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Environmental, Economic, and Social Consequences of the Oil Palm Boom

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Abstract

Rising global demand for vegetable oil during the last few decades has led to a drastic increase in the land area under oil palm. Especially in Southeast Asia, the oil palm boom has contributed to economic growth, but it has also spurred criticism about negative environmental and social effects. Here, we discuss palm oil production and consumption trends and review environmental, economic, and social consequences in different parts of the world. The oil palm expansion has contributed to tropical deforestation and associated losses in biodiversity and ecosystem functions. Simultaneously, it has increased incomes, generated employment, and reduced poverty among farm and nonfarm households. Around 50% of the worldwide oil palm land is managed by smallholders. Sustainability trade-offs between preserving global public environmental goods and private economic benefits need to be reduced. We discuss policy implications related to productivity growth, rainforest protection, mosaic landscapes, land property rights, sustainability certification, and smallholder inclusion, among others.

1. INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the world's most important oil crops. It is cultivated throughout the tropical belts of Africa, Asia, and Latin America and is widely traded internationally. While oil palm has been grown and used locally for centuries (Hartley 1988), it has boomed during the last few decades due to the rising global demand for vegetable oil (Byerlee et al. 2017, Sayer et al. 2012). Oil palm can produce more vegetable oil per unit of land than any other crop. Due to this comparative advantage, palm oil is now commonly used for direct human consumption, as biofuel, and as an ingredient in many processed foods, cosmetics, pharmaceuticals, and other industrial products (Corley & Tinker 2016). The global area under oil palm increased from less than 5 million hectares in 1980 to more than 20 million hectares in 2018 (FAO 2019). Most of this increase occurred in Indonesia and Malaysia. Exports from these two countries now account for almost 85% of the internationally traded palm oil (FAO 2019).

Although this oil palm boom has been a driver of economic growth in producing countries, it has also led to substantial criticism due to negative environmental and social effects (Obidzinski et al. 2012, Pye 2019, Sayer et al. 2012). The expansion of the oil palm area has contributed to tropical deforestation and associated biodiversity loss, greenhouse gas emissions, land degradation, forest and peatland fires, as well as air and water pollution (Clough et al. 2016, Dislich et al. 2017, Foster et al. 2011, Saharjo & Munoz 2005, Wilcove & Koh 2010). From a social perspective, local rural communities are often claimed to suffer from the oil palm expansion driven by large companies due to conflicts over land and worker rights (Hidayat et al. 2018, Overbeek et al. 2012, Pye 2019). On the other hand, local communities may benefit from the oil palm boom. In addition to large companies, smallholder farmers are significantly involved in oil palm production. It is estimated that smallholders cultivate around 50% of the oil palm area globally (Byerlee et al. 2017). Recent research with data from Indonesia showed that oil palm contributes to rising farm and employment incomes and reduced poverty rates at local, regional, and national levels (Bou Dib et al. 2018b, Edwards 2019a, Kubitza et al. 2018a). These positive economic and social effects are rarely mentioned in the public debate, possibly because they do not fit the popular narrative of oil palm being a major evil (Edwards 2019a, Meijaard & Sheil 2019).

While the research literature about the effects of the oil palm boom is growing, most studies look at specific outcome variables without including other relevant sustainability dimensions. Also, studies on the environmental effects are typically published in different journals than studies on the economic and social effects, leading to coexisting bodies of literature with too little interaction. Broader reviews that synthesize the evidence from an interdisciplinary perspective are rare. One exception is the book by Byerlee et al. (2017) that provides a broad and aggregate overview of various important dimensions of the tropical oil crop revolution. However, due to the breadth of topics covered, Byerlee et al. (2017) hardly discuss the increasing number of microlevel studies on the environmental, economic, and social effects of the oil palm boom. This is what we do in the present article. While we cover evidence from all parts of the world, we put particular emphasis on Indonesia, not only because Indonesia is by far the largest palm oil producer worldwide, but also because of the existence of a large interdisciplinary research project on land-use change in Sumatra that we have been involved in for several years (Clough et al. 2016, Drescher et al. 2016, Krishna et al. 2017b).

2. TRENDS IN GLOBAL PALM OIL PRODUCTION AND USE

2.1. Production Trends

Oil palm is native to Central and West Africa and grows best in the lowland humid tropics (Corley & Tinker 2016). Historical records show that palm oil had already been used in ancient Egypt

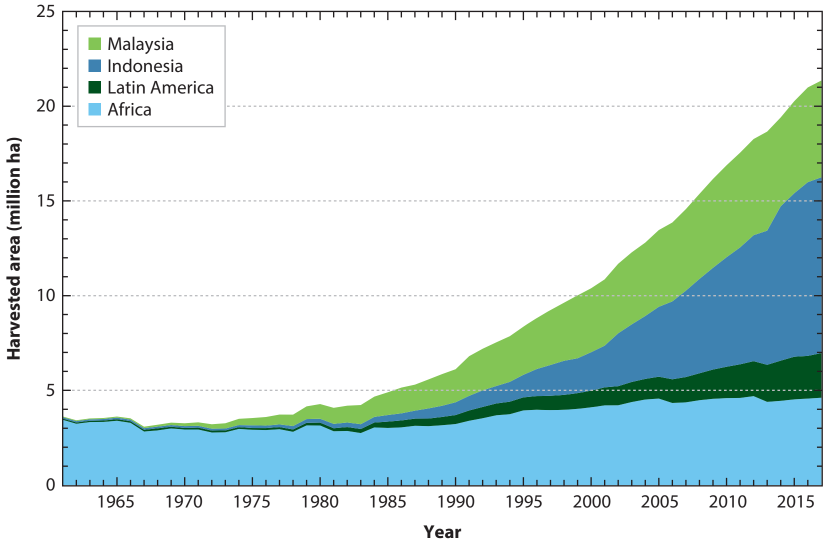

Figure 1

Global oil palm harvested area (1961–2017) in million hectares (ha). Based on data from FAO (2019).

several thousand years ago. During the colonial era, palm oil also started to gain attention in Europe, but production remained largely confined to Africa (Carrere 2013). In Africa, oil palm is mostly grown by smallholders (Ordway et al. 2019). Only in the early twentieth century, a few large oil palm plantations were established mainly by European companies (Byerlee et al. 2017).

In Latin America, oil palm was probably introduced by people of African descent starting in the coastal regions of Brazil (Hartley 1988). The first commercial oil palm plantations were established in Honduras and Costa Rica in the 1940s, and later also in other parts of Latin America (Corley & Tinker 2016). In Southeast Asia, oil palm was introduced in the late nineteenth century by the Europeans, first as an ornamental plant and later for the production of vegetable oil (Cramb & Curry 2012). However, until the second half of the twentieth century, oil palm production outside of Africa remained relatively small. In the 1960s, more than 95% of the global oil palm area was located in Africa, with Nigeria being the dominant producer (**Supplemental Table 1**).

Supplemental Material >

Since the mid-1970s, major developments occurred. The global oil palm area increased drastically, and most of this increase occurred in Southeast Asia, especially Indonesia and Malaysia (**Figure 1**). The production increase coincided with rising international demand for vegetable oil and was supported through public investments and subsidies in several Southeast Asian countries (Cramb & Curry 2012). Interestingly, in Africa, oil palm production hardly increased during the last few decades, which is mainly attributed to unstable political conditions and lack of encouragement by governments and private investors (Carrere 2013).

