Towards a Sustainable Palm Oil Supply Chain

A scientific basis for transparency creation that strengthens sustainability interventions

Final Report

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Word count: 19.850

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Track: Energy & Materials
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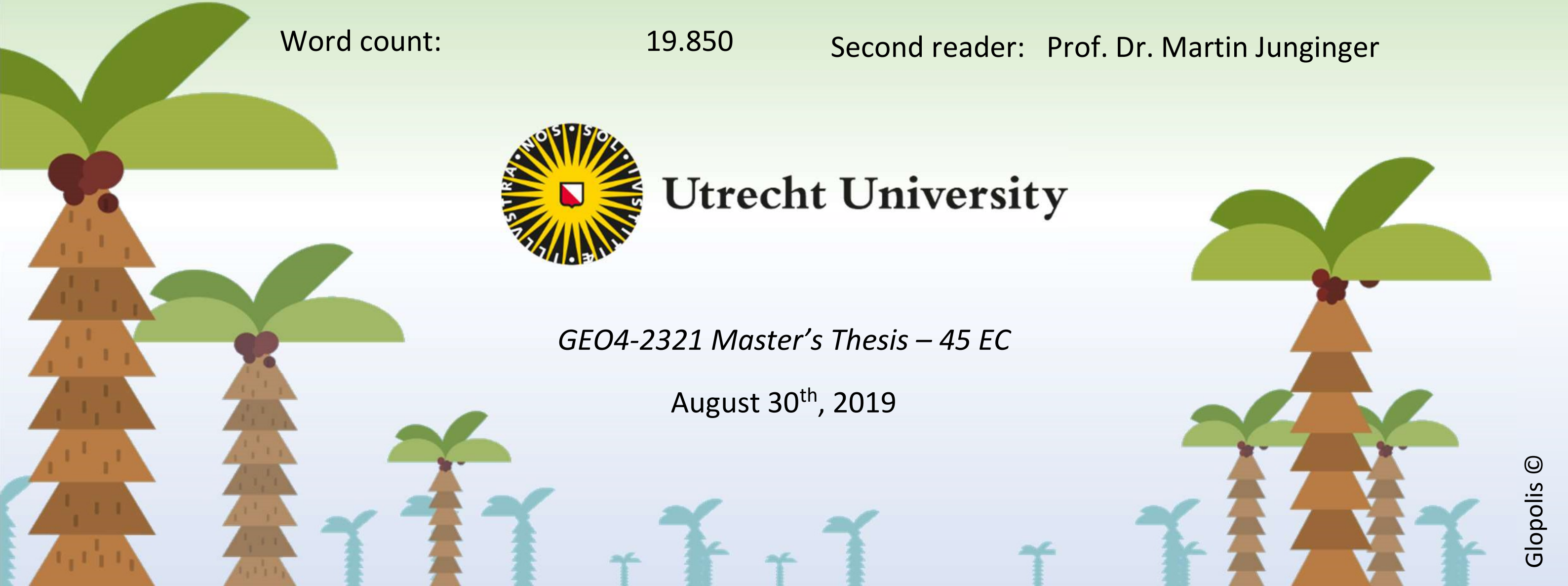
Utrecht University

GEO4-2321 Master's Thesis – 45 EC

August 30th, 2019



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Summary

The palm oil industry has developed from a local supply chain to a global industry with over seventeen million hectares of oil palm plantations. This expansion is often accompanied by the alarming conversion of tropical forests, peatlands, and land assigned for indigenous communities and local food supply. Mitigating these issues has so far been unsuccessful as the increasing complexity of this global supply chain has posed a barrier for the implementation of effective sustainability interventions. Transparency on the relation between consumption and its embedded impacts can once more strengthen supply chain governance. In order to meet the lasting need for accessible, comprehensive and comparable data, the aim of this study is to establish a common understanding on the scope, definitions and methodology for impact assessment and supply chain analysis that strengthens sustainability interventions in the palm oil supply chain.

Insight in the effectiveness of current interventions has been created. Besides inaction, that entails the uncontrolled expansion of oil palm plantations, moving away from palm oil was found to be no option. Considering the uniquely high yield and low production costs, palm oil is regarded the only option to meet the majority of the increasing demand for vegetable oils in food, cosmetics, biobased materials. For biodiesel alternative feedstocks that do not increase land scarcity are possible. Interventions from a national governance perspective proved subject to impact migration, which demands a shift to trans-national or preferably global governance. The analysis of the Roundtable on Sustainable Palm Oil (RSPO) certification has shown that certification schemes must furthermore increase monitoring of the affiliated actors, sharpen the criteria for sustainable production and include the plantation expansion process in their scope. As this certification scheme is currently ineffective, upholding the claim of certified sustainable palm oil is thus considered greenwashing.

A global solution involving all responsible actors is advised. Independent consumption-based impact assessment can act as a tool to monitor progress towards each sustainable target. The suggested indicator that captures the environmental strain best is the land use footprint, expressed in the biogenic carbon emissions of deforestation and peatland destruction. To operationalise this indicator and link the impact at conversion to the worldwide consumption, a methodology based on Environmentally Extended Multi-Regional Input-Output (EMRIO) is proposed. This approach should yield the accessible, comprehensive and comparable data that allows for clear communication, mutual comparison and unambiguous decision making, ultimately leading towards a sustainable palm oil supply chain.

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List of abbreviations

AGB	Above Ground Biomass
BGB	Below Ground Biomass
CBS	Statistics Netherlands (*Centraal Bureau voor de Statistiek)*
CPO	Crude Palm Oil
CSC-LUC	Carbon Stock Change due to Land Use Change
CSPO	Certified Sustainable Palm Oil
DASPO	Dutch Alliance Sustainable Palm Oil
EMRIO	Environmentally extended Multi-Regional Input-Output model
ESPO	European Sustainable Palm Oil alliance
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
GHG	Greenhouse Gas
ILUC	Indirect Land Use Change
IO	Input-Output
ISPO	Indonesian Sustainable Palm Oil
LCA	Life Cycle Analysis
LUC	Land Use Change
LULC	Land Use and Land Cover
MDGs	Millennium Development Goals
MFA	Material Flow Analysis
MVO	The Netherlands oils and fats industry (*Maatschappij Vetten en Oliën)*
NGO	Non-Governmental Organisation
PME	Palm-Methyl Ester
PKO	Palm Kernel Oil
RBD	Refined, Bleached and Deodorised
RPO	Refined Palm Oil
RSPO	Roundtable on Sustainable Palm Oil
SDG	Sustainable Development Goal
SEI-PCS	Spatially Explicit Information on Production to Consumption Systems
TAGs	Triacylglycerols
UN	United Nations
WWF	World Wide Fund for Nature

1 Introduction

The year is 1848, and Indonesia as we know it was colonised by the Dutch. In the then Dutch East Indies several exotic trees were introduced by the European settlers. These oil palms, originating from the African continent, started to bear fruit only five years after arrival in the Bogor Botanical Gardens, 60 km south of the present-day Jakarta. These treatises and the following dispersion of the oil palm across Indonesia, as documented by Dr. F.W.T. Hunger (1924), contributed to an industry with over seventeen million hectares worth of oil palm plantations (Lai, Tan, & Akoh, 2012; Noleppa, Cartsburg, Petersen, & Schlembach, 2016). This area is equivalent to over four times the area of the Netherlands and ten percent of the world's permanent cropland (Pirker, Mosnier, Kraxner, Havlík, & Obersteiner, 2016). The international trade relation continues to exist as Indonesia is the number 1 exporter and the Netherlands the third largest importer and (re-)exporter of palm oil, with a total of 1.22 million tonnes of Indonesian palm oil being processed in the Netherlands (FAO, n.d.; TRASE, n.d.)[1].

This massive expansion, that is expected to persist, can be explained by the unique quality of the oil palm (*Elaeis guineensis*) to produce fruits that contain a multi-purpose vegetable oil against high yields and low production costs (Corley, 2009; K. T. Tan, Lee, Mohamed, & Bhatia, 2009). "One hectare of oil palm plantation is able to produce up to 10 times more oil than other leading oilseed crops" (Lai, Tan, et al., 2012; Mba, Dumont, & Ngadi, 2015). Furthermore, the few soil requirements make the oil palm suited to grow on more different terrains than for example the coconut tree, which often has been replaced by the oil palm since shortly after its introduction to Indonesia (Hunger, 1924; K. T. Tan et al., 2009). Due to high demands for a cheap vegetable oil in processed foods, detergents, cosmetics and biodiesel, it can be concluded that palm oil is unlikely to become obsolete, even though current practices are unsustainable (Pirker et al., 2016). On the contrary, palm oil is even considered the only option to meet the majority of this increasing demand (Lai, Tan, et al., 2012). In food, palm oil can be adapted to suit many purposes due to a favourable combination of saturated and unsaturated fats (Lai, Tan, et al., 2012). Even though palm oil is technically not the most suitable for the production of biofuels, it is commonly used due to its low costs (Fitzherbert et al., 2008). The chemical structure of the oil moreover enables the production of an array of possible derivates at a relatively low amount of energy, with applications ranging from personal care to animal feed and electronics (APAG, 2019).

Oil palm cultivation is even regarded a driver for socioeconomic development in the tropical regions of Asia, Latin America and Africa (Corley, 2009; Lai, Tan, et al., 2012). Nonetheless, multiple sustainability issues arise with the fact that oil palms are among the fastest expanding crops in the world, while palm oil is already the most abundant vegetable oil globally (Smit et al., 2013). In this expansion, Indonesia recently became the biggest producer of palm oil, responsible for 53% of global production in 2013 (Ruysschaert & Salles, 2014). Oosterveer (2015) provides a list of disastrous effects on both the social and natural environment. These are tropical deforestation, threats to biodiversity, wildlife and ecosystems, soil erosion, greenhouse gas emissions, risks from using pesticides and other pollutions. Social concerns include large-scale expansion at the cost of indigenous communities, social conflicts on land access and ownership, and marginalisation of small-holders by the large-scale palm oil sector. Already Indonesia experiences the highest deforestation rate in the world, even higher than Brazil (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014). Where 9.4 million hectares were already occupied by oil palm plantations, a further 10 million to even more than 20 million hectares were planned (Colchester and Chao, 2011). If the sustainability issues cannot be dealt with, and expansion continues to take place uncontrollably, the consequences will be unparalleled.

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[1] Data for 2014

1.1 Problem definition

That the palm oil supply chain is currently unsustainable is an undisputed fact. The specific issues are many and well researched, so why have we not been able to stop deforestation, reduce pollutions and include small-holders and indigenous communities? As it stands today, the translation of this seemingly straight-forward end goal into effective interventions has proven to be a huge challenge. Many actors of all kinds have tried, but they have all proven to be ineffective. This has been the case for individual nation states (Oosterveer, 2015), as well as corporations (Berger, 2018; Lyons-White & Knight, 2018), consumers (DASPO, 2018; Smedley, 2015) and now 'the main hope' (Corley, 2009), or even 'the only hope' (Lai, 2012) that is the Roundtable on Sustainable Palm Oil (RSPO) seems to undergo the same fate (Lyons-White & Knight, 2018; Ruysschaert & Salles, 2014; van der Ven, Rothacker, & Cashore, 2018). The recurring cause named in these sources is the great complexity of the palm oil supply chain.

In 2004, the RSPO was established as a response by the palm oil sector to these governmental shortcomings, meant to administer certifications and thereby safeguarding just practices (Pirker et al., 2016). Other certification standards are applied by the European Union (EU), United States, Indonesia, Malaysia, the International Sustainability and Carbon Certification and Rainforest Alliance (European Palm Oil Alliance, n.d.; Pirker et al., 2016). With the introduction of RSPO-certified palm oil among others, the need arose for the distinction between certified and non-certified oil. Traceability of the Certified Sustainable Palm Oil (CSPO) from production to consumption became key in creating value for the certification process. Traceability for the purpose of monitoring sustainable production is however a relatively recent development. Formerly, tracing consumer goods throughout the supply chain had only been executed in relation to possible contaminations and the associated risks. Moreover, traceability of palm oil comes with additional complications. Palm oil is usually handled as a commodity, which means it is sold in large volumes and different consignments are often mixed and interchanged. Hereby, distinction between different consignments is easily lost. (Lai, Tan, et al., 2012)

The lack of information and the sheer distance between consumption and production has made it practically impossible to link consumption patterns to its impacts and thus make educated decisions (Marques, Verones, Kok, Huijbregts, & Pereira, 2017). Now that the need for effective sustainability interventions is more pressing than ever, transparency creation in the supply chain is key in mitigating the environmental and social strain that is associated with the consumption of palm oil (Godar, Persson, Tizado, & Meyfroidt, 2015). Gardner et al. (2018) explain in detail how sustainable governance is strengthened by establishing transparency in global commodity supply chains.

To date, progress has been made on the generation of transparency information[2], as in 2017 for example 99% of palm oil imported in Europe was traceable to the mill (ESPO, 2017; Gardner et al., 2018). However, this information does not suffice for detecting opportunities for interventions and the accurate implementation thereof. Instead, information on consumption patterns and impacts of production need to be linked on a relevant scale (Godar, Suavet, Gardner, Dawkins, & Meyfroidt, 2016). This can be achieved by coupling the footprint accounts – yielded by impact assessments – with the traceability that is obtained in supply chain analyses (Godar et al., 2016). Godar et al. (2015) even propose a model that allows international trade data to be connected with specific impacts on the location of production. However, as all transparency initiatives, its success fully depends on the availability of suitable data (Godar et al., 2015). Quite frankly, Gardner et al. (2018) summarise the predominant knowledge gap that undermines transparency initiatives and resultantly effective sustainability interventions as well, as "the lack of accessible, comprehensive and comparable data".

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[2] For all 6 types of information that constitute to supply chain transparency, see Gardner et al. (2018).

1.2 Research aim & questions

Most definitely, the palm oil sector needs to change in order to preserve valuable ecosystems, mitigate climate change and support local livelihoods. Therefore, this research aims to contribute to the development and application of effective sustainability interventions, specifically for distant actors in the palm oil value chain[3]. The process of developing and applying interventions is structured according to the intervention cycle, see Figure 1.

The evaluation of the current interventions has pointed out their ineffectiveness, as discussed in the problem definition. A diagnosis of the shortcomings of these specific interventions can shed light on the causes and the possible improvements that would aid successful implementation in the future. This information on the effectiveness of interventions is also considered a form of transparency by Gardner et al. (2018). As, furthermore, transparency on the origin and distribution of palm oil is crucial to sustainable governance, impact assessment and supply chain analysis need to be conducted, see Figure 2.

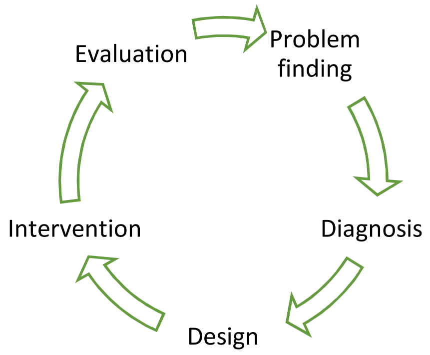

Figure 1: The intervention cycle.

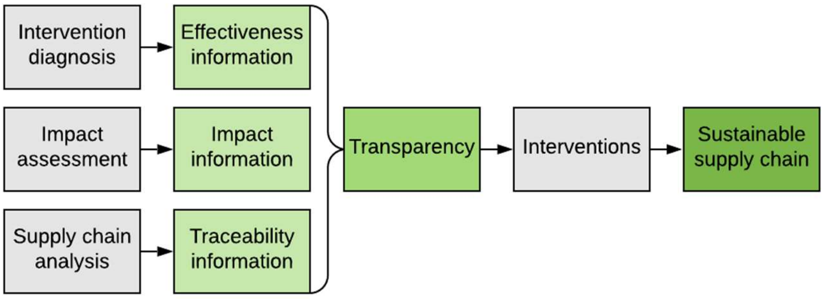

Figure 2: Schematic overview of the approach for a sustainable supply chain, in which transparency plays a central role. Actions are displayed in grey and their results in green.

