Comparative study on the sustainability of vegetable oils

Comparing the contributions of palm oil in Indonesia, soybean oil in Brazil and rapeseed oil in Germany until 2030/2040 for achieving UN SDGs

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Contents

Summary		**5**
1	**Introduction**	**9**
2	**Approach**	**10**
2.1	General approach	10
2.2	Scenario analysis	10
2.3	Six main impact categories	10
3	**Description of the current and future vegetable crop systems**	**12**
3.1	Oil palm in Indonesia	12
3.1.1	Current cultivation	12
3.1.2	Processing	12
3.1.3	Future scenario descriptions	14
3.2	Soybean in Brazil	15
3.2.1	Current cultivation	15
3.2.2	Processing	16
3.2.3	Future scenario descriptions	17
3.3	Rapeseed in Germany	17
3.3.1	Cultivation	17
3.3.2	Processing	18
3.3.3	Future scenario descriptions	18
4	**Land use efficiency of vegetable oils**	**20**
4.1.1	Land use efficiency of palm oil production	20
4.1.2	Land use efficiency of soybean production	20
4.1.3	Land use efficiency of rapeseed oil production	21
4.1.4	Comparison in land use efficiency between vegetable oils	21
4.1.5	Discussion and conclusions	21
5	**GHG performance of vegetable oils**	**23**
5.1	GHG performance of palm oil production	23
5.2	GHG performance of soybean oil production	25
5.3	GHG performance of rapeseed oil production	26
5.4	Comparison in GHG performance between vegetable oils	27
6	**Biodiversity effects**	**29**
6.1	Methods	29
6.1.1	Deforestation / land-cover change	29
6.1.2	Loss of biodiversity	29
6.2	Results and discussion	30
6.2.1	Current situation - Indonesia	30
6.2.2	Current situation - Brazil	31
6.2.3	Current situation – Germany	32
6.3	Discussion and conclusions	32
7	**Pollution effects**	**34**
7.1	Methods	34
7.2	Results and Discussion	35
8	**Livelihood**	**39**
8.1	Contribution to food security (SDG 2)	39

8.1.1 Vegetable oil contribution to dietary energy supply globally 39
8.1.2 Contribution to food security of consumers and producers: prices and revenues 40
8.1.3 Contribution to local food and nutrition security 41
8.2 Importance for rural employment (SDG 8, 2, 5) 41
8.2.1 Methods 41
8.2.2 Smallholder employment and mechanisation 42
8.2.3 Labour productivity 42
8.2.4 Inclusivity of employment opportunities (SDG 2 & 5) 43
8.3 Contribution to welfare (SDG 1, 2, 3,4) 43
8.3.1 Methods 44
8.3.2 Results and discussion 44
8.4 Conclusions 44

9 Economics 46

9.1 Contribution of oil crops to the national economies 46
9.1.1 Methods 46
9.1.2 Results & Discussion 46
9.2 Vegetable oil destination 47
9.2.1 Methods 47
9.2.2 Results and discussion 47
9.3 Investments and SDGs 49
9.3.1 Methods 49
9.3.2 Results and discussion 49
9.4 International Certification schemes and SDGs 51
9.4.1 Methods 51
9.4.2 Results and discussion 51
9.4.3 Conclusion 52
9.5 References 53

10 Conclusions 56

11 Literature 57

Annex: GHG emissions from oil palm on peat 61

Summary

This study, executed for the Dutch Ministry of foreign affairs, compares the contributions of vegetable oils from oil palm (in Indonesia), soybean (in Brazil) and rapeseed (in Germany) to Sustainable Development Goals of the UN. The assessment is focused on crude oil delivery to the port of Rotterdam and the port of Jakarta with an outlook to 2030/2040.
Indicators were chosen in six categories that link to the Sustainable Development Goals:

- Land Use Efficiency, which links to SDG 15 (Life on Land) and SDG 12 (Responsible Consumption and Production);
- Greenhouse gas (GHG) performance, which links to SDG 13 (Climate Action);
- Biodiversity effects, which links to SDG 15 (Life on Land) and SDG 14 (Life below Water);
- Pollution effects, which links to SDG 15 (Life on land), SDG 14 (Life below Water) and SDG 6 (Clean Water and Sanitation);
- Livelihood, which links to SDG 8 (Decent Work and Economic Growth), SDG 1 (no poverty), SDG 2 (No Hunger) and SDG 5 (Gender);
- Economic impacts, linking to SDG 1 (no poverty), SDG 7 (clean energy) and SDG 2 (no hunger).

Assessments were made for the current situation (~2020) and the future situation 2030/2040. For this purpose, scenarios were developed for business as usual (BAU) extrapolated from current to 2030 and 2040 and for (very) ambitious developments until 2030 and 2040. For the very ambitious scenario's maximum effort was assumed to increase yield, halt deforestation, make maximum use of residues, maximize intercropping and double cropping, methane emission reduction, efficient use of fertilizers, optimization of pesticide use, etc. The ambitious scenario is in between BAU and the very ambitious scenario.

Land use efficiency of vegetable oil crops
Oil palm has the highest land use efficiency, producing 3.2 ton crude oil/ha. If the co-products and by-products are also accounted for (using economic allocation), oil palm is still the most efficient producing 3.8 ton crude oil per ha. This is about 2.4 times more efficient than soybean and 2.1 times more efficient than rapeseed in the current situation. Under the very ambitious scenario, when improvements are maximized by 2040, oil palm is still the most efficient crop producing 4.8 ton crude oil/ha compared to 3.1 ton crude oil for soybean and 2.6 ton crude oil for rapeseed. Relatively, comparing the values in the very ambitious scenario in 2040 by the values in 2020, the highest improvement potential was assumed for soybean (+94%), followed by rapeseed (+44%) and oil palm (+26%). The large difference in land use efficiency between the two allocation methods (economic versus 100% allocated to oil), illustrates that the production of the by-product cake or meal, next to oil, is very important economically, especially for soybean cultivation.

Table 1 Land use efficiency of producing crude palm oil (Indonesia), soybean oil (Brazil) and rapeseed oil (Germany) in current situation, and under two future (2040) scenarios.

	Current (2020)			Business as usual 2040			Very ambitious 2040		
	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed
Crude oil yield	---------------------------------- ton crude oil per ha per year------------------------------------								
- 100% allocated to oil	3.2	0.6	1.4	3.2	0.8	1.4	4.0	1.3	1.9
- economic allocation	3.8	1.6	1.8	3.8	1.9	1.8	4.8	3.1	2.6

GHG performance of vegetable oil crops
Table 2 shows the GHG emissions per ton of crude oil per crop for delivery to Rotterdam or Jakarta under 100% allocation to oil and under economic allocation (impact allocated to all products on the basis of economic value). The current (2020) GHG emission was lowest for rapeseed with an emission of 2.0 and 2.2 ton CO_2-eq/ ton crude oil and highest for oil palm at 3.6/4.5 resp. 3.3/4.3 ton CO_2-eq/ton crude oil. The high oil palm values were due to large GHG emissions from methane emissions from POME and CO_2 emissions when palm is grown on (drained) peat land. Only 10% of the oil palm is grown on peat, but it emits an estimated 40 to 78 tons of CO_2-eq/ha/year, thereby having a large impact on the total average GHG emission. The emissions due to deforestation apply to just 18% of the palm area in Indonesia. Emission of methane from anaerobic POME treatment currently apply to more than 90% of the mills. Under the very

ambitious scenario (in 2040), the emission are reduced significantly to 1.0/1.1 and 1.2/1.3 ton CO_2-eq/ton crude palm oil compared to 1.1 CO_2-eq/ton for soybean oil and 1.4 and 1.6 CO_2-eq/ton for rapeseed oil. So, the potential for GHG emission reduction is highest for palm oil, while the differences in GHG emission among the three crops are strongly reduced under the very ambitious scenario in 2040 compared to the current situation.

Table 2 Total GHG emission of producing, processing and transport to Rotterdam or Jakarta of crude palm oil (Indonesia), crude soybean oil (Brazil) and crude rapeseed oil (Germany) in the current situation, and under two future (2040) scenarios.

	Current (2020)			Business as usual 2040			Very ambitious 2040		
	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed
GHG emissions	ton CO_2-eq/ton crude oil								
Delivery to Rotterdam									
- 100% allocated to oil	4.2 / 5.3	5.4	2.6	3.4 / 4.6	4.0	2.6	1.4 / 1.5	2.2	1.8
- economic allocation	**3.6 / 4.5**	**2.4**	**2.0**	**3.0 / 3.9**	**1.9**	**2.0**	**1.2 / 1.3**	**1.1**	**1.4**
Delivery to Jakarta									
- 100% allocated to oil	3.0 / 5.1	5.5	2.9	2.3 / 4.4	4.1	2.9	1.3 / 1.3	2.3	2.1
- economic allocation	**3.3 / 4.3**	**2.5**	**2.2**	**2.7 / 3.7**	**1.9**	**2.2**	**1.0 / 1.1**	**1.1**	**1.6**

Biodiversity

Deforestation is a global issue which is directly linked to biodiversity loss, which in many cases is caused by food production (e.g. Meijaard et al 2024). Both oil palm plantations in Indonesia and soy-bean fields in Brazil have replaced substantial areas of forest over the last 20 years. In Brazil the area covered by soybean increased from 13.4 Mha in 2001 to 34.5 Mha in 2020. Between 2002 and 2019 a total forest area of 4.8 Mha was lost due to soybean development in Brazil. Soy bean driven deforestation mainly took place in the Amazonian and Atlantic rain forest area (3.1 Mha) as well as in the Cerrado woodland area (1.7 Mha). In Indonesia the area covered by oil palm plantations increased by some 8.7 Mha in 2000 to 16.3 Mha in 2020. Of the total area deforested over that period some 29% (2.9 Mha) was cleared and converted into oil palm plantations in the same year. In 2020 for each hectare of oil-palm plantation developed in Indonesia 2% of primary forest is lost; in Brazil for each ha of soy bean developed some 10% of primary forest is lost (see table 3). In Germany no (recent) deforestation took place over the past 2 decades. The scenarios show that if measures are taken that forest- and biodiversity loss can greatly be reduced for both oil palm and soybean cultivation.

We conclude that:

- Biodiversity loss due to deforestation in recent years (25 years) was lowest for rapeseed in Germany and highest for oil palm and soybean (in Indonesia and in Brazil).
- The difference in biodiversity loss due to deforestation between oil palm (Indonesia) and soybean (Brazil) is harder to assess.

Pollution

Several of the pesticides found to be associated with the oil crops of this study are classified as being highly hazardous. This means that these are pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment. Some of these health impacts include an increased risk of cancer, neurological disorders, reduced fertility rates and endocrine disorders, among others.

In current practice, the pesticides used in all three crops have highest counts for being very toxic to aquatic life with long lasting effects followed by the potential to pollute ground water. Hence the crops do not differ much in the main ecotoxicity impacts of the pesticides used. In palm the pesticides used have higher counts for toxicity for bees than the pesticides used in the other crops.

Livelihood

The contribution of soybean oil to global food security is more important than that of the other vegetable oils in terms of traded volume. However, palm oil has lower price and is more affordable as cooking oil for people with low income and an important contributor to close the “fat gap” in countries with low energy diets.

Table 3 Summary of livelihood relevant parameters.

Crop	Volume for food (million l)	Gross income/ha (USD)	Price on world market (2003-2018) (USD/t)	Oil crop/farm (ha)	ha/FTE	oil/FTE (1000 l)	area to earn minimum wage (ha)
Oil palm	20	4332	730	5.7	2.5	6 - 13	0.47
Soybean	25.2	2107	880	130	34	8 - 54	6.69
Rapeseed	9.4	2892	930	25.8	175	275	15.39

The higher revenues per ha for oil palm compared to soybean and rapeseed, makes it a more important contributor to farmer income. Less ha of land is needed to reach minimum wage from oil palm in Indonesia than from soybean in Brazil or rapeseed in Germany. The Purchasing Power Parity (PPP) calculations also show that for each US dollar earned, the purchasing power in Indonesia, Brazil and Germany is 2.69, 2.21 and 1.42 higher than in the USA. These indicators explain the relatively higher contribution of oil palm to farmer income. In Indonesia this oil palm-based income translates into access to nutritious foods.

Oil palm has lowest ha per labour unit (FTE) and therefore contributes more to employment than soybean and rapeseed, which are more mechanized. Expansion of oil palm has created jobs for landless people while expansion of soybean led to larger farms replacing many smallholders by a few workers thereby contributing to unemployment in agriculture. For rapeseed the effect on employment is minimal as it mainly replaced crops in rotations.

Economics

Soybean adds most value to the export, mainly in the form of beans (39 billion USD) and cake (7.5 billion USD). For the three oils, palm oil has the highest export value with 27.3 billion USD and the highest contribution to the GDP with 2.3% followed by 2.06 billion USD and 0.12% for soybean in Brazil and 1.77 billion USD and 0.04% for rapeseed in Germany.

Table 4 Economic value of oil crops.

2021	Value (USD)	Oil seed	Oil	PKO	Cake
Indonesia	Export value (10^9)	NA	27.30	1.30	1.05
	% of GDP	NA	2.30	0.11	0.09
Brazil	Export value (10^9)	39.0	2.06	NA	7.5
	% of GDP	2.37	0.12	NA	0.45
Germany	Export value (10^9)	0.20	1.77	NA	0.65
	% of GDP	0.005	0.04	NA	0.02

In Indonesia oil palm provides 100% of the feedstock for biodiesel while in Brazil soybean only provides 75% and in Germany rapeseed only provides 62%. In Germany 26% of the feedstock for biodiesel is used cooking oil. For Indonesia and Brazil biodiesel production and consumption are in balance, but in Germany production is larger than consumption leading to about one third of the volume being exported. Biodiesel production is highest in Indonesia. Given population growth the demand for vegetable oil to close the fat gap in people's diets may compete with an increasing demand for biodiesel. Putting used cooking oil in biodiesel may reduce this competition as this oil has already first been used as food and its GHG contribution is lower than from “virgin” vegetable oils.

In voluntary sustainability standards (VSS) for the three oil crops only few criteria address climate adaptation, climate mitigation and water pollution compared to the needs of impact investors. The criteria in the Round Table for Sustainable Oil Palm (RSPO) and in the Round Table for Responsible Soy (RTRS) do hardly address SDG 7 (clean renewable energy) and SDG 13 (Climate action). The potential beneficial effect of addressing climate action through VSS can be seen from the reduced GHG emission in the ambitious scenarios in this report.

1 Introduction

Vegetable oils are worldwide traded commodities. Palm oil is the most important vegetable oil (80 million metric tons per year[1]) with Indonesia producing 59% of all palm oil in the world. Soybean oil is the second largest vegetable oil in the world with 62 million tons currently (2023/2024) produced from 398 million tons of soybeans. Brazil is the largest producer with 156 million tons per year. Rapeseed oil is the third largest vegetable oil with a volume of 33 million tons produced from 84 million tons of rapeseeds. The EU is the largest producer of rapeseeds with 20 million tons produced currently, containing 40% oil.
On the one hand, these vegetable crops are of great benefit to humanity because they provide efficiently produced food, and they provide a livelihood to farmers worldwide. On the other hand, they are also controversial because of the impacts they can have on the environment by the way they are produced. Comparisons are regularly made between the main vegetable oils and crops with respect to their benefits and impacts. These claims center around land use change, GHG emissions, economic benefits, social benefits and problems, deforestation[2], pollution effects, and health benefits and problems when consuming these oils (Reis & Prada Mora, 2022; Patel et al., 2022; Chiriaco et al., 2024; Fearnside, 2001; Teng, 2020 and others). Understanding the positive and negative impacts is important for changing and improving production methods, policies, and transparency toward consumers.

In this report a comparative study is presented on the impacts of soybean oil, rapeseed oil and palm oil on achieving a number of SDG goals for 2030/2040. It is focused on environmental and social economic SDGs. The selected indicators are related to six impact categories linked to different SDGs.

- Land Use Efficiency. This addresses SDG 15 (Life on Land) and SDG 12 (Responsible Consumption and Production)
- Greenhouse Gas performance. This links to SDG 13 (Climate Action).
- Biodiversity effects. This includes effects of the use of land and pollution on biodiversity and links to SDG 15 (Life on Land) and SDG 14 (Life below Water).
- Pollution effects. This includes pollution effects of pesticides and fertilizers on land and water and links to SDG 15 (Life on land), SDG 14 (Life below Water) and SDG 6 (Clean Water and Sanitation).
- Livelihood. The chosen indicators for livelihood express how important a sector is for food security, employment, income, smallholder production and inclusivity (SDG 2.3). This is also linked to SDG 8 (Decent Work and Economic Growth), SDG 1 (no poverty), SDG 2 (No Hunger) and SDG 5 (Gender).
- Economic impacts. This expresses the importance for national economies, destiny of the biodiesel for export or domestic use, attractiveness of oil crops for investment (SDG2.5.2a), and the contribution of international certification schemes to achieving SDGs. This is linked to SDG 1 (no poverty), SDG 7 (clean energy) and SDG 2 (no hunger).

To make the comparisons, we have chosen the largest production countries per vegetable oil;

- For oil palm the focus is on Indonesia, the largest palm oil producer.
- For soybean the focus is on Brazil, the largest soybean producer.
- For rapeseed the focus is on Germany, the largest rapeseed producer in the EU.

[1] Statista 2024; Production of major vegetable oils worldwide.
[2] https://www.sustainablepalmoilchoice.eu/deforestation-palm-oil/

2 Approach

2.1 General approach

The cropping systems have been divided into subsystems per crop if appropriate. For soybean, two sub-systems have been defined (following Alcock et al., 2022). Soybean in Brazil is cultivated with conventional tillage and in a no/reduced till system. For rapeseed, only one system exits in Germany, where rapeseed is mainly cultivated on mineral soils. For oil palm, four production subsystems are defined that differ in their impacts for the SDG indicators. These four subsystems result from industrial or smallholder cultivation on peat or mineral soils (industrial on peat and on mineral soil, smallholder on peat and on mineral soil).

2.2 Scenario analysis

For the three crops we have calculated the impacts on six environmental and economic aspects for different scenarios:

- First, the current performance is assessed for ~2020 and then an outlook is given based on a **business as usual** (BAU) extrapolation to 2030 and 2040.
- We have also added scenario's defining improved performances in 2030 and 2040. Here, we have made assumptions for yield improvements, no deforestation starting in 2020, increased intercropping, increased double cropping (for soybean), phasing out oil palm on peat, applications for residues for more added value, intercropping and cattle integration (for oil palm), reduced pesticides and fertilizer applications, etc. This is detailed in the crop sections (3.1.3 for oil palm; 3.2.3 for soybean and 3.3.3 for rapeseed). Care has been given to make similar assumptions for each crop.
- For soybean and rapeseed, we defined two improvement scenarios (**ambitious** and **very ambitious**) but only present the **very ambitious** scenario for oil palm. The very ambitious scenario's assume that maximum improvements are introduced. Improvements in the ambitious scenarios are roughly 50% of the maximum improvements of the very ambitious scenarios.

See chapter 3 below where for each of the three crops the details of the future scenarios are further explained. For two impact categories, livelihood and economic, we only looked at the current situation.

2.3 Six main impact categories

Comparisons are made of the current and possible future performances of soybean, rapeseed and palm crude oil production in six main impact categories:

Land use efficiency
For the land use efficiency (ton of vegetable oil per ha), we use the method described by Poore & Nemecek (2018) as starting point. The method accounts for fallow land which is allocated to all crops in the rotation system and the unproductive juvenile phase in oil palm when there is no yield yet. In case of multiple cropping (2 or more crops in a field per year), the land is allocated to both crops according to time the land is used.

When more than one product is produced (e.g. soybean oil and soybean meal), the calculations of land use efficiency are made using three allocation methods:

- **100% allocated to the vegetable oil**: 100% of the land is allocated to the vegetable oil - no land allocation to by- and co-products.
- **Mass allocation**: The land use is allocated on the basis of mass (dry matter) to the main products, by- and co-products.

- **Economic allocation**: This means that the land is allocated on the basis of the monetary values of all products (price x yield per ha), i.e. main products, co-products (i.e. protein cake for soybean and rapeseed) and by-products. In case of oil palm this also includes electricity if biogas is produced and when trunks are sold for wood products, etc. In case of intercropping or animal grazing in oil palm, a land rent is assumed to represent the monetary value.

We will mainly discuss the comparison between vegetable oils on the basis of the third method (economic allocation).