Much of the oil palm expansion in Southeast Asia occurred on land that was previously cultivated with food and cash crops, or on degraded forest and fallow land (Gatto et al. 2015). However, many oil palm plantations were also established through direct clearing of pristine forests (Gibbs et al. 2010, IUCN 2018, Margono et al. 2014). In Indonesia and Malaysia, around 60% of the oil palm area is managed by large private and public companies that hold long-term land concessions issued by the state; the rest is managed by smallholder farmers (Byerlee et al. 2017, Euler et al. 2016b, Jelsma et al. 2017). Smallholders were often supported to start oil palm cultivation through government subsidies and contract schemes, although more recently many smallholders have expanded their areas independently, without government support or company contracts (Cahyadi & Waibel 2016, Cramb & Curry 2012, Krishna et al. 2017a).

Due to further rising demand, the global production of palm oil will likely continue to increase in the future. While Southeast Asia still has some available land that could be converted to oil palm plantations, environmental concerns and competition with nature and rainforest conservation objectives increase. Hence, more significant future expansion of the oil palm area may occur in other parts of the world, including Africa and Latin America (Pirker et al. 2016).

2.2. Usage Trends

Oil palm bears fruit bunches that can be harvested year-round. The fruits have to be milled in order to derive the vegetable oil. There are two types of oil, which are generally marketed separately: the palm oil from the fleshy mesocarp of the fruit (around 90% of total oil) and the palm kernel oil from the endosperm of the seed (Corley & Tinker 2016). The fruits are perishable and should be milled within 24 hours after harvest. In Africa, the milling was traditionally done on the farm before the palm oil was sold in local markets (Ordway et al. 2019, Ruml & Qaim 2019). This traditional milling leads to unprocessed palm oil that has an intense red-orange pigment because of the high content of beta carotene. This red palm oil is healthy and nutritious (Canfield et al. 2001), but it has a relatively short shelf-life and is therefore not used by larger-scale industries or for international trade (Osei-Amponsah et al. 2012). Outside of Africa, where oil palm is not a traditional crop, farmers mostly sell the fruit bunches to large-scale mills. These large mills produce refined palm oil that has a much longer shelf-life but is bleached and no longer contains beta carotene. More recently, larger mills that produce refined palm oil have also gained in importance in Africa (Ruml & Qaim 2019).

Supplemental Material >

Until the 1980s, palm oil was primarily used as food for human consumption. Since the mid-1980s it has also gained in importance for nonfood industrial uses (**Supplemental Figure 1**), including biodiesel. Palm kernel oil is mostly used for industrial products, including in the chemical, pharmaceutical, and cosmetics industries. Today, around 70% of the total global palm oil production is used for food and 30% for nonfood industrial purposes. Of the industrial quantities, around two-thirds are used to produce biodiesel (USDA 2019). The largest total palm oil quantities are consumed in Indonesia, India, and the European Union (EU) (**Supplemental Table 2**). The EU is the largest importer of palm oil, as there is hardly any domestic production in Europe.

Palm oil has high saturated fatty acid content and is therefore sometimes considered less healthy than other vegetable oils for human consumption. However, a meta-analysis of 51 original studies did not find systematic effects of high palm oil consumption on indicators of coronary heart and cardiovascular diseases (Fattore et al. 2014). Beyond health aspects, palm oil is very popular because of its unique chemical properties that make it useful for a wide range of purposes. Moreover, palm oil is cheaper than alternative vegetable oils, which is due to the high productivity of oil palm per unit of land. One hectare of oil palm typically yields more than three tons of vegetable oil, whereas one hectare of soybean, rapeseed, or sunflower yields less than one ton of vegetable oil (FAO 2019). Soybean, rapeseed, and sunflower have higher protein meal yields, but in terms of oil yield there is no other crop that outcompetes oil palm. Further adding to oil palm's comparative advantage is that it needs less fertilizer and energy and fewer pesticides than other crops to produce one ton of vegetable oil (Byerlee et al. 2017). In 2017, around 40% of the total vegetable oil produced globally was derived from oil palm, even though oil palm only accounted for 10% of the total area cultivated with oil crops (**Figure 2**).

The large differences in land productivity between oil crops imply that oil palm may actually help to reduce the land-use change associated with satisfying the rising global demand for

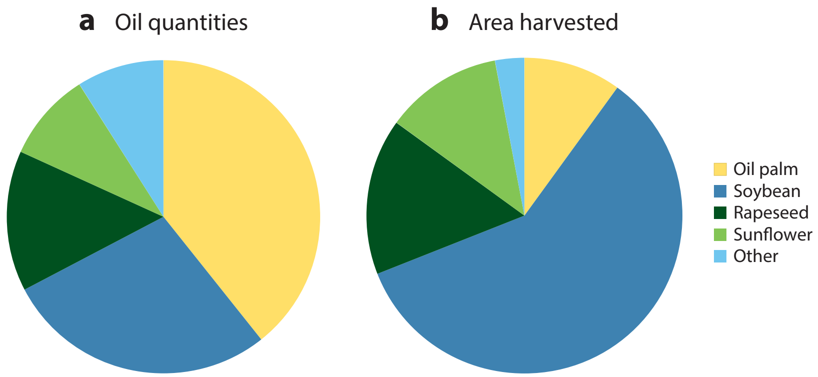

Figure 2

Importance of oil palm in comparison to other oil crops in 2017. (*a*) Percentage contribution of different crops to worldwide vegetable oil quantities produced. Based on data from USDA (2019). (*b*) Percentage contribution of different crops to worldwide oil crop area harvested. Based on data from FAO (2019).

vegetable oil. One drawback is that oil palm only grows in the humid tropics where it competes with tropical rainforest. Oil palm is not the only reason for the observed high rates of tropical deforestation. Nevertheless, international concerns about climate change and biodiversity loss have increased recently, which is also felt in the palm oil industry. International standards and certification schemes have been developed and implemented with the goal to reduce the negative environmental impact of oil palm production. Several EU countries have set certification targets for palm oil imports. The largest certification initiative is the Roundtable on Sustainable Palm Oil (RSPO), which had certified close to 20% of global palm oil production in 2019 (**https://www.rspo.org**). Beyond certification, the EU has indicated that it may ban palm oil–based biodiesel in the future. Such policies in importing regions can have major effects on producing countries and international trade flows (Taheripour et al. 2019).

3. ENVIRONMENTAL EFFECTS

The oil palm boom has contributed to economic growth, but it has also led to negative environmental effects. Numerous studies identified oil palm as a driver of deforestation and land-use change, as well as associated losses in biodiversity and ecosystem functions. In this section, we first provide an international overview of environmental effects in producing countries of Asia, Africa, and Latin America, including comparisons between oil palm and major competing oil and plantation crops. We then focus in more detail on Indonesia, where we have ourselves collected data on biodiversity and ecosystem functioning for many years.

3.1. International Overview

We provide an international overview of the environmental consequences of oil palm expansion, differentiating between tropical forest loss, effects on biodiversity, and effects on ecosystem functions such as carbon storage, soil regeneration, and air and water purification, among others.

