry because major plantations (approximately 60%) are in the south, while seaports for international shipping are located in the south and eastern regions.
Department of Industry Works (online) indicated that there are about 300 rubberwood factories in Thailand and less than 80% are located in the south. The industry supports workforce about 26,215 workers.

Figure 22

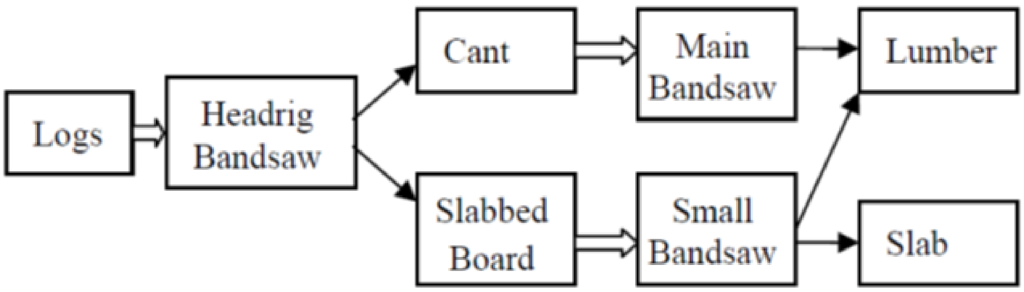
Number of sawmill, lumber shop and furniture manufactures
Source: RFD (2023)



For preliminary processing of rubberwood logs include sawing and drying. The normal sawing line always consists of transportation of logs, primary sawing with headrig bandsaw with carriage, secondary breakdown of cant with small bandsaw, and processing of flitch with small bandsaw. The technical flow is shown in Figure 23.

Figure 23

The general sawing techniques
Source: Yongdong *et al.* (2007)



The production line after sawing include sawn lumber, slap, shaving and saw dust. Sizes of sawn woods ranges from 0.5 inch (thick) x 1.5 inch (width) x 1.3 m (length) to 0.75 inch (thick) x 5 inch (witdth) x 1.3 m (length) depending on customer’s demand. Prices of sawn wood, slap, branch and wood shaving, saw dust are 4,000-6,000 baht/m^3, 0.6 baht/kg, 0.8 baht/kg, and 1,100 baht/ton, respectively.

Thus, the total capacity of standing mature rubber plantation (100,000 ha) can generate the value of preliminary rubberwood products about 1.18 billion, including 786 million USD for sawn wood, 113 million USD for slap; 32 million USD for shaving parts, 88 million USD for saw dust, and 161 million USD for other residues, (Figure 24).

Figure 24

Rubber logyard at the sawmill factory and Sawing rubber wood.
Credit: Yongyut Trisurat

ii) Drying
As discussed before, the freshly felled rubberwood is quickly susceptible to wood-rotting fungi and insects in tropical and sub-tropical areas due to the availability of high amount of carbohydrates in parenchymatous tissues and high moisture content (more than 100%). The common preservative, a mixture of borax and boric acid, is widely used for treating rubberwood for indoor use. The advantage of this method of treatment is that the wood’s natural colour is reained. It cannot be used outdoors as it is leachable in water.

Chemical treatment is highly toxic to humans and animals and causes environmental problems.
For outdoor use Copper Chrome Arsenate (CCA) or Copper Chrome Borate (CCB) is being used by adopting pressure treatment method. The treated rubberwood kiln dried (or kept for air drying under shade is the) common practice in Thailand.

Combining the pre-drying (air-drying) with conventional kiln drying is a practical solution to avoid drying defects to obtain quality rubberwood for various end-uses.

The pre-drying methods include lowering the temperature pre-drying and air-drying. Air-drying rubberwood can contribute to not only shorten drying time, reduce drying cost but also cut down energy consumption.

However, we do not have a control over drying time as it depends on the surrounding atmospheric humidity and temperature. Proper air-drying time for rubberwood takes less than two months, and the final moisture content (MC) should be around 20%～30%.

Kiln drying is an artificial drying method which incur considerable investment cost to dry the timber in a drying kiln (it can be both electric drying and steam drying) in controlled conditions of temperature and humidity.

The desired drying quality and finial moisture content can gain if the proper drying technology is adopted. The appropriate time for klin drying is 12 to 21 days.

iii) Secondary products

Dry sawn wood and wood residues can produce several products such as lumber, plywood, veneer, wood chip, pallet particle boards, MDF, etc. According to the Rubber Research Institute, the rubberwood derived from 32,000 ha (200,000 rai) can produce the sawn-wood of 1.6 million m3, and other products (Table 4), veneer of 0.2 million m³, particle board of 0.88 million m³, and MDF of 0.85 million m³. Using these figures, the standing mature rubber plantations of 100,000 ha have capacity to produce sawn-wood, veneer, particle board, and MDF of 5.00, 0.62, 2.66, and 2.75 million m³, respectively. The total value of secondary products is about 1.81 billion USD.

Figure 25

Sawn-wood from rubber wood (left) and veneers rubber wood (right).
Credit: Yongyut Trisurat

Table 3

Rubberwood volume from 1 rai, 2000,000 rai and 500,000 rai (100,000 ha) with the ages between 19-24 years.

Component	From 32,000 ha [1/]		%	From 100,000 ha [3/]	
	Rubber volume (million ton)	Rubber biomass (million m^3) [2/]		Rubber volume (million ton)	Rubber biomass (million m^3)
Preliminary products					
Sawn wood	1.6	1.04	19.6	5.0	3.25
Slap	2.1	1.365	25.5	6.6	4.27
Dust	0.9	0.585	36.7	2.81	1.83
Branches	3	1.95	7.3	9.4	6.09
Shaving	0.6	0.39	10.9	1.9	1.22
Total	8.2	5.33	100.0	25.6	16.66
Processed products					
Veneer	0.2			0.62	
MDF	0.85			2.66	
Particle board	0.88			2.75	

Notes: 1/ Rubberwood volume from 1 rai (6.25 rai = 1 ha; Phukaoluan, 1988); 2/ Average annual target for replanting aid; 3/ Total stock of standing mature plantation (EIC, 2022)

However, not all mature rubber plantations are cut and transported to the sawmills and wood manufactures for processing. The Department of Industry Works reported that there were 300 rubberwood factories across the countries in 2022 with the full capacity to produce approximately 4 million m³ of rubber products, but they actually produced about 2.8 million m³ or 80% of the total capacity (Table 3) as a consequence of COVID-19 pandemic and declining international demands.

3) Downstream (tertiary) products

The secondary processed wood products, especially sawn-wood will be used to produce several wood products such as construction lumber, toys, door and window frames, furniture, kitchen utilities and solid rubber woods. Rubber Authority of Thailand (2003) reported that the sawn rubberwood of 1.6 million m³ derived from the replanting can produce 0.8 million m³ of furniture and sawn wood. Based on this standard figure, it is estimated that the available mature stock of 100,000 ha can produce sawn wood of 3.25 million m³ (5.0 million ton) and furniture and sawn wood 1.62 million m3 (2.5 million ton).

Due to lack of a complete database of wood industry, the actual rubberwood processing and manufacturing units are unknown. Based on the reports of 300 factories (one third of factories found in the south), the production line of wood products in 2022 was about 2.8 million m³ or 70% of the total capacity of all factories. Major products include dry sawn wood, wood furniture, plank, pallets, and other solid woods. Dry sawn wood and other sawn wood products account about 2.37 million m³ or 85% of all products.

Table 4

Production capacity and reported production in 2022

Source: Department of Industry Works

Products	Capacity			Actual production		No. of workers
	No factory	(ton/yr.)	Unit/year	(ton/yr.)	Unit/year	
Rubberwood products	**300**	**3,966,750**	**22,758,345**	**2,779,414**	**16,698,285**	**26,215**
Dry sawn wood	94	1,910,860	9,349,240	1,224,901	7,177,124	9,201
Furniture	88		4,770,285		3,681,364	9,195
Other		86,000		68,466		728
Sawn wood products	**121**	**1,969,890**	**8,638,820**	**1,486,047**	**5,839,797**	**9,090**
Plank	17	137,000	5,486,200	87,180	3,603,723	1,324
Plywood	<5	219,000	200,000	156,550	152,900	333
Solid wood	<5		4,500		3,800	104
Wood chip	6	22,250		16,814		156
Ladder wood board						
Door frame	<5		6,000		5,150	62
Pallet	<5	26,000	720,000	18,929	427,500	403
Particle board	<5		200,000		182,000	90
Veneer						
Other sawn wood	74	1,482,680	2,014,120	1,144,499	1,457,974	6,284
Other	11	82,960	8,000	62,075	6,750	456

Figure 26

Door frames, furniture components and toys (Trang province, Thailand).

Credit: Yongyut Trisurat

4.3 Carbon storage of rubber plantations in Thailand

Rubber trees are vital economic crop in Thailand, mainly in the Northeast and South regions. Rubber plantations accumulate significant amounts of carbon in their biomass (Maggiottoet *et al*., 2014; Jong *et al*., 2021; Huang *et al*., 2022). These plantations have been established since 1899 and now span across 70 out of 77 provinces in Thailand, covering nearly 24 million rai or 3.8 million ha with different age classes from 1 year old to over 25 years. Thus, the stand structural characteristics such as girth size, height, basal area, tree carbon, and overall carbon stock differ significantly among different age classes, leading to variations in carbon sequestration.

Based on a nationwide inventory, Thailand's total greenhouse gas (GHG) emissions, excluding those from land use/land cover and forestry (LULUCF)rose from 245.76 MtCO2eq in 2000 to 354.36 MtCO2eq in 2016, increasing at an average annual of 2.31%. based on the business-as-usual projection from the 2005 reference year. Without significant climate change policies, total GHG emissions are projected to reach around 555 MtCO2eq in 2030 (ONEP, 2020).