Green House Gas performance

For the calculation of the GHG emission (ton CO_2-eq per ton of vegetable oil), we use IPCC (2019) guidelines as starting point. This includes the emissions in the chain due to inputs and transport. We also include the CO_2 emissions from deforestation, discounted over a 20-year period and the GHG emission per ha when peat land is used and drained. We calculated the emissions for cultivation and processing into crude oil, including palm oil mill effluent management and transport of oils (rapeseed oil, soybean oil and palm oil) to Rotterdam and to Jakarta. Downstream processing of crude oils into refined oils (refinery) is not included as we report the performances of the production of crude vegetable oil.

Similar to the calculation of land use efficiency, we also used above three allocation methods for the calculation of GHG emission per ton of oil:

- **100% allocated to the vegetable oil**: 100% of the GHG emission is allocated to the vegetable oil.
- **Mass allocation**: Allocation of the GHG emission is performed on the basis of mass (dry matter) of all products (vegetable oil, by- and co-products).
- **Economic allocation**: Allocation of the GHG emission is performed on the basis of the monetary values.

Biodiversity effects

Deforestation is a global issue which is directly linked to biodiversity loss (FAO & UNEP, 2020). In our study we therefore estimate the effects of crop cultivation on biodiversity as the forest area lost due to the expansion of oil crop cultivation. This was limited to Indonesia and Brazil as in Germany there has not been any recent deforestation for rapeseed. In studying the effect of deforestation in Indonesia and Brazil we made a distinction between primary (highly biodiverse) forests and secondary or logged over (lower biodiverse) forests.

For more details on the methodology used for the biodiversity effect of crop cultivation see chapter 6.1.

Pollution effects

Pollution effects include impacts of pesticides on land and water. Indicators are biocide use (kg active ingredient per ha or ton of oil), nitrogen (N) surplus, phosphorus (P) surplus and wastewater production.

Livelihood impacts

Livelihood impact indicators express how important a sector is for food security, income, employment, land and labour productivity, and inclusivity, comparing large scale and smallholder producers.

For more details on methodologies and data sources for each of the indicators see chapter 8.

Economic impacts

Economic indicators include the importance of oil crops for GDP and their contribution to export. Aspects that are analysed are the destiny of oils towards biodiesel production, export and internal consumption, attractiveness of certified oil crops for investment, and the contribution of international certification schemes to achieving SDGs.

For more details on the methodologies and data sources for each of the indicators see chapter 9.

3 Description of the current and future vegetable crop systems

3.1 Oil palm in Indonesia

3.1.1 Current cultivation

The oil palm (*Elaeis guineensis*) is native to west Africa and has been introduced to Indonesia in the 19^{th} century. Over the last 30 years it has grown into the most important oil crop worldwide with Indonesia producing some 45 million tons of palm oil (in 2022) which is more than 50% of total oil palm production. The oil palm is adapted to the wet tropics and typically grows between 20 degrees north and south of the equator. The oil palm is typically established as a 30 cm large seedling that start producing FFBs (fresh fruit bunches) after 3 to 4 years. Typically, an oil palm produces a fresh fruit bunch every 40 days which is harvested by hand. Old fronds (leaves) are also removed and left in the field as mulch. As the palm ages the yield increase from 0 at year 3 to a maximum yield at 6 to 7 years of age after which it starts slowly declining after 12 years of age. At 25 to 30 years after planting, when palms are typically more than 10 m tall, Yield are low, and harvesting becomes difficult, and replanting is required.
Monzon et al (2021) reported that the average smallholder and large-scale plantation achieve average yields of 16.1 and 19.7 t FFB/ha/year respectively in 2019 averaging 18 t FFB/ha for Indonesia. The study estimated that a yield gap (equivalent to 70 to 80% of water limited yield) exists of 38% and 47% for large plantations and smallholders' plantations respectively in Indonesia. However, a wide range of measures can be applied to improve yields.

At replanting the palms (tops and trunks) are chopped and left in the field serving as mulch or they are burned in the field. There are options to utilize trunks at replanting which are currently not frequently implemented. i.e. The top of trunks can be tapped for gula (sugar) production, over a 4-to-6-week period, which is cooked into sugar (gula). The top of the trunks contains starch which is slowly converted into glucose. Trunk wood has very different characteristics than tree wood making it difficult to use for wood applications. Technology has been developed to use the denser lower parts of the trunk. For example, for veneer production.

Figure 3.1.1.1. Pictures illustrating the fresh fruit bunch harvest, the returning of EFB to the plantation and tumbling of old palms at replanting

3.1.2 Processing

The FFBs are transported to a local palm oil mill for processing within 24 hours to prevent decay. A typical palm oil mill will process the production of 2.000 to 10.000 ha of palm plantation. The main product of the palm oil mill is CPO, crude palm oil the oil contained in the fruit surrounding a little nut. CPO is a yellow oil that is typically shipped for further processing to remote refineries. In the mill the fruit is separated from the fruit bunch generating empty fruit bunches (EFB). EFB still has little application other than returning it to the field as mulch or burning for production of bunch ash a potassium containing fertilizer. Added value applications have been developed for EFB including different pulp applications such as cardboard and pellets for energy generation, but implementation is limited. Palm kernels are separated from the mesocarp fibre (MF) and shell (surrounding the kernel). The palm kernel is generally processed separately into palm kernel oil (PKO) and palm kernel meal (PKM) also called palm kernel cake. PKO is the main co-product generally fetching a higher price than CPO. The mesocarp fibre is typically burned with part of the shells to generate steam to sterilize the FFBs and run the mill. The palm kernel meal is sold as animal feed. Part of the palm shells are sold and used for energy generation or specific applications such as the production activated char production. The MF is burned in a boiler for generating steam to run the mill. The palm oil effluent (POME) is typically processed anaerobically in open ponds (releasing methane), to reduce BOD before it is recycled to the field or discharged. In Indonesia only some 6% of the POME is used for biogas production thereby avoiding methane emission (best estimate from literature and pes communication with experts). The biogas can be used for electricity generation for mill and local grid. Biogas can also be burned in the boiler for steam generation (after sulphur removal) or is also converted into bioCNG (bio-compressed natural gas) and sold for energy generation. Empty fruit bunches (EFB) is bulky and contains silica and nutrients making it difficult to use for added value applications. Though initiatives appear to be taking off. The EFBs are now used for production of bunch ash, which is used as fertilizer, or EFBs are returned to the field to serve as mulch. EFB is also used or compost production and generally mixed with processed POME. EFB can also be used for fibre applications or pellet production for energy generation. So, different improvements are possible to add value to mill residues and reduce impacts (i.e. less methane emission from POME).

Figure 3.1.2.1. Picture of mesocarp fibre that is used as fuel for generating steam at the mill and of EFB (empty fruit bunch)

Palm oil production in Indonesia was divided into 4 main systems that differ in performance and impacts:
- Industrial mineral
- Industrial peat
- Smallholder Mineral
- Smallholder peat

For each of the systems parameters were determined based on literature data. In Table 3.1.2.1 the current (2020) data for each of the systems is given.

Table 3.1.2.1. Current parameter assumptions for the 4 palm production system categories in Indonesia. (based on: Monzon et al. 2021; Hooijer et al 2012 and own estimates).

	Industrial		**Smallholder**	
	Mineral	**Peat**	**Mineral**	**Peat**
Plantation lifetime (yr)	25	20	32	25
Non-productive period (yr)	4	4	5	5
Productive period (yr)	21	16	27	20
Productive area/plantations area (ha/ha)	84%	80%	84%	80%
Attainable yield (ton FFB/ha/yr)	31.6	31.6	29.1	29.1
Current yield (% of attainable yield)	62%	62%	53%	53%
FFB Yield (ton/ha/yr)	19.6	19.6	15.4	15.4
Average peat drainage	-	-73 cm	-	-73 cm

Further parameters in land use history and emission from deforestation and peat draining are given below.

3.1.3 Future scenario descriptions

We present current production system and scenarios to 2030 and 2040 under Business as usual (BAU) and under an (very) ambitious scenario. Assumptions were made for land use change history for the 4 palm oil production systems defined for Indonesia. Table 3.1.3.1 shows the current palm area and the area of land that was previously classified as primary or disturbed forest. The table also shows the development under BAU and ambitious scenarios to 2030 and 2040 when loss of forest is avoided.
For further discussion we have taken the averages over the 4 the land use systems (peat vs no peat and industrial vs smallholder systems) in Indonesia. The data for current performance and business as usual until 2030 and 2040 and under assumed (very) ambitious scenario for 2030 and 2040.

Part of the assumptions are summarized in the Table 3.1.3.2. below. For palm grown on peat we assume that under BAU the current system will continue while under ambitious scenario we assume that peat drainage is maximally reduced for and that replanting of oil palm on peat takes place. This will lead to 80% phasing out of palm on peat by 2040. We also assume that intercropping is applied by 20% of smallholders under BAU in 2040. Under ambitious scenario it is applied also in industrial settings up to 40% in 2040. We also assume that methane capture from POME is implemented form an estimated 6% currently (2020) to 24% under BAU in 2040. For the ambitious scenario 90% methane capture is assumed in 2040. For the use of mill residues and the use of oil palm trunks assumptions are for value addition. Specific sale prices and volumes per ton oil were assumed that can be found in the annex. For ambitious scenario we also assume a yield growth on 1.25% per year leading to a yield increase of 12.5% in 2030 and 25% in 2040.

Table 3.1.3.1. Oil palm land used and land conversion history of oil palm plantations in Indonesia for industrial estates and smallholder on mineral and on peat soil. (based on: Gaveau 2022, https://nusantara-atlas.org/; Descals et al 2020 ; Rozendaal et al 2022; Ferraz et 2018; Hooijer et al 2012; Haasjes 2014; Page et al 2011; Warren et al 2017)

Period		Industrial		Smallholder	
Scenario		**Mineral**	**Peat**	**Mineral**	**Peat**
	Land Use				
2020	Area covered by plantations (ha)	9,252,242	1,156,000	5,487,956	433,000
2001-2010	Loss of primary forest (ha)	32,207	26,289	14,393	11,706
	Loss of disturbed forest (ha)	716,804	315,129	320,337	140,323
2011-2020	Loss of primary forest (ha)	33,967	23,285	7,480	4,716
	Loss of disturbed forest (ha)	755,965	279,122	166,463	56,526
Business as usual	**Expansion & loss of forest**				
Recent 2019-2020	Expansion (ha/yr)	82,385	8,871	34	895
	Loss of primary forest (ha/yr)	1,238	683	1	0
	Loss of disturbed forest (ha/yr)	27,545	8,188	33	0
Very ambitious	Expansion (ha/yr)	53,602	0	0	0

Table 3.1.3.2. ***Current and scenarios assumptions until 2040 for oil palm production in Indonesia (averaged for smallholder and industrial estates and for mineral and peat soils).***

	Current	Business as usual		Very ambitious	
		2030	2040	2030	2040
Peatland					
- drained to -73 cm below ground level	100%	100%	100%		
- drained to -50 cm below ground level				60%	20%
- phased out (no replanting)				40%	80%
Yield improvement				12.5%	25.0%
Intercropping (in non-productive period)					
- Industrial				20%	40%
- Smallholder	10%	15%	20%	30%	60%
Cattle grazing (in productive period)	3%	3%	3%	10%	30%
POME CH4 capture/emissions avoidance	6%	12%	24%	40%	90%
Shell sold for other applications	50%	50%	50%	70%	90%
MF sold for other applications	1%	1%	1%	20%	40%
EFB sold for other applications	2%	2%	2%	20%	40%
POME CH4 sold for energy	3%	6%	12%	20%	45%
Trunk sold for applications	1%	1%	1%	20%	40%

Table 3.1.3.3. ***Assumed CPO and by-product selling values and value of intercropping and cattle integration in 2020. (based on: IndexMundi & USDA (2023); BPS-Statistics Indonesia, 2022; and own estimates).***

FFB	**193**	**$/ton FW**
CPO	1194	$/ton DW
PKO	1561	$/ton DW
PKM	100	$/ton DW
Shell	100	$/ton DW
MF	50	$/ton DW
EFB	20	$/ton DW
POME	25	$/ton DW
Trunk	15	$/ton DW
Intercropping	100	$/ha/yr
Cattle grazing	50	$/ha/yr

3.2 Soybean in Brazil

3.2.1 Current cultivation

Soybean (*Glycine max* (L.)) is an annual oil and protein crop, mostly suitable for tropical moist climate zones. It can be found in the middle-south-east part of Brazil (Marin et al., 2022) and has been expanding north reaching into the Amazon region. It has a growth period of approximately 4 – 5 months. In Brazil, it was the largest crop with respect to harvested area in 2019 – 2021 with a share of 44 – 45% of the total harvested area of all crops (FAOSTAT). In these years its acreage was close to 37 million hectares. Most of this area is found in the Cerrado, followed by Atlantic Forest, Amazon and Pampa (Marin et al., 2022). In recent years (since 2007), there has been a steady increase in harvested area of soybean in Brazil with on average almost 1.4 Mha per year and close to a total of 15 Mha during 2007 – 2019 period (Figure 3.2.1.1)

Most of this increase occurred in the Cerrado (46% of total increase), followed by the increase in Amazon (25%) and Atlantic Forest (20%; Marin et al., 2022). Soybean yields have also increased in that period, although at a lower relative rate compared to the area increase. Total yield increase was almost 0.4 ton FW/ha during 2007 – 2019. The increased production has mainly been realized by an increase in cultivated area (78%) while the remaining part is due to the yield increase (22%).

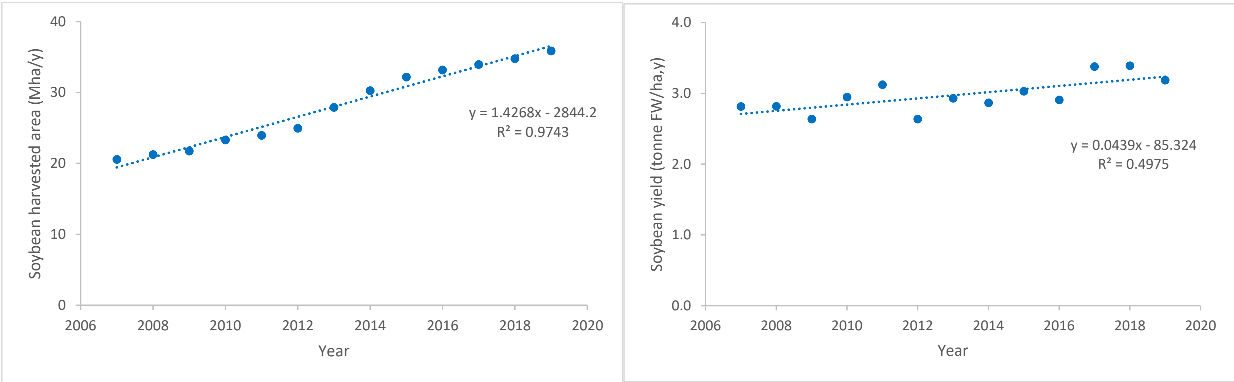

Figure 3.2.1.1. ***Trends in soybean harvested area and yields per ha in Brazil during 2007 – 2019 (Marin et al. 2022)***

Soybean can be grown as single crop in a year (single cropping) or together with a second crop, such as maize (double cropping). Double cropping can be practiced only if the length of the growing season is long enough to allow two crops within one year. Those conditions exist, e.g. in the Amazon region. In other parts of the country the rainy season may be too short for two crops. Soybean is commonly grown each year on the same fields. At harvest time, straw and seeds can be harvested, when leaves are often already shed. The oil content of the seeds is approximately 19%. Approximately 80% is soybean meal which has many applications, including making food products, but its main application is as a protein-rich animal feed. Soybean straw is usually left in the field in Brazil where it acts as soil cover and provides organic matter to the soil, especially in no tillage systems (see below).

In many areas of soybean cultivation in Brazil highly mechanized practices are used for e.g. ploughing, applying chemicals and harvesting. These activities are usually driven by fossil diesel as energy source. In the current situation on average 10 – 20 kg of diesel is used per ton FW soybean yield. Soybean is a leguminous crop that can have a symbiotic relationship with bacteria (*Bradyrhizobium* species), especially when seeds are inoculated with these bacteria. These bacteria live in nodules of the soybean roots and are capable of fixing atmospheric nitrogen into ammonia. If the forming of nodules is successful, a lower amount of nitrogen fertilization is needed, because the bacteria 'trade' ammonia for carbohydrates, produced by the soybean plant. So, relatively low amounts of nitrogen fertilizer can be used, while still obtaining a high yield, with values less than 5.0 kg of N fertilizer per ton FW soybean yield. Sufficient lime application is needed to manage soil pH for successful nodulation. In the current situation an estimated 118 kg CaCO3 per ton FW soybean yield is applied. Chemicals to protect the crop are also used with in total 1.0 – 1.5 kg active ingredients per ton FW soybean yield.

In this study we have followed Alcock et al. (2022) who distinguished two cultivation systems with respect to tillage management: conventional vs. no/reduced tillage.
Approximately 25% of the total area of soybean in Brazil is under conventional tillage while the remaining area is under no/reduced tillage (ploughing is not practiced or limited). Results in this study have been determined for both systems separately, and as weighted average for the country as a whole.

3.2.2 Processing

The post-harvest operations for soybeans to produce refined food-grade oil and soybean meal in Brazil have recently been described by Barreiros et al. (2020). After harvest of seeds a pre-cleaning is required before storage and often also drying. Storage requires humidity to be controlled below 13%. Peeling generates the hulls (> 7%) which can be used for energy generation or as feed. The pulp (circa 90%) is processed into soybean meal and crude soybean oil and small amounts of other co-products such as lecithin. In this report we assess the system up to crude soybean oil production. In case biodiesel is produced from crude oil, refining is not required, only degumming and drying. The crude oil is then used in a transesterification process to produce Fatty acid Methyl Ester (FAME) used as fuel.

3.2.3 Future scenario descriptions

For the two soybean production systems conventional and no/reduced tillage, assumptions are made for BAU which extended the recent trends. These changes from 2020 to 2040 include:

- Increased yield from 3.18 to 3.70 ton per ha in 2040.
- An increase in double cropped land from 46% to 51% in 2040.
- Increased GHG emissions from land use change (deforestation GHG emission discounted over 20 years) from 75 ton to 91 ton CO_2-eq/year in 2040.
- An increase in total area of soybean harvested from 35.9 to 65.6 Mha/year in 2040.

For the ambitious and very ambitious scenarios, a faster rate of improvements is assumed. Assumptions for changes from 2020 to very ambitious in 2040 include:

- A reduction of area under conventional tillage from 25% to 10% in 2040.
- A yield increase from 3.18 ton/ha to 4.41 ton/ha in 2040.
- A reduction of the fraction of land under fallow from 17% to 0% in 2040.
- An increase in the area with double cropping from 46% to 63% in 2040.
- The nitrogen rate application is reduced from 6.1 kg N/ha to 0 kg N/ha in 2040.
- Lower rates of pesticide use from 100% to 50% in 2040.
- The GHG emissions from land use change (deforestation GHG emission discounted over 20 years) are decreased to from 99.5 ton CO_2-eq/year to 0 ton CO_2-eq/year in 2040.
- The total area harvested is changed from 35.9 to 43.2 Mha/year in 2040.

In 2020, the price for soybean oil was 1330 $/ton and 462 $/ton for soybean meal and we applied a price increase in 2040 of 0.5% (oil) and 2.5% (meal) in the very ambitious scenario.

Table 3.2.3.1. Assumed soybean oil and meal selling values 2019/2020 (based on: USDA (April 2023).

Price of soybeans	$/tonne FW	567
Price of straw	$/tonne DM	111
Price of soybean oil	$/tonne	1330
Price of soybean meal	$/tonne FW	462

3.3 Rapeseed in Germany

3.3.1 Cultivation

Rapeseed (*Brassica napus*) is an annual oil (and protein) crop, suitable for temperate climate zones. It is cultivated throughout the whole of Germany. It has a growth period of approximately 6 – 9 months and can be sown before winter (winter rapeseed) or in spring (spring rapeseed). It is harvested in the summer. In Germany it was the third largest crop with respect to harvested area in 2019 – 2021 (after wheat and barley) with a share of 10 – 12% of the total harvested area of all crops (source: production data from FAOSTAT). As shown in Figure 3.3.1.1, the production area has decreased from 1.5 million ha in 2006 – 2009 to just over 900.000 ha in recent years (2021). The increase since 2000 and the decrease since 2010 (Figure 3.3.1.1, left) can be attributed to the growing and declining interest to grow rapeseed for biodiesel due to changing legislation of the European Union. Contrary to the harvested area, rapeseed yields in Germany did not have a clear trend in recent years (Figure 3.3.1.1, right). Average annual yield in 2000 – 2021 was 3.6 tons per ha (fresh weight) with minimum and maximum values of 2.9 and 4.5 tons per ha, respectively (Figure 3.3.1.1, right).