3.1.1. Effects on tropical forests. The expansion of oil palm since the mid-1970s has heavily transformed tropical landscapes. One major outcome has been deforestation of tropical forests, with strong impacts on biodiversity and ecosystem functions. During the last 40 years, oil palm accounted for 47% and 16% of total deforestation in Malaysia and Indonesia, respectively (IUCN 2018). With an average forest loss of 350,000 hectares annually, deforestation is particularly dramatic on the island of Borneo, where about half of the deforestation between 2005 and 2015 was directly linked to industrial oil palm plantations (Gaveau et al. 2016, IUCN 2018).

In Africa, deforestation rates due to oil palm expansion are much lower than in Southeast Asia, coinciding with the lower economic importance of the crop. Only about 3% of forest loss in Nigeria between 2005 and 2015 was attributed to oil palm development (Okoro et al. 2016). Also in Latin America, oil palm has not been the main contributor to deforestation. While overall deforestation rates have been high in many Latin American countries, around 80% of the regional oil palm expansion occurred not at the expense of forests but on abandoned pastures and other land-use systems (Furumo & Aide 2017). In Brazil, oil palm is mainly produced in the eastern Amazonian state of Pará, where the crop's area doubled between 2004 and 2010 (Villela et al. 2014). Plans by the Brazilian government to significantly increase biofuel production suggest that large-scale future oil palm expansion is likely (Lees et al. 2015). However, much of this expansion is expected to occur on already cleared land, thus potentially minimizing additional deforestation (Lees et al. 2015). Of course, indirect effects cannot be ruled out.

Globally, about half of the current oil palm area was developed at the expense of forests (ranging from 68% in Malaysia to 5% in Central America), whereas the other half replaced pastures, shrubland, and other land uses (IUCN 2018). However, from a longer-term perspective, the vast majority of the replaced land uses had been previously converted from natural land, including biodiversity hotspots such as the Amazon rainforest or the Brazilian Cerrado savannah.

Although comprehensive data sets on industrial palm oil production are available, the role of smallholders in oil palm expansion and deforestation remains less well understood (Carlson & Garrett 2018). It is clear that smallholders are also involved in deforestation to a significant extent (Krishna et al. 2017b, Kubitza et al. 2018b). Cohn et al. (2017) used data from different world regions to show that smaller mean farm size is associated with a higher forest loss per hectare of agricultural land, meaning that smallholders tend to have a disproportionately large effect on their natural environment. This can be partly explained by lower crop yields of smallholder farms and a lack of formal land titles.

3.1.2. Effects on biodiversity. Clearing tropical forests for oil palm results in strong local and regional biodiversity declines (Clough et al. 2016, Fitzherbert et al. 2008, IUCN 2018, Rembold et al. 2017). While rainforests can harbor >470 tree species per hectare (Valencia et al. 1994), oil palm is commonly produced in monocultures. Compared to the forests that they replace, these monocultures are far less structurally complex; that is, they have only one canopy layer instead of multiple forest strata, they lack a complex and rich understory vegetation, and they are almost devoid of leaf litter and woody debris, all of which are needed to support the high biodiversity of tropical forests. In addition, pesticides, chemical fertilizers, and frequent human disturbance make oil palm plantations unhospitable for the great majority of forest species. Popular examples of species incompatible with plantations include the critically endangered orangutans and tigers of Borneo and Sumatra (Luskin et al. 2017). Equally at risk are certain birds (Edwards et al. 2013, Lees et al. 2015), amphibians (Paoletti et al. 2018), fishes (Giam et al. 2015), plants (Rembold et al. 2017), insects (Mumme et al. 2015, Scriven et al. 2017), and belowground-living species (Brinkmann et al. 2019, Sahner et al. 2015, Susanti et al. 2019).

Knowledge of the biodiversity effects of oil palm in regions other than Southeast Asia is scarce. From their study of multiple land uses in eastern Amazonia, Lees et al. (2015) concluded that oil palm plantations supported less bird diversity than pastures and similar or less diversity than soybean and eucalyptus plantations. However, the forest fragments that oil palm companies are obliged to protect under Brazilian environmental legislation support high bird diversity (Lees et al. 2015).

To thoroughly evaluate biodiversity effects, oil palm should not only be compared to forest but also to alternative land uses. Another major plantation crop in Southeast Asia is rubber. Like oil palm, rubber is nowadays mainly produced in monoculture plantations with comparable effects on biodiversity (Clough et al. 2016, Zhang et al. 2017). Studies in Indonesia and Thailand found similarly low levels of bird diversity in oil palm and rubber monocultures (Aratrakorn et al. 2006, Prabowo et al. 2016). The biodiversity value increases strongly when rubber stands are intermixed with native trees in agroforestry systems (Clough et al. 2016). However, owing to their low yield and high labor costs, traditional rubber agroforestry systems were almost completely transformed to monocultures in most parts of Southeast Asia.

Soybean is another major crop that has contributed to heavy transformations of tropical landscapes since the 1960s. In the two years preceding Brazil's soy moratorium in 2006, nearly 30% of soybean expansion occurred through deforesting the Amazon (Gibbs et al. 2015). In the world's most biodiverse savannah ecosystem, the Brazilian Cerrado, the moratorium does not apply, and soybean expansion remains sizeable (Gibbs et al. 2015). Despite soybean's economic and environmental importance, apparently no studies on how this crop affects biodiversity exist (Carlson & Garrett 2018). Hence, direct comparisons with oil palm are difficult.

3.1.3. Effects on ecosystem functions. Forest conversion to oil palm plantations also affects ecosystem functions. Among others, the functions affected include carbon storage, nutrient cycles, soil regeneration, and air and water purification. These and many other functions of ecosystems also contribute to human well-being, and can therefore be additionally classified as ecosystem services, as popularized by the United Nations' Millennium Ecosystem Assessment (MEA 2005).

Tropical forest conversion to agriculture, often achieved by land clearing with fire, is a major source of global greenhouse gas emissions (Carlson et al. 2012). The standing carbon stock of a tropical rainforest ranges from 175 to 272 tons per hectare (Katayama et al. 2013, Sayer et al. 2012). For comparison, depending on age and planting density, the standing carbon stocks of oil palm plantations range between 2 and 60 tons per hectare (Kho & Jepsen 2015). Comparing old-growth forests to oil palm plantations on Sumatra, Kotowska et al. (2015) showed that carbon pools are reduced by 167 tons per hectare (from 195 tons per hectare in forests to 28 tons per hectare in oil palm plantations). However, with an average carbon pool loss of 157 tons per hectare, reductions are equally high for conversion of old-growth forest to rubber monoculture (Kotowska et al. 2015). Also important to note is that the standing carbon stock of mature oil palm plantations is still far higher than that of other oil crops, such as soybeans with a standing biomass of approximately 6 tons per hectare at the end of a 120-day crop period (Sayer et al. 2012).

With a focus on biofuels, it has been argued that carbon debts resulting from deforestation are, over time, compensated by carbon savings from producing biodiesel from palm oil instead of diesel sourced from petroleum. However, the necessary time for compensation strongly depends on the previous land use; it is around 86 years when oil palm replaces tropical lowland rainforest, and up to 840 years when peatland is deforested and drained (Fargione et al. 2008). Hence, relative to emissions caused by fossil fuels, biofuel production from oil palm in fact increases net CO_2 emissions for decades or even centuries (Fargione et al. 2008).