Thailand's long-term low GHG development strategy (LT-LEDS) outlines clear targets and measures towards achieving net zero GHG emissions. Firstly, it aims to reduce the greenhouse gas emissions intensity by 20–25% compared to 2005 levels or peak GHG emissions at around 370 MtCO2eq by 2030. Secondly, Thailand's net greenhouse gas emissions are projected to be approximately 200 MtCO2eq in 2050 and achieve net zero GHG emissions by 2065, aligning with the global 2-degree pathway (Department of Climate Change and Environment, 2023).

To meet that vision, the Government of Thailand formulated the Nationally Determined Contribution (NDC) roadmap to guide the nation toward climate resilience and low greenhouse gas emissions. The NDC action plans cover various sectors like energy, transport, industry, agriculture, and waste management with specific measures and emission reduction targets.
Yet, the inventory data reveals that only the forestry sector, including rubber plantations, holds immense potential for absorbing atmospheric CO2.

GHG emissions and absorption in Thailand's LULUCF sector were assessed based on the 2006 IPCC Guidelines for three land categories viz., forest land, cropland (mainly rubber plantation), and other land, resulting in -5,117.65, -73,457.96, and 7,199.54 GgCO2eq, respectively. The LULUCF sector showed increasing net removals as total removals surpassed total emissions, particularly in rubber plantations, growing at a rate of 3-4% per year. However, the national inventory relied on rough estimates due to limited data available.

A recent study examined 3 stands of rubber plantations in southern Thailand: Stand A (20 years old) with ongoing rubber production in Songkhla Province, Stand B (25 years old) just undergoing clear-cutting, and Stand C (30 years old) where rubber production has ceased but replanting had not occurred. The rubber was planted using high-yielding rubber clones such as RRIM 600 which are commonly used in Thailand (Hytonen *et al.*, 2019).
The stand density of A and B was 357 trees/ha, while Stand C had a density of 410 trees/ha.

Dry biomass of the tree compartments was determined using biomass equations based on diameter at breast height (DBH) from the same area measured for trees at the clear-cutting stage as per Hytonen et al., (2019). Total dry mass, encompassing leaves, stumps, and roots was 157 Mg/ha (or ton/ha) in the 20-year-old stand and 289 ton/ha in the 30-year-old stand, as shown in Table 5.

Stems contribute around 74%–76% of the total dry biomass, while stumps and roots range from 23–40 ton/ha, containing 14%–15% of dry mass depending on the stand age. Branch dry biomass varies, with about 17 ton/ha in the 20-year-old stand and 29 ton/ha in the oldest stand. Both smaller (<3 cm) and larger (3–5 cm) diameter branches account for 5%–6% of the total biomass, while leaves make up only 1%. Residual biomass without leaves in the three mature rubber tree stands was 25%.
The average green density of rubber wood is in the range of 0.56 – 0.65 g/cc, while air-dry density (moisture content at 12-15%) is in the range of 0.67-0.76 g/cc. With an average density of 0.65 g/cc, the 20-year-old stand, 25-year- old stand, and 30-year-old stand would have wood volumes of 241, 264 and 482 m^3/ha, respectively or 38.56, 42.58 and 77.12 m^3/rai, respectively. These figures align with previous findings by Phukaoluan (1988).

Table 5

Dry biomass and wood volume of rubber tree at different stand ages
Source: Hytonen et al. (2019)

Stand (age-year)	Mean DBH (m)	Mean H (m)	Dry biomass (ton/ha)							Volume (m3) *
			Leaves	Branches (<3 cm)	Branches (3-5 cm)	Branches (<5 cm)	Stems (>5 cm)	Stumps and roots	Total	
A (20)	23.7	19.8	1.97 (1.3)	8.92 (5.6)	7.53 (4.8)	16.45 (10.5)	115.98 (73.8)	22.72 (14.5)	157.12 (100.0)	241.72
B (25)	24.6	20.1	2.14 (1.2)	9.70 (5.5)	8.17 (4.8)	17.87 (10.5)	126.98 (74.0)	24.67 (14.4)	171.67 (100.0)	264,11
C (30)	28.4	20.9	3.47 (1.2)	15.82 (5.5)	12.96 (4.5)	28.78 (10.0)	217.39 (75.1)	39.72 (13.7)	289.35 (100.0)	482.25

Note: Average density = 0.56 – 0.65 g/cc (Forest Research Division/RFD, 1986); Volume = Biomass/Density

Based on the data from the Office of Agriculture and Economics (2023), existing rubber plantations can be classified into 6 age classes: 5, 10, 15, 20, 25 and 30 years old, mainly variety RRM600 plantations. However, older trees that cover a small portion may remain in the planted rubber areas because most farmers fell the mature rubber tree either to apply for replanting aid or due to lack of economic benefit.

According to IPCC (2008), the carbon content in various parts of rubber trees was estimated by multiplying with the 0.5 conversion factor for both aboveground and belowground biomass. Carbon storage increases with the plantation age (Table 6), with older plantations exhibiting the highest carbon storage values, reflecting biomass accumulation resulting from the balance between photosynthetic activity and respiration.

The aboveground and belowground biomass carbon accumulation in 5, 10, 15, 20, 25, and 30-year-old plantations were 20.00, 36.01, 56.01, 78.56 85.84, 144.68 ton/ha, respectively. These figures are lower compared to estimations in northeast Thailand by Saengruksawong *et al.*, (2012), which reported biomass carbon stocks of29.87, 52.54, 70.13, and 83.74 ton/ha, respectively. The difference is attributed to calculations based on densities ranging from 469-500 trees/ha, whereas this report uses the density of stands ranging from 357-410 trees/ha, with Stand C at 410 trees/ha (Hytonen *et al.*, 2019).

Table 6

Carbon storage in different ages of rubber plantations
Source: Hytonen et al. (2019)

Age	DBH	Aboveground (ton/ha)1/	Belowground (ton/ha)1/	Dry biomass (ton/ha)	Carbon storage (ton/ha) 2/	Extent of rubber plantation (1,000 ha) 3/	Total carbon storage (mill ton) 4/
≥30	28.40	249.63	39.72	289.35	144.68	1,749.70	253.14
25	24.60	147.00	24.67	171.67	85.84	39.80	110.25
20	23.70	134.4	22.72	157.12	78.56	451.10	98.34
15 5/	16.90	95.83	16.20	112.03	56.01	1,056.30	56.99
10 5/	10.86	61.60	10.41	72.02	36.01	224.10	13.26
5 5/	6.04	34.22	5.79	40.01	20.00	355.60	5.45
Total						**3,876.60**	**537.43**

Note: 1/ Leaves, branches, and stems; 2/ stumps and roots; 3/ rubber stands in 2022 (OAE, 2023); 4/ carbon accounts approx. 0.5 of dry biomass (IPCC, 2008); 5/ estimated dry biomass and carbon storage based on the average growth of rubber (clone RRM 600)

Young plantations (1-5 years) stored approximately 5.45 million tons of carbon. Middle-aged plantations (10, 15 and 20 years) contributed 13.26, 56.99 and 98.34 million tons, respectively. The oldest plantations (25 and ≥ 30 years) contained 110.25 and 253.14 million tons, respectively. The total carbon storage in the landscape is about 537.43 million tons. Note that soil carbon storage is not included in this assessment, which accounts for 16.83, 18.52, 16.05, and 13.37 ton/ha, respectively in the 5, 10, 15, and 20-year-old stands (Saengruksawong *et al.*, 2012).

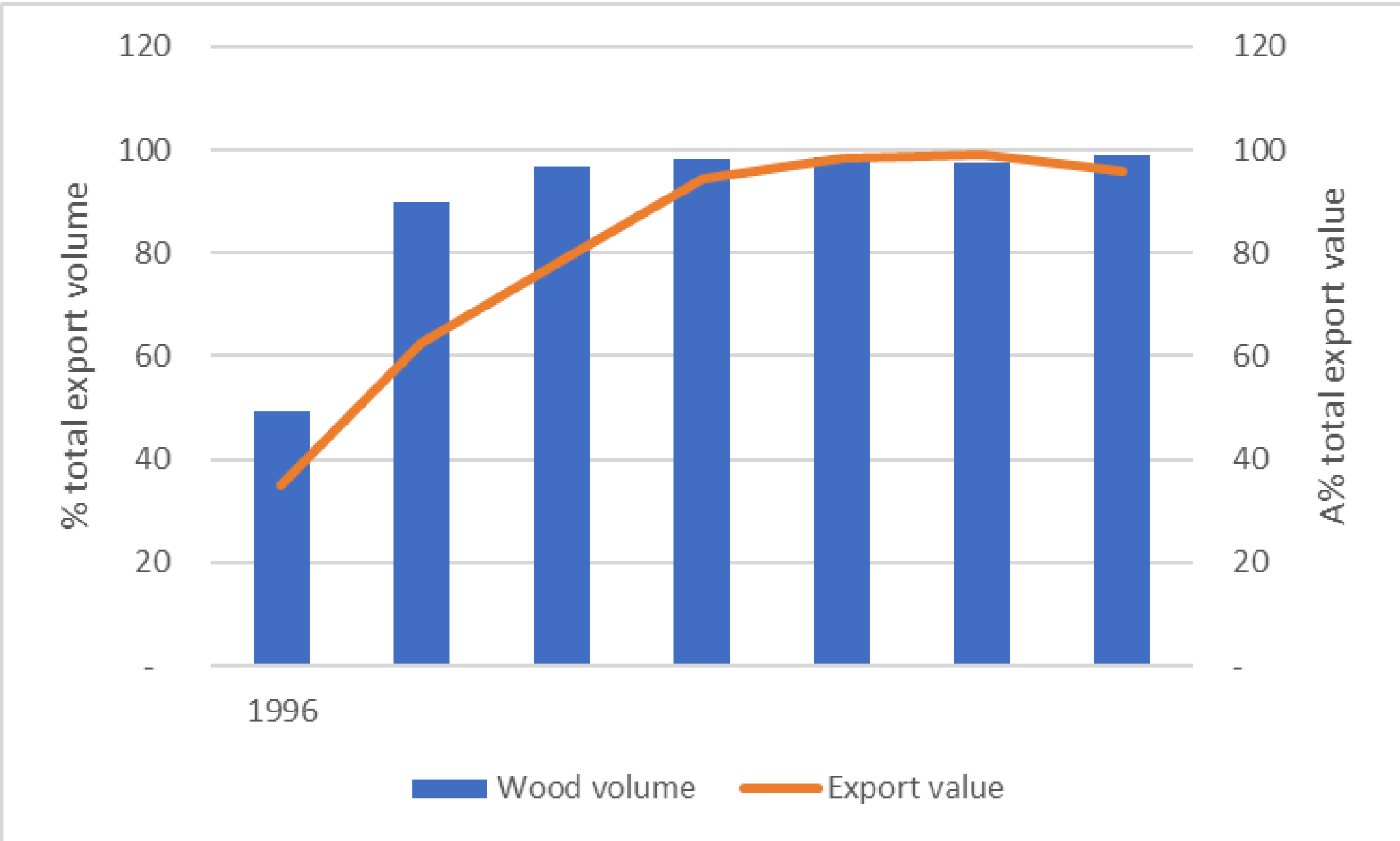
Soil carbon storage is significantly quite high depending on soil texture and soil depth, necessitating further research. However, the assessment highlights that when the mature rubber trees are felled for wood products, carbon is harvested, while during growth, they fix CO2, aiding in reducing atmospheric greenhouse gas emissions. Moreover, the potential for carbon sequestration of rubber plantations in Thailand and elsewhere offers immense scope for future carbon credits and incentives.

