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Abstract submission

The keys to reduce environmental impacts of palm oil

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ABSTRACT

Oil palm is largely criticised for its impact on the environment. According to Life Cycle Assessment studies, the agricultural stage proved to be a major contributor to most of the potential environmental impacts, notably global warming, eutrophication and acidification. Focusing on global warming impact, main contributors are land use change and peat cultivation, N-related GHG emissions from fertilisers and residues in the plantation and methane emissions from palm oil mill effluent (POME) treatment. Impact from POME can be drastically reduced if POME is used for composting or if the biogas from anaerobic treatment is captured with electricity recovery. However, the impact from the plantation establishment becomes overwhelming when forests or peatland areas are converted to palm plantations. Oil palm plantations have significantly driven deforestation in Indonesia, together with logging and mining. It remains the most important agricultural driver despite the governmental moratorium and the certification schemes in place since 2011 and 2007; respectively. In order to protect primary forests and peatlands, which is absolutely mandatory to avoid irreversible carbon and biodiversity losses, it is paramount to define a sustainable land planning at national and landscape levels, as well as to implement agroecological practices in the plantations in order to sustainably increase yields and limit further land clearing.

1. Introduction

Quantifying the impact of our production systems onto the environment has become a milestone. Given the various pollution risks along agricultural value chains (pesticides, greenhouse gas (GHG), etc.), but also mitigation opportunities, *i.e.*, to reduce global warming for instance, it is crucial to have an understanding of impact hot spots and to identify best practices in order to reduce environmental impacts. It is particularly critical in the case of palm oil, whose production has drastically increased in the past decades in areas where it competes with natural ecosystems, such as tropical forests, that contain great pools of carbon and biodiversity.

Today there is a single standardized internationally recognized methodology for estimating the environmental impact of human activities along a value chain: Life Cycle Assessment (LCA). In the last decade, LCA has become the worldwide standard for reporting on environmental product declarations (ISO 14025 Type III Environmental Declarations) and the baseline model behind various GHG calculators and GHG certification schemes (*e.g.* IPCC, 2006; European Renewable Directive, 2009).

In this article, we first briefly present the LCA modelling principle and detail the drivers of palm oil environmental impacts. We then discuss the keys to reduce these impacts, including practices in the field and the potential role of sustainability certification schemes.

2. Life Cycle Assessment fundamentals

LCA is based on two fundamental principles. First, environmental impacts are quantified throughout the commodity chain or “life cycle”, from raw material extraction (“cradle”) to end-of-life of the product or service (“grave”). Then, the impacts are quantified with respect to a functional unit, either a product quantity (one tonne of palm oil, one car, etc.) or a usage or service (use hours, km, etc.). From a global perspective, the entire life cycle of a product has to be taken into account so that local environmental improvements at one production stage or in one place are not merely the result of problem-shifting to another stage or place (Jolliet et al., 2010). Similarly, the comparison based on a common provided functional unit is paramount in order to avoid problem-shifting from one chain to another compensating one. Finally, LCA assesses environmental performance across multiple impacts, such as climate change, acidification, ozone layer destruction, etc. A priori, such a multi-criteria approach does not emphasize any one impact but pinpoints the greatest impacts and their origins at certain production stages. The necessary trade-offs and arbitrations can thus be documented.

Life Cycle Assessment (LCA) employs a four-stage methodology: 1) definition of the study objectives and boundaries of the system studied from the beginning to end of the chain; 2) inventory of all resource flows used and substances released within the system; 3) characterisation or modelling of impacts based on the inventory; and 4) interpretation of the results (ISO 14040 series 2000-2006). The definition of the study objectives (step 1) implies the definition of the functional unit (FU) and the scope of the system processes to be assessed (*e.g.* the LCA of FU = 1 tonne fresh fruit bunch (FFB) includes all processes, from raw material extraction up to the harvest of FFB at the edge of the palm block, in relative proportions to produce 1 tonne of FFB). The respective further transformation process steps would be added to the system if the functional unit was 1 tonne of palm oil or palm biodiesel. The flows (resources used and substances emitted) are inventoried (step 2) according to the technical specificities of the studied system. Finally, potential environmental impacts are calculated (step 3) based on a linear model that accounts for dose, fate and exposure of all emissions or resources used that may contribute to various environmental impacts along the commodity chain (Eq. 1). This linear model is the simplification of actual environmental impact mechanisms that do not account for local medium sensitivity or threshold effects. LCA impacts are hence potential impacts and not actual ones. Interpretation of results (step 4) is done in light of uncertainties related to all the previous steps. LCA allows for identifying environmental impact hotspots, process impact contributions and potential trade-offs between impact categories or process stages.

(Eq.1) $$I_P = \sum_i^n m_i \,.CF_{i,P}$$

where

I_p is the indicator for the potential impact P

m_i is the mass of the substance i contributing to the potential impact P

$CF_{i,P}$ is the characterisation factor for the contribution of the substance i to the potential impact P

For example, the impact on climate change is calculated by taking an inventory of all GHG emissions per unit product into account. The emissions are then aggregated into a single impact indicator using IPCC's linear model, which characterises what happens to GHGs in the atmosphere and their relative contributions to the global greenhouse effect. Characterisation factors in the case of climate change are expressed in CO_2equivalent (CO_2e) based on mass.

3. What are the environmental impacts of palm oil products?

3.1 The need to account for impacts all along the perennial cycle

When assessing the impacts of palm oil, it is paramount to account for the whole crop cycle. Indeed, oil palm is a perennial crop whose production cycle lasts around 25 years. During the first three years, oil palm fruits are generally not commercially harvested, but the establishment phase and the agricultural management over those first three years critically affect the performances of the crop all along the 25-year cycle. Figure 1 shows the contributions to the environmental impacts of 1 kg FFB by the various production stages over the perennial cycle. In this study, field data were collected for the same plantation over 21 years. Across the cradle-to-farm-gate life cycle of oil palm fruit, the productive phase accounting for 18/21 (86%) of the whole cycle contributed to the largest share of most impact categories (75-95%) except for freshwater eutrophication and water depletion.

Although the non-productive phase only accounted for 14% of the cycle length, it contributed to 7-40% of all impact categories, which stresses the need to account for the whole crop cycle. When palm plantations are not irrigated, as in this case study, the water depletion impact, considering the used tap water only, was half related to water inputs to produce seeds and irrigate the seedlings in the nursery, and half due to pesticides and fertiliser dilution along the whole cycle (Bessou et al., 2016). Across the other impact categories, fertilisers (production, transport from manufacture site to storage point, and field emissions) contributed greatly to climate change, terrestrial acidification, marine eutrophication, and fossil depletion (70-90%).