Oil palm plantations strongly affect local and regional air and water quality. When plantations are established with land-clearing fires, large amounts of smoke, CO_2, and toxic gases (CO, CO_3, NO_2) are released, causing respiratory problems and increased human mortality (Johnston et al. 2012). Fires and related health problems increase in dry years with El Niño episodes (Dislich et al. 2017). Once established, oil palm plantations emit volatile organic compounds that can promote the production of aerosols and haze, lowering local air quality (Pyle et al. 2011). Large-scale oil palm cultivation also affects regional water quality, mainly through excess application of fertilizers that cause nitrate pollution (Comte et al. 2012), and the redistribution of water flows that may cause periodic water scarcity in villages surrounding oil palm estates (Merten et al. 2016). In addition, millions of tons of palm oil mill effluent—a polluted mix of crushed shells, water, and fat residues—are returned each year by some of the mills to watercourses without treatment (Comte et al. 2012).

3.2. Microlevel Evidence from Indonesia

We have collected biodiversity and environmental data in Jambi Province on Sumatra since 2012. Jambi has been one of the hotspots of the Indonesian oil palm boom during the last 25 years. Our data include ecological surveys across 24 study plots, with 8 plots situated in protected old-growth rainforest, and 8 plots situated in smallholder oil palm and rubber monocultures, respectively (Clough et al. 2016, Drescher et al. 2016). We also studied ecological functions in 8 traditional rubber agroforestry plots (Clough et al. 2016); however, as this traditional agroforestry system is of limited practical relevance today, we do not report those results here.

3.2.1. Biodiversity and ecosystem functions in rainforest, oil palm, and rubber. Deforestation of the tropical lowland rainforests in Jambi already started more than 100 years ago, long before oil palm was introduced. In the 1970s, logging and conversion to other land uses intensified. With high rates of deforestation between 1990 and 2000, Jambi Province lost most of its lowland rainforests (Clough et al. 2016). Today, land use in the province is dominated by monoculture plantations, with rubber and oil palm being the two most important crops in terms of area. Our comprehensive analysis of the biodiversity of 12 different taxonomic groups revealed an overall strong decrease in species richness with forest conversion to smallholder oil palm plantations (**Figure 3*a***). With few exceptions (e.g., bats, understory plants), most taxa are also less abundant in oil palm plantations than in forests. Differences between oil palm and rubber are less clear. In fact, rubber plantations frequently support similar or even less species diversity than oil palm plantations (**Figure 3*b***).

Besides effects on biodiversity, we also quantified ecosystem functions in oil palm and rubber. Compared to forests, tree biomass, litter decomposition, root health, and microbial activity and biomass were significantly reduced in both monoculture plantations, while nutrient-leaching fluxes (an agricultural disservice) were higher in oil palm (Clough et al. 2016). Similarly, the air inside oil palm and rubber plantations is on average warmer (ca. 2°C) and drier (ca. 12% less relative humidity) than the air inside forests, underlining that plantation agriculture changes the local climate (Meijide et al. 2018). Quantifying both aboveground and belowground carbon stocks, carbon losses due to forest conversion to oil palm and rubber average 61% and 56%, respectively (Guillaume et al. 2018). Focusing on invertebrate communities in forests and oil palm plantations, we detected up to a 51% reduction in the energy flux in food webs, which indicates that species interactions, such as predators feeding on prey, are strongly impaired (Barnes et al. 2014). Taken together, our findings echo the strong environmental effects of oil palm, but they also highlight similarly negative effects of other agricultural land uses in Jambi Province.

3.2.2. External validity. The concrete numerical results from Jambi Province should not be directly extrapolated to other parts of the world, even though many of the general findings may also hold more broadly, at least for Southeast Asia. Where management intensity of oil palm plantations and pressure on natural ecosystems are similar (e.g., in Malaysia), comparable negative

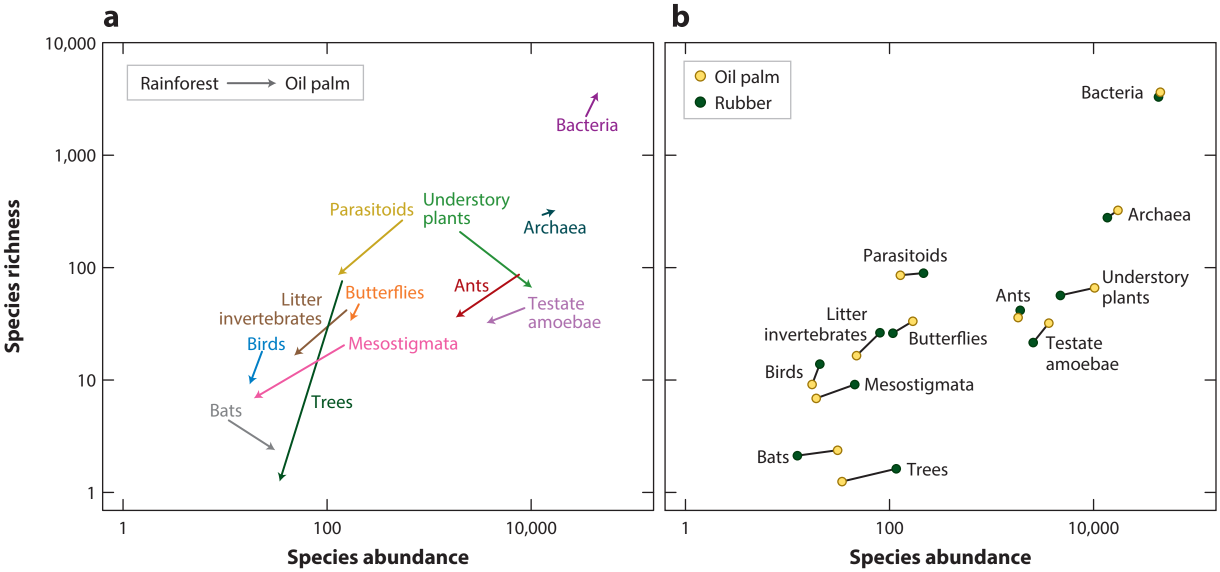

Figure 3

Biodiversity of rainforest and smallholder oil palm and rubber plantations in Jambi Province, Indonesia. (*a*) Biodiversity effects of rainforest transformation on smallholder oil palm. Arrows indicate changes in species richness (total number of species) and species abundance (total number of all individuals) for 12 taxonomic groups, with arrow tips marking biodiversity outcomes in oil palm plantations. (*b*) Comparison of biodiversity in oil palm (*yellow circles*) and rubber (*green circles*) smallholder plantations. Values of richness and abundance are averages based on standardized biodiversity surveys in twenty-four 50 × 50 m study plots in the tropical lowlands of Sumatra, Indonesia. Figure based on data from Barnes et al. (2014), Clough et al. (2016), Drescher et al. (2016), Grass et al. (2020), Krashevska et al. (2016), Rembold et al. (2017), Sahner et al. (2015), and Schneider et al. (2015).

effects on biodiversity and ecosystem functions can be expected. Where oil palm is cultivated less intensively, for instance, in extensive agroforestry or organic systems, the negative environmental effects per unit of land may be smaller, but the effects per unit of output may not differ or even be higher, as less-intensive systems also have lower yields (Meemken & Qaim 2018). So far, very few studies have analyzed in detail the environmental effects of oil palm in Africa and Latin America, which is a research gap, especially considering that these may be the regions with major oil palm expansion in the future.

