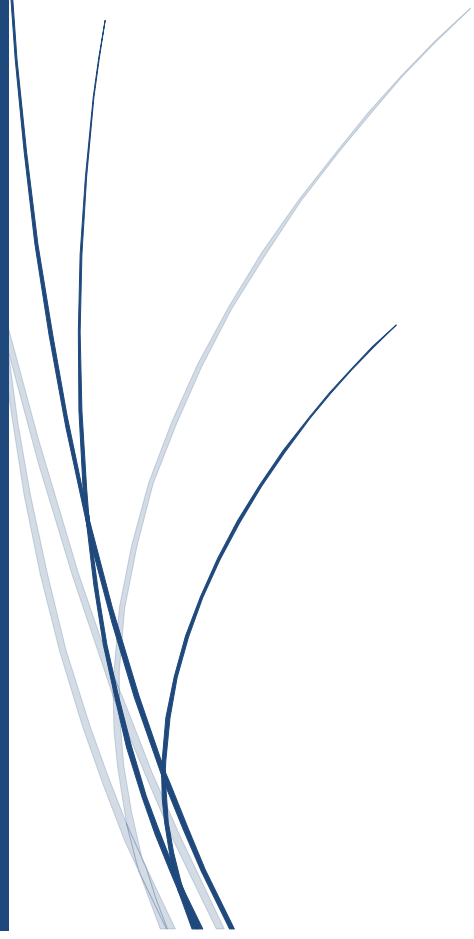
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Land Use Change and the European Biofuels Policy

The expansion of oilseed feedstocks on lands with high carbon stocks

Full Draft for Public Comment



LCAworks

LCAworks Limited (United Kingdom) was commissioned to develop this technical report by Terres Univia (France) on behalf of the organisations of the French vegetable oil and protein sector to in preparation for the EU delegated act defining high and low ILUC risks to be agreed by February 2019. The work was carried out independently from the funder with minimal input and guidance provided in the preparation of this document.

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Executive Summary

This study was commissioned by Terres Univia on behalf of the organisations of the French vegetable oil and protein sector and provides an assessment of land use changes for the major biodiesel crops, soybean, oil palm and oilseed rape (OSR), from 1990 to the present. The context of the study is the compromise reached in June 2018 between the European Parliament and the EU Council. This reopens the Indirect Land Use Change (ILUC) issue with a focus on the ILUC risk of feedstocks whose expansion is observed on high carbon stock land. The compromise text from Council and Parliament provides for a freeze on all high ILUC risk feedstocks at the level reached in 2019 from 2021 until 2023 and with a complete cessation by 2030. Crop based biofuels overall will be permitted by Member States at 2020 levels up to a cap of 7%. The Commission is expected to provide a delegated act by 1st February 2019, defining the High ILUC-risk feedstocks. They may also provide a methodology for the certification of low ILUC-risk production which could be exempted from the cap. This report does not address the question of the certification of low ILUC-risk production.

While we do not yet know how the term 'significant' will be defined in the delegated act we conclude from the analysis of the historical data and using the high ILUC-risk definition as it stands, that the emissions associated with palm and soy are significant. For oil palm we take Indonesia and Malaysia as proxy for the global position. We calculate an average expansion of 29% on high carbon stock land. For soy we calculate a global average of 19% expansion. We calculate the global average greenhouse gas emissions intensities based on the ILUC-risks as 56 gCO_2eq/MJ for soy oil and 108 gCO_2eq/MJ for palm oil. Future projections (OECD & FAO, 2017) suggest these numbers could drop significantly. We do not find evidence for high ILUC-risk expansion of oilseed rape.

Method

We start from the definition of high indirect land-use change-risk food or feed crop-based biofuels as 'bio-liquids and biomass fuels produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed'. In addition, the Renewable Energy Directive (RED) requires that biofuels shall not be made from raw materials obtained from land with high carbon stocks such as forests and wetlands if the land had that status in January 2008.

The report assesses the land use expansion of soybean, oil palm and oil seed rape at regional, country and global levels. The assessment is prepared based on: 1) a literature review of land use change (e.g. dynamics of cropland, pasturelands, forestlands and wetlands), emissions associated with Agriculture, Forest and Other Land Use (AFOLU), oil crop productivity, and the production of vegetable oils; and 2) estimates using historical data (e.g. oil production, land area and crop yields) from FAO, USDA and EUROSAT databases. Countries which presented a net reduction in natural vegetation (e.g. forestlands, wetlands and natural grasslands), where subject to further investigation in order to identify the impacts of their respective oil crops on areas with high carbon stocks. Average values for the expansion in different biomes were taken from the literature and the IPCC (2000) data.

From the published records we:

1) Calculate the land use changes, A_0, per year for soybean, oil palm and oilseed rape by country and in sub-national regions where the data permits it.

2) Calculate what part of this land use change occurs on high carbon stock lands, A_1. The risk ratio A_1/A_0 is then the measure we adopt.

3) Calculate the average CO_2 emissions from vegetation and soil per ha, E_m, from the conversion of A_1 to cropland. These carbon emission values were estimated based on IPCC (2000), as further explained in Section 2.2 of the report (Table 3).

4) Finally, calculate the CO_2 emission intensity, E_i, in g/MJ, using Equation 1, by country and then globally, where Y_{oil} is the established oil yield on new land per year in t crop/ha and E_{oil} is the energy content of the oil. We allocate the emission by value (V_a) and amortise over 20 years as is standard. We arrive at the equation:

$$E_i = \frac{A_1}{A_0} . \frac{E_m}{Y_{oil}\, E_{oil}} . \frac{V_a}{20} \qquad (1)$$

Equation 1 is the carbon footprint for the production of vegetable oil associated with the expansion of oil crops over natural vegetation lands per year attributed to the total land use expansion of that crop per year. Hence the use of the term risk ratio. Table S1 shows value allocation ratios and the energy contents (E_{oil}) used in the calculation are taken from the INRA-CIRAD-AFZ feed tables. The value allocation ratios are taken from Edwards *et al.* (2014). Yields (Y_{oil}) the land areas by country (A_0), and the high carbon stock land use emissions (E_m) are given in Table S2 and Table S3.

Table S1: Values used in calculating the CO_2 emissions per MJ (Equation 1)

Oil crop	Value allocation ratio (V_a)	Energy content (E_{oil}), GJ/t
Soybean	0.36	39.4
Oil palm	0.98	39.4
Oilseed rape	0.58	39.4

This work follows on from previous studies by Overmars *et al*. (2015) and Edwards *et al*. (2014). Our method is consistent with these studies and LCA practice. While also using historical data to assess the share of expansion in crop area associated with the conversion of high carbon stock land, this report differs from Overmars *et al.* in its approach to calculating land use change and emissions. Rather than utilising models of global cropland expansion (IMAGE and CSAM), this report bases the assessment on literature review of expansion at the national (and in some cases subnational) level. Overmars *et al.* also assume a counterfactual for crops grown on abandoned land on the grounds that the land would otherwise have reverted to a more natural landscape. We take the position that the land remains as cropland. Edwards *et al.* also assess the historical deforestation associated with biofuel crop expansion by allocating deforestation to crop expansion rather than estimating deforestation based on production trends. This allocation may not sufficiently account for the indirect link between crop expansion and deforestation (a delay between logging activities and crop establishment) that is frequently observed (Wicke *et al.*, 2011). This report attempts to address this complex issue through the literature review, including several satellite-based analyses of land use change.

The countries assessed here are Argentina, Brazil, Canada, China, Czech Republic, France, Germany, Indonesia, Malaysia, Poland, Romania, the United Kingdom and the United States, as well as the European Union (EU28) as a whole.

Discussion

Table S2 shows our calculated values of the expansion ratios on high carbon stock lands, and energy intensities at the national levels, and from these we determine the global values. We see a range for palm from 20-30% for the two main producers. For soy the range is from 0% to 28%. At the level of regions within nations these variations are larger still as is seen in the main body of the report and these are used to determine the national averages. The amortised emission intensities for additional production are consistent with recent studies (for example, Valin *et al.*, 2015; Edwards *et al.*, 2014) although our values are lower. Where we differ entirely is for oilseed rape (OSR) where our methodology does not support a position that oilseed rape nationally or globally expands directly over high carbon stock lands.

Table S2: Annual CO_2 emissions from soy, palm and rapeseed expansion on lands with high carbon stocks.

Oil crop	Country	Forest area change kha y^{-1}	Production Mt y^{-1}	Oil crop expansion, harvested area, A_0 kha y^{-1}	Expansion over native land, A_1 kha y^{-1}	Expansion ratio over native land, A_1/A_0	Emission factor expansion over native land, E_m tCO_2eq ha-1	Emission factor tCO_2eq/t oil	Emission intensity, E_i gCO_2eq/MJ oil with economic allocation
Soybean (grain)	Argentina	-305	45.7	437	122	28%	415	10.3	95
	Brazil	-1252	96.3	1111	189	17%	415	5.7	52
	China	1531	12.0	-266	0	Not applicable	-	0.0	0
	USA	482	117.2	329	0	Not applicable	-	0.0	0
	ROW	-3806	50.6	-	-	-	-	-	-
	World	**-3350**	**334.9**	**1611**	**311**	**19%**	**415**	**6.2**	**56**
Palm oil (oil)	Indonesia	-685	36.0	522	157	30%	1080	4.8	126
	Malaysia	107	18.9	84	17	20%	1242	3.3	69
	ROW	-2772	10.4	-	-	-	-	-	-
	World	**-3350**	**65.3**	**606**	**174**	**29%**	**1095**	**4.3**	**108**
Oilseed Rape (oil)	Canada	-50	18.4	275	0	Not applicable	-	0.0	0
	China	1531	15.3	163	0	Not applicable	-	0.0	0
	India	274	6.8	-151	0	Not applicable	-	0.0	0
	USA	482	1.4	27	0	Not applicable	-	0.0	0
	EU28	421	19.7	107	0	Not applicable	-	0.0	0
	ROW	-5792	7.2	-	-	-	-	-	-
	World	**-3350**	**68.9**	**421**	**0**	**Not applicable**	**-**	**0.0**	**0**

Source: prepared by the authors.

Notes: **1)** Total oil crop production as in 2014 base year (FAO, 2018). **2)** Oil crop expansions over native vegetation were estimated by the authors for approximately the last ten years of historical values, based on literature review and assumptions described in this assessment report. Native vegetation includes forestlands and natural grasslands, as well as peatlands. **3)** Uncertainties involved: some peatlands may be misclassified in the assessed databases and not included as either forestlands or grasslands, but instead in the category of other lands, which includes deserts, ice covers, settlements and infrastructure. This may be particularly critical for Malaysia, which may have its potential impacts underestimated. **4)** Annual oil crop expansion from 2006-2016 (FAO, 2018). Annual oil crop expansion over native vegetation based on estimates described in the report, including assumptions for GHG emissions from IPCC (2000), and all carbon release from deforestation occurring within the same year. **5)** Although Malaysia shows a net afforestation/reforestation based on FAO (2018), it has expanded part of its oil palm area over forestland, peatland and bare soils, which may be classified as "other land" (see annex). **6)** The oil fraction yield for soybean is 20% for the calculations shown in this table. ROW – Rest of the World.

Future OECD & FAO (2017) projections suggest that the yield increases will outstrip the requirement for land use change to meet increased demand. While we recognise these studies, our work is based on the historical record rather than projections and we have not considered it in the calculations of the expansion ratios on high carbon stock lands. Table S3 is a summary of our estimates of the GHG emissions for soy and palm expansion over native vegetation (base 2006-2016).

Table S3: Annual GHG emissions due to soy and palm expansion over native vegetation (base 2006-2016)

Oil crop	Country	Crop expansion kha y^{-1}	Crop expansion over natural vegetation kha y^{-1} B_0	Assumed type of natural vegetation converted	Carbon stock in natural vegetation tC ha^{-1} D_1		Carbon stock in crop land tC ha^{-1} D_2	Carbon stock loss tC ha^{-1} $D_1 - D_2$	Emission factor t CO_2eq ha^{-1} B_1	Oil share in total crop production B_2	GHG emissions from the conversion of natural vegetation for oil production $MtCO_2eq\ y^{-1}$ $B_0 * B_1 * B_2$
Soybean	Argentina	437	122	50% Tropical Forest	243	195	82	113	415	20%	10
				50% Chaco and others	147						
	Brazil	1111	189	50% Tropical Forest	243	195	82	113	415	20%	16
				50% Cerrado and others	147						
	Total	**1548**	**311**			**195**	**82**	**113**	**415**	**20%**	**26**
Oil Palm	Indonesia	522	157	50% tropical forest	243	464	170	294	1080	100%	169
				50% wetland (incl. peatland)	686						
	Malaysia	84	17	40% tropical forest	243	509	170	339	1242	100%	21
				60% wetland (incl. bare soil)	686						
	Total	**606**	**173**			**470**	**170**	**300**	**1095**	**100%**	**190**

Source: prepared by the authors.

Note: Annual oil crop expansion from 2006-2016 (FAO, 2018). Crop expansion over natural vegetation calculated from ratio A_1/A_0 (Table S2). Emission factor estimated from IPCC (2000), including both above ground vegetation and soil carbon changes. One tonne of Carbon (C) is equivalent to 3.67 tonnes of Carbon Dioxide (CO_2). See further explanations in the full report (Chapter 2). Conversion unit: 1 tC equals 3.67 tCO_2.

Any calculation of this sort contains a considerable uncertainty, particularly in the calculation of the expansion ratio, but also the specific prior land use. Where there is a significant range in the high carbon stock land use change, we have used the data covering the most recent period and where available the value at the lower end to reflect the increasing efforts to reduce the conversion of high carbon stock lands seen more recently. We have not considered counterfactual land use changes. This might include using otherwise abandoned cropland, where the counterfactual would be a return to a more natural landscape. This would not be consistent with an analysis based on the historical record.

In the rest of this executive summary we give further details of the analysis of the three crops. Considerably more detail is contained in the body of the report on the background to the oil markets, carbon stocks, the land use change assessments and estimates of future production.

Soybean

We consider the four nations that supply 85% of world production: Argentina, Brazil, China, and the USA. Table S4 summaries the expansion onto high carbon stock lands in these regions.

Table S4: The expansion of high carbon stock lands for soy production

Country	Sub-region	Forestland dynamics	Total soy production in grain (2016 base-year) Mt	Share of global production	Approximate share of recent soy expansion over natural vegetation
Argentina		Net deforestation	58.8	17%	28%
Brazil	MATOPIBA	Net deforestation	11.6	4%	62%
	All other regions	Net deforestation	84.7	25%	11%
	Total	Net deforestation	96.3	29%	17%
China		Net afforest./reforestation	12.0	4%	Not applicable
United States		Net afforest./reforestation	117.2	35%	Not applicable
Other nations		-	50.6	15%	-
WORLD		Net deforestation	334.9	100%	19%

Source: prepared by the authors.

Note: total soy production based on FAO (2018). Approximate share of recent (about past 10 years) soy expansion over native vegetation were estimated by the authors, based on literature review. World share assumes a weighted average of the situation occurred in the listed countries, excluding other nations. MATOPIBA region is comprised of the Brazilian State of Tocantins (TO) and parts of the States of Maranhão (MA), Piauí (PI) and Bahia (BA).

Argentina: Recent land use changes in Argentina have occurred over forestlands as well as Chaco, with an almost linearly decrease in the past decades. Pastureland and cropland have both expanded near linearly, directly or indirectly affecting these land use changes observed in forestlands and possibly in the "other land" category (see annex). Argentina established a new forest code (Ley de Bosque Nativo) in 2007. Since then, the country was expected to reduce its deforestation rates, but the problem continued. From 2007 to 2014, 5 Mha of native vegetation were lost, with 90% of the deforestation occurring in the North Region, including the Gran Chaco area (Larraquy, 2016). The country produces soybean in different states, from North Region (e.g. States of Salta, Chaco and Formosa) to Centre Region (e.g. States of Cordoba, Santa Fe, Buenos Aires and La Pampa). Among other initiatives to reduce deforestation related to the cultivation of soybean, the Round Table on Responsible Soy – RTRS (2018) sets standards for its sustainable production but has had limited success to date (Goni, 2018).

The Argentinian environmental legislation aims at reducing the deforestation rates observed in many biomes across the country, but there is a risk of non-compliance (NEPCon, 2017). There is a high deforestation including from soy expansion, which has partially expanded over critical wetlands (Herrera *et al.*, 2013). Argentina increased its soy production by 10.9 Mha from 8.6 Mha in 2010 to 19.5 Mha in 2016, according to data from FAO (2018). In the same period, total cropland increased by 11.6 Mha from 28.6 Mha (2010) to 40.2 Mha (2016), while total pastureland increased by 8.6 Mha from 99.9 Mha (2010) to 108.5 Mha (2016). Cropland was 57% of the total agricultural land, and pastureland 43%, in 2016. At the same time 5 Mha of deforestation from 31.7 Mha (2010) to 26.8 Mha (2016) occurred. Based on these data and keeping the area share in the same proportion as in 2016, as well as the share of soybean in total cropland, we to estimate that approximately 28% of the total expansion of soybean may have occurred over forestlands and Chaco. In support of this, FAO data (2018) from 2007 to 2016 shows Argentina's soybean area expanded approximately 352 kha/year, out of which 99 kha/year occurred over natural vegetation and in line with our 28% estimate.

Brazil: Soy production occupies on 38% of Brazilian cropland. Most of the soybean production in Brazil occurs in consolidated agricultural lands, but significant expansion areas have affected the Amazon and Cerrado. Most of its recent expansion occurred in the State of Mato Grosso (MT) and this includes areas in the so-called 'Amazon deforestation arc'. Amazon deforestation is complex (Strapasson, 2014). Barona *et al.* (2010) assessed the role of pasture and soybean in Amazon deforestation from 2000 to 2006. They concluded that "The proximate cause of deforestation in the Legal Amazon was predominantly the expansion of pasture, and not of soybeans. However, in Mato Grosso, an increase in soybeans occurred in regions previously used for pasture, which may have displaced pastures further north into the forested areas, causing indirect deforestation*".*

The deforestation of Cerrado is a major issue. The expansion of soy in the MATOPIBA region was approximately 62% over forestlands (mainly Cerrado). In all the other states it occurred at about 11% (including Amazon, Cerrado and Atlantic Forest). MATOPIBA accounted for approximately 12% of total soy production in Brazil (2016/2017 crop season), whereas all the other states combined provided 88%. Based on a weighted average of the soybean production in these regions, we obtain that around 17% of the Brazilian soy area has expanded over forestlands in recent years.

From 2007 to 2016, Brazil's soybean area expanded approximately 1,259 kha y^{-1} (FAO, 2018), out of which 214 kha y^{-1} occurred over natural vegetation in correspondence with our 17% estimate. Soybean area has approximately the carbon stock for average cropland. The expansion occurred over areas with an average

carbon stock similar to tropical forestland. The soy expansion over native vegetation has emitted about 88 $MtCO_2eq\ y^{-1}$, including changes in soil carbon.

China: Forestlands have been linearly increasing in China in the past decades, mainly driven by planted forests. Pastureland has been almost stable, as have soybean and oilseed rape areas. China is a major importer of soybean. Total cropland has oscillated along a downward trend in the past decades. Soybean production in China has varied substantially in the past decades. Using OECD & FAO (2017) forecast of increasing linear crop yields we may nevertheless see an increase in land for soy. The current dynamics do not correlate with the movement of soy onto high carbon stock lands.

USA: Forestlands have increased slightly and croplands significantly decreased grown at the expense of croplands in the last few decades. Soybean area has been substantially increasing while total cropland has decreased. The OECD & FAO (2017) project a near linear expansion of soybean production in the US as the potential for yield increases is good. The total required land may not be significantly affected in the coming decade. In terms of emissions, forestlands are a substantial carbon sink. As for China we cannot correlate the change in soy production with expansion on high carbon stock lands.

Oil Palm

Malaysia and Indonesia produce 84% of global oil palm. In this work these two nations stand as representative of the global production.

Indonesia: The majority of Indonesian oil palm plantations by area are located in Sumatra, followed by Kalimantan. Kalimantan has experienced particularly rapid growth in oil palm plantations since the year 2000 (Gunarso *et al.*, 2013; Austin *et al*., 2017). Estimates of the contribution of oil palm to deforestation are challenging and variable (Wicke *et al*., 2011). In Indonesia, the primary direct driver of deforestation has been logging (often illegal) rather than the expansion of oil palm plantations. However, oil palm plantations have frequently replaced previously forested land after logging and therefore are associated with the carbon loss from this land use change (Gunarso *et al*., 2013). Several studies have quantified the proportion of growth in oil palm area linked to deforestation (Table S5). Based on FAO data (2018), the expansion of oil palm in Indonesia was approximately 477 kha y^{-1} between 2007 and 2015.

The expansion of oil palm over forestlands in Indonesia has ranged from approximately 18% to 63% in recent years. We conservatively take a value of 30%. Of this conversion, Austin *et al*. (2017) report that the majority (94.9%) occurred in secondary forests and 5.1% in primary forests. In the body of the report we give further details for Sumatra and Kalimantan.

Table S5: Expansion over high carbon stock lands in Indonesia

Timeframe	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation (ha)	Study
1990-2005	56-100%	1,704,000 to 3,017,000	Koh *et al.*, 2008
1990-2010	63%	Not available	Geographical magazine, 2018
1990-2010	33.5%	2,143,000	Gunarso *et al.*, 2013
1990-2013	51.5%	Not available	Vijay *et al.*, 2016
1995-2000	53.9%	788,000	Austin *et al.,* 2017
2000-2005	Not available	357,000	Austin *et al.,* 2017
2005-2010	Not available	616,000	Austin *et al.,* 2017
2010-2015	18%	585,000	Austin *et al.,* 2017

Source: prepared by the authors, using references cited within the table.

Conversion of peatlands, often through the use of fire (although no longer legal), has contributed to considerable loss of carbon stocks (Gunarso *et al.*, 2013). The estimated area of industrial oil palm plantations on peatlands in Indonesia increased from 19 kha in 1990 to 1,311 kha in 2010 (Miettinen *et al.* 2012). Austin *et al.* (2017) estimate an expansion of 305 kha on peatlands between 1995-2000 and 619 kha between 2010-2015 (20% proportion for both periods). From Austin *et al*. (2017) and Gunarso et al. (2013) we estimate that for Sumatra, Kalimantan and Papua the total expansion over native vegetation was approximately 50% occurred in areas analogous to "tropical forest" and the other 50% in areas analogous to "wetland" (peatland). Carlson *et al.* (2013) projected that the land use change the expansion of oil palm from 2010-2020 will conservatively result in emission for which 56% are from the clearing of forests and 25% from the conversion of peatlands.