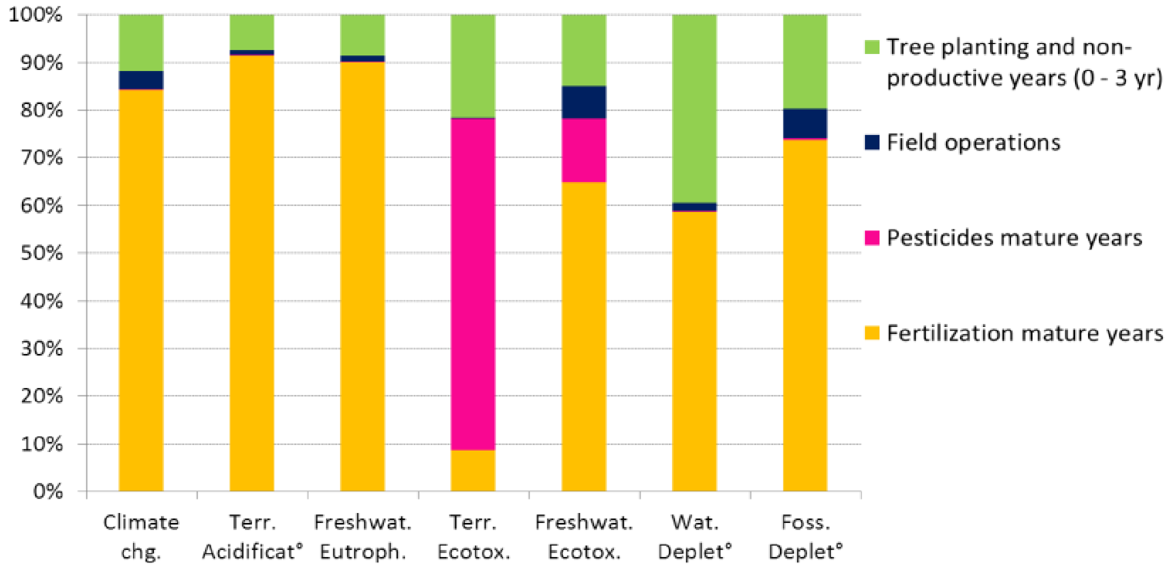

Figure 1: Contribution analysis from cradle-to-farm-gate for environmental impacts (ReCiPe-Midpoint (H)) of palm oil fruit from an Indonesian industrial plantation modelling the full cycle. Results are expressed per kg of fresh fruit bunches (source: Bessou et al., 2016)

From the wider perspective of the agro-ecosystem functioning, the specificities of perennial crops also induce long-term complex and evolving interactions with the ecosystem. For instance, the expansion of the root system in many directions down to deep soil layers influences both long-term bio-geochemical nutrient cycles and fertilisation strategy (Bessou et al., 2013). Moreover, palm plantations are notably sensitive to climatic stresses such as drought events. The alleviation of stress factors impacts upon yield for the subsequent 40 months (Härdter and Fairhurst 2003). Those mid-term and long-term phenomena underpin the need to account for the whole perennial cycle.

Figure 2 highlights differences in LCA impact results depending on the timeframe considered for the assessment. These comparative LCA results were done based on primary field data of a palm plantation monitored over a 21-year cycle. Compared to the baseline scenario, where the 21-year cycle is considered, the alternative scenarios, where only individual years or an average of the last three years were assessed, all show discrepancies. The impact calculation for the year 4 only was misleading due to the consequences of a previous stress. The other scenarios also had different impacts that for the baseline one, notably due to the non-accounting for the immature phase. Despite these evidences, LCA of palm oil products do not systematically assess the whole cycle or discuss the consistency of the timeframe used (Bessou et al., 2013, 2016).

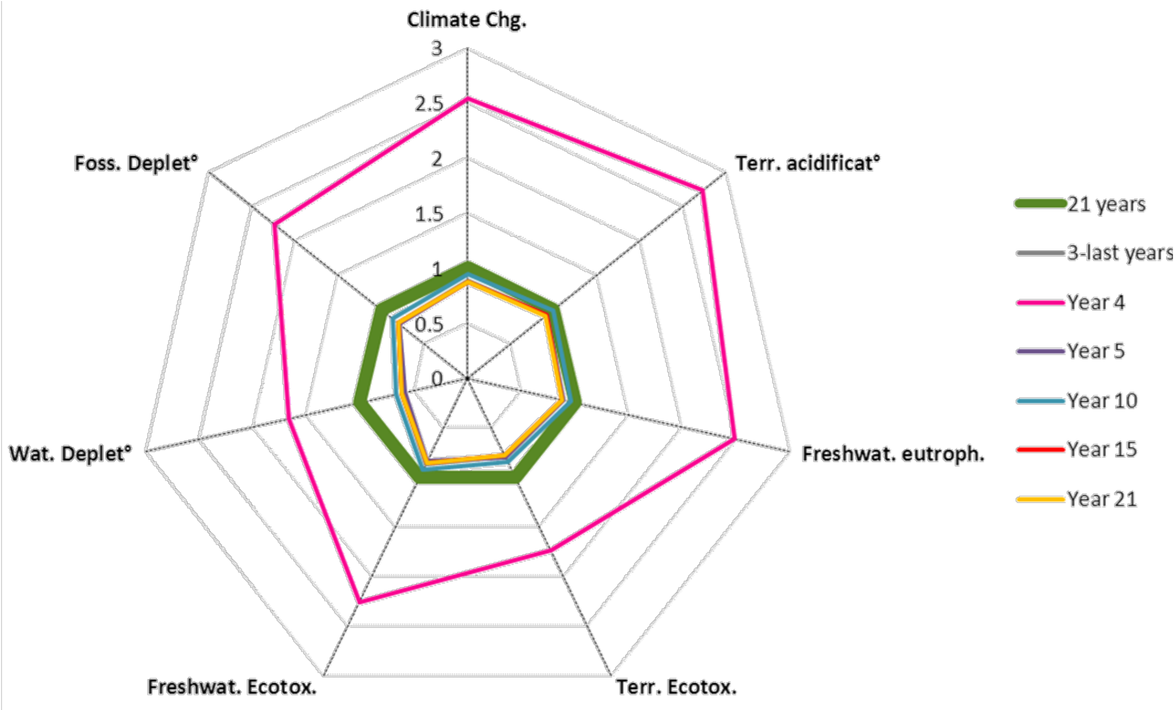

Figure 2: LCA results variability in function to the timeframe considered for the assessment, *e.g.* including the whole cycle or some/individual years (source: adapted from Bessou et al., 2016)

3.2 The environmental impacts of crude palm oil products

When assessing the impact of crude palm oil (CPO), the agricultural phase appears to be the main contributor to most of the impact except for human toxicity or respiratory inorganics impact to which boiler emissions contribute mainly (Stichnothe and Schuchardt 2011; Bessou et al. 2012). Mill emissions can also contribute to eutrophication which is driven by N- and P-compound emissions. The main eutrophication factors at the agricultural stage are nitrate leaching and phosphorus and nitrate run-off. Other N-compound emissions also contribute to acidification and photochemical ozone impact categories. While palm oil generally performs worse than other oil crops on climate change impact due in particular to land use change (LUC), it performs better than rapeseed oil regarding eutrophication, acidification, ozone depletion and photochemical ozone impacts (Schmidt 2010).

Focusing on the climate change impact, published results range between -0.55 and 24 tCO_2e/t CPO with median values around 1-2 tCO2e/t CPO when LUC concerns mixed previous land uses and less than 10% peatland, and methane is not captured (Reijnders and Huijbregts 2008; Schmidt 2010; Choo et al. 2011; Bessou et al. 2012). Main drivers along the value chain are LUC and peat oxidation due to peat drainage for oil palm cultivation (Schmidt 2007; Reijnders and Huijbregts 2008; Zulkifli et al. 2009), followed by methane emissions from palm oil mill effluent (POME) treatment and fertiliser-related emissions notably N_2O field emissions (Schmidt 2007; Chase and Henson 2010; Choo et al. 2011; Bessou et al. 2014). Nevertheless, the impact of POME can be significantly reduced if biogas is captured at the mill (Chavalparit et al. 2006; Choo et al. 2011; Harsono et al. 2014; Bessou et al. 2014) or, to a lesser extent, if raw or partially treated POME are injected in the composting process (Singh et al. 2010; Stichnothe and Schuchardt 2010).