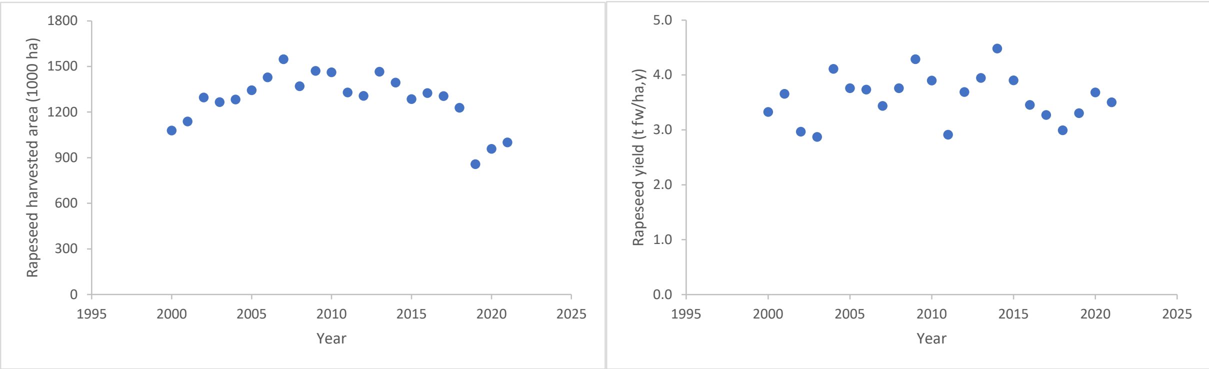

Figure 3.3.1.1. Rapeseed harvested area and yields in Germany 2000-2021 (source: FAOSTAT)

Rapeseed is commonly grown in rotation with other annual arable crops. Due to the built-up of soil pathogens, it is not advised to grow rapeseed at high frequencies, e.g. 1:3 or even 1:4. By having enough years with other crops in between two rapeseed years, the built-up of soil pathogens can be managed. At harvest time, leaves and flower petals have been shed, while straw (stem) and seeds can be harvested. The seed is rich in vegetable oil, i.e. circa 42% of the seed fresh weight (Poore and Nemecek, 2018), while the remaining part can be used as protein-rich animal feed (rapeseed meal or cake). Straw can be harvested and used as bedding material for livestock, or it can be directly ploughed into the soil, with a positive effect on subsequent crops. Rapeseed honey produced by bees can be seen as a by-product of the cultivation of rapeseed. In this study we have not taken the impacts of honey production into account, because it was assumed that it has a very low contribution to the impacts, and it is difficult to estimate the scale at which rapeseed fields are used for honey production.

The cultivation of rapeseed, like many other crops in Germany, is highly mechanized. For e.g. ploughing, sowing, weeding and harvesting, machines are used that are usually driven by fossil diesel as energy source. In the current situation on average 24 kg of diesel is used per ton of rapeseed yield. Besides, relatively high amounts of various fertilizers are applied to obtain a high yield, such as an average of almost 49 kg of N fertilizer and 246 kg of CaCO3 (lime) per ton rapeseed yield. Chemicals to protect the crop are also used with in total 0.53 kg active ingredients per ton of FW rapeseed yield (see also chapter 8). It can be concluded that conventional rapeseed cultivation in Germany strongly depends on chemical inputs.

3.3.2 Processing

After harvesting, rapeseeds are transported to a facility for drying and purification. Drying is needed to avoid spoilage during storage and is usually carried out in a kiln heated by gas. Purification takes place through sieving using gravity and wind power (Fridrihsone et al., 2020). Subsequently rapeseed is transported to the oil extraction mill. In Germany, most rapeseed oil mills use hot pressing in combination with hexane extraction (Alcock et al., 2022). Cold pressing is also used at smaller mills. Per ton of crude rapeseed oil circa 1.520 ton of rapeseed cake (or meal) is produced (Alcock et al. 2022). Rapeseed is therefore converted into 40% crude oil and 60% rapeseed meal. The main uses for the oil are food applications (after refinery) and biodiesel production. The cake is mainly used as fodder.

3.3.3 Future scenario descriptions

Under BAU conditions, the assumption is that the planted area and the yields will not change until 2040, relative to their values in 2020 (as has been the case for the last decades). Also the fallow area remains stable at 3%. Rapeseed is not grown on recently deforested areas which is a situation assumed to continue until 2040.

For the very ambitious scenario, improvements are assumed from 2020 to 2040 that include

- A yield increase from 3.6 to 4.9 ton/ha in 2040 (38% in 20 years)
- A reduction in fallow area from 3% to 0% in 2040
- An increase in N fertilization from 176 to 197 kg N per ha, due to the higher yield
- A reduction in pesticide use from 100% to 20% in 2040

The current (2020) price of rapeseed oil was 1578 Euro per ton and the rapeseed cake price was 363 Euro per ton. A small increase of 3% in 2040 is assumed for both prices. For all scenarios, a constant planted area is assumed of 950.000 ha per year until 2040. Also, the selling of straw is assumed to be 5% in all scenarios.

Table 3.3.3.1. Assumed rapeseed oil and rapeseed meal selling values 2019/2020 (based on: USDA (April 2023) and markt.agrarheute.com).

Price of rapeseed	**€/tonne FW**	**708**
Price of straw	€/tonne DM	122
Price of rapeseed oil	€/tonne	1578
Price of rapeseed meal	€/tonne FW	363

4 Land use efficiency of vegetable oils

4.1.1 Land use efficiency of palm oil production

The results for the land use efficiency (ton crude palm oil or CPO per ha) are presented in the Table 4.1.1.1. For BAU we assume no yield growth of oil palm, as has been the case in Indonesia in the past years (Monzon et al. 2021). We assumed that the CPO yield will increase from its current 3.2 ton/ha to 4.0 ton/ha in 2040 under the very ambitious scenario. Under economic allocation, where part of the land is allocated to the by- and co-products, the oil land use efficiency goes from 3.8 ton/ha currently to 4.8 ton/ha in 2040 (Table 4.1.1.1). Under mass allocation, we calculated an oil land use efficiency of 8.7 ton/ha in 2040, because of the large amount of residue that can be sold. This allocation method does not make a lot of sense because of the much lower price of most residues compared to the vegetable oil price (see Table 4.1.1.1). It does show the potential of utilizing residues in increasing the oil land use efficiency. The more value can be added to residues, the larger the land use efficiency of the CPO production will become in ton oil/ha.

Table 4.1.1.1. Allocated land use efficiency (ton of crude palm oil (CPO) per allocated ha) in current situation and in 2030 and 2040, under business as usual (BAU) and the very ambitious scenario. The main assumptions for yield increase and increased land use are also shown.

	Current	Business as usual		Very ambitious	
		2030	**2040**	**2030**	**2040**
Total plantations area (Mha)	16.3	17.3	18.2	16.9	17.4
Crop yield of productive area (ton FFB /(ha·yr))	18.1	18.2	18.2	20.4	22.7
Productive area/plantations area (ha/ha)	84%	84%	84%	84%	84%
Net land use (plantations ha/productive ha)	119%	119%	119%	119%	119%
Crude palm oil yield					
(ton CPO/(ha·yr))					
- 100% allocated on crude oil	3.2	3.2	3.2	3.6	4.0
- mass allocation	4.4	4.5	4.6	6.4	8.7
- economic allocation	**3.8**	**3.8**	**3.8**	**4.3**	**4.8**

4.1.2 Land use efficiency of soybean production

The land use efficiency (ton crude soybean oil or CSO per ha) is presented in Table 4.1.2.1 below. It shows that under BAU, the crude soybean oil production is increased from 0.65 to 0.78 ton per ha, if all land is allocated to the oil. If we apply economic allocation using oil and meal as products, the oil land use efficiency goes from 1.6 currently to 1.9 ton/ha in 2040. Under (very) ambitious scenarios, we estimated an oil land use efficiency of 3.1 ton/ha in 2040.

Table 4.1.2.1. Allocated land use efficiency (ton of crude soybean oil (CSO) per allocated ha) in current situation and in 2030 and 2040, under business as usual (BAU) and two ambitious scenarios. The main assumptions for yield increase and increased land use are also shown.

	Current	**Business as usual**		**Ambitious**		**Very ambitious**	
		2030	2040	2030	2040	2030	2040
Planted area (Mha)	35.9	51.4	65.6	45.5	54.4	39.7	43.2
Crop yield per harvest (ton soybean/ha)	3.2	3.6	3.7	3.8	4.1	4.0	4.4
Harvested area/planted area (ha/(ha·yr))	112%	114%	116%	122%	130%	136%	149%
Net land use (planted ha·yr/harvested ha)	90%	88%	86%	82%	77%	73%	67%
Crude soybean oil yield							
(ton CSO/(ha·yr))							
- 100% allocated on crude oil	0.65	0.74	0.78	0.85	1.0	1.0	1.3
- mass allocation	2.9	3.3	3.5	3.8	4.5	4.7	5.7
- economic allocation	**1.6**	**1.8**	**1.9**	**2.1**	**2.4**	**2.6**	**3.1**

4.1.3 Land use efficiency of rapeseed oil production

The current and future scenario land use efficiencies of crude rapeseed oil (CRO) production is shown in Table 4.1.3.1. We assumed that the rapeseed oil production will increase from 1.4 ton in BAU to 1.9 ton per ha in 2040 under the very ambitious scenario. When economic allocation is applied on rapeseed oil, meal and part of the straw, the oil land use efficiency increases from 1.8 ton/ha in BAU to 2.6 ton/ha in 2040 under the very ambitious scenario.

Table 4.1.3.1. Allocated land use efficiency (ton of crude rapeseed oil (CRO) per allocated ha) in current situation and in 2030 and 2040, under business as usual (BAU) and two ambitious scenarios. The main assumptions for yield increase and increased land use are also shown.

	Current	Business as usual		Ambitious		Very ambitious	
		2030	2040	2030	2040	2030	2040
Planted area (Mha)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Crop yield per harvest (ton rapeseed/ha)	3.6	3.6	3.6	3.9	4.3	4.2	4.9
Harvested area/planted area (ha/(ha·yr))	97%	97%	97%	98%	98%	99%	100%
Net land use (planted ha·yr/harvested ha)	103%	103%	103%	102%	102%	101%	100%
Crude rapeseed oil yield (ton CRO/(ha·yr))							
- 100% allocated on crude oil	1.4	1.4	1.4	1.5	1.7	1.7	1.9
- mass allocation	3.2	3.2	3.2	3.5	3.9	3.9	4.5
- economic allocation	1.8	1.8	1.8	2.0	2.2	2.2	2.6

4.1.4 Comparison in land use efficiency between vegetable oils

We compare the land use efficiencies of palm oil, soybean oil and rapeseed oil in Table 4.1.4.1, based on the values above. When 100% of the land use is allocated to the crude oil, oil palm has the highest efficiency of 3.2 ton oil/ha and soybean has the lowest efficiency of 0.6 ton oil/ha in the current situation. With this allocation method in the very ambitious scenario for 2040, land use efficiencies increase with again oil palm having the highest efficiency (4.0 ton oil/ha) and soybean the lowest (1.3 ton oil/ha).

Above comparison is however not fair because the land use is completely allocated to the crude oil. All three crops also produce by- and co-products that have a significant weight and value. Therefore, we also report our results under the economic allocation method. We see that the land use efficiency of all oils increases when economic allocation is applied. In the current situation, oil palm has again the highest oil land use efficiency (3.8 ton oil/ha) and soybean the lowest value (1.6 ton oil/ha). Under the BAU scenario, in 2040, soybean oil has a slightly higher land use efficiency than rapeseed oil, 1.9 vs 1.8 ton oil/ha, whereas palm oil still has the highest value (3.8 ton oil/ha). Under the very ambitious scenario, oil palm has an oil land use efficiency of 4.8 ton oil/ha, compared to 2.6 and 3.1 ton oil/ha for rapeseed and soybean, respectively.

Table 4.1.4.1. Comparison of the land use efficiency of producing crude palm oil (Indonesia), soybean (Brazil) and rapeseed (Germany) in current situation and in 2040, under future scenarios.

	Current (~2020)			Business as usual 2040			Very ambitious 2040		
	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed
Crude oil yield	------------------------------------ ton oil per ha per year---------------------------------------								
- 100% allocated to oil	3.2	0.6	1.4	3.2	0.8	1.4	4.0	1.3	1.9
- mass allocation	4.4	2.9	3.2	4.6	3.5	3.2	8.7	5.7	4.5
- economic allocation	3.8	1.6	1.8	3.8	1.9	1.8	4.8	3.1	2.6

4.1.5 Discussion and conclusions

The land use efficiency of palm oil is highest compared to soybean and rapeseed oil. This is the case in the current situation (2020) and in the future scenarios (2040).

We also see that by 2040 significant improvements in land use efficiency are possible for all crops. The largest relative improvement (value in 2040 / value in 2020) is estimated for soybean, because higher yields and more double cropping are assumed in the very ambitious scenario. This will reduce the net land use allocated to the soybean crop. For rapeseed, the improvement is mainly due to assumed yield increase, while no double cropping has been assumed by 2040. For oil palm the efficiency improvement is due to both yield increases and better use of residues and implementation of intercropping and cattle incorporation.

5 GHG performance of vegetable oils

5.1 GHG performance of palm oil production

The GHG performance of CPO production is shown in Table 5.1.1. Under BAU and economic allocation, the GHG performance for delivery of CPO to Rotterdam decreases from a current estimate of 3.6/4.5 ton CO_2eq to 3.0/3.9 ton in 2040, mainly due to introduction of methane capture from POME and less impact of GHG emissions associated with previous deforestation. Under the very ambitious scenario, the GHG emission is reduced to 1.2/1.3 ton GHG-eq. per ton of CPO in 2040 for shipment to Rotterdam. For shipment to Jakarta, GHG emission is lower, viz. 1.0/1.1 ton CO_2-eq /ha, due to shorter transport distance. The low values in 2040 under the very ambitious scenario are due to almost complete phasing out of methane emissions from POME, phasing out of palm on peat, and no more GHG emission due to deforestation, which is discounted over 20 years. Due to extra value created from intercropping (in first four years), residue valorisation and animal integration, GHG emissions are also allocated to the intercrop and value addition to the residues, thereby reducing the GHG emissions allocated to the CPO.

Table 5.1.1. Total GHG emissions of crude palm oil, expressed as ton CO_2-eq/ton CPO, with transport to Rotterdam or Jakarta, in current situation and under different scenarios, using three allocation methods. For CPO two estimates are shown, reflecting estimates for emission from peat based on the consensus value and recent (lower) field measurements in Indonesia.

	Current	Business as usual		Very ambitious	
		2030	**2040**	**2030**	**2040**
GHG emissions to Rotterdam					
- 100% allocated on crude oil	4.2 / 5.3	3.8 / 4.9	3.4 / 4.6	2.5 / 2.9	1.4 / 1.5
- mass allocation	3.1 / 3.9	2.8 / 3.6	2.5 / 3.3	1.6 / 1.8	0.8 / 0.9
- economic allocation	3.6 / 4.5	3.3 / 4.2	3.0 / 3.9	2.2 / 2.5	1.2 / 1.3
GHG emissions to Jakarta					
- 100% allocated on crude oil	3.0 / 5.1	2.6 / 4.7	2.3 / 4.4	2.1 / 2.7	1.3 / 1.3
- mass allocation	2.8 / 3.7	2.5 / 3.4	2.3 / 3.1	1.3 / 1.5	0.6 / 0.6
- economic allocation	3.3 / 4.3	3.0 / 4.0	2.7 / 3.7	1.9 / 2.3	1.0 / 1.1

Figure 5.1.1. shows the GHG emission sources for current, BAU and the very ambitious scenario with economic allocation and delivery to Rotterdam. Peat oxidation is currently the largest contributor to GHG emission of palm oil even though only an estimated 10% of palm is grown on peat out of an estimated total palm area of 16,4 Mha in Indonesia (See chapter 6). This value can be reduced significantly if the use of peat soils is phased out by not replanting oil palm in peat areas (which is an existing RSPO recommendation).

The next largest emission contributor is methane emission from POME management. It is estimated that under the current situation (2020) more than 90% of POME management leads to methane emissions. The current pace (2020) of implementing measures for better POME management would lead to a reduction of methane emission. Faster implementation as envisioned in the very ambitious scenario could reduce the methane emission to close to zero. The third largest contributor in GHG emissions are the field operations, including fertilization. Here, there are fewer options for improvements. We did not include possible improvements such, as using sustainable hydrogen to produce nitrogen fertilizer or using renewable electricity-based transport. The effect of land use change (deforestation) contributes almost 0.6 ton CO_2-eq. per ton CPO. This is due to the 20 year discounting of GHG emissions from deforestation. Currently (2020), 18% of the total palm area is on recently deforested land and therefore carries a GHG emission over a period of 20 years. If expansion of palm area on recently deforested land is prevented, this emission will go to 0 within 20 years, as has been assumed in the very ambitious scenario.

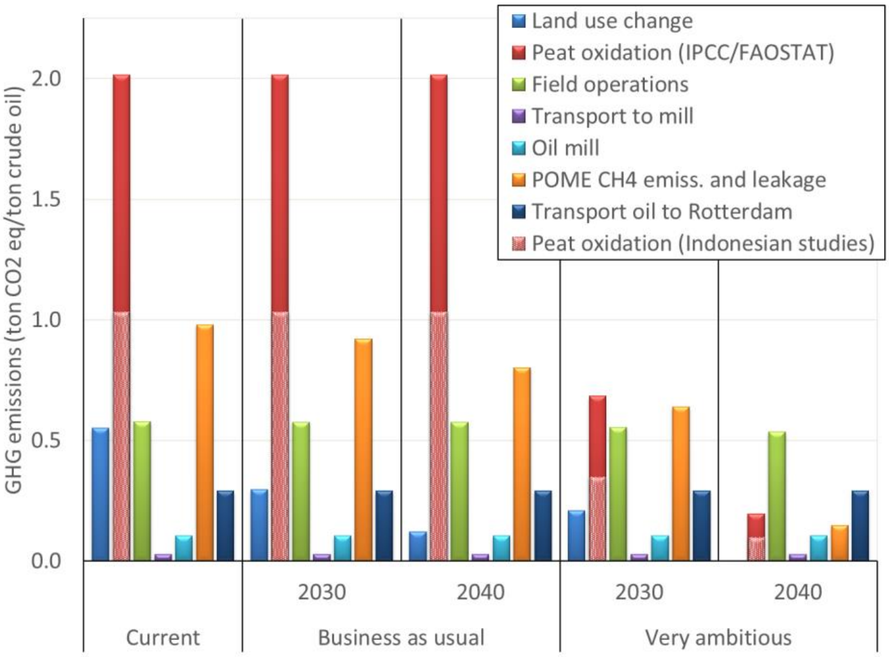

Figure 5.1.1. ***GHG emissions per emission category of crude palm oil production (using economic allocation). For peat oxidation two estimates are shown, the consensus value and a (lower) estimate based on recent field measurements in Indonesia.***

Figure 5.1.2 a and b illustrate the contribution of different GHG sources to the average GHG emission of CPO in Indonesia. It shows that almost 80% of the CPO produced only has GHG emissions due to field operations, transport and POME management. It also shows that 9.5% of the CPO is produced on peat land causing 59 to 41% of the GHG emission of CPO.