Malaysia: Forestlands in Malaysia have been relatively stable since 2010. On the other hand, oil palm has expanded significantly onto croplands and into the land use category 'other' (see annex). Some of these 'other' land use classes may have originated on previously forested areas (Gunarso *et al*., 2013). A decline in permanent cropland has been observed since 1990 (Wicke *et al.*, 2011). There is also evidence of an increase in clearing of land by 150% in Malaysia in the last decade (Geographical Magazine, January 2018). The national harvested plantation area reached an estimated 4.86 Mha in 2015 (FAO, 2018). Estimating this impact is challenging due to the often indirect relationship between deforestation and the establishment of new oil palm plantations (via prior logging). However, oil palm establishment has more directly driven deforestation in Malaysia than in Indonesia (Gunarso *et al.*, 2013). This applies for the regions of Sabah and Sarawak (Gaveau *et al.*, 2016), while deforestation in the Malaysia Peninsular has been more driven by the expansion of rubber and other crops (Gunarso *et al*., 2013).

Estimates of deforestation associated with palm oil production in Malaysia vary and are given in Table S6. In short, the expansion of oil palm over forestlands in Malaysia has ranged from approximately 17% to 39% in recent years. We take a conservative estimate of 20% but note that it may be underestimated, due to the uncertainties related the definition of "other land", which are not considered as forestlands, but which may include peatlands and bare soils. On the other hand, the Malaysian government reports that the emissions associated with land use, land use change and forestry sector have roughly stabilised since 1995 (Ministry of Natural Resources and Environment Malaysia, 2015).

Table S6: Expansion over high carbon stock lands in Malaysia

Timeframe	Region	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation (ha)	Study
1990-2005	Malaysia	55-59%	1,040,000 to 1,109,000	Koh *et al.* (2008)
1990-2010	Malaysia	17%	Not available	Geographical Magazine (2018)
1990-2013	Malaysia	38.9%	Not available	Vijay *et al.* (2016)
1990-2010	Malaysia	42%	1,365,700	Gunarso *et al.* (2013)
1990-2010	Peninsular Malaysia	25.1%	281,000 ha	Gunarso *et al.* (2013)
1990-2010	Sabah	59.6%	689,000 ha	Gunarso *et al.* (2013)
1990-2010	Sarawak	40.5%	396,500 ha	Gunarso *et al.* (2013)

Source: prepared by the authors, using references cited within the table.

Oilseed Rape

The production of rapeseed oil also has a concentrated market, with Canada, China and EU28 dominating the global production with about 78% of the global production. Including India and the United States, this total share increases to 90%. It is third most important vegetable oil crop worldwide, behind oil palm and soybean. All the assessed countries presented net afforestation / reforestation in the past decade, apart

from Canada, which presented a small net deforestation area, based on data from FAO (2018). Thus, as shown in Table S7, there is no apparent correlation between the recent expansion of oilseed rape and forest dynamics.

Table S7: Oilseed rape producing countries and risks associated with high carbon stock lands.

Country	Forestland dynamics	Total rapeseed oil production (Mt of oil)	Share of global production	Approximate range of OSR expansion over native vegetation
Canada	Net deforestation	18.4	27%	0%
China	Net afforestation/reforestation	15.3	22%	Not applicable
Czech Republic	Net afforestation/reforestation	1.4	2%	Not applicable
France	Net afforestation/reforestation	4.7	7%	Not applicable
Germany	Net afforestation/reforestation	4.6	7%	Not applicable
India	Net afforestation/reforestation	6.8	10%	Not applicable
Poland	Net afforestation/reforestation	2.2	3%	Not applicable
Romania	Net afforestation/reforestation	1.3	2%	Not applicable
United Kingdom	Net afforestation/reforestation	1.8	2%	Not applicable
United States	Net afforestation/reforestation	1.4	2%	Not applicable
Other nations	-	7.2	10%	-
EU28	*Net afforestation/reforest.*	*19.7*	*29%*	*Not applicable*
World	**Net deforestation**	**68.9**	**100%**	**Not applicable**

Source: prepared by the authors.

Note: total rapeseed oil production as in 2014 base-year (FAO, 2018). Risk associated with the likelihood that OSR may expand over native vegetation within the respective country, including forestlands and natural grasslands.

1. Introduction

In 2011, Terres Univia on behalf of the organisations of the French vegetable oil and protein sector commissioned a study from LCAworks and E4tech on the 'Modelling of indirect land use change (ILUC) impact of OSR biodiesel production in Europe' (Prolea III report) (Kalas *et al*., 2011). In June 2018, a political compromise on REDII was reached between the European Parliament and the EU Council which reopens the ILUC issue with a focus on the risk of ILUC of feedstocks whose expansion is observed on high carbon stock land. The compromise text Council and Parliament provides for a freeze on all high ILUC risk feedstocks at the level reached in 2019 from 2021 until 2023 and with a complete cessation by 2030, whilst also increasing second generation fuels (e.g. lignocellulosic ethanol), for the purpose of their accountability in the EU targets. The REDII states that renewable energies (not only biofuels) should account for at least 14% in the EU transport sector.

The negotiations continue. The requirement now is that the Commission provides a delegated act by 1st February 2019, defining the High ILUC-risk feedstocks as well as a methodology for the certification of low ILUC-risk production which could be exempted from the cap. The definitions for low and high ILUC risk (Article 2: COM(2016) 767 final/2) are:

> '**Low indirect land-use change-risk biofuels and bioliquids**' means biofuels and bio-liquids, the feedstocks of which were produced within schemes which avoid displacement effects of food and feed crop based biofuels, bio-liquids and biomass fuels through improved agricultural practices, as well as the cultivation of crops on areas which were previously not used for cultivation of crops and which were produced in accordance with the sustainability criteria for biofuels and bioliquids set out in Article 26.
>
> '**High indirect land-use change-risk food or feed crop-based biofuels**', [meaning] bio-liquids and biomass fuels produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed, [these products] shall not exceed the level of consumption in 2019 in the Member State, unless they are certified as low indirect land-use change-risk biofuels.
>
> '**Land with high carbon stock**' [Com 2016:767final2] 'Biofuels and, bioliquids and biomass fuels produced from agricultural biomass taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:
>
> (a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;
>
> (b) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;
>
> (c) land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10% and 30%, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in part C of Annex V is applied, the conditions laid down in paragraph 72 of this Article

would be fulfilled. The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.'

1.1. Aims and objectives

The focus of this report is on the potential land use change impacts associated with the oilseed-based biodiesel consumption. The three main crops used for biodiesel production to date are oilseed rape (OSR), soybeans and oil palm. Therefore, the objective here is to provide a technical assessment of potential land use change for these three major crops at global level, obtained through a broad country-level analysis for their respective major producing countries. The report presents a historical data analysis, evaluating the interaction between the expansion and contraction of these three crops over the last three decades (with a closer look from 2008) together with the carbon stock changes to the land. The intention is to categorise these land uses by carbon stock and carbon stock changes. More detailed analysis (below the country level) are also provided where possible. Crops aimed at the production of ethanol, such as maize (corn), sugarcane, wheat, cassava and sugar beet, although extremely relevant for biofuel policies, are not the subject of this present report.

1.2. Methodology

This assessment was prepared based on literature review and estimates using historical data (e.g. oil production, land area and crop yields) and market forecast (e.g. OECD & FAO projections) for determining the main land use impacts associated with the expansion of major oil crops worldwide, in the context of REDII. The first step was to assess the available database (such as the FAO, USDA and EUROSAT online statistics) and key articles related to this topic, especially on land use change (e.g. dynamics of cropland, pasturelands, forestlands and wetlands), emissions associated with Agriculture, Forest and Other Land Use (AFOLU), oil crop productivity, and the production of vegetable oils. After this, countries which presented a net reduction in natural vegetation (e.g. forestlands, wetlands and natural grasslands), where subject to further investigation in order to identify the impacts of their respective oil crop (e.g. soybean, oil palm) on areas with high carbon stocks. Average values for the expansion in different biomes (e.g. Chaco, Cerrado, Amazon, Peatlands, etc.) were obtained from the available literature. Changes in carbon content from land use change were estimated mainly from IPCC (2000) data.

From the published records we:

1) Calculate the land use changes, A_0, per year for soybean, oil palm and oilseed rape by country and in sub-national regions where the data permits it.

2) Calculate what part of this land use change occurs on high carbon stock lands, A_1. The risk ratio A_1/A_0 is then the measure we adopt, apart from the many uncertainties involved (Strapasson *et al*., 2017). Our proposal is also different to other modelling approaches available in the literature (Woltjer *et al.*, 2017).

3) Calculate the average CO_2 emissions from vegetation and soil per ha, E_m, from the conversion of A_1 to cropland. These carbon emission values were estimated based on IPCC (2000), as further explained in Section 2.2 (Table 3).

4) Finally, calculate the CO_2 emission intensity, E_i, in g/MJ, using Equation 1, by country and then globally, where Y_{oil} is the established oil yield on new land per year in t crop/ha and E_{oil} is the energy content of the oil. We allocate the emission by value (V_a) and amortise over 20 years as is standard. We arrive at the equation:

$$E_i = \frac{A_1}{A_0} \cdot \frac{E_m}{Y_{oil}\, E_{oil}} \cdot \frac{V_a}{20} \qquad (1)$$

Equation 1 is the carbon footprint for the production of vegetable oil associated with the expansion of oil crops over natural vegetation lands per year attributed to the total land use expansion of that crop per year. Hence the use of the term risk ratio. Table 1 shows value allocation ratios and the energy contents (E_{oil}) used in the calculation are taken from the INRA-CIRAD-AFZ feed tables. The value allocation ratios are taken from Edwards *et al.* (2014). Yields (Y_{oil}) the land areas by country (A_0), and the high carbon stock land use emissions (E_m) are presented in the end of this report (Table 22 and Table 23 in Chapter 3).

Table 1: Values used in calculating the CO2 emissions per MJ (Equation 1).

Oil crop	Value allocation ratio (V_a)	Energy content (E_{oil}), GJ/t
Soybean	0.36	39.4
Oil palm	0.98	39.4
Oilseed rape	0.58	39.4

This work follows on from previous studies by Overmars *et al*. (2015) and Edwards *et al*. (2014). Our method is consistent with these studies and LCA practice. While also using historical data to assess the share of expansion in crop area associated with the conversion of high carbon stock land, this report differs from Overmars *et al.* in its approach to calculating land use change and emissions. Rather than utilising models of global cropland expansion (IMAGE and CSAM), this report bases the assessment on literature review of expansion at the national (and in some cases subnational) level. Overmars *et al.* also assume a counterfactual for crops grown on abandoned land on the grounds that the land would otherwise have reverted to a more natural landscape. We take the position that the land remains as cropland. Edwards *et al.* also assess the historical deforestation associated with biofuel crop expansion by allocating deforestation to crop expansion rather than estimating deforestation based on production trends. This allocation may not sufficiently account for the indirect link between crop expansion and deforestation (a delay between logging activities and crop establishment) that is frequently observed (Wicke *et al.*, 2011). This report attempts to address this complex issue through the literature review, including several satellite-based analyses of land use change.

The next sections provide an assessment of the three main vegetable oils (OSR, soybean and palm oil), including a global context, national analyses and, in some critical cases, also sub-national analyses.

2. Vegetable oils and land use change

This section presents an assessment of land use change and carbon dynamics for the production of vegetable oil. It provides an analysis and simulation for the three target crops (i.e. oilseed rape, soybean and oil palm), covering their main producing countries, namely: Argentina, Brazil, Canada, China, Czech Republic, France, Germany, India, Indonesia, Malaysia, Romania, United Kingdom and United States. A glossary with the descriptions of land use classifications adopted in this report while using FAO data is available in the Annex.

2.1. Global bioenergy context

The relationship between bioenergy and land use has gained momentum in the global climate change agenda. The opinions vary from those totally against the production of any type of energy crops to those extremely in favour of bioenergy whatever it means (Rosillo-Calle *et al.*, 2010). In the middle of this range of different views are those trying to find ways to reconcile what seems to be a paradox. While land is a finite resource, the use of land resources for food, fuel and environmental services may have dynamics and consequences that are not always intuitive. This is why the use of system dynamics and integrated systems models are fundamental to understand the complex variables involved. Strapasson *et al.* (2017) suggest that while either negative or positive scenarios for bioenergy are possible, the main issue is the magnitude of bioenergy potentials over time and the way it may be expanded worldwide. World bioenergy production currently accounts for 55 EJ (primary energy) and, according to these authors, the potentials by 2050 could be as low as 60EJ to as high as 360 EJ, with a moderate scenario around 160 EJ, which corroborates with estimates from the International Energy Agency (IEA) and IPCC reviews for global bioenergy scenarios (Smith *et al.*, 2014). In order to achieve these potentials, the availability of land is key for the production of crops for energy purposes. In practice, apart from the controversial debate on food vs. fuel, what has usually occurred is a synergy between food and fuel production in most nations. In many cases, the production of bioenergy occurs via crop-rotation schemes and with an associated production of food and feed.

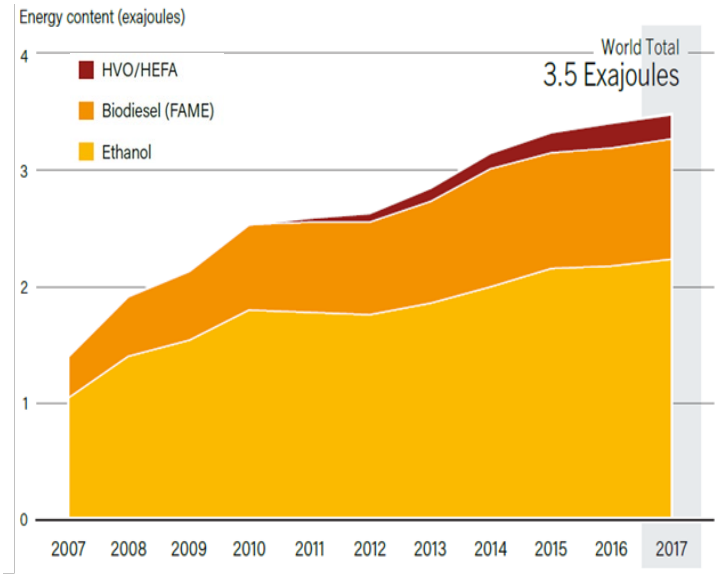


Figure 1: World biofuel production by chemical type, in EJ

Note: HVO – Hydrotreated Vegetable Oil; HEFA – Hydrotreated Esters and Fatty Acids; FAME – Fatty Acid Methyl Esters.

Source: REN21 (2018).

The production of biofuels (i.e. liquid fuels such as ethanol and biodiesel) is just a small component of a broad bioenergy picture, currently accounting for 3.5 EJ (Figure 1). According to REN21 (2018), 80% of all biofuels are produced and consumed in the United States (mainly corn-based ethanol), Brazil (mainly sugarcane-based ethanol) and the EU (mainly OSR biodiesel), with France and Germany leading the European ranking. Ethanol has been expanded more rapidly than biodiesel globally, although both fuels have reduced their expansion rate since about 2010. The main reasons include a domestic crisis in the Brazilian ethanol production, an unexpected decrease in world oil price (affecting the competitiveness of biofuels against gasoline and diesel), growing concerns about food vs. fuel, and technological advancement delays. The United States, for example, had initially expected a large increase in 2G ethanol in the 2010s, which has not occurred.

In regard to the European Union, the production and consumption of biodiesel have been gradually increasing in the past decade, with some variations along the years, and using different feedstocks for its domestic production, as shown in Figure 2. Rapeseed oil remains as the major source (44.4% of the total

biodiesel production), followed by palm oil (28.7%), used fried oil – UFO (15.5%), soybean (4.9%), fats (4.1%), sunflower (1.9%) and other sources (0.5%), as for 2018 forecast.

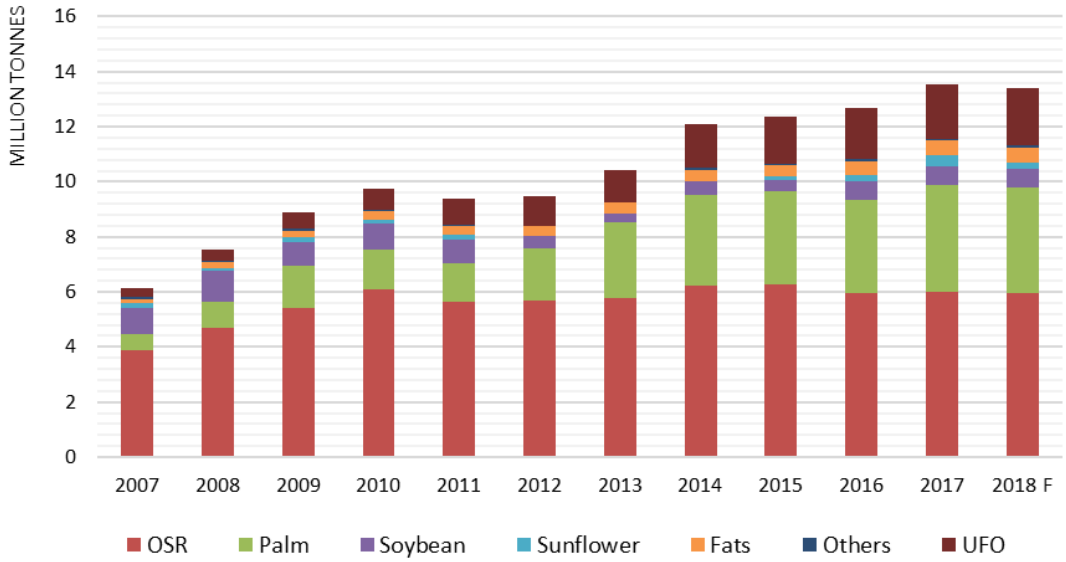


Figure 2: EU biodiesel feedstocks, in million tonnes of biodiesel produced.

Note: OSR – Oilseed Rape, UFO – Used Fried Oil.

Source: Oil World (2018).

In terms of the global production of vegetable oils for biodiesel (including HVO, HEFA and FAME), the three main crops that have been used to date are soybean, oil palm and oilseed rape. Biodiesel represents just a small fraction of the final destination of their vegetable oil. However, the expansion of these crops motivated by a potentially higher biodiesel demand in the coming years may (or may not) cause relevant land use change impact. This potential impact will depend on the characteristics of their producing countries, type of energy crop and bioenergy scenarios, among other issues. In terms of greenhouse gas emissions, the main environmental risk is associated with land use change affecting areas containing high carbon stocks, such as forestlands and peatlands, as described in following section. As earlier mentioned in the Introduction, it worth noting that under the current EU policy discussions on land use change for biofuels, the original land use is considered as its use post-2008. For example, if a forest was converted into cropland before 2008, a future expansion of energy crops on this cropland will not be classified as a land use change over forestland but, instead, over a consolidated cropland. The EU current regulation (since 2010) on the eligibility of feedstock for biofuel production requires sustainability criteria, one of which being that the feedstock does not come from cropland deforested after 2008. This 2008 reference currently applies to all "crop-based" biofuels – and is expected to continue to be applied after 2021 to all of them, including for those categorised as high ILUC-risk and low ILUC-risk.

2.2. Carbon stocks in land resources

The characteristics of forestlands, including its average carbon stock, may vary according to the type of forest, its climate and geographical location. Peatlands, which can be classified either as forestlands or wetlands (sometimes also as natural grasslands, depending on the methodology used) are areas with soils rich in turf. It is often also associated to areas called mires, muskegs, moors, and bogs. Peatlands serve as a global carbon sink, given that their vegetation usually captures more CO_2 (via photosynthesis) than the

carbon released through plant respiration and decomposition of decayed vegetation in these areas and, hence, gradually accumulating a significant amount of soil carbon until reaching an equilibrium over centuries. Thus, the expansion of productive systems over peatlands, often using fire, drainage systems and ploughing machines, which contribute for speeding up the oxidation of organic matter and hence emitting carbon back to the atmosphere, are very critical in terms of GHG balance.

Among the assessed nations earlier mentioned, Brazil, Canada, USA and China have substantial amount of carbon stocks in their forestlands, followed by Indonesia, India, Argentina, Malaysia and other countries, as shown in Table 2.

Table 2: Forestlands and carbon stocks in top producers of soybean, oil palm, or oilseed rape.

	Total forestlands (kha)	Carbon stock in forestlands (MtC)	Carbon stock per forest area (tC ha^{-1})
Brazil	492,554	59,142	120
Canada	347,022	13,981	40
United States	310,370	17,383	56
China	209,864	6,872	33
Indonesia	90,326	12,216	135
India	70,860	2,616	37
Argentina	26,815	2,989	111
Malaysia	22,209	2,837	128
France	17,102	1,387	81
Germany	11,421	1,203	105
Romania	6,930	661	95
United Kingdom	3,161	241	76
Czech Republic	2,669	370	139
TOTAL	**1,611,304**	**121,897**	**76**

Source: prepared by the authors, using data from FAO (2018).

Note: Soil carbon stocks are not included.

Table 3 shows the vegetation and soil carbon for the major biomes. Globally, there are on average 164 tC ha^{-1} in land resources, with 31 tC ha^{-1} in soil carbon (1m depth) and 133 tC ha^{-1} in vegetation. Croplands have on global average about 2 tC ha^{-1} in vegetation, so substantial amounts of carbon are release to the atmosphere when converting forestlands, grasslands, wetlands (swamplands), including peatlands, to croplands. These values are subject to significant variations, depending on the region, the methodology applied, and soil depth.

Table 3*: Global carbon stocks in vegetation and soil carbon pools down to a depth of 1m*

Biomes	Area (10^9 ha)	Global Carbon Stocks (Gt C)			Global Carbon Stocks per unit of area (t C/ha)		
		Vegetation	Soil	Total	Vegetation	Soil	Total
Tropical forests	1.76	212	216	428	120	123	243
Temperate forests	1.04	59	100	159	57	96	153
Boreal forests	1.37	88	471	559	64	344	408
Tropical savannahs	2.25	66	264	330	29	117	147
Temperate grasslands	1.25	9	295	304	7	236	243
Deserts and semideserts	4.55	8	191	199	2	42	44
Tundra	0.95	6	121	127	6	127	134
Wetlands	0.35	15	225	240	43	643	686
Croplands	1.6	3	128	131	2	80	82
Total	**15.12**	**466**	**2011**	**2477**	**31**	**133**	**164**

Source: prepared by the authors, adapted from IPCC (2000).

