FROM JUNGLE RUBBER TO RUBBER AGROFORESTRY SYSTEMS

History of Rubber Agroforestry Practices in the World

Éric Penot, editor

éditions Quæ

Chapter 4

Expectations of RAS, impacts and contribution to current's main challenges in 2024

Éric Penot, Bénédicte Chambon, Alexis Thoumazeau, Phillipe Thaler

Like all other commodities, rubber plantations have less rich biodiversity than natural forests. Both forest degradation and deforestation cause loss of biodiversity (Jongrungrot et al., 2014; Fern, 2018; Peerawat et al., 2018). According to Orozco and Salber (2019), the expansion of industrial plantations also increases pressure on animal biodiversity in non-degraded forest located on the margins of plantations and can disturb wildlife corridors used by primates or elephants.

However, the impact of the expansion of rubber plantations differs depending on (i) the previous land use, and (ii) the current cropping system. For instance, agroforestry rubber plantations can have a positive effect on biodiversity when planted following monoculture (Feintrenie and Levang, 2009; Penot and Ollivier, 2009; Jongrungrot et al., 2014; Penot and Feintrenie, 2014; Fern, 2018).

⏩ Agroforest cropping systems provide miscellaneous goods and services

Multiple roles

Farmers worldwide, but especially in developing countries, do not only focus on agricultural production. While they are seldom sensitive to global issues such as biodiversity conservation or carbon sequestration, as opposed to their own family priorities, they nevertheless contribute a series of "goods and services" that are not always marketed or even recognised. The multi-functional role of agriculture is now acknowledged and promoted in some parts of the world (e.g. in Europe) in reaction to "productivist" agriculture, and has enabled the reduction of direct subsidies for production in favour of paying subsidies for the environmental functions of farms.

Agroforests can fulfil this multi-functional role better than other cropping systems because they have more positive externalities than land-use options based on monocrops. Agroforests, consequently, merit tailored economic analyses to account for both goods and environmental services as well as short- and long-term issues.

Agroforests, particularly home gardens, generally combine a long-term strategy for the production of resin, nuts, fruits and timber, for instance and annual or bi-annual food crops such as legumes, cassava, banana, with short-term products for immediate consumption. Farming systems models can include components on externalities or services to analyse this multifunctionality, but some components including biodiversity conservation may be easier to treat at regional or macro level. While so far, priority has been given to plant biodiversity, some studies have pointed to the role of agroforests as buffer zones for game (Nyhus and Tilson, 2004).

Another important role of agroforests is the production of a "forest rent" as defined by Ruf (1995a), i.e., a reduction in the cost of – and risks involved in – establishing a perennial plantation thanks to the positive externalities provided by forests, such as preserving or improving soil quality, controlling weeds and pests. The "forest rent" concept was extended to agroforests by Penot (2001), based on the fact that agroforests have similar attributes. Among other functions, agroforests do maintain (and sometimes improve) the forest rent whereas conventional monoculture plantation crops (cacao, coffee, oil palm), generally –at least partially– consume it. Therefore, when the time comes to renew plantation crops in an agroforest, economic sustainability is favoured because the cost of establishment is similar to that of replanting after a forest.

On the other hand, agroforests also have certain constraints. Crop mixtures being the rule, some crops are favoured while others are not. Agroforests sometimes provide such small yields of a particular crop that it can only be sold locally. The period before associated trees may produce a yield will increase the length of the wait before the farmers receive a return on their investment, and this is even more true for timber. Most smallholders use unimproved genetic planting material which may be of questionable quality, particularly in the case of fruits that may be not suitable for export. Most agroforests are extensive, and rely only on family labour, but some –including RAS– could be made more intensive by applying fertilisers during the immature period to improve growth and reduce the length of the immature period of the main crop, as well as by using improved planting materiel (coconut trees, rubber clones, selected grafted durian and grafted fruit trees, for instance).

Agroforests are particular cropping systems with a range of specifications which makes them more difficult to analyse than monocropping systems or even than multiple cropping systems comprised of associations of annual crops. It is hypothesised that this lack of analysis has made it difficult for agronomists and extension agents to promote agroforests and has prevented research on agroforests going beyonddescriptive studies to become truly analytical (Penot, 2001; Kumar and Nair, 2004).

Plant biodiversity in RAS

Planted biodiversity

By essence, RAS host higher planted biodiversity than monoculture rubber plantations due to the large number of associated trees and plants. Moreover, monocrop plantations mostly contain very few clones. Where estates tend to use up to a dozen different clones in their large plantations, smallholder plant only a few clones, usually only one (Clément-Demange et al., 2007). Moreover, one clone tends to dominate in any given country, in which case, intra-rubber biodiversity may also be very reduced.

For example, according to RAOT, in Thailand, 95% of the total area under rubber is planted with clone RRIM600. Rubber tree intra-diversity is extremely limited in such systems. In this case, any association with another planted species increases total plant biodiversity. The most diverse systems are traditional "jungle rubber" systems (see details in chapter 1). In their basic form, they are indeed secondary forests enriched in rubber seeds. Hence, in Indonesia, to give an example, their plant biodiversity is almost 60% of that of natural forests. In other words, only natural forests can be richer. However, jungle rubber systems have tended to be replaced by other land uses, including rubber monoculture, because of their low productivity. Clonal RAS have intermediate plant biodiversity. Although some RAS systems (e.g. RAS 1) could theoretically host the same plant biodiversity as traditional jungle rubber at least in the inter-rows because they consist in rows of monoclonal rubber trees planted in secondary forest, in practice, they probably host fewer plant species than jungle rubber, as most species are partially weeded out at least once during their life span.

As explained in chapter 2, the composition of RAS in Indonesia varies widely. Some RAS are extremely complex, and may include more than 20 cultivated plant species, but some include only one. Thus, RAS in itself does not ensure plant species richness, which depends on the pattern chosen by each farmer. The type of plant that can be intercropped in RAS depends on the rubber planting design and density. If, as in most cases in Thailand, the standard row pattern is used (6-7 m between rows, 2.5-3.5 m between the trees in a row, i.e., a density of 450-600 trees/ha), only shade tolerant species can be permanently intercropped. These are usually perennial fruit trees, shrubs that provide leafy vegetables (*Gnetum*) or fruit trees, or alternatively, semi-perennial species like banana and bamboo (Jongrungrot et al., 2014; Stroesser et al., 2018). Tall timber trees can also be included in this type of design. These trees are usually shade tolerant species that are planted in the rubber inter-row some years after the rubber trees to avoid too much competition with the rubber trees they will eventually overtop (Wu et al. (2016) on below-ground interspecific competition for water; Yang et al. (2020) on intercrops and surface water availability improvement; Zhao et al., 2023; Zhu et al., 2019).

An interesting option was proposed by Langenberger et al. (2017): planting endangered forest tree species, preferably of local/regional origin, in normally spaced rubber tree plantations, with financial support from conservation agencies. A similar idea was developed in Sabah, Malaysia, with on-farm trials with oil palm and local riparian forest species to create biodiversity corridors for endangered local animal species. This project, called the "Trails" project[66], was implemented on a private estate. Such schemes would have a remarkable impact on high-value tree biodiversity. Double-row spacing is also possible in RAS to provide more space (up to 25 m) between the rows of rubber trees, which themselves are often planted in double or triple rows. In such cases, because more light is available, more species can be grown, including annual crops such as maize or rice, or perennials such as coffee, cocoa, or tea (as is already the case in Sri Lanka, Penot et al., 2023a).

Niche effect and management

Beyond the direct increase in biodiversity obtained by planting other species with rubber, the complexification of the ecosystem can host additional plant species such

---

[66] Trails: climaTe Resilient lAndscapes for wIldLife conservation.

as epiphytes that can grow on the associated species. Palm trees in particular often harbour ferns and are known to provide favourable conditions for epiphytes (Bekuma et al., 2007). Associating shrubs like pakliang (*Gnetum*) with rubber, like in Thailand, also probably favours the development of understorey vegetation as does monoculture with other non-productive shrubby vegetation. A network of plants of different heights would ensure a connection between the ground and the rubber tree canopy. In turn, this would provide habitats for other organisms (microorganisms, mesofauna, etc.) paving the way for restoring richer ecosystems on rubber farms. These aspects require further study. Conversely, wider spacing between rubber rows creates heterogeneous environmental conditions in a given plot, which also favours biodiversity, with plant species adapted to varying degrees of shade (Jongrungrot et al., 2014).

Whatever the type of plantation, the way it is managed has a fundamental impact on plant biodiversity. In practice, in RAS, some crops are intensively managed including pesticide use and tillage, but rubber monocrops can be lightly managed, particularly after canopy closure. When crops are permanently associated with rubber, typically in alley systems, the natural understorey can be seriously limited by the agricultural practices applied to the associated crops. Manual or chemical weeding can affect a more extensive area in RAS than in monocrops, where only the vegetation growing along the rubber tree rows is controlled. It is not rare to see the whole surface of the plot "cleared" of natural vegetation in RAS. In such a system, plant diversity is obviously very low. Conversely, many farmers, notably those living in traditional areas, use very limited weed control, and let natural vegetation grow almost freely in the inter-rows. They only "clear" a strip of land along the row of rubber trees to facilitate the task of the tappers. In this kind of monoculture system, plant biodiversity can be quite high. Indeed, Panklang et al. (2022a) found either land covered by profuse natural vegetation or almost bare soil in the 4 rubber systems they compared: monoculture rubber, shrub RAS, fruit-tree RAS and timber RAS. This confirms that management (i.e. the farmers' practices), rather than the system per se (RAS vs. monoculture) limits or adds to plant biodiversity in rubber plantations.

Animal biodiversity

Association with cattle and poultry

Livestock is seldom included in RAS. The presence of a large number of big animals (cows, buffalos, or even pigs) hardly seems compatible with rubber cropping, as they pose a risk for the tapping equipment, if not for the trees themselves. This kind of husbandry is consequently usually limited to letting few animals graze close to homestead. Poultry (chicken or ducks) are more common in rubber plantations and may represent one of the main activities of some farmers. However, the surface area concerned remains limited. Creating fish ponds between the rubber rows is also possible, but rare. On the whole, animal husbandry cannot be considered to have a significant influence on animal biodiversity in RAS.