In a pilot application of PalmGHG v2 (Chase et al. 2012) on mills in Southeast Asia and Latin America, the average GHG balance was 1.67 tCO_2e/t CPO and ranged from -0.02 to +8.32t CO_2e/t CPO (Bessou et al. 2014). Across the mills without supply from peat area, land clearing, POME methane emissions, and fertiliser-related emissions represented 41-80%, 15-35%, and 3-19% of total GHG emissions, respectively. The impact of fossil fuel use was not significant (0-5% and 0-2% of total emissions at the field and mill levels, respectively). This low impact was due to a low mechanisation level in the plantations and the recycling of numerous residues that provides heat and power to operate the mill (with potential excess electricity production). Most of field fuel use is dedicated to FFB transport. Hence, the impact of fuel use may greatly vary according to FFB collection logistics. A scenario testing on key drivers of GHG emissions was carried out with PalmGHG highlighting the relative importance of those drivers (Figure 3).

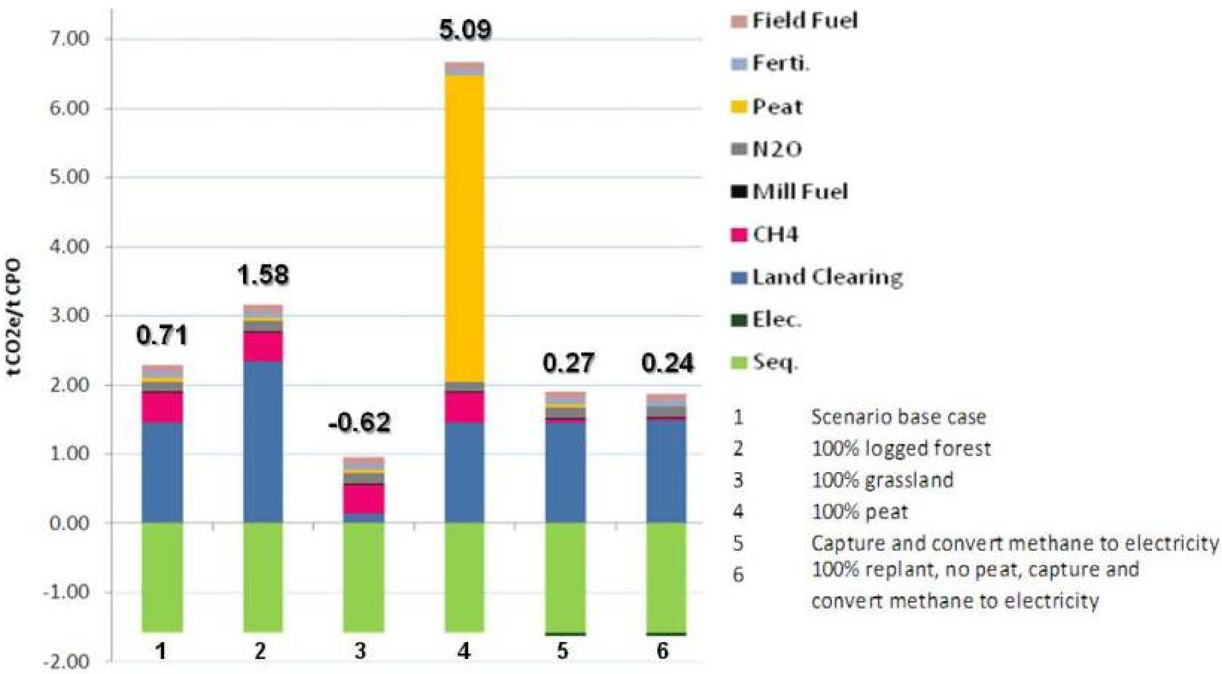

Figure 3: GHG balances (*i.e.* net emissions in tCO_2e/tCPO) according to various scenarios of CPO production; Scenario base case (1): mixed previous land uses, peat 3%, no POME treatment, OER 21%, own crops mean yield 20 t FFB/ha, outgrowers' mean yield 14 t FFB/ha (adapted from Bessou et al., 2014)

When assessing the environmental impacts of palm biodiesel, the agricultural stage also appears to be the key contributor to most impact categories (Puah et al. 2010; Achten et al., 2010; Arvidsson et al., 2011). The use of biodiesel in engine also adds to eutrophication and acidification potential impacts (Arvidsson et al. 2011) and particularly contributes to the impact category respiratory inorganics (Puah et al. 2010).

In terms of GHG balance, although results greatly vary among studies, the LUC and peat cultivation remain the key drivers. The mean GHG balance, accounting for various LUC scenarios, reaches 40 gCO2e/MJ (9 gCO2e/MJ without LUC), but is multiplied tenfold when peatland forest is converted to palm plantations. Compared to fossil fuels, palm biodiesel is disadvantageous in terms of GHG if peatland forests are cleared and if tropical forests are cleared and the palm plantation lasts less than a century (Reinhardt et al., 2007). Otherwise, GHG savings between 55-89% compared to fossil diesel can be achieved (Wicke et al., 2008; Pleanjai et al., 2009; Thamsiriroj and Murphy, 2009; Achten et al., 2010). Besides LUC, main GHG sources are fertilisers (70-90% in field emissions, 10-30% emissions at manufacture site), methane emissions from palm oil mill effluent treatment when it is not captured (POME), and the transesterification process (methanol and electricity) (Pleanjai et al. 2009; Thamsiriroj and Murphy 2009; Achten et al. 2010; Choo et al. 2011).

3.3 The role of palm oil in deforestation

Given the rapid expansion of palm plantations, there have been severe concerns regarding its impact on deforestation, especially in Indonesia and Malaysia, the two global production leaders. As shown previously, land use changes at the expense of forest cover losses lead to large GHG emissions due to the long-term stored carbon in the biomass that is lost through land clearing. Those emissions are even worsened if forest or other land uses are cleared on peat soils. Moreover deforestation leads to the loss of very rich and in some cases endemic and irreplaceable pools of biodiversity (Barlow et al., 2007; Koh and Wilcove, 2008; Fitzherbert et al., 2008; Feintrenie, 2014; Chaudhary et al., 2015).

Most of oil palms are currently grown between 15° latitude North and South of the equator below 500 m above the sea level without irrigation (Cock et al., 2016). This zone, where optimal conditions for palm oil production are met, also hosts the most intact tropical forests and the largest tropical peatland areas. Figure 4 & Figure 5 show the distribution of forest, deforestation fronts and peatlands. It is clear that those land areas are threatened in Indonesia and Malaysia, but also in other regions, where oil palm plantations is also being developed, notably Amazonia and Western and Central Africa (Feintrenie, 2014; Ocampo-Peñuela et al., 2018; Strona et al., 2018).