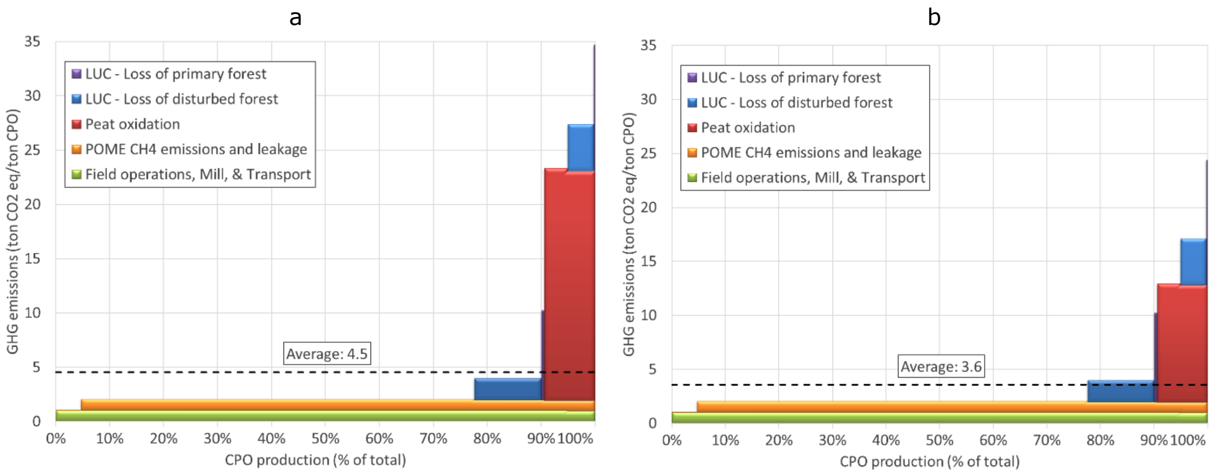

Figure 5.1.2. ***GHG emissions per emission category of crude palm oil production for transported to Rotterdam using economic allocation. Peat oxidation based on a) IPCC/FAOSTAT data (78 ton CO2 eq ha-1 yr-1) or b) recent studies (40 ton CO2 eq ha-1 yr-1). The area of the bars represents the total GHG emission per category.***

Table 5.1.2. ***Relative contribution of different GHG emission categories for CPO production in Indonesia. Using peat oxidation data from IPCC/FAOSTAT or recent studies in Indonesia.***

	IPCC/FAOSTAT data	Recent studies
Field operations, Mill, & Transport	22%	28%
POME CH4 emissions and leakage	22%	28%
LUC - Loss of disturbed forest	10%	13%
LUC - Loss of primary forest	2%	3%
Peat oxidation	44%	29%

5.2 GHG performance of soybean oil production

The GHG performance of CSO production is shown in Table 5.2.1, using the same scenarios and methods as with palm oil. Under BAU and economic allocation, the total GHG emission for soybean oil is currently (2020) 2.4 to 2.5 ton CO_2-eq./ton oil, which is decreased to 1.9 ton CO_2-eq./ton oil in 2040 for the delivery in Rotterdam or Jakarta. Under the very ambitious scenario, the GHG emission per ton of soybean oil is reduced to 1.1 ton CO_2-eq./ton oil in 2040 (economic allocation). Roughly 50% of the total GHG emission for soybean oil production is allocated to soybean meal in the economic allocation (for current and all scenarios). Figure 5.2.1. shows the GHG emissions over the different categories under economic allocation and delivery to Rotterdam. The most important emission source for soybean is land use change which is currently close to 1.1 ton CO_2-eq./ton soybean oil. Under the BAU scenario, this is reduced to 0.6 ton CO_2-eq./ton oil in 2040. Under the very ambitious scenario, by preventing expansion of soybean on recently deforested land, this contribution is further reduced to 0 in 2040. Field operations are the second largest contributor to the total GHG emission and can be lowered by higher yields and lower nitrogen and pesticide use. The third largest contributor is the emission due to transport from the mill to Rotterdam. We made no improvement assumptions for the emissions due to transport from field to mill and from mill to Rotterdam or Jakarta.

Table 5.2.1. ***Total GHG emissions of soybean oil, expressed as ton CO_2-eq/ton CSO, with transport to Rotterdam or Jakarta, in current situation and under different scenarios, using three allocation methods.***

	Current	Business as usual		Ambitious		Very ambitious	
		2030	2040	2030	2040	2030	2040
GHG emissions to Rotterdam							
(ton CO_2 eq/ton CSO)							
- 100% allocated on crude oil	5.4	4.6	4.0	4.1	3.3	3.2	2.2
- mass allocation	1.5	1.3	1.2	1.2	1.0	1.0	0.8
- economic allocation	**2.4**	**2.1**	**1.9**	**1.9**	**1.5**	**1.5**	**1.1**
GHG emissions to Jakarta							
(ton CO_2 eq/ton CSO)							
- 100% allocated on crude oil	5.5	4.7	4.1	4.1	3.3	3.3	2.3
- mass allocation	1.5	1.3	1.2	1.2	1.0	1.0	0.8
- economic allocation	**2.5**	**2.1**	**1.9**	**1.9**	**1.6**	**1.6**	**1.1**

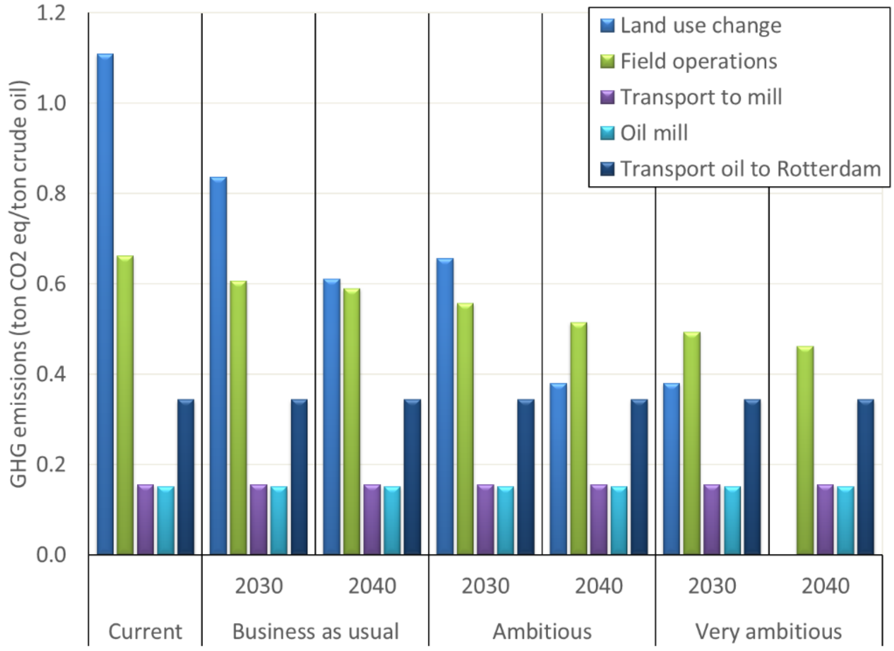

Figure 5.2.1. ***GHG emissions per category of crude soybean oil production (using economic allocation).***

5.3 GHG performance of rapeseed oil production

The GHG emission of crude rapeseed oil production and delivery to Rotterdam is currently (2020) 2.6 ton CO_2-eq./ton oil, if all emissions are allocated to the oil (Table 5.3.1). If economic allocation is used, the GHG emission is reduced to 2.0 ton CO_2-eq./ton oil in the current situation. Under the very ambitious scenario and economic allocation, the GHG emission per ton of rapeseed oil amounts to 1.4 ton CO_2-eq./ton oil in 2040 for delivery in Rotterdam.

Table 5.3.1. ***Total GHG emissions of rapeseed oil, expressed as ton CO_2-eq/ton CRO, with transport to Rotterdam or Jakarta, in current situation and under different scenarios, using three allocation methods.***

	Current	Business as usual		Ambitious		Very ambitious	
		2030	2040	2030	2040	2030	2040
GHG emissions to Rotterdam							
(ton CO_2 eq/ton CRO)							
- 100% allocated on crude oil	2.6	2.6	2.6	2.3	2.1	2.0	1.8
- mass allocation	1.2	1.2	1.2	1.0	0.9	0.9	0.8
- economic allocation	2.0	2.0	2.0	1.7	1.6	1.5	1.4
GHG emissions to Jakarta							
(ton CO_2 eq/ton CRO)							
- 100% allocated on crude oil	2.9	2.9	2.9	2.6	2.4	2.3	2.1
- mass allocation	1.4	1.4	1.4	1.3	1.2	1.2	1.1
- economic allocation	2.2	2.2	2.2	2.0	1.8	1.8	1.6

Figure 5.3.1 shows the GHG emissions over the different categories under economic allocation and delivery to Rotterdam. By far the most important emission source for rapeseed oil are the field operations, contributing 1.7 ton CO_2-eq./ton rapeseed oil in the current (2020) situation and under BAU. This can be reduced to 1.1 ton CO_2-eq./ton rapeseed oil in 2040 under the very ambitious scenario. The second and third contributor, i.e. oil mill and transport to Rotterdam, are relatively small for which we did not assume improvements under future scenarios.

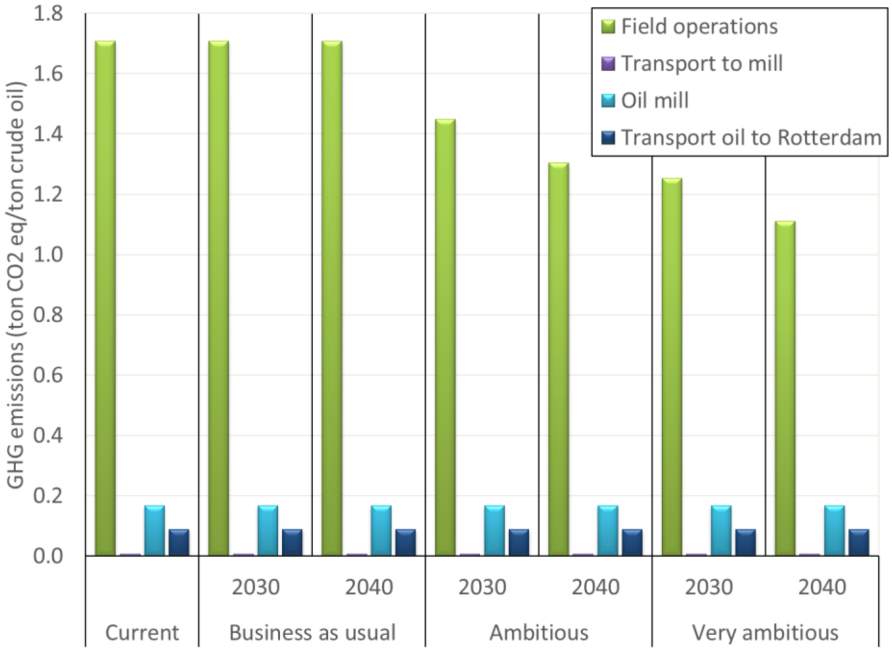

Figure 5.3.1. GHG emissions of crude rapeseed oil (economic allocation)

5.4 Comparison in GHG performance between vegetable oils

The comparison of the GHG emission for crude palm oil, soybean oil and rapeseed oil is presented in Table 5.4.1., based on the values above. With delivery of the crude oil to Rotterdam in the current (2020) situation, results show that the GHG emission of rapeseed oil production is lowest at 2.6 ton CO_2-eq./ton oil and highest for soy oil at 5.4 ton CO_2-eq./ton oil, if 100% of the total emission is allocated to the oils. However, significant amounts of by- and co-products are also produced with significant monetary values. Therefore, we discuss the differences on the basis of economic allocation. The allocated emission to Crude palm oil (CPO) is then the highest at 3.6/4.5 ton CO_2-eq./ton for palm oil vs 2.0 ton CO_2-eq./ton rapeseed oil in the current situation. Under the BAU scenario, there are improvements for oil palm and soybean. For rapeseed, the yield is stable under BAU scenario. Under the very ambitious scenario in 2024, several improvements are further assumed for all three crops, leading to significant GHG emission reductions. The GHG emission of soybean oil is lowest at 1.1. ton CO_2-eq./ton oil vs. 1.4 ton CO_2-eq./ton oil for rapeseed oil and 1.2/1.3 CO_2-eq./ton for palm oil. For the delivery of the crude oil to Jakarta, the GHG emission of palm oil is reduced compared to the delivery to Rotterdam, the same for soy oil and increased for rapeseed oil reflecting the longer transport distance.

Table 5.4.1. GHG emission of producing and delivering crude oil from oil palm (Indonesia), soybean (Brazil) and rapeseed (Germany) in the current situation, and in 2040, under different scenarios. For oil palm two estimates are shown, reflecting the assumed GHG emission of palm oil on peat using consensus data and recent measurements of CO_2 emissions of palm on peat in Indonesia.

	Current			**Business as usual 2040**			**Very ambitious 2040**		
	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed	Oil palm	Soybean	Rapeseed
	---------------- ton CO_2 eq/ton crude oil ----------------								
GHG emissions to Rotterdam									
- 100% allocated to oil	4.2 / 5.3	5.4	2.6	3.4 / 4.6	4.0	2.6	1.4 / 1.5	2.2	1.8
- mass allocation	3.1 / 3.9	1.5	1.2	2.5 / 3.3	1.2	1.2	0.8 / 0.9	0.8	0.8
- economic allocation	**3.6 / 4.5**	**2.4**	**2.0**	3.0 / 3.9	**1.9**	**2.0**	1.2 / 1.3	**1.1**	**1.4**
GHG emissions to Jakarta									
- 100% allocated to oil	3.0 / 5.1	5.5	2.9	2.3 / 4.4	4.1	2.9	1.3 / 1.3	2.3	2.1
- mass allocation	2.8 / 3.7	1.5	1.4	2.3 / 3.1	1.2	1.4	0.6 / 0.6	0.8	1.1
- economic allocation	3.3 / 4.3	**2.5**	**2.2**	2.7 / 3.7	**1.9**	**2.2**	1.0 / 1.1	**1.1**	**1.6**

Figure 5.4.1 shows the contribution of the different emission categories to the GHG emission per ton of CPO transported to Rotterdam, using economic allocation. For palm oil, peat oxidation has the highest effect on

current and BAU (2040) emissions, but also on the assumed reduction in 2040 under the very ambitious scenario. Peat oxidation is not an issue for soybean and rapeseed. Also, the emission of methane from POME is a significant contributor for palm oil with large reduction options in 2040 under the very ambitious scenario. Again, as with peat, methane from POME is not an issue for soybean and rapeseed. GHG emission associated with land use change (deforestation) is not an issue for rapeseed but is the highest contributor for soybean in current and BAU scenario. The land use change emission for oil palm is currently about half as large compared to the value for soybean. For both crops it is assumed zero in 2040 under the very ambitious scenario.

The emissions from field operations include a wide range of emissions including diesel, pesticide, and fertilizer use. Here, rapeseed has the highest emissions in all scenarios, which can be explained by the high N fertilizer use. For soybean, we assumed a very low N fertilizer use, due to its symbiotic relation with nitrogen fixing microbes and lower N fertilizer application rates are required for oil palm, because oil palm is a perennial crop with a low amount of nitrogen that is annually harvested. The lower price for rapeseed protein meal compared to soybean meal, mostly reflecting their value as feed, is also relevant here.

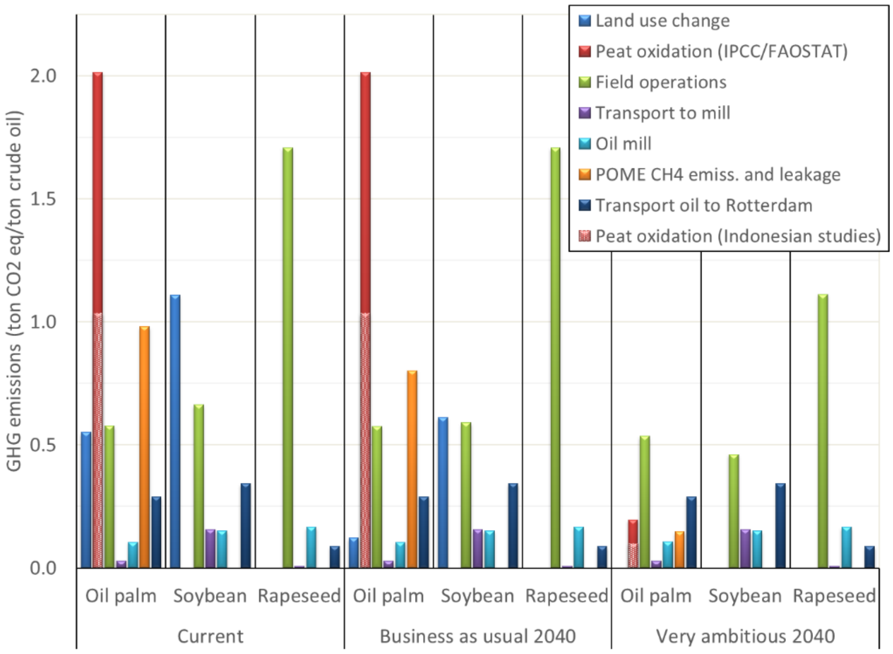

Figure 5.4.1. GHG emissions per category for oil crops under different scenarios using economic allocation. For oil palm on peat two estimates are shown, the consensus value and a (lower) estimate based on recent field measurements of GHG emissions of palm on peat in Indonesia.

6 Biodiversity effects

6.1 Methods

Deforestation is a global issue which is directly linked to biodiversity loss (FAO & UNEP (2020). Here we elaborate on the methodology which was used to determine the effect of the cultivation of oil palm, soybean and rapeseed on deforestation and biodiversity loss. As a proxy for biodiversity loss we used the percentage of primary and secondary forest recently lost per ha of oil palm plantation developed.

6.1.1 Deforestation / land-cover change

For each crop we focused on one of the main countries where the crop is grown:

- Oil Palm: Indonesia, where we made a distinction between smallholder plantations (< 25 ha in land cover) or estate/industrial plantation (> 25 ha in land cover) and whether plantations were located on peat soils (organic soils > 1 m in depth) or non-peat soils (mineral soils);
- Soybean: Brazil where we made a distinction between conventional cultivation and minimum (tillage) cultivation
- Rapeseed: Germany (just one system)

To quantify the deforestation caused by oil palm, soybean and rapeseed plantations we used a mix of satellite imagery, remote sensing data, and government statistics from e.g. the Nusantara database (https://nusantara-atlas.org/), the global forest watch website (https://www.globalforestwatch.org/), and recently published papers such as Austin et al. (2017), Gaveau et al (2021), Goldman et al (2020), and Song et al (2021).

We calculated the total area of forest loss over the last 20 years and analysed several trends to understand the scale and pace of deforestation in each of the three countries. In doing so we quantify the direct land conversion for the cultivation of the crop cf Goldman et al. (2020). This direct effect refers to the immediate impact of cultivating a crop on land use change. In addition, Goldman et al (2020) define direct deforestation as when oil palm establishment occurs within four years of deforestation, or when soybean establishment occurs within three years of deforestation – this also follows others like Austin et al (2017) and Song et al (2021). The indirect effect refers to the secondary impacts that occur as a result of cultivating a crop that are not directly tied to immediate land use change. For example, conversion of primary forests to oil palm plantations may indirectly lead to deforestation in neighbouring areas as displaced communities seek new land for agriculture or logging. Indirect effects may also include environmental impacts, such as alterations in hydrological regimes, soil fertility, biodiversity loss, and carbon emissions, which can further influence ecosystem functioning at the landscape level. In our analysis we focus on direct effects only as this is most accurately measurable through for instance satellite imagery or field surveys.

Following several authors (e.g. Austin et al 2017; Song et al 2021) we make a distinction between primary forests and secondary (logged over) forests as follows:

- **Primary forests** are forests which are not affected by human activities and which represent the most intact and biodiverse ecosystems on Earth;
- **Secondary (logged over) forests** are forests that experienced some degree of human intervention, for instance through selective logging or hunting. While the forest structure may be altered, logged forests may retain some level of biodiversity and ecosystem function compared to completely cleared areas.

6.1.2 Loss of biodiversity

In calculating the loss of biodiversity associated with oil palm, soya and rapeseed we used data and outcomes from articles which were published over the last decade.

In Indonesia mainly two natural forests biomes have been converted into oil palm plantations (1) lowland rainforests (characterized by high species diversity, dense vegetation, and tall emergent trees) and (2) peat swamp forests (growing on waterlogged, acidic organic soils (peat) and adapted to regular flooding, with unique flora and fauna). These peat layers may be 10-15 meters in depth and store vast amounts of carbon in the form of organic material accumulated over thousands of years. In Indonesia, peatland covers some 13.4 million hectares mainly on Sumatra (5.85 million hectares), Kalimantan (4.54 million hectares) and Papua (3.01 million hectares) (Anda et al., 2021).

In Brazil the expansion of soybean cultivation has primarily affected two major biomes: the Amazon rainforest and the Cerrado savanna biome. The Amazon rainforest is (like the Indonesian lowland rainforest) characterised by a very high species diversity and dense, evergreen forest vegetation. The Cerrado biome is a more open tropical savanna ecosystem with a mixture of open grasslands, shrub lands, open woodland, and closed canopy woodlands along streams. Both systems cover large areas and are biodiversity hotspot, with high levels of plant and animal diversity, including many endemic species.

In Germany there has not been any significant expansion of rapeseed cultivation in forest areas over the last twenty years. Rapeseed (also known as Canola) is primarily cultivated in agricultural fields rather than forested regions, and expansion of rapeseed areas has mainly affected other agricultural crops.