Note 1 (from the authors of the original source): There is considerable uncertainty in the numbers given, because of ambiguity of definitions of biomes, but the table still provides an overview of the magnitude of carbon stocks in terrestrial systems.

Note 2: One tonne of Carbon (C) is equivalent to 3.67 tonnes of Carbon Dioxide (CO_2).

Pan *et al.* (2011) offer some alternative updated values to the IPCC suggested values in Table 3. They also estimated carbon sinks and sources for major forest biomes, as shown in Figure 3. However, as already mentioned, carbon stocks may vary significantly at national and sub-national levels, and methodology applied. Susan Ward *et al*. (2016) and Richard Bardgett (private communication, 2018), for example, have doubled the estimated carbon stocks under pasture in the UK simply by measuring down to 1 m depth (rather than just the arable fraction); whereas, Keith *et al*. (2009) have shown significantly higher carbon stocks in some temperate forests than usual values available in the literature. Notwithstanding these uncertainties, it is clear that the carbon stock changes and the biodiversity losses associated with these land use changes are high. It is unlikely that the further refinement in the numbers will reduce the importance of assessing LUC-risk (either directly or indirectly) on high carbon stock lands.

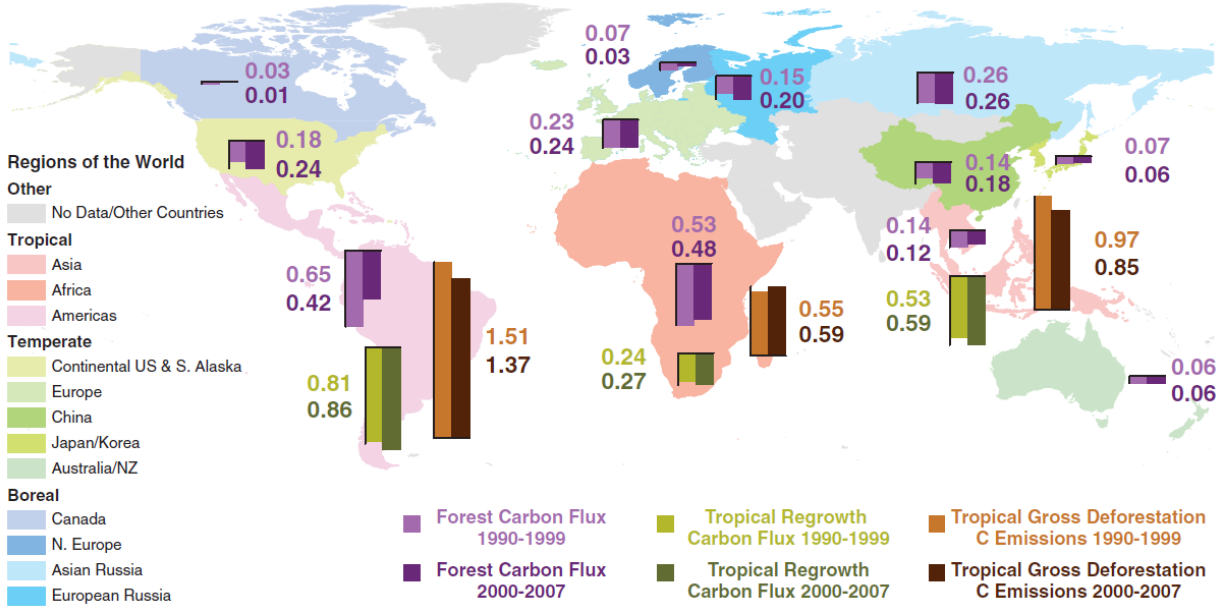


Figure 3: Carbon sinks and sources (Pg C year^{-1}) in the world's forests.

Notes (from the authors of the original source): coloured bars in the down-facing direction represent C sinks, whereas bars in the upward-facing direction represent C sources. Light and dark purple, global established forests (boreal, temperate, and intact tropical forests); light and dark green, tropical regrowth forests after anthropogenic disturbances; and light and dark brown, tropical gross deforestation emissions.

Source: Pan *et al.* (2011).

Land use classifications used in most of this report are based on FAO (2018), unless otherwise stated, as shown in the definitions in the annex. We note that there are uncertainties associated with the definition of "other land", which excludes from the total territory of a certain country all the other land use categories (e.g. forestlands, croplands and pasturelands). It is usually comprised of lands with ice cover, ice sheets, deserts, settlements and infrastructure (e.g. roads, ports etc.). However, there is a risk that "other land" may also include types of degraded lands not considered as arable land, pastureland or forestland, and which may have high-carbon content. For example, it is not clear if "upland shrub and grasslands" or "swamp shrub and grasslands" as well as "bare soil" are included in this category or not. Bare soil is described by Gunarso *et al.* (2013) as bare rock, gravel, sand, silt, clay, or other exposed soil, and it often includes recently cleared (deforested) areas, landscapes impacted by fire and portions of estates undergoing replanting procedures.

In order to assess future land use change impacts of biodiesel production, including ILUC-risk, the following sections show key figures on land use change for the production of oil crops (soybean, oil palm and oilseed rape) by nation, including discussions on the potential expansion over forestlands and peatlands, i.e. areas with high carbon content.

2.3. Soybean

Four nations supply 85% of the world soy production: Argentina, Brazil, China and the United States (Figure 4). While Argentina, Brazil and the USA are net exporters of soybean, China is a substantial net importer, especially as a high-protein source for livestock production domestically. Brazil trades most of its soybean production to China, usually bulk exports.

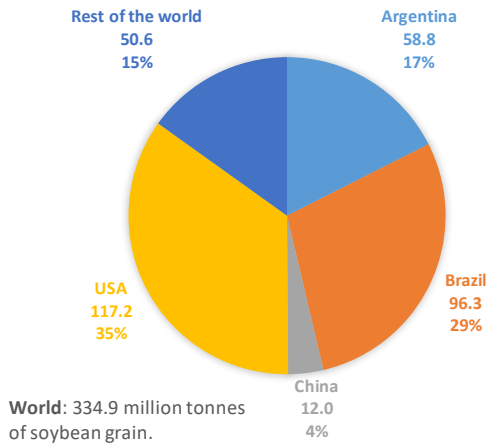


Figure 4: Soybean production (grains), in million tonnes (2014 base year).

Source: Prepared by the authors, using data from FAO (2018).

All these nations have also been increasing soy oil production from 1990 to 2014, according to the FAO (2018), see Figure 5. World production increased 187% in this period, Argentina at 520%, Brazil at 178%, China at 1216% and the United States at 65%. All other nations combined grew at 77%. This clearly demonstrate that soybean oil has a growing importance in the word vegetable oil market, as the main co-product of the soybean protein chain used for animal feed.

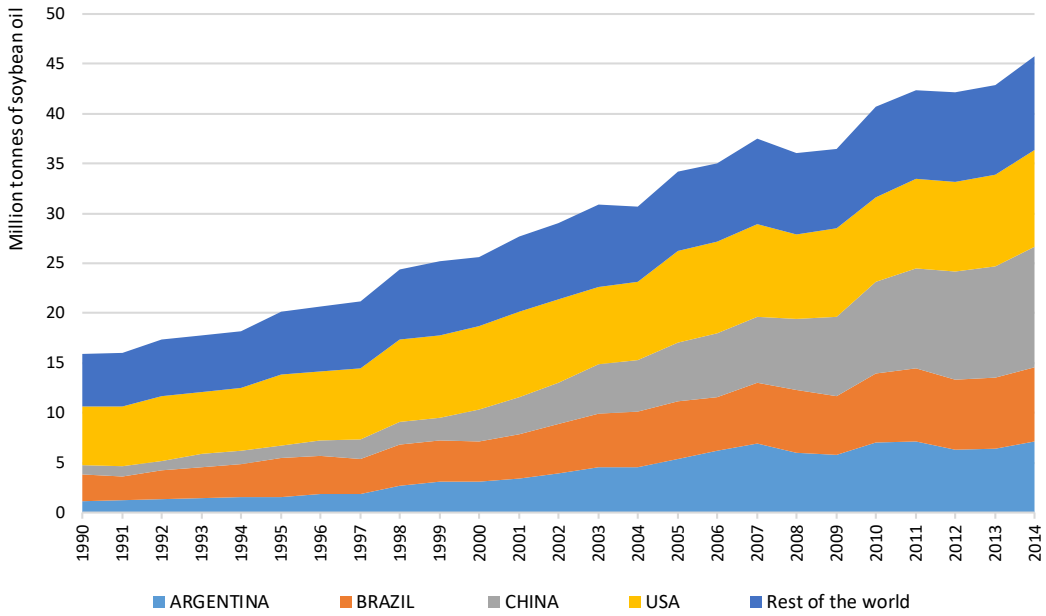


Figure 5: Production of soybean oil in selected nations and rest of the world.

Source: prepared by the authors, using data from FAO (2018).

The expansion of soybean production may have different levels of land use impact, depending on the producing country and level of technology applied. WWF (2014) assessed the impacts of soybean expansion in South American countries (including Argentina and Brazil) and found strong correlations with deforestation rates at different levels. Crop yields may also substantially vary not only per country, but per county level, because of differences in climate and soil conditions, among other factors. Figure 6 shows geographic differences in soybean productivity in the United States, Brazil and Argentina.

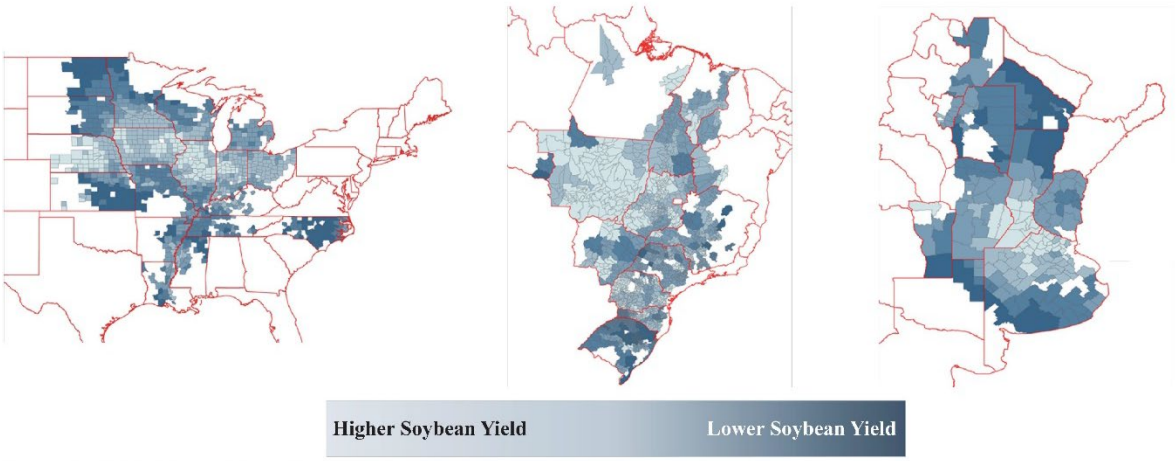


Figure 6: Soybean yield maps by county in the USA (left), Brazil (center) and Argentina (right).

Source: Bioceres (2015), using data from USDA, Ministry of Agriculture, Livestock and Fishing, Brazilian Institute of Geography and Statistics.

Note: yield data averaged from 2004 to 2014 by country.

The EU domestic production of soybean is small compared to the world production. On the other hand, the EU is a substantial net importer of soybean in the form of grains (bulk imports), which are then processed locally into soymeal (mostly for animal feed) and vegetable oil (mostly for the food industry, and a small fraction converted into biodiesel). Figure 7 show the soybean trades in Europe in the form of grains. Data from 2004 to 2013 refer to EU-27, whereas from 2014 to 2017 refer to EU-28. Small variations of imports/exports/crushing are often related to changes in stocks. Total imports have slightly oscillated from 2004 to 2017.

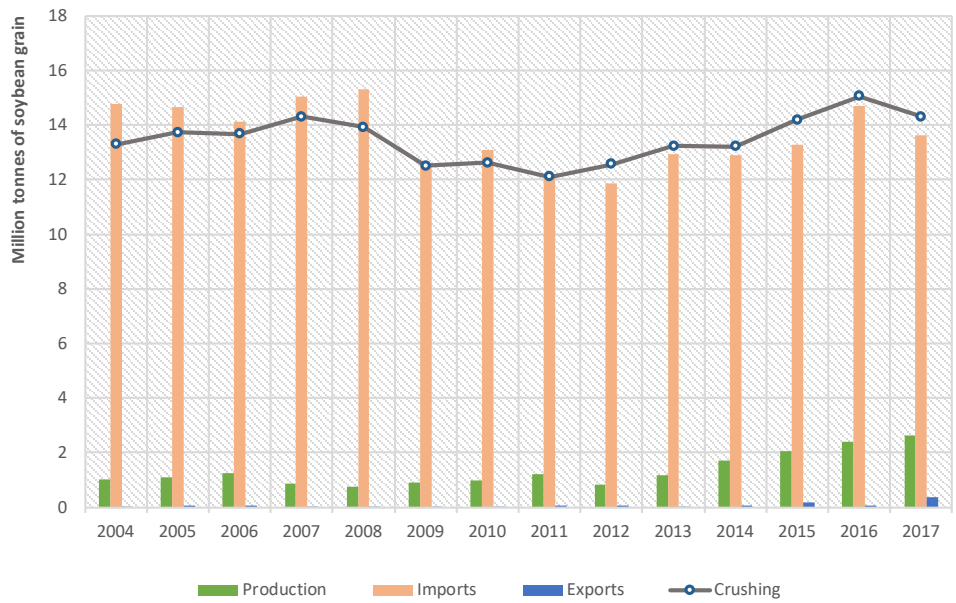


Figure 7: EU soybean grain trade.

Source: prepared by the authors, based on Eurostat (2018).

The EU imports substantial amounts of soymeal (Figure 8) for feed. It also has a stable local production of soymeal mostly produced from imported grains. EU soymeal exports are small at a global level. EU soymeal exports are small at a global level. Soymeal consumption has slightly decreased from 2004 to 2017, but the EU remains very dependent on this source of high-protein feedstock for feeding its local livestock production for meat, milk and eggs. Around 35-50% of the soymeal (dry matter) is made of protein (Landgraf, 2015; Pípolo *et al.*, 2015). Soybean and maize (corn) are the main sources of animal feed worldwide.

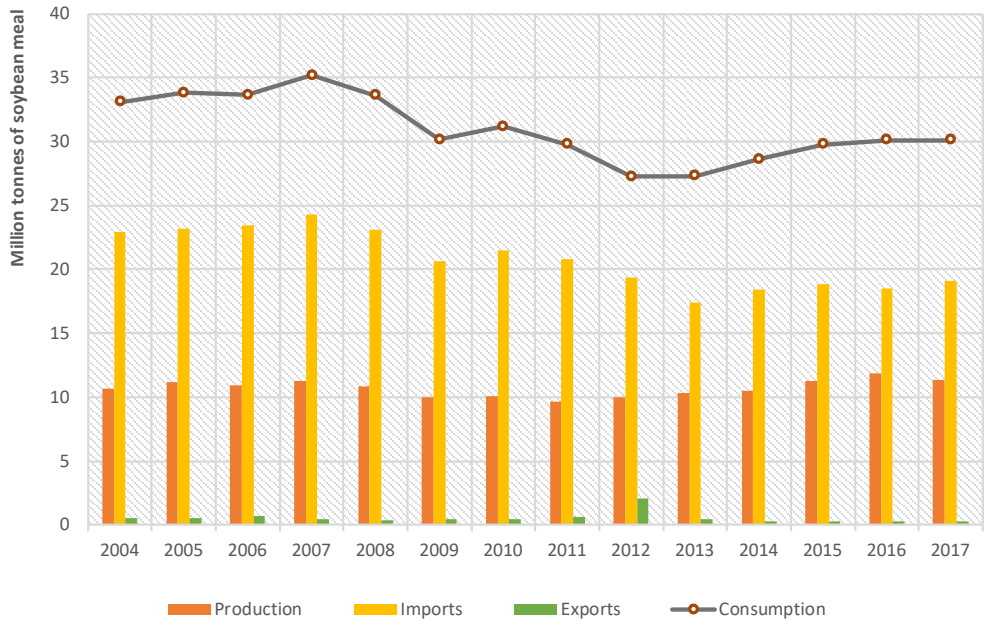


Figure 8: EU soymeal trade.

Source: prepared by the authors, based on Eurostat (2018).

The EU produces considerably more soy oil than it imports. Domestic production comes mainly from processing the soybean grains imported. After crushing, the oil is extracted as a co-product from the meal production. Soybean has about 21% of oil in its grain, in terms of dry matter (Pípolo *et al.*, 2015). Apparently, the EU re-exports some of the soybean oil from imported soy crushed in EU, because there is not enough demand neither for soy oil as a biodiesel feedstock nor for genetically-modified (GM) soy oil to use all the soy oil from EU crush. As previously shown in Figure 2, the use of soybean oil for biodiesel production in the EU is relatively small (about 2% of total feedstocks). This is not the case of Argentina and Brazil, which have been using soy oil as the major feedstock for their national biodiesel programmes. The EU consumption of soy vegetable oil varies over time, but has slightly increased from 2011, reaching about 2 million tonnes in 2017 and similar to 1994 levels. The following sections provide a country level description for the four major soybean producers, i.e. Argentina, Brazil, China and USA.

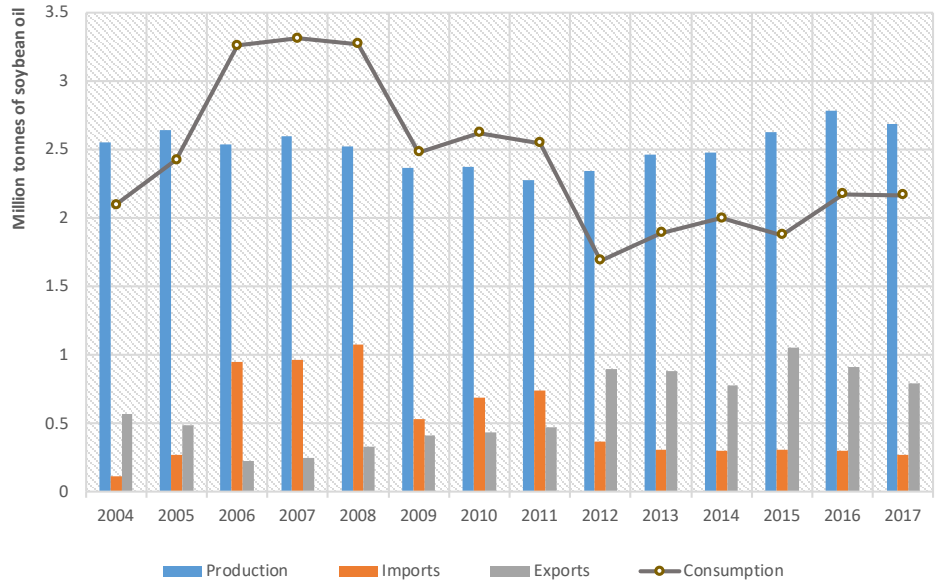


Figure 9: EU soybean vegetable oil trade.
Source: prepared by the authors, based on Eurostat (2018).

2.3.1 Argentina

Argentina is the world's 8th largest nation, with 278 Mha of total territory. The country has a substantial area of non-productive land, such as ice covers and sheets (including in the Andes Mountains), deserts (e.g. Patagonia), and parts of the Chaco area. Some of these non-productive lands have been gradually converted into commercial agricultural lands, especially since 2001. Figure 10 shows changes in land use distribution in Argentina over time. Currently, pastureland for animal grazing is the dominant land use.

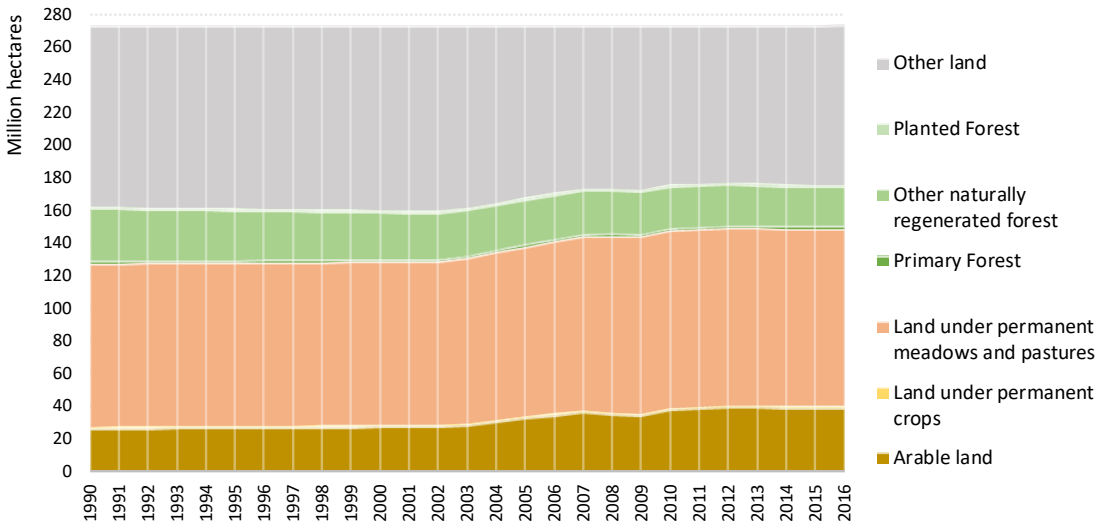


Figure 10: Land use in Argentina.

Source: prepared by the authors, based on data from FAO (2018).

Recent land use changes in Argentina have occurred over forestlands as well as Chaco, which had its total area decline almost linearly in the past decades, as shown in Figure 11. Pastureland and cropland have both expanded (also near linearly) in the same period, while also directly or indirectly affecting these land use changes observed in forestlands and possibly in "other land" too (see land use descriptions in annex). Soybean is a major annual crop in Argentina, one of the biggest exporters of these grain. Soybean consumption is mostly dedicated for protein markets. Biodiesel is a small fraction of the vegetable oil chain. Soybean oil is the major feedstock for the Argentinian biodiesel programme.