In order to deliver the accessible, comprehensive and comparable data that is currently lacking, a common understanding needs to be established on the scope, definitions and methodology for impact assessment and supply chain analysis. Subsequently, transparency needs to be created by the execution of these procedures and the diagnosis of the shortcomings of current interventions. Thirdly, the opportunities for sustainability interventions need to be assessed. And lastly remains the implementation of these measures, see Figure 2. Executing all of these steps proved to be out of reach for this master thesis, due to time constraints and insufficiently available data. Instead the aim for this research is the following:

> *"to establish a common understanding on the scope, definitions and methodology*
> *for impact assessment and supply chain analysis that strengthens*
> *sustainability interventions in the palm oil supply chain."*

For the assessment of impacts a quantitative approach is proposed. Experience with the Millennium Development Goals (MDGs) has shown how quantification of development ambitions into goals and targets aided the implementation of "successful, targeted interventions" (UN, 2015). Quantification allowed for monitoring specific and time-bound goals and targets, enabled performance tracking, and

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[3] Actors that are distant to the actual production of palm oil and are not directly responsible for the impact embedded in the palm oil; For the actors in the value chain, see Scope.

addressing the accountability of the involved actors. Determining the made progress is hardly possible without quantitative assessments. Quantification can be applied to operationalise a vague ambition as 'a sustainable palm oil supply chain'. This quantification requires the establishment of impact indicators. (UN, 2015)

To conclude, several steps are undertaken to realise the aim of this study. First off, the effectiveness of current interventions is reviewed along with its shortcomings and suggestions for improvement. Secondly, quantification of the environmental impact is enabled through the selection of an indicator. And finally, the scope, definitions and methodology for impact assessment and supply chain analysis are created. Thereby the research can be divided in three parts, structured by the following research questions and sub-questions:

1. How can the effectiveness of sustainability interventions be improved?
    a. How do current interventions contribute to their sustainable development ambitions?
    b. Where do current interventions fail to realise their ambitions?
    c. What recommendations can be drawn therefrom?
2. What impact indicator(s) can best capture the impact of palm oil production?
    a. What are the relevant impact categories of palm oil production?
    b. What are the corresponding indicators?
    c. What indicator(s) score(s) best on the selection criteria?
3. How can impact assessment and supply chain analysis of palm oil best be executed?
    a. What methodology framework is most suited for impact assessment and supply chain analysis?
    b. How can this methodology best be operationalised?

1.3 Research strategy

This research is structured according to the steps as displayed in the framework in Figure 3. Here, a distinction is made between research objects (what will be examined?), research perspectives (how will this be examined?), and the outcome. In three different occasions a research object (*white*) will be confronted with a research perspective (*grey*) resulting in new information (*green*). In the first part, addressing the first research question, current interventions will be subjected to a diagnosis. This diagnosis will reveal where current interventions have failed to realise their ambitions. Consequently, recommendations can be made for future interventions. Furthermore, insights in the role of transparency in current effectiveness can aid in constructing a basis for transparency in such a way that it strengthens future interventions. This information can be included in the selection criteria for the impact indicators and methodology. The selection of impact indicators and choices for operationalisation are both executed by means of multi-criteria analysis. The resulting methodologies are collectively forming the basis for transparency creation. The effectiveness information resulting from the first research question constitutes to transparency as well.

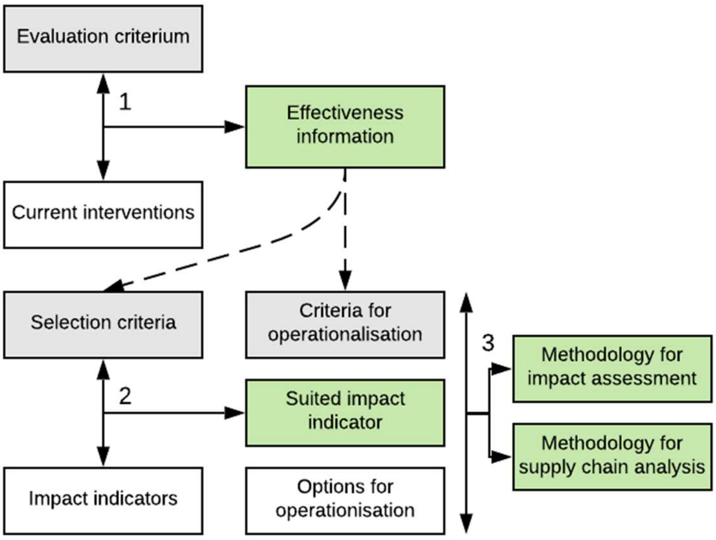


Figure 3: The research framework. Research objects in white; research perspectives in grey; and the outcomes in green. The arrows indicate the cause-effect relationships.

In this framework, a clear differentiation between theory-oriented and practice-oriented research can be made. Part 1 is intended to advance existing interventions according to the intervention cycle. On the other hand, part 2 and 3 are theory-oriented. However, the resulting methodology is meant to be implemented and thereby contributes to future practice.

The approach for this research is in-depth and qualitative. The required information is predominantly obtained via desk research. The first research question will yield explanatory knowledge; Why current interventions are ineffective and how they can be improved. The second question yields evaluative knowledge; What indicator is currently best suited to capture the environmental impact. And the third research question yields prescriptive knowledge on how transparency should be created in order to obtain the accessible, comprehensive and comparable data that is required for strengthening sustainability interventions in the palm oil supply chain.

1.4 Scope

To set the scope of this investigation, the palm oil industry needs to be understood. RSPO categorises 7 sectors that are part of the value chain: oil palm producers, processors or traders, manufacturers, retailers, investors, and NGOs (RSPO, 2018). Although investors and NGO's are part of the value chain, they play no role in the commodity supply chain. To establish the material flows, only the actors that process the physical goods are of interest. This shows that there is a differentiation between the palm oil supply chain, and the palm oil value chain which includes all monetary transactions. A second adaptation for the supply chain, is the combination of processors and trades in one category. Processing of palm oil can be executed before, after, or in between trade, so for convenience processors and traders are combined in one step. These choices lead to the palm oil supply chain as displayed in Figure 4. Regarding transparency creation, this chain will be used to trace palm oil and its impacts. To assess interventions to improve this chain, the role of other actors (i.e. investors and NGOs) are also included.

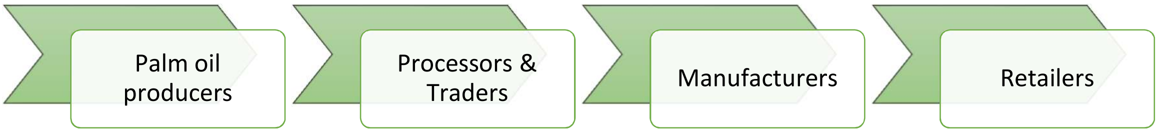


Figure 4: A flowchart of the main actors within the palm oil supply chain, based on a categorisation by the RSPO (2018).

Palm oil producers can be found across the tropical regions of Asia, Latin America and Africa (Lai 2012/Corley 2009). Since the dynamics in oil palm cultivation might vary geographically, focussing on one country will allow for more specific analyses. For the purpose of this study Indonesia will be the producing country of interest. As mentioned in the introduction Indonesia has a long history of palm oil production. Furthermore, a large share of production is situated in Indonesia, and an even more extensive expansion is planned. Moreover, the social and natural impacts are well-researched in this South Asian country, allowing for in-depth assessments (Gardner et al., 2018).

The impact made during production is transferred along the supply chain to downstream actors. These diverse and globally active players enable the worldwide consumption of palm oil in all possible forms. Describing all these processes and processors is extremely challenging and goes beyond the aim of this study. To further limit their amount, the choice is made to focus on the Netherlands. This small country is responsible for a large share of global consumption, knows a long history of international trade and is active in the sustainable development of their industry. Furthermore, it plays a pivotal role in the supply chain, as the harbour of Rotterdam is the first step into Europe for a large amount of the entering palm oil.

In this study only impacts on the natural environment are considered. The implications of palm oil production on the social or economic situation requires additional research.

2 Theoretical background

To unravel the key concepts and show how they should be understood, the conceptual framework in Figure 5 is drafted. Figure 4 displays a rather simplified version of the supply chain, based on a categorisation of the actors. In this chapter a more elaborate exposition will be given, to show to some extent the processes that palm oil undergoes, and the strain that the production process puts on the environment.

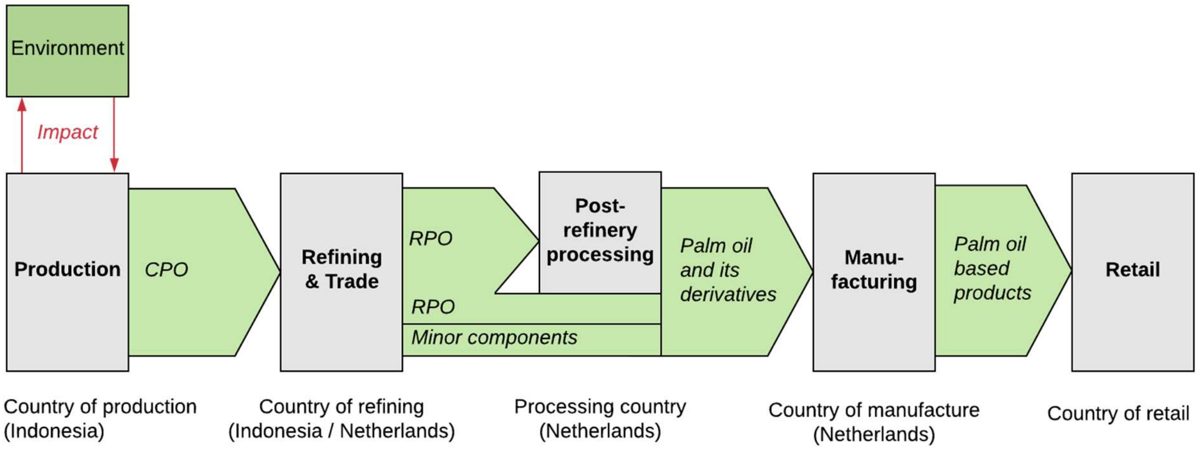


Figure 5: Conceptual framework, showing the palm oil supply chain and the interactions with its environment. Processes are displayed in boxes, and the (intermediary) materials in arrows. Below, the countries of interest for each process are given. CPO = Crude palm oil; RPO = Refined palm oil.

Transparency creation consists of impact assessment and supply chain analysis as can be seen in Figure 2. Impact assessment concerns the start of the supply chain in Figure 5, as it addresses the interactions between palm oil production and environment. Supply chain analysis covers the totality from production to retail. Coupling both parts will allow to track the embedded impact throughout the entire supply chain. In order to understand how this can be achieved, the methods for both supply chain analysis and impact assessment are clarified. Supply chain analysis is executed by means of a Material Flow Analysis (MFA). Key concepts of this method are reviewed the first section, based on the Practical Handbook of Material Flow Analysis by Brunner & Helmut (2011). How this material is defined is clarified in section 2, through a short review on the chemistry of palm oil and its derivatives. Lastly, the methodology for assessing the impact of palm oil production is explained.

2.1 Supply chain analysis

Analysing the flow of a material is based on the single principle of conservation of matter. The amount of material that is used in a process must reoccur in the outflow, as product, waste or other traceable losses. In an MFA, the global commodity supply chain is deduced to a system with flows and stocks of a certain material. In this system sources, pathways, intermediate and final sinks are described. In real life these flows are generally coupled to external effects – e.g. deforestation – and important parameters – e.g. associated actors and geographical location. In general, the term material stands for both substances and goods. In chemistry, a substance is defined as a single type of matter consisting of uniform units. In this case the substance of interest, palm oil, can undergo chemical conversions to a variety of derivatives. Although these products are a chemically different substance, they still fall within the scope of the MFA. In this paper the term material therefore concerns the totality of palm oil and palm oil derivatives, as is explained in the section below.

The system regarded in the MFA consists of all material flows, stocks, and processes within a defined boundary, which is in this case the palm oil supply chain. A process can be defined as an alteration that is made to a material, whether is it transformed, transported or stored. The cause of the process can both be natural or human. When a certain amount of material does not undergo a process and is stationary, it is called a stock. A material can shift from a stock to a process and vice versa by means of a flow. These in- and outflows connect the processes and stocks in a system and are bound to the law of conservation of matter. To give meaning to the outcome of a material flow analysis and interpret its results, other factors need to be included. In this case the MFA is coupled with an analysis of the impact of the palm oil as explained the third section. Only then the analysis of material flows can aid resource conservation and environmental protection, otherwise known as sustainable materials management. As Brunner & Helmut (2011) point out ultimately "the method of Material Flow Analysis enables the planning of processes and systems that facilitate careful resource management".

2.2 Palm oil and its derivatives

Crude Palm Oil (CPO) is in most cases just an intermediary product. It is one of the desirable attributes of palm oil that it is easily converted to suit many purposes. To make CPO suited for certain applications, the oil is refined, mixed, separated or chemically converted. In order to determine the impact embedded in a palm oil based product, some mathematical conversion needs to be made as well. Here only a limitary context is provided for the readers understanding.

Performing MFA and defining the material in question is not straight-forward for palm oil. Over 200 alternative names are used for palm oil and its derivatives in consumer products (Palm Oil Investigations, n.d.). For clarity, the following categorisation is proposed: Crude palm oil (CPO), refined palm oil (RPO), modified edible palm oil, oleochemicals and minor palm oil constituents, see Figure 6. The palm kernel and its oil and cake are not included in the definition of palm oil and its derivatives, since these are side products and not derivatives of CPO. The major transformations occur when the material is treated so that is transitions from one category to another. For example, the process in which oil palm fruits are converted to crude palm oil is called palm oil production, and the conversion from CPO to RPO and minor components is known as refining.

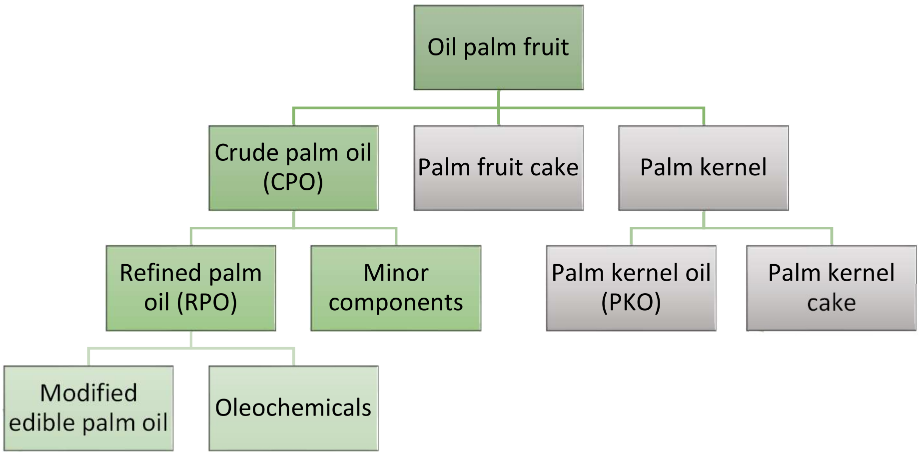


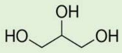
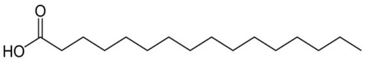
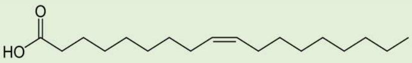
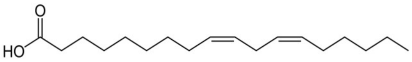
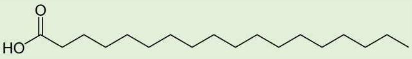
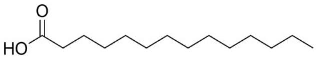
Figure 6: A schematic and simplified representation of the derivatives of the oil palm fruit. In green are the categories that correspond to the supply chain of palm oil and its derivatives. The grey categories are not included in the scope of this study.