To estimate the biodiversity-loss associated with the expansion of vegetable oil we determined the percentage of primary and secondary forest lost per ha of vegetable oil developed and used that to determine the loss of high biodiverse and low biodiverse forest.

6.2 Results and discussion

6.2.1 Current situation - Indonesia

Over twenty years (2000-2020), the area covered in Indonesia by oil palm plantations increased by some 8.7 Mha, reaching 16.3 Mha in 2020 (64% industrial; 36% smallholder) (Table 6.2.1.1).

Table 6.2.1.1. Overview of Oil Palm Plantation coverage in Indonesia by 2020 (in ha).

	Small Holder (36%)	Estate (64%)	TOTAL
Peat	433,000	1,156,000	1,589,000
Non-Peat	5,487,956	9,252,242	14,740,198
TOTAL	5,920,956	10,408,242	16,329,198

(based on Nusantara database (https://nusantara-atlas.org/)

Over the same period the forest area in Indonesia declined by 11% (9.8 Mha). Of the total area deforested over that period 29% (2.9 Mha) was cleared and converted into oil palm plantations in the same year (Table 6.2.1.2). Based on Austin et al. 2017 deforestation between 2000-2015 was affecting 5% primary and 95% secondary forest; we used this ratio between primary and secondary forest loss in our calculations. In that same period 32% (3.1 Mha) was initially cleared for other purposes and later converted into oil palm plantations. As this cannot be accounted directly to oil palm deforestation we did not take this into account in our deforestation calculations.

Table 6.2.1.2. Deforestation directly caused by Oil Palm expansion between 2001-2020 (in ha) in Indonesia.

	Peat		Non-peat		TOTAL
	Smallholder	**Estate**	**Smallholder**	**Estate**	
Primary Forest	16,422	49,575	21,873	66,175	154,044
Secondary Forest	196,849	594,251	486,800	1,472,768	2,750,668
TOTAL	213,271	643,825	508,673	1,538,943	2,904,712

(based on Nusantara database (https://nusantara-atlas.org/)

Our data show that between 2019-2020 a total of 92.151 ha of new oil palm plantations were developed of which 37,688 ha were developed in forested areas, most of which was secondary (logged over) forest (Table 6.2.1.3).

Table 6.2.1.3. Deforestation directly caused by oil palm expansion between 2019-2020 (in ha) in Indonesia.

	Peat		**Non-peat**		**TOTAL**
	Smallholder	**Estate**	**Smallholder**	**Estate**	
Primary Forest	0	683	1	1,238	1,922
Secondary Forest	0	8,188	33	27,545	35,766
TOTAL	0	8,871	34	28,783	37,688

(based on Nusantara database (https://nusantara-atlas.org/)

Based on the figures for 2020 as given in Table 6.2.1.3 and using a value of 92.151 ha as the total area of oil palm developed in 2020, we estimate that for each hectare of oil palm developed in 2020 some 2,09 % of highly biodiverse primary forest and 38,81 % of less biodiverse logged over forest was lost (Table 6.2.1.4).

Table 6.2.1.4. Deforestation directly caused by oil palm expansion between 2019-2020 as percentage of the total area of oil palm developed (92.151 ha) in that same period.

	Rainforest	***Peat Forest***	All
Primary forest loss as % of new oil palm area	1.34%	0.74%	2.09%
Secondary forest cut as % of new oil palm area	29.93%	8.89%	38.81%
Total forest loss (% of ha new oil palm developed)			**40.90%**

6.2.2 Current situation - Brazil

In Brazil the area covered by soybean increased from 13.4 Mha in 2001 to 34.5 Mha in 2020 (Song et al 2021). Between 2002 and 2019 a total forest area of 4.8 Mha was lost due to soybean development in Brazil. The total area loss of the biomes (4.7 Mha) was compared to the accumulated annual expansion since 2000 in order to estimate how many ha per year were cleared for soybean in Brazil, based on the annual expansion in each year and the ratio of total biome loss and total expansion of soybean. Based on this we estimate that soybean was an important driver of deforestation in both the Amazonian and Atlantic rain forest area (3.1 Mha) as well as in the Cerrado woodland area (1.7 Mha, Table 6.2.2.1). Of the total forest area some 1.3 Mha of primary Amazonian rain forest was cleared between 2002 and 2019. This is in line with findings of others like Goldman et al. (2020) who estimated that global soybean driven deforestation between 2001 and 2015 to be 8.2 Mha of which 3.9 Mha as a direct driver.

Table 6.2.2.1. ***Deforestation caused by soybean expansion between 2002-2019 in Brazil (ha). A distinction is made between different biomes and primary and secondary (logged) forests***

Biomes Brazil	Area lost due to soybean development (ha)
Amazon primary	1,344,000
Amazon secondary	714,000
Atlantic Forest secondary	1,000,000*
Cerrado secondary	1,700,000*
Pantanal secondary	16,000*
TOTAL	4,774,000

**data based on Song et al. 2021 – Primary forest loss in Atlantic Forest, Cerrado and Pantanal was not neglectable.*

Between 2019-2020, the area planted with soybean increased with some 1,15 Mha. Around 9.6% of soybean expansion occurred on land that was previously primary forest (Table 6.2.2.2). Unfortunately, we did not have data on secondary forest loss due to soy development for this period.

Table 6.2.2.2. ***Deforestation directly caused by soybean expansion between 2019-2020 in Brazil (ha).***

Biomes Brazil	Soybean expansion between 2019 -2020 on primary forest area(ha)
Amazon	105,063
Atlantic	1,045
Cerrado	5,387
Pantanal	4
TOTAL	111,498

6.2.3 Current situation – Germany

As mentioned above in Germany there has not been any discernible expansion of rapeseed cultivation in forest areas over the recent twenty years. Rapeseed is primarily cultivated in agricultural fields rather than forested regions, and expansion of rapeseed areas has mainly affected other agricultural crops. We assume that the cultivation of rapeseed in Germany did not lead to any loss of forests and did also not affect biodiversity in term of loss of biodiversity rich forest.

6.3 Discussion and conclusions

Deforestation is directly linked to biodiversity loss, which in many cases is caused by expansion of crop production (e.g. Meijaard et al 2024). Both oil palm plantations in Indonesia and soybean fields in Brazil have replaced substantial areas of forest over the last 20 years. Rapeseed in Germany has not led to any discernible deforestation over the last two decades.

Goldman et al. (2020) give an estimation of the deforestation caused globally by seven important commodities (including soybean and oil palm) for the period between 2000-2018. They indicate that worldwide, cattle is the largest cause of deforestation with some 45.1 million hectares of land deforested between 2001 and 2015. On a global scale oil palm replaced the second highest amount of forest (10.5 million hectares) followed by soybean (8.2 million hectares). It should be noted that the deforestation rates for the latter two crops include deforestation not only in Indonesia and Brazil but other countries (like Malaysia, Argentina etc) as well. They also show fluctuating patterns with both crops showing a decline in the global deforestation rates over the last 18 years (Goldman et al., 2020). Our findings are in line with other observations on global deforestation. According to Global Forest Watch (https://www.globalforestwatch.org/), Indonesia lost 9.75 Mha of forest between 2002 and 2020 by a multitude of causes, including oil palm but also rubber and tree plantations. Total tree cover loss, with a tree cover density of 30% or more, was 27.7 Mha in this period.

We estimate that for each hectare of oil palm plantation currently developed (approx. 2020) in Indonesia 2% of primary forest is lost, and 39% of disturbed or secondary forest lost. Under the ambitious scenario no forest is lost due to plantation development, reducing the loss of biodiversity significantly. In Brazil the expansion of soybean generally takes place on cropland, primary forest, non-primary forest, or pasture/grassland. Direct deforestation linked to soy is however more difficult to assess (as compared to oil palm) as forest is often cleared initially for other land use (e.g. cattle grazing) and is only converted to soybean after 4-5 years (Song et al., 2021). It is clear however that also soybean has been developed on areas previously covered (in 2000) by primary forest.

Perennial crops like oil palm have potential advantages over annual crops (such as soybean and rapeseed); they may minimise the loss of natural ecosystems and biodiversity while maintaining long-term production. Because oil palm is a perennial crop lasting for at least 20 years the plant diversity inside oil palm plantations generally exceeds that of annual oil crops. For instance, in one study 298 plant species were found in the undergrowth of an oil palm plantation, and in another study 16 different species of fern were identified on oil palm trunks (Meijaard et al 2024). Also, oil palm can be grown in polyculture which allows more complex and diverse vegetation to develop over time adding to overall biodiversity values.

Therefore we can conclude that:

- Biodiversity loss due to deforestation in recent years (25 years) was lowest for rapeseed in Germany and highest for oil palm and soybean (in Indonesia and in Brazil).
- The difference in biodiversity loss due to deforestation between oil palm (Indonesia) and soybean (Brazil) is harder to assess.
- Oil palm has higher biodiversity within the cropping area than soybean and rapeseed.

7 Pollution effects

This includes pollution effects of pesticides on land and water. Indicators are biocide use (kg active ingredient per ha or ton of oil), N surplus, P surplus, wastewater. This links to SDG 15 (Life on land) and SDG 14 (Life below Water) and SDG 6 (Clean Water and Sanitation).

7.1 Methods

The focus of this section is on the use agrochemicals, specifically pesticides. Pesticides here refers to the collective grouping of insecticides (e.g. chemical protection against insect attacks and infestations), herbicides (e.g. chemical protection against unwanted plant species) and fungicides (e.g. chemical protection against unwanted fungal species).

For the application of pesticides in Brazil, a short list of potential active ingredients was compiled from the comprehensive studies of (Pollak, 2020) and (Maciel et al., 2015). This list was then cross referenced with the annual bulletins of "Production, Import, Export and Sales of Pesticides in Brazil", published by the Brazilian environmental agency[3] (IBAMA). In Brazil every year actors which are involved in the pesticides industry (e.g. manufacturing) are required to report to IBAMA, the volumes they produce, import, export and sell. This provides data on the total number of active ingredients, organized into product classes (e.g. herbicides, fungicides, insecticides) at both the national and state levels. For ease of calculation and keeping in line with the approach for rapeseed, we selected the active ingredients associated with each product class which contributed the greatest sales volume. We used a cut-off point of 1%, meaning that the sales of an active ingredient was greater than 1% to the total sales of all product classes. Thus, forming a list of 10 active ingredients.

For Germany the types of active ingredients being applied to rapeseed for a particular year was determined from the Papa (pesticides)[4] database of the Julius Kuhn institute, the Federal research center for cultivated plants. The results are based on annual survey data extrapolated to national level and provide an overview of the active ingredients for each type of pesticide associated with a particular crop for a particular year. For simplicity, those active ingredients were selected per product class (e.g. herbicides, fungicides, insecticides) which when combined had a total weight greater than 75% of the active ingredients of that product class. Thus, forming a list of approximately 13 active ingredients found to be applied to rapeseed grown in Germany for the production year 2018.

For oil palm production it was difficult to determine an accurate inventory for pesticide use throughout the lifespan of the crop, from nursery phase (<1 year) up to and including the plantation phase period (~ 24 years). This is because, for example, in most cases of insect or fungi infestations the application of crop protection products will only be on a need-by-need basis (i.e. if there is an infestation) (Fairhurst et al., 2019). Therefore, there are no "standard applications", which are commonly used for annual crops. This is particularly pertinent for insecticides and fungicides. The most standard crop protection product found to be applied in oil palm production systems are herbicides and many times these products are applied on an annual basis for maintenance of the site, as well as weed control (Hakim et al., 2020). Therefore, the list derived from this study comes from (Syafrani et al., 2022), in which they surveyed pesticide application in the Indonesian provenance of Riau. This list was then cross referenced with other studies and handbooks (Fairhurst et al., 2019; Moulin et al., 2017; Woittiez et al., 2016) (Hakim et al., 2020). A final list of 14 pesticides was determined.

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[3] Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) https://www.gov.br/ibama/pt-br/assuntos/quimicos-e-biologicos/agrotoxicos/relatorios-de-comercializacao-de-agrotoxicos
[4] https://papa.julius-kuehn.de/index.php?menuid=54&reporeid=361

7.2 Results and Discussion

These finalized lists of pesticides were then qualitatively assessed for potential direct human effects and indirect human effects, using an adapted approach of (Pollack, 2020), which used the database of the Pesticide Action network[5] and the European Chemicals Agency[6] to classify the pesticides according to the parameters outlined in table 7.2.1.

Table 7.2.1. Overview of agrichemicals associated with the three oil crops, as well as their potential health effects and ecotoxicity potentials.

Soy-bean	Oil Palm	Rape-seed	Active Ingredient	CAS No.	Type	PAN bad actor/ HHP	Potential health effects[1]	Ecotoxicity potentials[2]
x			2,4-D	94-75-7	H	NL	7,10,14,18	d,g
x	x		Acephate	30560-19-1	I	Yes	7	a,e,g
	x		Aminopyralid potassium	566191-87-5	H	NL		b
		x	Azoxystrobin	131860-33-8	F	NL	4	b,g
		x	Boscalid	188425-85-6	F	NL		c,f,
	x		Carbaryl	63-25-2	I	Yes	7,8,12	a,b,g
x			Carbendazim	10605-21-7	F	Yes	15,16,17,18	b
	x		Carbosulfan	55285-14-8	I	Yes	1,5,18	a,b
x			Chlorothalonil	1897-45-6	F	Yes	1,10,12,14,18	b
x			Copper oxychloride	1332-40-7	F	NL	7,8	b
	x		Cypermethrin	52315-07-8,	I	Yes	4,5,9,11,14, 15,16,	a,b,e
	x		Deltamethrin	52918-63-5	I	Yes	4,5	a,b
		x	Dimethenamid	8764-68-8	H	No	7,8,18	b
x			Diuron	330-54-1	H	Yes	7,11,12	b,e,f,g
		x	Ethofenprox	80844-07-1	I	Yes	19	a,b
	x		Glufosinate	51276-47-2,	H	NL	7,8,9,11,15, 16	c
x	x	x	Glyphosate	1071-83-6	H	Yes	10	c,g
x			Imidacloprid	138261-41-3	I	Yes	5	a,b,f,g
	x		Lambda-cyhalothrin	91465-08-6	I	Yes	1,5,9	a,b

[5] https://www.pesticideinfo.org/
[6] https://echa.europa.eu/home

x	x		Mancozeb	8018-01-7,	F	Yes	11, 12,15,16,18	b,e
		x	Mepiquat	15302-91-7	F	NL	7	d
		x	Metazachlor	67129-08-2	H	NL	12,18	b
	x		Metsulfuron-methyl	74223-64-6,	H	NL		b,g
x	x		Paraquat (dichloride)	1910-42-5	H	Yes	1,5,6,10,11, 14,18	b,f,g
		x	propyzamide	23950-58-5	H	Yes	12	b,f,g
		x	Prothioconazole	178928-70-6	F	No		b
		x	Quinmerac	90717-03-6	H	NL		d
		x	Tau-fluvalinate	102851-06-9	I	Yes	7,18	b
		x	Tebuconazole	107534-96-3	F	NL	7,15,16	b,f,g
		x	Thiacloprid	111988-49-9	I	Yes	5,8,12, 15,16,20	b
	x		Triadimenol	55219-65-3	F	Yes	7,15,16,19	c,f
	x		Triclopyr	55335-06-3	H	NL	7,10,11,18	b

1. Source of data provided in this column: European Chemicals Agency (ECHA)
2. Source of data provided in this column is combined information from ECHA and PAN

Acronyms are as follows: H=Herbicide, I=insecticide, F=Fungicide; NL=Not listed (no data provided)

Potential Health Effects codes refer to: 1.fatal if inhaled, 2.fatal if swallowed, 3.fatal if in contact with skin, 4.toxic if inhaled, 5.toxic if swallowed,6.toxic in contact with skin, 7.harmful if swallowed,8.harmful if inhaled 9.harmful in contact with skin, 10.causes serious eye irritation or damage, 11.causes damage to organs through prolonged or repeated exposure, 12.suspected of causing cancer, 13.suspected of causing genetic defects.14.may cause respiratory irritation, 15.may damage fertility, 16.may damage the unborn child, 17.may cause genetic defects, 18.may cause or can cause an allergic skin reaction or irritation, 19.may cause harm to breast-fed children, 20. may cause drowsiness or dizziness.
Ecotoxicity potentials codes refer to: a-Toxic to bees; b-Very toxic to aquatic life, with long lasting effects; c-Toxic to aquatic life, with long lasting effects; d-Harmful to aquatic life with long lasting effects; e-Potential to be a persistent pesticide, bio-accumulative and toxic substance in fresh water; f-Potential to be a persistent pesticide, bio-accumulative and toxic substance in soil; g-Potential to pollute ground water

Oil crop diseases and pests can result in yield reductions and crop mortality and thus, can have knock on effects on the viability, sustainability and economics of these systems. Particularly vulnerable to these shocks are those dependent on oil crops for their livelihoods (Goulson 2020; Rizzo et al., 2021). The use of agrochemicals within oil crop systems is complex, coupling issues of food security, food safety, the health of the environment and human health (Rizzo et al., 2021). Several of the agrochemicals found to be associated with the oil crops of this study are classified as being highly hazardous. This means that these are "*pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment according to internationally accepted classification systems such as WHO or Global Harmonized System (GHS) or their listing in relevant binding international agreements or conventions.*

In addition, pesticides that appear to cause severe or irreversible harm to health or the environment under conditions of use in a country may be considered to be and treated as highly hazardous"[7]. Some of these health impacts include an increased risk of cancer, neurological disorders, reduced fertility rates and endocrine disorders, among others. In relation to impacts to the environment these range from contamination of water sources and soils, as well as toxicity to bees and aquatic life. Therefore, many of the management strategies currently implemented for protecting oil crops, dependent on HHP, need to be reconsidered.

Table 7.2.2. Ecotoxicity potential counts per crop (based on table 7.2.1).

Ecotoxicity potential	Oil palm	Soybean	Rapeseed
a	6	2	1
b	10	7	8
c	3	1	2
d	0	1	3
e	3	3	0
f	2	3	3
g	5	6	4
total	29	23	21

All three crops had highest counts for being very toxic to aquatic life with long lasting effects (b) followed by the potential to pollute ground water (g). Hence the crops did not differ much in the main ecotoxicity impact categories affected by use of agrichemicals. In addition, palm had higher counts for toxicity for bees (a).

Under the alternative scenarios, oil palm livestock integration saves herbicide use as animals graze the understory weeds and these weeds need not to be killed by spraying chemicals (Tohiran et al, 2017; Azhar et al, 2021). Intercropping oil palm fields may also reduce use of herbicide as the intercrop occupies space where weeds cannot grow (Nchanji, 2016).

Figure 7.2.1. Examples of oil palm integrated with watermelon intercrop and with grazing cattle

There are also studies that indicate that in integrated systems nutrient use efficiency increases leading to lower spill over to the environment. For instance, nutrients from weeds that end up in animal manure will be readily available to the oil palm crop (Ruiz Alvarez et al, 2024). Corley (2009) reported that available nutrients from the felled oil palm trunk at replanting were found to exceed the required amount of nutrients

[7] https://www.unep.org/explore-topics/chemicals-waste/what-we-do/emerging-issues/highly-hazardous-pesticides-hhps

needed for the first-year growth of newly planted palms. An intercrop may capture the excess nutrients from the decomposing trunks, thereby preventing run-off to adjacent water bodies or leaching to deeper layers. However, intercrops may also need fertilizer and pesticides depending on the chosen crops and the level of management. On a per ha basis the load of inputs may then increase but when compared to equivalent monoculture fields the load per kg product or per litre palm oil may then decrease.

8 Livelihood

8.1 Contribution to food security (SDG 2)

Fats contain essential fatty acids and fat-soluble vitamins which the human body cannot produce therefore fats are indispensable in human diets. Compared to protein and starch (4 calory/g) fats are energy dense (9 calory/g) which means that relative low amounts of fat provide considerable amounts of energy. According to recommendations by WHO fats should contribute between 20 and 35% to the energy in our diet. Taking the mid-value of 27.5 % as a target, Bajželj et al (2021) assessed whether these contributions are realised in different regions of the world. The fat intake of the regions North, East, South, Middle and West Africa, Caribbean, and South and Southeast Asia does hardly reach 20%, showing a "fat gap" compared to the target of 27.5 %. In 2018, the world fat gap is estimated at about 45 million tons per year. Can we count on palm oil, soybean oil or rapeseed oil to close this "fat gap"?

8.1.1 Vegetable oil contribution to dietary energy supply globally

Currently vegetable oils are responsible for ca. 1/3 of fat provided energy hence 10% of dietary energy (Bajželj et al, 2021). While production of palm oil is largest, soybean oil provides most oil for human consumption (Table 8.1.1.1).