5 IMPORTS AND EXPORTS

Thailand has been recognized as a major exporter of rubberwood, exporting over 70% of its rubberwood product. In 1996, the contribution of rubberwood was 35% of the total wood products and rapidly increased to 63% in 2000 and 96% in 2022 (Figure 26). This is due to the total logging ban in natural forests imposed by the Government of Thailand in 1989,Thus most of raw materials rubberwood (20-25 million tons) come from the mature rubber plantations, while teak wood contributes about 40,000-60,000 m³ (32,000- 48,000 tons) derived from plantations. Although neighboring countries such as Indonesia and Malaysia produce large quantities of rubberwood, they do not compete directly with Thailand since most products are used domestically (Shige matsu *et al.,* 2011). In addition, Thai rubberwood is competitive with other species such as pine, oak, conifer in terms of its quality and price.

Figure 27

Contribution of rubberwood for international export.
Source: RFD (2023)



Thailand exports approximately 73.5% of all rubber wood products, especially sawn wood to international markets abroad. The value of rubber sawn wood and rubber furniture in 2018 was about 3.1 billion USD, including sawn wood of 1.08 billion USD, furniture products of 0.83 billion USD, and fiber board of 0.53 billion USD. Almost 100% of rubber sawn wood are exported to China, while the markets for rubber furniture are Japan and USA. Most fiber board products are shipped to Middle East countries. Office of Industrial Economics, the Ministry of Industry reported that the export value fall to 2.6 – 2.7 billion USD in 2019-2020 during the COVID-19 pandemic as the result of problems/availability in container logistics. However, the value raised to 3.4 billion USD in 2021 after the international markets resume operation as usual (Figure 27).

It is to be noted that Thailand’s rubberwood furniture export value remains relatively small, compared to Malaysia, which does not export raw rubberwood. Since 1990, Malaysia on developing its rubberwood furniture export market. Currently furniture value in Thailand accounts less than 30% of the country's wood products export.

China reprocesses the sawn rubber wood to produce furniture or tertiary products for international trade.

In 2019, China exported furniture and processed wood about 33.7% of the global products with the value of 25.3 billion USD (1st furniture exporter). Thailand was ranked as 28th, followed by Malaysia and Indonesia. Hence, Thailand should focus on enhancinge its export value and competitiveness by investing in the production of rubberwood furniture and other rubberwood-based products rather than relying mainly on raw rubberwood exports. This is because Thailand is the main source of raw material and the export value of wood furniture is 10.7 times that of sawn rubberwood.

China accounts for about 63% of all export value compared to Japan (17.1%) and Malaysia (9.1%) (Figure 28). It is estimated that China’s imports of sawn rubberwood and rubberwood products from Thailand remained stable in the last decade and accounted for about 3% of China’s total import of goods from Thailand. In the last decade, the quantity and value of exports increased rapidly due to the average economic growth of 9-10% per year, in particular the expansion and growth of real estate sector by approximately 14% per year. The total value in 2015 was more than 1 billion USD. In 2016 alone, domestic sales in China totaled approximately 1.5 trillion USD. A spike in domestic market raised the demand for rubberwood as it can be used for furniture production and related construction needs.

Figure 28

Contribution of rubberwood for international export.
Source: RFD (2023)

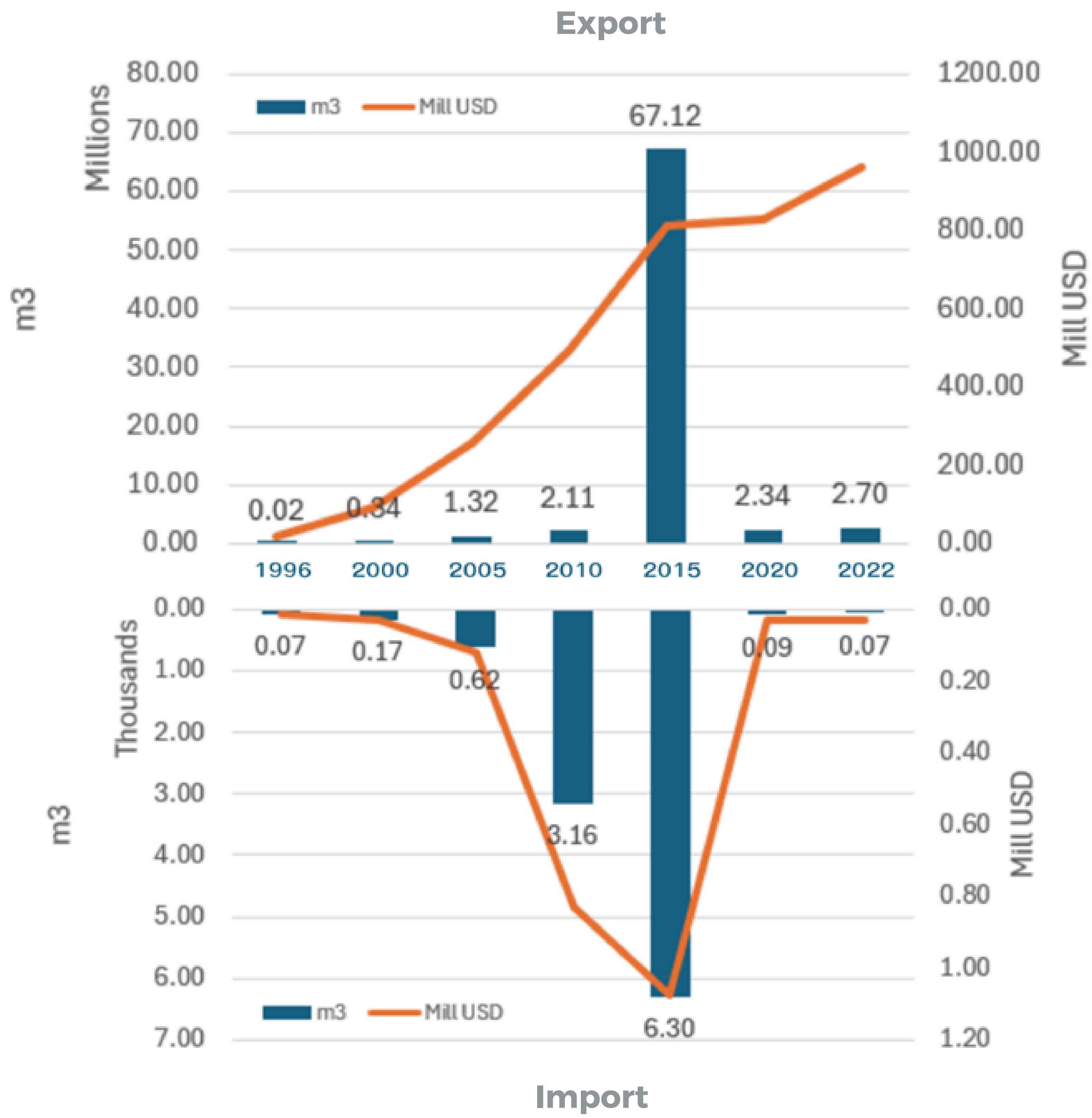


Figure 29

Percentage of rubberwood export value to abroad
Source: 182 Thai companies reported to the Custom Department