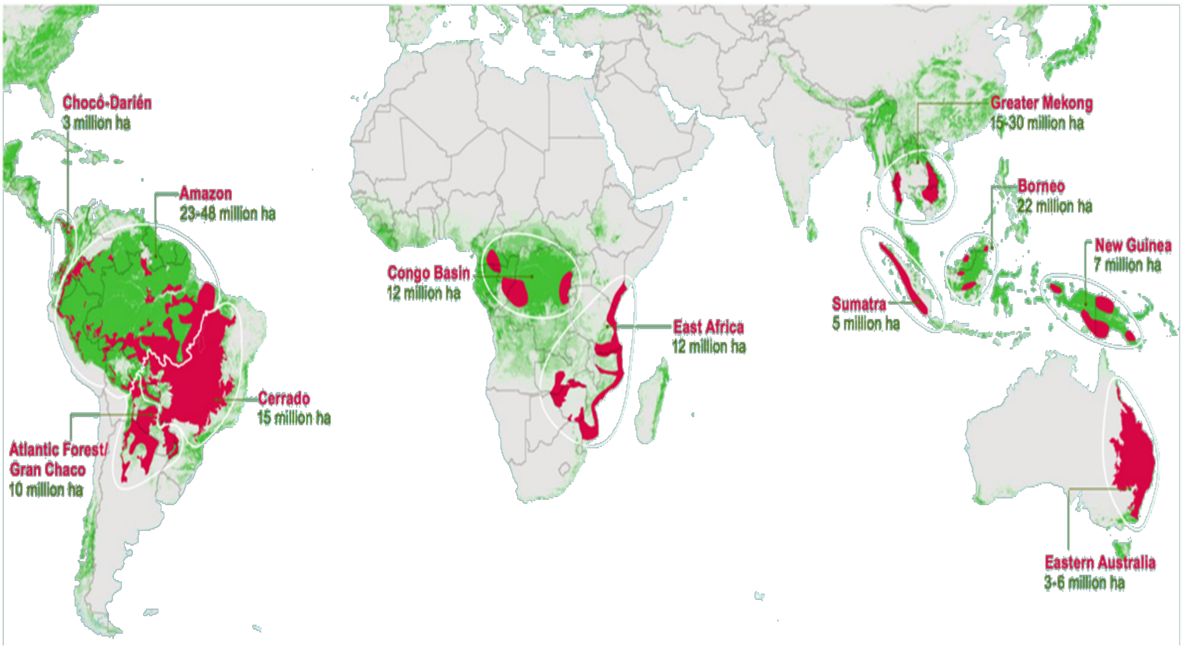

Figure 4: Map of deforestation fronts in the Southern hemisphere; green=forest, red=projected deforestation by 2030 (source: Mongabay 2015)

In 2008, peatlands covered around 20.2 Mha in Indonesia (11% of the total surface area), with the largest area found in Papua and the deepest peats in Borneo (Kalimantan) (Figure 6). Between 1-2 m depth peat soils are considered "moderate", while they are considered deep up to 4 m depth, then very to extremely deep (Murdiyarso et al., 2011). These peatlands stored more than 30 Gt of carbon (Murdiyarso et al., 2011)[1]. Since 2011, there has been a governmental moratorium in Indonesia (third extension ongoing) for "The postponement of issuance of new licences and improving governance of primary natural forest and peatland"[2]. However, this moratorium is a set of presidential instructions (Inpres) that impose no legal consequences if they are not implemented. After 6 years, there was no evidence that the moratorium had had any effect on limiting the deforestation as the deforestation rate did not significantly change before and after 2011 and it was even worst in Papua, where large peatland areas are endangered (Wijaya et al., 2017[3]).

[1] The total terrestrial ecosystem stores some 3,170 GtC, of which 2,500 GtC (~80%) is stored in the soil (Lal, 2008)

[2] On 20 May 2011, the government of Indonesia released Presidential Instruction (Inpres) No. 10/2011

[3]https://www.wri.org/blog/2017/05/6-years-after-moratorium-satellite-data-shows-indonesia-s-tropical-forests-remain consulted on 9/10/2018

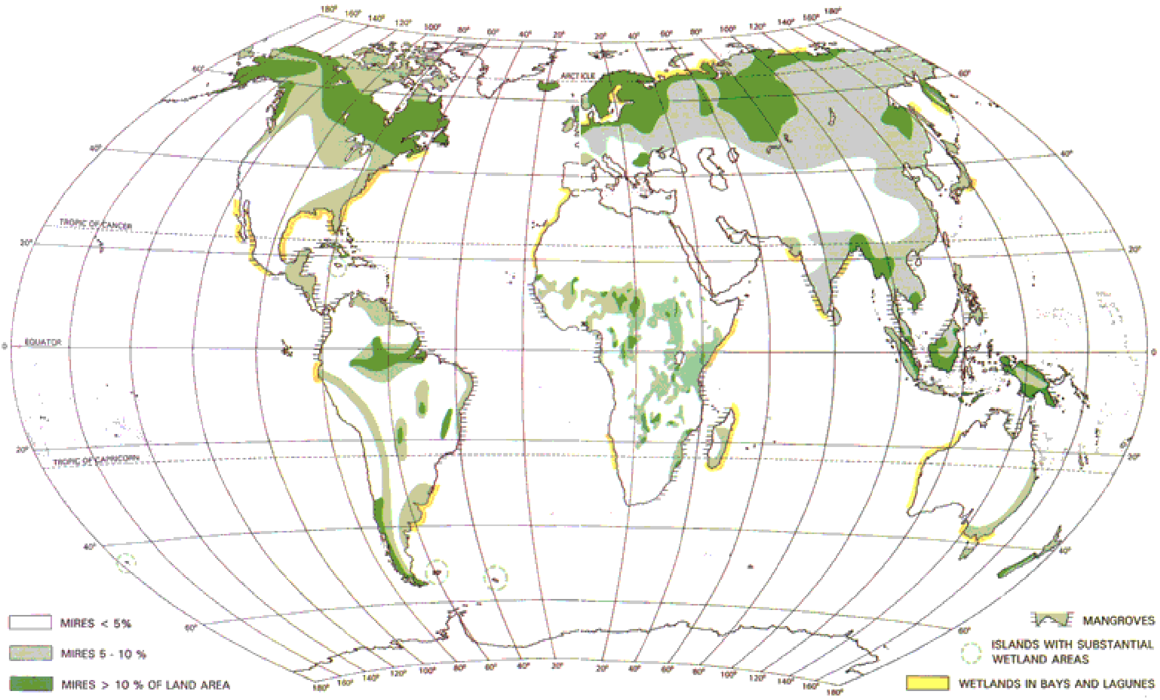

Figure 5: Maps of peat soils (MIRES) (source: International Peatland Society, 1999)

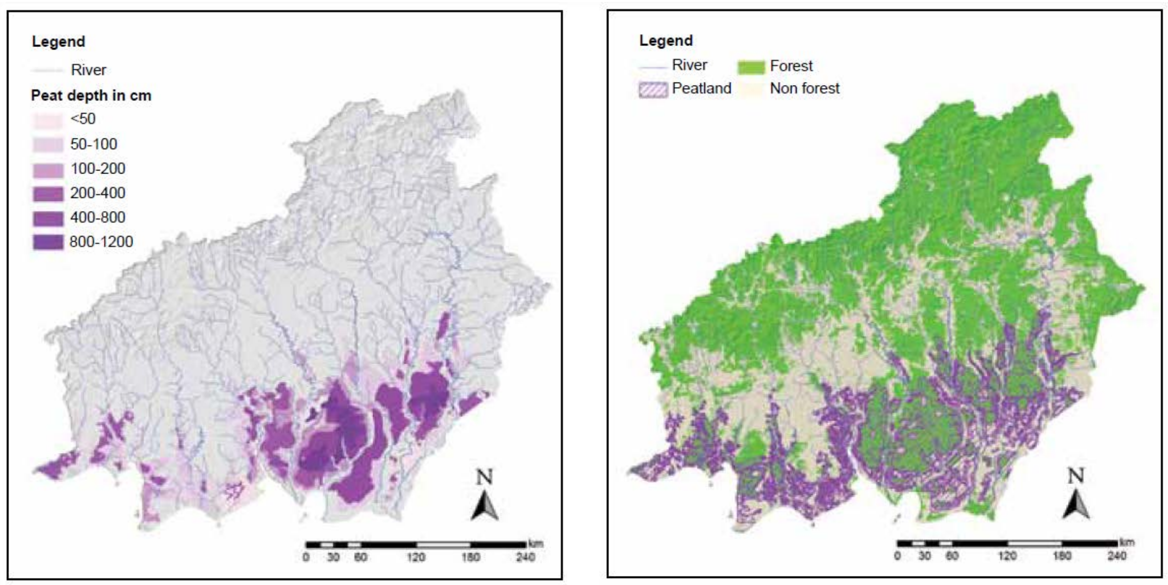

Figure 6: Distribution of peatland areas in Borneo per peat depth (left hand side) and with overlay of forest cover (right hand side) (source: Murdiyarso et al., 2011)