Table 8.1.1.1. Global production of vegetable oils and their contribution to total vegetable oils consumption.

2020/2021	production (million ton)	used for food (million ton)
Palm oil	73.1	20
Soybean oil	59.2	25.2
Rapeseed oil	29.1	9.4
Palm kernel oil	8.4	1.4
Other	36.7	17.1

Source: Food and Agricultural Organisation (FAO)

Over time palm oil production and its use has increased drastically and is still growing because palm oil is cheap and is high yielding. Soybean oil production has increased because of increased demand for soybean cake as pork and chicken feed. In 2022/2023 palm oil still had the highest volume of production, at 79.4 million ton, against 59.2 million ton for soybean oil.

For oil palm, substantial yield increases are still possible. In Indonesia alone, average yield gaps are up to 3 t CPO/ha (Monzon et al, 2021). In Indonesia, closing this yield gap through increased yield per ha would provide 20-million-ton additional crude palm oil on existing area by 2035, potentially closing 44% of the current "fat gap". For soybeans, oil yields per ha are smaller than for oil palm and while there is potential to increase yields the absolute additional oil production would be much smaller. Hence many more hectares will be needed to generate the same amount of oil. Furthermore, soybean production is not (only) driven by demand for oil but by demand for soybean cake as animal feed. On the other hand, when an increase in soybean oil occurs it will be associated with an increase in pork and chicken fat which can also contribute to closing the fat gap. For rapeseed oil the production per ha is also much smaller than for palm. There is limited possibility to increasing absolute rapeseed oil yield per ha and increase in hectares will be constraint by the need to cultivate rapeseed in rotation to control pests and diseases.

8.1.2 Contribution to food security of consumers and producers: prices and revenues

Using the prices of 2020 the revenues per harvested area (ha) have been calculated for the four different oil palm systems in Indonesia, the average soybean system in Brazil and rapeseed system in Germany. The average outcomes can be found in Table (8.1.2.1). Details can be found in the annex.

Table 8.1.2.1. Revenues (USD) per ha for oil palm, soybean and rapeseed oils and meals in 2020.

Crop	Oil Palm	Oil Palm	Oil Palm	Soybean	Rapeseed
	Large plantations	Smallholders	Average*	Average	Average
Crude oil	4936	3886	4516	770	2212
Meal	53	42	48,6	1120	773
Kernel oil	782	615	715		
Total	5771	4543	5280	1890	2985
Corrected**	4732	3733	4332	2107	2892
PPP***	2.69	2.69	2.69	2.21	1.42

Revenues in USD against prices in 2020

* weighed averages based on 40% smallholders, 60% large plantations

** corrected by including land use for multiple cropping, fallow, seed production, and long land preparation of peat land

***Purchasing Power Parity calculated using the International Comparison Program, World Bank | World Development Indicators database, World Bank | Eurostat-OECD PPP Programme.

For oil palm, the correction factor to compare harvested area with effectively used area is considering the number of years the plantation is not yet producing and the length of one full cycle before replanting. This factor differs per system. For details look at the section on oil palm. For soybean the correction factor depends amongst others on whether other crops are cultivated on the same land in the same year. Then soybean occupies the land only part of the year thus the yield and revenue per actually used area of land is higher than for harvested area. For details on the correction factor look at the section on soybean and rapeseed.

Large industrial plantations generate more revenue per ha than smallholder plantations, and when applying the correction factor, mineral soils generate more revenue than peat soils: 4847 vs 4617 for industrial plantations and 3833 vs 3634 USD/ha for smallholders.

The yield of soybean meal is higher than of soybean oil and despite the lower meal price the revenue of the meal per ha is also higher. The yield of rapeseed meal is also higher than of rapeseed oil, but at a much lower price per ton the revenue of meal per ha is lower than for oil.

Palm oil (CPO) has the lowest price per ton compared to soybean oil (CSO) and rapeseed oil (CRO) is the most expensive. For consumers palm oil is hence the most affordable, which partly explains why it is so popular as cooking oil for the people with ow income but also why it is widely used as substitute for other fats and oils in multiple products.

On the other hand, oil palm cultivation has the highest revenue per ha, with soybean last after rapeseed. This makes oil palm the most profitable and hence attractive crop for producers. Its contribution to income increases purchasing power to buy items for a nutritious diet. In 2020 minimum wages were 2060, 2432 and 21163 USD/yr for Indonesia, Brazil, and Germany, respectively. For Indonesia oil palm revenues per ha were 1.8 to 2.4 times higher than minimum wage in the four systems whereas they are less to about equal for soybean and almost insignificant for Germany. Another way to express the importance of earning USD in societies with different costs of living is the Purchasing Power Parity (PPP) calculations which show that for each US dollar the purchasing power in Indonesia, Brazil and Germany is 2.69, 2.21 and 1.42 higher than in the USA. Of course, revenues at farm level will be lower than world market prices and need to be reduced by costs to give net income at farm level. The numbers indicate that oil palm revenues per ha are proportionally more important in Indonesia than soybean revenues in Brazil and rapeseed revenues in Germany.

Monthly prices of all vegetable oils were compared for about 15 years (2003-2018) in Table 8.1.2.2.

Table 8.1.2.2. Global monthly vegetable oil prices January 2003 to March 2018 (USD per t).

	Palm oil	Soybean oil	Rapeseed oil
Mean	730	880	930
Median	716	837	853
Max	1292	1537	1577
Min	395	497	552
SD	232	259	248

Source: IMF and UNCTAD (2020) in Abdul Hafizh Mohd Azam et al. 2020

Palm oil came always out the cheapest, in minimum, maximum and mean price. Palm oil was the cheapest every month followed by soybean, with rapeseed the most expensive (Abdul Hafizh Mohd Azam et al. 2020). The conclusion for 2020 represents thus a pattern that was also present in the past.

Worldwide palm oil is thus the cheapest cooking oil for consumers. While soybean contributes globally most to dietary fat, palm oil contributes most to fat supply in the regions with the highest “fat gap” showing its relative importance to food security for those that are food insecure (Bajželj et al, 2021). Palm oil will therefore also likely play a key role in closing the “fat gap” in the future. Furthermore, because of its low price, palm oil progressively substitutes other vegetable oils. In Indonesia palm oil gradually replaced coconut oil as cooking oil, from 20% of the consumption in 1980 to 52 % in 2000 and to 97% in 2020 (Source: Ministry of Agriculture, BPS).

8.1.3 Contribution to local food and nutrition security

Does oil palm adoption also contribute to local food security? In Indonesia, where oil palm replaced rubber, it contributed to better nutrition of households, because of higher household income. This income increased because return to labor for oil palm was much higher than in rubber allowing a family to cultivate more ha or to have other income generating activities alongside. Jelsma et al. (2009) reported on positive effects on quantity and quality of diets and on reducing stunting of children. Euler et al (2017) showed significant positive impacts of oil palm adoption on food (+14%) and non-food (+37%) expenditures, as well as on calorie consumption (+13%) and dietary quality (+22% calorie intake of higher nutritious foods). Shibatu et al (2019) showed that on average, the adoption of oil palm increased the probability of consuming fruits and vegetables by 33.6%, calorie adequacy by 38.6%, iron adequacy by 36.4%, zinc adequacy by 54.9%, vitamin A adequacy by 33.1%, and adequacy of the three micronutrients by 35%. The nutritional outcomes for farm households shifting from one plantation crop to another are hence positive. Shifting from commercial rice cultivation to oil palm has shown similar labor-saving and income effects (Feinterie et al, 2010; Mehraban et al, 2022), but nutritional effects have not been investigated. Findings from more heavily forested communities in Papua and Kalimantan, where traditional subsistence-based livelihoods are still widely practiced, have shown more mixed and nuanced effects of oil palm adoption upon dietary intake and nutrition (Purwestri et al., 2019; Santika et al 2019). Oil palm adoption has been positive for income and diets of communities with farmers that were already engaged in agricultural production for the market but less so for more subsistence-oriented households (Santika, et al, 2019). For soybean and rapeseed no data were found. However, as rapeseed fitted in existing rotations of farmers already producing for the market and buying all their food, no changes are expected. For soybeans, its contribution to unemployment due to mechanization may have had negative effects on food and nutritional security of those that lost their jobs.

8.2 Importance for rural employment (SDG 8, 2, 5)

8.2.1 Methods

Data on the amount of land used for oil crops per farm was collected from the national census. In this section we call this area “farm” although this is not entirely correct. Rapeseed is cultivated in rotation and only part of the land of a farm will therefore be allocated to rapeseed, while the smaller soybean farms are less specialized and therefore cultivate other crops next to soybean. We also compared two census data for soybean (2006 and 2017) to show development over time. Literature review was used to look at inclusivity of employment.

8.2.2 Smallholder employment and mechanisation

Average soybean “farms” with 130 ha oil crop/farm are larger than rapeseed and oil palm farms with 25.8 and 5.7 ha/farm respectively, including smallholders and large plantations (Figure 8.2.2.1.). Both soybean and rapeseed cultivation are mechanized which may explain their larger sizes than the non-mechanized palm areas. Soybean can be cultivated year after year on the same field, but rapeseed must be cultivated in rotation partly explaining the lower farm sizes for rapeseed. For oil palm and rapeseed about 99 and 89% of the farms are smaller than 50 ha and for each crop they only contain about 40% of the area.

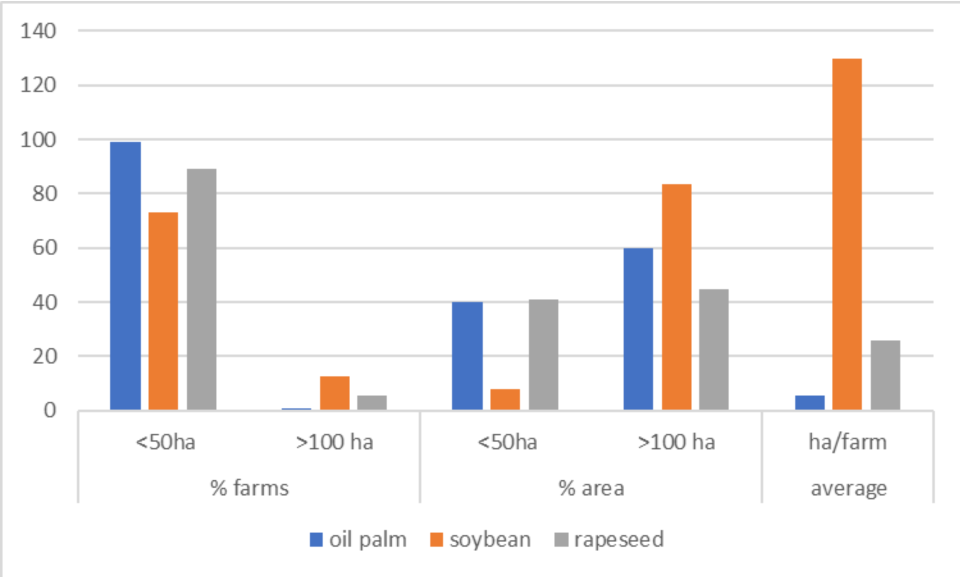

Figure 8.2.2.1. ***Percentage of farms and area per farm size class and average area per farm for oil palm, soybean and rapeseed***

8.2.3 Labour productivity

Labour productivity was calculated as l of oil per full time equivalent labour unit (FTE) see Table 8.2.2.1.

Table 8.2.3.1. ***Land and labour productivity data palm oil (Indonesia), soybean (Brasil), rapeseed (Germany).***

Crop	oil palm*	oil palm*	soybean**	soybean**	soybean**	rapeseed***
System	smallholder	large plant.	smallholder	large plant.	average	average
ha oil crop/ farm	<50	average 4000	<50	>2000	130	25
yield/ha (kg)	15.3	19.7	3,349	3,068	3,200	3,500
oil/ha (l)	3,060	4,728	603	552	576	1,400
FTE/ha	0.51	0.36	0.0735	0.0101	0.0294	0.0057
ha/FTE	1.96	2.78	13.6	99.4	34	175
l oil/FTE	6,000	13,133	8,198	54,893	19,584	245,000
FTE/t oil	0.1667	0.0761	0.1220	0.0182	0.0511	0.0041

Yields, Monzon et al (2021); labour, Ngadi (2013) confirmed by Badirsono (2012); OER 20% for smallholders and 24% for large plantations; 1 FTE =1750 h; Bicudo de Silva et al 2020;*** Data from BML Germany: Labour of 10 hour/ha; 1 FTE = 1750 h

Despite highest oil yields per ha for oil palm (4728 l/ha), labour productivity in terms of oil yields per FTE (6000l/FTE) is amongst the lowest. Largest oil yields/FTE were reached for highly mechanised soybean and rapeseed fields with up to 55 and 245 t/FTE respectively. This confirms that the oil pam sector provides most labour per l of oil.

8.2.4 Inclusivity of employment opportunities (SDG 2 & 5)

Landless

In Indonesia expansion of oil palm has replaced subsistence farming and traditional gathering from forests but created many jobs. Smallholders massively replaced their rubber cultivation on their farms because oil palm required much less labor. Some also rendered their land to a company to become "plasma” farmers, benefiting from technical assistance, improved seeds, and credit till the palms start bearing fruit. The transmigration program allowed landless people to formally access land and become oil palm farmers. Larger plantations also attracted many spontaneous migrants as laborers from the whole archipelago and especially from areas where wages were low, or job opportunities were absent. When oil palm smallholders became more affluent, they also started hiring labor or bringing in family members from other locations. In addition, land sharing is practiced with landless crop farmers cultivating crops in oil palm plantations the first three years after oil palm establishment. Similarly landless livestock keepers graze cattle in plantations older than 6 years after planting.

In Brazil, soybean expansion did not create smallholder soybean fields but rather replaced traditional smallholder agriculture without creating additional jobs. The export-oriented development of the sector with mechanization in large fields made it difficult for smallholders to compete. Such fields also replaced natural areas and their inhabitants (indigenous people) at the frontiers with the Amazon. All these plantations had low labor demand adding to the already high unemployment rates and stimulating migration of the rural poor to the cities. Currently soybean expansion is often taking place on low quality soils which means that high yields per ha are not immediately possible and even larger areas need to be cultivated to benefit from economies of scale. Over time the total area has increased much faster than the number of farms and farmers.

In Germany, rapeseed first occupied abandoned (set-aside) lands and as such created an increase in area under agriculture. Yet as rotational crop, rapeseed did not increase the number of farms and given its mechanization degree it also did not increase labour demand compared to other crops.

Gender

Gendered effects can be expected, as oil palm requires less labor than alternative crops, and the resulting labor savings may influence male and female household members differently (Chrisendo et al. 2020). Mehraban et al (2022) examined in Sumatra how oil palm cultivation – in comparison to cultivating traditional crops – is associated with women’s and men’s time allocation and decision-making power. Women in oil palm cultivating households spend much less time in farming and more time for household chores and leisure than women in households only cultivating traditional crops. These differences increase with the share of the farm area under oil palm, as oil palm requires less labor than traditional crops. This reduction in women’s workload can have positive social effects. However, the study also suggests that oil palm cultivation is associated with women having less decision-making power in terms of farm management and income control. Especially as land titles for oil palm fields have been handed out to heads of households which were mostly men (Villamor et al. 2015). Furthermore, women can be included to work in oil palm plantations, but often against lower wages than men.

8.3 Contribution to welfare (SDG 1, 2, 3,4)

For livelihood of smallholders, it is important how profitable a crop is per ha and per labour unit. How many ha's a family needs and can cultivate to earn at least a minimum wage.

8.3.1 Methods

We combine average global oil price, with oil production averages per ha and average minimum wage data. As oil prices were averaged between 2003 and 2018, minimum wage was averaged over the same period. Unfortunately, Germany only knows national minimum wage till 2015. Therefore, we also compare to average minimum wage for period 2015-2018. We ignored the fact that farm gate prices are different from world market prices, that farmers in Germany get subsidies, and that farmers need to make costs. The calculations are meant to give an impression of the relative scope of the respective oil crops for smallholders to gain a minimum wage.

8.3.2 Results and discussion

Palm oil has lowest price in the world market but highest yield per ha. Therefore, it is still the most interesting crop for smallholders, having few ha's each. Based on average oil yields per ha, smallholders need less than half a ha to gain a minimum wage in Indonesia while 5-7 ha are needed for soybean in Brazil and even 15 ha for rapeseed in Germany (see Table 8.3.2.1)

Table 8.3.2.1. Oil revenues compared to minimum wages in Indonesia, Brazil and Germany.

Crop	Palm oil	Soybean oil	Rapeseed oil
Mean Price 2003-2018 (USD/t)	730	880	930
Yield (t/ha) 2020	3.3	0.6	1.4
Revenue (USD/ha)	2409	528	1302
MW 2003-2018 (USD/y)	1027	2794	NA
MW 2015-2018 (USD/y)	1132	3533	20,041
ha needed to gain MW (2003-2018)	0.43	5.29	NA
ha needed to gain MW (2015-2018)	0.47	6.69	15.39

MW = minimum wage Oil prices average 2003-2018

While farmers do not receive the world market prices at the farm gate and they also need to make costs, it is quite clear from the Table 8.3.2.1. that in the oil palm sector in Indonesia there is much more room for the small landholders to earn a minimum wage than in the other sectors in the other countries. Many papers in Indonesia mention that wage labour in oil palm plantations but also income from smallholders with 2 ha oil palm, allow earning more than minimum wage. Budidarsono et al (2012) showed that even when return to labour is averaged over the entire plantation life including the first non-productive years, average return to labour equalled 2 to 7 times minimum wage, with best results for plasma smallholders.

8.4 Conclusions

The contribution of soybean oil to global food security is more important than that of the other vegetable oils in terms of traded volume. However, palm oil is cheaper and therefore important as cooking oil for people with low income. In countries with fat gaps most fat is provided by palm oil. Closing oil palm yield gaps by similar yield increase percentages as for soybean or rapeseed will yield more oil from palm in absolute terms as its oil yields per ha are much larger. Together with the lower price this makes palm oil the most important vegetable oil for closing the “fat gap” in regions that suffer most from food insecurity.

The higher revenues per ha for oil palm, particularly compared to the much lower local minimum wages in Indonesia, makes it a more important contributor to farmers income than soybean and rapeseed oils in Brazil and Germany, where revenues per ha are lower and compared to higher minimum wages. The purchasing power parity shows that for each USD earned the purchasing power is 2.69, 2.21 and 1.42 times higher for Indonesia, Brazil and Germany respectively. Therefore, palm oil cultivation proportionally contributes most to income allowing purchasing items for a nutritious diet.

Locally, in Indonesia, the adoption of oil palm cultivation by market-oriented farm households has led to positive nutritional outcomes via higher incomes, but the picture is mixed for heavily forested communities adopting oil palm cultivation. For soybean and rapeseed no data are available.

Oil palm expansion has created a large smallholder oil palm sector plus millions of agricultural jobs in larger plantations, for landless, for men and for women. From all vegetable oil sectors, the highest percentage of farms with small oil cropping areas can be found in the oil palm sector. The soybean sector is slowly transforming from a smallholder sector into a highly mechanized sector with only few farm labourers, contributing to unemployment rates which are already high in Brazil. Rapeseed has not changed much in the rural area of Germany as it is a crop that could be included in rotations of mechanized existing farms. The crop does not need migrant labour as there is hardly any manual work. The absolute numbers of farmers with small vegetable oil crop areas of 2.6 million in oil palm in Indonesia, 171.6 thousand in soybean in Brazil and 32.8 thousand in rapeseed in Germany, emphasizes the importance of oil sector for rural employment in the respective countries. All rapeseed fields and the larger soybean fields are mechanized, but larger oil palm areas are not. Oil palm labour productivity is therefore much lower than for the other crops. However, for any equal area cultivated, oil palm will contribute more to employment and livelihood of smaller producers than soybean or rapeseed.

The oil palm sector allows smallholders to earn more than a minimum wage with very few ha because return to ha is high. Furthermore, smallholders' family labour can easily manage 2 ha. For the other oil crops more ha are needed, and this is only possible with mechanisation.

9 Economics

In this section we discuss SDGs in terms of vegetable oil crops' contributions to national economies, in particular through their contribution to export and GDP and to renewable energy. For renewable energy we look at the contribution of the oils to biodiesel production, biodiesel consumption and export for the three vegetable-oil-producing countries. Finally, we discuss how attractive investment in vegetable oils is for investors that aim to have positive impact and for investors that go for lowest financial risk. We assess to what extent voluntary sustainable standards (VSS) address their concerns and we compare to which extend principles of RSPO and RTRS contribute to the SDGs.