4. ECONOMIC AND SOCIAL EFFECTS

Oil palm is cultivated by large companies and smallholder farmers. Numerous studies have analyzed the effects of oil palm cultivation and expansion on economic growth and other dimensions of human welfare. As in the previous section on environmental effects, in this section we start with an overview of the economic and social effects in different parts of the world, before then focusing in more detail on Indonesia.

4.1. International Overview

For many tropical countries, palm oil is an important contributor to gross national product and foreign exchange earnings. In 2018, the total value of international palm oil trade amounted to US$30 billion, with Indonesia and Malaysia being the biggest exporters. In Indonesia, palm oil accounts for almost 10% of total national exports. Also in several smaller countries, such as Honduras, Papua New Guinea, Solomon Islands, and Guatemala, palm oil exports account for around 5% of total national exports (**Supplemental Table 3**).

Supplemental Material >

In many situations where oil palm was recently expanded, farmers switched from food or other cash crops to cultivating oil palm. Elsewhere, fallow land or forests were converted to oil palm plantations, with negative environmental effects, as described above. Numerous studies in different countries showed that oil palm cultivation has contributed considerably to rural economic development. A general finding is that the expansion of oil palm has brought about significant income gains for farmers, laborers, and other people involved in the supply chains, including traders, intermediaries, and small-scale processors. Rural households and communities benefit in terms of higher farm profits, new employment opportunities, and improved rural infrastructure (Edwards 2019a,b; Feintrenie et al. 2010; Gatto et al. 2017; Naylor et al. 2019; Obado et al. 2009; Obidzinski et al. 2012; Rist et al. 2010). Nevertheless, not all households and communities benefit to the same extent (McCarthy 2010, Obidzinski et al. 2012, Santika et al. 2019a).

4.1.1. Effects on farm households.

In Southeast Asia, numerous studies showed that the cultivation of oil palm contributes to income gains, capital accumulation, and higher expenditures on food, health, education, and durable consumer goods in smallholder farm households (Alwarritzi et al. 2016, Cramb & Curry 2012, Feintrenie et al. 2010, Kubitza et al. 2018a, Obidzinski et al. 2012, Rist et al. 2010, Sibhatu 2019, Susila 2004). In Africa, farm households are also generally better off when they cultivate oil palm than when they do not. A study in Guinea found that oil palm farmers had more stable incomes and higher levels of food security than farmers not involved in oil palm or other cash crops (Balde et al. 2019). A study in Ghana showed that oil palm farmers have higher incomes and suffer less from multidimensional poverty than other farmers, also after controlling for possible confounding factors (Ahmed et al. 2019).

4.1.2. Effects on nonfarm households.

Effects on nonfarm households were also analyzed in several studies. Oil palm is relatively labor intensive because most of the operations are carried out manually (van Noordwijk et al. 2001). In Indonesia, oil palm on large company plantations and smallholder farms created rural employment and economic benefits for many landless laborers (Obidzinski et al. 2012, Santika et al. 2019b). In Ghana, working in oil palm is an important source of income for many rural households, and those employed in oil palm are better off than those employed in other agricultural subsectors (Ahmed et al. 2019). Studies in Ghana and Cameroon showed that rising demand for palm oil allowed small-scale entrepreneurs, including poor rural women, to start artisanal processing mills and thus generate extra income (Awusabo-Asare & Tanle 2008, Nkongho et al. 2014). A study in Nigeria showed that small-scale processing mills also generate employment for rural households (Ohimain & Izah 2014). In Uganda, many young adults are migrating to oil palm regions because of lucrative new employment opportunities (Green Livelihoods Alliance 2019).

In Mexico and Guatemala, rural households also benefit from new jobs and higher employment incomes in the palm oil sector (Abrams et al. 2019, Mingorría et al. 2014). However, in spite of higher wage incomes, employment in the palm oil sector does not necessarily improve welfare in terms of food security and other nonincome dimensions, as this also depends on the local availability of food, the efficiency of food markets, and intrahousehold gender roles (Castellanos-Navarrete et al. 2019, Hamann 2018, Mingorría et al. 2014).

4.1.3. Broader rural development effects.

Beyond individual farm and nonfarm households, several studies examined the impact of the oil palm boom on broader economic and social development with village- or regional-level data. Studies from Indonesia showed that the oil palm boom led to improved rural electrification, road and market infrastructure, new schools, and better healthcare facilities (Edwards 2019b, Gatto et al. 2017). Edwards (2019a) used municipality-level data from Indonesia and a difference-in-difference framework to show that the expansion of oil palm was responsible for a 9-percentage-point reduction in the national poverty rate. Kubitza & Gehrke (2018) also used municipality-level data from Indonesia to show that the oil palm expansion led to economic growth and increasing returns to education, thus contributing to changes in family planning and declining population growth over time.

Santika et al. (2019a) used village-level data from Kalimantan, Indonesia, pointing out that oil palm cultivation contributed to positive trends in economic well-being in some but not all communities. Positive effects on broader socioeconomic development were also found in other countries. Castiblanco et al. (2015) used regional data from Colombia to show that municipalities with oil palm cultivation have lower poverty rates and higher levels of food security than similar municipalities without oil palm cultivation.

4.1.4. Social problems. Most of the economic studies with representative samples or higher-level regional data show that the oil palm expansion has benefited rural households and communities on average. However, often the benefits are not distributed evenly. The establishment of oil palm plantations requires a lot of capital that not all smallholders have access to. Hence, farm households with better access to capital may adopt oil palm earlier and faster, which can contribute to rising inequality (Colchester 2011, McCarthy 2010). In some cases, poor farm households without sufficient access to capital sold their land to other farmers (Obidzinski et al. 2012). At the community level, some communities may also benefit more than others due to differences in agroecological and socioeconomic conditions (Edwards 2019a). With their village-level data from Kalimantan, Santika et al. (2019a) showed that communities that had experience with market-oriented production systems prior to cultivating oil palm benefited more than communities that previously relied primarily on subsistence agriculture. In remote villages, the effects of oil palm plantations on socioeconomic well-being were even negative (Santika et al. 2019a).

The institutional context also matters for the distribution of benefits. Particularly in Indonesia, many smallholders started their engagement in the palm oil sector through production contracts with large companies (Baudoin et al. 2017, Morgans et al. 2018, Rist et al. 2010). Even though these contracts were beneficial for farmers and communities in general (Cahyadi & Waibel 2016, Gatto et al. 2017), details of the contractual arrangements were not always sufficiently clear, which sometimes led to dissatisfaction and conflict (Abram et al. 2017, Persch-Orth & Mwangi 2016, Santika et al. 2019b).

Beyond contractual disputes between companies and farmers, conflicts sometimes arise due to unclear land property rights. Local communities often claim property rights for forest or previously forested land under customary law, even though they rarely have formal land titles (Krishna et al. 2017b). This can lead to clashes when palm oil companies obtain land concessions from the state that overlap with community land (Fitzpatrick 1997). In some cases, negotiations with compensation measures and/or the involvement of local communities through outgrower schemes can help to settle conflict, but this requires that both parties are willing to negotiate, which is not always the case (Andrianto et al. 2019, Rist et al. 2010). Even with compensation of local communities, outcomes can be unfair due to unequal power relations (McCarthy 2010, McCarthy & Cramb 2009, Pye 2019). Much of the existing literature on conflicts between palm oil companies and local communities refers to Southeast Asia, but similar issues related to land property rights were also reported in various countries of Latin America (Castellanos-Navarrete et al. 2019, Castiblanco et al. 2015, Moser et al. 2014).