Habitat for insects, arthropods, birds, wild mammals and reptiles

Several studies have shown that the presence of birds in rubber monocrop plantations is very limited. In studies in which bird life is considered to be an indicator of natural biodiversity, rubber plantations score very poorly. The main reasons are that the fruits and seeds produced by rubber trees are basically inedible for birds (Bekuma et al., 2007) and the structure of rubber tree canopy is not suitable for nesting, at least when the standard planting design and density are used (Putri et al., 2020). In this context, including fruit trees or shrubs can have a very positive effect on insect and bird populations, both in terms of diversity and number. Warren-Thomas et al. (2020) found that agroforestry had a positive effect on butterflies, but not on birds in southern Thailand. For the same reasons, rubber plantations do not offer a very favourable habitat for mammals. However, as rubber plantations are often located on forest margins, roaming elephants are not rare and may damage the trees. In the 1990s, many trial plots included in the SRAP research project in Jambi were also damaged by local monkeys, as forests were still extensive in the area.

In regions where some forest remains or where there are national parks, the co-existence of wild elephants and agriculture is an increasing problem, as is the case for instance in the RLU (Royal Lestari Utara/Michelin) plantation in Jambi province in Indonesia because the plantation is located close the "Bukit Tigapuluh" national reserve. As food for elephants is freely accessible in RAS, vegetal biodiversity attracts these animals and RAS are considered to be more at risk than monoculture. In young RAS, elephants not only eat the associated crops, but sometimes uproot the rubber trees, for no obvious reason (Penot, personal observation in Gabon). Snakes, in particular arboreal species such as cobras or mambas are common in the rubber canopy. Like for birds, the association of rubber with fruit trees or shrubs is favourable for mammals and reptiles, with fruit eating species in turn becoming prey for other predators. The food web is improved when species of different height and size are associated and create a more complex and better connected habitat for the fauna. However, for the reasons explained above, RAS will not necessarily enrich wildlife when only a few plant species are associated and "harmful" practices are used such as spraying insecticides or herbicides. Rubber monocrops also provide an appropriate habitat for wildlife when the natural vegetation in the inter-row is only lightly controlled. According to the farmers, the presence of dangerous species such as venomous snakes or insects in dense and high understorey is the main reason for more intensive weeding in rubber plantations.

Considered as a whole, plantations provide connections with surrounding ecosystems. Deforestation affects wildlife not only directly through the destruction of habitats, but also indirectly due to fragmentation of the forest. When portions of forest are fragmented by a rubber plantation, the connectivity between the remaining patches of forest can be disrupted, since, as shown above, rubber monocrops offer few food resources and opportunites for shelter. RAS in general, and particularly the most complex ones, are thus considered to favour ecosystem connectivity.

⏩ Impact on soils

Including crops/trees between the rows of rubber trees can improve soil health. Several multi-criteria studies focussed on soils have underlined the positive effects of associated crops on soil systems (Chen et al., 2017; Zhu et al., 2019a). The choice of associated species can also have different impacts on the soil, as reported by Chen et al. (2017). It is thus important to take the soil characteristics into account when designing RAS. Several soil ecosystem services can be affected by RAS, and several soil processes/components are discussed below.

Erosion

Rubber cultivation can also have negative effects on soil quality, particular when the soil is bare, and soil erosion can be severe in the rainy season. The main drivers of soil loss in plantations are applying herbicides and removing understory vegetation (Liu et al., 2016). The efficiency of the increased soil cover under agroforestry has been demonstrated (Liu et al., 2017). Diversification combined with proper understorey management is thus an efficient way to limit soil losses. On the other hand, multiplying the number of cycles of rubber cultivation in monoculture has been shown to have negative effects on soil fertility – at least, this has been demonstrated in the third cycle (Panklang et al., 2022b). The serious disturbance of the soil that happens during planting also results in soil loss. Fewer disturbances after planting combined with protecting the soil with cover crops can help to reduce soil loss during the rubber immature stage (Hu et al., 2023).

Water cycle

Similar problems are frequently mentioned concerning water resources (IUCN, 2011; Guardiola-Claramonte et al., 2010; Hauser et al., 2015; Fern, 2018; Higonnet et al., 2019). In rubber monoculture (particularly when it replaces natural forest), disturbance of the hydrological cycle and use of agrichemicals are responsible for surface water pollution. There are obviously significant differences between cropping systems, particularly between monoculture and agroforestry. Firstly, the use of chemicals has a major impact, and as a matter of fact, the majority of rubber plantations (whether or not under agroforestry) do not really need fertilisers or pesticides during the mature period as nutrient exports are very low. Secondly, according to Penot and Ollivier (2009), Jongrungrot et al. (2014) and Fern (2018), complex agroforestry systems like jungle rubber have less impact on water and soil quality (and hence on erosion and fertility) than most simple agroforestry systems, in particular, than monocropping.

Nutrient availability

In addition to possible effects of crop associations on the water cycle, nutrient cycles may be affected by diversification. The nutrient requirements of each of the associated crops need to be evaluated to avoid nutrient deficiencies and hence reduced yields. Research only recently identified the exact nutrient requirements of rubber (Chotiphan et al., 2019; Vrignon-Brenas et al., 2019). However, associations with other crops under rubber agroforestry systems may alter the nutrient balance and, depending on which species of trees are associated with rubber, nutrient availability may also be affected (Wu et al., 2020), and can lead to nutrient deficiency in the main crop, in this case rubber. Zhao et al. (2023) reported that using several intercropped species had a negative impact on the soil nutrient status and resulted in a shortage of phosphorus. The design of the RAS should thus account for the number of species, their functional role and their needs in order to avoid depending on fertilisation to overcome competition for nutrients among plant species.

Carbon storage in soils

Rubber is the only crop recognised by the Kyoto protocol for its carbon storage capacity (Penot and Ollivier, 2009). Indeed, in certain conditions, for instance, when rubber trees are planted on cleared land or to replace another crop, rubber plantations can store carbon. However, according to Hauser et al. (2015), these cases are rare, and the balance is more often negative when monoculture rubber plantations replace primary forest, secondary forest or even swidden cultivation. Rubber agroforestry systems are more virtuous in terms of carbon storage because they contain more trees per ha (Penot and Ollivier, 2009; Jongrungrot et al., 2014; Penot and Feintrenie, 2014).

Real impact of rubber agroforestry on soils?

Soils can also be restored after 40 years of rubber by using good management practices (Perron et al., 2022; Brauman and Thoumazau, 2020) in the absence of agroforestry practices. The impact of the practices is what counts for soil conservation

Soils can store a large quantity of carbon thereby mitigating the effects of climate change. The effect of land-use change on soil organic carbon (de Blécourt et al., 2013) and the evolution of soil carbon stocks in rubber tree stands (Blagodatsky et al., 2016; Sun et al., 2017) are widely described in the literature. Agroforestry practices are considered promising ways to increase soil carbon stocks (Albrecht and Kandji, 2003), but the results of experiments on rubber agroforestry systems are still limited. Esekhade and Okore (2012) reported an increase in soil organic carbon during the immature stage in a study in which rubber was associated with banana. Increased carbon sequestration has also been reported in the rubber mature stage when certain tree species are associated with rubber (Li et al., 2020; Wu et al., 2020). The increased carbon inputs thanks to litter and via roots which are an integral part of the RAS system can thus increase soil organic carbon in rubber plots. In addition to crop associations, proper management of the understorey vegetation can also help build soil carbon stocks (Ren et al., 2023).

Soil biodiversity

Soils are one of the main reservoirs of biological diversity. Soil organisms probably represent around 25% of all species described worldwide. Such diversity is critical to sustain soil health and related ecosystem functioning including nutrient cycling, the transformation of organic matter, provision of physical support for micro-organisms (Bardgett and van der Putten, 2014). Soil biodiversity not only depends on a large number of organisms, the roles played by the organisms are critical in maintaining soil function. Increasing aboveground diversity through agroforestry systems has been highlighted as a key to fostering soil biodiversity, particularly in agroforests compared to croplands (Marsden et al., 2019). In the case of rubber agroforestry, the effects of increasing the number of planted species in this perennial-based system have been less studied than other components such as soil water and nutrient availibility. In their study, which focussed on the abundance of bacteria and/or fungi, Tongkaemkaew et al. (2018) found no difference in soil macrofauna between monoculture and RAS in South Thailand.

In mature plantations, Wang et al. (2017, 2020) and Jessy et al. (2017) showed that the microbial communities increased under RAS with certain associated crops. This increase in microbial abundance builds a more resilient system and may help to counteract the negative effects of rubber monoculture, e.g., acidifiction and nutrient depletion (Liu et al., 2019). However, other factors have been identified as being more important in explaining changes in soil diversity than which crops are associated with rubber. Management practices such as the use of chemical inputs or the management of understorey vegetation explain the differences in soil biodiversity better than the the fact of associating a particular crop with rubber (Liu et al., 2021; Therumthanam et al., 2014).

⏩ Adaptation to climate change

Agroforestry is considered to be one of the best alternative cropping systems for adaptation to climate change based on three main assumptions: (i) plant diversification within a plot can mitigate the risk of damage caused by climate change, as different species differ in their reaction to a given climatic event. Next, the likelihood of having one or several species that are tolerant or resistant to the given stress is higher than with a monocrop. Similarly, the probability for the ecosystem to recover (resilience) is considered to be higher in a diversified system; (ii) agroforestry can mitigate some of the effects of climate change, particularly the increase in temperature, at the microclimate scale as trees provide shade for understorey crops; (iii) multilayer vegetation can protect the ecosystem from extreme events, which will be more frequent in future, because several layers of vegetation protect the soil from erosion more efficiently, while trees protect smaller plants from strong winds.

However, in RAS, such positive effects often remain theoretical, as literature on the topic is sparse and because certain effects may be complex and have unintended consequences.

Plant diversification for risk mitigation

The susceptibility of different species to different kinds of climate stress may improve tolerance to future climate change, although this is difficult to demonstrate. Future predicted events including higher mean and extreme temperatures, more frequent and intense drought events, irregular rainfall patterns including more frequent rainstorms, will certainly affect all the crops that are usually planted in rubber growing areas. One possible mitigation factor is that the different crops used in RAS display varying degrees sensitivity to a given form of climate stress. For example, one species could be more sensitive to direct heat and another to soil drought, meaning there is less risk that all the plants in a given plot are affected by a given event. This is linked to asynchronous development of different plants, as sensitivity to climate stress depends on the phenological stage. To give but one example, rubber trees would be strongly affected by a heat wave during the leaf growth period early in the season, whereas fruit trees would be more sensitive during the fruit growth period, which comes later.