9.1 Contribution of oil crops to the national economies

To assess the importance of the different oils to the national economies different indicators can be used. We selected export value of the oil crops, oil and oil cake and their relative contribution to export and to GDP.

9.1.1 Methods

The OEC (2023) provides trade data which were used to derive the export values for 2021. The WB (2023) derived GNP data. From WDI (2023) we derived contribution of the sector agriculture, forestry, and fishery to GDP.

9.1.2 Results & Discussion

From Table 9.1.2.1 we derive that the contribution of the export to national GDP varies from 20.9% for Indonesia, and 17.4% for Brazil to 37.4 % for Germany in 2021. Palm oil is the oil that has highest export value with 27.3 billion USD, compared to only 2.06 and 1.77 billion USD for the oils of soybean and rapeseed. On the other hand, soybean is the vegetable oil crop that adds most value to export but rather as beans with 39 and as cake with 7.5 and not as oil with only 2.06 billion USD.
The vegetable oils exports are responsible for 11% of the export value for Indonesia but only 0.71 % for Brazil and 0.11 % for Germany. Palm oil export value contributes the most to national GDP with 2.3%, compared to soybean oil with 0.71% and rapeseed oil with only 0.04%.

Table 9.1.2.1. Values and % contribution of oil crops products to export and GDP 2021. PKO=palm kernel oil.

2021	Value		Oilseed	Oil	PKO	Cake
Indonesia	* 10^9 USD	Export value	NA	27.30	1.30	1.05
GDP (1000 *)	1186	% of GDP	NA	2.30	0.11	0.09
Export	248	% of export	NA	11.00	0.52	0.42
Brazil	* 10^9 USD	Export value	39.00	2.06	NA	7.5
GDP (1000 *)	1649	% of GDP	2.37	0.12	NA	0.45
Export	288	% of export	13.50	0.71	NA	2.60
Germany	* 10^9 USD	Export value	0.20	1.77	NA	0.65
GDP (1000 *)	4278	% of GDP	0.005	0.04	NA	0.02
Export	1600	% of export	0.01	0.11	NA	0.04

* oils include crude oils, simple refined oil derivates without chemical modification, oil fractions
For export values: OEC (2023). For GDP: WB (2023)

To put 2021 in a longer-term perspective we compared 2021 with 5-year and 10-year averages. The pattern remains the same. The total export value of products from the soybean sector was consistently larger than of the oil palm products, because of the export of the soybeans and to a lesser extend of the soybean cake. The rapeseed sector export average value grew slowly from 1.05 (10 years average) to 1.1 (5 years average) to 2.6 billion USD (2021) and remained of low importance to its producing country, with less than 0.1 % of its export value. The palm oil export value was always highest of the three oils and its contribution to export increased from 18.32 (10 years average) to 19.36 (5 years average) to 27.3 billion USD (2021) representing 9.43, 9.67 and 11% of total export, respectively.

The contribution of the sector agriculture, forestry and fisheries to the national GDP was 13% for Indonesia, 7 % for Brazil and 1 % for Germany (2021) showing that Germanies economy is more industrialised than Indonesia and Brazil. Palm oil, soybean oil and rapeseed oil are responsible for 17%, 1.7% and 0.04 % of this sector's contribution to GDP, respectively. This shows that palm oil is responsible for the largest share of the sectors contribution to the GNP.

9.2 Vegetable oil destination

Apart from crude oil exports, vegetable oils have also been transformed to biodiesel and not only been exported but also been domestically used. Over time both palm oil and soybean oil have increasingly been used as feedstock for the domestic demand for biodiesel, largely because of government set blending targets. In Germany both domestic consumption and export of rapeseed oil-based biodiesel has been the result of EU biofuel policy with its blending mandates.

9.2.1 Methods

We used data from (USDA/GAIN, 2021) reports for palm oil and soybean and FNR (2023) and VDB website for rapeseed.

9.2.2 Results and discussion

The following Figures (9.2.2.1, 9.2.2.2, 9.2.2.3) show biodiesel production, export, consumption, and feedstock being palm oil in Indonesia, soybean oil in Brazil and rapeseed oil in Germany.

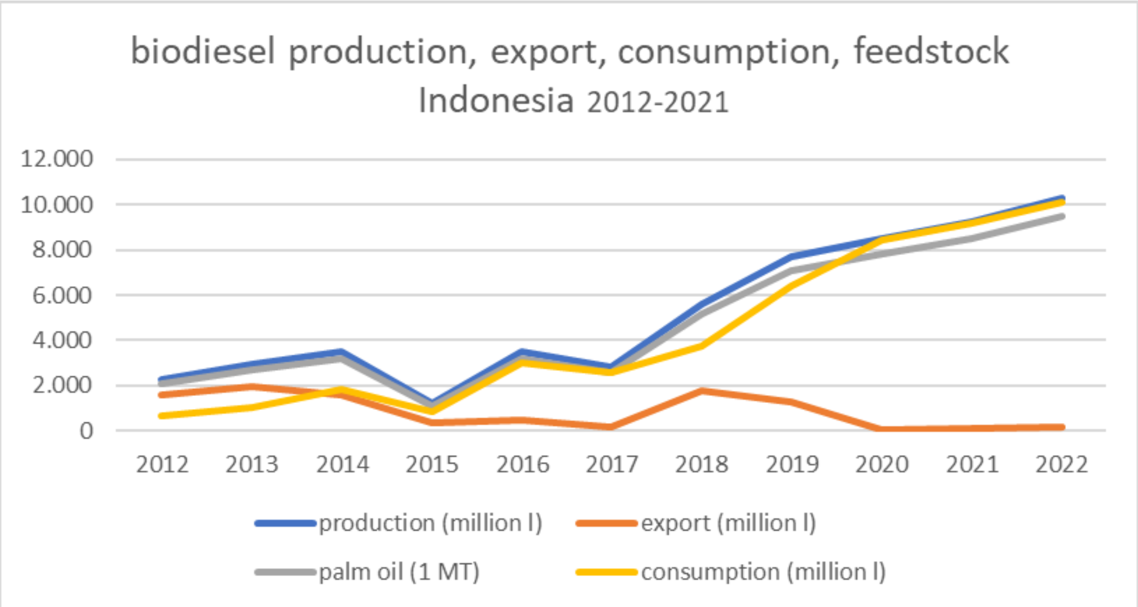

Figure 9.2.2.1. ***Biodiesel production, consumption, export, and feedstock in Indonesia (USDA/GAIN, 2021); 1MT = 1 million ton***

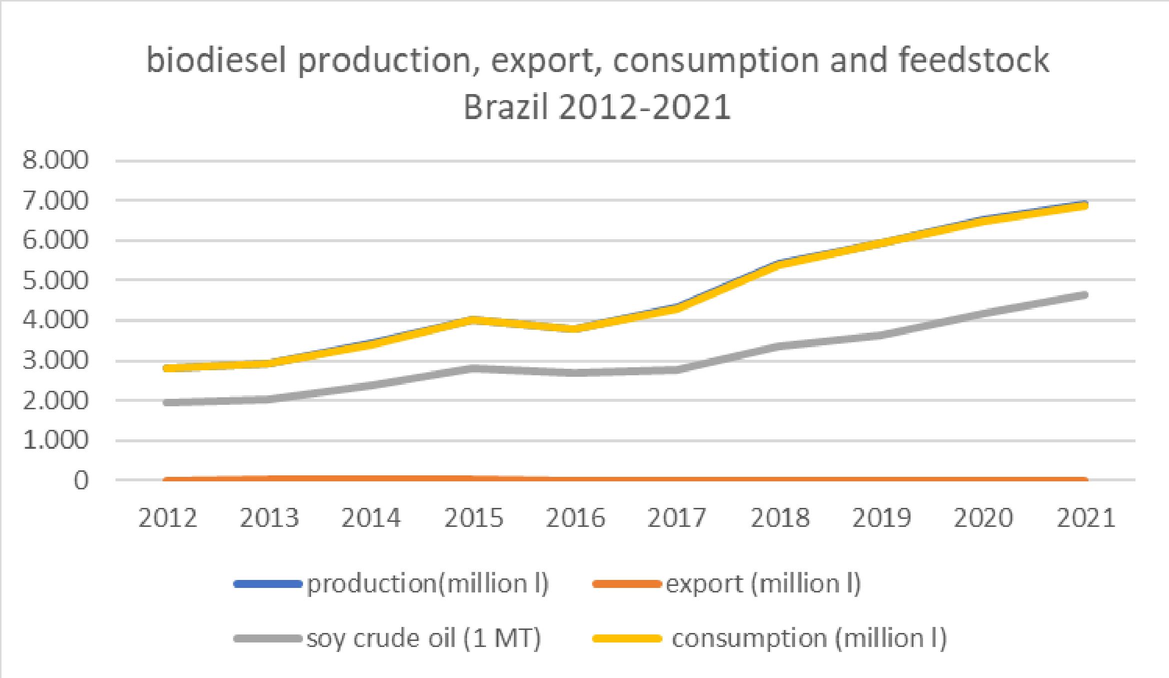

Figure 9.2.2.2. ***Biodiesel production, consumption, export, and feedstock in Brazil (USDA/GAIN, 2021). Consumption and production volumes are equal (same line). 1 ton of crude soybean oil = 1,113 liters of biodiesel; 1 ton of biodiesel = 1,136 liters of biodiesel 1MT = 1 million ton***

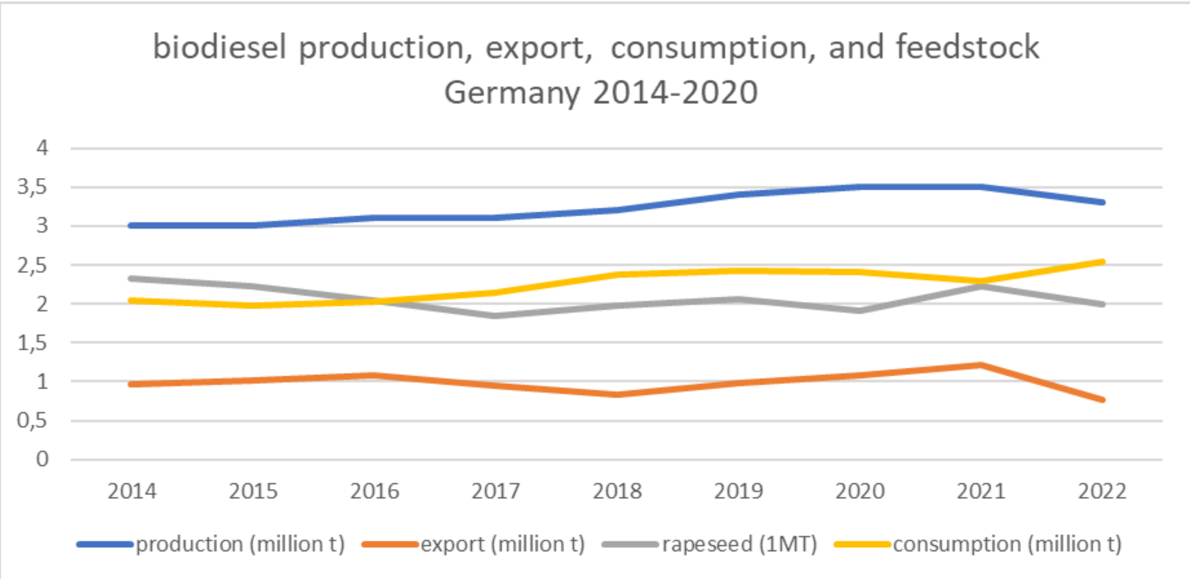

Figure 9.2.2.3. ***Biodiesel production, consumption, export and feedstock in Germany (https://biokraftstoffverband.de/biokraftstoffe/marktdaten) 1MT = 1 million ton***

In Indonesia production and consumption are currently in balance while before 2020 some biodiesel was exported. Only palm oil is used as feedstock. In Brazil production and consumption were in balance hence only one line is visible, and export of biodiesel was close to zero. About 75 percent of biodiesel produced is made from soybean oil and 6.5 percent is made from animal fat (tallow). In addition, 12 percent of the production is generated from other fatty materials. The remaining feedstock is palm oil (2 percent), cooking oil (1.4 percent), cottonseed oil (1.7 percent) and others. In Germany biodiesel Production (3-3.5 million t) is much large than domestic consumption (2-2.5 million t) hence around 1 million t is exported. Apart from rapeseed oil feedstock also consists of imported palm oil and soybean oil and local waste oils 1.2%, 11% and 26% respectively in 2022.

9.3 Investments and SDGs

One important aspect of economics is investments and how these are linked to SDGs in the three broader sustainability dimensions. In the economic dimension we distinguish six criteria for business environment and three for governance (transparency, corruption/bribery, legal compliance) aligning with SDG 16 (justice and accountability). In the social dimension we distinguish four criteria for working conditions and four for local community development, which were addressing SDG 5 (gender) and SDG 8 (labour). In the environmental dimension we distinguish two on climate change (SDG 13), three on pollution prevention (SDG6), one on biodiversity and three on preservation of other natural resources aligning with SDG15.

9.3.1 Methods

Voora et al. (2022) considers Voluntary Sustainable Standards (VSS) as primary risk mitigators of reputational management, access to capital and associate services, security of supply, improved compliance with legislation, efficiency, and productivity. Their review presents a detailed benchmarking among 13 VSS, and the perception by 51 financial service providers (FSP) with regards the importance of a suite of aspects covered by the VSS to reduce investment risks and/or promote sustainable development impact. From this report we identified criteria that two types of investors (impact investors versus lowest risk investors) appreciate when choosing to invest in commodities. We compared these preferences with criteria covered by voluntary certification schemes that are both recognized by ITC standards map (2021), explicitly include our target crops oil palm, soybean, and rapeseed, and are amongst the ones scored in Voora et al. (Chapter 3 Benchmarking) 2022. The selected certification schemes per crops are presented in Figure 9.3.1.1

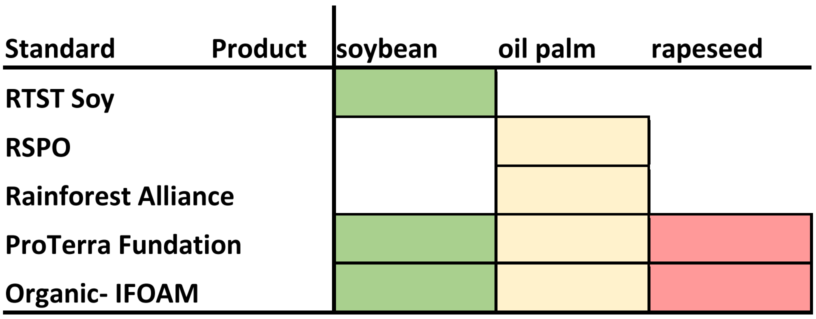

Figure 9.3.1.1. Selected Voluntary Sustainable Standards (VSS) per crop.

The percentages in all the figures in the result section show to what extent the scores for the criteria of voluntary certification schemes address requirements or concerns of two types of investors.

9.3.2 Results and discussion

The Figures below (9.3.2.1; 9.3.2.2: 9.3.2.3) provide a comparison between the three commodities on criteria addressed in voluntary certification schemes in the social, economic, and environmental sustainability dimensions and the extent to which they meet the requirements by two types of investors. The percentage is the percentage of the total scored criteria per category covered by the commodity.

We see that in the social and environmental dimensions investors that aim to enable impact (blue lines) have higher requirements than investors aiming for lower financial risk (red lines) for all criteria, but the opposite is true in the economic dimension where investors aiming for low financial risk have higher requirements.
To exclude selection bias, we did a similar exercise with fair trade (not available for all crops) and global gap (not scored by Voora et al., 2022) but even than the gap between economic investor concerns and economic criteria coverage remains, therefore the results are not biased by the choice of certification schemes.

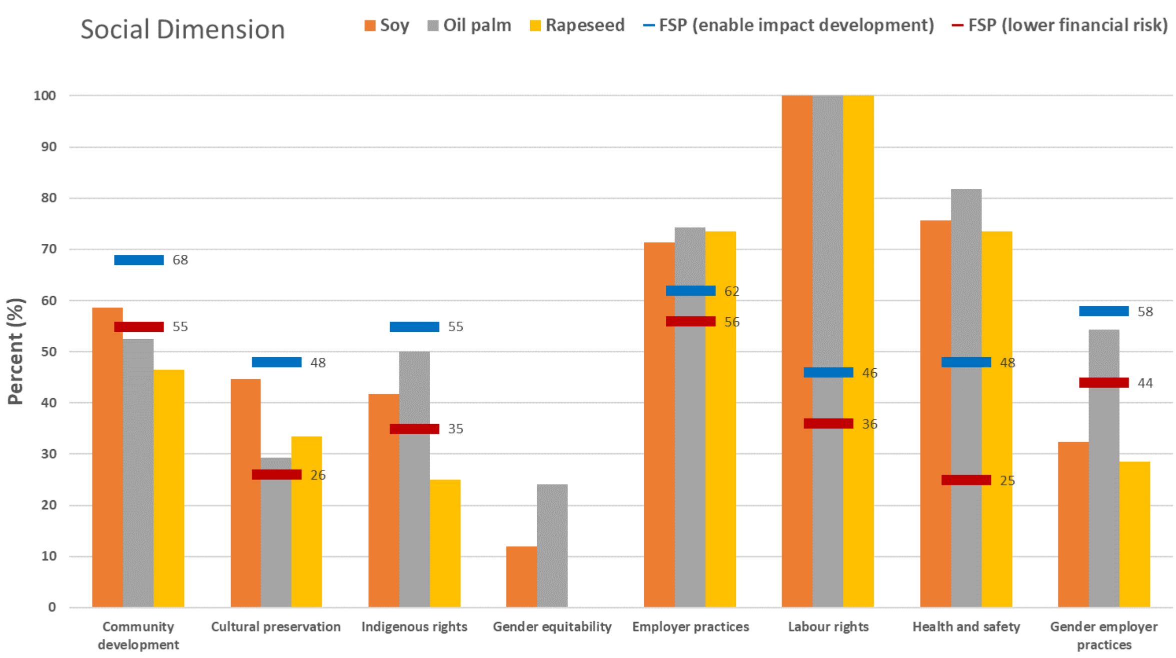

Figure 9.3.2.1. ***Social requirements of two types of investors as covered by criteria of certification schemes for three crops.***

In the social dimension we see that in employer practices, labour rights, health and safety all investors' criteria are satisfied in all crops. For indigenous rights and gender employer practices, impact investors are not fully satisfied but oil palm is doing better than the two other crops. For community development and cultural preservation, impact investors are also not satisfied but soybean is doing better than the other crops. Oil palm is doing best or equal to soybean in 6 of the categories and soybean doing best in two.

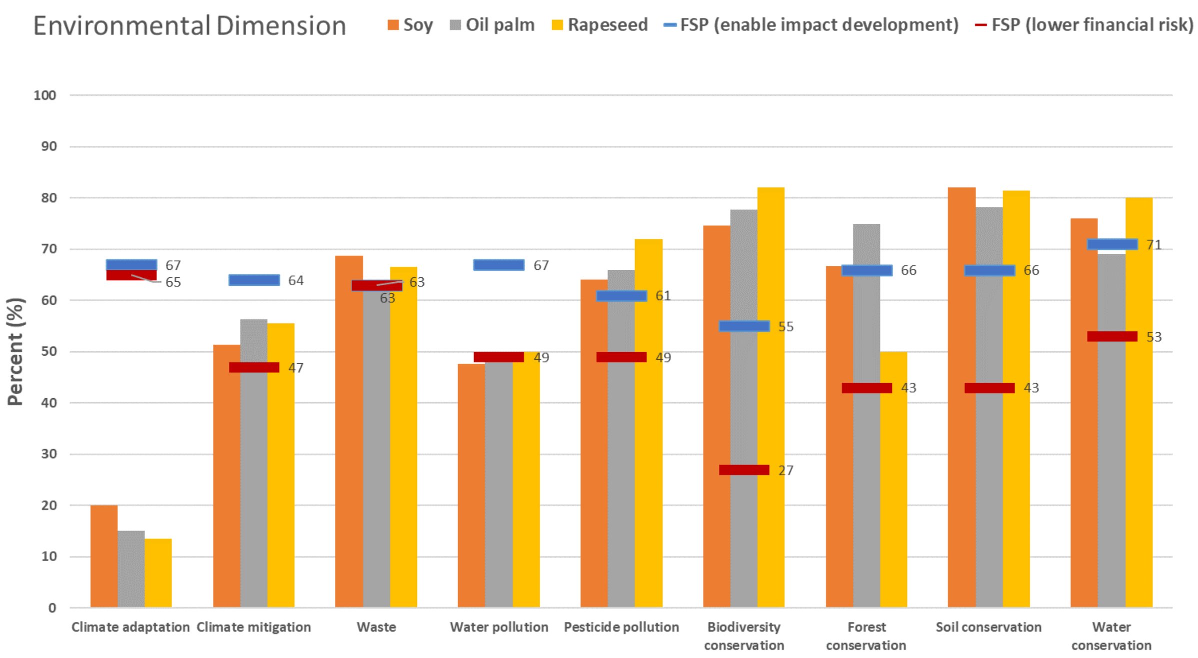

Figure 9.3.2.2. ***Environmental requirements of two types of investors as covered by criteria of certification schemes for three crops***

In the environmental dimension five categories score high enough for both impact investors and low-risk investors. For climate mitigation and water pollution the concerns of low-cost investors are covered but those for impact investors are not sufficiently considered, for none of the crops. For climate change adaptation there is a huge gap between VSS criteria and investors' concerns for all crops. Forest conservation is covered sufficiently for both type of investors for soybean and oil palm, but not for rapeseed.