Besides the categories displayed in Figure 6, more possibilities exist. For one, chemical derivatives of minor components can be obtained, or fractions of CPO. Furthermore, specifications can be made within each category. Oleochemicals can be subdivided in precursory and successive oleochemicals and refining can be applied in multiple degrees as well. This framework is however sufficient to understand the main processes and the corresponding compounds.

Figure 7: Palm oil and oil palm fruits. (Smith, 2018)

This main compound, the vegetable oil itself as displayed in Figure 7, consist of what chemists call triacylglycerols. These molecules consist of three fatty acids, mostly palmitic and oleic acid, that are connected to glycerol. In palm oil a mix of saturated and unsaturated fatty acids is present, see Table 1. Regarding edible palm oil several modifications can be made to obtain a desired combination of fats. Based on different melting points a solid fraction of palm oil, called palm stearin, can be separated from the liquid fraction, called palm olein. Stearin consists largely of glyceryl tripalmitate and is therefore higher in saturated fats than olein, which consists largely of glyceryl dipalmitate monooleate. By further fractionation and mixing of fractions different melting points can be achieved to suit specific purposes. (Pande, Akoh, & Lai, 2012)

Table 1: An overview of the elementary compounds in palm oil.

	Compound	Systematic name	Structural formula	Content[4]
	Glycerol	Propane-1,2,3-triol		-
Fatty acids	**Palmitic acid**	Hexadecanoic acid		43.5%
	Oleic acid	9-Octadecenoic acid		36.6%
	Linoleic acid	9,12-Octadecadienoic acid		9.1%
	Stearic acid	Octadecanoic acid		4.3%
	Myristic acid	Tetradecanoic acid		1.0%

Compounds that arise when the triacylglycerols are decomposed or chemically altered are called oleochemicals. Among them are the fatty acids and glycerol and all derivatives thereof. Functional groups can be altered or the molecules are recombined to form many chemicals that can be applied as e.g. detergent or emulsifier (Yeong, Idris, & Hassan, 2012).

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[4] Relative content; Source: United States Department of Agriculture (USDA; 2018).

2.3 Impact assessment

In principle the concept of environmental impacts refers to any interaction between the palm oil supply chain and the environment. More precisely the ISO standards for Life Cycle Analyses (LCA) can be maintained, whereby impacts are identified as the flows that cross the boundary between the product system and the environment (ISO, 2006). If the flow is directed into the system, it indicates resource extraction, and if the flow exits the product system, it indicates an emission. These impacts are often related to a specific process within a clearly defined product system. In this research only the controversial production of crude palm oil (CPO) is considered, instead of the whole life cycle. This product system, as introduced in Figure 5 can be subdivided in the individual processes 'plantation expansion', 'agricultural practices' and 'milling'. In Figure 8, these processes and their impact on the environment are displayed. If the whole life cycle were considered, more processes would be included, from raw material extraction up to disposal. In that case, the Figure would need to be expanded sideways.

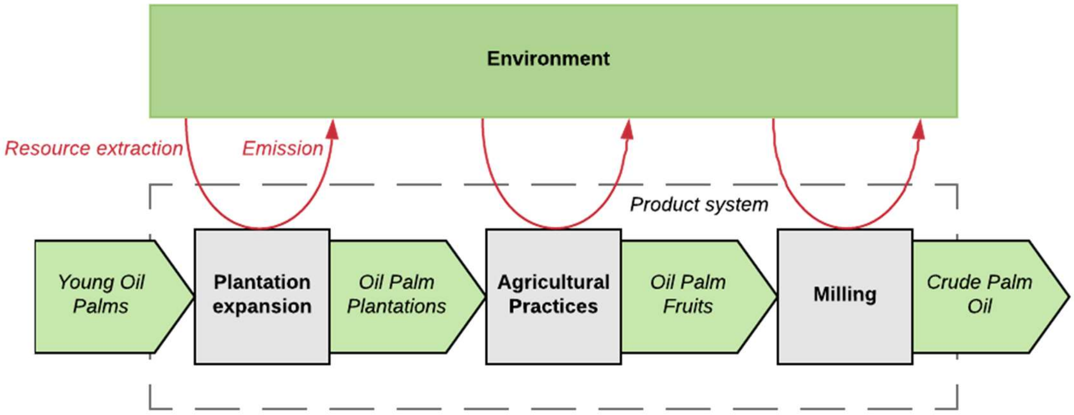

Figure 8: Schematic representation of the palm oil production system as used in LCA, with the processes in grey, (intermediate) products in italic, and the impacts in red arrows. Interactions between the product system and its environment are known as the impacts.

The environmental strain of consumption has repeatedly been traced by means of Environmentally Extended Multi-Regional Input-Output (EMRIO) analysis and Life Cycle Assessment (LCA) (Marques et al., 2017). As Marques et al. (2017) set forth, the tools of LCA and EMRIO have in principle been developed for different purposes. The aim in LCA studies is to consider the interactions between a production system and its environment across all the stages from resource extraction to the end-of-life. Thereafter, the resultant pressure of these interactions is calculated for different 'characterisation factors', i.e. indicators of impact. In 2008 the first ever LCA on palm oil was conducted that was compliant with all ISO regulations (Smidt & De Rosa, 2018). As the name suggests, the main strength of EMRIO analyses lies in the discernment of international trade relationships. The Input-Output (IO) trade analyses describe the physical or monetary transactions between a collection of exporting entities on one side and importing actors, regions or sectors on the other. The addition of a multi-regional approach includes an additional spatial dimension to the analysis. These regions can refer to nation states, or in a more disaggregation approach to provinces or among others. Lastly, the environmental extension can enable insight in the link between the consumption of a specific commodity and the impacts at production via the aforementioned trade analysis. (Marques et al., 2017)

3 Methods

3.1 Diagnosis of current interventions

The effectiveness of current interventions is further examined in this first research part. To solve the complex issues related to the unsustainable palm oil production, responsibility is assigned to various actors. Therefore, first the actors in the Dutch palm oil industry will be examined. To determine their effectiveness, the ambition of the responsible actors is elucidated. The successfulness towards these goals will be evaluated, with the following questions in mind: Where do current interventions fail to realise their ambitions? A diagnosis of the shortcomings of these specific interventions is executed through an analysis of the underlying causes of (in)effectiveness. This yields insight in the role of transparency for successful implementation of interventions as well as possible improvements for the future. This information on the effectiveness of interventions is also considered a form of transparency by Gardner et al. (2018). Resultantly recommendations will be formulation for future interventions. The materials for this research part are predominantly collected through desk research. A review of literature, supplemented with information from sustainability reports and associated websites delivered the information required for this diagnosis.

3.2 Impact indicator selection

The selection of a suitable impact indicator is conducted by means of a simplified multi-criteria analysis. This indicator will operationalise the target 'towards a sustainable supply chain' by focussing on the main issues and inspire action. However, in the search for an indicator the current knowledge on consumption-based indicators is consulted first. Based on a literature review, the collection of impacts, impact categories and impact indicators are established that are associated with palm oil production. Of these impact categories, the most pressing environmental concern is selected. Following on this review, the impacts and corresponding indicators are subjected to a set of criteria, see Table 2. The confrontation between the impact indicators and the selection criteria will yield the most suited indicator for impact assessment in the palm oil supply chain. Criteria 1-5 are proposed in UN (2015) guidelines. The criterium of representativeness is added as a prerequisite for suitability of the impact indicator. If the indicators meet these criteria is tested in this simplified analysis, based on a literature review. Accordingly, the suited indicator(s) is/are selected.

Table 2: Criteria for indicator selection.

Nr.	Criteria	Subcriteria
-	Representative	Representative for the environmental issues
1	Relevant	Linked to target
		Policy relevant
		Applicable at the appropriate level
2	Methodologically sound	Based on sound methodology
		Tested to be valuable
		Coherent and complementary
3	Measurable	Stable and sustainable
		Disaggregated
		Managed by one or more responsible agencies
4	Easy to communicate and access	Easy to interpret and communicate
		Easily accessible
5	Limited in number and outcome focused at the global level	Limited in number
		Outcome focused at the global level

3.3 Basis for impact assessment and supply chain analysis

Interventions should reduce the negative impact associated with palm oil. In order to objectively assess these interventions, the impact must be defined, quantified and linked to the material in question. In order to establish a justified method for linking processes to the impacts, the underlying relationships between palm oil production and the environment are examined in a literature review. Based on the nature of the environmental issues and the previously chosen indicator(s), the methodological framework, measurement techniques, data sets, allocation methods, and other methodological steps are determined. Each of these choices is made based on the aspects of quality and compatibility of the available options, see Table 3.

Table 3: Criteria for the methodology construction.

Nr.	Criteria	Subcriteria
1	Quality	Well researched
		Peer-reviewed
		Etc…
2	Compatibility	Spatial disaggregation;
		Location;
		Time; and
		Unit of the recorded parameters

4 Results

4.1 Diagnosis of current interventions

To solve the complex issues related to the unsustainable palm oil production, responsibility is assigned to various actors. How effective each of these actors is, depends on their successfulness in producing the desired or intended result. Therefore, first a clarification of the actors and their ambitions is given. Secondly, the current interventions will be discussed, namely banning palm oil, two instances of national governance, and the RSPO as a case of certification schemes. Subsequently, the diagnosis will show how they have contributed to realising these ambitions and where their effort fell short. This ultimately leads to the drawn recommendations for future interventions.

4.1.1 Actors

In the societal discourse, often the major suppliers of palm oil rich products and investing bodies are held accountable based on their corporate social responsibility, thereby facing increased risks to their reputation (McCarthy, Gillespie, & Zen, 2012). Private companies have multiple reasons to cooperate, yet regardless of their intentions, the implementation of corporate no-deforestation commitments is grounded by the complexity of the palm oil supply chain (Berger, 2018; Lyons-White & Knight, 2018). For consumers, the number of options to decrease their footprint is even more limited. Informing consumers and engaging them in the transition is complicated, since palm oil is an unnoted ingredient in many consumer products. Due to a lack of affinity with the palm oil content in consumer items and the intent not to flood the market with labels, the RSPO logo that indicates sustainable palm oil content is barely displayed on consumer products. Besides the choice for those few labelled goods, all consumers can do is avoiding palm oil based products at all or financially supporting local sustainability initiatives (DASPO, 2018). (Smedley, 2015)

Among the current interventions, certification schemes play a dominant role. The certifications that are administered by the RSPO and ISPO are highest in regard, as these are 'high profile initiatives' (Oosterveer, 2015). The RSPO standard recurs in national governance initiatives, and by some this organisation is perceived as the main hope to address the detrimental effects of palm oil production. On the other hand, the ISPO standard has only been implemented since 2011, and its reputation is "dubious at least" (Pye, 2018). "The ISPO has been criticised for inadequate environmental protection, neglect of human rights, weak law enforcement and poor governance", according to the Environmental Investigation Agency (EIA; 2018). Since the ISPO is generally perceived as the weaker standard, the choice is made to focus only on the RSPO (Pye, 2018).

Besides, national governance initiatives in the Netherlands have been active since 2010. This governance was formed through a collective effort of Dutch actors. The cooperation between palm oil sectors in the Dutch supply chain was first named the Task Force *Duurzame Palmolie*, and in 2016 passed into the Dutch Alliance for Sustainable Palm oil (DASPO). (DASPO, 2015)

4.1.2 Sustainability ambitions

The concept of sustainable development is based on the objective to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The triple bottom line that is needed to sustain future generations refer to the social, environmental and economic conditions. These are equally important, since all three aspects are necessary to sustain current and future generations. In principle every sustainability intervention should aim to enhance these conditions. When considering the current interventions that are in place in the Netherlands, each organisation has set its own goal. Realistically, these goals must be feasible. From a Dutch perspective, actors in the value chain are only indirectly responsible for the impact of palm oil production. They partake in the incurred damage by investments that they make, the goods they process and the collaborations they engage in. Where the responsibility for foreign malpractices is limited, conversely the influence that these parties can exercise to alter the current production system is limited too. In addition, the ability to effect change is restricted by the supply chain complexity as mentioned in the introduction.

The ambition of the RSPO can be summarised in transforming the palm oil market and making sustainable palm oil the new norm (RSPO, 2018a). The triple bottom line reoccurs in the summarised criteria that the RSPO maintains for its certified sustainable palm oil (CSPO): “legal, economically viable, environmentally appropriate and socially beneficial” (RSPO, 2018b). The RSPO claims that through proper implementation of elaborate criteria for sustainable palm oil, the harmful consequences of oil palm cultivation on the natural and social environment can be diminished (RSPO, 2018a). The DASPO applies national governance with the intend of obtaining 100% CSPO used in food and animal feed in the Netherlands (DASPO, 2015). Hereby, the Dutch Alliance is a first, whose example has been followed by other alliances in Europe, North America and South-East Asia. Furthermore the ambition has been expressed to end the consumption of palm biodiesel in the Netherlands (MVO, 2018). (DASPO, 2018)

4.1.3 Banning palm oil

On the one hand, inaction (i.e. the unregulated consumption of palm oil) is not an option, as this equals uncontrolled expansion with all its consequences. On the other hand, moving away from palm oil may not have the desired effect. First and foremost, Corley (2009) note that the high yield of oil palms makes it the ‘land sparing’ option in comparison with alternative oil crops. Replacing palm with alternative vegetable oils would induce even more land use change. Moreover, Corley (2009) explains that “anti-palm oil campaigns may even be counter-productive: exclusion of palm oil from Europe would destroy the market for certified ‘sustainable’ oil.” The Dutch Alliance put forward a more comprehensive set of arguments, see Table 4. Proof that palm oil could in practice be even more sustainable than alternative vegetable oils is given by Smidt & De Rosa (2018).

Table 4: Argumentation by the Dutch Alliance for the use of palm oil (DASPO, 2018).

“Why we use palm oil	Moving away from palm oil leads to
Global food security	More agricultural land needed
Highest yield	More poverty in rural areas
Versatile properties	No incentive for sustainable production
Rural income and development	More trade with markets which don’t value the environment”

Nevertheless, a ban on palm oil is still often suggested. In 2015, French Minister of Ecology Ségolène Royal made a statement wherein she urged consumers to stop eating Nutella because it contains palm oil. Afterwards she apologised and deeply regretted this statement (HLN, 2015). In a reaction, Ferrero who produces Nutella has put forward that their palm oil is certified as 100% sustainable, based on RSPO certification (HLN, 2015). On another account, Friends of the Earth Netherlands (*Milieudefensie*; 2018) is urging banks to “cease financing the industrial palm oil sector”. In their own words, “these banks pave the way for serious human rights violations (…) by financing palm oil companies” (Milieudefensie, 2018).

Financing the palm oil sector is however not intrinsically harmful, as Corley (2009) explains. One of the reasons oil palm plantations are established on forest land instead of grasslands is financial. Forest clearing creates a revenue stream during land conversion, whereas concessions on grassland bring no income until 2.5 years after field planting. Financing institutions – some of which are RSPO members – could play an important role in overcoming this discrepancy and thus reduce deforestation.

4.1.4 National governance

Oosterveer (2015) explains how the palm oil production network is an exemplar result of globalisation in food chains. Since the 1970s and '80s the trend in agricultural food production has shifted from a local supply chain with (sub)national regulations to global networks and governance structures. Oosterveer (2015) argues that a transnational problem benefits from a transnational solution based on an understanding of the global value chain. It can therefore be expected that national governance is ineffective at managing a global supply chain. Nevertheless, the Dutch alliance has taken on two nationwide interventions: The ambition to obtain 100% certified palm oil for the production of food and animal feed (DASPO, 2015, 2018), and zero consumption of palm biodiesel (MVO, 2018). The first target was set for 2015, but to date has not been successful. Since 2011, the share of processed CSPO in the participating sectors has increased from 21% to 88% in 2017 (Taskforce, 2012; DASPO, 2018). The ambition to obtain 100% certified palm oil in the short future is still upheld. The exclusion of palm biodiesel in the Dutch consumption mix has been effective since 2016 (MVO, 2018).