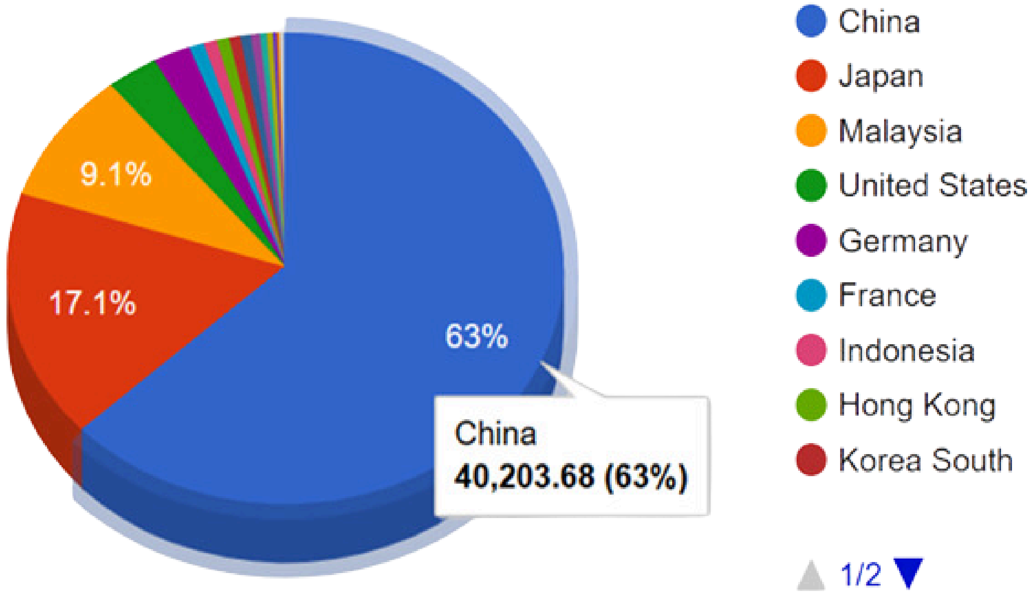
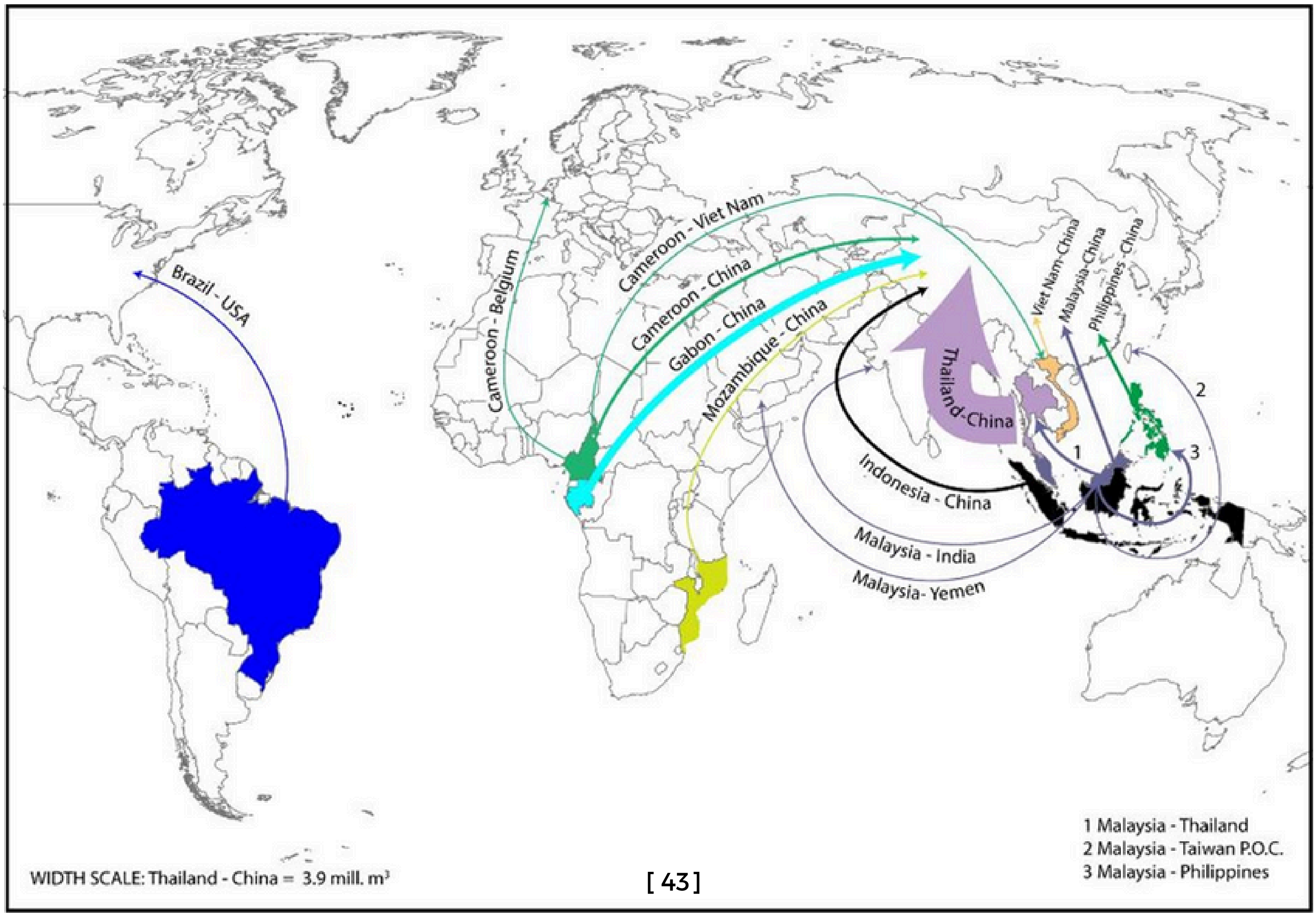


Figure 30

Global trade of rubberwood
Source: ITTO (2023)



However, China's GDP growth during 2009-2010 was 8-9% and significantly dropped to 2% during 2019-2020 during the COVID-19 pandemic and picked up to 4-5% at present. The short-term economic challenges facing China include the real estate sector, weak confidence, and local government debt. The era of rapid growth in real estate is facing oversupply problem, eventually reduce the demand of rubberwood in the real estate sector. Rubber wood furniture exports have declined from 4.5 billion USD in 2015 to 2.4 billion USD in 2022 or decreased 50%.

In terms of wood volume, China’s sawn rubberwood imports fell from 4.82 million m3 in 2017 to 3.97 million m3 in 2022. In addition, the average CIF price for China’s sawn rubberwood imports fell from USD 316/m³ in 2017 to USD 250/m³ in 2022 (ITTO, 2023). Experts think that China is in a transition mode rather than in any long-term decline. Its economy is projected to rise at a slower rate. Thus, China remains as the important importer of Thailand’s rubber wood products.

6 CHALLENGES IN RUBBER INDUSTRY SUPPLY CHAINS

Based on literature review and consultation with various stakeholders, challenges in rubber industry in Thailand are shown in Figure 30 and are described as below.

6.1 Farmer and Producer Challenges

1) Low productivity

One of the most prominent challenges faced by natural rubber smallholders is low productivity. Smallholders typically have limited resources and knowledge of modern farming practices, which leads to low yields. Rubber Research Institute of the Agriculture Department and scientists have conducted breeding program for producing high quality rubber clones and rubber varieties to obtain more latex yields that are resistant to pests diseases. However, the results of research and development projects, as well as innovations are not effective in delivering the desired results to smallholder rubber farmers. Therefore, rubber farmers have to incur more costs for fertilizers and pesticides.

The average yield of rubber latex in Thailand falls from 241 kg/rai in 2013 to 223 kg/rai in 2022 (OAE, 2023). Although the average productivity is greater than the global average of 180 kg/rai, but it is less than the Vietnam (271 kg/rai), Philippines (288 kg/rai), and India (354 kg/rai), and are competitors to Thailand.

2) Variation of capital cost

Rubber is an important economic crop for Thailand and over 1.2 million households or 6 million population (~10% of total population) are involved in rubber plantation. However, rubber price fluctuated in the last 2 decades from 1 to 5 USD/kg. Usually, the government provides subsidy to help farmers through various financial mechanisms to tide over the situation, and occasional price interventions. In long-term, Thai government has a policy to reduce plantation areas in order to reduce rubber supply. In addition, the government also convince the farmers to grow other economic crops, that provide more economic returns.

However, the investment cost per unit area varies from province to province (44-62 baht/kg of rubber latex) such as variation in input costs, number of rubber trees planted etc. For example, the unit cost to grow rubber in Thailand is 44.2 baht/kg of rubber latex, while it is 27.1 baht/rai in Malaysia (Phinsanwanich, 2021). These research studies showed that the investment capital in Thailand is greater than neighboring countries. This leads to an ineffective policy to manage rubber price.