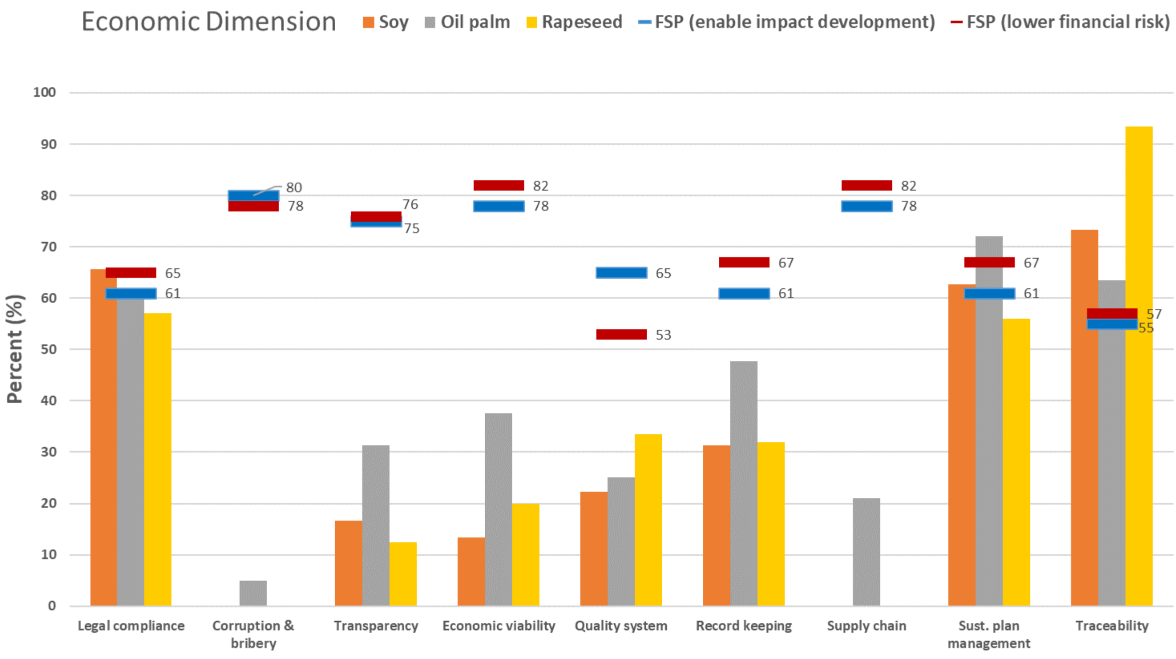

Figure 9.3.2.3. Economic requirements of two types of investors as covered by criteria of certification schemes for three crops.

For the economic dimension, most VSS criteria do not meet the concerns of either type of investor for any of the crops, but in 5 out of 6 categories oil palm is doing better than the other crops. Traceability criteria seem to satisfy both investor types for all crops. Legal compliance and sustainable management plan in place are insufficient for both investor types for rapeseed. They are good enough though for impact investors in both oil palm and soybean and additionally good enough for low-risk investors in soybean for legal compliance or oil palm for management plan.

9.4 International Certification schemes and SDGs

9.4.1 Methods

Certification schemes aiming for sustainability can be assumed to target the SDGs. Both Round Table for Sustainable Oil Palm (RSPO) and Round Table for Responsible Soy (RTRS) certification schemes have been assessed on their potential contribution to the SDGs. We combined the results of these assessments in one figure below.

9.4.2 Results and discussion

Neither of the certification schemes claims to contribute to SDG 14 (life below water) or 19 (partnership for the goals). The schemes also differ in emphasis. While RSPO has gender equality as the most cross cutting theme, featuring in most principles, RTRS has community as the most cross cutting theme. RSPO also puts more emphasis on the SDG industry, innovation, and infrastructure than RTRS, while the latter emphasizes the SDG reduced inequalities.

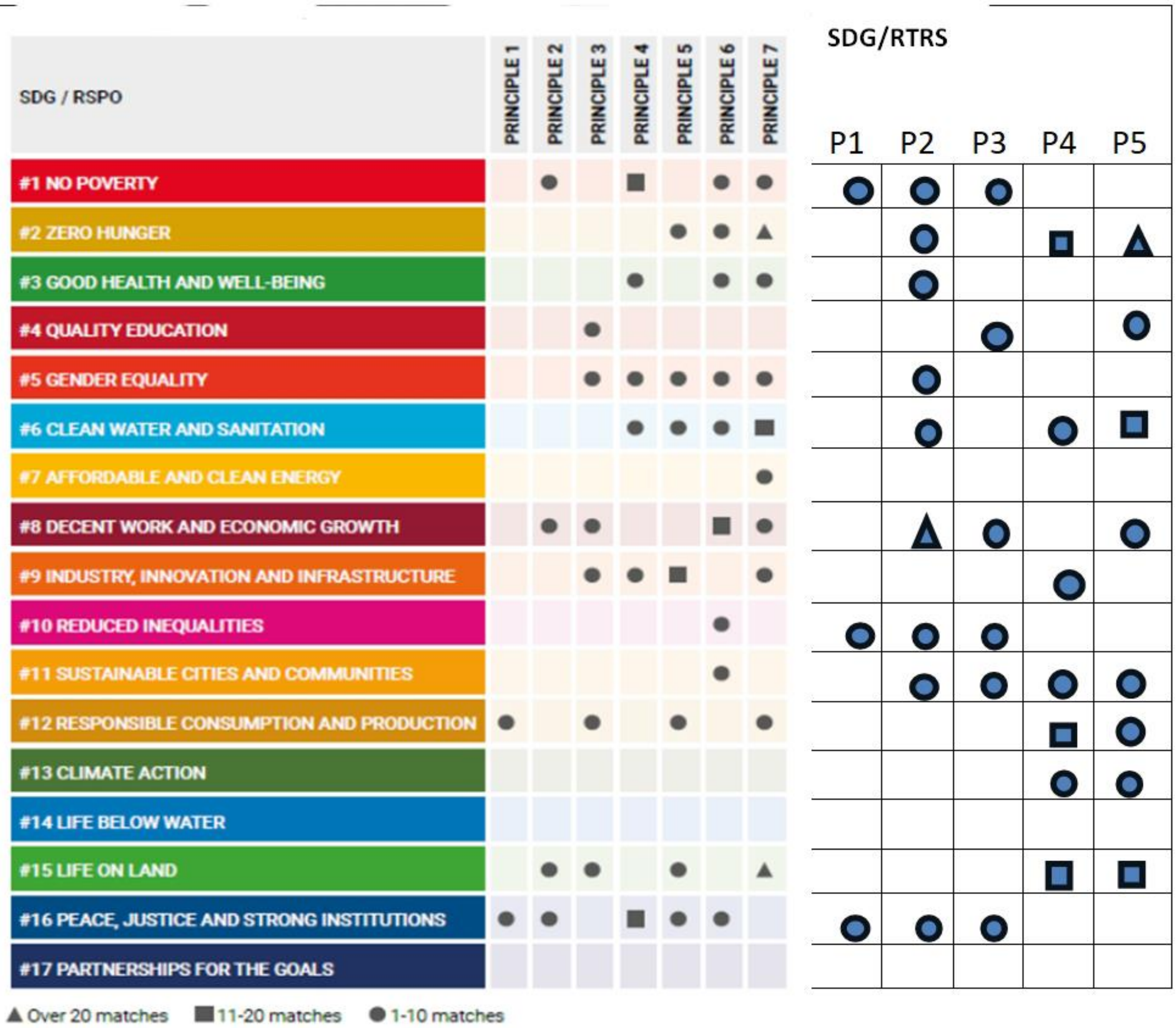

Figure 9.4.2.1. ***Overview of the extent to which the principles of RSPO and RTRS contribute to the SDGs. Source: https://responsiblesoy.org/rtrs-makes-important-contributions-to-the-sdgs?lang=en. Source: K. Jespersen, Copenhagen Business School.***

According to the Figure 9.4.2.1, RTRS does not aim to contribute to affordable and clean energy. This suggests that efficient use of fossil fuels in field operations and in the factories are not amongst the priorities. In Brazil soybean oil is currently used for biodiesel and although not all countries producing soybean may make biodiesel, it would potentially contribute to clean energy.
RSPO does aim to contribute to affordable clean energy by most efficient use of fossil fuels and contribution to renewables where possible. In the document the PalmGHG Calculator is mentioned as a tool to monitor GHG emissions, yet biodiesel is also not mentioned probably because not all palm oil producing countries can currently make biodiesel.
According to the Figure 9.4.2.1, RSPO does not have the ambition to contribute to climate action. This is strange as using the tool to monitor (and reduce) GHG emissions would fit under climate action. Furthermore, good management practices such as proper use of fertilizer, prevention of oil palm cultivation on peat and good practices at the mill such as capturing methane from Palm Oil Mill Effluent (POME) to be used for biogas, could all contribute to decreased GHG emissions which would count as climate action. And finally making biodiesel to reduce GHG emissions from fuel might also contribute to climate action.

9.4.3 Conclusion

Based on the oils only, palm oil contributes most to export value and rapeseed oil the least. Palm oil also contributes most to the value added of the sector agriculture/forestry/fishery to the GNP in Indonesia compared to the other oils in their countries. Based on the entire vegetable oil sector, the soybean sector contributes most to export value followed by oil palm with rapeseed the least. The importance of the soybean sector is not only because of the value of soybean meal as livestock feed (which can be seen as a coproduct of oil production) but mainly because of export of entire soybeans.

The production of biodiesel in Indonesia is higher than in Brazil and will certainly continue to increase. EU regulation aims to phase out palm oil for biodiesel, reducing export opportunities of palm oil for Indonesia. Hence using palm oil domestically becomes attractive and while B35 is already in place, much higher blending percentages are foreseen. When biodiesel is produced without deforestation, without peat drainage, and with methane capture from wastewater, its GHG emissions are indeed lower than for fossil fuel. For all oils, an increase in use of oil for biodiesel will leave less available for food and make it more difficult to close the fat gap in people's diets. Increasing use of waste (cooking) oil for biodiesel may alleviate the pressure as this oil has already been used for food.

For investments we can conclude that voluntary certification schemes matter, and that currently investor concerns are better covered for palm oil than for the other oil crops. The new EU import restrictions (EUDR) for commodities produced on recently deforested areas (before 2020), effective from December 2025, will make some certification criteria redundant as laws and regulations will take over from voluntary standards and create a level playing field for all commodities (for import in the EU). Similarly, national standards such as ISPO and MSPO which are mandatory for sustainable production of palm oil in Indonesia and Malaysia respectively, may also replace some criteria from voluntary standards by making them subject to laws and regulations enforced by national government. However, these national standards do not create a level playing field between commodities, and are not yet globally accepted, hence voluntary standards remain important for investors.

It is recommended to appreciate the GHG tool as part of the climate change goal and to include concrete recommendations to reduce GHG emissions in the principles of RSPO to concretely contribute to climate change mitigation (SDG 13). Similarly, it is recommended that RTRS includes contribution to clean energy in its principles to align with reality.

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https://oec.world/en/profile/country/ for export data for different countries

WB for GNP per country

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10 Conclusions

In this study the performance of the three main oil crops was assessed for important impacts linked to achieving the Sustainable Development Goals.

Land use efficiency is a relevant trait for these crops as a high land use efficiency may spare land and thereby spare natural areas and free land for other crops. Oil palm was the most efficient crop, producing 2.4 times more efficient than soybean and 2.1 times more efficient than rapeseed in the current (~2020) situation. Under the very ambitious scenario oil palm is still the most efficient crop. Relatively, comparing the values in the very ambitious scenario in 2040 by the values in 2020, the highest improvement potential was assumed for soybean (+94%), followed by rapeseed (+44%) and oil palm (+26%).

The current GHG emission, expressed per ton of crude oil produced, was lowest for rapeseed and highest for oil palm. The high oil palm values were due to large GHG emissions from oil palm on peat and methane emissions from POME. Only 10% of the oil palm is grown on peat but it has a large impact on the average emissions. The emissions due to deforestation apply to just 18% of the palm area in Indonesia. Emission of methane from anaerobic POME treatment currently applies to more than 90% of the mills. Under the very ambitious scenario the emissions can be reduced significantly for all three crops, but the potential for GHG emission reduction is highest for palm oil. The differences in GHG emission among the three crops are strongly reduced under the very ambitious scenario in 2040 compared to the current situation.

Biodiversity loss is mainly caused by oil palm and soybean driven deforestation, affecting highly diverse and unique biomes in both Brazil and Indonesia. In Brazil the deforestation over the last 2 decades mainly took place in the Amazonian and Atlantic rain forest area (3.1 Mha) as well as in the Cerrado woodland area (1.7 Mha). In Indonesia a total forest area of 2.9 Mha including tropical rain forest and peat swamp forest areas was cleared and converted into oil palm plantations between 2001-2020. Deforestation per hectare of land developed was higher for soybean than for oil palm for primary forest loss, while this situation was reversed for secondary forest loss. In Germany no (recent) deforestation took place over the past two decades, which means that rapeseed oil is not associated with biodiversity loss due to deforestation like the other two oils.

The contribution of soybean oil to global food security is more important than that of the other vegetable oils in terms of traded volume. However, palm oil is cheaper and therefore important as cooking oil for poor people and an important contributor to close the “fat gap” in countries with low energy diets.

The higher revenues per ha for oil palm compared to soybean and rapeseed, makes it a more important contributor to farmers income especially when considering the lower costs of living in Indonesia. Oil palm contributes more to employment than soybean and rapeseed which are mechanized. Expansion of oil palm has created jobs for landless people while expansion of soybean replaced smallholders by fewer workers thereby contributing to unemployment in agriculture. For rapeseed effects on employment is minimal as expansion of rapeseed area mainly replaced other crops in rotations.

Indonesian palm oil has the highest export value and the highest contribution to the GDP followed by soybean oil in Brazil and rapeseed oil in Germany. But soybeans add most value to the export in the form of beans and cake. In Indonesia oil palm provides 100% of the feedstock for biodiesel, soybean in Brazil 75% and rapeseed in Germany 62%. In Germany 26% of the feedstock for biodiesel is used cooking oil. For Indonesia and Brazil biodiesel production and consumption are in balance, but Germany exports 30% of its production. Given population growth, the demand for vegetable oil for food may compete with an increasing demand for biodiesel. Using used cooking oil for biodiesel may reduce this competition as this oil has already first been used as food and its GHG contribution is lower than from “virgin” vegetable oils.

Impact investors find that voluntary sustainability standards (VSS) contain too few criteria addressing climate adaptation, climate mitigation and water pollution. The need for the last category aligns with the found main impact categories of the currently used agrochemicals. While the potential beneficial effect of addressing climate action can be seen from the reduced GHG emission in the scenarios in this report.

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Annex: GHG emissions from oil palm on peat

When oil palm is grown on peatland, drainage of peat is needed. The drainage depth has to be sufficient to allow palms to grow. Drainage of peat will start a process of subsidence that is mainly due to peat compaction, oxidation and runoff. In this process CO_2 is emitted. This CO_2 emission is part of the GHG balance of oil palm production. Therefore, it is important to have an estimate of the yearly CO_2 emission from a hectare of palm grown on drained peat.

The amount of CO_2 emission from oil palm on peat has been studied in a range of studies over the past 30 years using different methods to measure or estimate CO_2 emissions, such as eddy covariance, soil chamber and subsidence measurements. Studies show that directly after peat drainage subsidence and CO_2 emissions are high and are reduced later on. Older stands have lower yearly CO_2 emissions. Studies also showed a positive relation between CO_2 emissions and drainage depth.

Page et al (2011) reviewed studies of GHG emissions from tropical peat and the way these have been estimated. They report that "Undifferentiated (i.e. peat decomposition plus root respiration) CO_2 emissions calculated through flux measurements ranged from below 30 Mg CO_2 ha^{-1} yr^{-1} to above 100 Mg CO_2 ha^{-1} yr^{-1}. Studies that provide differentiated emissions for peat decomposition, range from 19 to 94 Mg CO_2 ha^{-1} yr^{-1}.". They also report that "subsidence monitoring yield emission values from 45 to 135 Mg CO_2 -eq ha^{-1} yr^{-1} for drainage depths of 0.5 to 1.0 m, and 54 to 115 Mg CO_2 -eq ha^{-1} yr^{-1} for the optimal drainage depth range for oil palm (0.6 to 0.85 m)".[8] They recommend using a CO_2 emission factor of 86 Mg CO_2 -eq ha^{-1} yr^{-1} (annualized over 50 years), which also accounts for higher CO_2 emissions observed in the early stages of plantation drainage.

In a later study on drainage of organic soils to validate country data for FAOSTAT, Conchedda and Tubiello (2020) reviewed CO_2 emissions from oil palm on drained peat. They conclude that the FAOSTAT emission factor for oil palm on peat (Indonesia and Malaysia) of 78 ton CO_2 eq ha^{-1} yr^{-1} is in close agreement with peer-reviewed literature and combined FAOSTAT and Petersen et al. (2016) spatial analysis. See table from Conchedda and Tubiello (2020). The emission factor of 78 in the FAOSTAT study is also similar to the IPCC (1997, 2006) and to the number mentioned by Page et al (2011) for agriculture on drained tropical organic soils (73.4 ± 66 Mg CO_2 ha^{-1} yr^{-1}).

Table 8. Comparison of EFs for oil palm plantations on organic soils from peer-reviewed literature and combined FAOSTAT and Petersen et al. (2016) spatial analysis.

Source	CO_2eq ha^{-1} yr^{-1}
Published studies	
Page et al. (2011)	86–100
Hooijer et al. (2012)[a]	78
Agus et al. (2013)[b]	43
Couwenberg and Hooijer (2013)[b]	66
Hashim et al. (2018)	13–53
Matysek et al. (2018)	86–117
Cooper et al. (2020)[c]	97
FAOSTAT/Petersen et al. (2016)	78

[a] Value 18 years after drainage. [b] Value more than 5 years after drainage.
[c] Value for mature oil palm plantations (over a 30-year cycle).

Note: unit of the values in above table is Mg CO_2eq $ha^{-1}yr^{-1}$. Table from Conchedda & Tubiello. 2020

[8] Additionally they conclude that CH_4 fluxes in drained tropical peatland are insignificant relative to losses of CO2 in the overall climatic impact. But they remark that "CH4 emissions from the drainage network may be significant, although this potentially important source of CH_4 remains to be quantified".

It is however clear from the above that there is large variation in published Emission Factor (EF) values from Indonesian peatlands. This is caused by a variety of factors explained by Page et al (2012) and others and include variation in peat composition, measurement methods, variation in drainage depth, time since drainage, season of measurement etc.. Recently there have been detailed Indonesian studies showing that the EF factor suggested by IPCC/FAOStat of 78 ton CO_2 eq ha^{-1} yr^{-1} for drained peatlands in Indonesian may be too high. Novita et al 2024 and Murdiyarso et al 2024 indicate that the average EF factors from drained peat in Indonesia are 39,1 and 43 ton CO_2 eq ha^{-1} yr^{-1} respectively.

For the calculation of GHG emissions from oil palm production in the current project, we need data specifically for the year 2020. Based on the discussion above we decided to use two values for EF from drained peatland areas, acknowledging the huge variation in EF factors:

1. The IPCC/FAOSTAT estimate of **78 ton CO_2 eq ha^{-1} yr^{-1}**
2. The value based on detailed recent studies of **40 ton CO_2 eq ha^{-1} yr^{-1}**

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