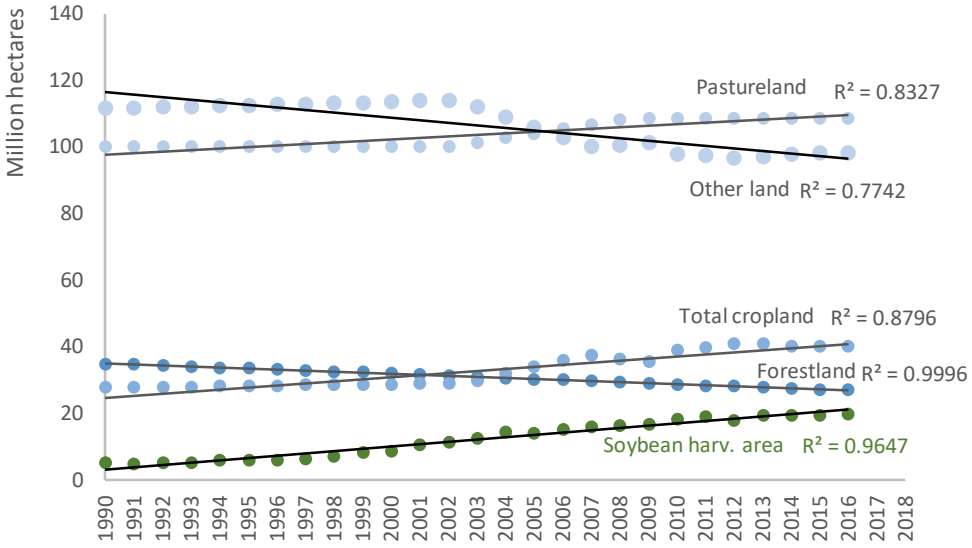


Figure 11: Dynamics of productive land use and forestlands in Argentina, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

Argentina established a new forest code (*Ley de Bosque Nativo*) in 2007. Since then, the country was expected to reduce its deforestation rates, but the problem continued. In just seven years (2007-2014) five million hectares of native vegetation were lost, with 90% of the deforestation occurring in the North Region, including the Gran Chaco area (Larraquy, 2016). The country produces soybean in different states,

from North Region (e.g. States of Salta, Chaco and Formosa) to Centre Region (e.g. States of Cordoba, Santa Fe, Buenos Aires and La Pampa), as shown in Figure 12. Among other initiatives to reduce deforestation related to the cultivation of soybean, the **Round Table on Responsible Soy** – RTRS (2018) sets standards for its sustainable production. The RTRS is a civil organization which promotes responsible production, processing and trading of soybean at global level, but had limited success to date (Goni, 2018).

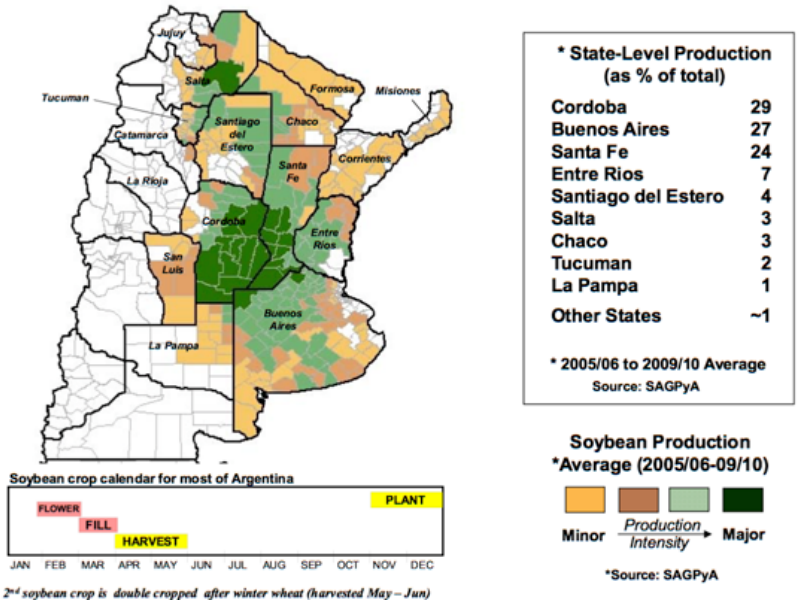


Figure 12: Map of soybean production areas in Argentina.

Source: USDA (2016)

According to OECD & FAO (2017) forecast, soybean production will keep increasing in Argentina in the coming years. However, its crop yields have also been increasing in the past decades and tend to keep increasing in the coming decades, too, given to its high agronomical potential still under explored and far from its photosynthetic limits. Productivity gains could be achieved through the use of better crop varieties, best practices of agricultural management, biotechnology, crop integration, agronomical assistance for farmers, and use of new agricultural technology. Assuming that soybean yields will keep increasing approximately linearly in the coming dates, Figure 13 shows the required area to meet the OECD & FAO projections. In this proposed simulation, soybean area may vary around 20 Mha in the coming years and, therefore, reducing the pace of its expansion rate. Moreover, Argentina still has potential to increase land use integration via multiple cropping.

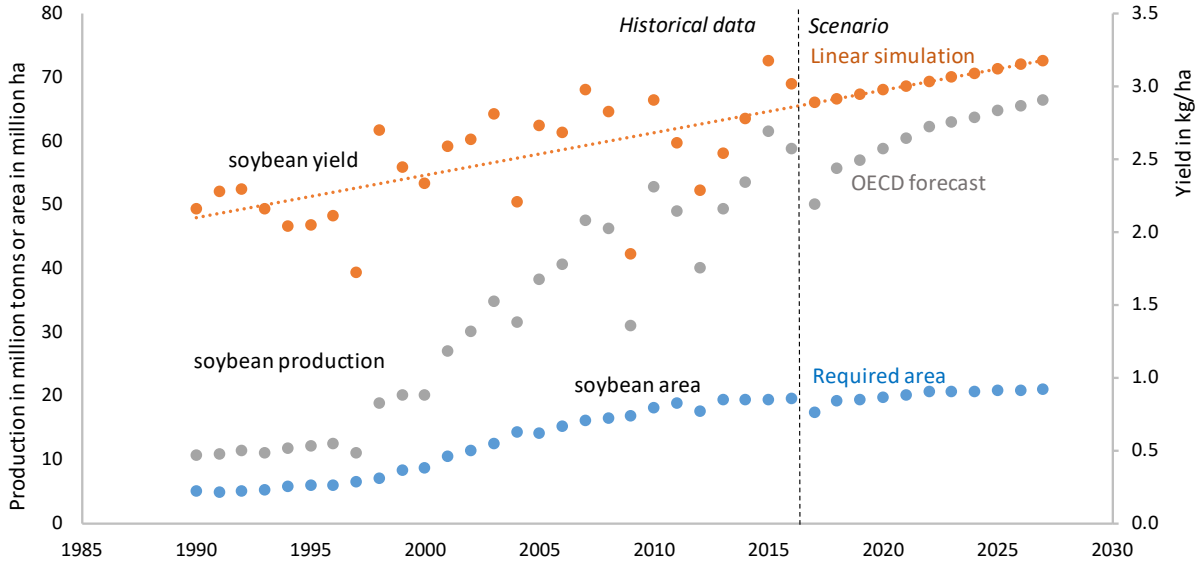


Figure 13: Soybean area, production and yields in Argentina, and future simulations.

Source: prepared by the authors, based on data from FAO (2018) and OECD & FAO (2017) forecast for soybean production.

Crop yields in Argentina have been increasing for all its major crops (Figure 14). On the other hand, soybean area has been increasing at a much faster rate than other major crops in the country (Figure 15), impacting on the increase of total cropland more broadly. The Argentinian environmental legislation, among other things, aims at reducing the deforestation rates observed in many biomes across the country. The country has made significant advances in terms of surveillance and policy regulations. Nevertheless, it still has shown high net deforestation, caused by several factors, including soy expansion in some areas, which has partially expanded even over critical wetlands (Herrera *et al.*, 2013). Hence, there is a clear risk of non-compliance of the existing environmental law (NEPCon, 2017).

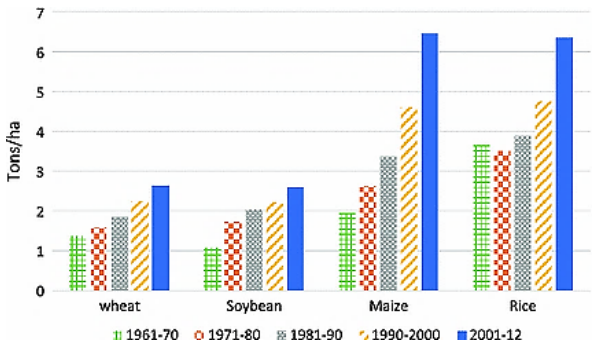


Figure 14: Crop yield growth in Argentina for major crops.

Source: Bouza *et al.* (2015)

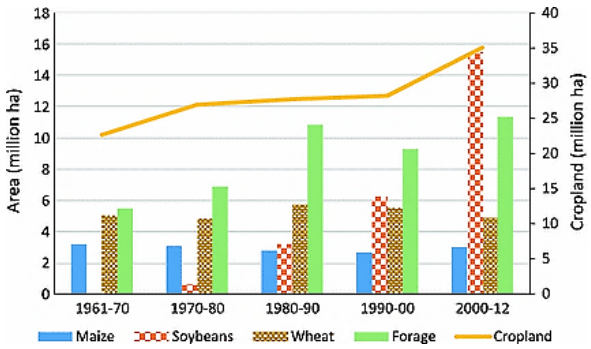


Figure 15: Harvested area and total cropland in Argentina for major crops.

Source: Bouza *et al.* (2015)

Argentina increased its soy production from 8.6 million ha in 2010 to 19.5 million ha in 2016, i.e. an increase of 10.9 million ha in this period, according to official data from the FAO (2018). In the same period, total cropland increased from 28.6 million ha (2010) to 40.2 million ha (2016), with a delta of 11.6 million ha; whereas total pastureland increased respectively from 99.9 million ha (2010) to 108.5 million ha (2016), with a delta of 8.6 million ha. Thus, while looking only at the productive lands combined (i.e.

croplands and pasturelands altogether), cropland was equivalent to 57% of the total agricultural land, whereas pastureland 43%, both in 2016. Conversely, forestlands decreased from 31.7 million ha (2010) to 26.8 million ha (2016), i.e. 5 million ha were deforested (net deforestation). Based on these data, and considering that the deforestation was driven mainly from part of the total expansion of croplands and pasturelands, keeping the area same proportion as in 2016, as well as the share of soybean in total croplands, it is possible to estimate that approximately 28% of the total expansion of soybean may have occurred over forestlands (see also Figure 11 against Figure 14 and Figure 15). This rough estimate has a low confidence interval, and its accuracy could be improved via field assessments and satellite monitoring, as a recommendation for future studies. On the other hand, this trend may not necessarily keep occurring, due potential soy yield gains expected for the coming years against demand forecasts, as earlier shown in Figure 13.

From 2007 to 2016, Argentina's soybean area expanded approximately 352 kha/year (FAO, 2018), out of which 99 kha/year occurred over native vegetation (i.e. 28%, as earlier estimated). Considering the carbon stocks associated with croplands and forestlands, for both above ground vegetation and soil C, as previously described in Table 3, it is possible to estimate the carbon footprint for this yearly expansion in critical areas. Assuming that the soybean area has approximately the carbon amount stated for "cropland" (on average) and that the expansion occurred over areas with an average carbon stock similar to "tropical forestland" (on average), the soy expansion over native vegetation has emitted about 41 $MtCO_2eq\ y^{-1}$, including changes in soil C.

In terms of total emissions, Figure 16 shows that agriculture, forest and other land use (AFOLU) in Argentina are a major source of greenhouse gas emission in the country, more notably CH_4 and N_2O from livestock production and CO_2 emission due to land use change.

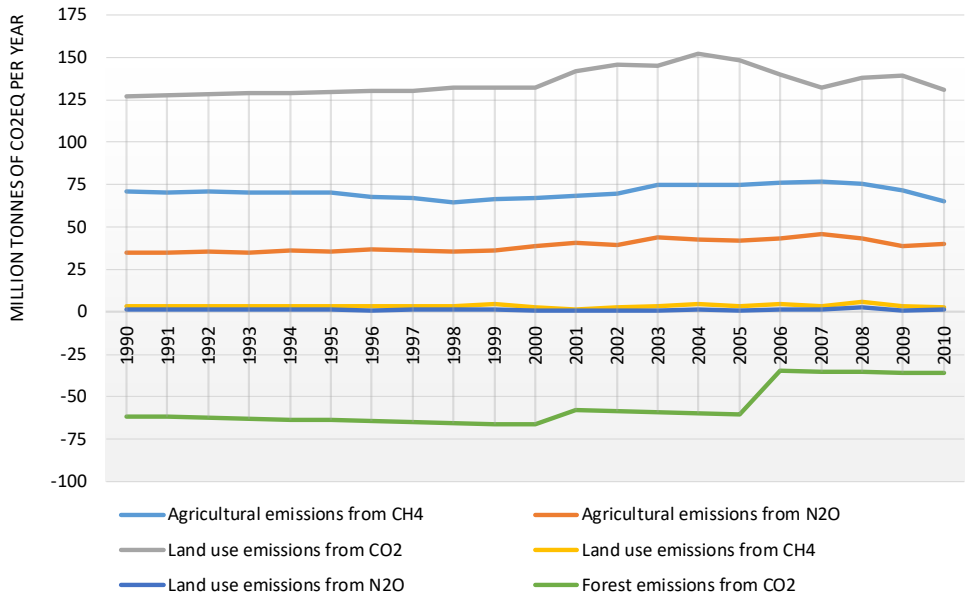


Figure 16: Greenhouse gas emissions from agriculture, forestry and other land uses (AFOLU) in Argentina.

Source: prepared by the authors, based on data from FAO (2018).

Note: Abrupt changes in emissions may result from changes in reporting protocols.

2.3.2 Brazil

Brazil is the 5th largest country in the world, with a total territory of 851 million hectares, being 835 of total land area. Figure 17 illustrates land use change in Brazil since 1990. Apart from the substantial deforestation occurred in the past decades, the country still holds more than half of its territory as forest, including the Amazon (humid equatorial forest), Cerrado (savannah-like biome), Pantanal (swampland), Caatinga (semi-arid land) and Atlantic forest (humid tropical forest). Similar to Argentina, pastureland is the dominant use of productive land.

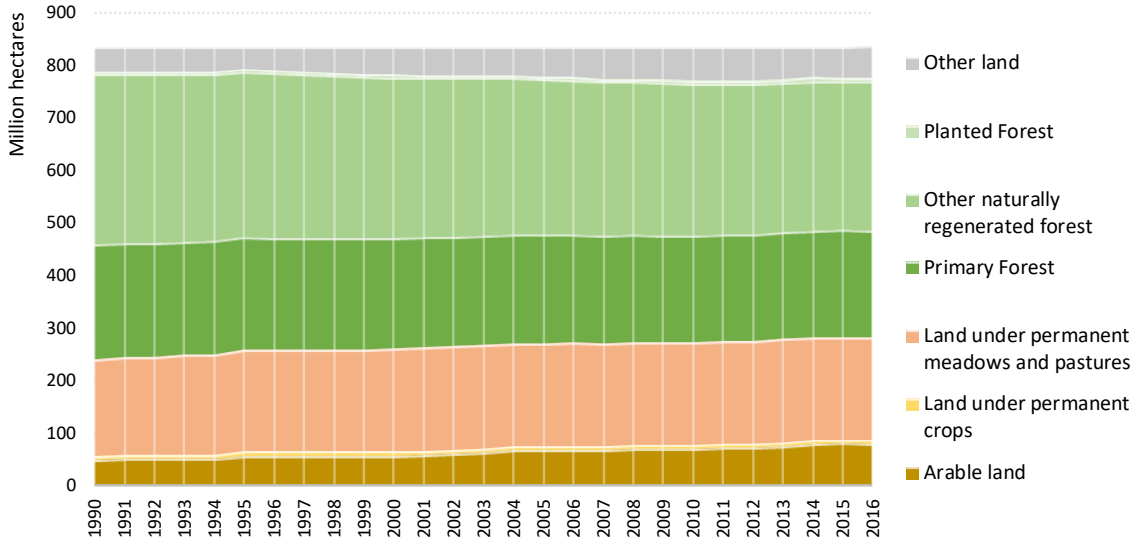


Figure 17: Land use change in Brazil

Source: prepared by the authors, using data from FAO (2018)

The dynamics of pasturelands in Brazil has varied substantially over time, whereas cropland (including soybean area) has been increasing approximately linear in the past decades, and forestland has decreased, as shown in Figure 18. Soybean is the most important crop in Brazil (approx. 38% of total cropland), alongside maize, sugarcane, coffee, cotton, wheat, rice, black beans (and other varieties), orange, apple, banana and other fruits, as well as potato, tomato, onions and horticulture more broadly.

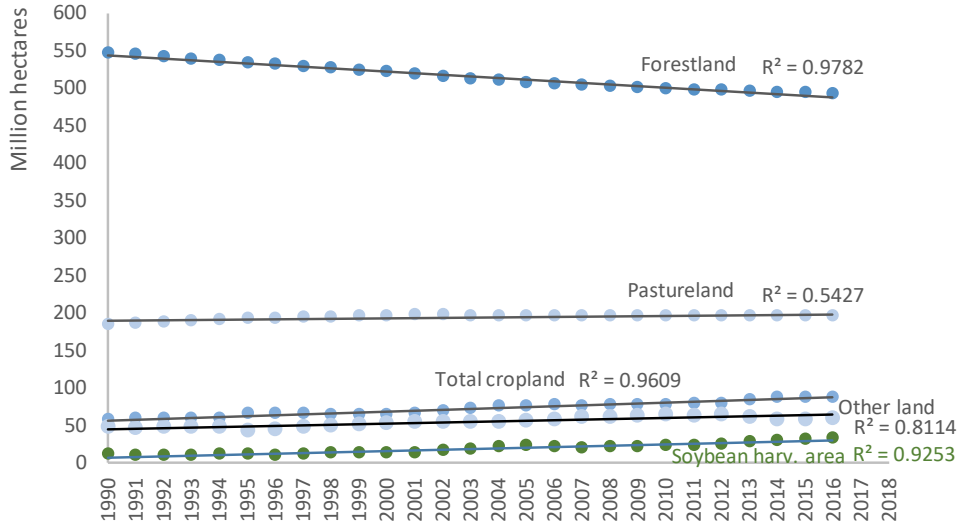


Figure 18: Dynamics of productive land use and forestlands in Brazil, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

Soybean has increased in Brazil not only in terms of total production, but also in terms of agricultural yield, with a clear potential to keep increasing in the coming years, possibly at a nearly linear rate. Considering the OECD & FAO (2017) forecast for soybean production in Brazil, and a linear simulation for crop-yield growth, the soybean-land expansion rate may (or may not, if forecasts are wrong) slow down and stabilise in the coming years, as shown in Figure 19.

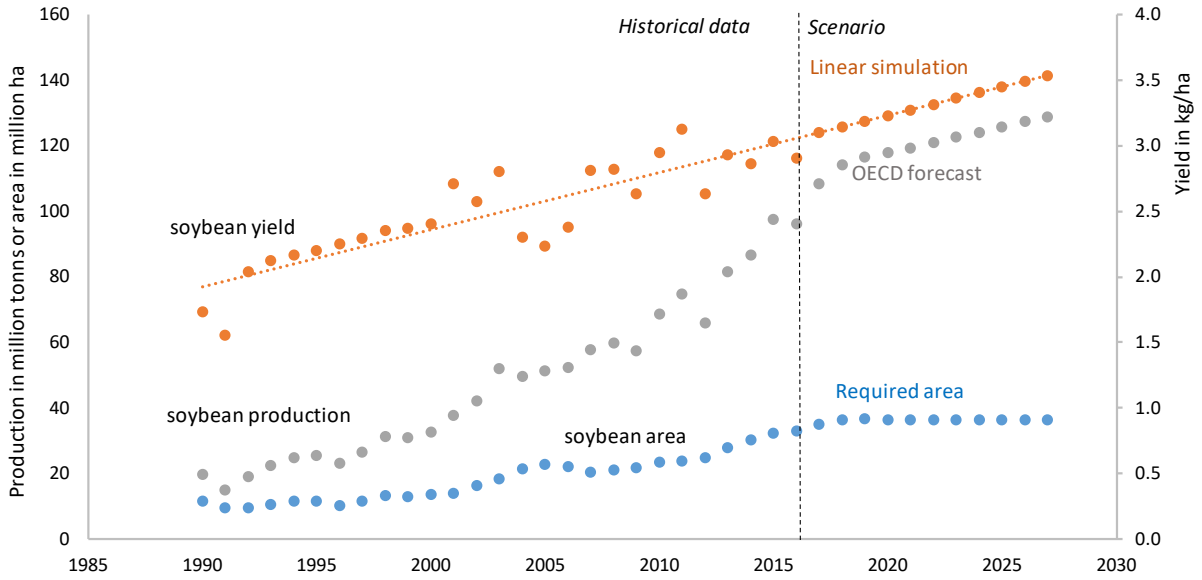


Figure 19: Simulation of land use change for soybean production in Brazil

Source: prepared by the authors, using data from FAO (2018), and OECD & FAO (2017) forecast for soy production.

Brazil uses part of its domestic production of soybean oil to support its biodiesel programme, which currently uses mandatory blends of 9% of biodiesel (B9) into conventional diesel nationwide, expected to increase at 10% (B10) from 2019. Soybean oil is the dominant feedstock used for biodiesel production in Brazil, followed by the use of animal fat from the livestock industry, and other crops of much lower importance for its biodiesel programme, such as *Jatropha curcas* (aka "pinhão-manso" or simply jatropha), oilseed rape, sunflower, cotton (core), oil palm (different species) and other vegetable oil sources. Soybean oil is considered a co-product from the soy meal industry, which is already well established in the country. Moreover, Brazil has an international benchmark ethanol programme, based on sugarcane ethanol, which has been used not only in fuel blending with gasoline (varying from 18% to 27.5% of anhydrous ethanol, currently set at 27%, i.e. E27) nationwide, but also as pure ethanol (E100 of anhydrous ethanol) in flex fuel vehicles (Otto-cycle engines). The expansion of sugarcane is regulated by a pioneering national Sugarcane Agroecological Zoning (AEZ), established in 2019 and which impedes the expansion of sugarcane industries over native forestlands, swamplands and other sensitive areas (Strapasson *et al.*, 2013). Brazil is the second largest biofuel producer, just behind the United States. Pacini and Strapasson (2012) prepared a comparative assessment to understand if the EU standards and requirements for biofuel production affected the Brazilian ethanol programme, but little correlation was found, apart from the fact that the Sugarcane AEZ was partially stimulated for meeting international requirements of sustainable biofuel production. The country currently implements its new national biofuels policy called RENOVABIO, which includes actions to foster carbon mitigation, such as the use of certified green bonds from decarbonisation credits called CBIOs (Grassi and Pereira, 2018). Brazil is one of the global leaders of the Biofuture Platform as well.