Based on the outcomes of both interventions, two issues are presented that undermine national governance: Leakage effects, and greenwashing. Phelps (2017) explains that environmental leakage refers to "how interventions aimed at reducing environmental pressures at one site may be locally successful, but increase pressures elsewhere". It can then seem as if impacts are mitigated in the area of interest. In reality, the impact is only displaced outside the scope of the interventions. For greenwashing the following description is maintained: "Today, the term tends to refer to exaggerated benefits or unsupported claims in support of the environment in advertising and other persuasive communications" (Kahle & Gurel-Atay, 2013)**.** Hereby greenwashing can wrongly portray a company as more environmentally friendly than it actually is. How these issues are related to the effectiveness of sustainability interventions will be discussed for both interventions.

4.1.4.1 Intervention 1 – Certified palm oil only

By demanding 100% CSPO in food and feed industry, DASPO is optimistic to have started an irreversible transition to mainstream sustainable palm oil (DASPO, 2015). The expectation was that the aim would be realised in 2015. This was not the case, so they have not been totally successful. Their ambition however includes contributing to the transformation of the supply chain. This is however where national governance and certification schemes show its shortcoming. Whereas the commitment of 100% CSPO is only national, it is prone to leakage effects; causing impact displacement as opposed to impact reduction. For remarks on the effectiveness of certification schemes, see the section below.

For RPSO certification to be successful, a strong demand is necessary (Corley, 2009). As it stands, the appeal for CSPO is has been insufficient to increase the market share above 15% (Pirker et al., 2016). According to Pirker et al. (2016) half of this produce "is marketed as conventional palm oil, since demand for certifies oil is still too low". According to a more recent source, 19% of palm oil production was certified (EIA, 2018). Concurrently, Pye (2018) reports a market penetration of 10% for CSPO and specifies that although it is considered a niche market by others, it dominates in those sections where sustainability is sought-after. With these low demands, there is no shortage in CSPO; the contrary is true. The surplus in certificates causes that a relatively small increase in the European CSPO demand does not incentivise change. It merely means that the portion of CPSO that is marketed as regular, now is redistributed to Europe. In return, uncertified palm oil is redistributed to the rest of the world. Hereby, the embodied impacts shift from Europe to the rest of the world. The resultant net impact reduction is however non-existent. Only above a certain threshold, when the global demand exceeds supply, will the choice for certified palm oil incentivise change.

The DASPO (2018) acknowledges that the entire supply chain can only be changed in case of a worldwide demand for sustainable palm oil. Meanwhile the example of the Dutch Alliance has been followed by other countries in the continent. In fact, the European industry has collectively assumed responsibility in the European Sustainable Palm Oil alliance (ESPO). The ESPO has announced the ambition to complete the transition to 100% sustainable palm oil by 2020 (HLN, 2015). Nonetheless, the EU consumption only constitutes to 12-15 % of global consumption (Fern, 2017). In this context a transformation in nations like China, India and Pakistan is more far more effective; Not to forget the domestic consumption of Indonesia and Malaysia. (T. Pasmans, personal communications, February 26, 2019)

4.1.4.2 Intervention 2 – Banning palm oil in biodiesel

Importing palm oil for the production of biodiesel has been stimulated by the Renewable Energy Directive of 2009, with success (Fern, 2017). On the contrary, biodiesel from palm oil is surrounded by even more sustainability issues than the applications in food, cosmetics and industrial applications. Mekhilef, Siga, & Saidur (2011) enumerate challenges in the form of "tough global competition, feedstock issue, food versus fuel war, sustainability, and limited land for use and deforestation". In the Netherlands palm oil as feedstock for biodiesel has been replaced by alternative energy carriers. Currently, old frying fat is the dominant raw material for the production of biodiesel, constituting to 61% of FAME[5] consumption in 2017 (Dutch Emissions Authority, 2017). When palm oil is replaced by waste streams instead of alternative oil crops, the arguments for moving away from palm oil do not apply here. Waste streams ensure no competition with food, and no additional agricultural area is needed, see Figure 9. For more information on the food versus fuel debate, see e.g. Tomei & Helliwell (2016).

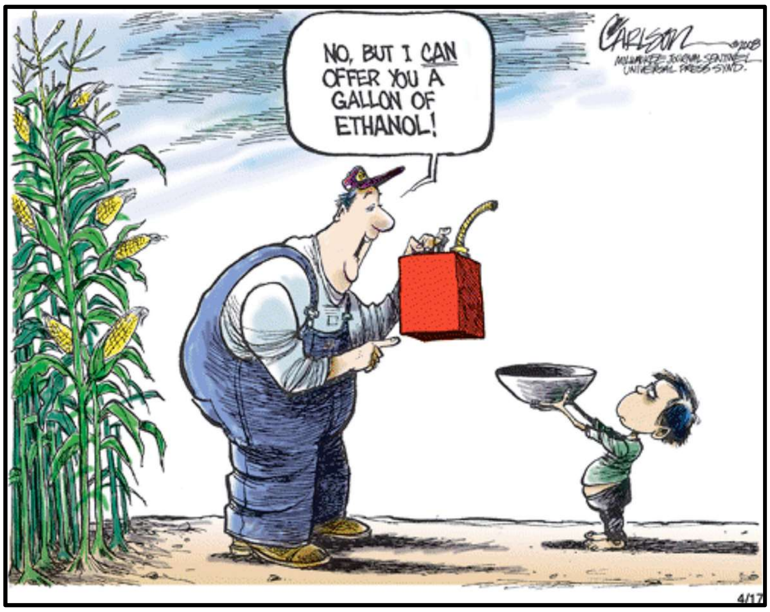

Figure 9: This image portrays the food versus fuel debate in the case of bioethanol from corn. Considering the land scarcity, biofuel production should not limit food production. (Tomei & Helliwell, 2016)

Reports on energy for transportation in the Netherlands show that the biodiesel consumption of palm oil is reduced to zero, but the amount of production is unrecorded (Dutch Emissions Authority, 2016). Leakage effects are to be expected, as production for export is furthermore not covered by the national ambition. Although the production of palm biodiesel in the Netherlands is not specifically mentioned, there are reasons to believe it does occur. For one, the Netherlands is a big exporter of biodiesel. Even most of the biodiesel we produce is exported, namely 1602 mega tonnes in 2017 (UN, 2019). This

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[5] FAME (fatty acid methyl ester) is a type of biodiesel.

amount is comparable to the capacity of the manufacturers listed below, see Table 5. Moreover, these companies or the associated groups are registered in RSPO as palm oil processors.

Table 5: Possible facilities of palm-based biodiesel production in the Netherlands, their founding year and capacity.

Company	Group	Location	Year	Capacity[6]
Neste Oil Netherlands BV	Neste	Rotterdam Maasvlakte	2011[7]	1,000,000
Biopetrol Rotterdam BV	Glencore	Rotterdam Botlek	2007[8]	400,000
Biopetrol Pernis BV	Glencore	Rotterdam Pernis	2009[9]	250,000

In 2012, only 29% of the imported palm oil in the EU was applied for biodiesel (Van der Laan, Wicke, Verweij, & Faaij, 2017). This was also the year that 1 Mt of additional capacity became available “for the European market” (MVO, 2014a). Since then the market has drastically changed, as in 2017 approximately 4 Mt – over half of the imported palm oil into the EU – is applied in biodiesel production (Jong, 2019). Considering the unnoticed character, high demands, and the strategic location of biodiesel production plants, the Netherlands probably still plays a significant role in palm oil biodiesel production. Unfortunately, information on feedstock mixes are generally not published by the biofuel industry (Valin et al., 2015). If Dutch facilities indeed redirect their sales to the European market, banning palm oil in the Netherlands will only cause impact displacement.

Here as well, a shift towards trans-national governance is being made. The EU parliament recently decided on an unprecedented phase-out of the use of a crop (Reuters, 2018). As promising as this seems, Jong (2019) explains its real implications: “(…) the phase-out doesn’t mean a ban on palm oil in biofuels. EU member states will still be able to import and use palm oil-based biodiesel, but it will no longer be considered a renewable fuel or be eligible for the attendant subsidies.” This raises the question if biodiesel will still be produced from palm oil, when it is no longer considered a sustainable fuel; And what the alternative will be.

4.1.5 Certification schemes

The Dutch Alliance believes to have made a first step towards mainstream sustainable palm oil, when palm oil processed in the food and animal feed industry is 100% RSPO-certified (DASPO, 2015). This transition towards a sustainable supply chain, however, fully depends on the effectiveness of RSPO certification. Regular palm oil is replaced by CSPO, as the label ‘certified sustainable’ is supposed to guarantee sustainable practices, see Figure 10. Yet despite its efforts, the RSPO has not brought about any significant improvement in its 15 years of existence.

For a product to be truly sustainable, it should be sustainable in every aspect. In this case, the environmental issue of deforestation is taken as example. Gatti, Liang, Velichevskaya and Zhou (2019) summarise that “in principle, RSPO-certified companies are required to ensure that forests are assessed for their high conservation values before new plantings and - since the recent reinforcement by the Palm Oil Innovation Group - plantations must not touch high carbon stock areas”. In turn, RSPO supervision on the affiliated actors should safeguard forest conservation. Lyons-White and Knight (2018) observe that recent findings merely indicate that RSPO certification mitigated primary forest loss. This weak relation furthermore only applies to a limited definition of forests, see part 3 on the definitions of forest. Ruysschaert & Salles (2014) focus specifically on the Sumatran orangutan and its habitat, and found that the rise of RSPO certification has not been effective in its conservation. On the

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[6] In tonnes per year; Source: Port of Rotterdam (2016)

[7] Source: Neste (n.d.)

[8] Source: Vopak (2006)

[9] Source: Roelfs (n.d.)

contrary, Gatti et al. (2019) observe that current certified plantations have often been established on formerly forested areas. In fact, the largest deforestation rates before 2007 occurred in now-certified areas. They thus conclude that certified palm oil production still causes “severe deforestation and may be no more sustainable than non-certified productions” (Gatti et al., 2019). The claim that certified palm oil equals sustainable palm oil is therefore unsupported and facilitates greenwashing.

Figure 10: The RSPO trademark logo for Certified Sustainable Palm Oil (CSPO).

In a broader sense, van der Ven et al. (2018) found that eco-labels and certification schemes have ‘neither abetted, nor hindered’ the transformation of tropical forests to agriculture in the case of palm oil among others. For RSPO-certification to be a success at least the following requirements are known already: traceability, and market penetration. Traceability for the purpose of monitoring sustainable production is discussed in the problem definition. This recent development has amounted to 99% of the palm oil that enters Europe to be traceable to the mill. Previously, operators only had to identify the actors directly successive and prior in the supply chain (Lai et al., 2012). In the section on national governance, the second condition of market penetration was discussed. The currently low market penetration does not incentivise increased sustainable production. However, this offers no explanation for the ineffectiveness of certification schemes in the already affiliated plantations.

4.1.5.1 Shortcomings of RSPO certification

RSPO calls their certified palm oil ‘sustainable’. But this is extremely misguiding. Something is only sustainable if it meets the requirements for it, not if some label says so. The label only indicates that the actors agreed to implement more sustainable practices. Resultantly, three shortcomings can be identified. First off, the affiliated actors break the agreement they have made. Secondly, often impact is often reduced and not eliminated, which is necessary for sustainability. Lastly, the scope of its interventions is often on the implementation of a monoculture approach instead of the nature of monoculture itself. These shortcomings will be further discussed in this section.

In 2013, already 61% of the palm oil processed in the Dutch food sectors was certified sustainable (MVO, 2014a). Greenpeace (2016) notes however that this achievement cannot have been accomplished, since one of the largest palm oil suppliers to the Netherlands, IOI, recently lost its RSPO certificate after eight years of ‘destructive practices’. More reports on destructive practices are available, as mentioned by Pye (2018): “Although clearing by burning is illegal in Malaysia and Indonesia, palm oil corporations are regularly shown to have used fire to clear forests and peatlands”. This shows that actors could break their word, and claim to be sustainable, yet act otherwise.

The criteria for CSPO are set to reduce the negative consequences of palm oil production, and thus realise the ambition of a sustainable supply chain. Establishing these criteria requires unambiguous definitions, rules and regulations. Specifically the design thereof has been troublesome. Ruysschaert & Salles (2014) observe conflicting demands between including all participants on the one hand and adapting to each different situation on the other. This conflict arises from the pivotal management principles that RSPO maintains, such as flexibility, inclusiveness and scientific robustness. Realistically, it is not possible to construct such a solution that all these conditions are met at once. An exemplar shortcoming is given in the formation of biodiversity conservation goals. Ruysschaert & Salles (2014) explain how tropical biodiversity science is still being developed, causing scientific robust statements to be meagre. Consequently, growers can exploit the lack of decisive evidence to conserve the bare minimum. This for example results in "all non-primary forests to be considered suitable for development," which equals to the regulation already installed by the RSPO, forbidding primary forest conversion as of November 2005 (Ruysschaert & Salles, 2014). Most definitively, the definition of valuable land covers must be extended beyond primary forest. For the definition of land use and land cover categories, see part 3. Furthermore, recent research merely indicates that the loss of primary forests has been reduced by RSPO certification (Lyons-White & Knight, 2018).

Another shortcoming of RSPO-certification is put forward by Azhar et al. (2017). They note that small-holdings are responsible for producing 40% of palm oil worldwide, yet the production of CSPO is predominantly lead by plantation companies. This discrepancy deserves extra attention, since small holder plantations are "usually characterized by intercropping systems and landscape heterogeneity" (Azhar et al., 2017). The conversion of forests to large-scale oil palm plantation cause a drastic decline in biodiversity and vast emissions of greenhouse gases (Pye, 2018). Inclusion of small holders in the certification process could benefit farmers livelihoods and promote biodiversity (Azhar et al., 2017).

Nonetheless, the most substantial difference between the two is found in the rate of deforestation. Nearly 90% of the reported deforestation due to oil palm development in Indonesia (2000-2010) can be attributed to "private palm oil corporations, including RSPO members, rather than smallholders" (Pye, 2018). As can be seen in Table 6, the high deforestation rate is particularly remarkable, because smallholder have expanded more than monocultures. Molenaar, Persch-Orth, Lord, Taylor and Harms (2013) describe how the share of smallholder has increased both in cultivated area, from 30% in 2000 to 41% in 2011, as in production volumes, from 27% to 38% in the same period. RSPO certification should therefore include small holders in particular. Meanwhile, the leading multinationals are responsible for as much as 90% of the produced 'certified sustainable' palm oil. Through certification of large-scale plantations, management of monocultures improves, yet the conversion *to* monocultures is not prevented. (Pye, 2018)

Table 6: the relative role of small-holder and large-scale plantations in cultivated area, palm oil production, deforestation and RSPO certification.

Share	Small holder plantations	Large-scale plantations[10]	Year	Source
Cultivated area	41%	51%	2011	(Molenaar et al., 2013)
CPO production	38%	53%	2011	(Molenaar et al., 2013)
Deforestation	10%	90%	2000-2010	(Lee et al., 2014)
CSPO production	10%	90%	-[11]	(Pye, 2018)

4.1.6 Recommendations

Although these current interventions were not particularly successful, their evaluation and the diagnosis of the shortcomings can aid the implementation of effective interventions in the future. A first conclusion can be drawn, that replacing palm oil with alternative vegetable oils or certified palm oil may not lead to increased supply chain sustainability. The environmental consequences of the alternatives are namely comparable, if not more substantial than in the status quo. Besides, these types of interventions are prone to impact migration, if they are only applied on a national scale. To

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[10] This category includes both state-owned and private estates.

[11] Pye (2018) refers to an unknown source from 2012.

conclude, the entire supply chain must change as the supply chain governance shifts from national to transnational, and preferably global regulations.