Direct environmental effects

Micro-climates: rubber trees provide shade for other crops

Using trees to shade crops reduces direct sunlight and hence the reduced temperature beneath the canopy is a widely used strategy in several RAS, as already well documented in coffee or cocoa agroforestry systems. Up to now, the shade provided by rubber has been too strong and has had negative effects on coffee or cocoa yields and so the association has not been recommended unless the inter-row is enlarged. However, with the continuing increase in temperature due to climate change, the need to reduce it could increase in parallel. Breeding for such systems should aim at developing shade-tolerant varieties of the associated crops on one hand, and rubber clones adapted to the association in question, on the other hand. However at the time of writing (2023), the required breeding criteria have not yet been clearly defined. In RAS, the presence of dense, multilayer vegetation under the rubber trees can also increase air humidity and reduce wind speed. But although the dense multilayer vegetation can limit damage caused by wind, higher air humidity can increase tapping panel diseases caused by *Phytophtora.*

Synergies (tapping different sources of water) versus competition for water

Another possible positive effect of plant diversification is that, when associated with annual crops or shrubs, trees tend to deepen their roots to avoid competition. As the trees then tap deeper sources of water, they become less vulnerable to drought (Panklang et al. 2022; Thoumazeau et al., 2022), while the associated crops exploit the more superficial water resource. Some associated species, like bamboo, can retain water in their dense root system, thereby increasing soil humidity. Nonetheless, it is important to be aware of possible competition for water between rubber and associated plants. In North-East Thailand, Clermont-Dauphin et al. (2018) showed that a cover crop of *Pueraria* competed too strongly with young rubber trees located in the upper part of a plot as the trees could not reach the water table, leading to the death of these trees in the dry season.

Protecting the soil against extreme events

Better soil cover can mitigate the effects of heavy rainfall on erosion. Erosion is already a major concern in rubber plantations, particularly – but not only – on sloping land. Using covercrops such as *Pueraria phaseoloides* or *Mucuna pruriens* during the immature phase of the plantations when the canopy cover is insufficient, is an efficient way to protect the soil. However, this practice is rarely used by smallholders because of the cost and labour required. Associated crops (e.g. rice, cassava) or pluri-annual crops (e.g. pineapple, banana) can play the same role if they are correctly managed. After the canopy closes, the cover crop or the associated crop decays naturally, leaving the soil almost bare. It is widely believed that the rubber tree canopy (or the canopy of other trees used as cover), will efficiently protect the soil from erosion. However, recent studies showed the contrary with a much higher rate of soil detachment and erosion in rubber monoculture than with open-field crops such as maize. The explanation is that the drops flowing off the relatively large rubber tree leaves are much bigger and heavier than normal raindrops that fall directly on the soil. Combined with the height of the canopy, this means the drops hit the bare soil with high kinetic energy. In RAS, the understorey crops can significantly mitigate this erosion process by intercepting these heavy drops of water before they hit the soil.

Sustainability in agroforests

Sustainability can be explained at different levels. It is the simultaneity of attributes in different domains which makes it a powerful concept. As far as agroforests are concerned, ecological sustainability is usually measured in terms of biodiversity conservation, natural resources management (soil, water) and pollution control (use of few phytochemicals or none at all). Economic sustainability can be visualized via the provision of stable, long-term diverse sources of income and patrimonial assets. The risk-buffering capacity of agroforests contributes to both ecological and economic sustainability. Social sustainability could be achieved through secure land tenure, secured by the capability of agroforests to avoid conflict (through people's common law or regulations, like *adat* in Indonesia), socialisation in a protected environment and the preservation of community values. These are values shared by a group and concern sustainability (preserving resources for the next generation), living environment (a "forest-like" landscape), a balance between fruit and timber resources and specific locations for social activities (holy forests or graveyard forests for the Dayaks in Indonesia, for instance). A vision shared by the members of a community reduces potential conflicts or sources of tension. A sense of sharing also reduces social differenciation. Again, among the Dayak people, timber that grows in the common *tembawang* can be used to build houses but not sold.

Provision of income for individual members of the population is very often balanced by collective decisions concerning the use of resources, attention paid to resources depletion and more generally, to social uses of agroforests. Institutional sustainability might be measured based on the fact that agroforests can be managed individually or jointly. Table 4.1 lists some arguments that link agroforests with sustainability.

Kumar and Nair (2004) rightly pointed out that home gardens may be on the verge of extinction due to new trends in agrarian structure, high market orientation, population pressure, land fragmentation, and acculturation. In the face of such constraints, the ecological foundations of home gardens may not be sufficient to ensure their survival. However, home gardens in Java persist despite an average population density of more than 800 people/km^2, and strongly market-oriented agriculture. The presence of some very high value crops (e.g. durian fruit) in the home gardens could explain this phenomenon. Yet, Java is not the only place where a positive correlation has been observed between the number of trees and human population density. Other examples have been found in Kenya (Tiffen, 1995), in Kerala, India, and in Sri Lanka (IRRDB, 1996).

Other multi-strata agroforests are also being influenced by changing economic factors. Jungle rubber (*Hevea brasiliensis*) and damar (*Shorea javanica*) gardens in Indonesia have had to face international price crises[67]. Diversification of local farming activities may occur at the expense of traditional agroforests, for instance, due to massive investment in oil palm. The effect of globalisation depends on access to markets and on the type of marketing involved. In Asia, most export products (rubber, oil palm, coffee, cocoa) have long been linked with international prices. In Africa, the commodity boards established in the 1970s to protect farmers from price volatility failed to deliver expected results and are now being called into question. As a result, globalisation has a stronger impact on African farmers than on Asian farmers, as the latter are used to adapting to international markets and to price cycles. We hypothesise that agroforests play a role in this adaptability, but other effects may have more impact: new decentralisation and local governance policies, new rules for access to credit, to projects or to information. Will agroforests be able to adapt to such changes more efficiently than conventional monocropping?

---

[67] Rubber prices fluctuated from 2 US$ per kg in 1996, to 0.6 US$ in 2001 and then back to 1.2 US$ in 2004. In 2024, rubber price is between 1.3 to 1.9 US$/kg.

For many years, jungle rubber represented a great opportunity for poor farmers in pioneer areas. Now, monoculture or RAS using clonal rubber is much more profitable: yields and labour productivity are three to four-fold that of jungle rubber. In some areas, traditional RAS may not be a good economic option compared to either rubber or oil palm monoculture, for instance; but jungle rubber has nevertheless been replaced by monoculture RAS in some cases.

⏩ Environmental concerns and externalities

If an economic perspective with emphasis on the local and regional levels were used to incorporate positive externalities such as agrobiodiversity management, improved nutrient cycling, integrated pest management, ecological sustainability and services, decision makers would possibly be convinced that home gardens and agroforests are profitable ventures. If an "agro-forest rent" approach is applied, policy makers and development professionals will consider agroforests as a profitable investment in the long term. This would lead to better consideration of agroforests in research and development programmes worldwide. If agroforests are still a success for many farmers, it is clearly not only for the sake of biodiversity conservation. Other values such as security (risk management and sustainability), diversity (and diversification), land control and reserve ("rights" to land and trees with emphasis on tree tenure), and social values, are included in the perception of agroforests, which are considered by most farmers as one cropping pattern amongst others.

Most farmers who continue to maintain agroforests also include some monocrops in their farming system, and these vary depending on the local context. The reason why farmers maintain agroforests in some countries, for instance, in India (Kerala), Indonesia (jungle rubber, *pekarangan*, damar systems), Sri Lanka (Kandy agroforests), or West Africa (oil palm based agroforests), is probably because their strategy has internalised the advantages of agroforests. A micro-economic analysis at farming system level including all sources of income, the cost-benefit of each activity and return to labour could explain such long-term strategies, provided it accounted for the dynamics (time effect) of perennial crops in home gardens and other types of agroforest.

Methods of economic analysis that use farming systems modelling capable of incorporating the outputs of mixtures of plants with different cycles and that allow smoothing of long-term and patrimonial strategies are certainly required to explain precisely what farmers do and why. Although agroforests are not a "panacea", their positive externalities and advantages seem to offer an ideal compromise between sustainability and risk spreading.

Beyond the economic advantages of agroforestry systems: what is the role and place of externalities in farmers' strategies?

Most RAS result from adaptations of cropping patterns to the local climate, local soil conditions, the farmer's cropping system, family self-consumption needs and in the case of AFS systems based on export crops, market conditions. AFS usually combine specific crops with the aim of producing different types of products, thereby helping diversify farmers' sources of income. Some systems are simply the result of local demand, for example, coconut tree-based systems in South East Asia that focus on food for self-consumption, or home gardens like the *pekarangan* in Indonesia (Torquebiau and Penot, 2006). Other systems are based on a main cash crop, usually rubber, cocoa, coffee, clove/nutmeg, resins (damar) fruits or timber species linked with the opportunity to grow a crop for export that developed during the colonial era in the 19th century (Michon et al., 1991, 1997). Both systems account for millions of hectares, particularly in South East Asia (jungle rubber covered 3 million ha in the 1990s). In 2024, agroforestry systems are still definitely part of local cropping systems largely used by local farmers but interest is reduces facing other opportunities such as oil palm.

Income diversification is a key to better global resilience of local cropping patterns through the production of the main crops and different kinds of fruit, firewood, timber wood, resin or rattan combined with other species including medicinal plants (Penot, 2001). The plants usually have a wide range of uses, health, home construction, food, handicrafts and furniture making (Momberg, 1993). Some products are sold and some self-consumed, usually depending on access to local markets. Some systems are based on the largest number of crops that can be combined while others focus on achieving the effect of associating one particular crop with the main crop, e.g., shading in the case of coffee and cocoa (Ruf, 1994). Most agroforestry systems result from marketing opportunities, which is the case of coffee, cocoa, rubber, cloves, or associations that are appropriate in a particular context (limited land availability, suitable soil and climate for a given tree/crop/livestock association) such as home gardens, AFS based on coconut, AFS based on fruit and timber trees, etc. Agroforestry systems with associations of trees host more biodiversity than monoculture, and their positive impacts on the soil which generally, but not always, include positive externalities. Most of these externalities, or those that are considered as such by external observers, for example by researchers or developers, are already an integral part of farmers' strategies and might not be perceived as externalities by the smallholders themselves, quite the reverse, they are an integral component of their cropping strategy. In other words, from the smallholders' point of view, do externalities deserve their name?

We believe they do not, particularly due to the social effects and the resilience of these components, as, right from the start, they are incorporated by the farmers in their decisions concerning the appropriate cropping systems, therefore, from the farmers' perspective, they are not considered as externalities. In other words, our main hypothesis is that most agroforestry farmers have already internalised externalities – mainly positive externalities – in their strategy and in their decision making concerning their choice of cropping systems.