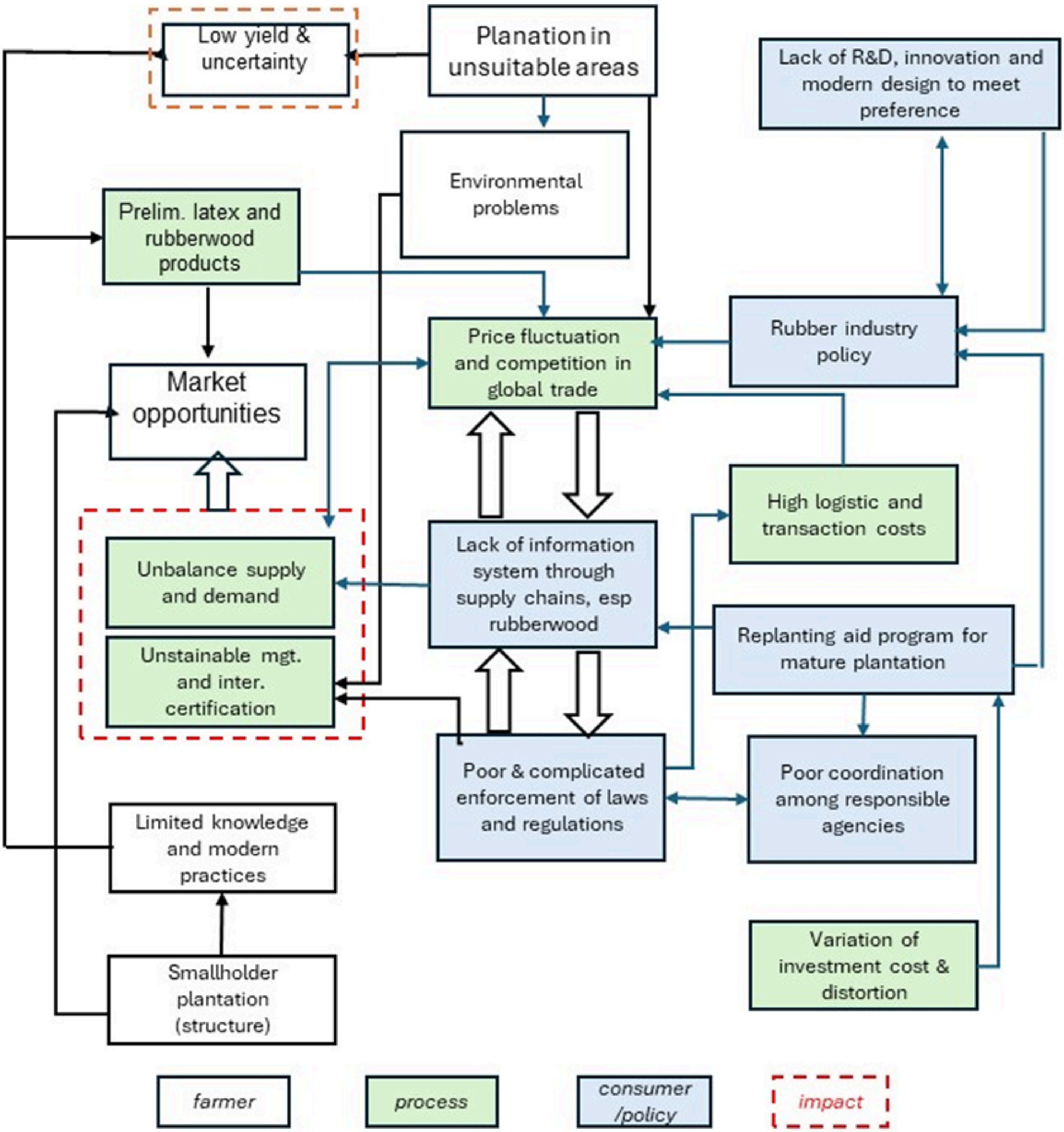
3) Smallholder plantation

The Office of Agricultural Economics (2022) reported 78.5% of rubber farmers were smallholders owning land less than 15 rai/household or 2.4 ha/household. Thus, they are forced to invest more cost per unit area and have limited resources to access modern technology. Using the average latex production of 223 kg/rai (35.7 kg/ha) and the average price of 60 baht/kg, each household (hh) can earn USD 5,734 per hh/year (223*15*60 = 200,700 baht) or net benefit of USD 1,510 (52,851 baht/hh/year) only after minus investment cost. If discount rate is included, rubber farmers can earn about 20,000 baht/hh/year. They can earn additional income of USD 3,428 (120,000 baht) from selling mature rubber wood logs. Their household income (average 4 persons/hh) is significantly less than the poverty line of 2,802 baht/person/month or 33,624 baht/person/year.

Additionally, natural rubber production is a labor-intensive process, which requires extensive maintenance. This problem is aggravated by limited access to credit and the high cost of inputs such as fertilizers and pesticides.

Figure 31

Challenges of natural rubber and rubberwood industry in Thailand.



4) Plantation in unsuitable areas
Land Development Department (2011) reported that about 1.32 million ha (8.26 million rai) or 33% of the total plantation areas were planted in unsuitable areas or marginal land leading to low productivity (Table 6). In addition, rubber farmers can harvest latex after 8-year-old with the average latex of 150 kg/rai. In contrast, the average tapping age in suitable areas is 6 years with the average latex production of 223 kg/rai. Using these productivity rates, rubber plantation in marginal land will have latex less than the average production in moderate and high suitable areas of 40% for 25 year cycle. In addition, inaccessible and unsuitable areas are situated in rugged terrains, thus the farmers had to incur more costs for transportation. Moreover, about 69,000 ha (4.1 million rai) are in in-legitimate lands such as natural reserves or protected areas. There are several disadvantages of rubber products from illegal supply chains. First, rubber farmers cannot apply for replanting subsidy of 16,000 baht/rai (2,850 USD/ha) from the Government. Second, all rubber, wood and wood-derived goods from intermediate and downstream rubber industries cannot be exported to international markets such as EU, USA and Japan, which consume approximately 65-80% of the total rubber products. This is due to the legal issues. (see more discussion in the international certification section).

Table 7

Land suitability of planted rubber by region in 2011 based on FAO framework.
Source: Land Development Department (2011)

Suitability	N	C	E	NE	S	Total
High	9.58	5.02	36.73	60.08	806.54	917.95
Moderate	35.34	24.36	134.97	141.60	766.75	1,103.02
Low	36.83	26.28	128.90	448.81	319.43	960.26
Not suitable	12.46	4.48	19.37	9.63	315.36	361.31
Inside forest reserve	61.33	23.53	77.39	83.46	413.10	658.79
Total	155.54	83.67	397.36	743.58	2,621.18	4,001.33

5) Environmental challenges, including climate change and deforestation. Although the rubber latex has a high commercial value which can support rural people in socio-economic development, rubber plantation in unsuitable areas such as steep slope and high biodiversity areas is harmful for watersheds and destroys forest ecosystems, respectively. It causes negative impact on hydrological balance, eliminates biodiversity, generate sediment and flood risks, etc.

Faksomboon *et al* (2019) conducted research in Kamphaemg Phet, northern Thailand and found that the soil erosion of field crops (cassava), rubber plantation and orchard area (Mulberry and Rambutan) were 110.87, 79.82 and 41.43 ton/ha/year, respectively, which were greater than soil erosion derived from mixed deciduous forests.

Similar study was conducted in rubber plantation in mountainous northern Thailand (Neyret *et al.*, 2020). The research results indicated that runoff and detachment increased in the rainy season with rainfall intensity. This led to high erosion rate of top soil in mature plantations (5.7 kg/m^2 on average) than in maize and young plantations with intercrop (0.36 kg/m^2). There are two main influencing factors explaining this difference: first, rubber tree leaf litter, although abundant, seemed ineffective in reducing runoff at the end of the rainy season.

Figure 32

Rubber plantation in steep slopes.
Credit: MGR online https://mgronline.com/south/detail/9550000011934

Secondly, the under story cover crops in mature rubber tree plantation was usually sparse and provided little protection. By increasing the under-story cover crops from quasi-null cover to >31% cover can decrease the runoff coefficient by 32%.

A similar study was conducted on 2 year old para rubber (RRIM 600) trees in Phitsanulok province. Para rubber plantation on hillside area without any soil conservation efforts lead to high soil loss and water runoff. The mono-culture rubber plantations gave the highest soil losses (14.0 ton/ha) and Para rubber with maize gave lowest amount of soil losses (3.2 ton/ha). para rubber with Vetiver grass gave the highest water runoff (2,634 m3/ha) and para rubber with Maize and Soya bean gave the least amount of water runoff (1,745 m3/ha) (Khamkajorn *et al.*, 2014).

Moreover, the production processes of intermediate products from natural rubber industries include ribbed smoked sheets, air dried sheets, block rubber, crepe rubber, and concentrated rubber latex may cause many environmental problems if appropriate technologies and operation are not implemented effectively. In rubber sheet drying industry, the main concern is the smoke particles from fuel wood burn because of the presence of hazardous components such as PAHs polycyclic aromatic hydrocarbons associated with the particles.The PAH concentration is very high in the workspace and this could have adverse effect on workers' health.

Moreover, the wastewater in rubber drying cooperatives is not treated properly. In rubber latex industry, main concern is wastewater, but it is generally well treated. The odor problem arising from ammonia used for latex preservation remains unsolved. In rubber glove industry, the main problem is the wastewater and it is treated the same way as in rubber latex industry (Tekasakul and Tekasakul, 2006).

6) Lack of access to information and technology

Finally, the lack of access to information and technology is a significant challenge faced by natural rubber smallholders. Many smallholders lack access to modern farming technologies that could significantly improve productivity, such as irrigation systems and mechanized equipment. Additionally, smallholders often lack access to market information, which makes it difficult for them to make informed decisions to sell their rubber.

Lastly, information on disease control, particularly leaf fall disease is very essential. Rubber Research Institute reported that leaf fall disease significantly reduces the latex production to about 30-50%.

For rubberwood industry, sawmill manufacturing owned by smallholders lack of knowledge to process the rubber wood logs in the sawmill and wood preservation methods to enhance the duability of rubberwood sawn products.

6.2 Processor and Factory (middle stream) Challenges

1) Low quality and raw products

Rubber plantations in the northeast and northern regions increased to 1.15 million ha or 32.8% in 2023 compared to 899,110 ha or 25% of the total plantation areas in 2011. In addition, the plantation areas are steadily increasing about 4-5% per year. It is noted that the establishment of rubber plantation in northeast and in the north started less than 30 and 20 years, respectively. They are all smallholders and rarely coordinate to form cooperatives like rubber farmers in the southern region. More than 80% of farmers sell raw products such as latex and cup lump to middlemen due to limited knowledge and resources to produce processed products (e.g., ribbed smoked sheets, air dried sheets). The quality of cup lump produced by farmers in the northeast and north regions usually does not meet the required market standards, (especially low moisture content), which are required by the factories. In addition, there are limited manufacturers to produce intermediate and tertiary products in these two regions. The rubber farmers in these 2 regions do not have power to negotiate the prices and terms with factories. Hence, they usually sell latex and cup lump at low price compared to the existing standard market price.