In regard to laborers on oil palm plantations, social problems were identified in some situations. Li (2018) reported about issues of child labor on oil palm plantations in Kalimantan, Indonesia. Naylor et al. (2019) detailed the use of illegal migrants and poor worker conditions in the Indonesian palm oil sector. Poor worker conditions were also reported in Guatemala (Hervas 2018). Finally, certain socioeconomic problems can also result from negative environmental externalities of oil palm production, such as the overuse of agrochemicals. Studies in Indonesia and Uganda found detrimental effects on water quality and the local fishing industry (Fearnside 1997, Green Livelihoods Alliance 2019).

4.2. Microlevel Evidence from Indonesia

In addition to the biodiversity and environmental data collected in Jambi Province (Sumatra, Indonesia), which were discussed in detail in Section 3.2, we have also collected comprehensive socioeconomic data in the same region since 2012. Our socioeconomic data are from a survey of 100 randomly selected villages (Gatto et al. 2015), a panel survey of 700 randomly selected farm households (Krishna et al. 2017a, Kubitza et al. 2018a), and a panel survey of 430 randomly selected nonfarm households (Bou Dib et al. 2018b). Results from these data are summarized below.

4.2.1. Oil palm adoption. As mentioned, deforestation in Jambi had started long before oil palm was introduced. In the first half of the twentieth century, rubber production in extensive agroforestry systems was an important economic activity of local communities. Increasing global demand for rubber has contributed to intensified production since the 1970s. Oil palm production started in the 1980s. Over the last 30–40 years, lowland rainforests and extensive agroforestry systems largely disappeared, making space for more intensive rubber and oil palm monocultures (Klasen et al. 2016, Krishna et al. 2017a).

Oil palm was first introduced in Jambi by large public-sector companies. During the 1980s and 1990s in particular, smallholder inclusion was promoted by the Indonesian government through the so-called "nucleus estate and smallholder" (NES) schemes (Euler et al. 2016b, Feintrenie et al. 2010). In these schemes, smallholders received financial and technical support to start oil palm cultivation under a company contract. The NES schemes were particularly relevant for the government's transmigration program of the 1980s and 1990s, in which families from Java's densely populated areas were relocated on a voluntary basis to Sumatra and other outer islands where they received land, credit, and technical support for agricultural production (Fearnside 1997). From the mid-1990s onward, similar smallholder contracting schemes were implemented by private-sector palm oil companies also involving autochthonous communities, yet with much less government support than in the initial NES schemes (Gatto et al. 2017, McCarthy & Cramb 2009).

Smallholder oil palm adoption in the late 1980s and early 1990s started through contract schemes, but since the mid-1990s smallholders have also adopted oil palm independently—without company contracts (**Figure 4*a***). Most of the contracts had durations of 15–20 years, so the share of farmers with contracts started to decline after 2005. Although oil palm adoption continues to rise, over 95% of the smallholder adopters now cultivate oil palm independently. A few medium-scale palm oil mills were also established recently. Overall, it is estimated that smallholders manage around 40% of the oil palm land in Jambi, with a further rising trend (Euler et al. 2016b, Krishna et al. 2017a).

4.2.2. Socioeconomic effects of oil palm adoption. Our data show that smallholder farmers in Jambi benefit significantly from oil palm adoption. Oil palm generates higher incomes than rubber, the most relevant competing cash crop in the local context. Although oil palm is more

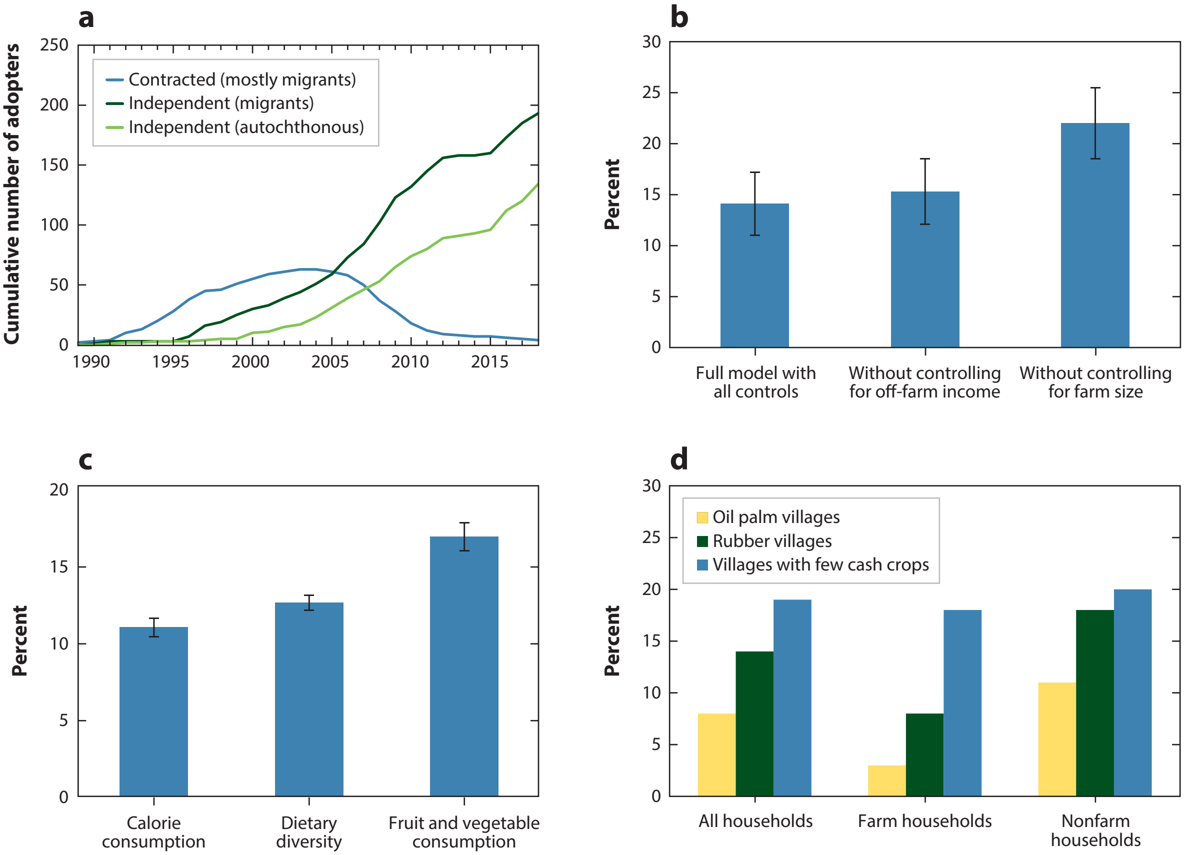

Figure 4

Adoption and socioeconomic impact of oil palm in Jambi Province, Indonesia. (*a*) Adoption of oil palm in a random sample of 700 farm households. Based on data from Euler et al. (2016b) and the authors' own unpublished data. (*b*) Treatment effects of oil palm cultivation on household consumption expenditure (with standard error bars). Based on data from Kubitza et al. (2018a). (*c*) Treatment effects of oil palm cultivation on household diets and nutrition (with standard error bars). Based on data from Sibhatu (2019). (*d*) Poverty rates in different types of villages. Based on data from Bou Dib et al. (2018a).

capital intensive than rubber, it is less labor intensive, so that a larger land area can be cultivated with a given amount of labor (Euler et al. 2017). Alternatively, the labor saved when switching from rubber to oil palm can be used for off-farm economic activities. Panel regression models show that the net treatment effect of oil palm adoption on household consumption expenditure, a common indicator of living standard, is around 14% when controlling for farm size, off-farm income, and other possible confounding factors (**Figure 4*b***). The effect slightly increases when not controlling for off-farm income, suggesting indeed that some of the labor saved is used for off-farm economic activities. The treatment effect further increases to 22% when not controlling for farm size (**Figure 4*b***), as many farmers increased their land area after oil palm adoption. Increasing the land area occurs through land market transactions as well as direct forest encroachment (Krishna et al. 2017b).