Moreover, the role of each actor in the value chain can be reconsidered. One example thereof was given by Corley (2009). Banks and other financing institutions can overcome financial barriers to the implementation of sustainable practices. Another example discusses the inclusion of smallholders, that is to a lesser extent related to deforestation and the associated effects on global warming and biodiversity.

Regarding certification schemes stricter monitoring on the affiliated actors is advised. Besides to avoid greenwashing, the criteria for sustainable production must be sharpened. Building criteria on a multitude of management principles has so far resulted in weak instead of perfectly finetuned definitions, rules and regulations. Instead, the focus should be on practical and effective management to solve the pressing issues at hand. Furthermore, the aim should be broadened beyond agricultural practices, and include the nature of the plantation expansion. Based thereupon small holders should be included in certification schemes, instead primarily focussing on companies that govern large-scale monocultures. Certification schemes and every other intervention for that matter should be compared with an objective transparent indicator on sustainability performance. Doing that will ultimately show the intervention has the desired effect. A comparison including RSPO market penetration will for example show the distinction between a certified and sustainable supply chain. A first comparison is performed by Gatti et al. (2019) by assessing tree loss in RSPO and regular palm oil concessions.

4.2 Impact indicator selection

As will become evident in this chapter, the concerns about the sustainability of palm oil are widely accepted. Even Tan et al. (2009), whose research is sponsored by Malaysian authorities, acknowledge that sustainable development is key if palm oil production continues to gain ground. The predominant issues they perceive are deforestation, biodiversity loss and peatland destruction. Tan et al. (2009) recognize that ecosystems are destabilised and several species face extinction, among which are Asian elephants and Sumatran rhinos, tigers and orangutans. However, a closer look reveals many more negative impacts of palm oil production on the social and natural environment.

For the selection of the impact categories, the obvious choice is to focus on land use changes, which causes all three of the major impacts. Gardner et al. (2018) for example directly target deforestation on the topic of transparency and sustainability in global commodity supply chains. On the other hand, the LCA study on palm oil by Smidt & De Rosa (2018) indicates that deforestation only contributes for a small portion to the total impact of production. However, they only include indirect land use changes caused by land scarcity. Additional inclusion of the direct land use change can largely affect the outcome. Reijnders & Huijbregts (2008) concluded that dependent on assumptions for losses of biogenic carbon, fossil fuel emissions and the treatment of palm oil mill effluent, total emissions can vary between 2.8–19.7 kg CO_2 equivalent per kg of palm oil. In the case of expansion on forested areas, GHG emissions associated with palm oil production can mainly be attributed to LUC processes, with peatland destruction causing an even bigger impact than deforestation on mineral soil (Reijnders & Huijbregts, 2008).

This Land Use Change (LUC) due to the consumption of palm oil will be expressed in a so-called land use footprint. In environmental studies the term ‘footprint’ is commonly applied to quantify the effects caused by certain consumption patterns. More specifically the definition by Marques et al. (2017) is retained: “metrics that capture the direct effects of an activity as well as the indirect effects that are transferred along a supply chain”. These footprints could express water use, energy use or carbon emissions, but more complex relations can also be expressed, like the ecological footprint (Galli et al., 2012).

4.2.1 Impacts of Land Use Change

The expansion of a palm oil plantation requires young oil palms and a suitable plot. Since germinating oil palm seeds is challenging and time-consuming, separate nurseries are established (FAO, 1977). When the young oil palms are large enough to be transferred to a new plantation, it will take only 2 or 3 years before they start bearing fruit (Lai, Tan, et al., 2012). When utilizing woodlands, removal of the original cover can be executed by means of forest fires if large machinery is unavailable, see Figure 11 (FAO, 1977). This practice, called ‘slash-and-burn’ is common in Southeast Asian agriculture to clear space for a plantation (Gatti et al., 2019). The FAO (1977) even used to promote this technique as part of a ‘better farming’ series throughout the 70s, 80s and 90s. Especially fires on peat soils have tremendous impacts. These fires can hardly be stopped and the formation of smog is harmful for both residents and the environment (Gatti et al., 2019).

> *“The expansion of the palm oil industry, particularly since the 1990s, often meant extending oil palm plantations into tropical forests. This process of burning and cutting large tracks of pristine forests generated widespread protests and growing concerns about the environmental and social impacts of palm oil production. It was in particular the vast forest fires in Indonesia and Papua New Guinea in 1997 that ignited a worldwide public debate on the destruction of tropical forests.”*
> *(Oosterveer, 2015)*

Figure 11: Tropical deforestation by means of forest fires. (Schiffman, 2015)

Large areas of valuable land have been converted to satisfy the increasing need for palm oil, mostly on Kalimantan, Sumatra and Papua (Van der Laan et al., 2017). Due to the conversion of forests and peatlands alone Indonesia emits vast amounts of carbon dioxide and ranks as the third largest greenhouse gas emitter worldwide (Ruysschaert & Salles, 2014). Besides, the ecosystem services that these tropical rainforests provide are degraded, along with the livelihood of many inhabiting species. A mean species reduction of 85% has been measured due to the conversion of primary forests to oil palm plantations (Pye, 2018). Among the remaining species typically abundant generalists, non-forest species and pests were found. Based on the existing literature, Corley (2009) concludes that biodiversity in oil palm plantations is similar to that in other monoculture plantations and inferior to that in secondary forests as well. Furthermore, peatlands are degraded that would otherwise perform as carbon sinks, since the internal anaerobic conditions halt organic materials from decomposing. Peatlands also stabilise water levels, resultantly mitigating both floods and droughts. Additionally, “rice fields and the agricultural lands of local communities” are expended, at the cost of local food production and the livelihoods of those communities (Van der Laan et al., 2017). These qualities (valuable biodiversity, ecosystem services and community use) are exactly what international sustainability guidelines aim to protect, according to Smit et al. (2013). (Tan et al., 2009)

Based on nationwide data on land cover and recent satellite imagery, Austin et al. (2017) assessed the land cover change to large-scale oil palm plantations in Indonesia. They found that between 1995 and 2000 over half (53.9%) of the plantation expansion on Sumatra, Papua and Kalimantan was located on forest area. In 2010-2015, this share had already dropped to 18.0%, as agricultural areas were more frequently converted to oil palm plantations (Austin et al., 2017). Despite this trend, palm oil is still rightfully considered a forest-risk commodity (Henders, Persson, & Kastner, 2015).

Locating future oil palm plantations on non-forest, non-peat land covers will reduce the strain on biodiversity and carbon stocks[12] (Spracklen, Reddington, & Gaveau, 2015). Alternatively, in some cases oil palm plantations contribute positively to the natural environment (Sayer, Ghazoul, Nelson, & Klintuni Boedhihartono, 2012). On the one hand, a positive carbon balance can be achieved when fallow or grass lands are converted. Secondly, when grown in a landscape mosaic, plantations “can play a role in biodiversity conservation” (Sayer et al., 2012). These grass lands should not be occupied otherwise, or else the competition for land may lead to unwanted land use and land cover (LULC) changes elsewhere. Azhar et al. (2017) support the potential role of smallholdings in biodiversity

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[12] See discussion for the potential of palm oil expansion in non-forested areas.

conservation, where they observed higher levels of biodiversity than in large-scale monocultures. In smallholdings besides monoculture farming, alternative agroforestry and diversified farming systems can be applied as well (Azhar et al., 2017). Expansion of agroforestry systems do cause a change in land use, yet the land cover can be partially retained.

4.2.2 Indicator selection

Among the unwanted LULC change caused by palm oil production, deforestation receives the most attention, hence the term 'forest-risk commodity'. The secondary impacts of deforestation are furthermore the most abundant and substantial. These impacts often interfere with the Sustainable Development Goals (SDGs) of the UN. These are e.g. the loss of ecosystem services and biodiversity (SDG 15), and the emission of greenhouse gases (SDG 13). Moreover, forest and peatland fires cause serious health issues (SDG 3). If forests are on peat soil, instead of mineral soil, peatland destruction leads to additional greenhouse gas emissions and undermines resilience to droughts and floodings (SDG 13).

Now that the environmental strain of palm oil production is narrowed down to the most essential and pressing issue of deforestation, the indicator needs to be constructed. To be more precise the environmental concern that is selected comprises the changes in land cover and land use to oil palm plantations at the expense of mineral soil and peatland forests and non-forested peatlands. In Table 7 the outcome simplified multi-criteria analysis is presented, showing carbon stocks to be the most suitable impact indicator.

Table 7: Overview of impact indicators and their suitability based on a simplified multi-criteria analysis.

	Criteria	**Deforested area**	**Species diversity**	**Essential biodiversity variables**	**Carbon stocks**
-	Representative	×	✓	✓	✓
1	Relevant	-	×	✓	✓
2	Methodologically sound	-	×	✓	×/✓
3	Measurable	-	×/✓	×/✓	✓
4	Easy to communicate and access	-	✓	×	✓
5	Limited in number and outcome focused at the global level	-	✓	×	✓

4.2.2.1 Deforested area

The most obvious indicator for this process would be the deforested area. Although the area is preferable for its simplicity, a suitable indicator should capture every important aspect as accurately as possible. The primary impacts were defined in terms of resource extractions and emissions, namely the loss of forest cover and the consequential emissions of greenhouse gases. Among the secondary impacts are the contribution to global warming, biodiversity loss and the degradation of ecosystem services. On this basic principle, the area of deforestation already falls short. Baccini et al. (2012) explain that the magnitude alone does not convey the nature of the converted forest cover. As every forest is different, a mechanism is required to capture the differences between the type, age and density of the forests, the inhabitant species and other relevant ecosystem services.

4.2.2.2 Biodiversity indicators

Ruysschaert & Salles (2014) previously noted that tropical biodiversity science is still inconclusive. Resultantly, the lack of decisive evidence has been exploited to conserve the bare minimum. A more in-depth review of the impacts on biodiversity reveals the complexity of the issue. Constructing an observation system that communicates the important developments in biodiversity can seem virtually insurmountable (Pereira et al., 2013). However, these effects can be captured by a proxy like species diversity, as observed by Marques et al. (2017), or through a framework of indicators, as suggested by Pereira et al. (2013).

Figure 12: Images of an Orangutan and Sumatran Tiger as posted on the Greenpeace (2019) website on palm oil.

On the one hand, an indicator like species diversity is limited in number and easy to communicate. In fact, the focus can even be narrowed down to a single species, like the orangutan or Sumatran tiger of Figure 12. The orangutan has even become an iconic symbol of the devastating effects of palm oil production in the Greenpeace campaign "Save Rang-tan. End dirty palm oil". In the scientific community, Ruysschaert & Salles (2014) have similarly taken the orangutan as the indicator of conservation goals. A single species allows for easy monitoring of the current situation and is sensitive to changes, especially the loss of habitat. However, the orangutan is not the only species facing extinction due to deforestation on Borneo and Sumatra. Tan et al. (2009) mention other large mammals, such as the Sumatran rhino, tiger and Asian elephant. Tropical rainforests are home to many species, some even unknown to this day. Marques et al. (2017) note that the first EMRIO was published with a biodiversity extension consisting of a description of the threats that each sector from each country exerts on different species. However, even species diversity, which is often used in both LCA and EMRIO analyses, is merely a proxy for biodiversity. Other biodiversity metrics applied so far in EMRIO include mean species abundance, potentially disappeared fraction of species (PDF), occupied bird ranges and missing individual birds. To construct conservation policies purely on species diversity is thus not relevant and not methodologically sound. (Marques et al., 2017)

On the other hand, sound methodology is provided in a framework of indicators. Pereira et al. (2013) critically screened biodiversity variables, whereupon they suggest an indicator framework that still consists of 50 essential biodiversity variables. This collection of indicators is however neither limited in number nor easy to communicate. The impacts on biodiversity are for example highly scale-dependent, as effects on biodiversity tend to differ between the local and regional or global scale. Disaggregated measurements on the desired level of spatial detail are therefore hardly comparable between locations and regions. The scale dependent and non-linear character of impacts on biodiversity, impede consumption-based impact assessment. Marques et al. (2017) conclude sceptically that the overall effects on biodiversity cannot be attributed to specific commodity, as the "relationship between the amount of resources used and the effects on biodiversity" is not linear (Marques et al., 2017).

4.2.2.3 Carbon stocks

As resultant biodiversity loss is hard to account for, “NGOs put forward greenhouse gas (GHG) emissions as a new argument” (Ruysschaert & Salles, 2014). Especially pristine forests and peat lands hold large amounts of carbon, and the removal thereof releases equally vast amounts of emissions. The decline of these valuable ecosystems have simultaneously contributed to Indonesia being “the third largest emitter of greenhouse gas in the world” (Ruysschaert & Salles, 2014). Besides the fact that carbon stocks are representative for the harmful effects of LUC, the results are comprehendible and focused at the global level. When carbon stocks are expended by cutting trees or fires on forested or peat land, the carbon is released in the atmosphere. An estimation of the emissions from fires in Indonesia immediately show why the 1997 forest fires led to a world-wide debate, see Figure 13. That year the fire emissions were namely comparative to EU’s 2013 fossil fuel use (Butler, 2015). Besides their relevance, these results can thus be easily communicated and inspire action.

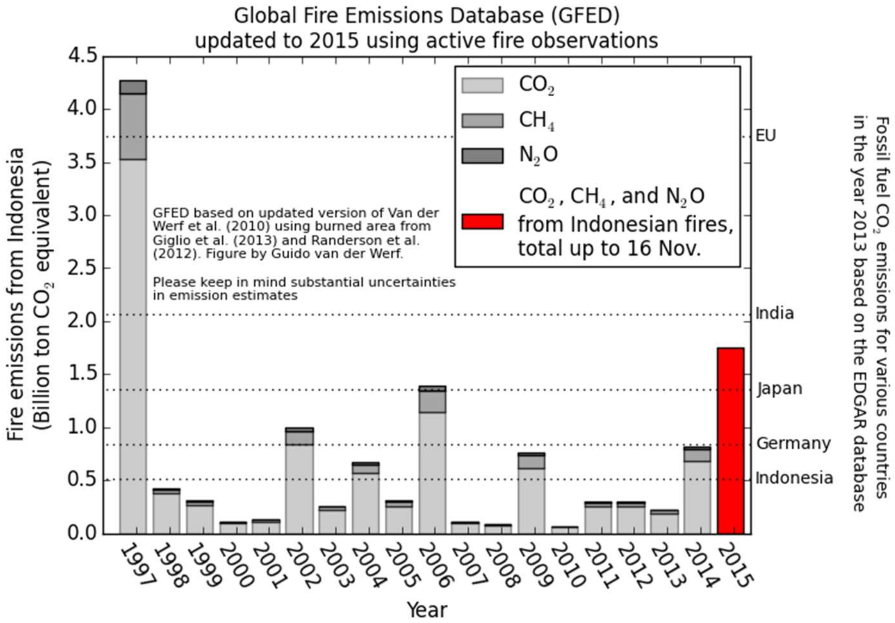

Figure 13: "Global Fire Emissions Database (GFED) updated to 2015 using active fire observations" (Butler, 2015).

The carbon stock indicator captures the most important issues of GHG emissions and deforestation, peat included. Carbon emission at land conversion both connects to global warming (via its global warming potential) and the expended carbon stocks. These carbon stocks in turn represent the ecosystems that were replaced by the established oil palm plantations. However, high carbon stocks do not necessarily equal a diverse ecosystem. Murray, Grenyer, Wunder, Raes and Jones (2015) found that “the relationship between carbon density and total species richness was either not significant or only weakly correlated for each of the major islands” of Indonesia. Murray et al. (2015) blame this lack of spatial congruence between carbon density and biodiversity to the inclusion of peat swamp forests. These areas hold enormous amounts of carbon, without maintaining the same biological wealth of mineral soil forests. Contrarily, also areas low in carbon stocks exist that support high levels of biodiversity, such as savannahs (Gardner et al., 2012). The proposed carbon footprint only measures emissions due to LUC and does not capture the entirety of sustainability. It measures a visible transformation and requires limited data, yet the addition of other indicators is desired.