In 2016, there were roughly 21 Mha of oil palm plantations harvested globally, *i.e.* an increased by 245% compared to 1990 (FAOstat). Between 1990 and 2008, 239 Mha of forest were lost globally; 53% of those losses were related to the agricultural sector, including 2.3% of the global deforestation due to palm plantations and 5.5% due to soybean production (Baron et al., 2017[4] based on Cuypers et al., 2013). The proportion of deforestation due to oil pam globally is still low. Other deforestation drivers are livestock production (24% out of the 53% of global deforestation due to agriculture Cuypers et al., 2013), logging, pulp and paper, and mining.

However, the deforestation pace due to palm plantations has been particularly critical in Indonesia, with varying patterns depending on the island (Margono et al., 2014; Abood et al., 2015) (see Figure 7). Between 2000 and 2010, oil palm plantations in Indonesia were responsible for 11% of the deforestation (17% between 1990 and 2008 *In* Cuypers et al., 2013) at roughly the same level as pulp and paper (12.8%) and logging (12.5%) and contributing far more than coal mining (2.1%) (Abood et al., 2015). The situation in Borneo in particular is critical, as 25% of the deforestation has been directly linked to palm plantations in the last 40 years, with potentially more development to come and potentially on peat land (Abood et al., 2015; Gaveau et al., 2016).

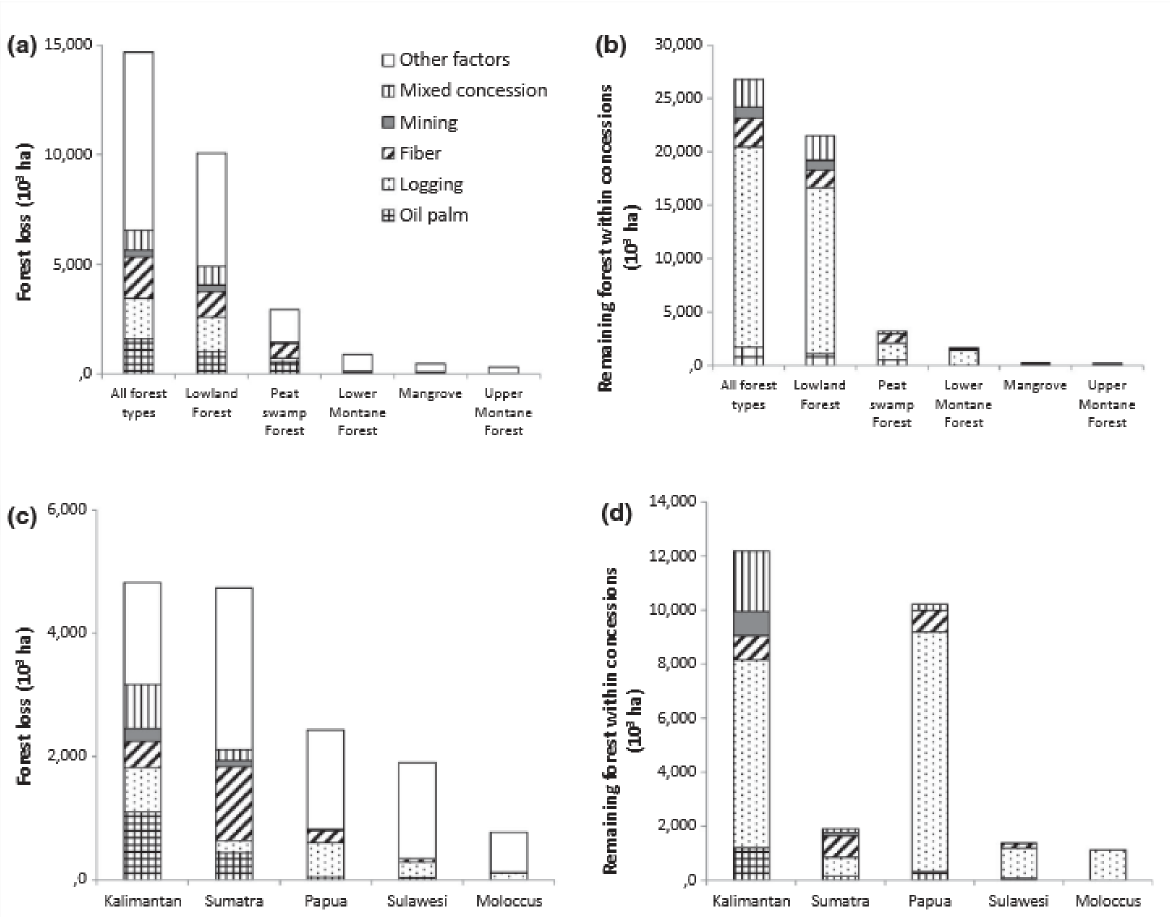

Figure 7: Forest loss in Indonesia from 2000 to 2010 within different industrial sectors, and forest remaining among different industrial sectors based on forest types (a) and (b), respectively, and

[4]https://theconversation.com/non-lhuile-de-palme-nest-pas-responsable-de-40-de-la-deforestation-76955, consulted on 8/10/2018

islands (c) and (d), respectively. Coal mining concessions were unavailable for Papua, Sulawesi, and Moluccas (source: Abood et al., 2015)

Estimations of direct links between deforestation and oil palm plantations are likely to be underestimated, since the long-term land use such as palm plantation can be implemented after a more or less short-term such as logging or just slash-and-burn fallows. In countries, such as Indonesia, where the forest cover still represents more than the half of the surface area[5], it is logical that deforestation accompanies rural development. In the end, especially in terms of biodiversity losses, it does not matter much which commodity replaces the natural forests. Nevertheless, profitable crops, such as oil palm, can accelerate the deforestation pace in proportions that may become uncontrollable and with irreversible impacts. Therefore, the attention paid to palm oil must be seen as an opportunity to build up new concepts of rural development that do not lead to another climbing to the fall.

4. What are the keys to reduce environmental impacts of palm oil?

There are three inter-dependent keys to foster best management practices in oil palm plantations and reduce their environmental impacts:

- A sustainable land planning for plantation development;
- The planting of seedlings with the best optimised production potential accounting for the local context characteristics; and
- The implementation of agroecological practices in the field.

4.1 A sustainable land planning for plantation development

When exploring the drivers of the palm oil environmental impacts, deforestation and peat drainage appeared to be the most serious ones. The Presidential moratorium, as well as all other incentives, such as the Roundtable of Sustainable Palm Oil (RSPO) principles and criteria, that aim to avoid the deforestation of primary forests and the preservation of peat soils should be fully enforced. Otherwise other actions will not be sufficient to avoid irreversible biodiversity loss and significantly reduce Indonesian GHG emissions.

Once avoiding land use change on primary forests and peatlands, the severity of deforestation impacts will depend on the type of land use, including potentially secondary or degraded forests, and its intrinsic biodiversity and carbon stock. There is no sustainable new oil palm planting possible without a proper land planning that allow for assessing the potential impacts of various land use change scenarios and identifying the optimised land use mosaic allowing for biodiversity and carbon stock maintenance.