We also analyzed effects on other dimensions of farm household welfare, such as food security and nutrition. Oil palm adoption has increased calorie consumption and dietary quality (**Figure 4*c***), mainly through the positive income effect. Rural households in Jambi obtain almost all of their food from the market; subsistence food production does not play an important role anymore in the local context (Sibhatu & Qaim 2018).

But not all farm households benefited to the same extent. Transmigrant farmers received subsidized credit and technical support through the NES schemes (Gatto et al. 2015). In addition, transmigrants received formal titles for the land allocated to them, whereas most of the autochthonous households in Jambi do not have formal titles (Krishna et al. 2017b). As land titles can be used as collateral, transmigrants also had easier access to credits when they wanted to expand their oil palm areas without contracts in subsequent years. Against this background, transmigrants adopted oil palm earlier and more extensively than autochthonous farmers (**Figure 4*a***). Nowadays, many autochthonous farmers also cultivate oil palm, but the earlier gains for transmigrants have led to capital accumulation and differences in wealth. Transmigrant communities are better off than autochthonous communities, and this even though transmigrants were poorer in the beginning when they started their farming activities in Jambi some 25–30 years ago (Gatto et al. 2017). In other words, historically, oil palm has helped to reduce income inequality, but today the crop's further expansion rather contributes to rising inequality among farmers in Jambi (Euler et al. 2017).

Rural nonfarm households are also affected by the massive land-use change, as many of them are employed in rubber and oil palm (Bou Dib et al. 2018b). On average, nonfarm households in Jambi are 30% poorer than farm households (Bou Dib et al. 2018a). Although rubber requires more labor than oil palm per unit of land, the oil palm boom has generated additional employment due to the expansion of the total land cultivated. And wages for workers in oil palm tend to be higher than wages in rubber. Bou Dib et al. (2018b) have shown that the oil palm expansion has benefited nonfarm households through new income-earning opportunities. Beyond the additional employment on farms, on plantations, and in processing mills, the oil palm boom has contributed to broader economic growth, also in local nonagricultural sectors (Gatto et al. 2017).

The additional employment income through oil palm has reduced income inequality among nonfarm households (Bou Dib et al. 2018a). Looking at farm and nonfarm households together, the oil palm boom had no significant effect on income inequality in rural Jambi (Bou Dib et al. 2018b, Kubitza et al. 2019). But it helped to reduce rural poverty: In villages with a lot of oil palm, the mean poverty rate is now around 8%, whereas it is 14% in villages where rubber is the dominant crop (**Figure 4*d***). In villages with little cash crop production, poverty rates are still higher, at around 20%.

Beyond poverty and income inequality, one important question that deserves further research is the gender dimension of the land-use change. While many women work in rubber, they are rarely employed in oil palm due to the greater physical strength required. Depending on the economic alternatives and possible cultural constraints, the release of female labor from agriculture may have positive or negative effects on women's empowerment (Chrisendo et al. 2019).

4.2.3. External validity. Although the socioeconomic data collected in Jambi are representative of the province, the evidence from Jambi cannot directly be extrapolated to other regions and countries. The effects of oil palm on income distribution may specifically differ depending on the local context. In Jambi, much of the rainforest had already been cleared, and local farmers were used to the production of commercial cash crops before oil palm was introduced in the 1980s. In other regions, where local communities are more dependent on forests and subsistence agriculture, the distribution of benefits would likely be different (Santika et al. 2019a). However, the more general findings from Jambi, namely that the oil palm expansion has contributed to poverty reduction and economic welfare gains among farm and nonfarm households, are consistent with recent studies that used nationally representative data from Indonesia (Edwards 2019a, Kubitza et al. 2019, Kubitza & Gehrke 2018).

5. TOWARD MORE SUSTAINABLE SYSTEMS

The previous sections have shown that the oil palm boom has created environmental problems, economic and social gains for many but not for all, and occasional conflicts over land. The global demand for vegetable oil will continue to grow. Against this background, banning or curbing oil palm cultivation is not a realistic option. Given oil palm's high land productivity, meeting the rising demand only through other oil crops would entail even more land-use change and natural habitat loss. Nevertheless, the trade-offs between private economic gains and the loss of global environmental goods have to be managed and reduced to the extent possible (Azhar et al. 2017, Bennett et al. 2019, Byerlee et al. 2017). In this section, we discuss policy options that could help toward establishing a more sustainable palm oil sector. This is relevant for Southeast Asia, but also for Africa and Latin America, where much of the future oil palm expansion is expected to occur (Laurance et al. 2014, Ordway et al. 2019, Rhebergen et al. 2016).

5.1. Increasing Oil Palm Productivity

The rising global demand can be met by further expanding the oil palm area and/or by increasing oil palm yields. As area expansion often means loss of tropical rainforest, increasing oil palm yields should be given higher priority. Significant gaps between actual and potential yields are observed: Although actually harvested oil yields rarely exceed three tons per hectare and year, up to eight tons could be harvested with better cultivation practices and quality inputs, including avoidance of counterfeit seedlings (Corley & Tinker 2016, Woittiez et al. 2017). Higher yields are not necessarily associated with proportionally higher quantities of agrochemicals; organic fertilizers and improved management can also play important roles in reducing the yield gaps (Darras et al. 2019). Developing and implementing improved practices at larger scale will require more agronomic research and improved extension systems.

Breeding research could also contribute to increasing oil palm productivity (Zulkifli et al. 2018). Oil palm grows particularly well in lowland regions with high temperatures and well-distributed rainfall patterns. However, because of land scarcity and rainforest conservation goals, oil palm is gradually expanding also into regions with suboptimal climatic conditions, which can reduce productivity significantly. Modern breeding technologies could help to develop oil palm varieties that are highly productive and more tolerant to altitude and climate stresses (Corley et al. 2018, Zulkifli et al. 2018).

5.2. Forest Protection and Land Property Rights

Agricultural productivity gains through improved technologies can reduce crop area expansion and deforestation globally, but locally they can also act as incentives for further forest encroachment, especially when protection policies are not in place (Villoria 2019). Efficient legal and institutional frameworks in oil palm–producing countries are therefore required (Ordway et al. 2017, Taheripour et al. 2019). One important policy area is the clear delineation of protected forest lands combined with strong rules on use rights, prohibitions, and effective sanction mechanisms. Customary land rights of local communities need to be recognized (Dauvergne 2018). Where customary rights have to be curtailed to achieve other sustainability goals, fair compensation mechanisms, such as payments for environmental services, should be developed. This does not mean that zero expansion of the oil palm area is the most sustainable strategy. But natural habitats that are particularly environmentally sensitive, such as peatland forests, certainly deserve special protection. Through proper combinations of rules, sanction mechanisms, technologies, and economic incentives, Brazil was able to reduce deforestation in the Amazon significantly between 2005 and

2015 while sharply increasing soybean and palm oil production (Benami et al. 2018, Byerlee et al. 2017).