4.3 Basis for impact assessment and supply chain analysis

Sustainability interventions in the palm oil supply chain should reduce the pressure of palm oil consumption on the natural environment. In order to objectively assess these interventions, a clear definition of the environmental strain is required. Secondly, the methodology for its implementation as consumption-based indicator should be agreed upon. Following these two steps, the consumption-based impact can be translated through the entire supply chain, based on a consecutive trade analysis. In this chapter proper and consistent impact assessment is facilitated by proposing a unified methodology for these steps, according to the current scientific understanding.

4.3.1 Methodology framework

For the purpose of this study the EMRIO analysis is most suitable and will form the backbone of the proposed methodology. Whereas in LCA's as many impact categories are included, the EMRIO analysis requires only one. The impact indicator from part 2 now acts as the environmental extension in this method. As Marques et al. (2017) explain, the environmental extension allows the measurement of "the direct environmental impact [or] pressure arising from the activity of a production sector in a certain country". In this case, the direct environmental impact is the Carbon Stock Change due to Land Use Changes (CSC-LUC).

Although EMRIO analyses are 'booming', the impact assessment and trade analyses have remained aggregated at the national level (Godar et al., 2015). Godar et al. (2015) argue that it is necessary to establish the direct and indirect cause-and-effect relations between consumption and the issues related to palm oil production in order to implement effective measures. Until recently however, methods to increase transparency in global commodity supply chains lacked fine-scale spatial resolution (Godar et al., 2015). "Precise information on the origin of a given product is an essential basis for achieving more sustainable resource supply systems, evaluate dependencies, and reduce environmental and social impacts associated with consumption" (Godar et al., 2015). Godar, Suavet, Gardner, Dawkins, & Meyfroidt (2016) explain that resultantly the impacts embedded in a certain product can be evaluated less accurately. Consequently, differences between the impacts associated with specific supply chain actors are less discernible. This ultimately results in a poor understanding of "the trade-offs associated with interventions to improve the governance of commodity supply chains" (Godar et al., 2016).

Where the EMRIO analysis lacks spatial detail, the Spatially Explicit Information on Production to Consumption Systems (SEI-PCS) model can fill in. Godar et al. (2015) introduce the SEI-PCS model as a potential solution for the recent inability to include the heterogeneous character of consumption-based impacts. This addition includes the determination of actual locations from where consumer goods are traded. By linking such spatially explicit information with international trade flows, existing country-level trade analyses can be downscaled and refined. In other words, the SEI-PCS model bridges the gap between country-level trade data, and the sub-national supply chain. (Godar et al., 2015)

Although numerous analyses have preceded with the aim to quantify the biogenic carbon emission due to the oil palm expansion, their results vary tremendously. In this collection, the first distinction can be made between a historical and projection CSC-LUC approach. The former is based on historical data, and the latter on forecasts. Since these methods have a different starting point, their results are incomparable. As deforestation always precedes the consecutive production of palm oil, the historical approach is most suited. In this way, the current production of palm oil can be linked to observed deforestation in the past, see also section 4.3.3.3. The second distinction is made between marginal en average allocation. Here as well the outcome varies based upon the approach and are mutually incomparable. The average calculation is chosen, because it presents the impact of consumption when all palm oil sources are included. (Goh, Wicke, Verstegen, Faaij, & Junginger, 2016)

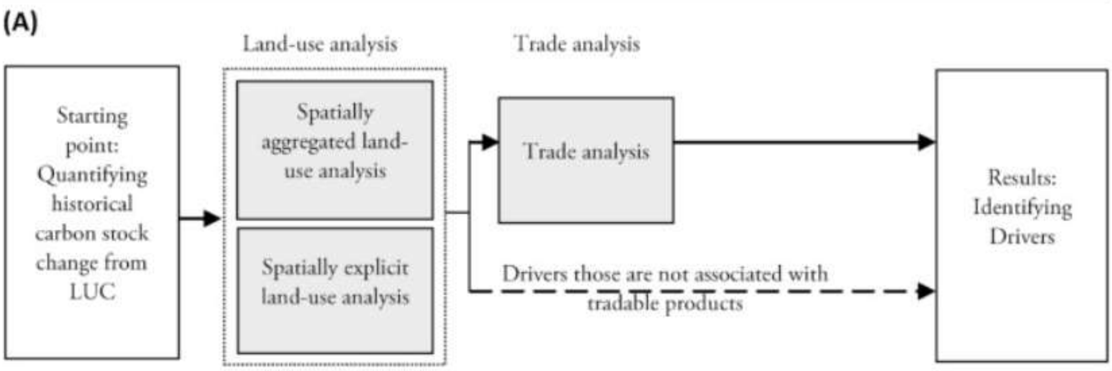

Figure 14: Methodological framework for an EMRIO analysis based upon a historical CSC-LUC approach. Source: Goh et al. (2016).

As Goh et al. (2016) explain the average, historical CSC-LUC approach consists of "different methodological components on the production side (linking land, land-use and product), consumption side (linking product and consumer) and/or trade (linking both sides)" (Goh et al., 2016). An overview of the components is given in Figure 14. Through these different steps in the methodology, the consumption-based indicator, namely the embodied emissions of palm oil consumption, are calculated. In a first step, the carbon emissions quantified and linked to the historic deforestation through so-called carbon stocks. In the land-use analysis the deforested area is linked to the plantations via proximate drivers. Here the definition of LULC categories is crucial to the outcome. The third step, that is also part of the land-use analysis is the translation from oil palm plantations to the production of CPO. This step is based on the linear amortisation of the impact, the yield in the respective areas and allocation between crude palm oil and its by-products. Lastly, the trade analysis allows the impact embedded in palm oil to be attributed to consumption elsewhere. In the following sections these methodological choices will be discussed, that ultimately enable the implementation of a consumption-based indicator.

4.3.2 Quantification of historical Carbon Stock Change due to Land Use Change

4.3.2.1 Step 1: Carbon stocks

To link carbon emissions to the change in land use and land cover, the carbon content that is converted in that specific area is key. This carbon content of forests, peatlands and the like are called carbon stocks. The amount of carbon in each area can be modelled based on the land cover type or measured by satellite or on location. Actual measurements are preferred, because the amount of carbon stored in forests highly varies over space and time. According to Baccini et al. (2012), "this variability arises from natural and anthropogenic disturbances, as well as differences in stand age, topography, soils and climate". Due to this high uncertainty in carbon stock values, extrapolating data to other areas is undesirable. Generalisation of forest areas into categories in turn leads to large uncertainties in the emitted biogenic carbon. Exemplar values are displayed in Table 8, showing large differences between logged and primary forests, different locations, sources and even within sources. (Baccini et al., 2012)

Assuming a single carbon stock value does not suffice for disaggregated, heterogeneous situations. Instead, "higher quality information on the spatial distribution of carbon stocks is needed" (Baccini et al., 2012). Besides, forest inventories are not an option, as in many countries these reports are obsolete or none-existent. The forest inventories Baccini et al. (2012) address, are mainly established through field research and designed for the commercial timber industry. Therefore, mostly the merchandisable share of biomass is taken into account.

Table 8: Summary of all the different values that are found. Mg C ha-1 (Mg = tonne C / ha). Primary forest, logged forest in parentheses. AGB = above ground biomass; BGB = below ground biomass.

Land cover	Carbon stock	Category[13]	Location	Source
Forest on mineral soil	282 (223); 231 (183)	ABG+BGB	Sumatra; Indonesian Borneo	(Persson, Henders, & Kastner, 2014)
	189 (104)	ABG	Southeast Asia	(Agus et al., 2013)
	175-215 (90-180)	ABG	Malaysian Borneo	(Sayer et al., 2012)
Forest on peat soil	220 (103)	ABG+BGB	Southeast Asia	(Hergoualc'h & Verchot, 2011)
	187 (148); 119 (94)	ABG+BGB	Sumatra; Indonesian Borneo	(Persson, Henders, & Kastner, 2014)
	162 (84)	ABG	Southeast Asia	(Agus et al., 2013)
Oil palm plantation	50-100	ABG	Malaysian Borneo	(Sayer et al., 2012)
	36	ABG	Southeast Asia	(Agus et al., 2013)
	32	ABG+BGB	Southeast Asia	(Hergoualc'h & Verchot, 2011)
Shrubland	30	ABG	Southeast Asia	(Agus et al., 2013)

For the sake of unambiguous definitions, the differentiation between annual carbon uptake (t/ha/y) and carbon sink (t/ha) should be made. For now, the focus will be on the carbon sinks. Secondly, carbon sinks can be divided in above ground (AGB) and below ground biomass (BGB), dead wood, litter and soil organic matter (Hergoualc'h & Verchot, 2011). The dead matter only contributes a small amount to the total biomass and is therefore neglected. As can be seen in Table 8, some sources do include the tree roots below ground in the carbon stocks. For the purpose of impact assessment, only the biogenic carbon that is released upon conversion is of interest. Much of the below ground biomass is contained in the soil, except during cultivation and peatland fires. On the contrary, above ground biomass is more easily expanded by disturbances from fire, wind, pest outbreaks and land use change. In the case of conversion from both forest as non-forest to palm oil plantation, the carbon stock in the mineral soil were found to be unaffected (Khasanah, van Noordwijk, Ningsih, & Rahayu, 2015). This proves that on mineral soil predominantly above ground carbon sinks are impacted by the oil palm expansion. On peat soil the carbon loss has to be accounted for as well. The yearly carbon emissions that arise from the decomposition of peat lands are estimated in the area of 10 to 15 tonnes per hectare (Hergoualc'h & Verchot, 2011). The above ground biomass can be measured with remote sensing. Wijaya et al. (2015) found that "careful interpretations of satellite data can provide reliable information on forest cover and change". Thanks to rapid developments in geospatial imagery in combination with field measurements, Baccini et al. (2012) have now been able to construct a map based on the above ground carbon density of forests, see Figure 15. This map is based on data from 2007 and 2008, and can thus be consulted for deforestation in the subsequent years. In any case it shows that the measurement of carbon stocks is feasible. (Baccini et al., 2012)

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[13] In some cases, dead matter was included as well; Its contribution is however relatively small.

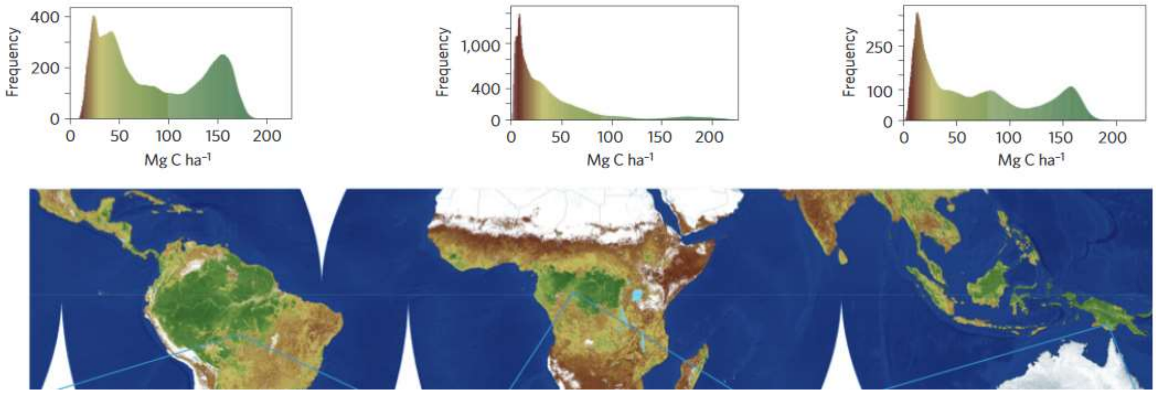


Figure 15: "Carbon contained in the aboveground live woody vegetation of tropical America, Africa and Asia (Australia excluded)" (Baccini et al., 2012).

4.3.3 Land Use Analysis

4.3.3.1 Step 2a: Proximate drivers

The causes of deforestation are more commonly known as drivers of deforestation. Direct drivers (i.e. proximate causes) comprise of all (human) activity that physically cause deforestation, whereas indirect drivers (i.e. distant causes) refer to underlying processes. In this case, plantation expansion is considered a direct driver, which in turn could be influenced by indirect drivers like changing consumption patterns. In order to correctly attribute the incurred loss to the palm oil industry, the contribution must be determined that expanding oil palm plantations make to deforestation. On this topic, even specifically for CSC-LUC in Indonesia, many studies have been conducted. (Goh, 2016)

Van der Laan et al. (2017) explain that not all unwanted LULC changes are caused by the booming palm oil industry. Among the four main drivers in North and East Kalimantan – the logging, pulpwood, palm oil and mining industries – the palm oil industry only ranks third. On the contrary, its contribution to undesired LULC changes in that area is expected to rise significantly in the near future. However, between uncovering how often oil palm expansions cause deforestation and ascribing specific losses to the palm oil industry is still a major step. Underlying drivers for deforestation are often entangled via complex interactions, making it hard to discern a specific cause for tropical forest loss (Persson, Henders, & Kastner, 2014). Persson et al. (2014) furthermore explain that "even at the level of proximate drivers (i.e., the land uses replacing forests after clearing) there is a considerable lack of empirical evidence." For transparency creation, best would be to link the process of land use change to the corresponding actors. As this is not realistic, the choice is made to assess the proximate drivers, see Figure 16.

Figure 16: An oil palm plantation bordering a tropical forest in Indonesia. As this plantation is located on a former tropical forest, it is considered a proximate driver of deforestation. (Fothergill, Scholey, & Butfield, 2019)

The question what land use succeeds forestry can be solved through the assessment of proximate drivers come. However, who is responsible and why it occurs cannot be observed this way. A deeper understanding of LULC mechanisms has to be developed from on-the-ground research. Spracklen et al. (2015) expect that the prevention of forest fires can only be obtained if land-tenure disputes of the different land users are resolved. In fact, the cause for tropical deforestation and fires seems to be a mixed social, political and economic affair. Here, Spracklen et al. (2015) appoint social NGOs as intermediary, and address plantation companies on their duty to provide benefits for the original land owners. This could include employment, or structures based on leases or partial ownership.

Legally, land is assigned for agricultural development via concessions. These concessions are granted to the concession holder, which in most cases is a company, but could also be a smallholder or local business. The real issue starts when claims of land ownership overlap. This, for example, is the case when land originally belongs to local communities. Azhar et al. (2017) explain that the neglect of the indigenous land rights or the sustainability procedures protecting them, has led to “the loss of livelihoods and increased poverty”. On the other hand, local businesses are known to find loopholes in jurisdiction to profit at the expense of concession holders. In a third possible case, actors can establish a ‘customary right’, regardless if they are the formal owners. This occurs when tree cover is removed after which the land is abandoned for various reasons. (Spracklen et al., 2015)

The dynamics of this last case are of particular interest. Romijn et al. (2013) namely explain two contrary motives for this behaviour. Large areas of open land and shrubland could indicate the large-scale abuse of oil palm concessions for logging by third parties. However, the conversion to open land could also be a first step in the development of oil palm plantations. Logging can create an additional revenue stream, which is particularly desirable during land conversion, as the income from the oil palm is expected in 2.5 years (Corley, 2009). From one perspective, oil palm development on recently cleared and abandoned land is preferred to the removal of additional forest. Yet, when the conversion to fallow land is part of the land use transition to oil palm, the deforestation can (partially) be attributed to the final post-forest land use, which is the oil palm plantation. In the latter case, the deforestation will take place as part of a multistep transition to oil palm plantations, and in the former, there is no relation between the environmental decay and the oil palm industry. In these situations, involving an intermediary land use category, especially involving open and/or shrubland, proximate drivers are insufficient to properly allocate the impact. The distinction between the underlying dynamics can only be made using on-the-ground surveys.