Soybean production in Brazil was initially concentrated in the South and Southeast Regions, but in the past decades it has substantially expanded over Centre-West and North Regions. According to the Brazilian National Food Supply Company - CONAB (2018), in the 2017/2018 crop season, Brazil produced around 117 million tonnes of soybean grain, harvesting 35 million ha and, therefore, reaching a mean productivity of 3.3 tonnes/ha. Brazil consumes 59 million tonnes of soy grains, and exports 68 million of soy grains, 14 million tonnes of soymeal and 1.3 million tonnes of soy vegetable oil to several nations, but mainly China. The State of Mato Grosso, which located in the North Region, is the production leader (32 million tonnes), followed by the States of Paraná (19 million tonnes) and Rio Grande do Sul (17 million tonnes), both in the South Region. The States of Goiás and Mato Grosso do Sul (both in Centre-West) and the State of Bahia (Northeast) are also large soybean producers.

Although most of the soybean production in Brazil occurs in consolidated agricultural lands and far from the boarders of native forests, significant expansion areas have affected biomes such as the Amazon and Cerrado. Most of its recent expansion occurred in the State of Mato Grosso (MT), for example, and this includes areas in the so-called 'Amazon deforestation arc'. In fact, Amazon deforestation has been caused by several complex reasons, which have different dynamics according to the region (Strapasson, 2014). In general, the main causes of deforestation in the Amazon region are: livestock expansion (sometimes followed by soybean few years later, but not necessarily); illegal timber; land tenure issues; difficulties for surveillance, patrolling, and legal enforcement at local level; local corruption and criminality; and illegal mining. In this region, deforestation is often made by firstly removing the profitable wood types, then burning the remaining biomass, followed by cattle ranching. In fact, some areas cannot be immediately ploughed by machines due to hard biomass materials remaining in the soil after deforestation (e.g. root system of tree species) and in areas often with poor infrastructure (e.g. road access), and this partially explains why livestock is the main land use vector over deforestation in a first instance. Deforestation is also related to the opportunity cost of keeping the forest conserved vs. deforesting for other land use purposes. On the other hand, Brazil's international commitments (e.g., UNFCCC and UNCBD agenda) should go beyond Amazon surveillance (Teixeira, 2018).

Barona *et al.* (2010) assessed the role of pasture and soybean in Amazon deforestation from 2000 to 2006 (Figure 20). The authors used only statistical methods and without establishing causation, but concluded that "*The proximate cause of deforestation in the Legal Amazon was predominantly the expansion of pasture, and not of soybeans. However, in Mato Grosso, an increase in soybeans occurred in regions previously used for pasture, which may have displaced pastures further north into the forested areas, causing indirect deforestation there. Therefore, soybean cultivation may still be one of the major underlying causes of deforestation in the Legal Amazon.*" It is worth noting that some Amazon areas has some large municipalities, which may distort the visual interpretation of impacts in this figure. Although not conclusive, the results present concerns about the soybean expansion in some critical regions of the Brazilian territory.

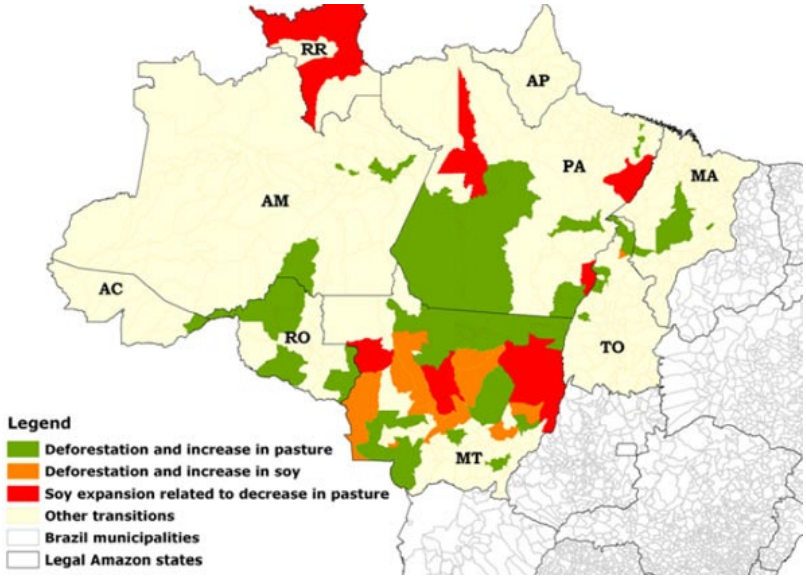


Figure 20: Amazon deforestation dynamics in Brazil.

Source: Barona *et al.* (2010).

On the other hand, only a small part of the total soybean production in Brazil comes from areas near the Amazon's 'arc of deforestation'. Most farmers are not directly responsible for the Amazon deforestation and have been producing soybean in consolidated agricultural areas for many years, especially in the Brazil's South, Southeast and Centre-West Regions, and usually quite far from the North Region, where the Amazon is located. In addition, Brazil has succeeded in obtaining a substantial reduction in the Amazon deforestation in the past 15 years. However, deforestation rates recently oscillated and increased again in the last assessments (Phillips, 2018), with the States of Pará, Mato Grosso, Rondônia and Amazonas presenting the worst indexes, and with 25%-30% of deforestation occurring in public forests.

The implementation of zoning schemes, better surveillance systems and the **soy moratorium** have contributed to the reduction in the Amazon deforestation rates. The soy moratorium, in particular, obtained successful results during its time of implementation. It was a temporary initiative, signed in 2006 and which has already expired, but it was a pioneering environmental agreement settled between major soybean producers' associations in Brazil[1], and environmental NGOs[2]. In this agreement, the producers' association committed that their affiliated members would neither produce nor trade soybean originated from Amazon deforestation areas (planted as of October 2006). Rudorff *et al.* (2011), by using satellite image data, assessed the impacts of the soy moratorium on the Amazon, and concluded that "*the initiative has certainly exerted an inhibitory effect on the soybean frontier expansion in this biome*". Similarly, Gibbs *et al.* (2015) in a study published in *Science* showed that the Soy Moratorium was five times more effective in reducing deforestation in the Amazon, than the Brazilian Forest Code.

However, the deforestation of Cerrado is also a major issue, which is often neglected or less discussed than the Amazon deforestation. Currently soya represents 90% (15.6 Mha) of the crops in the Cerrado biome. In the 2013/2014 crop season, 52% of soy harvested was concentrated in the Cerrado. Between

[1] The Brazilian Vegetable Oil Industry Association (ABIOVE - *Associação Brasileira da Indústria de Óleos Vegetais*) and the Brazilian Association of Cereal Exporters (ANEC - *Associação Brasileira dos Exportadores de Cereais*).

[2] Greenpeace, WWF, Amazon Environmental Research Institute (IPAM), The Nature Conservancy (TNC).

2000 and 2014, soy production in the MATOPIBA[3] region increased from around 1 Mha to 3.4 Mha, a growth of 253%. A geospatial assessment by Agrosatelite (2015) looked at more than 2500 satellite images in 204 Mha in the Cerrado biome. This assessment allowed the researchers to understand the dynamic of the harvested area, its expansion and the correlation to land use change in the region between 2000 and 2014, period of largest soy expansion in the region, as also shown by Carneiro Filho & Costa (2016). The largest expansion in the MATOPIBA Region was on native vegetation – 68% between 2000 and 2007 and 62% between 2007 and 2014. In the states outside the MATOPIBA region 80% of the changes (2000-2007) and 89% (2007-2014) occurred in pastures and other crop areas. Mato Grosso was an exception as the expansion occurred into native vegetation: 88% (2000-2007) and 68% (2007-2014).

The expansion of soy in the MATOPIBA region was approximately at 62% over forestlands (mainly Cerrado). In all the other states it occurred at about 11% (including Amazon, Cerrado and Atlantic Forest). MATOPIBA accounted for approximately 12% of total soy production in Brazil (2016/2017 crop season), whereas all the other states combined provided 88%. It is possible to roughly estimate that around 17% of the Brazilian soy area has expanded over forestlands in recent years, as a weighted average. Further studies would be necessary to estimate a national average more accurately, including field studies and satellite data. Moreover, according to the Brazilian Forest Code (Federal Law no. 12651, stablished in 2012), not all deforestation should be considered illegal, given that farmers are allowed to use their lands according to different proportions, depending on the biome. The impact of the recent expansion of soybean in Brazil is a controversial subject in the country (Schipani & Leahy, 2018).

From 2007 to 2016, Brazil's soybean area expanded approximately 1,259 kha y^{-1} (FAO, 2018), out of which 214 kha y^{-1} occurred over native vegetation (i.e. 17%, as earlier estimated). From the carbon stocks associated with croplands and forestlands for both above ground vegetation and soil C in Table 3 it is possible to estimate the carbon footprint for this yearly expansion in critical areas. Assuming that the soybean area has approximately the carbon amount stated for "cropland" (on average) and that the expansion occurred over areas with an average carbon amount similar to "tropical forestland" (on average), the soy expansion over native vegetation has emitted about 88 $MtCO_2eq\ y^{-1}$, including changes in soil C.

Regarding the soil carbon stocks more broadly in Brazil, the country shows a large variation across its territory (Figure 21). Despite the expansion of croplands over forestlands and pasturelands often releases soil carbon back to the atmosphere, this is not always the norm and depends on several issues, such as the technology applied. For example, soy areas can also have high carbon content, particularly when soy is produced through no-tillage systems and crop rotation, which currently occurs in most producing areas of Brazil.

[3] MATOPIBA is the name of the region formed by the Brazilian State of Tocantins (TO) and parts of the States of Maranhão (MA), Piauí (PI) and Bahia (BA).

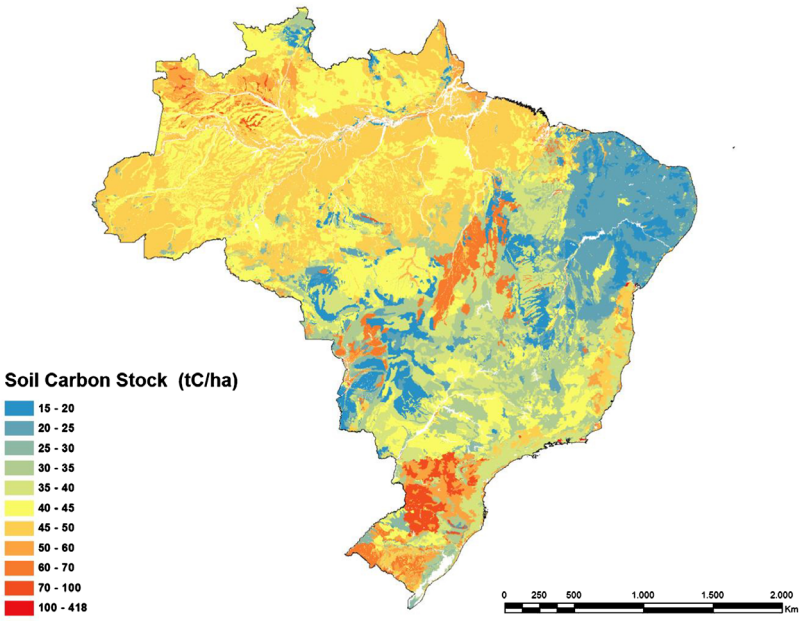


Figure 21: Variation of soil carbon stocks in Brazil

Source: Bustamante *et al.* (2018), citing Bernoux *et al*. (2002)

In terms of emissions, Brazil has significantly reduced Amazon deforestation rates from 2004, apart from recent oscillations, so that total associated emissions have also decreased. Besides, the country has increased the use of no-tillage systems, particularly for maize and soybean plantations, as well as the use of crop-livestock-forestry integration (known as "integação lavoura-pecuária-floresta"). Figure 22 shows emissions from agriculture, forest and other land use (AFOLU).

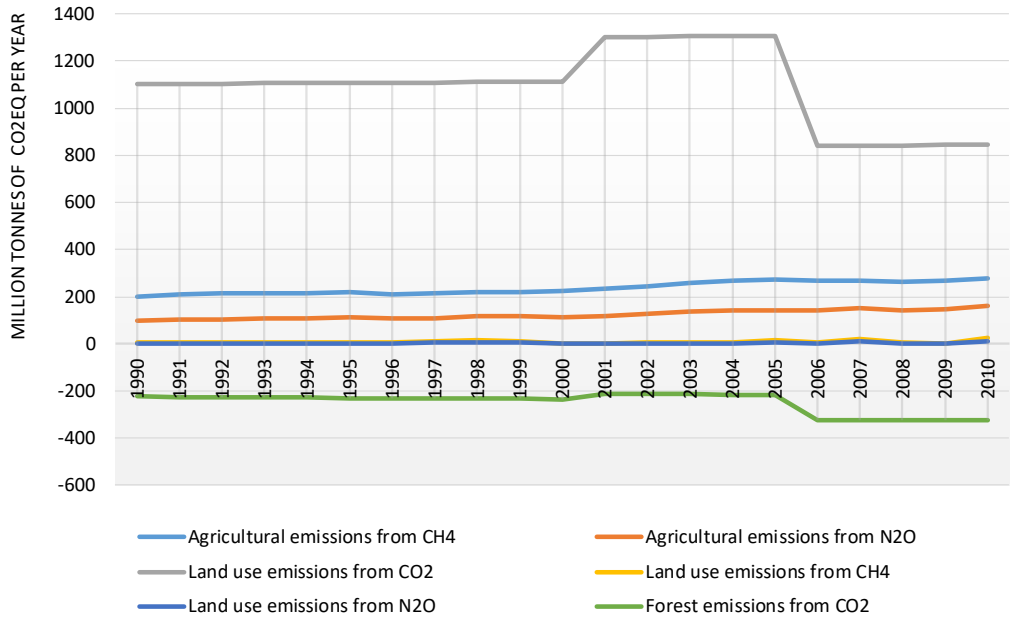


Figure 22: AFOLU emissions in Brazil

Source: prepared by the authors, using data from FAO (2018)

Note: Abrupt changes in emissions may result from changes in reporting protocols

2.3.3 China

China is the second largest country in the world with 960 million ha and the most populated with 1.4 billion inhabitants. The country faces the challenge of keeping food security while also increasing forestlands and reducing carbon emission in the AFOLU sector. The country also has a considerable area under deserts (e.g. Gobi Desert) and mountains with ice cover. Figure 23 shows the changes in land use patterns in China since 1990.

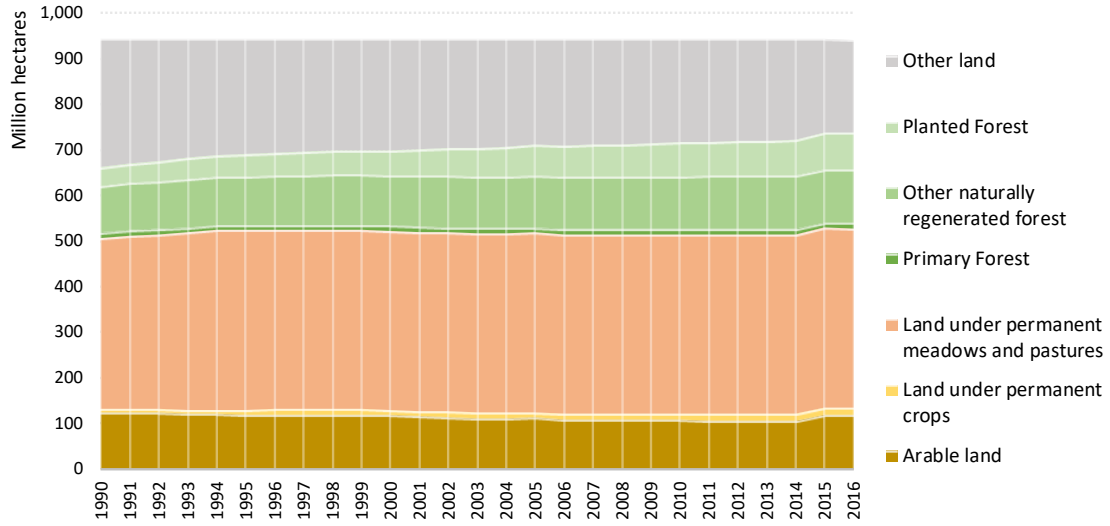


Figure 23: Land use distribution in China.

Source: prepared by the authors, based on FAO (2018) database.

As seen in Figure 24, forestlands have been linearly increasing in China in the past decades, mainly driven by planted forests, as previously shown in Figure 23. Pastureland has been almost stable, as have soybean and oilseed rape areas. China is a major importer of soybean. Total cropland has oscillated along a downward trend in the past decades, whereas other land (which includes settlements, infrastructure, among other things, see Annex) has increased.

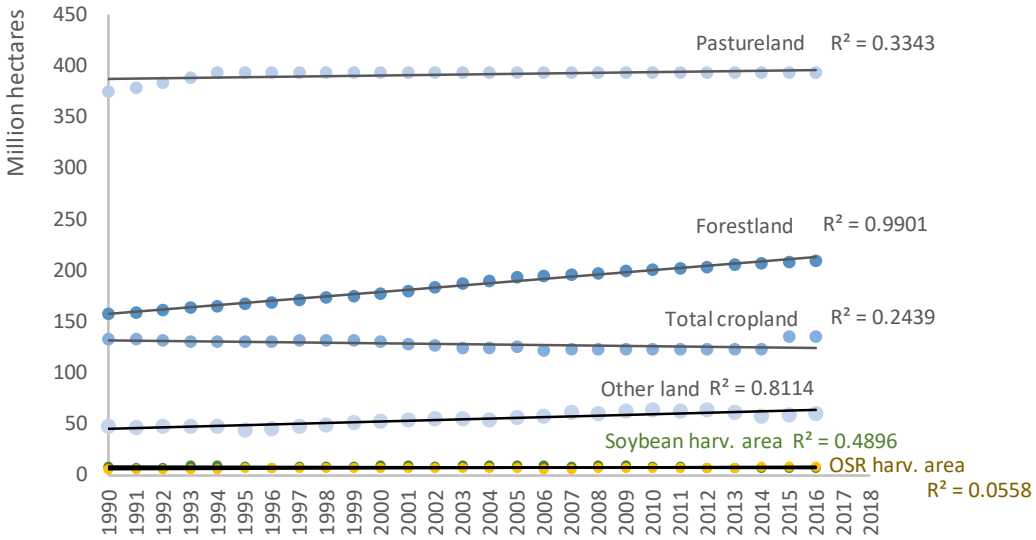


Figure 24: Dynamics of productive land use and forestlands in China, including linear regressions.

Source: prepared by the authors, based on FAO (2018) database.

Soybean production in China (Figure 25) has varied substantially in the past decades. Using OECD & FAO (2017) forecast, it is possible to estimate the area, assuming that crop yields would tend to keep increasing linearly. Therefore, in order to meet this forecast, China would have to increase its total harvest are of soybean, potentially affecting the dynamics of other crops and land uses.

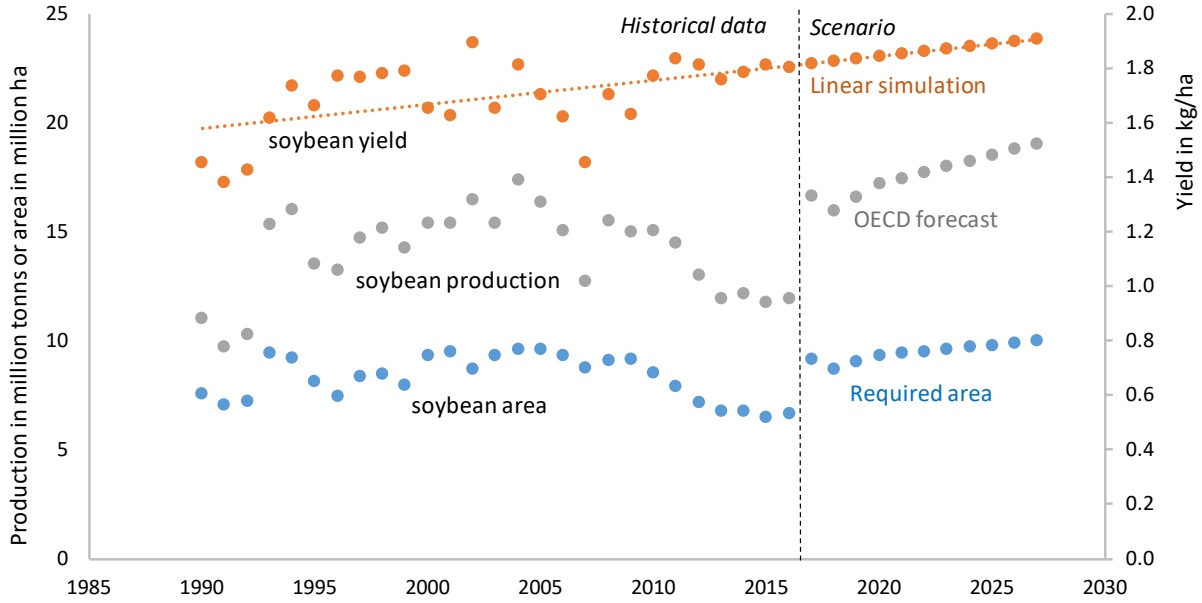


Figure 25: Simulation of land use change for soybean production in China

Source: prepared by the authors, using historical data from FAO (2018) and OECD & FAO (2017) forecast for soybean production.

In regard to the AFOLU emissions in China, total emissions from agriculture and land use have been compensated by forestlands (Figure 26). China is the largest producer of rice in the world, usually via irrigated paddy fields, and this partially explain the high methane emissions coming from agriculture.