Many tools exist, such as the High Conservation Value or the High Carbon Stock approaches that allow for identifying patches of forests and other natural vegetation to be preserved. The RSPO PalmGHG tool also helps to assess GHG emissions and savings depending on the land planning scenarios. Besides land planning, it is then paramount to allocate the means needed to enforce it, especially to prevent encroachments on preserved

[5] Pers. com Dania Chalil, 5.10.2018: 60% of the Indonesian surface area is still covered by forest. According to (Murdiyarso et al., 2011), half of this forest area are secondary forests.

areas and to allow for an efficient fire prevention and control. Other actions, such as fostering regeneration in conservation areas for compensation may contribute to limit the damage. Moreover, there have been studies underlying the positive feedback of natural vegetation habitats for integrated pest management in the plantations. Hence, protecting natural forests can turn to be a win-win situation both at global and local levels.

4.2 Planting good selected seedlings

In a context of constrained land area, agricultural land use must be optimised in order to produce more and better. The oil palm cycle is long compared to the great majority of cropping systems, it is hence even more critical to make sure that the established crop is fully suitable to the location where it is planted.

Oil palm selection has been the object of decades of researches worldwide. Thanks to this research, the palm oil yield has been increased by 137% over the last 70 years (Louise et al., 2018). The full genome was identified recently (Singh et al., 2013), which opened up to further research tracks. Besides yield improvement, assisted selection research aims at developing varieties that would be tolerant to various stresses, including climatic and disease related stresses, such as *Ganoderma*, etc. Difficulties in such selection programmes come from the long crop cycle that delays the analysis of varieties' performances and the need to anticipate future impacts of climate change in order to model the needed plasticity of selected varieties to adapt to uncertain future conditions.

The access to selected palm seedlings with high yield potentials for all, including smallholders, is on the agenda of most governmental supportive programmes worldwide and of supportive NGOs. Once allocated over the whole cycle and given the cumulated long-term benefits from selected seedlings, the initial cost of good selected seedlings is worth it, but smallholders[6] are not at first aware of this calculation (pers. com Diana Chalil, 5/10/2018). Moreover the choice of the best suitable seedlings for a given context requires knowledge on the local context, soil quality and environmental pressures as well as on the correlated good practices to be implemented at the nursery stage as well as all along the cycle. There is currently a lack of extension services globally (Bessou et al., 2017a). As smallholders represent globally 40% of the oil palm production[7], with commonly lower yields than industrial producers (Rival and Levang, 2013), yield increase in smallholders' plantations is a promising way to limit the pressure extension on land and to increase benefits for smallholders and secondary beneficiaries within the production area.

[6] pers. com Diana Chalil, 5/10/2018: In Indonesia, 40% of the palm oil is produced by roughly 2 millions of smallholders. It is difficult to know for sure, but roughly 60% of these smallholders would be independent ones.

[7] It is extremely difficult to have precise figures on the proportions of smallholders' palm oil. 40% is the average figure given globally but based mostly on data from Malaysia and Indonesia that represent 85% of the global volumes. However, in some countries this proportion is higher, *e.g.* >80% in Thailand. In many countries of Western Africa, from where *Elaeis guineensis* originated from, palm oil has been the primary source of vegetable oil for generations. It is produced mostly the artisanal way largely from wild palms or non-selected palm plantations, whereby yields could be drastically increased. However, there are very few official datasets allowing for assessing the real plantation extend and the actual produced and locally consumed volumes.

4.3 Implementing agroecological practices

Agroecology is a paradigm shift in agronomy. Its conceptual framework was developed recently, when the limits of the green revolution were reached (Conway, 1996; Altieri, 1999; Griffon, 2007). Agroecology is about understanding and enhancing the mechanisms that can ensure agroecosystem productions and resilience on the long-term. In the search for long-term efficiency, various agroecological practices have been developed in oil palm plantations. Some have become quite standard, such as the legume cover crop during the immature stage (Corley and Tinker, 2016) or are being promoted through best practice recommendations (*e.g.* Donough et al., 2009) and incorporated as criteria in several certification schemes (*e.g.* RSPO[8], ISPO[9]).

All agroecological practices are connected through the continuum of the ecosystem functioning. There are, at least, two main pans of action: i) the management of soil quality and nutrient cycling; and ii) the integrated pest management. Soil quality is defined as the complex resultant from various chemical, physical and biological properties that determines "the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Hence ensuring a good soil quality, through the understanding and fostering of its functions, makes it possible to maintain good conditions for the agricultural production.

In palm plantations, soil quality can be maintained or enhanced through an appropriate fertiliser management, including a systematic recycling of residues. For instance, the field application of empty fruit bunches (EFB) as organic amendment, progressively developed at the end of the twentieth century (Caliman et al., 2001; Carron et al., 2015), proved to contribute to improving chemical properties of the soil, in particular its nutrient content for the purpose of fruit production, *i.e.* the "support function". EFB application rates depend on the soil context and also on the management strategy. Recommended rates vary between 30 to 100 $t.ha^{-1}.yr^{-1}$, with a median rate at 40 $t.ha^{-1}.yr^{-1}$ (several authors *In* Bessou et al. 2017b). Short-term and long–term studies (10 year application) showed an improvement of soil chemical quality through the following indicators: soil organic carbon, total nitrogen, CEC, and available phosphorus (Caliman et al., 2001; Abu Bakar et al., 2011, Comte et al., 2013).

Other residues, such as POME, especially through composting, can be recycled in the field allowing for nutrient recycling, erosion control and soil quality improvement. Besides the role in soil quality maintenance, composting is a promising way in terms of GHG reduction. Several studies have highlighted potential savings compared to conventional POME treatment (Singh et al., 2010; Stichnothe and Schuchardt, 2010; Chin et al., 2013; Harsono et al., 2014). However, there is still a need for further LCA studies in order to

[8] http://www.rspo.org/key-documents/certification/rspo-principles-and-criteria, consulted on 28/1/2017
[9] http://www.ispo-org.or.id/index.php?lang=en, consulted on 28/1/2017

investigate potential problem shifting and trade-offs regarding savings against increased emissions due to i) the building and daily operation of the composting plant, and ii) the potential increase in volatilisation of nitrogen compounds in the field (Figure 8).

The integrated pest management is the most widespread field application of agroecological principles, as it relies on the understanding of relations and interactions between various species within an agroecosystem (Figure 8). As an example, rat control by barn owls has long been reported to be effective in controlling rats in oil palm plantations (Lenton, 1980; Ho and Teh, 1997; Duckett, 2008). However, further investigation is needed to have a more comprehensive understanding of the role of other rat predators within the landscape (Verwilghen et al., 2015). Foster et al. (2011) stressed the importance of conserving biodiversity and ecosystem processes within the oil palm habitat itself. However, little is known about the effect of local management practices and landscape design on biodiversity and its relation to ecosystem services or dis-services (Tscharntke et al., 2005; Zhang et al., 2007), and more investigation is needed especially in the oil palm agroecosystems (Foster et al., 2011; Savilaakso et al., 2014).

Figure 8: Illustrations of agroecological practices in palm plantations: parasitoids and barn owls attracted to fight against pests and diseases (first row), field application of compost and EFB (second row) (source: Bessou et al., 2017b)

5. What can be the role of sustainable certification schemes?

The development of certification schemes for sustainable palm oil was initially motivated, in particular, by the fight against deforestation and the preservation of biodiversity. This was the case in 2003 with the creation of RSPO in which WWF spearheaded the protection of forests and biodiversity. These issues were also at the origin of the sustainability criteria defined in the European Directive for renewable energies in 2009. They are, still today, one of the main stumbling blocks at the origin of the development of new schemes such as the High Carbon Stock Standard (HSC).