From the point of view of agroforestry, we do need to know whether what economists call "externalities" are perceived as such by local farmers (even if the farmers are not familiar with the concept per se) or are already an integral part of farmers' strategies and consequently leave room for other aspects in addition to productivity such as resilience, long-term stability, and environmental concerns. In any case, measuring externalities is difficult as most services can be attributed a value indirectly or because unexpected advantages only emerge in the long run. We aimed to identify the role these externalities play in the survival and expansion of agroforestry as well as in the farmers' strategies and perceptions. We aimed to distinguish between the type of externalities that can be re-internalised to calculate economic value, those that are no longer considered as externalities by the farmers themselves (since they are an integral part of the technological package) and hence, whether technical, environmental, economic and social externalities attribute value to products that cannot be traded directly.

The concept of externalities in economics

In economics, the "externality" concept characterises the fact that through his/her activity, an economic agent has an "external effect", or more exactly an "unexpected effect", with no monetary compensation, i.e., that has a value or produces a benefit –positive externality–, or on the contrary, is a nuisance, causes damage without compensation – negative externality (Meade, 1952). In this way, an economic agent may be in a position to consciously or unconsciously influence the situation of other agents, who are not necessarily part of the decision. Externalities can involve different modalities depending on the topic: (i) technical components – erosion, fertility, water system, etc., (ii) economic components –margin, risks, (iii) environmental components –biodiversity, etc., and (iv) social components –farmers' patterns of organisation, etc. (Archibald et al., 1988; Oluyede, 2012).

A technical externality in production occurs when the production function of an actor is modified by the action of a third party. An economic externality in production occurs when the utility the actor derives from a good depends on the usefulness other consumers derive from the same good, and particularly on the position of the actor with respect to the position of the other actors in possession of the good, which is typically an "economist's perspective". An adoption externality, or network effect, occurs when the fact that other people perform the same action increases its usefulness (or value). In that case, the value of the product depends on how many users it has, which is typically the case of rubber agroforestry in Thailand, which concerns fewer than 5% of rubber farmers in the southern rubber production area. But that relatively small number concerns farmers who are organised in groups or networks (Theriez et al., 2017) and who are deeply involved in agroforestry and the specific knowledge and behaviour associated with it. In such cases, productivity and a purely "economic vision" are far from reality and do not explain the real components of farmers' strategies. Although concern for the environment has become a priority for most people, it was already a key component of farmers' perception of agroforestry, particularly stable production, agricultural sustainability and respect for the social value of biodiversity. In other words, externalities can be considered from different angles and need to be explored through different typologies to understand which components can be taken into account and potentially re-internalised.

Typologies to explore the concept

A standard typology can be identified by the type of economic and/or environmental effects it has: (i) "positive externalities", i.e., when an actor provides an economic service to a third party without being rewarded, and (ii) "negative externalities" when an actor economically disadvantages a third party without being obliged to compensate the affected parties (including him/herself) for the damage he/she caused. This typology is very efficient for descriptions and is by nature mostly qualitative. In agriculture, this typology is often used for technical or environmental externalities (Gomiero et al., 2011a). From a practical point of view, it is very effective for agroforestry.

Another typology can be identified based on the nature of the economic act. The term (i) "flow externalities" describes situations in which the economic action is a flow (for example, a flow of pollution), and the term (ii) "externalities of stock" applies where the economic action is a stock (for example, a stock of pollution). This typology is probably easier to use to quantify externalities, as flows and stocks are usually well documented and exploited in economics. The typology could be very useful in agroforestry, for example, to measure the long-term effect of pollution on soils, or the long-term negative impact on yield (for instance) or the positive impact of the biodiversity of the associated crops on soil fertility. But although such calculations are theorically possible, such long time series are very rarely available.

The final typology (Figure 4.1) can be identified by the type of economic act: (i) a "production externality" is when an actor profits by preventing the deterioration of a service or a product caused by another actor and (ii) a "consumption externality" in the case of consumption by another actor. This approach is rarely used in agroforestry.

Assessing externalities is a real challenge

Analysing externalities is difficult because relevant local agronomic or environmental data are rarely available (Pretty et al., 2000). Some negative externalities, like erosion, can be calculated using an appropriate equation (for instance Vishmayer's equation) plus information on soils and rainfall. Some, for example, global biodiversity, are impossible to calculate or to be attributed a value. Some can be extrapolated and valued by comparing them with other samples with no externalities. For instance, the value of collecting medicinal plants can be evaluated by indirectly calculating the health costs of a similar group of people with traditional cropping systems, but no positive externality like associated biodiversity.

Externalities cannot be measured directly by the consumer or by any other actor, but some, particularly technical externalities, can be measured at the level of the producer (Gomeiro et al., 2011b). Negative externalities (Figure 4.1) can penalise certain categories of economic agents (for instance, the cost of pollution caused by agricultural inputs for the production of Vittel mineral water in France (Benoit et al., 1997), nuisance, effects on health, etc.). Concerning positive externalities (Figure 4.1), a value has to be attributed that is recognised by all the actors, but such a value is usually not included in cost benefit analyses as it has no immediate return. Concerning negative externalities, as most are long term, they are also difficult to incorporate in economic calculations. However, the concept of multi-functionality in agriculture enabled the EU to recognise and attribute a value to some externalities by incorporating agro-environmental measures in the "Second Development Pillar", dedicated to rural development, established by the European Union (1999 reform). Originally externalities were an economic concept applied to value chains, products, and economic impacts on actors.

However, it is now clear that the technical and environmental dimensions of externalities are also required to adequately account for the impact of any complex system, particularly in agriculture, where environmental concerns are now priorities, as well as for complex multi-layered agroforestry systems. Producers' perspectives and perceptions consistent with global social evolution towards a more responsive civil society and more concerned consumers better account for externalities. In addition, the social value of externalities now has to be taken into account as the externalities concerned may be of importance in farmers' strategies based on their own perception of how agriculture should be implemented. However, as underlined above, externalities are very difficult to assess and measure, even in the long term. They may be considered as externalities that are "internalised" by smallholders right from the outset, as they very often contribute significantly to a smallholder's choice of a particular cropping system; this is the case in many local societies, for example rubber agroforestry farmers in Thailand, or clove agroforestry farmers in Madagascar. This social dimension is challenging to evaluate in terms of economic output but is now considered as one of the main assets in the livelihood approach (Serrat, 2017). The positive externalities of agroforestry may not be entirely "calculated" but they are definitely part of farmers' strategies, particularly their contribution to stablising agricultural income.

From an economic perspective, externalities reveal that a market price may not include all costs, and that services may not have all the effects expected. In terms of income analysis, whenever possible, efforts should be made to assess the cost and/or economic advantages of externalities to be able to include them when calculating the cost or margin. Re-internalising externalities is a real challenge. The three main difficulties involved in attributing a value to externalities are (i) the information required on all topics is not available locally, (ii) externalities may play a role in the long run and assessing long-term economic impacts is not easy, and (iii) social values, which are very important in some rural societies, may be impossible to evaluate economically. Thus it is almost impossible to account for all the costs and services provided by and/or the advantages of certain societal features (Alliot, 2003). Even if some features are well known, e.g., the impact of biodiversity on soil fertility and water management, their long-term effects are rarely well documented,

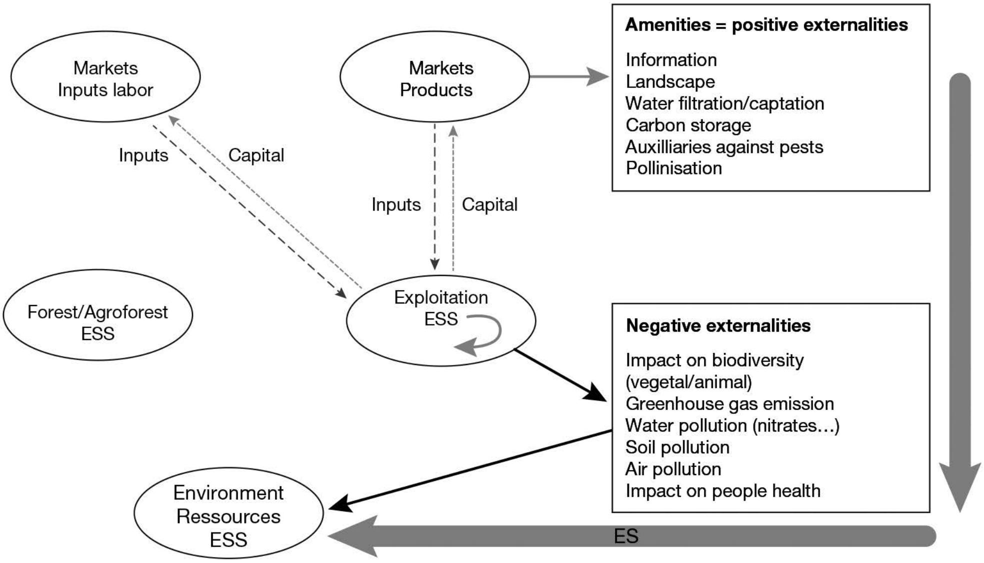

Figure 4.1. Schematic representation of positive and negative externalities of an agricultural production system

ESS: ecosystem services; ES: environmental services.

Most farmers who practice agroforestry have intuitive knowledge of positive externalities or have acquired genuine knowledge on their own and generally take these different types of knowledge into account in their strategies (Momberg, 1993). The same applies to other agricultural technologies such as conservation agriculture or permaculture, which are perceived as ecological intensification processes (FAO, 2001).

Most externalities are considered as environmental services. Aznar et al. (2007) offered three definitions of environmental services:
– Products of natural capital: environmental services are defined as services rendered by nature to man, not as products.
– Positive production externalities: the work of the Organisation for Economic Co-operation and Development (OECD) on rural amenities (1994) and on the multi-functionality of agriculture (1999) fit this definition. Environmental services are considered to be positive production externalities. The services provided are not planned, but are the result of practices in the same way as economic assessments measure the economics of environment (Baumol, 1988).
– The economy of services through the intentional character of the supply of a service: for instance, improving the environment is intentional from the point of view of a service provider (e.g. in the case of providing drinkable water).

Typical examples of environmental services are carbon sequestration by agroforests and the biodiversity of the associated crops, both of which are real externalities, but are not considered as such by farmers in their strategies.