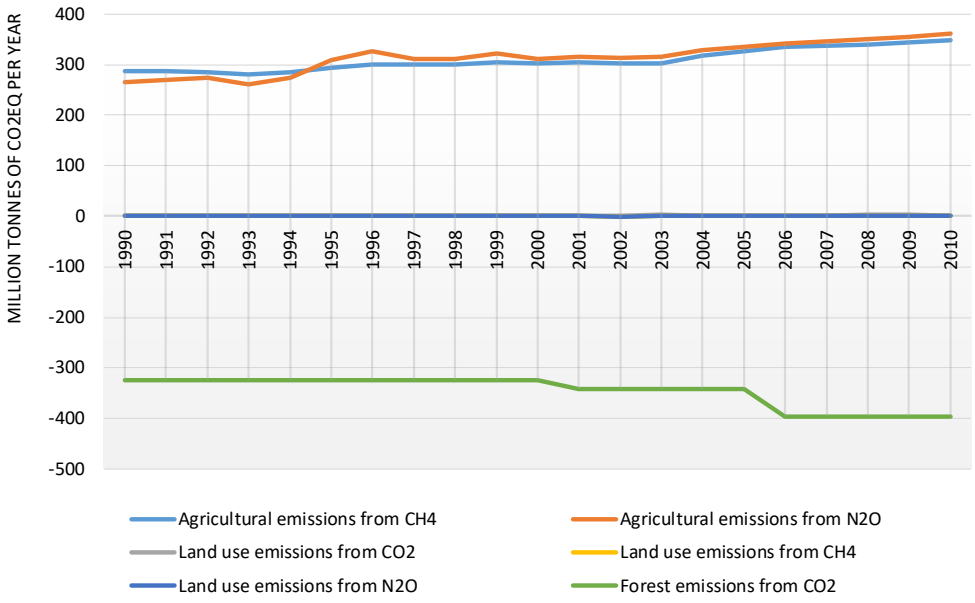


Figure 26: AFOLU emissions in China.

Source: prepared by the authors, using data from FAO (2018).

Note: Abrupt changes in emissions may result from changes in reporting protocols.

2.3.4 United States of America

The United States is the fourth largest nation at 980 million ha. Its territory has a substantial amount of unproductive land, such as deserts (e.g. Chihuahua and Mojave) and ice cover (most parts in the State of Alaska). However, the country also has highly productive lands, such as in the corn belt. Figure 27 shows change in land use from 1990 to 2016. Total primary forest has been relatively stable in past decades, although mostly deforested in the past centuries.

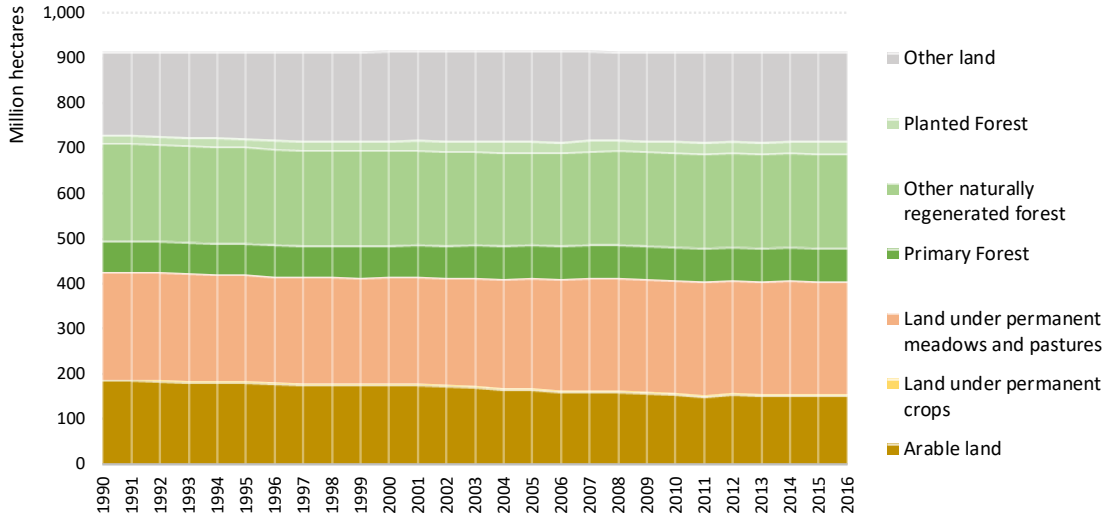


Figure 27: Land use in the United States.

Source: prepare by the authors, using data from FAO (2018).

Several land use types have changed almost linearly in past decades (Figure 28). This is the case of forestlands, which slightly increased (including planted forests), whereas total croplands substantially decreased. Oilseed rape occupies a relatively small harvested area in the U.S., but soybean area has been substantially increasing while total cropland has decreased. The country is the largest soybean producer (117 million tonnes in 2017), closely followed by Brazil (Ferreira, 2017). The US has a biodiesel programme, based on vegetable oil crops, but the most important biofuel source is corn-based ethanol. The country is the largest ethanol producer, followed by Brazil and other nations, as well as the global leader in biofuels production more broadly.

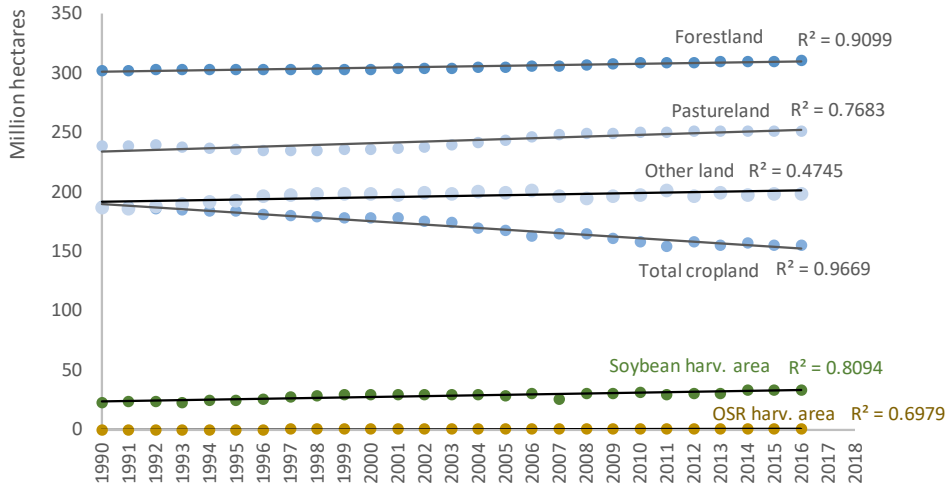


Figure 28: Changes in land use patterns in the United States, including linear regressions.
Source: prepared by the authors, using data from FAO (2018)

The OECD & FAO (2017) project a near linear expansion of soybean production in the US. Considering that the country still has agronomical conditions to keep increasing its crop yields also approximately linear, then the total required land may not be significantly affected in the coming decade (Figure 29).

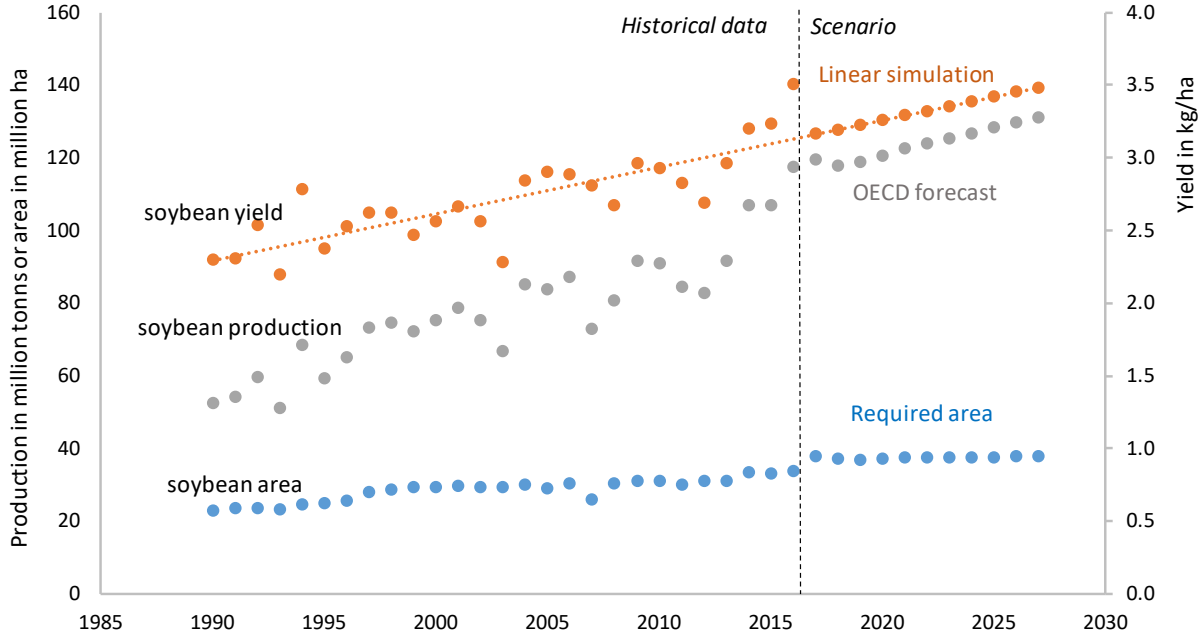


Figure 29: Simulation of land use change for soybean production in the United States.

Source: prepared by the authors, using historical data from FAO (2018) and OECD & FAO (2017) forecast for soybean production.

In terms of emissions, the AFOLU sector in the United States has not been subject to major abrupt changes, except for some changes in CO_2 emissions in land use (Figure 30). Forestlands have been acting as a substantial source of carbon sinks.

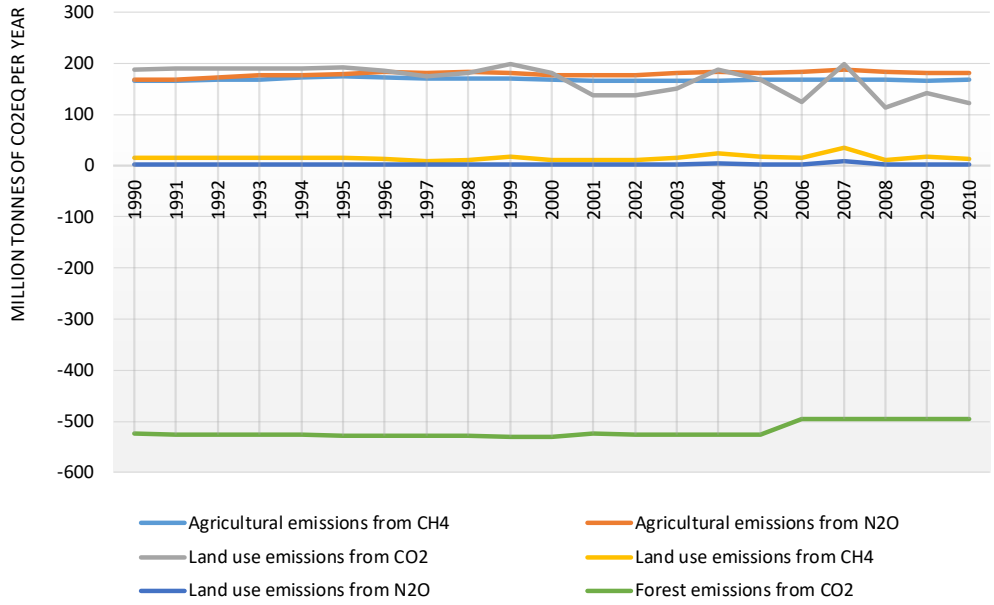


Figure 30: Greenhouse gas emissions in the AFOLU sector in the United States.

Source: prepared by the authors, using data from FAO (2018).

2.3.5. Summary for soybean oil

The production of soybean has occurred mostly on consolidated agricultural lands worldwide, especially because its global production was already high in the 2000's and, therefore, the problem is in its new expansion areas. Soy vegetable oil is a co-product from the soy production chain, which has the meal as its core business. Among the assessed countries, China is a net importer, whereas Argentina, Brazil and the United States are net exporters. China has substantially increased its forestlands. The United States has also increased the total area of its forestlands, although marginally. Hence, China and the USA have shown no correlation between soybean expansion and the depletion of natural vegetation lands, which usually have high carbon stocks. On the other hand, in some subnational regions of Argentina and Brazil the expansion of new soybean fields has clearly occurred over forestlands, including in areas with high carbon stocks. However, it is also important to recognise that most of the total production of soy in both countries has also occurred in consolidated areas (i.e. not derived from recent expansion over forestlands) and, therefore, most of farmers are not responsible for recent direct deforestation at all. At the same time, looking at the recent expansion of soy in these countries, the impacts on lands with natural vegetation have been substantial.

Table 4 gives an overview on the potential relationship between soybean expansion and their potential impacts on high carbon areas, approximately in the past 10 years. In the MATOPIBA region in Brazil, the expansion on natural vegetation lands (mainly Cerrado biome) was very high, as well as in other regions of Brazil and Argentina, as already discussed. As an approximate average, the total soy expansion on areas with natural vegetation in Brazil and Argentina were respectively 17% and 28%. Hence, as a weighted average for world impact about 19% of the recent global area expansion could be related to impacts on lands with high carbon stocks, whilst assuming no correlation with deforestation for China and the USA, and disregarding other nations, which were not the focus of this report.

Table 4: Soybean producing countries and share of expansion in high carbon lands.

Country	Sub-region	Forestland dynamics	Total soy production in grain Mt	Share of global production	Approximate share of recent soy expansion over natural vegetation
Argentina		Net deforestation	58.8	17%	28%
Brazil	MATOPIBA	Net deforestation	11.6	4%	62%
	All other regions	Net deforestation	84.7	25%	11%
	Total	Net deforestation	96.3	29%	17%
China		Net afforestation/reforestation	12.0	4%	Not applicable
United States		Net afforestation/reforestation	117.2	35%	Not applicable
Other nations		-	50.6	15%	-
WORLD		**Net deforestation**	**334.9**	**100%**	**19%**

Source: prepared by the authors.

Note: total soy production as in 2016 base-year (FAO, 2018). Approximate share of recent (about past 10 years) soy expansion over native vegetation were estimated by the authors, based on literature review. World share assumes a weighted average of the situation occurred in the listed countries, excluding other nations. MATOPIBA region is comprised of the Brazilian State of Tocantins (TO) and parts of the States of Maranhão (MA), Piauí (PI) and Bahia (BA).

In addition to the share of soy expansion in critical areas, Table 5 summarises its average annual carbon footprint observed in the ten recent years (2006-2016). The values shown in this table were estimated based on the approximate share of soy expansion over native vegetation (Table 4) and the previous estimates on the GHG emissions associated with their conversion into soy land (see further explanations in Sections 2.3.1 and 2.3.2). As previously shown in Table 3 (with data from IPCC, 2000), carbon stocks

including above ground vegetation and soil carbon in tropical forests are approximately 243 tC ha^{-1} and in tropical savannahs about 147 t ha^{-1}, whereas in croplands about 82 tC ha^{-1}, similar to soy areas. Assuming that the soy area that expanded over natural vegetation occurred approximately 50% over tropical forest and 50% over biomes with similar carbon stocks to tropical savannahs, the representative average is 195 tC ha^{-1}. Therefore, once converting this natural vegetation area into soy, the total carbon difference is 113 tC ha^{-1}, which in terms of carbon dioxide emission means 415 tCO_2 ha^{-1} (1 tC equals 3.67 tCO_2). Given that soy oil represents about 20% of total soy production (MAPA, 2015), being the rest soy meal, the associated emissions with the oil for Argentina and Brazil are 10 and 16 $MtCO_2$ y^{-1}, respectively.

Table 5: Annual GHG emissions due to soy expansion over native vegetation (base 2006-2016).

Country	Soy expansion kha y^{-1}	Soy expansion over natural vegetation kha y^{-1}	Assumed type of natural vegetation converted	Carbon stock in natural vegetation tC ha^{-1}		Carbon stock in soybean land tC ha^{-1}	Emission factor t CO_2eq ha^{-1}	Oil share in total soy production	GHG emissions from the conversion of natural vegetation for oil production $MtCO_2$eq y^{-1}
Argentina	437	122	50% Tropical Forest	243	195	82	415	20%	10
			50% Chaco and others	147					
Brazil	1111	189	50% Tropical Forest	243	195	82	415	20%	16
			50% Cerrado and others	147					
Total	**1548**	**311**							**26**

Source: prepared by the authors.

Note: Annual soy expansion over native vegetation based on estimates described in the report, including assumptions for the GHG emission from IPCC (2000). Values include emissions from above ground vegetation and soil C (1m depth). Conversion unit: 1 tC equals 3.67 tCO_2.

2.4 Palm Oil

The palm oil market is more concentrated than for soybeans, with only two nations (Indonesia and Malaysia) accounting for 84% of the world production, as shown in Figure 31. There are some studies on irrigated palm oil being carried out by Embrapa Cerrado in Brazil, which may open potential for oil palm production outside equatorial regions, but they are at an experimental scale. Moreover, the palm oil fruits need to be crushed right after being harvested in order to preserve their quality from rapid decomposition and oxidation and, hence, they are usually processed in nearby facilities to the production sites. This is why the EU imports only palm oil (i.e. in the form of vegetable oil) and not oil palm fruits.

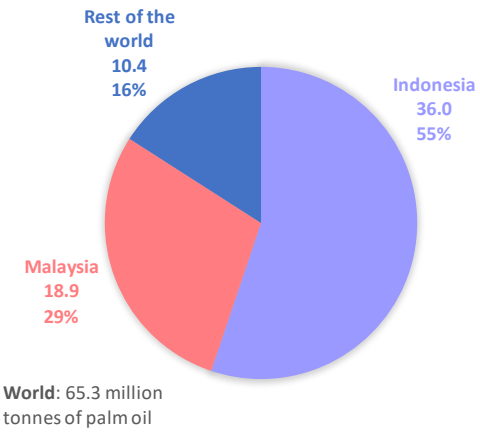


Figure 31: Palm oil production (veg. oil), in million tonnes.
Source: Prepared by the authors, using data from FAO (2018).

The processing of oil fruits generates Crude Palm Oil (CPO) and Palm Kernel Oil (PKO). Most of CPO is then converted into Edible Palm Oil (EPO), which is mainly dedicated to supply the food industry, and currently just a small fraction of palm oil goes to biodiesel production. Moreover, the biorefining process of palm oil produces a Palm Fatty Acid Distillate (PFAD), which is a refining process by-product oil (a fatty acid without the glycerol molecule attached), representing about 4-5% of the EPO (Ljungblom, 2017), generally used as animal feed or in the oil-chemistry, and which can also be readily converted into biodiesel without generating glycerine.

Indonesia is the global leader in palm oil production, with a growing production capacity, followed by Malaysia (Figure 32). These two nations have different expansion rates and, hence, with different associated land use impacts. In 10 recent years (2004-2014), Indonesia increased its palm oil production from 10.8 to 29.3 Mt (+170%), whereas Malaysia increased from 14.0 to 19.7 Mt (+41%) and the rest of the world from 5.3 to 8.4 Mt (+60%).

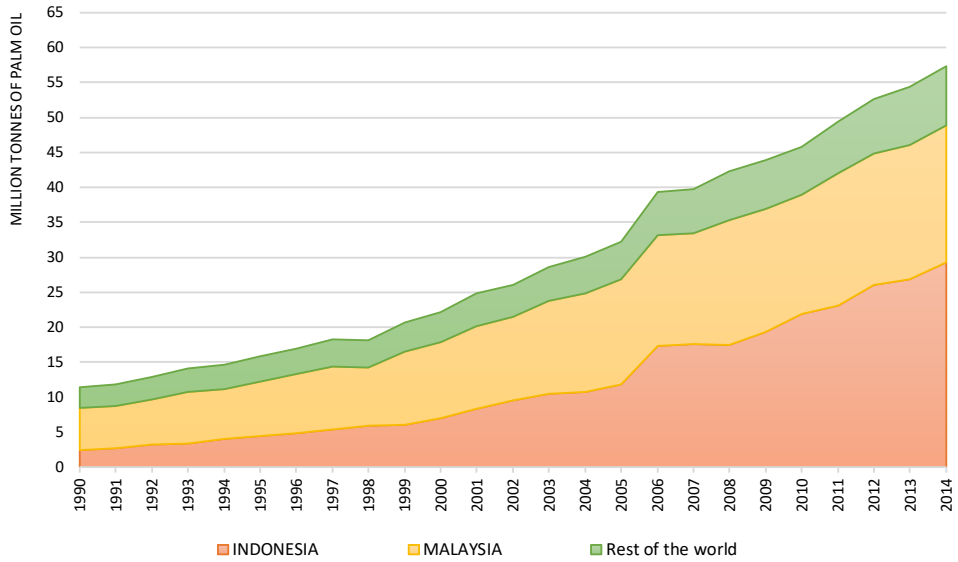


Figure 32: World palm oil production.

Source: Prepared by the authors, using data from FAO (2018).

Several other nations in the equatorial region have been producing palm oil (Figure 33) and some of them have also been expanding their local production. Palm oil is one of the most efficient oil crops, producing about 4.5 tonnes per hectare, whereas soybean produces about 600 kg of vegetable oil per hectare, although soy's main product is the meal. Besides, oil palm requires manual harvest and therefore it is labour intensive, generating a substantial number of jobs and income in rural areas. However, although the crop itself can have multiple benefits, its expansion at the expense of deforestation or peatland damage has significant carbon implications.