Since the creation of RSPO, the various actors upstream of the sector, including producers, banks, national and international NGOs etc., have worked on the definition and implementation of sustainability criteria for the sector (Figure 9). Some have even developed specific strict standards regarding certain criteria such as carbon footprint (*e.g.* development of the HSC standard). Nevertheless, these certifications or regulations do not convince. Faced with skepticism, initiatives are also growing downstream of the sector and even beyond the palm sector, particularly on the creed "zero deforestation", *e.g.* the Consumer Goods Forum. Despite the more or less open will for complementarity between some of these regulatory instruments (*e.g.* RSPO & ISPO/MSPO), the proliferation of standards and initiatives is increasing the confusion and criticism and is fueling the lack of coordination and credibility of actions to effectively protect forests and their biodiversity and promote sustainable development for local people.

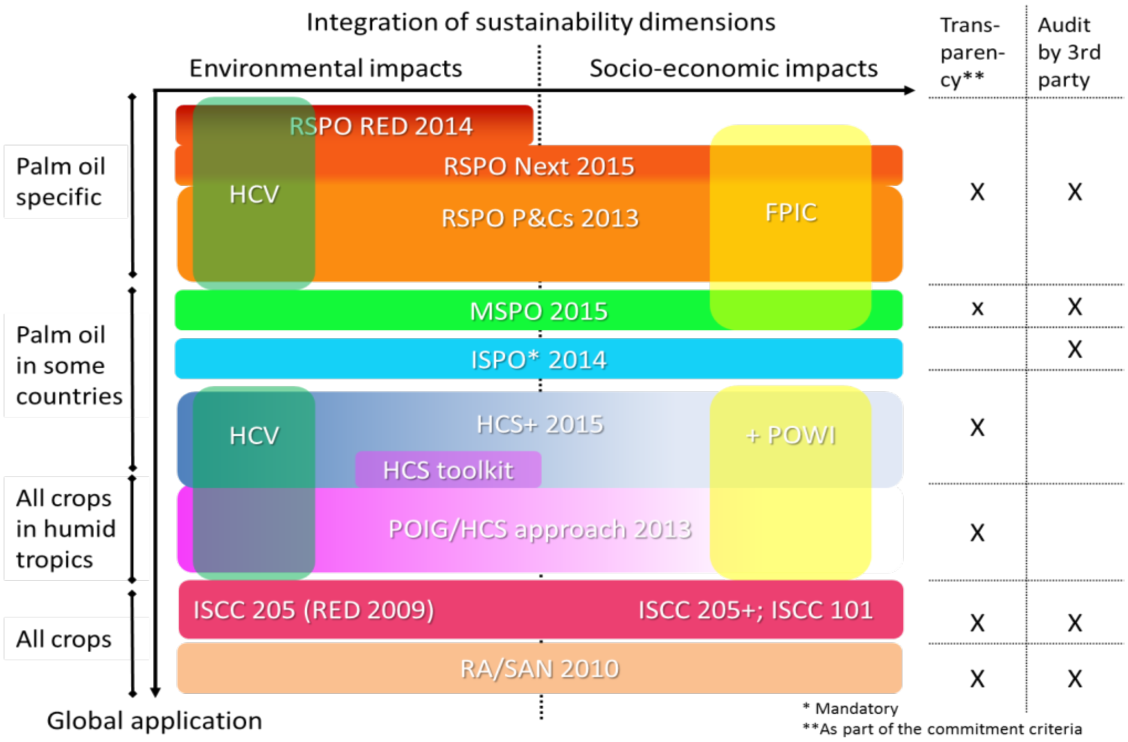

Figure 9: Summary of key certification schemes notably related to palm oil. FPIC: Free Prior Informed Consent; HCS: High Carbon Stock; HCV: High Conservation Value; ISCC: International Sustainability & Carbon Certification; ISPO: Indonesian Sustainable Palm Oil; MSPO: Malaysian Sustainable Palm Oil; POIG: Palm Oil Innovation Group; POWI: Palm Oil Wealth Index; RED: European Directive on Renewables 2009; RA/SAN: Rainforest Alliance/Sustainable Agriculture Network; RSPO: Roundtable on Sustainable Palm Oil

Various recent studies, including that conducted by the recent French Ministries mission on the sustainability of palm oil and other vegetable oils (Auber et al., 2016), offer different grids for reading and comparing initiatives. The criteria for recurrent differentiations are the voluntary or mandatory nature, the level of completeness in relation to the three dimensions of sustainability, the mono or multi-sector approach and the actors at the origin or involved in the development of the criteria. But the comparison of the certification schemes with their theoretical content is of little value, since the main criticisms mainly concern shortcomings in the criteria implementation and field efficiency rather than the criteria themselves. The ex-post evaluation of certification schemes and the analysis of their comparative efficiencies are unfortunately difficult because of the lack of quantified data on the impacts on the ground.

The multiplication of geo-spatialized data available has given rise, in recent years, to numerous studies analysing the changes in land use, particularly in relation to palm plantations (*e.g.* Abood et al., 2015; Miettinen et al., 2016; Vijay et al., 2016). Nevertheless, these studies do not compare certified and non-certified plantations. On the other hand, researchers have recently been studying the issue of fire starts in Indonesia by comparing RSPO and non-certified certified plantations (*e.g.* Cattau et al., 2016; Noojipady et al., 2017). The first study first recorded a difference of a factor of 5 in the number of fires detected between 2012 and 2015, less numerous within the limits of the concessions (~ 40,000) than outside the palm plantation concessions (200,000) with a preponderance of fire starts on peat (Cattau et al., 2016). The same study showed a significant difference between the number of fire starts in certified and non-certified plantations, but only when the risk of fire was low, *i.e.* during dry years and on mineral soils. In other cases, the difference was not significant and did not always go in the same direction. The second study looked at the same factors but encompassed more areas and years, comparing certified (154) and non-certified (1,536) plantations between 2002 and 2014 (Figure 10; Noojipady et al., 2017). On average, the annual rate of deforestation (canopy> 30% area) was similar at 1.25% of the concessions certified against 1.72% in those not certified (peats apart). Total deforestation was, however, 10 times higher in non-certified plantations, since concessions were 10 times larger. On the other hand, most of the deforestation took place before 2009 in certified plantations while the process is more continuous throughout the period in non-certified plantations. Between the launch of RSPO (2004) and the issuance of the first certificates (2009), the rate of deforestation was higher in certified and non-certified plantations, despite the critical date of November 2005, as the ultimate date of tolerance for deforestation as part of the RSPO certification. Trends were comparable on mineral soil and peat in certified plantations, while deforestation of peat in uncertified plantations peaked in 2009, 2012 and, to a lesser extent, 2014. Similarly, beyond 2009, the number of fires and the extent of slash-and-burn agriculture were lower in the case of certified versus non-certified plantations.