In addition to unequivocally defined property rights for forest land, clear property rights for agricultural land are also important to reduce deforestation. Kubitza et al. (2018b) showed with data from Indonesia that formal land titles help increase crop productivity, thus reducing farmers' tendency to convert additional forest land. However, due to policy restrictions, farmers near the forest boundaries rarely have access to land titles, so they are more inclined to encroach into the forest in order to increase crop production (Kubitza et al. 2018b). Existing land policies may need to be reconsidered to allow more sustainable development.

5.3. Mosaic Landscapes

While land-sparing strategies with clearly separated intensive agriculture and pristine forest have an important role to play for preserving biodiversity and other ecosystem services, land-sharing strategies can often be effective complementary tools (Mertz & Mertens 2017). The combination of land-sparing and land-sharing strategies involves the development of mosaic landscapes composed of a mix of agricultural and agroforestry plots, forest patches, and other natural landscape elements (Grass et al. 2019, Koh et al. 2009). Recent studies suggest that the enrichment of oil palm plantations with trees and natural landscape elements could lead to substantial gains in biodiversity with only modest decreases in oil production per unit of land (Gerard et al. 2017). More research is required to design mosaic landscapes that can reconcile economic, social, and environmental objectives and develop policies to implement them on a larger scale (Dislich et al. 2018, Grass et al. 2019, Mertz & Mertens 2017).

5.4. Sustainability Certification

Sustainability certification is a market-based mechanism where consumers pay more in order to promote certain environmental and social standards in production and along the value chain. The best-known international certification for palm oil is RSPO, but national schemes also exist in different countries (Morgans et al. 2018, Moser et al. 2014). Recent research with data from Indonesia shows that oil palm certification can help reduce deforestation and social conflict in some situations (Carlson et al. 2018, Persch-Orth & Mwangi 2016), whereas other studies find no effect on key sustainability indicators (Morgans et al. 2018).

One criticism of existing certification schemes is that the standards are too weak, sometimes difficult to monitor, and not always strictly enforced (Morgans et al. 2018, Pye 2019). Another problem is that the schemes are not yet sufficiently smallholder inclusive (Garrett et al. 2016). Smallholders producing under contract with large palm oil companies can be certified more easily, but independent smallholders often lack land titles, information, and training on specific management practices, which are important preconditions for certification (Brandi et al. 2015, Kunz et al. 2019). These problems can be addressed through improvements in design and implementation. One possibility is to consider the landscape and not the farm as the certified unit (Tscharntke et al. 2015). In any case, certification is a complement, not a substitute, for other policies to promote more sustainable oil palm systems.

5.5. Supporting Smallholders

The results above show that oil palm production by smallholders can contribute to poverty reduction and broader rural development. Hence, appropriate mechanisms to include smallholders should have high policy priority in countries with growing palm oil industries. Especially in Africa, where poverty in the small farm sector is still widespread, countries can learn from the experiences made with smallholder inclusion in Southeast Asia. In addition to the socioeconomic benefits, smallholder oil palm production in diversified landscapes can also be more environmentally friendly than large-scale plantations (Feintrenie et al. 2010, McCarthy 2010, Potter 2018, Rist et al. 2010). However, without appropriate policies, smallholder production is not necessarily more rainforest-preserving, as smallholders are also significantly involved in deforestation (Krishna et al. 2017b, Kubitza et al. 2018b, Ordway et al. 2017).

Sustainable inclusion of smallholders in palm oil requires secure land titles, access to credit, and technical support while accounting for the existing heterogeneity (Bennett et al. 2019, Euler et al. 2016b, Jelsma et al. 2017, Schoneveld et al. 2019). In Indonesia, considerable support was provided to transmigrants who started oil palm cultivation under NES contracting schemes, but this support later ceased and was not offered to autochthonous farmers (Gatto et al. 2017, Krishna et al. 2017a). A recent study in Ghana also showed that smallholder oil palm farmers with resource-providing contracts are doing much better than farmers without such support (Ruml & Qaim 2019). Access to credit and technical support not only facilitates farmers' oil palm adoption but also helps to increase productivity. Currently, the average yields obtained on smallholder farms are much lower than those obtained on large plantations (Euler et al. 2016a, Lee et al. 2014, Soliman et al. 2016). Reducing these smallholder yield gaps through appropriate support policies could save rainforests and thus contribute to economic, social, and environmental sustainability.

6. CONCLUSION

In public discussions, the increasing use of palm oil is often criticized because of the negative environmental effects associated with oil palm production, especially tropical deforestation and the resulting problems for biodiversity, ecosystem functioning, and climate stability. Narratives about negative social effects for local communities are also widespread. What is less known in the wider public is that local communities in producing countries have also benefited significantly from the oil palm boom. Much of the oil palm land is managed by smallholder farmers. Especially in Southeast Asia, oil palm has contributed considerably to rural income growth and reduced poverty among farmers and workers. In this article, we have reviewed the literature about environmental, economic, and social consequences of oil palm cultivation, documenting the existing trade-offs between global public environmental goods and private socioeconomic benefits. These trade-offs need to be eased through appropriate policies.

Oil palm plantations harbor much less biodiversity and have much lower carbon stocks than tropical forests, so that banning the use of palm oil has been suggested as a possible measure to improve sustainability. However, completely banning palm oil would not only result in large economic losses but could actually lead to even bigger environmental problems, because palm oil would then be replaced by other vegetable oils with higher land requirements per unit of output. Therefore, other types of policies are required. We have discussed various policies to promote productivity growth in oil palm and protect rainforests through clear property rights and economic incentive and sanction mechanisms. Sustainability certification and the design of mosaic landscapes with a mixture of agricultural and agroforestry plots, forest patches, and other natural landscape elements can also help to reconcile economic, social, and environmental objectives in many situations. Successful inclusion of smallholder farmers is important from a social perspective and requires specific support to overcome capital, knowledge, technology, and market access constraints. The appropriate policy mix needs to be adjusted to the local context.

There are also a few knowledge gaps that should be addressed in future research. First, while a lot of the existing research on the sustainability of oil palm focuses on Indonesia and Malaysia, much less research is available for Africa and Latin America, even though these are the regions where much of the future growth of oil palm production is expected. Second, even in Southeast Asia, the concrete effects of oil palm on ecosystems and human welfare were mostly analyzed at the micro level, with individual plots or households as the unit of analysis. Sustainable land use also requires a landscape perspective, which is not just the sum of the individual parts. Understanding the role of landscape composition and configuration and how the emergence of certain desired landscape mosaics can be incentivized is important for policy making and can be challenging in smallholder environments. Third, most of the existing economics studies analyze effects of oil palm production, with much less research available on downstream effects in trade, processing, and consumption. Strong supply increases must have led to significant price decreases on the markets for vegetable oil and large consumer surplus gains, including in importing countries. Such broader welfare effects have hardly been evaluated, but they should not be ignored when designing sustainability policies for the palm oil sector.

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The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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