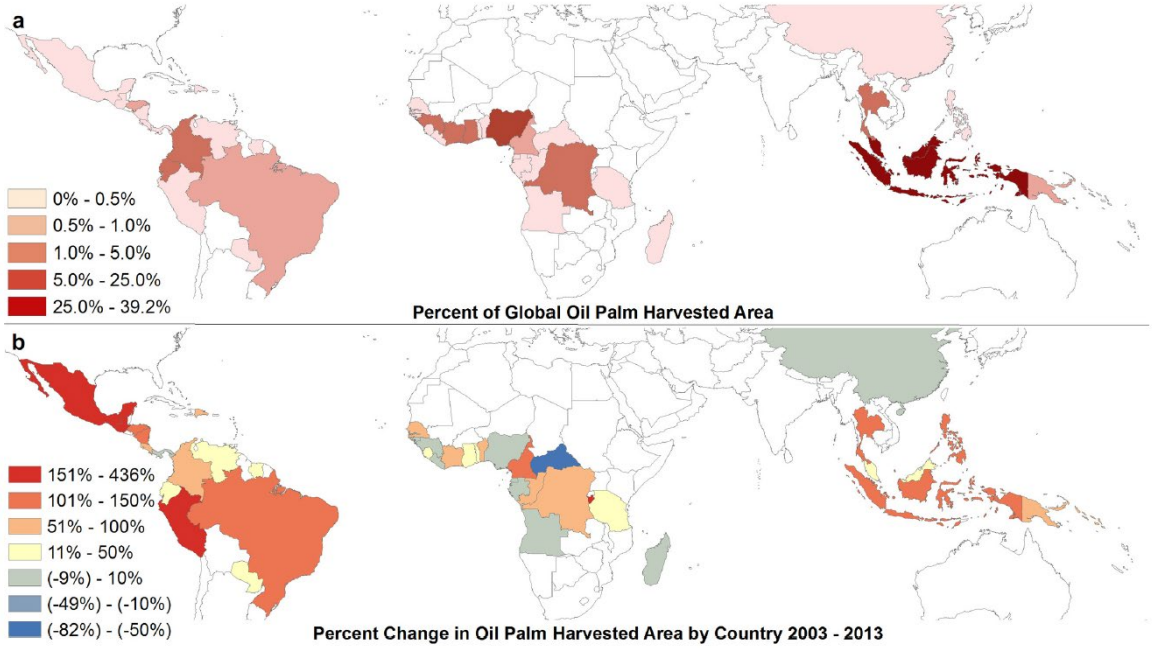


Figure 33: World production of palm oil: a) Percent of FAO reported total global oil palm harvested area in 2013; (b) Percent changes in FAO reported oil palm.

Source: Vijay *et al*. (2016).

Europe consumes around 12% of total global palm oil production. These imports meet not only the food industry, but also the local demands for biodiesel production (about 55% of total imports). The palm kernel oil also often goes to the cosmetic and pharmaceutical industry. Europe consumes almost all the palm oil that it imports, with a residual amount of exports (Figure 34). The consumption has been substantially increasing in the past decades. As earlier shown in Figure 2, its use for biodiesel production in the EU has also increased from 2007 to 2013, but slowed subsequently, showing just a slight increase from 2014 to 2018; whereas the use of rapeseed oil for biodiesel has been relatively stable in the same period, although still remaining the dominant feedstock for biodiesel production in Europe to date.

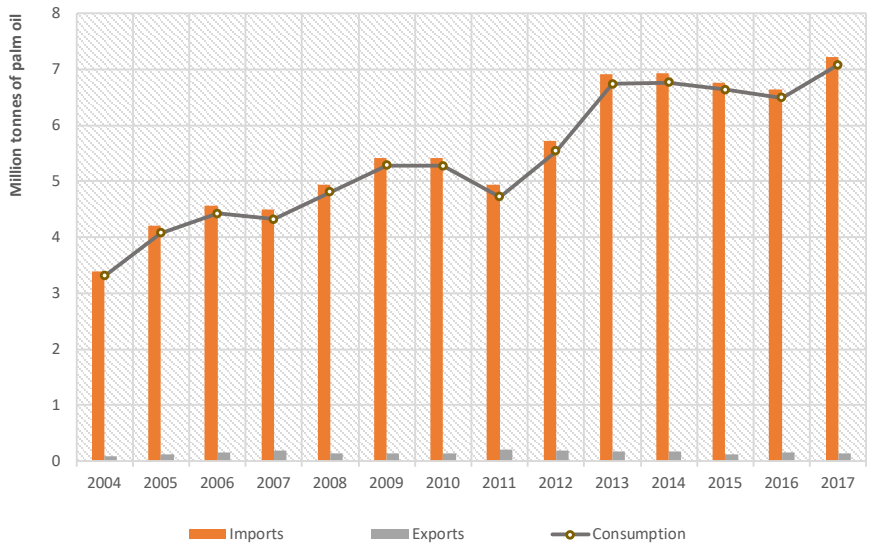


Figure 34: Palm oil imports, exports and consumption in Europe.

Source: prepared by the authors, based on FAO (2018).

2.4.1 Indonesia

With a total territory of about 191 Mha and a land area of about 181 Mha, Indonesia is the 14th largest country in the world. Figure 35 shows the land use trends in Indonesia since 1990. The country has a considerable forest area and is a region with high biodiversity, with an estimated 10% of global plants, 12% of mammals, 16% of reptiles/amphibians and 17% of bird species (Margono *et al.*, 2014). However, this area has been heavily utilised in recent decades through logging, oil palm plantations and other land use transitions. Humid equatorial forests, particularly primary forests, are usually high biodiversity areas under constant threat in past decades.

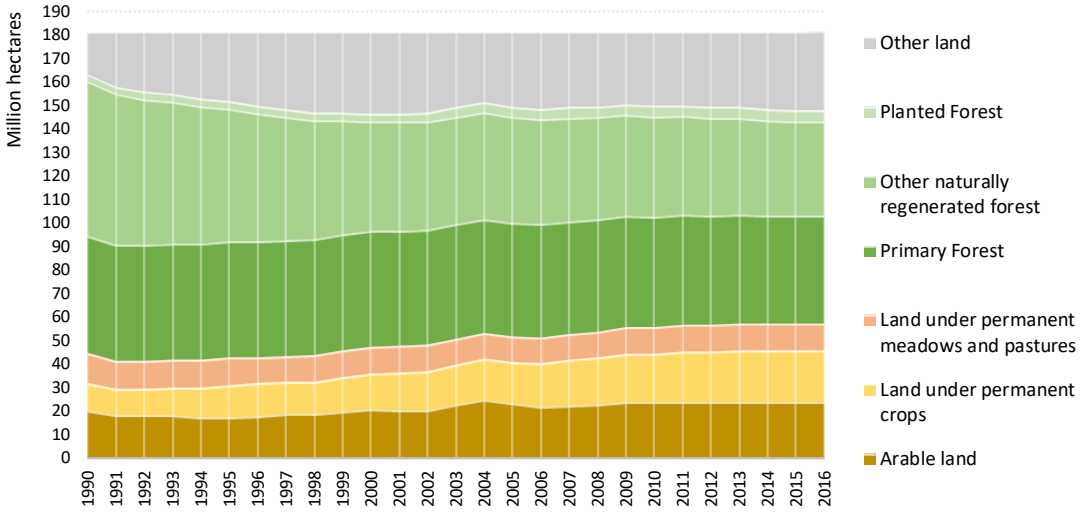


Figure 35: Land use in Indonesia.

Source: prepared by the authors, using data from FAO (2018).

Indonesia is the global primary producer of palm oil, contributing more than an estimated 54% or 32 Mt to global production in 2015 (USDA-FAS, 2018). Production has expanded rapidly in recent decades, as has the oil palm plantation area (Figure 36). On the other hand, other crop species have also been expanding over forestlands in Indonesia, showing that the deforestation issue is much more complex than a linear relationship between oil palm plantation and forestlands. At least one third of this production has been attributed to smallholders (Austin *et al.*, 2017). The majority of Indonesian oil palm plantations by area are located in Sumatra, followed by Kalimantan. However, the latter region has experienced particularly rapid growth in oil palm plantations since the year 2000 (Gunarso *et al.*, 2013; Austin *et al*., 2017).

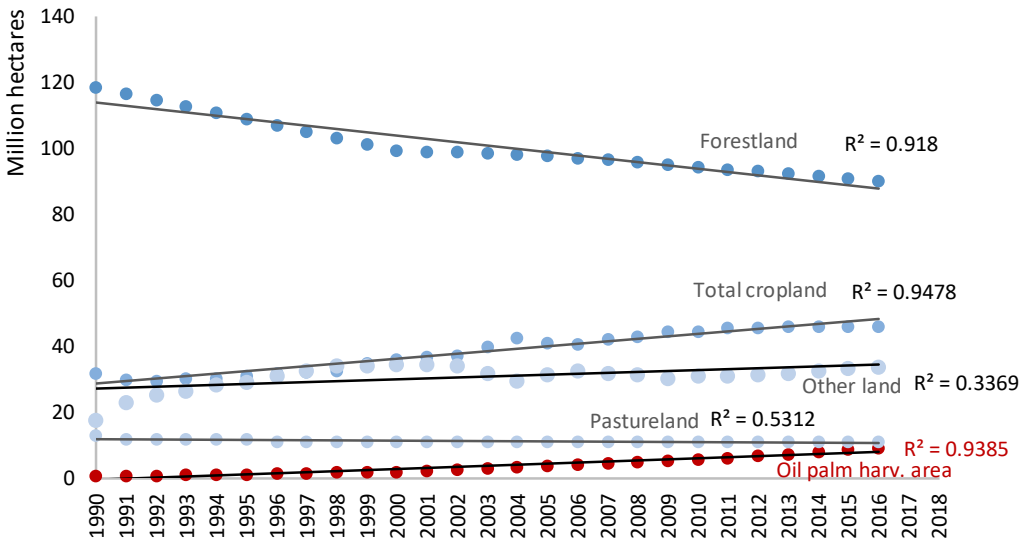


Figure 36: Dynamics of productive land use and forestlands in Indonesia, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

Considering the OECD & FAO (2017) projection of oil palm in Indonesia and a potential small increase in agricultural yields (estimated through a linear extrapolation from past yield gains), the area is likely to keep increasing in the coming years (Figure 37), representing a major concern for forest conservation, biodiversity and carbon.

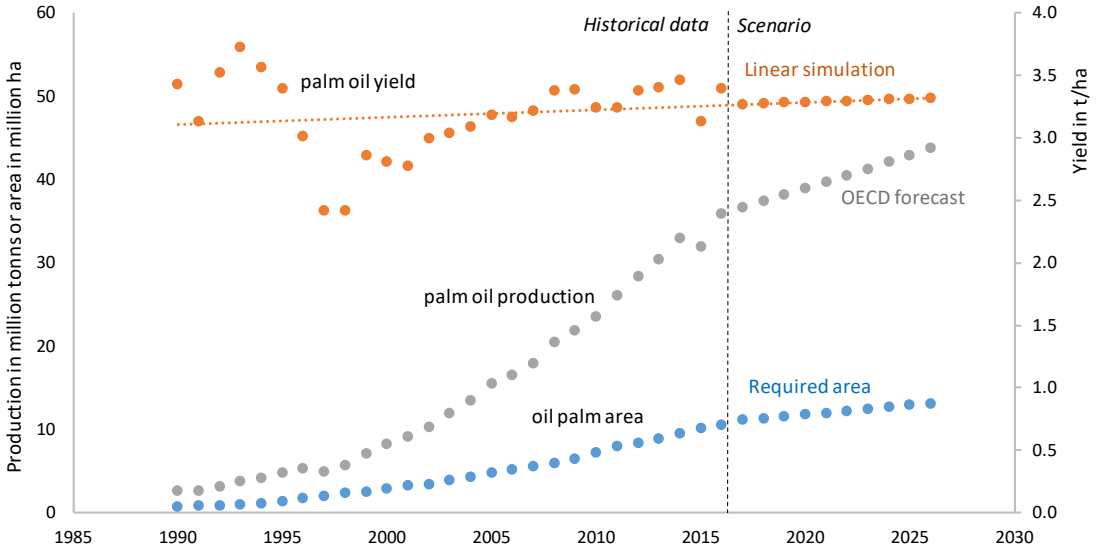


Figure 37: Oil palm area, production and yields in Indonesia, and future simulations.

Source: prepared by the authors, based on data from USDA (2018) and OECD & FAO (2017) forecast for oil palm production.

Oil palm plantations in Indonesia have contributed to the conversion of forests and other high carbon stock land. As the link between oil palm plantations and deforestation activities is often indirect, estimates of the contribution of oil palm to deforestation are challenging and variable (Wicke *et al.*, 2011). In Indonesia, the primary direct driver of deforestation has been logging (often illegal) rather than the expansion of oil palm plantations. However, oil palm plantations have frequently replaced previously forested land after logging and therefore are associated with the carbon loss from this land use change

(Gunarso *et al*., 2013). The country has plans to regenerate ("rewet") some peatland areas (Bennett, 2018), but net deforestation continues. Several studies have quantified the proportion of growth in oil palm area linked to deforestation (Table 6). In short, the expansion of oil palm over forestlands in Indonesia has ranged from approximately 18% to 63% in recent years.

Table 6: Estimates of the contribution of oil palm expansion to deforestation in Indonesia, according to different references.

Timeframe	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation (ha)	Study
1990-2005	56-100%	1,704,000 to 3,017,000	Koh *et al.*, 2008
1990-2010	63%	Not available	Geographical magazine, 2018
1990-2010	33.5%	2,143,000	Gunarso *et al.*, 2013
1990-2013	51.5%	Not available	Vijay *et al.*, 2016
1995-2000	53.9%	788,000	Austin *et al.,* 2017
2000-2005	Not available	357,000	Austin *et al.,* 2017
2005-2010	Not available	616,000	Austin *et al.,* 2017
2010-2015	18%	585,000	Austin *et al.,* 2017

Source: prepared by the authors, using several sources cited within the table.

Of this conversion, Austin *et al*. (2017) report that the majority (94.9%) occurred in secondary forests and 5.1% in primary forests. However, the proportion of plantations that have expanded onto previously agricultural land has increased from 22.1% between 1995-2000 to 37.9% between 2010-2015, which raises the possibility of leakage through crop displacement. The conversion of peatlands, often through the use of fire (although this is no longer legal), has also contributed to considerable loss of carbon stocks (Gunarso *et al.*, 2013). The estimated area of industrial oil palm plantations on peatlands in Indonesia increased from 19 kha in 1990 to 544 kha in 2000, 957 kha in 2007 and 1,311 kha in 2010 according to Miettinen *et al.* (2012). Austin *et al.* (2017) estimate an expansion of 305,000 ha on peatlands between 1995-2000 and 619,000 ha between 2010-2015 (20% proportion for both periods). Indonesian oil palm plantations have also expanded into other land use classes.

Table 7 shows the previous land use for new oil palm expansion in the three major producing regions of Indonesia, namely: Sumatra, Kalimantan and Papua. It is worth noting that definitions of land classifications may vary between studies and FAO classifications. This table is followed by maps of Indonesia with the oil palm plantations from 1995 to 2015 (Figure 38) and biophysically suitable areas (Figure 39), both by Austin *et al*. (2017). Based on this table and assuming that the land uses potentially considered as "native vegetation" are the undisturbed and disturbed upland forest and swamp forest, as well as swamp shrub & grasslands, and bare soil, it is possible to suggest that from the total expansion over native vegetation, approximately 50% occurred in areas analogous to "tropical forest" and the other 50% in areas analogous to "wetland" (peatland), as described in Table 3, from 2005 to 2010.

Table 7: Prior land use of all new oil palm plantations established in the three main oil pam regions of Indonesia (Sumatra, Kalimantan and Papua), between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 -2005		2005 -2010		1990 - 2100	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest	1.3	0.1	2.6	0.2	8.7	0.3	13	0.2
Disturbed Upland Forest	475	20.3	88	6.0	644	25.1	1,207	18.9
Upland Shrub & Grasslands	370	15.8	217	14.7	681	26.5	1,268	19.9
Undisturbed Swamp Forest	374	16.0	0.4	0.0	9.5	0.4	384	6.0
Disturbed Swamp Forest	174	7.4	78	5.3	288	11.2	539	8.4
Swamp Shrub & Grasslands	60	2.6	32	2.2	319	12.4	411	6.4
Agroforest & Plantation	824	35.2	977	66.2	375	14.6	2,176	34.1
Intensive Agriculture	17	0.7	56	3.8	139	5.4	212	3.3
Bare Soil	6.1	0.3	21	1.4	48	1.9	74	1.2
Others	40	1.7	5	0.1	57	2.2	102	1.5
Total New Plantations	2,341		1,477		2,569		6,387	

Source: Gunarso *et al.* (2013)

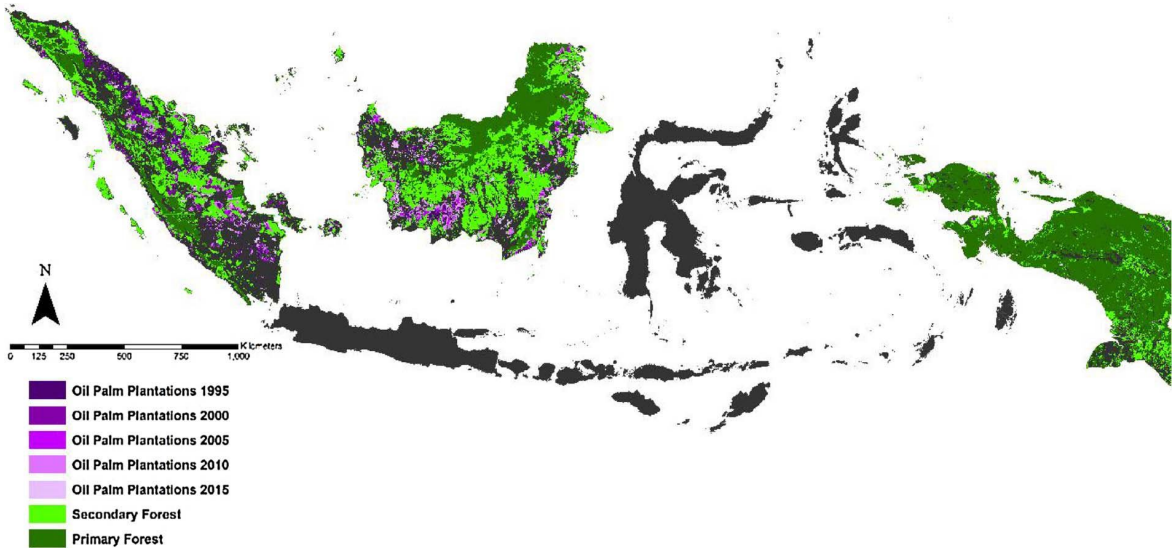


Figure 38: Industrial-scale oil palm plantations (1995-2015) in Indonesia, and forest cover in the year 1996 from the Ministry of Environment and Forestry.
Source: Austin *et al*. (2017).

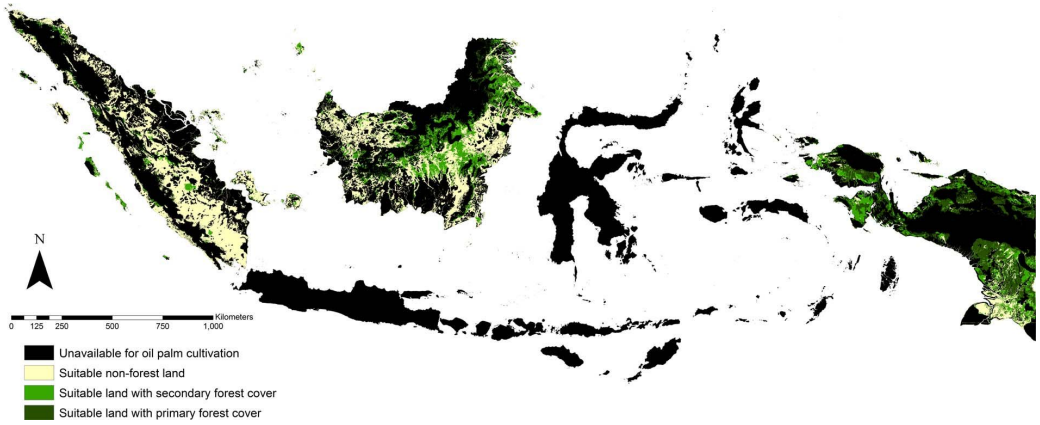


Fig. 4. Biophysically suitable land for oil palm cultivation. Yellow represents suitable non-forest areas, while green represents suitable secondary and primary forested areas. Black areas are not suitable for oil palm cultivation, or are peat lands, protected areas, above 500 m elevation, or existing oil palm plantations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 39: Biophysically suitable land for oil palm cultivation in Indonesia.

Source: Austin *et al*. (2017).

In regard to deforestation causes in the broader region of Southeast Asia, Figure 40 illustrates changes in forest cover between 1990-2010, including Indonesia and its neighbouring countries.

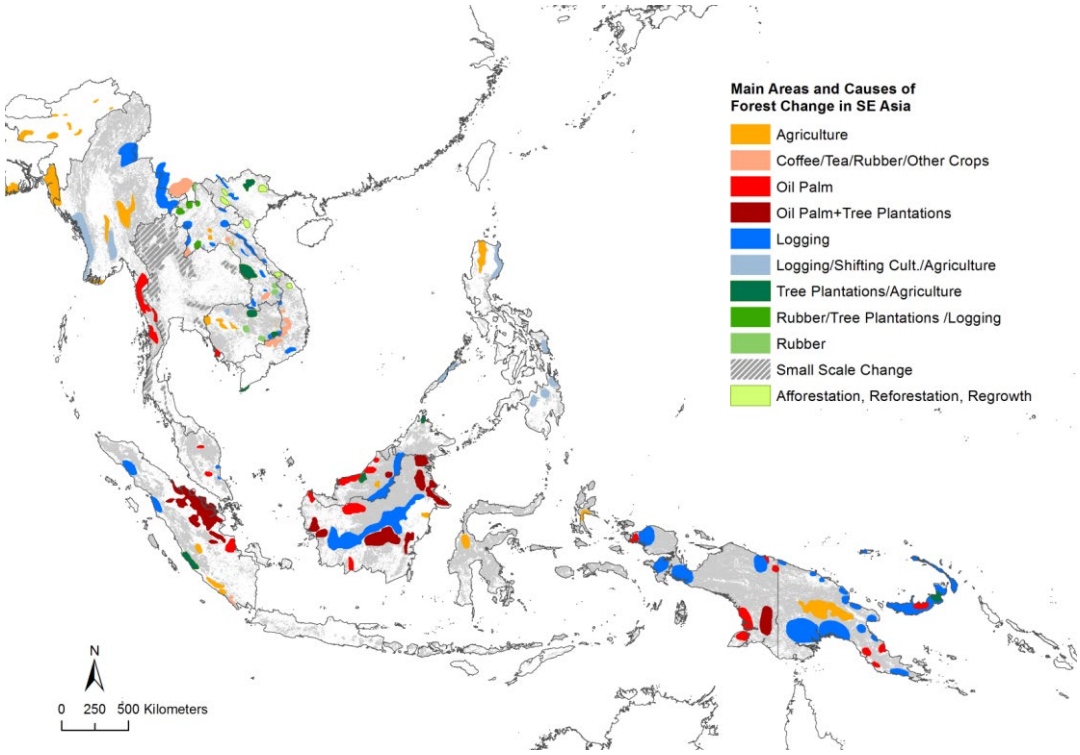


Figure 40: Regional pattern of main areas and causes of forest change in Southeast Asia, as identified by expert consultation.