For institutions, evaluating externalities at a macroeconomic level – national or international – allows them to demonstrate the merits of their proposals – advocacy, public policies, bills, etc. (de Foresta, 2013). This could be the best way to measure the global impact of externalities at regional or national level, given the previously mentioned difficulty in effectively assessing certain externalities and their real impact at the level of a territory. For private companies and/or estates, the question could be "what is the value of services the company renders indirectly, or the benefits obtained from using our products?"

Some technical and economic externalities can be included in the operating budget as costs and services for a particular product, but may be far more difficult to include in national accounts. The question is therefore how to transform services and problems into costs and advantages (Conway, 1993). Some attempts were made at the beginning of the 2000s in the European Union. In France, to give one example, with the Territorial Farming Contract (*Contrat Territoriaux d'Exploitation*, CTE; Aznar et al., 2005) in which subsidies were not only linked to the production of specific product (e.g. wheat) but also to some ecosystem services. Some methods of calculation are controversial, for example, contingent valuation, which consists in undertaking monetary valuations via surveys of the type "how much would you be willing to pay to preserve such a resource?"

It is also difficult to accurately measure the value of public goods. Any estimates will continue to be the subject of controversy by some actors (Pearce, 1998).

The objective: to re-internalise externalities in the case of agroforestry

All recent studies conclude that, with the exception of most agroforestry systems, the intensification of agricultural practices leads to loss of biodiversity and to degradation of some ecosystem services, e.g., pollination of flora by bees (Warren-Thomas, 2020).

Some important questions concerning agriculture in 2024 are thus:
– How can global ecosystem services be incorporated at the scale of a territory?
– How can nitrate pollution of an underground aquifer by a river be incorporated?
– How to account for the silting up of irrigated rice fields linked to the erosion of the surrounding hills? (Cacho and Hean, 2001)
– Does agroforestry limit greenhouse gas emissions thanks to its carbon sequestration potential?
– Do agroforests contribute as much as most forests?

Agroforestry should not only be assessed from the point of view of carbon storage. Agroforestry has other ecological advantages including (i) protecting drinking water resources (reducing nitrate and pesticide leaching), (ii) creating ecological corridors and more attractive landscapes, (iii) reducing soil erosion thanks to better control of runoff, (iv) improving the fertility of agricultural soils (Boonkird et al., 1984). It is difficult to attribute an economic value to such externalities, however, life cycle analysis (LCA) is probably a useful tool to give a value to some externalities, although to our knowledge, as yet, it has not been used for that particular purpose and further research is needed (Hendrickson et al., 2006). The exploitation of timber in agroforestry systems does contribute to a very long use of agroforestry products and long-term carbon storage, which could be demonstrated using LCA.

The existence of externalities partially explains the gap between the potential and actual adoption of sustainable land-use practices. There is substantial evidence for the advantages of biologically diversified agroforestry systems in conserving biodiversity, controlling certain pests, weeds and diseases, enabling pollination, maintaining soil quality, increasing energy-use efficiency and mitigating the effects of global warming by reducing the temperature, or an example of the other extreme, by protecting arabica coffee from freezing at 1,000 meters above sea level, a high altitude for coffee, in northern Vietnam. AFS may even allow rubber production when the maximum temperature (28 °C) needs to be reduced to enable the lactiferous system to continue to function. Agroforestry systems increase resistance and resilience in the face of extreme weather events. AFS enhances carbon sequestration and the water-holding capacity of surface soils (Gomiero et al., 2011a; Kremen and Miles, 2012). The real challenge is to re-internalise externalities in the economic analysis of agroforestry systems either as costs or as economic advantages. To this end, we need to:
– attribute a value to both positive and negative externalities, which is possible at plot level, difficult at land use/territory level;
– re-incorporate valued externalities as margin/ha or margin/farm account and whenever possible, when calculating income;
– evaluate certain externalities that are currently not fully or accurately evaluated, for example, maintaining the original soil fertility at plot level, or the global impact of ensuring the survival of pollinating bees.

Farmers are considered as key components of sustainability when they adopt agroforestry as the main component of their strategy with the aim of reducing vulnerability and increasing resilience, both at farm and environmental level. If the data are available, the technical and economic externalities can then be included in an operating budget.

Managing externalities in agroforestry

The environmental costs of agriculture have limited the ecosystem services on which we depend. To ensure the global sustainability of agroforestry systems, it is essential to include the costs (externalities) of agriculture which were originally "invisible", in particular in smallholder decision-making processes, in order to identify the "true" cost of using certain agricultural inputs and practices, both negative effects (chemical pesticides, pollution, etc.) and positive effects (soil fertility, biodiversity conservation, providing a natural habitat for birds and insects, etc). Externalities can be identified at different levels in agroforestry systems ranging from (i) the externalities of a particular cropping system to those of the plot itself, (ii) externalities to other actors (at landscape/farming systems/land-use level). The positive externalities of AFS are (i) biodiversity conservation (as a sanctuary, niche, or reservoir), (ii) protection against erosion, (iii) provision of ecosystem services, and (iv) social value (for instance, the religious offerings and traditional gifts of fruits in Thailand). The negative externalities of AFS are (i) their impact on and reduction in the yields of associated crops, (ii) labour requirements.

A typical example of an externality is the "biodiversity concept" with: (i) "Useful" biodiversity (timber, fuelwood, wild fruits, resin, etc.) is widely known and its components are combined to increase the resilience of AFS, (ii) crop diversification, which depends not only on a single product but provides several sources of income in the short and/or medium term, and also includes (iii) biodiversity with no marketable value as a way of providing long-term ecological services thereby making a significant contribution to long-term sustainability. Then, the following questions arise: (i) What is the role of these externalities in agroforestry development and in the associated farmers' strategies? (ii) Even if most income analyses find it difficult to attribute a value to these externalities, they may nevertheless play a key role in farmers' choices and preferences for agroforestry over monoculture –if they have the choice. Biodiversity is also a major component of landscape management (Schroth et al., 2013).

At land-use level, the main externalities are (i) mitigating greenhouse gas emissions due to "forest-like" carbon sequestration, (ii) protection of drinking water resources (by reducing nitrate and pesticide pollution), (iii) creating ecological corridors as sources of biodiversity and enabling the passage of a wide range of organisms including large animals, (iv) controlling soil erosion through better control of runoff, (v) improving the quality and fertility of agricultural soils, (vi) reducing negative externalities on health caused by pesticides (see Tables S8-S10 in appendices). Table S9 lists positive and negative economic externalities, while Table S10 lists externalities at landscape level. In the end, some externalities are not perceived as "externalities" by most smallholders as they are an integral part of their strategy and can be considered as major factors behind their decision-making process. Where is exactly the frontier?

Some examples of incorporating externalities in RAS in Thailand and Indonesia

In southern Thailand, rubber agroforestry is considered by some farmers as a specific cropping design because, since the 1960s, most farms have been based on monoculture through the actions of ORRAF/RAOT[68]. The main features of rubber based agroforestry systems are the following: (i) initially, the social value of fruits in fulfilling the tradition of welcoming any visitor and even family members with fruit, and later on, faced with the low rubber prices since 2012-2013, as a source of income diversification to cope with rubber price volatility, (ii) following the late sovereign's recommendations: respecting nature and re-introducing trees and forest-like environments (social value), (iii) attributing a value to medicinal plants[69] and (iv) a process of land intensification in areas where land availability is limited or scarce (like in South Thailand where all land is already being cropped, or in transmigration areas in Indonesia). In 2015, a survey of 34 local rubber farmers was conducted in 4 districts in Thailand (See Figure 3 in Stroesser et al., 2018) and showed that agroforestry systems were more resilient to rubber price volatility thanks to income diversification. Figure 2 (in Stroesser et al., 2018) shows the net gross margin/ha of 5 types of AFS. The 6th type is an RAS involving early tapping with low rubber production. All of them are compared with the current rubber monoculture system and an average international price for rubber of US$1.3/kg which remained stable over the period 2015/2020. The study by Stroesser et al. (2018) showed that in 2015, rubber agroforestry systems provided an average income equivalent to that obtained from rubber monoculture at a rubber price of US$3.2/3.7/kg. In other words, RAS do help maintain a stable agricultural income, reduce vulnerability and contribute to global resilience. Income stability is a key priority in farmers' strategies in which AFS play a key role in sustainability.

Such AFS have other externalities that are currently not taken into account to calculate the gross margin. The most important ones that are easy to calculate are:

– The value of stored carbon: a rubber plantation can produce up to 200 m3 of wood to be used to build furniture. If we add the 50 m3 of associated timber trees: the total quantity of wood produced is 200 × 500 kg + 50 × 600 kg = 130 tons of wood (with both forest equivalent carbon sequestration for 30/35 years and substitution through the use of the wood produced)[70] . The CO_2 value is therefore equivalent to 130/2= 65 tons of C/ha, valued at 1,625 euros (i.e. 25 euros/ton) in 2019. If the carbon market were efficient, this value would largely contribute to the cost of replantation (the average cost of replanting in AFS is between 2,000 and 4,000 US$/ha for the first five years).

– The presence of weeds and/or associated shrubs, small trees and/or small crops help maintain soil fertility, or even enable improvement, but real data are unfortunately rare (Neyrey et al., 2018). In 2019, Liu showed that using herbicides in rubber plots had a negative impact on erosion. Thoumazeau et al. (2018) demonstrated that the presence of weeds and shrubs maintains and even increases soil fertility in rubber plots. In the long run, the final output is environmentally sustainable agricultural production, which can be measured in terms of income stability, for instance. The difficulty in visualising a long-term impact is that it requires including 2 or 3 complete cycles of the perennial concerned.

---

[68] RAOT (Rubber Authority of Thailand) is in the process of replacing ORRAF (Office of Rubber Replanting Aid Fund).

[69] That point is also very important for Dayak farmers in Kalimantan for access to fuelwood and fruits in transmigration areas where forests have disappeared (from trees growing outside the forest).

[70] The density of rubber wood is 450/650 kg/m^3 (average 500), that of teak wood (often present in AFS) is 480/850 kg/m^3 (average 600). One cubic meter of wood contains 1 ton of CO_2 and 1 ton of wood contains 0.5 tons of CO_2.