These intermediary land use changes were often overlooked in analysis involving large timesteps of 5 to 10 years, according to Goh et al. (2016). When consulting satellite imagery, spatially explicit interpretation has been too costly to execute on a yearly basis. High costs are also a barrier for conducting ground surveys on an equally large scale. Over the years remote sensing has become ever cheaper, shown by e.g. the Global Forest Watch initiative (Gardner et al., 2018). Consequently, geospatial and earth observation data have developed rapidly in the last few years. Austin, Schwantes, Gu and Kasibhatla (2019) have now been able to assess the direct drivers of deforestation across Indonesia between 2001 and 2016 with a time-step of only one year through satellite imagery. In their own words, this has “enabled the observation of trends that may be obscured by less frequent assessments” (Austin et al., 2019). Austin et al. (2019) choose to allocate the destructive LUC to latest land cover category, if the conversions succeed one another within 4 years.

4.3.3.2 Step 2b: Definition of Land Use and Land Cover categories

If one wants to express environmental strain based on the amount of deforestation, the terms forest and deforestation need to be defined. Romijn et al. (2013) found that globally over 100 definitions of forests are applied, “based on landcover; land use; declared, legal, or administrative unit; or other properties. These definitions vary from international, to national, to state, province and local scales” (Romijn et al., 2013). Use of different definitions hampers comparison between studies and overall clear communication of results. Policy making based on contradictory results is impossible, yet basing a conclusion on a single study is not advised as well (Goh et al., 2016). The combination of different approaches can solve more intricate questions on the relative role of various drivers, or the differences between the global and regional scale (Goh et al., 2016). However, the scope is selected, the drivers strongly depend on the definition of forest. Therefore, this definition should be agreed upon consistently.

In their study, Romijn et al. (2013) compared three commonly applied definitions, which are the FAO definition, the national (Indonesian) definition, and the natural forest definition. Land use and land cover types were categorised in forest and non-forest groups based upon these definitions. In all three categorisations these groups were considered non-forest: “commercial agriculture, subsistence agriculture, urban and infrastructure, mining, aquaculture and open land”. These LULC types can therefore act as drivers of deforestation if they occur post-forest. The national forest definition is more limited than the FAO definition as shrubland also counts as a post-forest land use. In the natural forest definition forest plantations are considered separately as well. Consequentially, the conversion from forest to scrubland does not count as deforestation by the definition of the FAO, but as forest conservation. However, when oil palm plantations are established on forests or shrublands, this both results in deforestation. The relative contribution of palm oil production to deforestation can differ tremendously between the definitions, although the actual process is of course constant under the different definitions. (Romijn et al., 2013)

As the results are influenced by the forest definitions, it is therefore important to considered what the designated impact of the study is. For one, the shrubland should not be included in the forest category, as we concluded in section 4.3.3.1 that the oil palm development on recently cleared and abandoned land is preferred to the removal of additional forest. Moreover, converting primary forests to shrublands should be treated as deforestation, as it contributes to global warming, biodiversity loss and the degradation of ecosystem services. Secondly, based on the diagnosis in section **Error! Reference source not found.**, protection must be extended beyond primary forests only. The lack of decisive knowledge on the effects on tropical biodiversity has led to minimal conservation so far. Why not – since tropical biodiversity science is still inconclusive – conserve as much as possible, based on the precautionary principle? This principle states that even if the consequences are not fully understood, precautionary action is justified based on the severity of the consequences and the likelihood of their occurrence. Destruction of non-primary forests and its secondary impacts are presumably sufficiently threatening to consider their impacts in policy making. According to Spracklen et al. (2015) logged forests “host an important fraction of the species found in intact primary forests as well maintaining many ecosystem services”. Besides, plantation expansion should be avoided in secondary forests as well. For example, Corley (2009) concludes that biodiversity in secondary forests, as displayed in Figure 17, is still superior to that of oil palm plantations.

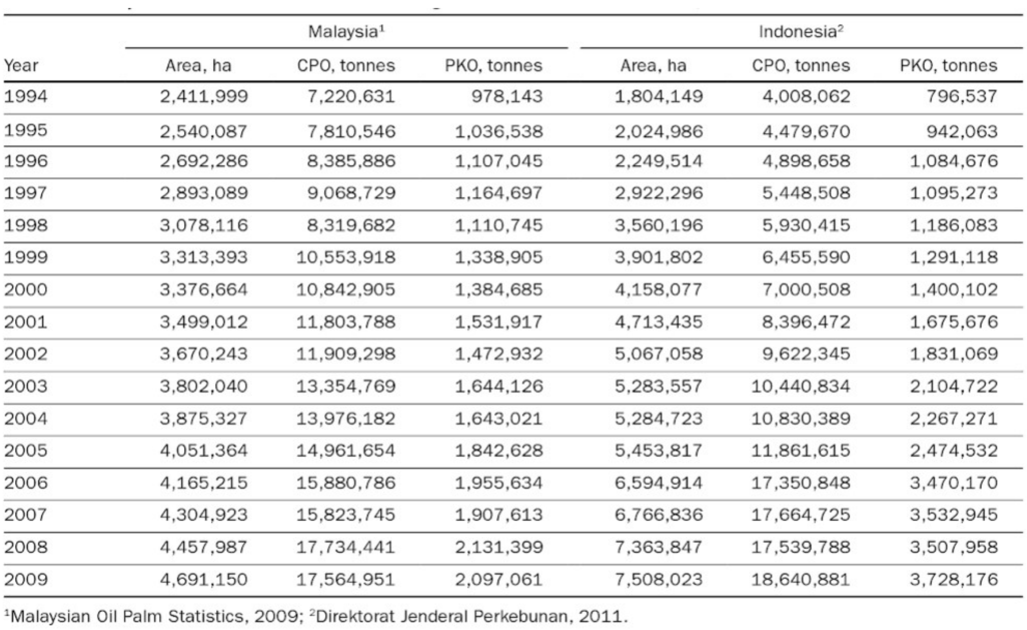
Figure 17: "An aerial shot from a drone showing the landscape of secondary forest inside the PT DAS concession in Ketapang, West Kalimantan" (Monro, 2018)

Lastly, based on the argumentation of Sayer et al. (2012) that agroforestry can go hand with biodiversity conservation and reduced GHG emissions, forest plantations should be promoted. How extensive the mitigated impact is, and if this justifies including forest plantations in the forest category needs to be further examined. If the transition from primary forest to agroforestry has a smaller impact than the transition from forest plantations to a monoculture plantation, this should be considered. Resultantly, the preferred definition is the (Indonesian) national or the natural definition.

4.3.3.3 Step 3a: Linear amortisation & yield

Following upon the determination the land use footprint of oil palm plantations, is the translation to the produced palm oil. This step consists of the attribution of a one-time event in the foundation of the plantation to the continuous production of CPO. This connecting can be made through linear amortisation, the yield, and the allocation key for the multiple products, like palm oil and Palm Kernel Oil (PKO).

A common solution to link a one-time event to a continuous process is proposed by the introduction of an amortisation period. This solution elegantly harmonizes with the fact that current plantations and their CPO production are related to previous deforestation, and add to the actuality of the historic CSC-LUC approach. If the impact is amortised, the impact of current and future palm oil consumption can be found by assessing historic LUC. Goh et al. (2016) note that "in many analyses, CSC-LUC is amortised over a period of time instead of attributing it to a single year". The choice for the length of the amortisation period– e.g. 20 or 30 years – is however debatable (Goh et al., 2016). As the change in land use is key, a logical decision would be to take the average period of one plantation cycle as amortisation period. Replanting young oil palms could be considered as the conversion of one plantation to another, which does not generate a deforestation footprint. This plantation cycle lasts 25 years, as oil palms generally remain productive up to 25 years after planting (Oosterveer, 2015). In this period, the yield of CPO does vary, peaking between 8-13 years after planting (Oosterveer, 2015). In the most basic assessment a constant, country average yield can be assumed, as provided by Lai, Tan, et al. (2012) for example, see Table 9. More specific production information preferred, if available.



	Malaysia[1]			Indonesia[2]		
Year	Area, ha	CPO, tonnes	PKO, tonnes	Area, ha	CPO, tonnes	PKO, tonnes
1994	2,411,999	7,220,631	978,143	1,804,149	4,008,062	796,537
1995	2,540,087	7,810,546	1,036,538	2,024,986	4,479,670	942,063
1996	2,692,286	8,385,886	1,107,045	2,249,514	4,898,658	1,084,676
1997	2,893,089	9,068,729	1,164,697	2,922,296	5,448,508	1,095,273
1998	3,078,116	8,319,682	1,110,745	3,560,196	5,930,415	1,186,083
1999	3,313,393	10,553,918	1,338,905	3,901,802	6,455,590	1,291,118
2000	3,376,664	10,842,905	1,384,685	4,158,077	7,000,508	1,400,102
2001	3,499,012	11,803,788	1,531,917	4,713,435	8,396,472	1,675,676
2002	3,670,243	11,909,298	1,472,932	5,067,058	9,622,345	1,831,069
2003	3,802,040	13,354,769	1,644,126	5,283,557	10,440,834	2,104,722
2004	3,875,327	13,976,182	1,643,021	5,284,723	10,830,389	2,267,271
2005	4,051,364	14,961,654	1,842,628	5,453,817	11,861,615	2,474,532
2006	4,165,215	15,880,786	1,955,634	6,594,914	17,350,848	3,470,170
2007	4,304,923	15,823,745	1,907,613	6,766,836	17,664,725	3,532,945
2008	4,457,987	17,734,441	2,131,399	7,363,847	17,539,788	3,507,958
2009	4,691,150	17,564,951	2,097,061	7,508,023	18,640,881	3,728,176

[1]Malaysian Oil Palm Statistics, 2009; [2]Direktorat Jenderal Perkebunan, 2011.

Table 9: "Malaysian and Indonesian Oil Palm Hectarage and Palm Products Production, 1994-2009" (Lai, Tan, et al., 2012).

4.3.3.4 Step 3b: Multifunctionality

Moreover, Table 9 displays the issue of multifunctionality, as the area of production for CPO simultaneously yields palm kernel oil (PKO). Although palm oil is the primary output of the palm oil production system, the associated impact is technically also embedded in PKO. PO and PKO fulfil similar roles, as both products are vegetable oils. Resultantly, the indirect driver for deforestation that is the increasing demand for vegetable oils, advances both PO and PKO production. Therefore, both products can be considered to cause deforestation. Allocation based upon the relative economic value of production solves the issue of multifunctionality. An alternative allocation key could be based on their energy value, however, Goh et al. (2016) found that the outcome only differs by 4%.

4.3.4 Trade analysis

4.3.4.1 Step 4: Traceability in the supply chain

The embodied emissions of palm oil consumption can now be linked to the consuming actors. In collaboration with palm oil processors and trader, the MVO has improved traceability of the palm oil and palm kernel oil traded in the harbour of Rotterdam (IOI Loders Crocklaan, 2015). This process of transparency creation has proven extremely successful, to the point that 99% of the palm oil that is imported in Europe is traceable to the mill of origin (ESPO, 2017). This result, however, still leaves two gaps in the supply chain traceability, one on the supply side, and the other on the consumption side. Although different pieces of information are available, the challenges lie in their combination and compatibility. Besides, Goh, Junginger, & Faaij (2014) found that companies have the tendency to conceal valuable information on trade and sustainability in particular. Most of their reports are incomplete and lack "concrete information in volumes, origins, destinations, and timing" (Goh et al., 2014). The MRIO trade analysis provides another one of the pieces, hence the combination with the SEI-PCS model to increase the spatial detail on the supply side. This addition includes the determination of actual locations from where CPO is traded. By downscaling the existing country-level trade data, the coupled impact assessment can be executed in more detail too. To explain which data is required and how they can be combined, the EMRIO analysis is discussed first. Figure 18 is included to provide a visualisation of the potential outcome of an EMRIO analysis.

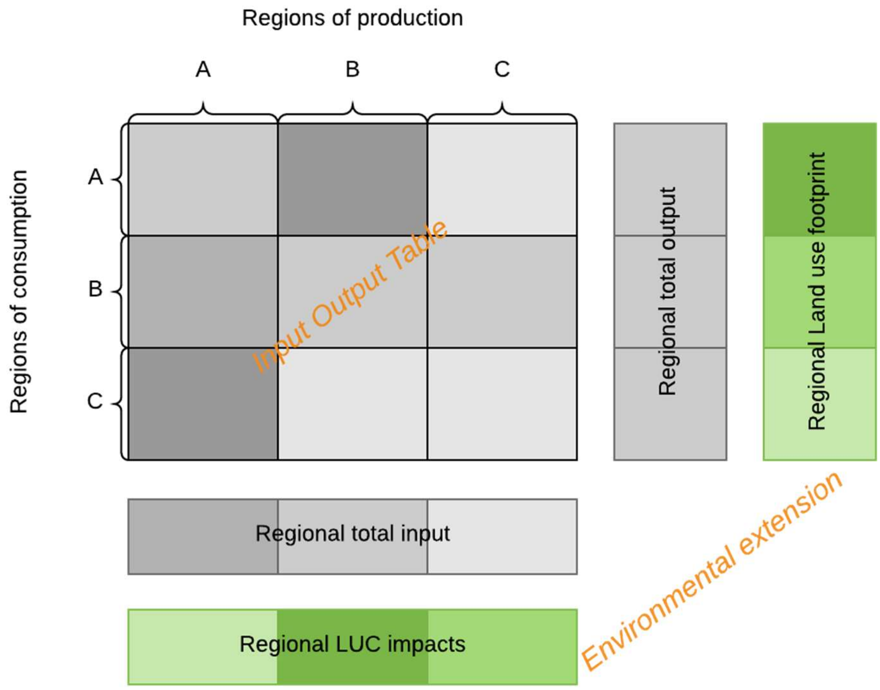


Figure 18: A schematic representation of the outcome of an EMRIO analysis. Darker colours indicate a higher input, output or impact value respectively.

The basis of the EMRIO analysis is the Input-Output (IO) table. This describes the flows of palm oil from each region of production to each region of consumption. These regions can be nation states, provinces, or even further disaggregated locations, based on the available data. Below and to the right of the IO table in Figure 18, the total input or output of each region is displayed. Both the total inputs, outputs and individual trade data are coloured in light to dark grey to show the amount of CPO from low to high respectively. By coupling regional LUC impacts to the regional total input, the Land Use footprint of the individual consuming regions can be calculated. Here again, a darker colour indicates higher values. Figure 18 shows that even consuming regions can have a similar total output, yet their land use footprint can vary based on different sourcing and regional embedded impact. Region of consumption A mainly sources from region of production B, which has a high embedded impact. Resultantly the land use footprint of consuming region A is high as well.

On the supply side, a clear connection between regional LUC impacts and the CPO output must be made. Disaggregation to the national level has been performed more often, whereas more spatial detail is required to assess the embedded impact correctly (Godar et al., 2015). On a national scale the regional boundaries are well-defined and data availability is relatively high. On the subnational level, e.g. in a study by Dawkins et al. (2016), the researchers diverted to ‘simple modelling’ based on transportation costs among others to determine the *kabupaten* (regency) of origin (J. Godar, personal communications, December 13, 2018). J. Godar (personal communications, December 13, 2018) has instead notified a collaboration with “several other institutions and researchers to get detailed data on mills, crushing, refineries, palm oil movements etc.” to produce more data-driven results. Actual trade data linking plantations on specific locations to mills and the corresponding actors will allow disaggregation to level relevant to the impacts being assessed. The already available traceability between the mills and importers then succeeds this step. The SEI-PCS describes how this information of the sub-national supply chain can be combined with country-level trade data to allow precise EMRIO analyses (Godar et al., 2015).

On the consumption side of the supply chain the material flow can be tracked further, from the importers and processors in e.g. Rotterdam to post-refinery processors and onwards, see Figure 19. This tracking and disaggregation within the country of import is rarely performed. T. Pasmans (MVO; personal communications, February 26, 2019) for example stated that he was not allowed to share additional information on the Dutch consumption of palm oil than published in the yearly report of the DASPO (2018). Dawkins et al. (2016) on the other hand, have been able to attribute palm oil consumption to a variety of end-uses, based on studies, existing data, and numerous contacted companies, market experts, associations and institutions expert. Nevertheless, increased transparency of supply chain actors is required to allow material flow analysis from production to consumption from one actor to the next, which will provide even more detail in the consumption-based impacts embedded in palm oil based products.