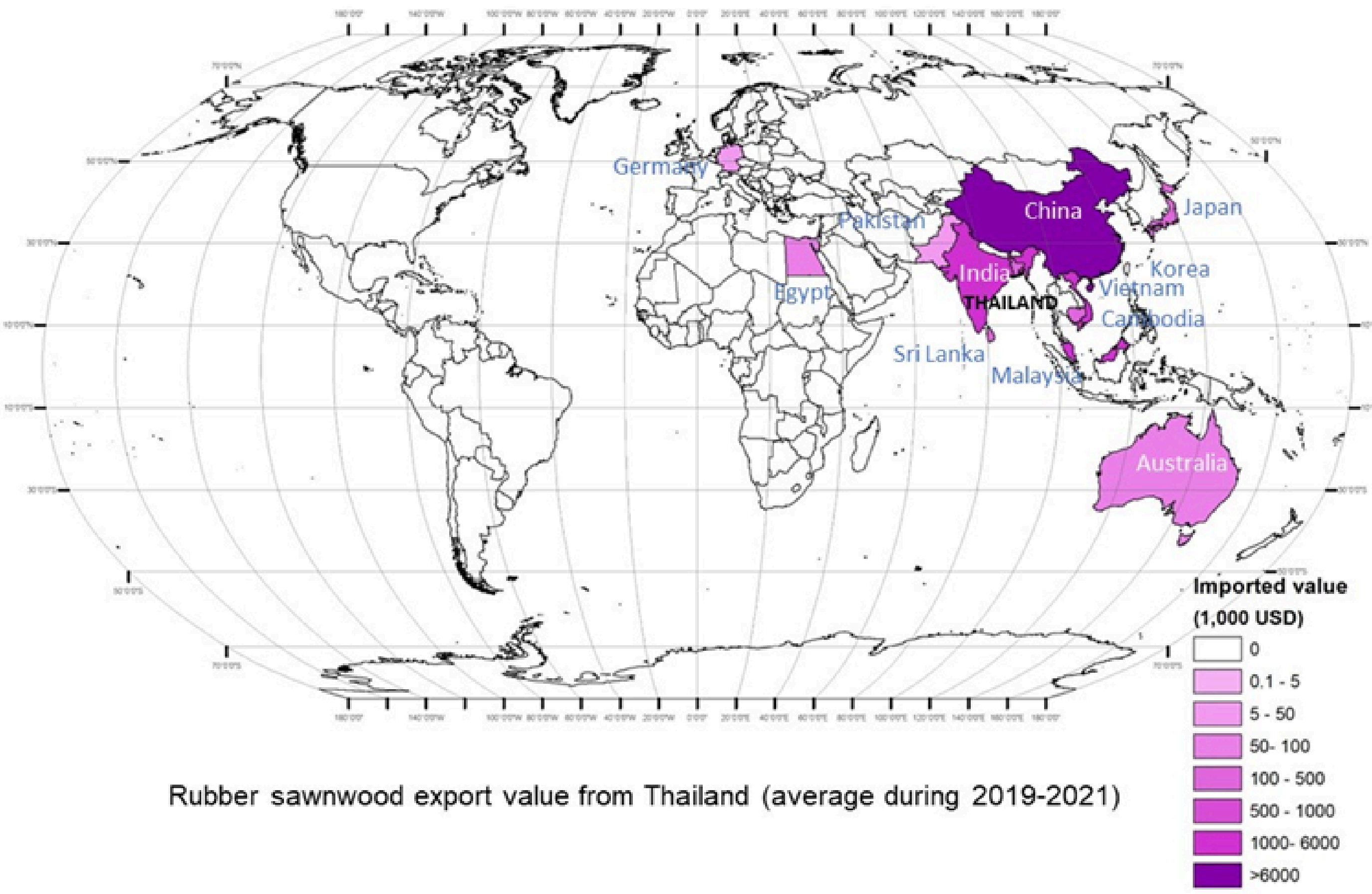
Similar to rubberwood supply chain, although a number of saw mills and lumber shops in the north and northeast similar to the south to process wood log/timber exists (Figure 22), they usually process teak and other valuable tree species. There are only limited rubberwood manufactures in northern and northeastern regions. In addition, the seaports to ship rubber products (e.g., sawn rubber wood and furniture) are far off from raw material sources. It is believed that most harvested mature rubber trees are used locally for fuelwood or other purposes. Meanwhile, over 90% of sawn wood are exported abroad, especially to China for reprocessing (Figure 33). Economically, exporting raw products such as cup lumps and sawn wood is less attractive and not economical and reduces competitiveness. The importing countries (e.g., China) can reprocess and become competitors to Thailand in global trade.

2) Fluctuation in rubber prices and uncertainty of market

Another challenge is the fluctuation in the market price of natural rubber. The price of natural rubber is highly dynamic and subject to various factors such as supply and demand, global economic conditions, and the weather. Previously, rubber price was highly related to the price of fossil fuel. Nowadays, the demand and supply of natural rubber products, and ending rubber stock play major role than the price of fossil fuel (Figure 34). This observation is noticed by the correlation coefficient between the price of natural rubber and the price of oil in Dubai. The correlation value was substantially declined from 0.76 during 2005-2011, 0.5 during 2014-2017 to 0.14 in 2021 (EIC, 2019).

Figure 33

Rubber sawn wood export value and imported countries.
Source: Office of Agricultural Economics (2023).



Although rubber plantations in Thailand gradually increases 3-4% in the last decade, the total area of rubber plantations in southern Thailand is slightly decreasing. Substantial areas of mature plantations are converted to oil palm and durian to avoid rubber price fluctuations.

Smallholders often have resilience and resources to hedge against these fluctuations, leaving them vulnerable to market shocks.
This problem is compounded by the fact that many smallholders sell their rubber to local intermediaries or brokers, who offer much lower prices than the market rate.

Their limited access to market opportunities forces them to be the most vulnerable stakeholder in the value chain. In addition, smallholders now face major attributes such as inflation and trade barriers happening globally.

3) Managing production and supply chain logistics

As discussed above, there are limited manufacturers to produce intermediate rubber products of natural rubber latex and rubber wood in the north and northeast to meet quality standards. Moreover, there are complicated permission processes and high transaction cost in supply chain logistics.

Marcel (2023) reported that informal fees accounted for up to 28.7% of the timber value for transaction cost.

Article 7 of the amended Forest Act 2019 permits landowners to cut down trees in private land and public land, which were earlier used to be listed as restricted species. However, the operators or smallholders who wish to transport wood logs is required to register their private seal with the RFD and pay transportation fee. In addition, the operators of wood processing plants (small- medium and large plants) must obtain a license from the government. At present, the factory that uses the machine greater than 50 horse-power is required to obtain a permission from the Department of Industry Works. However, it is not the case to establish a sawmill with the same capacity of machine. Individual farmers or smallholders establishing wood processing plant with the machine greater than 5 horse-power have to request permission from the RFD. Local people must submit lot of documents and paperwork to various institutes (district office, provincial forestry office, and Provincial Natural Resources and Environment Office). They have to renew the permission certificate every 6 months compared to 3-5 years period for other manufactures.

Moreover, during the COVID-19 pandemic and early stage of ending pandemic, there was containers shortage of cargo for international shipping resulting disruption in logistics and supply chain.

6.3 Consumers and Management

1) Quality products and preferences
The global COVID-19 pandemic remains a significant problem in the tropical timber trade market, and the international prices and demand of wood-based products declined substantially. There have been disruptions in supply chains, leading to limited sales of tropical timber in the global market. The ITTO Market Information Service (MIS) and Thailand's Forest Statistics reported that exports of primary wood products to international markets (e.g., Japan and EU27) in 2021 declined more than 20% compared to 2019 before the pandemic.
In contrast, the consumption of wood and wood products in the domestic markets steadily increase due to demand of residential properties development in big cities and the government's property stimulus package for buying new houses.

The Forestry Development Strategy (2017 – 2036) predicts a wood demand of 47 million tons. Rubberwood (mostly domestically sourced) supplies 87% of wood furniture production, while eucalyptus supplies a large part of Thailand's domestic pulp and paper demand. This is due to the rising population, especially the urban population from 52% at current rate to 60% by 2030), especially the young generation living in big cities.

However, the design and styles of wooden furniture produced by Thailand's smallholders or community manufactures do not match with market needs and preferences.

Therefore, the imported wood furniture has increased steadily from 79 million USD in 2012 to USD 140 million in 2020, while the export of wood furniture remains stable at USD 539 million during this period.

2) Concerns around sustainability and ethical sourcing of raw materials. Natural rubber smallholders face various environmental challenges, especially climate change and deforestation. As mentioned in the previous section (unsuitable plantation), about 1.32 million ha (8.26 million rai) are planted in natural reserves or protected areas. In addition, only 8,000 ha (50,000 rai) or 0.2% of the total plantations are certified by international standards such as Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification: PEFC). This is due to the fact that most rubber plantations are being owned by smallholders; and they cannot afford the high transaction cost of international certification. However, the smallholders are least concerned and truly aware of the benefits of forest certification and sustainable forest management (Duangsathaporn *et al.*, 2020).

Rubber products from illegal supply chains and unsustainable forest management faces a significant obstacles to the export to European countries, the United States and Japan. This is due to the fact that 82% of intermediate natural rubber latex and 70% of rubberwood products are exported too abroad.

The European Union’s ‘Deforestation Regulation’, or EUDR, came into effect on 29 June, 2023, and full implementation will begin on 30 December 2024. The imports and exports of goods in seven product categories, namely rubber, oil palm, cattle, wood, coffee, cocoa, and soya, together with derived products such as latex gloves, paper, and wooden furniture need to pass strict provenance controls and to demonstrate that production of these did not encourage the degradation of existing forests or their complete deforestation. Or in other words, it should come from sustainably managed legal sources for acceptance in Euopean markets.

Besides legal perspective, young generation usually have a wrong perception that wood is scarce and utilization of wood products either from legal or illegal sources lead to deforestation and climate change impact. This mindset and wrong understanding are stimulated by mass media, social movements on environmental activists. This leads to more use of substituted materials, including wood composite, grass, concrete, etc. that in fact create more problems to the environment.

3) Lack of coordination and poor enforcement of regulations and policies Rubber industry in Thailand is managed under three legislations, including Rubber Control Act B.E. 2542 (1999), Rubber Authority of Thailand Act B.E. 2558 (2015), and Forest Act 2562 (2019), which are under the administration of Department of Agriculture, the Rubber Authority of Thailand and the Royal Forest Department, respectively.

The Rubber Control Act B.E. 2542 (1999) provides administrative guidelines and authorize the National Rubber Policy Committee chaired by the Prime minister in which the Director-General of the Department of Agriculture acts as the secretary to implement policy and measures based on rubber information gathered from various governments and stakeholders.

The Rubber Authority of Thailand Act B.E. 2558 (2015) administered by the Rubber Authority of Thailand, which combines 3 organization under the Ministry of Agriculture and Cooperatives, including the Office of the Rubber Replanting Aid Fund, Rubber Plantation Organization and Rubber Research Institute of Thailand. This agency has overall responsibility to support rubber farmers and manufactures through the supply chains and provide replanting aid to farmers. In addition, it also aims to enhance research and development, as well as support innovations to increase productivity and competition in rubber industry. The RFD is responsible to protect and manage forest resources in a sustainable manner.