– It would be possible to measure the effect of AFS on the soil by comparing it with total yield and the income to be obtained from a second rubber cycle if soil fertility were not maintained and the result was consequently a decrease in yield. However, the result would be questionable, as climate and diseases also have a major influence on yield.
– As most actors mentioned, the social value of AFS is real but probably cannot be measured economically, which is true of both non-marketable plant and animal biodiversity.
– In Indonesia, farmers who have no easy access to health facilities, but instead use the medicinal plants that grow in the jungle rubber version of RAS, save between 5% and 8% on their normal family expenditure (Courbet et al., 1997). According to a survey conducted in Indonesia in 1997, using timber from AFS plots enabled farmers to build houses for their children at 30% of the normal cost.
– Re-internalising such costs and advantages will not fundamentally alter the analysis of farmers' strategies, as a value is attributed to services and factors that does not affect their immediate income, but does make it possible to compare different types of systems and to assess their sustainability over time, for instance oil palm AFS vs. RAS. Including the cost of fertiliser or of the pollution of water by pesticides, loss of soil fertility after several cycles and of the impact on diseases would enable a better assessment of the long-term sustainability of the different AFS cropping patterns.

One of the most important features we observed in RAS in South Thailand as well as among Dayak farmers in Kalimantan (Indonesia) with similar systems (Penot, 2001), is the social value attributed to AFS by local farmers (Stroesser et al., 2018; Theriez et al., 2017; Penot, 2001) before it also acquired economic value when there was a sharp fall in the prices of rubber.

Conserving biodiversity and the "original social value" of biodiversity (for instance of medicinal plants, but not exclusively) have been explored in Indonesia (Werner, 1997; Diaz-Novellon et al., 2002), and in Thailand (Warren-Thomas et al., 2020) where farmers referred to the need to protect local biodiversity reflecting the late king's recommendations concerning South Thailand ("*protect the environment and keep trees in the landscape*"). From a practical point of view, the use of medicinal plants either as a general health treatment or to treat a specific disease allows farmers to save on what they would normally spend on doctors and medicines in a context where most smallholders do not have a social security safety-net. Externalities that provide stability (erosion control, etc.) became more qualitative over time, and were perceived by local smallholders as inherent to a cropping system.

Conclusion

All potential components that render agricultural production more resilient and sustainable are already an integral part of local farmers' long-term strategies. In other words, some externalities (or which are considered as such by socio-economists), may not be considered as such by local farmers who incorporate the expected output right from the outset even if they cannot give it a monetary value. They do have a clear perception of environmental ecosystem services to which they attribute a social value that is locally recognised in the same way as its economic value. Among the expected outputs that are no longer externalities for farmers are fire prevention, protection against erosion, preservation of the water catchment and of soil fertility, and biodiversity conservation to ensure continued access to fuelwood and other products. To these can be added all factors that indirectly contribute to income stability, better return to labour and the overall long-term sustainability of cropping systems. This explains why – when they have the choice – so many farmers prefer agroforestry systems, particulary because it is usually easy to incorporate local plants (fruit and timber tree species, local non-timber forest products, etc.).

It would be useful to calculate the real value of externalities to be able to compare the economic and environmental efficiency of different types of cropping patterns as well as their impact on the landscape, for instance at watershed level. However, this might not even be necessary given that local farmers consider the "social value" of agricultural sustainability to be its most important aspect, whatever its real economic value. It seems more logical for local communities to respect social values by, for instance, referring to the late king's philosophy concerning forest and trees in Thailand than to a hypothetical calculated economic value that in fact is only of interest to researchers who need to compare situations.

Whenever possible – and when data were available – most values have been attributed and calculations made at plot level and rarely at landscape or land-use level (village, region, watershed, etc.). The real impact of externalities at landscape/land-use level is still largely under-estimated in 2024. The positive externalities of AFS have become key components in the adoption of AFS and in local farmers' strategies. We also observed that negative externalities are very limited in AFS (Table 4.4).

Other multi-strata agroforests are also under the influence of changing economic factors. Jungle rubber (*Hevea brasiliensis*) and damar (*Shorea javanica*) gardens in Indonesia have also had to cope with international price crises[71]. Diversification of local farming activities may take place at the expense of traditional agroforests, for instance due to massive investments in oil palm. Agroforests are hypothesised to play a role in this adaptability. Other effects might have a bigger impact: new decentralisation and local governance policies, new rules for access to credit, projects or information. Will agroforests be able to react to such changes more efficiently than conventional monocropping?

Natural rubber is a renewable resource when rubber plantations are well managed, unlike petroleum, which is used to make synthetic rubber. What is more, as a large proportion of rubber comes from village plantations, which has many positive social effects (Hauser et al., 2015; Pirard et al., 2017). As summarised by Gitz (2019) and developed in this work, the potential impacts of rubber expansion depend on three main factors: (i) the land use or land cover that rubber replaces (natural ecosystems or cultivated or degraded areas); for example, in a context of climate change, a rubber plantation will store more carbon than an oil palm plantation and rubber wood can be harvested at the end of the tree's life cycle; (ii) the type of production system (monoculture or agroforestry and its overall efficiency); for example, an agroforestry system has a less negative impact on biodiversity or water than industrial monoculture, and (iii) benefits smallholders and local populations by contributing to their economic and social resilience.

---

[71] Rubber prices dropped from US$2/kg in 1996, to 0.6 in 2001 and then back to 1.2 in 2004.

Table 4.4. Summary of sustainability attributes of agroforests

Ecological	Economic	Social and institutional
Reduces soil erosion, Increases soil organic matter content, Buffers soil moisture and temperature, Closes the nutrient cycle Improved soil physico-chemical properties, Efficient use of light and water, High wild plant and animal biodiversity, Use of endogenous resources, Contribution to on-farm production of wood and fuel wood, High soil biotic activity, Better scope for evolution and diversification of plants with an economic value, Differentiated vertical and horizontal management zones and related ecological niches, Potential for organically grown products.	Significant use of endogenous resources, High safety factor against marketing and seasonality hazards, Reduces need for cash, thanks to the many diverse bio-physical outputs (plant and animal food, medicines, fibres, etc.), Socio-economic outputs are diversified and distributed over time, Balance between subsistence and cash income, Possibility to build capital, boosts rural industries and employment, Can adjust to different contexts, Stabilises yields, Offers management flexibility (intensive vs. extensive), Economic resilience (value as "land reserve").	Reduced and flexible labour requirements, Contributes to nutritional security, Contributes to community socialisation, Preserves traditional knowledge, Biodiversity linked to traditions and practices, Gives women a key role, Enables equitable distribution of products, Functions as a land reserve (for alternative land uses), Maintains right of access to common goods (e.g., fruits), Ensures flexibility of ownership (private vs. communal).

Source: Adapted from Torquebiau (1992), Penot (2003), and Kumar and Nair (2004).

These three factors will play a determining role in the sustainability of rubber production in the future. According to Gitz (2019), the rubber sector needs measures to connect downstream and upstream that involve different stakeholders, that build on science and knowledge and that promote transfer from one system to another in a practical way.

Evaluating the real economic impact of agroforests – a challenge for both agronomists and social scientists

Part of this section has been originally published as a keynote paper[72]. The advantages of sustainable agroforests originate from a trade-off between ecological and socio-economic attributes. Conventional economic approaches might have a hard time combining the two series of attributes in a comprehensive manner. Compared to a simple yield analysis, which is possible in conventional monocropping agriculture, the array of attributes of agroforests are a challenge to agronomists and social scientists alike.

---

[72] See Penot (2016), Xishuangbanna Tropical Botanical Garden by the Chinese Academy of Sciences, Yunnan Province, China.

Among other facts, (1) the products are varied, their production is spread out over time, the plants have life cycles of different lengths, and combine subsistence, cash, capital and patrimonial objectives, (2) ecological benefits are crucial but are not internalised in analyses, and (3) some ecological attributes have no market value.

If neoclassical economics is used to assess the performance of agroforests, yield criteria, cost-benefit analysis and net present value may disqualify agroforests as opposed to conventional monocropping, because the analysis will exclude a series of agroforest outputs which are not traded on the market or adequately accounted for in farm economics. A value can be attributed to a good, whatever its final use (including savings made thanks to self-consumption), but services and positive externalities are far more difficult to assess. Risk buffering by agroforests needs to be measured, e.g., in the case of a drought, in an El Niño year, or in the face of commodity price volatility. Farm system models can perform this task and will produce different comparative scenarios.

The overarching question is simply: How can we measure the agricultural sustainability of agroforests?

Farming systems approach

The flexibility of tree and crop production in agroforests is tied to the mature and immature stages of the trees or crops involved. It is thus essential to take the life cycles of the different plants into account in long-term economic analyses. Specific discounting rates may be necessary as cycles can last up to 40 or 50 years. Different scenarios will be needed, as bias can occur in valuing products depending on the discounting rates chosen. For instance, in agroforests based on tree crops, rubber or resin is produced for more than 30 years, whereas annual and bi-annual crops are usually only cultivated during the first 3 to 6 years of the life of a plantation. Timber can only be harvested at the end of the life span of the agroforest. Thus, if detailed data are available to reliably assess real income (including self-consumption), comparing systems will be more valuable than absolute data (Penot, 2001).

When the benefits of agroforests can be analysed using the market value of their products and services, then neo-classical environmental economics can be used and externalities can be internalised (or re-internalised) in the process of income generation. The increase in pollution and its cost can be taken into account as negative externalities or constraints to further development. Environmental services (e.g. carbon sequestration; Albrecht and Kandji, 2003; Montagnini and Nair, 2004) can be valued according to a “system of values” recognised locally as being relevant at a higher level, that of the community or province. The problem is knowing whether farmers really do benefit from externalities and from the advantages of agroforestry, or at least have the potential to benefit.

Whether agroforests are commercially or subsistence oriented, a long-term perspective must be part of each farmer’s strategy. However, there is obviously a bias in the debate between the short term (economics) and the long term (ecology). In both cases, farmers have developed their own long-term farming practices through a long-haul innovation process which may or may not account for economics through the risk buffering capacity of agroforests. In most cases, social organisation is tightly linked with technical production constraints, food security, reliable income and control over land. There is a strong coherence between technical systems (technical pathways) and social systems (Penot and Chambon, 2003).

⏩ Interest of certification

Today, rubber production is facing both environmental and social challenges. Additionally, acording to Fern (2018), compared to other agroindustries like palm oil, the rubber industry has been lagging behind in terms of sustainable and responsible production, and has been slow to act on deforestation, labour and human rights issues. Tire manufacturers are threatened by potential public scandals concerning the sources of their supplies (deforestation, exploitation of the poor for labour, etc.) and the pollution caused by the production of tires. Tire manufacturers may be using certification to partially protect themselves against such scandals. If a media scandal were to break out over deforestation or other environmental or social damage, companies that have not yet begun certifying their rubber as sustainable will be consigned to the sidelines.