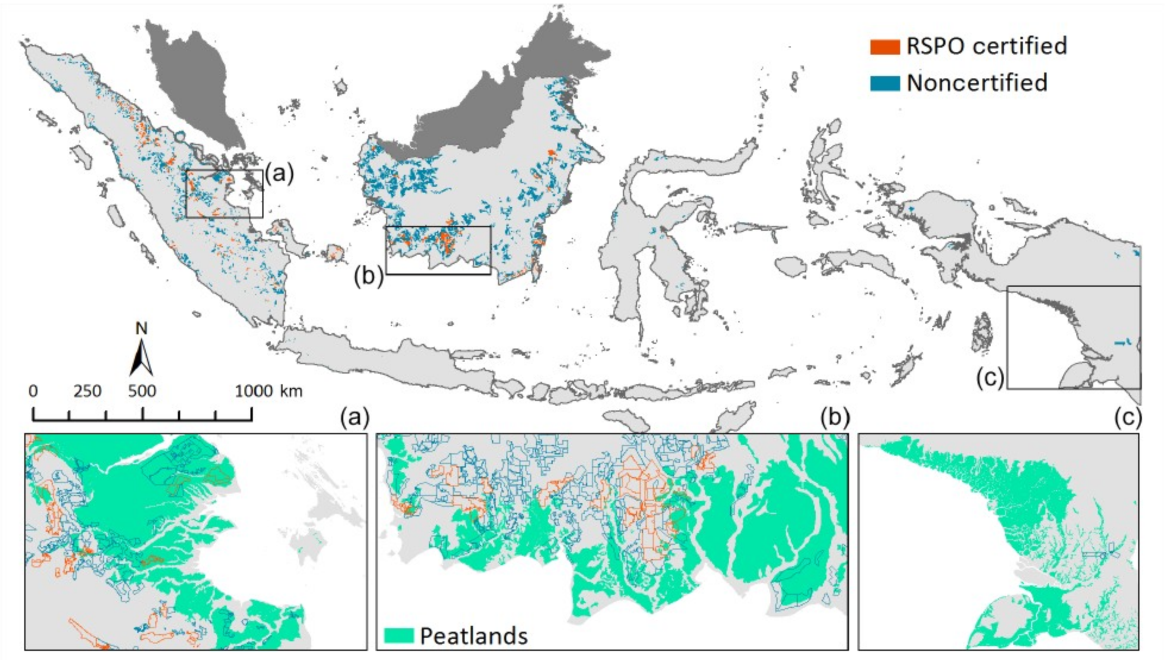

Figure 10: Extent of RSPO certified (red) and noncertified (blue) oil palm plantations in Indonesia. Regional subsets highlight plantation boundaries on peatlands (green) in the lowlands of Sumatra (a), Kalimantan (b), and Papua (c) (source: Noojipady et al., 2017)

A third study in Indonesia - a technical report not published in a peer-reviewed journal - confirmed that between 2000 and 2015 the rate of deforestation was lower in certified plantations than in non-certified plantations, despite a more important total development rate within the concessions: 82% of the area of concessions planted in the case of certified plantations against 41% in non-certified plantations. The study also showed no relative difference in terms of decreasing orangutan populations between certified and non-certified plantations, stressing the need to better apply RSPO 5.2 for certified plantations and to improve criteria and/or audits in the case of non-certified plantations still subject to sustainability criteria according to ISPO (Meijaard et al., 2017).

These first comparative studies tend to illustrate better forest protection in RSPO-certified concessions. Nevertheless, the failures to the principles or rules, according to the scheme of certification, are not rare. Thus forest fires persist despite the prohibitions both according to RSPO and according to Indonesian law and the ISPO regulation. On the other hand, RSPO certified plantations account for only 13% of the total area allocated to palm concessions in Indonesia (Noojipady et al., 2017). Hence, the protection of the tropical forest and its biodiversity requires more safeguards concerning larger surface areas; *e.g.* following governmental schemes such as ISPO in Indonesia or MSPO in Malaysia, and strengthened controls for the implementation of good practices in the field. These controls are expensive and not exhaustive, whatever the system, they remain the absolute weak point of all current schemes.

Despite the pitfalls observed as well as supposed ones, which motivated the development of parallel systems, RSPO remains the most widespread an recognised certification scheme in terms of certified members and hectares (Noojipady et al., 2017, FAO Compendium, 2017), the most proven and the most dynamic in terms of stakeholder consultation and continuous improvement. This is also the scheme that currently offers the most systemic control procedures. The RSPO-RED certification ensures compatibility of the palm oil supply with the cumulative RSPO criteria with those of the RED. Unlike the ISCC certification, the RSPO-RED certification is assumed, because of its full-supply basin certification unit, not to conceal impact transfers between a certified plantation and a non-certified one (except in the case of mass balance but which is normally a transitional stage of the certification of an oil mill). Avoiding this impact transfer is critical when it comes to avoiding greenwashing. There is currently no field study that analyzes the impacts of ISCC certification in terms of the environmental impacts of the oil palm industry compared to other certifications. It is therefore impossible to know if ISCC certification, by construction, actually promotes pollution transfer in the field or if, on the contrary, its stricter criteria in terms of carbon stock preservation for example make it possible to better protect the environment compared to RSPO.

In the case of a palm oil supply chain, it is essential, in order to overcome pitfalls, to ensure traceability of the product until planting and to invest, especially through the payment of premium, in a segregated industry to avoid pollution transfers. Unfortunately, today in the market, only half of the sustainable palm oil is bought at the certified price, that is to say including the premium. We must create a relationship of trust between producers and buyers to get out of this vicious circle. RSPO, like ISPO and MSPO or the other standards did not succeed this bet. Only the complete traceability of the sector can facilitate controls and thus restore confidence. On a positive note, more buyers have recently committed to and moved from sourcing certified palm oil through “book and claim” mechanisms to buying through physical supply chains (FAO Compendium, 2017). Nevertheless, the overall positive impact will only be possible if sustainability standards are applied more generally to all concessions; this may be possible through the encouragement of the development and continuous improvement of the RSPO scheme as complementary schemes, provided that efforts are concentrated on creating synergy for less confusion and more efficiency.

6. Conclusion

Independently from the system boundaries, LCA studies showed that the agricultural phase is the key of palm oil environmental impacts. In particular land clearing of rich forests and cultivation of peat soils are hot spots of biodiversity and carbon losses, the latter contributing to a great share of the total GHG balance and subsequent climate change impact.

In Indonesia, oil palm expansion has contributed to deforestation and peat drainage. The enforcement of laws, moratorium and certification criteria that aim to avoid primary forest clearing and peat cultivation is a prerequisite to reduce significantly the environmental impact of palm oil products and to make it possible to reach the national target in terms of

GHG reduction. Alternatives to oil palm on swallow peatland areas should be investigate to propose alternative and less impacting uses of peatland areas.

Fertiliser inputs also play a key role in determining the final environmental profile, contributing to climate change but also further impact categories such as eutrophication and acidification. Agroecological practices that aim to recycle palm oil residues as organic fertilisers in the field are interesting alternatives that may allow for both impact savings and gains in terms of soil quality and positive feedback on the yields and the agroecosystem. Integrated pest management also makes it possible to reduce the use of pesticides that contribute to toxicity impacts. The practices and the long-term performances and impacts of the crop all over its cycle will at first depend on the planting material. Therefore, the choice of good suitable seedlings adapted to the local conditions at the very beginning of the plantation is essential.

The development of agroecological practices requires having a comprehensive understanding of all mechanisms connecting species within the agroecosystems. Much research effort is still needed to get there. As more knowledge is available, the modelling of impact pathways within LCA can be improved, like the progressive inclusion of soil quality and ecosystem services in LCA (Milà i Canals et al., 2007; Koellner et al., 2013; de Baan et al., 2013), which reduces the uncertainty on the results and allows for an even more comprehensive view of trade-off issues. In the meantime, other approaches, such as agro-ecological indicators, can be complementary as they may allow for a better accounting of local conditions and practices to build-up the LCA inventories.

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