However, it is found that there is a lack of complete rubber information through the supply chains, especially rubberwood industry. The Department of Agriculture cannot enforce all rubber farmers to register and provide information. Therefore, there is no up-to-date information on rubber products (supply), and market trends available to farmers. Meanwhile, the Rubber Authority of Thailand receives limited budget and cannot provide replanting aid fund to all applicants. Knowledge on pests and disease control is lacking or not effectively disseminated to rubber farmers to control emerging diseases such as leave fall disease.

The RFD cannot effectively protect remaining forest cover. Forest encroachment for agriculture, especially rubber plantation still happens in the north and northeast regions.

Policymakers lack a decision support system and integrated and up-to-date rubber information. For example, there is variation of investment cost for rubber plantation. Thus, the government and the National Rubber Policy Committee cannot implement policies effectively such as financial subsidies and price assurance, supply and demand management.

7 POLICY RECOMMENDATIONS

In conclusion, natural rubber smallholders face various challenges that affect their productivity and profitability of rubber plantations. Addressing these challenges requires a multi-faceted approach that involves investment in research and development, access to credit, sustainable farming practices, and market access. The environmental challenges requires sustainable farming practices and investment opportunities in reforestation initiatives to protect the natural rubber supply chain and forest certification are recognized as important factors.

There is a need for collaboration with larger stakeholders and commercial operators to develop new and improved varieties/clones of rubber trees that are more resistant to pests and diseases. Smallholders need access to credit and training on modern farming practices, including sustainable farming and mechanization. Governments and development agencies can also work with smallholders to improve market access and develop value chains that provide fair prices for their rubber.

By addressing these challenges, smallholders can increase their productivity and contribute to a more sustainable natural rubber supply chain. They are attributed as follows:

1) Rubber Information Management
It is noted that the supply chains and value chains of rubber latex production from upstream industries, intermediate stream and downstream industries is almost completed. We can investigate in details for each product as shown in Figure 14. However, there are a lot of gaps for rubberwood industry supply chains. For example, the Office of Agricultural Economics has gathered information on rubber plantation since 1947 and the production of rubber yields.
In addition, the Rubber Authority of Thailand worked with Geo-informatics and Space Technology Development Agency (Public Organization) or GISTDA to develop GIS-based information on rubber plantation.
In contrast, the rubberwood supply chains are fuzzy (Figure 21). Recently, we only know information gathered from the replanting aid program of 200,000 rai or 1% of the total plantations of 23 million rai. The total stock and rubberwood processing at the upstream and middle stream industries are not estimated. In addition, there are many institutions involved in the supply chains. This lead to ineffective management and administration of rubber industry, which is heavily competitiveed by other countries, particularly in the CLMV and China.

Rubber Control Act, B.E. 2542 (1999) authorizes the Agriculture Department as the focal point to coordinate and manage rubber information under the guidance of Ministry of Agriculture and Cooperatives. It is recommended to establish the Rubber Information Management Center (RIMC). The RIMC should haves overall responsibility to gather and collect information, analyze and forecast rubber supply chains (natural rubber latex and rubberwood), and propose recommendation to the National Rubber Committee chaired by the Prime Minister to make informed decisions. The RIMC comprises representatives from various government agencies and multi-stakeholders (academia and private sectors). The RIMC will engage rubber farmers to register and provide information as well as consolidate relevant information in a Big Data for rubber industry for Thailand.

2) Promote domestic consumption
According to the statistical data, about 82% of the intermediate natural rubber products (ribbed smoked sheets, technically specified rubber, concentrated latex, compound rubber and skim rubber, etc.) and 65% of rubberwood products such as sawn wood were exported to overseas, particularly China, Switzerland, USA and Japan. The long-term strategy of Thailand has a policy to increase domestic consumption of rubber products to 30% of the total products or increase 3% annually.

In addition, several policies and measures are proposed to promote private investment in rubber processing, innovation and advanced technology, tax incentive, modern designs to meet market demands, especially involvement of young generation. Moreover, the quality of rubber products should be updated to meet the national and international standards.

3) Optimize rubber plantation areas
Rubber plantation expanded rapidly during 1990-2010 owing to the rising rubber latex prices and international demands. However, rubber was planted in unsuitable areas (1.32 million ha or 8.26 million rai) or in national reserved forests and protected areas (0.65 million ha or 4.1 million rai). Besides Thailand, rubber plantations also increased in other countries, particularly in Southeast Asia and China. The rapid expansion of rubber plantation affects global rubber price. Thus, the Thai-Government has a policy to reduce rubber plantation to 1.0-1.5 million ha. Rubber plantations in unsuitable areas or in in-legitimated areas should be replaced by other crops or economic tree species. In addition, Thai Government also has a policy to increase latex yield production from 223 kg/rai/year at the current to 360 kg/rai/year or increase about 50% from the baseline by 2036 using good quality clones such as clone RRIM 600 or RRIC 101 and adopting modern farming practices.

4) Promote rubber processing in the community

Thailand should enhance its export value and competitiveness by investing in the production of rubberwood furniture and other rubberwood-based products rather than relying mainly on raw rubberwood exports. Thailand has been a major exporter of raw rubberwood, but the percentage of rubberwood furniture export value remains relatively small when compared to Malaysia, which does not export raw rubberwood. For example, Thailand exported raw rubberwood (sawn wood, veneer, plywood, fiber board), which accounted 80% in 2019 and 85% in 2021, while processed products and furniture products accounted less than 20% of the total export value (Ministry of Commerce). EIC of Siam Commercial Bank reported that wooden furniture price 4,091 USD/ton) has 10.7 folds of sawn rubberwood (383 USD/ton).

Malaysia is the world’s 7th largest producer and 8th largest consumer of natural rubber in the world. Malaysia is a major importer of natural rubber from Thailand, as most Malaysian-grown natural rubber goes to tire applications. For the rubberwood sector, around 90 to 95% of rubberwood goes towards the furniture segment in Malaysia. This segment accounts for 70 to 75% of the rubberwood sector of export value. Since 1990 Malaysia has continually focused on developing its rubberwood furniture export market. Today, furniture accounts for 30% of the country's wood products export, while timber, previously its major product, now make up only 10% of wood products exports.

5) Price assurance

Rubber prices fluctuated during the last two decades ranking from 160 baht/kg (4.5 USD/kg) in 2011 to less than 1 USD/kg in 2021. Previously, rubber price was highly related to the price of fossil fuel. Nowadays, demand and supply of natural rubber products, and ending rubber stock play major role than the price of fossil fuel.

The average investment costs to produce cup lump, latex and rubber sheet are 44.2, 52.5, and 55.3 baht/kg. The average value of rubberwood with a 25-year-old cycle (45 m3/rai) is about 40,000 baht/rai, However, majority of smallholder avoid direct commercialization due to extensive administrative burdles and transaction costs incurred to obtain a harvest and transportation permits. They usually sell rubberwood to middleman with the average price of 8,000 baht/rai. Hence, selling rubberwood is not the main income for rubber farmers, but additional benefit. It is proposed that the National Rubber Committee may establish rubber price assurance to minimize rubber price uncertainty.

6) Sustainable forest management and certification

Besides price competition from other countries for the export of rubber wood products, which are again related to price and market competitions. Thailand is also facing a significant obstacle to the export of rubber wood products to European countries, the United States and Japan. This is due to the fact that only 8,000 ha (50,000 rai) or 0.2% of the total plantations are certified by international standard such as

Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification: PEFC). However, 82% of intermediate natural rubber latex and 70% of rubberwood products are exported abroad.

Moreover, the European Union's 'Deforestation Regulation', or EUDR, came into effect on 29 June, 2023, and full implementation will begin on 30 December 2024 will have impacts on Thai rubber suppliers particularly companies involved in the processing or export of rubber, wood, and oil palm. These impacts will include: (i) higher costs for both manufacturers and exporters connected to reporting and supply chain checking and verification; (ii) the possible loss of competitiveness for smaller players if they cannot meet the EUDR requirements; and (iii) the gradual exclusion of Thai players from manufacturing supply chains and the diversion of global investment flows away from Thailand, if the country is classified as high risk by the EU.

Thailand can adequately prepare and adapt, particularly in the development of data collection and tracking systems for supply chain traceability, effective enforcement of environmental, social, and governance laws, as well as the support for sustainable production standards among farmers and business owners, particularly SMEs.These adaptation measures will open up opportunities for trade and investment in the European Union and throughout a wider participation across the global production chain.

Moreover, it will contribute to elevating forest conservation efforts, aligning environmental and social policies within the country that are pushing forward with the increasing global sustainability trends. Moreover, Rubber Authority of Thailand with the support of Thailand International Standard (TIS) is implementing pilot project aiming for Thailand Forest Certification System (TFCS or TIS14061) and Chain of Custody (TIS2861), covering 200,000 rai or 32,000 ha (1% of the total plantations) in 7 provinces in southern Thailand, including rubber manufacturers in these provinces. It is noted that TIS became an official member of PEFC in 2016.

To facilitate the understanding of smallholders and relevant agencies, a manual of certification should be developed, including 1) FSC definition, 2) FSC scop, 3) FSC evaluation and surveillance, 4) FSC scop assessment, and 5) implementation in accordance with FSC standards. In fact, the RFD and ITTO already developed criteria and indicators of sustainable forest management for smallholder plantations and community forest in Thailand (RFD/ITTO, 2019). The proposed criteria and indicators meet the minimum requirements of sustainable forest management. It is strongly recommended that the RFD and the Rubber Authority of Thailand can adopt and use this guideline for national certification.

REFERENCES

Ahrends *et al*. 2015. Current trends of rubber plantation expansion may threaten biodiversity and livelihoods. *Global Environmental Change* 34 (2015) 48–58.

Arias, M. and van Dijk, P.J. 2019. What Is Natural Rubber and Why Are We Searching for New Sources Front. Young Minds. 7:100. doi: 10.3389/frym.2019.00100

Azizan, F.A., Astuti, I.S., Young, A. Aziz, A. 2023. Rubber leaf fall phenomenon linked to *increased temperature. Agriculture, Ecosystems & Environment*, Vol. 352, 108531, ISSN 0167-8809, https://doi.org/10.1016/j.agee.2023.108531.

Chee, K.H. 1969. Leaf fall due to *Phytopthora botryosa*. *Planters' Bulletin* 104, 190-198.