Stakeholders in the rubber industry began to focus on the sustainability of the natural rubber industry in 2012, by creating a think tank in the IRSG (International Rubber Study Group), which resulted in an SNR (Sustainable Natural Rubber) initiative (iSNR). The main weakness of the IRSG is that it includes neither the main producers (e.g. Thailand) nor the main consumers (e.g. China). The working group produced a first draft of specifications, entitled iSNR, to promote sustainable rubber. So far, the project has led to the identification of 5 major axes: (i) productivity, (ii) quality, (iii) child labour, (iv) treatment and use of water, and (v) deforestation.

The limited involvement of producing countries led the tire manufacturers to launch a global platform for sustainable natural rubber (GPSNR) via the World Business Council for Sustainable Development (WBCSD) Tire Industry Project (TIP) at the end of 2017. The goal is to establish a fair, equitable and environmentally sound natural rubber value chain. Based on 12 criteria, the mission of GPSNR is to lead improvements in the socioeconomic and environmental performance of the natural rubber value chain.

⏩ Rubber and oil palm

Role and place of oil palm

Local smallholders rapidly included rubber in agroforestry systems when it was first introduced in Indonesia, in Bogor (Java), North Sumatra and then West Kalimantan Province. Since the 1970s, many government projects have been implemented with the aim of replanting using more productive rubber clones in monoculture systems (SRDP, TCSDP[73]).

During the same period, transmigration centres[74] were created to enable the settlement of Javanese immigrants in Kalimantan, based either on food crops (which was a dismal failure) or on tree crops, first with the rubber and then with oil palm NES[75] which was a relative success (Levang et al., 1997). The Indonesian government's transmigration projects were intended to relocate Javanese transmigrants from overcrowded Java to the outer, less populated islands. The presence of the official Javanese trans-migrant

---

[73] SRDP: Smallholder Rubber Development Project. TCSDP: Tree Crop Smallholder Development Project.

[74] The policy of moving surplus populations from Java island to the outer islands began in 1905. It was re-launched in 1950 following independence, and peaked in the 1980s. The Ministry for Transmigration was established in 1984.

[75] NES: Nucleus Estates Smallholder Scheme (PIR in Indonesian).

populations almost never led to either social or land ownership conflicts with the local Dayaks. The conflicts that did break out in the province in 1998 and again in 2001 involved the Dayak and Madurese communities. Occupation of land by Madurese farmers in the absence of prior negotiation with local communities may well have been one source of conflict, but it was not the only one. Cultural differences and behaviours also triggered tensions between the two communities, and the process accelerated from 1985 to 2010.

This section has been partly originally published in Penot and Geissler (2004). Land occupation in West Kalimantan Province (Borneo), particularly in Sanggau district, changed considerably between the 1980s and 2020. Since the introduction of rubber in agroforests at the turn of 20th century, the Dayak's original slash-and-burn agriculture shifted to jungle rubber, and then, in the 1990s to oil palm. Oil palm and *Acacia mangium* estates were established at a very large scale between 1990 and 2015 thanks to the Indonesian government concession policy. Since the 1980s, the different actors (the State, private companies, local Dayak communities and Javanese transmigrant populations) have adopted land-use strategies that have caused a considerable modification of overall land use. The government policy of issuing concessions for oil palm and *Acacia mangium* led to a new legal redistribution of land to the detriment of local populations whose rights were based on "customary rights" (*adat* in Indonesian). This situation is a potential source of conflict between concession holders and local communities. In 1985, local communities had legal control over 52% of the district, but only over 29% in 1998. Protected forests accounted for 7% and transmigration projects for 3% of the total area. In reality, the situation is less alarming, because only a portion of the land under concessions was actually planted (20% on average in oil palm concessions and 10% in *Acacia mangium* concessions). According to a 1999/2000 survey (Geisser and Penot, 2000), at the end of the last century, in fact 54% of the area was still available for use by local communities. The alarming "legal situation", a source of potential conflict, was therefore tempered by the real rate of land occupation. What has changed in the meantime?

The new legal redistribution of land in the 1990s from the government lend to oil palm and *Acacia mangium* concession policy that took place to the detriment of local populations who, in addition, had not received any clear information on the subject[76]. If the situation continues and land becomes increasingly scarce, it might generate conflict between concession holders and local communities.

Oil palm is now the main crop grown both by local farmers in the area (in 2024 oil palm accounts for 72% of the cropped area) and by the estates, although rubber remains important for those local farmers who want to keep a certain level of crop diversification. In 2020 we found that most of the former jungle rubber area (90% of the whole rubber area in 1994) had been converted to oil palm and/or to a lesser extent, to clonal rubber. In other words, although rubber production continues, the majority of jungle rubber has disappeared because yields of clonal rubber are 3 times higher. In the landscapes under study, oil palm had the effect of a steamroller. Most local Dayak farmers exchanged land in a way that benefited the oil palm estates (the farmers gave up 5 ha of land in exchange for 2 ha planted with oil palm trees provided by the estate).

---

[76] Published in Penot E, 2021. Rubber Agroforestry systems (RAS) in West Kalimantan, Indonesia: an historical perspective. *E3S Web of Conferences* (Vol. 305, p. 02001). EDP Sciences.

In 2024, most farmers cultivate an average of 2 ha of oil palm, 2 ha of rubber (partly clonal and some remaining jungle rubber) and have a small area for food crops or other crops. These farmers can no longer count on land being available, as they did some 25 years ago. We do not know the exact proportion of clonal rubber currently cultivated as agroforestry, but it could be more than 30%.

It is important to grasp the "pros" and "cons" of oil palm and how oil palm has significantly influenced land use, farmers' strategies and cropping patterns. The pros of oil palm are (i) limited labour requirements: 8 days a month/ha compared to 14 for rubber, (ii) secure income up to now, despite fluctuations, (iii) access to homes and to some social benefits, (iv) new roads and access to markets. The cons of oil palm are (i) loss of land (5.5 ha) according to concession regulations, (ii) the risk implicit in a monoculture: less resilience, (iii) one hectare of oil palm requires 700/1,000 kg of fertilisers/year so the farmers must have the necessary capital, and (iv) a recent decrease in the price of fresh fruit bunches.

Because of its advantages, oil palm is now the number one crop for local smallholders, jungle rubber has almost completely disappeared but clonal rubber is still being cultivated, partly as rubber agroforestry. Some local Dayak farmers also kept some jungle rubber as a land reserve while preserving *tembawang* (man-made agroforests with fruits and timber trees, which is possible under *adat* common law). In 2020, in our study area, we were able to estimate that in the 4 villages where the SRAP (Smallholder Rubber Agroforestry Project) was implemented, 70% of available land was under oil palm, 20% under clonal rubber (either monoculture or agroforestry) and 10% remained as old jungle rubber and *tembawang,* according to the farmers. In transmigration areas, the situation was different, as most farmers owned only 2 ha (sometimes 3 ha) mainly planted with clonal rubber. Oil palm companies did not intend to penetrate areas that enjoyed a special status. The Dayak farmers do not have the possibility to cultivate oil palm on new land on their own initiative (Penot and Chambon, 2003).

Deforestation

The very first responsibility for deforestation belongs to Indonesian logging companies. Theoretically, the terms and conditions of the forest exploitation contracts guaranteed sustainable logging (so-called "productive" forest status). It was the failure of forestry companies to respect these terms, leading to considerable over-logging, that made them largely responsible for the first deforestation (Gouyon, 1993), not slash-and-burn agriculture, which long served as an ideal scapegoat[77]. In fact, the TPI law of 1972 and the 1989 TPTI law on management systems[78] laid down in the land ownership legislation were far from being respected by the entire private sector (Cossalter, 1992; Durand, 1999). Indonesia passed legislation classifying 75% of its land as forest production area. In reality, the forestry potential of Indonesia in 1998 was 66 million hectares (Durand, 1999), i.e., 35% of the total area. For Dayak farmers in the Sanggau district of West Kalimantan Province (Borneo), the forest had long been a major resource for

---

[77] In June 1998, the new Minister for the Environment in the first post-Suharto government (the Habibie government) officially recognised that the forest management situation was similar to that in the American Far West in the 19th century, i.e. lawless.

[78] TPI (*Tebang Pilih* Indonesia) and TPTI (*Tebang Pilih Tanam* Indonesia) are laws defining felling methods and the duration of concessions.

hunting, gathering, collecting supplies of wood, medicinal plants, etc. However, the resource diminished following the introduction of tree crops: rubber in 1911, and oil palm and commercial forest crops, primarily *Acacia mangium*, in the 1990s.

Around the Indonesian State plantations (PTP), smallholder plantings (in practice they were controlled by the PTP) have developed and are referred to as NES (Nucleus Estate Smallholder Scheme). The very first tools of government action were smallholder development projects. Two types of projects were designed: sectorial development projects that targeted local farmers (rubber, oil palm, coconut) and transmigration projects that targeted external Javanese populations (rubber, oil palm, coconut and food crops). The State also acted through its policy of issuing forestry concessions, industrial concessions (HTI) and concessions for tree crop plantations to private companies, and through its transmigration programme. Two types of concessions exist: concessions for perennial crop estates (the majority decided to plant oil palm) and concessions for industrial tree crops (most planted *Acacia mangium* for pulp).

The second factor that without doubt intensified deforestation was the official concession policy, particularly that for oil palm. Deforestation was exacerbated by new planting companies (Potter, 1999), particularly in 1997, an El Niño year with a severe drought, when most of the fires that occurred in the area were associated with the planting operations undertaken by these companies (Laumonier and Legg, 1998). Oil palm boomed from 1997 to 2010. The concession policy ended officially in 2015. In the 1990s, many Indonesian companies obtained big concessions (mainly for oil palm) to profit from the oil palm boom. The government considered oil palm to be a “modern” development pathway as well as a valuable source of income and employment for the local population. In 1998, the total area under oil palm area in Indonesia was estimated at 2,634 million ha, up from 500,000 ha in less than 15 years. The different forest status classes are listed in Table S11 (Appendices), and the different types of forest and concession are listed in Table S12 (Appendices) along with their respective actors.

From *adat* to concessions, or the legal wresting of land control from local populations

Common law (*adat*) and land occupation in 1980

Until rubber was introduced at the turn of the 20th century, common land was abundant, it was managed by the community and had no value because there was no market for it. The extension of rubber plantations was accompanied by a gradual shift to land ownership but still based on *adat* local law (Michon et al., 1986). The traditional shared land ownership law grants individual tenure of any plot that is really farmed, and for as long as it continues to be farmed. Planting trees, including rubber, was thus a direct way of acquiring land, and, under the rules of usufruct, ultimately, this is comparable to the private ownership system (Roman law).