Figure 19: IOI Bunge Loders Crocklaan Amro plant II in Rotterdam, which is the largest palm oil refinery in the Netherlands. (Bunge Loders Croklaan, 2019)

5 Discussion

Transparency in the palm oil supply chain has to be created in order to implement effective measures for the preservation of valuable ecosystems, climate change mitigation and the support local livelihoods. This study aimed at tackling the barrier that exists in current transparency initiatives, which is posed by the lack of "accessible, comprehensive and comparable data" (Gardner et al., 2018). For example, the first LCA on palm oil that was fully compliant with the international ISO standards was only conducted in 2008 (Smidt & De Rosa, 2018). This lack of data has furthermore been encountered in multiple instances. Goh, Junginger and Faaij (2014) found that most company reports are incomplete and lack "concrete information in volumes, origins, destinations, and timing". They explain that companies wilfully conceal information to protect business interests, especially considering the biofuel production (Goh et al., 2014). This conclusion is shared by e.g. T. Pasmans (personal communications, February 26, 2019), and Valin et al. (2015). On the international trade of biodiesel additional issues considering high levels of aggregation limit transparency. "In some instances, trade flow classifications may simply not be fine enough to differentiate between what are in fact different products" (Meyer, Schmidhuber, & Barreiro-Hurlé, 2013). For example, biodiesel from palm oil and second-generation biodiesel from waste fats and oils are not distinguishable in this categorisation.

Gardner et al. (2018) also specify what transparency information is lacking and should be developed. The method for impact assessment and supply chain analysis that is proposed in this study is a step in the right direction. However, the scope of this study is limited to a more well-known subject. It comprises one of the major forest-risks commodities (palm oil), in a country with high levels of deforestation (Indonesia). Besides, the consuming actors are considered in one of the major consuming countries (the Netherlands). The focus on a more developed topic can yield more sophisticated results, and provide an outcome that is closer to actual and effective implementation. Many intermediate steps in the construction of this methodology were namely already devised. This enabled to narrow down the most pressing issue of (Indonesian) palm oil to the carbon stock losses due to land use changes during plantation expansion. Along with the implementation of the methodology for the assessment of this issue, the focus should be broadened to create transparency in other areas as well. Gardner et al. (2018) explain that on the lesser discussed impacts, the need for "information on the methods and data sources used to generate such indicators" is even larger.

As followed from the diagnosis in section 4.1, criteria for sustainable production should first and foremost inspire action, considering the pressing nature of the sustainability issues. Thereafter, completeness and scientific robustness is pursued. In further research, additional and more fine-tuned indicators should be developed and added along to the biogenic carbon emissions. This consists of the inclusion of impacts on the social and economic environment, as well as fossil fuel emissions and tropical biodiversity among others. In literature, divergent perspectives are portrayed on the severity of the socio-economic impacts. On the one hand, the expanding palm oil industry might even be beneficial to the local residents. The palm oil industry is repeatedly mentioned as "the main source of income for a significant proportion of the Indonesian population" (Bissonnette & De Koninck, 2015). Bissonnette & De Koninck (2015) estimate the creation of 4.5 milling jobs among 1.7 million small-holder farms, that collectively cultivate more than 3 million hectares. Alternatively, Pye (2018) questions if this growth is an 'engine of development', or merely an 'elite-led development' that brings forth inequality and poverty. Oosterveer (2015) furthermore attenuates this reasoning, as it neglects the effects that NGOs not driven by economic or political power can sort. In any case, the social impact of land disputes, large-scale land acquisition and labour provision and/or exploitation should be further examined.

Besides, the focus solely on Indonesian palm oil production has its drawbacks. For one, Indonesian palm oil is mixed with oil from various countries, which influences the embedded impact of consumption. Secondly, the conclusions for the Indonesian situation may not be representative in other parts of the world. As mentioned before, palm oil production can be found across the tropical regions of Asia, Latin America and Africa, and plantations can be cultivated by the state, private companies, or small-holders. The underlying dynamics are expected to vary across the entire spectrum. Palm oil production in Indonesia has been exercised for decades, which has led to many areas to be in an advanced state of deforestation, see Figure 20.

Figure 20: "Forest transition trajectory across main Islands in Indonesia (...)" (Wijaya et al., 2015).

These distinct dynamics in the case of Indonesia are e.g. that expansion often takes places in "poorer soils and unfavourable climates," as the more fertile location are already occupied (Corley, 2009). Other examples of country-specific variables are the expansion rates, yields and carbon density of forests. In many African countries, deforestation rates are currently low, but rapidly increasing (Gardner et al., 2018). These cases are equally important, yet currently underexposed in the development towards a sustainable supply chain.

In an even broader perspective, the impact assessment of high-forest risk commodities also concerns commodities like soy, beef and timber. In Indonesia, logging, pulpwood and mining were found to be direct drivers of deforestation too. The collective of agricultural demand can cause mutual competition that leads to indirect land use change. In this light, any demand for agricultural area forms an indirect driver of deforestation, as it reduces the potential of available land area. With world population rising, the demand for palm oil will increase accordingly. Colchester & Chao (2011) stated for Indonesia that the most vigorous expansion has yet to come. In the meantime, palm oil has become the most abundant vegetable oil globally, overtaking soybean oil (Mba et al., 2015). The destructive land use change will only be put to a halt, when the collective demand for land area is reduced to the amount of available and suitable land for crop cultivation. Otherwise the required agricultural land will be found in currently forested areas. A reduction in demand is however completely opposite to the current and projected trend. The Netherlands oils and fats industry anticipate a growth of 35% in global demand of oils and fats in 2050 compared to 2013 (MVO, 2014a). A lasting change in consumption patterns is required to durably constrain the land use footprint within certain boundaries. Consequently, monitoring this development requires transparency on consumption-based impacts to cover each of the forest-risk commodities. This affords information in the land-scarcity posed by consumption and the resulting implications on future deforestation.

This change in consumption patterns furthermore requires a critical assessment of the demand for vegetable oils. When the destructive consequences of palm oil can be mitigated, it becomes the more sustainable and 'land sparing' option among the vegetable oils, based on the high land efficiency of oil palms (Corley, 2009). Furthermore, the renewable and biobased character of vegetable oils contribute to a circular economy (MVO, 2014a). Therefore, controlled production of palm oil can form a great option among the vegetable oils within a sustainable economy. When palm oil replaces other vegetable oils land use is reduced and for the chemical industry it offers the possibility of a bio-based economy. Besides, and many palm oil derivatives are biodegradable (MVO, 2014a). The choice for palm oil can thus offer a sustainable alternative to a variety of vegetable oils and some fossil fuel uses. However, a reduction in consumption can avoid high demands in the first place. As palm oil is widely used in processed food, switching diets to non-processed food is one of the options to reduce palm oil demand (Sayer et al., 2012). Secondly, alternatives for palm oil in the biodiesel production exist that do not compete over land use with food production. Soon, biodiesel from palm oil will not be considered a sustainable fuel anymore and replacement is necessary (Jong, 2019). A study from Transport and Environment even concluded that the impact of palm-based biodiesel on the climate is three times worse than that of regular diesel (Dings, 2016). The Netherlands have proven that biodiesel production does not depend on palm oil inputs. Other countries should follow the example of Dutch energy suppliers and consume only biodiesel from second generation and waste oils and fats. Resultantly, the Dutch production of palm-based biodiesel for export will be halted too.

Most importantly, the sustainability issues surrounding the palm oil supply chain have raised the question "how to direct development away from forest towards grassland?" (Corley, 2009). If demand increases as projected (up to twice the 2009 value), and biodiesel will not be produced from palm oil, sufficient grassland is available for edible purposes in 2050 (Corley, 2009). Romijn et al. (2013) confirmed the surprising result that much of the deforestation is not linked to the cultivation of food crops. Instead 47.1% of the open land and 74.6% of the shrublands remained unused after six to nine years. To put this potential area in use is preferred to clearing additional forest. However, Corley (2009) came across two barriers for sustainable practices in the underlying LUC dynamics that remoting sensing does not detect. These barriers demonstrate deficiencies in current business models and in resolving land ownership disputes. Respectively, financial institutions and social NGOs can play a crucial role in the sustainable development of these instances (Corley, 2009).

The attempted interventions have not sorted the desired effect of reducing deforestation rates, which the responsible actors start to see. Greenpeace (2019) has put out the statement on their website that "we need more than a boycott; we need the entire industry to change". The Dutch alliance (DASPO, 2018) has joined forces with other European initiative as they realise that "we need global demand for sustainable palm oil to transform the entire supply chain". Even the European Parliament (2018) acknowledges the supply chain complexity and "emphasises the importance of developing a global solution based on the collective responsibility of many actors". Moreover, all concerned actors ought to cooperate on resolving the multitude of issues related to the unsustainable palm oil production chain (European Parliament, 2018). This includes all supply chain actors, financial institutions and NGOs. More in-depth research is required as to discovered what these limiting factors are, and how they can be solved effectively and durably.

Smallholder inclusion is expected to play a significant role in this transition, as monocultures do not perform well on important environmental issues (Bissonnette & De Koninck, 2015). Whereas small holdings can support higher levels of biodiversity, and possibly avoid social issues, their yields fall behind (Azhar et al., 2017; Molenaar et al., 2013). Although smallholder yields are expected to remain inferior to that of monocultures, – currently 3.31 t/ha compared to 3.67 t/h – there is a large unused potential for improvement (Molenaar et al., 2013). Bissonnette & De Koninck (2015) "suggest that the government should extend and intensify training, support replanting efforts, insure more direct communication between producers and mills, and provide smallholders with a better access to finance".

Based on the argument of impact migration, supply chain actors must not transfer to alternative suppliers, but instead manage their own supply chain (T. Pasmans, personal communications, February 26, 2019). Each actor can assume responsibility to approach their suppliers and demand sustainable produce. In that case, impact assessment becomes a tool to track progress towards one's supply chain sustainability, instead of a tool to select the least destructive supply chain actor.

The role for certification schemes in this global solution is to regulate sustainable production based on the important environmental and social consequences. Regulations should inspire action, be strict and unambiguous. Only then can processors and consumers adopt the RSPO trademark among others worldwide, to transform the palm oil supply chain. Meanwhile, independent, strategic impact assessment can monitor its effectiveness. This furthermore allows certification schemes to regain its trustworthiness, whilst traceability of the produce enhances value creation.

Current developments show the intend to transform the current market and develop towards a sustainable supply chain. However, the evaluation of the attempted interventions so far mostly shown the ineffectiveness so far. The generated effectiveness information and methodology for impact assessment and supply chain analysis is intended to advance transparency creation in the palm oil supply chain. The author hopes that upcoming transparency initiatives, such as TRASE, will base their analyses on a standardized method that yields accessible, comprehensive and comparable data. Accordingly, clear communication, comparison of results and unambiguous decision making is facilitated, ultimately leading towards a sustainable palm oil supply chain.

6 Conclusion

With the intend of ultimately finding and applying effective sustainability interventions in the palm oil supply chain, this study was conducted. Although that aim proved out of reach, a common understanding has been created whereupon science-based impact assessment and supply chain analysis can be executed. This transparency information, along with the effectiveness information on current interventions can strengthen future sustainability interventions in the global supply chain.

The diagnosis of attempted interventions has shed light on the causes of their ineffectiveness. An intervention that can be applied by all actors is to ban palm oil, in the hope to reduce the impacts of consumption. Considering that alternatives to palm oil are not necessarily more sustainable and require much more agricultural land, this is not advised. An exception thereof is found for waste and second-generation oils and fats as alternative for the production of biodiesel. Furthermore, a demand for sustainable palm oil is required to increase the market penetration of certified oil, like the CSPO issued by the RSPO. The market penetration along with traceability is one of the conditions for the effectiveness of certification schemes. The analysis of RSPO certification has shown that certification schemes must furthermore increase monitoring of the affiliated actors, sharpen the criteria for sustainable production and include the plantation expansion process in their scope. Increased monitoring, through independent impact assessment, allows minimal room for affiliated actors to break their commitments. Secondly, criteria based on practical definitions, rules and regulations instead of ‘correct’ management principles like flexibility, inclusiveness and scientific robustness can add to effective conservation. Lastly, the focus on the type and location of established plantations can disclose the true impact of deforestation and monocultural concessions, and permit to adjust the criteria accordingly. Only then can the RSPO realise her ambition to administer certifications that safeguard sustainable practices. Upholding the claim that RSPO certified palm oil is sustainable, is thus considered greenwashing.

Besides, national interventions in the Netherlands headed by the Dutch Alliance were discussed. These interventions embody the ambition to obtain 100% certified palm oil processed in the food and animal feed industry in the Netherlands, and the exclusion of palm oil as feedstock for biodiesel consumption in the Netherlands. In both instances the issue of impact migration was concluded to undermine national governance. Considering certified palm oil in food and animal feed, due to a lagging demand for palm oil, palm oil suppliers are merely interchanged and the influence of certification schemes does not increase. Palm-based biodiesel was eliminated from Dutch consumption in the last few years, however its production for is expected to be unaffected by this intervention. Increasing the scope of these interventions by transitioning to transnational or preferably even global governance can limit impact migration, and enforce impact reduction in the global palm oil supply chain.

To create dependable information on the impact of palm oil, an impact indicator is selected based on a simplified multi-criteria analysis. Of all the impacts on the natural environment, those associated with the plantation expansion are most pressing. Within the scope of land use changes, the land use footprint can best be expressed in terms of carbon stock losses (i.e. carbon emissions). Alternatively, the amount of deforested area fails to accurately represent the complex sustainability issues associated with the production of palm oil. Besides, the biodiversity proxy of species diversity is easy to communicate, but proved to be too limited. A more methodologically sound framework of indicators, on the other hand, consists of 50 essential biodiversity variables. As furthermore, consumption-based impacts on biodiversity are known to be scale-dependent and non-linear, their measurement is complicated. In contrast, carbon stock losses are representative for the most pressing issues, enable clear communication and are outcome-focused at the global level. Nonetheless, it should be understood that this indicator does not capture the entirety of sustainability and careful impact assessment requires additional indicators to be constructed.

To operationalise this indicator and link the impact at conversion to the worldwide consumption, a combination of impact assessment and supply chain analysis must be performed. In this study, the EMRIO analysis was selected as most the suitable approach and will form the backbone of the proposed methodology. The addition of the SEI-PCS model allows for a more spatially explicit analysis of the material flows, whereas the aforementioned indicator functions as the environmental extension. To effectively calculate embodied emissions, several steps need to be undertaken, which are elaborated in this research in further detail. The methodology for impact assessment and supply chain analysis that is proposed in this study is a step in the right direction. However, the scope of this study is limited to a more well-known subject. Along with the implementation of the methodology for the assessment of this issue, the focus should be broadened to create transparency in other areas as well.

Current developments show the intend to transform the current market and develop towards a sustainable supply chain. However, the evaluation of the attempted interventions so far mostly shown the ineffectiveness so far. The realisation has come that a global solution based on the collective responsibility of many actors is needed for a successful transformation. In this transition, consumption-based impact assessment can act a tool to pinpoint the environmental strain and monitor the progress of implemented interventions. The generated effectiveness information and methodology for impact assessment and supply chain analysis is intended to advance transparency creation in the palm oil supply chain. The author hopes that upcoming transparency initiatives will base their analyses on a standardized method that yields accessible, comprehensive and comparable data. Accordingly, clear communication, comparison of results and unambiguous decision making is facilitated, ultimately leading towards a sustainable palm oil supply chain.

7 References

Cover image adapted from: https://www.behance.net/gallery/47465539/Palm-oil-and-deforestation

Footer adapted from: https://www.eatresponsibly.eu/en/palm-oil/

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