Dean, W. 1987. Brazil and the Struggle for Rubber. Cambridge University Press, Cambridge, UK.

Department of Climate Change and Environment, 2023. Thailand's National Adaptation Plan (NAP). Ministry of Environmental and Natural Resources. Bangkok.

Duangsathaporn, K., Prasomsin, P., Omule, Y., Palakit, K. and Lumyai, P. 2020. Development of a manual for rubber plantation owners and rubber wood consumers in Thailand for obtaining international forest management certification. The International Conference on Materials Research and Innovation (ICMARI). doi:10.1088/1757-899X/773/1/012050

Economic Intelligence Center. 2022. Rubber Industry. Business and Industry Trends. Krung Sri Research, Bank of Ayudhya. Bangkok.

Fabriani, F. and Hills, R. 2020. Hevea brasiliensis. *The IUCN Red List of Threatened Species*. p.e.T62003521A62003529. Retrieved 28 October 2022.

Faksomboon, F., Phunlao, B., Buasruang, S. 2019. Response of Land Use Patterns on Soil Erosion and Organic Matter in Khlong Lan Watershed Area Kamphaeng Phet Province. *Journal of Science and Technology*. 6(2). July – December 2019.

Forest Planning Division. 1984. Para rubber growth rate. Royal Forest Department, Bangkok.

Fox J., Castella J.C., 2013. Expansion of rubber (*Hevea brasiliensis*) in Mainland Southeast Asia: What are the prospects for smallholders *Journal of Peasant Studies* 40 (1), 155-170. http://dx.doi.org/10.1080/03066150.2012.750605

Guyot, J., Guen, L. Vincent. 2018. A Review of a Century of Studies on South American Leaf Blight of the Rubber Tree. *Plant Disease. American Phytopathological Society*. 102 (6): 1052–1065. doi:10.1094/pdis-04-17-0592-fe. ISSN 0191-2917. PMID 30673445

Hevea brasiliensis (*Willd. ex A.Juss.*) Müll.Arg. *Plants of the World online. Kew Science*. Retrieved 31 March 2017.

Huang, C., Zhang, C. and Li, H. (2022). Assessment of the impact of rubber plantation expansion on regional carbon storage based on time series remote sensing and the invest model. *Remote Sensing*, 14 (24), 6234.

Hytonen, J., Nurmi, J., kaakkurivaara, N. and Kaakkurivaara, T. 2019. Rubeer tree (*Hevea brasiliensis*) biomass, nutrient content, and heating values in Southern Thailand. *Forests*. 10, 638; doi:10.3390/f10080638.

IPCC, 2008. Climate change 2007. Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report. *In*: Pachauri, R.K., Reisinger, A. (Eds.), Intergovernmental Panel on Climate Change (IPCC), Geneva-Switzerland, p. 104.

Ismail, F. and Grunder, J. 2020. The future of SA-UK trade in a post-Brexit world. *South African Journal of International Affairs*, 27(2), 131-146.

ITTO. 2023. Prices for rubberwood imports into China from Thailand falling. Panels and Furniture Asia. https://panelsfurnitureasia.com/prices-for-rubberwood-imports-into-china-from-thailand-falling/

Jong, Y. W., Beirne, C., Meunier, Q., Biyogo, A. P. M., Mbélé, A. E., Stewart, C. G., & Poulsen, J. R. (2021). Expected carbon emissions from a rubber plantation in Central Africa. *Forest Ecology and Management,* 480, 118668.

Khamkajorn, T., Pansak, W., Takrattanasaran, N. and Homhuan, W. 2014. Erosion in Hillside Para Rubber Plantation of Northern Thailand as Affected by Soil Conservation Measures: A Case Study. Conference: ICC Jeju, Korea

Kou, W., Xiao, X., Dong, J., Gan, S., Zhai, D., Zhang, G., ... and Li, L. 2015. Mapping deciduous rubber plantation areas and stand ages with PALSAR and Landsat images. *Remote Sensing*, 7(1), 1048-1073.

Land Development Department. 2011. Extent of suitability classes of planted rubber. Ministry of Agriculture and Cooperatives, Bangkok.

Langenheim, J.H. 2010. Introduction to Rubber Usage among the Maya. *Maya Archaeology*. Retrieved 29 May 2017.

Maggiotto, S. R., Oliveira, D. D., Marur, C. J., Stivari, S. M. S., Leclerc, M., & Wagner-Riddle, C. (2014). Potential carbon sequestration in rubber tree plantations in the northwestern region of the Paraná State, Brazil. *Acta Scientiarum. Agronomy*, 36, 239-245.

Neyret, M., Robain, H., Rouw, A.D. Janeau, J.L., Durand, T. Kaewthip, J., Trisophon, K. and Valentin, C. 2020. Higher runoff and soil detachment in rubber tree plantations compared to annual cultivation is mitigated by ground cover in steep mountainous Thailand. *CATENA*, Volume 189, 104472. https://doi.org/10.1016/j.catena.2020.104472

Office of Agricultural Economics, 2022. Agricultural Statistic 2022. Ministry of Agriculture and Co-operatives, Bangkok.

ONEP. 2020. Thailand’s Updated Nationally Determined Contribution. A report submitted to UNFCCC Secretariat. Office on Natural Resources and Environmental Policy and Planning, Ministry of Environment and Natural Resources, Bangkok.

Ong, S.H., Othman, R. and Benong, M. 1998. Breeding and selection of clonal genotypes for climatic site stress condition. In M.E. Cronin (Ed.). *Proc. IRRDB Symp. Rubber: General, Soils and Fertilizer, and Breeding and Selection* (pp. 149-154). IRRDB, Herford, U.K.

Phisanwanicvh, A. 2021. Optimal investment cost for rubber plantation in Thailand. The Center for International Trade Studies. Thai Commerce University, Bangkok.

Preechapanya, P. and Tangtham, N. 1973. Soil and water losses from agroforestry systems: a case study of coffee plantation under hill evergreen forest at Doi Pui, Chiengmai Province. Royal Forest Department and Kasetsart University, Bangkok.

Phuc, T. X. and Nghi, T. H. 2014. Rubber expansion and forest protection in Vietnam. *Tropenbos International Viet Nam*: Hue, Vietnam.

Phukaoluan, C. 1988. Rubber wood and national security. Dissertation of National Security Academy. Ministry of Defense, Bangkok.

Priyadarshan, P. M. 2011. *Biology of Hevea rubber* (pp. 1-6). Wallingford, CABI, UK.

Ratnasingami, J., Ramasamyi, G., Ioras, F., Kaner, J. and Wenming, L. 2012. Production Potential of Rubberwood in Malaysia: Its Economic Challenges. *Not Bot Horti Agrobo*, 40(2): 317-322.

Research and Rubber Development, 2023. Rubber plantation situation. *Para Rubber Bulletin* 43 91): 22-31.

RFD/ITTO. 2019. Thailand criteria and indicators for sustainable management of planted forests and community forests. Royal Forest Department, Bangkok and International Tropical Timber Organization, Yokohama.

Royal Forest Department. 2023. Annual Forest Statistic Report 2023. Ministry of Natural Resources and Environment, Bangkok.

Royal Forest Department. 2018. The Forestry Development Strategy 2017 – 2036 (B.E. 2560-2579). Ministry of Natural Resources and Environment, Bangkok

Rubber Research Institute of Thailand. 2010. Thailand rubber statistics. (Annual report). Ministry of Agriculture Bangkok, Thailand, 39(2), 29

Rubber Research Institute of Thailand. (2012). Standard growth rate of rubber tree. Ministry of Agriculture and Cooperatives, Bangkok.

Saengruksawong, C., Khamyong, S., Anongrak, N., & Pinthong, J. (2012). Growths and carbon stocks in rubber plantations on Chakkarat soil series, Northeastern Thailand. *Journal of Science and Technology*, 19 (4), 271-278.

Shigematsu, A., Mizoue, N., Kajisa, T. and Yoshida, S. 2011. Importance of rubberwood in wood export of Malaysia and Thailand. *New Forests*, 41, 179-189.

Strahler, A.N. 1969. Physical geography, 3rd ed. Wiley, New York.

Sungsingh, K. and Phumchai, T. 2022. Monitoring leaves fall disease using Geo-informatic technology. *Para Rubber Bulletin* 43(1). 2-11.

Sungsingh, K. and Prommee, W. 2010. Comparison of rubberwood production, quality and characteristics from normal extraction and combination with Ethylene. E*lectronic Para Rubber Bulletin* (1): 10-15.

Tekasakul, P. and Tekasakul, S. 2006. Environmental Problems Related to Natural Rubber Production in Thailand. *Journal of Aerosol Research* 21. DOI: 10.11203/jar.21.122.

Trisurat, Y., Shrestha, R. and Havmoller, P.(eds.). 2018.Thailand: Environmental natural issues and related policies. Nova Publishers Inc, New York.

Tsao, P.H., Kasim, R. and Mustika, I. 1985. Morphology and identity of black pepper Phytophthora isolates in Indonesia. Food and Agriculture Organization of the United Nations (FAO). *Plant Protection Bulletin*, 33, 61–66.

Watson, G. A. 1990. Tree crops and farming systems development in the humid tropics. *Experimental Agriculture,* 26(2), 143-159.

Yongdong, Z, Mingliang, J., Ruiqing, G., Xiaoling, I. 2007. Rubberwood Processing manual, FC/ITTO/72 PD103/01 Rev.4 (I). "Demonstration of Rubberwood Processing Technology and Promotion of Sustainable Development in China and Other Asian Countries". Research Institute of Wood Industry Chinese Academy of Forestry, Beijing, China.

ITTO Project :
"PROMOTION OF SUSTAINABLE DOMESTIC CONSUMPTION OF WOOD PRODUCTS IN THAILAND"
(PD 926/22 Rev.1 (I))

RUBBER
SUPPLY CHAINS IN THAILAND

JAPANGov
The Government of Japan

MAFF
Ministry of Agriculture, Forestry and Fisheries

ISBN 978-616-278-843-7