West Kalimantan Province as an illustration: the situation in 1995

The case of West Kalimantan Province is typical of the Indonesian situation. In the 1990s, there were 463,000 ha of rubber smallholdings in the province, of which 97.2% used jungle rubber systems (DGE, 1998). Smallholders were also responsible for deforestation, but the damage they caused was gradual, spread out over a whole century, and above all, was relatively limited. Jungle rubber systems are complex agroforests whose end-of-cycle biodiversity is similar to that of secondary forests (de Foresta, 1997). It has even been suggested that most of the remaining forest biodiversity could be found in jungle rubber systems in the 1990s in the central plains of Sumatra and in Kalimantan (de Foresta, 1992a) in the 1990s. Officially, in the 1980s, 74% of the land area of Indonesia was classified as "forest", and hence as under direct State control. The 1960 agrarian law recognised the common law used in the outer islands on one condition: "*in agrarian matters, common law applies provided it does not run contrary to the interests of the Nation and the State*" (Levang, 1997). The State therefore recognised *adat* in these areas until it decided how the land should be used. This enabled the government to recover land under its "royal prerogative" (in the sense that it can do what it likes with the land by virtue of a prerogative that is nevertheless not strictly legal) and redistribute it according to the policies it chooses. In practical terms, there is no way of opposing this, and the State thus behaves as if it were the "owner", in practice, if not entirely legitimately.

This kind of land allocation system can lead to conflict with local communities when land that does not appear to have an owner (particularly on maps), but in fact belongs to a smallholder community, is "given away" for projects (e.g., for transmigration programmes) or for concessions for private plantations. It is worth noting that the local populations are generally not informed about the changed status of the land. This gives rise to two worlds incapable of understanding one another, since they do not perceive land in the same way[79]; one perception is ancestral, based on *adat*, i.e., tradition, while the other is based on "legal" logic.

In West Kalimantan Province, a landscape previously dominated by a mosaic of fallows and jungle rubber was mostly replaced by oil palm plantations. In 2000, most forest had already disappeared. Data from the Ministry of Agriculture showed that Kapuas district became one of the districts with the largest oil palm plantations (Rahayu et al., 2021). Official data from Balai Penelitian Statistik (PBS) for Sanggau showed that between 1994 and 1996, the quantity of oil palm in that area was negligible, whereas in 2019, the land-use distribution was: (i) *Hutan lindung*/watershed protection forest: 100,221 ha, (ii) *Hutan produksi*/production forest that could be converted: 453,300 ha, (iii) plantations: 723,000 ha, (iv) smallholder rubber: 107,000 ha (52,300 families) = 28% of total tree crops, and (v) oil palm (including estates and smallholders): 283,500 ha (58,900 families) = 72% of total tree crops.

In 2024, oil palm represents almost 75% of land planted with tree crops. There was significant replacement of old jungle rubber gardens by smallholder oil palm. This was not the case in Rantau Pandan, where clonal rubber and upland rice mixed with fallows replaced natural forest.

1985-2000: very rapid changes in land occupation resulting from a government policy of granting concessions to planting companies

In view of the still high forestry potential of the area, as early as 1985, the government was planning significant extension of both forest and commercial plantations, and a major policy of concessions through the REPPROT[80] programme launched by

---

[79] In 1980, the local communities were almost the only players, and they controlled the major part of Sanggau district, which was still mainly covered in secondary forest, logged forest (degraded primary forest), smallholder plantings (mainly jungle rubber or rubber agroforests) and *Imperata* savannah.

[80] RePPProT: Regional Physical Planning Programme for Transmigration.

the Ministry for Transmigration. To this end, the State planned to grant "forest for conversion" in these areas. Under conventional logging, had these forests retained their "productive forest" status, they would have been left as they were for 30 years to enable tree regeneration, but as it was, they often burned, either accidentally or fires were set deliberately, with a view to requesting their classification as "forest for conversion", which opened the way for logging in the form of plantations.

Such practices reccurred each time there was a major drought (in 1983, 1987, 1991, 1994 and above all in 1997[81]), with often uncontrolled fires affecting several hundred thousand hectares. There was subsequently a marked increase, particularly in the 1990s, in the conversion of existing land to oil palm and *Acacia mangium*, which eventually jeopardised land availability to local communities.

The government policy of redistributing land to planting companies was linked to the introduction of new crops (oil palm and *Acacia mangium*), which proved to be extremely profitable alternatives for the agricultural sector, not only in Indonesia (high land availability, low labour costs) but worldwide (attractive prices and fast-growing markets). For smallholders, rubber continued to be worthwhile. However, despite the limited area in Kalimantan (less than 13,000 ha), existing rubber estates have not been extended. The size of agricultural concessions varies between 10,000 ha and 300,000 ha, while the area planted on each concession is generally between 3,000 and 20,000 ha.

For the last 20 years, the oil palm industry has played a leading role on the international oils and fats market thereby explaining the recent oil palm planting boom, which resembles the one in Malaysia in the 1980s. Moreover, as mentioned above, the Indonesian government considered oil palm to be a "modern means" of development, and as well as a source of income and employment, direct or indirect, for local populations in the outer provinces. Palm oil also became the leading non-petroleum export commodity in terms of value starting in 1988, ahead of rubber, and continues to be a precious source of foreign currency.

In 15 years, the total area under oil palm and production increased considerably (Figure 4.2), from 500,000 ha in 1984 to 2,634,000 ha in 1998 (DGE 1998), almost 2/3 of which were estates (either State owned or private). The development of private oil palm projects in Sanggau district has given some farmers a new way of diversifying their cropping systems, by benefiting from the loans offered by the planting companies. Palm oil became a serious rival for rubber, which was also confronted by major replanting problems after the original switch from traditional extensive jungle rubber systems to intensive clonal plantings (monoculture or agroforestry systems) in the 1990s.

Preliminary comparative analyses showed that the income per hectare from "clonal rubber" resembled that of oil palm under the conditions in the province (Penot, 2001). However, labour productivity is higher for oil palm except when a reduced-frequency tapping system with stimulation is used for clonal rubber (which in 2023 is not yet the case in Indonesia). Rubber still has a role to play in the rural economy, but the full credit policy and loans provided by planting companies and the relatively short three-year immature period of oil palm are a significant advantage for smallholders, who generally do not have sufficient capital to replant with clonal rubber.

---

[81] Over 5 million hectares of land, including a small proportion of natural forest, burned in 1997, a figure that was exacerbated by "El Niño" (Laumonier, 1998).

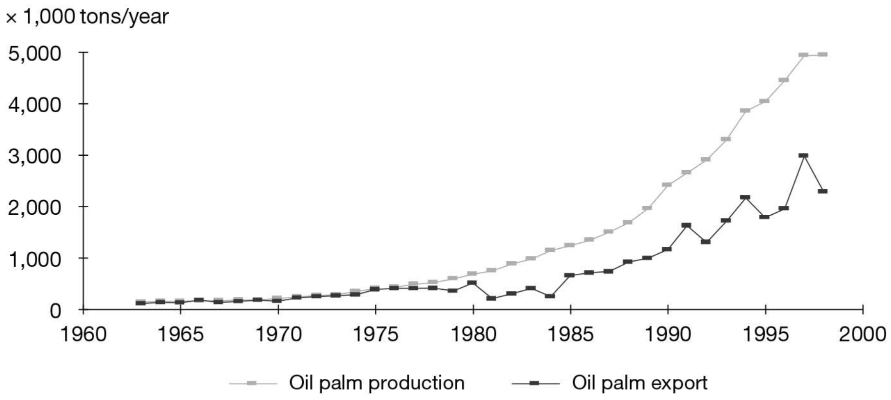

Figure 4.2. Palm oil produced in and exported from Indonesia (1960-1998)

⏩ Conclusion

The communities concerned by the change in the status of their land continue to receive no information about the real legal threat their land is under. The map we were able to obtain for our 1998 study was published, but the local communities were not aware of it. There is one possible way of ensuring harmonious development in the province and that is by accounting for the rights and needs of farming communities on the one hand, and creating an economic environment that will favour the development of an industry centered on plantations, either smallholdings or estates, on the other. However, indicators that could be used to design an appropriate, rational development policy aimed at preventing conflict over land management and occupation, remain to be identified.

The eight points proposed and discussed by Durand in 1999 seem to us to be more relevant than ever in 2023. In fact, they have already been more or less incorporated in forestry policy, the problem is, the policy has never really been applied. We therefore consider it essential to follow the following eight pointers before making any changes to land management practices: 1) officially acknowledge deforestation has been and continues to be due to badly managed logging (and failure to enforce current legislation); 2) conduct a serious inventory of forest cover; 3) reactivat the traditional rights of local populations, not only over forest areas but also over other areas; 4) oversee the practical application of the results of community forestry research and development of agroforestry practices; 5) design and implement viable forest management systems; 6) reduce the size and extent of the concessions; 7) undertake realistic and precise planning of forest use. We would add rational management is required of the switch from "productive forest" to "forest for conversion" status, which opens the door to planting companies.

The main problem with rational and equitable use of land designated a forest area (whether or not it is actually covered by forest) in Indonesia does not stem from the lack of legislation, but rather from the failure to apply it and the lack of means or determination on the part of the State to control forestry and planting companies' activities. The State's wholesale encouragement of planting companies has made it largely responsible for deforestation and for redistributing land to the detriment of local populations. Instead, the State should act as a regulator to reconcile the issues involved in encouraging the private sector to develop a plantation economy which generates foreign currency, the different agricultural development projects, and meet the aspirations of the local community. It is worth noting that the areas conceded are already being reduced, as is the conversion of forested land into agricultural land, which have been achieved by encouraging optimum use of existing concessions before granting new ones.

In 2016, the Indonesian government recognised the need to respond to the interest shown by local populations in agroforestry systems, particularly those that can generate substantial income while maintaining a forest environment and a degree of biodiversity (as is the case with improved RAS. The merits of rubber and oil palm monocultures are also recognised as local development alternatives. It is crucial that local populations are able to manage their own land according to *adat*, which in practice, varies considerably from one region to another. It is consequently important to acknowledge – which was previously the case – that local (Dayak) or transmigrant (Javanese) populations are able to manage their own development without needing to rely on the development of estates and private companies.

In terms of land occupation, the development rationale of private planting companies is diametrically opposed to that of local populations. The State should therefore act as a “distributor”, ensuring the right balance between the various development players and overseeing the rights and duties of each and every stakeholder.