Note (from the authors of original source): Background map in grey shows forest cover in 2000.

Source: Stibig *et al*. (2014).

Based on data from FAO (2018), the annual expansion of oil palm in Indonesia was approximately 477 kha between 2007 and 2016. As previously discussed, from 18% to 63% of this expansion has occurred over native vegetation in recent years, and therefore the expansion of palm over critical areas was

approximately between 38 and 301 kha per year, respectively. Considering the carbon stocks associated with forestlands, for both above ground vegetation and soil C, as previously described in Table 3, it is possible to estimate the carbon footprint for this yearly expansion in critical areas. Assuming that the oil palm area has approximately 70% of the carbon amount stated for "tropical forest" (on average)[4] and that its expansion occurred half over areas with a carbon amount similar to "tropical forestland" (on average) and the other half over peatlands (assumed analogous to "wetlands", on average), the palm expansion over native vegetation has emitted (including changes in soil C) between 41 and 325 $MtCO_2eq$ per year. The AFOLU sector more broadly represent a major source of GHG emissions in Indonesia, along with the use of coal for power generation. Forestland has increased its emissions since 2000 (Figure 41).

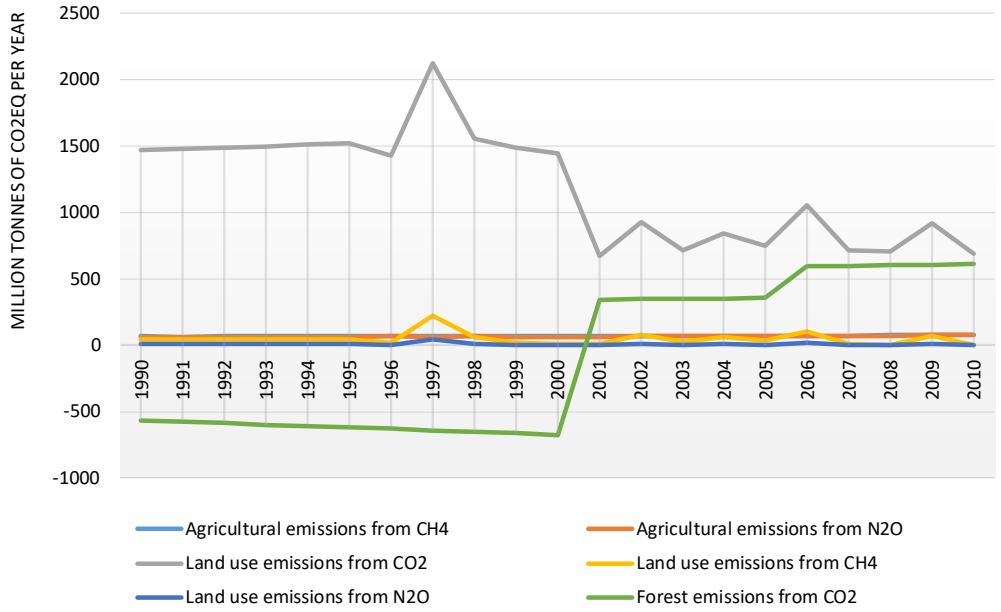


Figure 41: Greenhouse gas emissions in the AFOLU sector in Indonesia.
Source: prepared by the authors, using data from FAO (2018).
Note: Abrupt changes in emissions may result from changes in reporting protocols.

In addition, Figure 42 and Table 8 show the result of the Indonesian UNFCCC Biennial Update Report 2015 (Ministry of Environment and Forestry Indonesia, 2015), providing data pertaining to the sources of emissions in the "land use emissions" described in category above (Figure 41).

[4] Approximate value estimated from Table 3, using IPCC (2000), and Butler (2007), including both above ground vegetation and soil carbon.

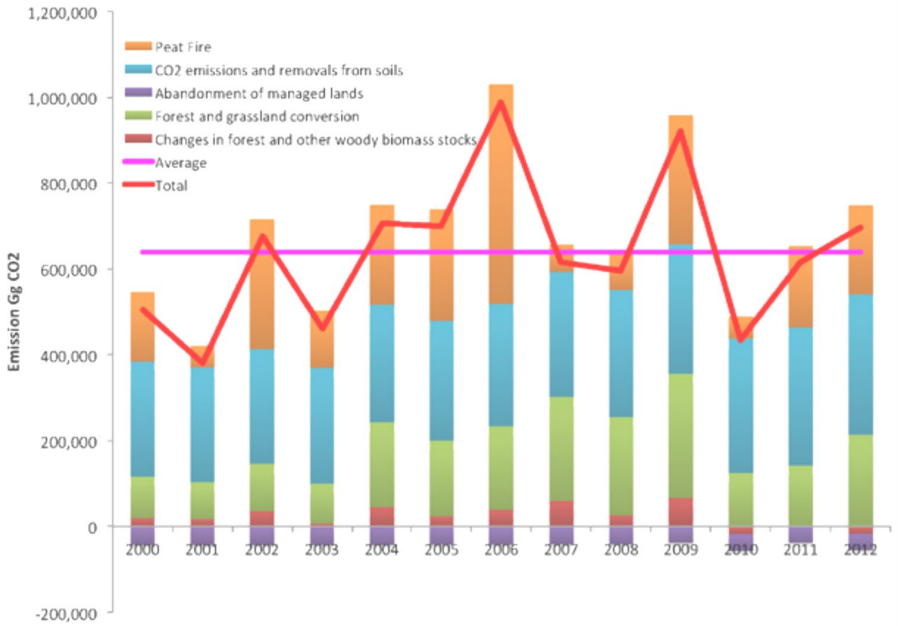


Figure 42: GHG emissions from land use change and forestry (LUCF) from 2001-2012 by source category. Source: UNFCCC Biennial Update Report 2015 (Ministry of Environment and Forestry Indonesia, 2015).

Table 8: Summary of emissions from LUCF Sector using the 2006 IPCC Guideline.

Code	Source Categories	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
3B1a	Forest remaining Forest	20,678	17,537	37,002	7,495	56,129	35,824	51,523	61,158	27,650	66,632	-17,655	77	-11,839
3B1b	Non-Forest to Forest	-1,260	-1,274	-1,320	-1,187	-2,647	-2,805	-2,603	-2,152	-2,225	-2,734	-5,183	-4,819	-4,095
3B2a	Cropland remaining Cropland	-41,587	-41,626	-41,541	-41,595	-41,450	-41,219	-40,778	-39,835	-38,855	-37,671	-37,464	-36,985	-36,758
3B2b	Non-Cropland to Cropland	29,609	22,931	36,709	29,186	93,413	71,680	90,222	140,197	131,466	167,580	38,641	45,658	95,266
3B3a	Grassland remaining Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
3B3b	Non-Grassland to Grassland	36,335	32,319	40,338	36,348	34,802	30,338	34,659	40,477	36,592	47,774	18,164	21,088	25,342
3B4a	Wetland remaining Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
3B4b	Non-Wetland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
3B5a	Settlement remaining Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0
3B5b	Non-Settlement to settlement	1,864	2,200	1,777	1,615	1,482	971	1,348	1,252	943	1,406	1,370	1,677	1,753
3B6a	Otherland remaining Otherland	0	0	0	0	0	0	0	0	0	0	0	0	0
3B6b	Non-Otherland to Otherland	29,585	29,626	31,679	27,448	59,692	64,031	58,587	59,892	60,804	74,028	72,564	78,020	89,692
	Other:													
	- Peat Decomposition	283,223	267,531	268,545	269,650	274,431	280,818	286,289	292,825	297,349	303,567	312,968	322,595	328,567
	- Peat Fire	161.571	50,885	301,753	132,075	232,018	258,887	510,710	62,747	81,744	299,920	51,383	189,026	207,050
	Total	**505,369**	**380,129**	**674,943**	**461,035**	**707,870**	**698,525**	**989,956**	**616,562**	**595,468**	**920,501**	**434,788**	**616,335**	**694,978**

Carlson *et al.* (2013) estimated that land use change associated specifically with the expansion of oil palm led to average annual emissions of 0.04 Gt C/yr between 1990-2000 and 0.44 Gt C/yr between 2000-2010. In Kalimantan, specifically, the authors estimated this to have resulted in cumulative net emissions of 0.09 Gt C between 1990-2000 and 0.32 Gt C between 2000-2010. They also projected further emissions of 1.21 Gt C between 2010-2020. 56% of these emissions were estimated to come from the clearing of forests, while 25% resulted from the conversion of peatlands (conservative estimate, assuming no use of fire).

In 2011, Indonesia implemented a moratorium on land concessions for oil palm plantations as well as logging and plantations for timber. While this has been criticised for issues such as not limiting deforestation in existing concessions, excluding secondary forests and having weaknesses in its

implementation, Busch et al. (2015) estimated that its implementation 10 years earlier in 2000 could have prevented 213-545 $MtCO_2e$ emissions associated with deforestation when leakage[5] is taken into account. This would have reduced an estimated 2.5-6.4% of the emissions from deforestation in this period. However, as described by Margono *et al.* (2014), there is also evidence of high rates of deforestation in 2012 after the moratorium was implemented. These authors also report that deforestation (from all drivers) "within official forest land uses that restrict or prohibit clearing totalled 40% of all loss within national forest land."

Sumatra

The majority of Indonesian oil palm plantations are located in Sumatra, where the harvested area of industrial plantations has risen from an estimated 1.6 to 5.9 Mha between 1995 and 2015 (Austin *et al.*, 2017). This growth has been associated with considerable forest conversion, although the rate of conversion appears to have slowed (Table 9).

Table 9: Estimates of the contribution of oil palm plantations to deforestation in Sumatra.

Timeframe	Proportion of national deforestation attributed to Sumatran oil palm plantations	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation	Study
1990-2010	Not available	25%	882,000 ha	Gunarso *et al.* (2013)
1995-2000	84.9%	54.7%	669,000 ha	Austin *et al.* (2017)
2010-2015	18.3%	9.2%	107,000 ha	Austin *et al.* (2017)

Source: prepared by the authors, using references cited within the table.

The expansion of plantations in Sumatra has also affected peatlands and other land use classes. Gunarso *et al.* (2013) estimate that 1.4 Mha (29%) of plantations in Sumatra occurred on former peatlands in 2010 (Gunarso *et al*., 2013). Miettinen *et al.* (2012) estimate that oil palm plantations on peatlands in Sumatra increased from 19,000 ha in 1990 to 528,000 ha in 2000, 846,000 ha in 2007 and 1.053 Mha in 2010. Similar to the previously described Table 7, the table below (Table 10) now highlights the previous land use for oil palm production in Sumatra more specifically, based on information provided by Gunarso *et al*. (2013).

[5] According to the European Commission - EC (2018), carbon leakage "refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions."

Table 10: Prior land use of all new oil palm plantations established in Sumatra between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 -2005		2005 -2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest								
Disturbed Upland Forest	170	10.2	11	1.0	28	3.7	209	5.9
Upland Shrub & Grasslands	115	6.9	24	2.2	6	0.8	145	4.1
Undisturbed Swamp Forest	364	21.8	0.3	0.0	7	0.9	370	10.5
Disturbed Swamp Forest	142	8.5	53	4.8	108	14.4	303	8.6
Swamp Shrub & Grasslands	56	3.4	11	1.0	126	16.7	192	5.5
Agroforest & Plantation	813	48.7	936	85.3	321	42.6	2,070	58.8
Intensive Agriculture	6.1	0	37	3.3	54	7.1	95	2.7
Bare Soil	4.8	0.3	21	1.9	47	6.2	74	2.1
Others			4.6	0.4	57	8.0	62	1.8
Total New Plantations	1,671		1,097		753		3,521	

Source: Gunarso *et al*. (2013)

As shown in Figure 43, the expansion of oil palm in past decades in Sumatra are visually represented via a set of images published by Gunarso *et al.* (2013).

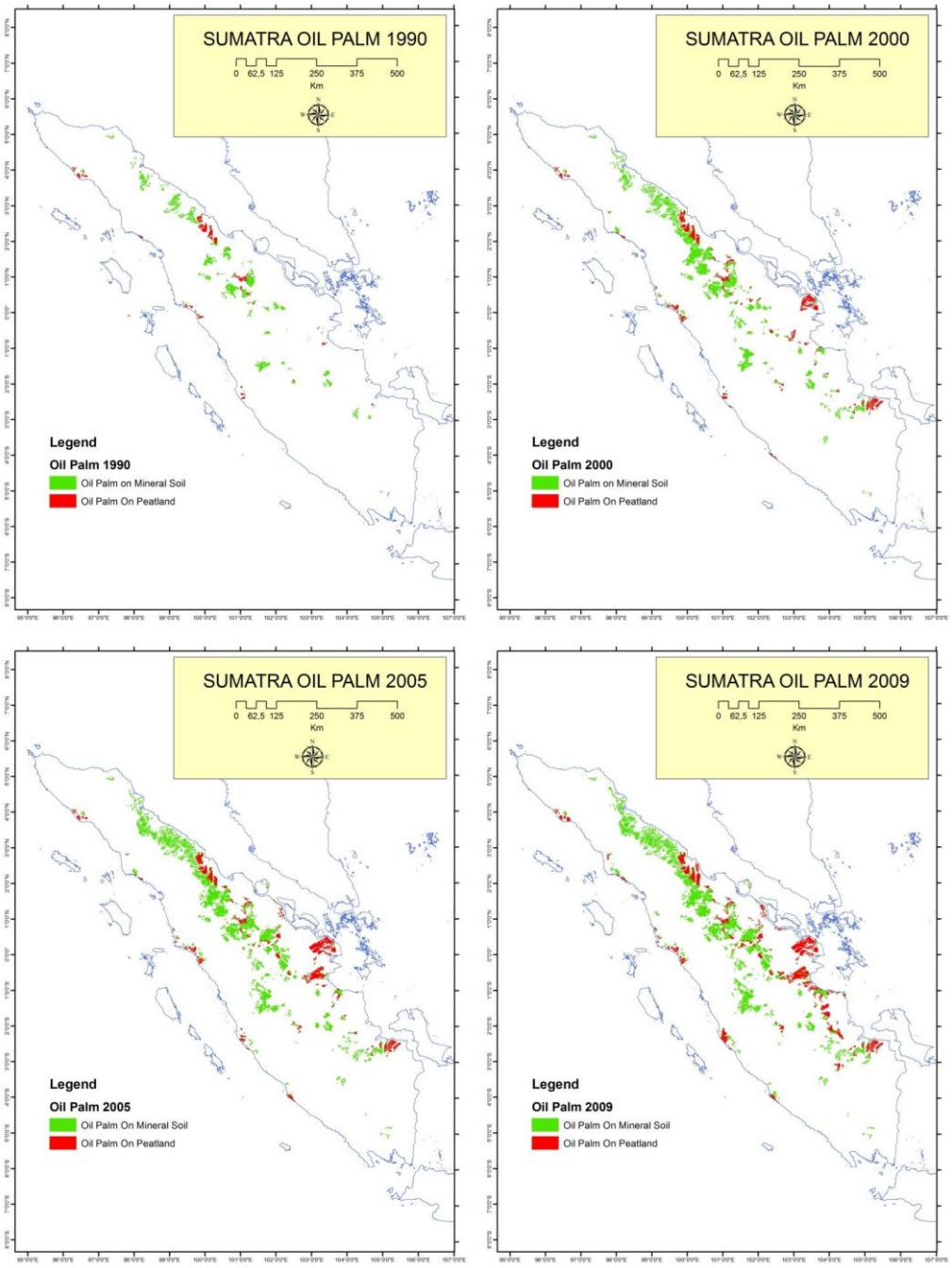


Figure 43: Expansion of oil palm plantations in Sumatra between 1990 and 2010.

Source: Gunarso *et al.* (2013).

Kalimantan

The region of Kalimantan, which is the Indonesian portion of the island of Borneo, contains fewer oil palm plantations by harvested area, although these have been associated with a high rate of deforestation in recent decades. This rate has increased considerably since 2005 (Gaveau *et al.*, 2016). The estimated plantation area increased from 90,300 ha in 1990 to 836,000 ha in 2000 and 3.164 Mha in 2010 (Carlson *et al.*, 2013). Gaveau *et al*. (2016) estimate an expansion of about 613,000 ha between 1990-2005, 781,000 ha between 1995-2000, 485,000 ha between 200-2005, 1.88 Mha between 2005-2010 and 1.69

Mha between 2010-2015. In 2015, Kalimantan oil palm plantations reached an estimated area of 5 Mha according to Austin *et al*. (2017) or 5.7 Mha according to Gaveau *et al*. (2016). Estimates of deforestation associated with oil palm plantations in Kalimantan vary (Table 11).

Table 11: Estimates of the contribution of oil palm plantations to deforestation in Kalimantan.

Timeframe	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation (ha)	Study
1990-2010	90% (47% intact, 22% logged, 21% agroforestry)	Not available	Carlson *et al.*, 2013
1990-2010	43.7%	1,226,800	Gunarso *et al.*, 2013
2000-2010	Not available	1,595,000	Carlson *et al.*, 2013
1995-2000	49.3%	107,000	Austin *et al.*, 2017
2010-2015	20.6%	407,000	Austin *et al.*, 2017

Source: prepared by the authors, using references cited within the table.

Note: The values here attributed to Gunarso *et al.* (2013) do not include agroforestry as deforestation.

Gaveau *et al*. (2016) estimate that 55% of the 3.3 Mha of oil palm plantations added between 2005-2015 occurred on land that had been deforested for at least five years, indicating other primary drivers in deforestation. However, the authors note that the rate of conversion to industrial plantations (both oil palm and pulpwood) that occurred within five years of deforestation has increased since 2005 (although rapid conversion is more prominent for pulpwood plantations).

As in Sumatra, oil palm expansion in Kalimantan has been associated with the conversion of peatlands. Miettinen *et al*. (2012) estimate that plantations on peatlands increased from 0 ha in 1990 to 16,000 ha in 2000, 111,000 ha in 2007 and 258,000 ha in 2010. Gunarso *et al*. (2013) estimate that 307,515 ha (11%) of plantations in Kalimantan occurred on former peatlands in 2010. Regarding the previous land use associated with the expansion of new oil palm field in Kalimantan, Table 12 shows an assessment prepared by Gunarso *et al.* (2013). It is worth noting again that the definitions of land classifications may vary between studies. This table is followed by a sequence of maps of oil palm in Kalimantan and Borneo more broadly by Gunarso *et al*. (2013) (Figure 44), Carlson *et al.* (2013) (Figure 45) and Gaveau *et al*. (2016) (Figure 46).

Table 12: Prior land use of all new oil plantations established in Kalimantan between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 -2005		2005 -2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest	1.3	0.2	1.1	0.3			2.4	0.1
Disturbed Upland Forest	298	45.8	74	20.7	614	34	986	35.1
Upland Shrub & Grasslands	254	39.0	192	53.4	675	38	1,122	39.9
Undisturbed Swamp Forest					2.4	0.1	2.4	0.1
Disturbed Swamp Forest	32	4.9	25	6.9	179	10.0	236	8.4
Swamp Shrub & Grasslands	4.2	0.6	21	5.9	193	10.7	219	7.8
Agroforest & Plantation	9.2	1.4	27	7.4	52	2.9	88	3.1
Intensive Agriculture	12	1.9	19	5.4	85	4.7	116	4.1
Bare Soil								
Others	40	6.2		0.0			40	1.4
Total New Plantations	652		359		1,801		2,811	

Source: Gunarso *et al*. (2013).

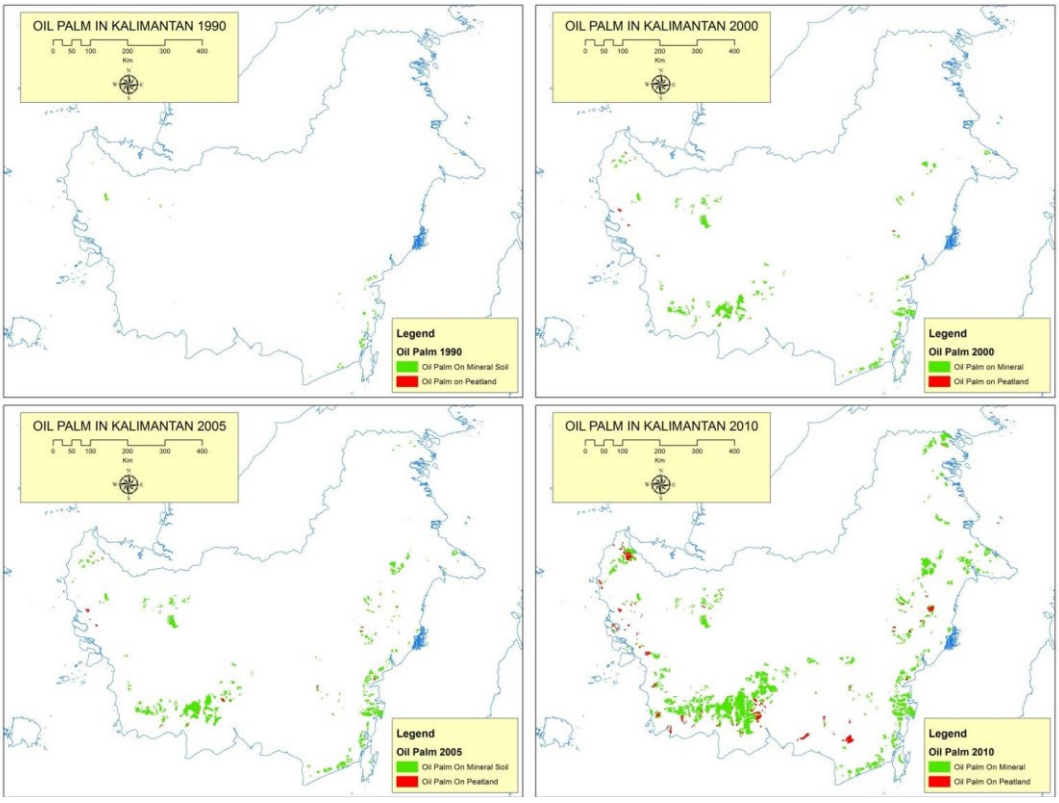


Figure 44: The expansion of oil palm plantations in Kalimantan between 1990 and 2010.

Source: Gunarso *et al*. (2013).

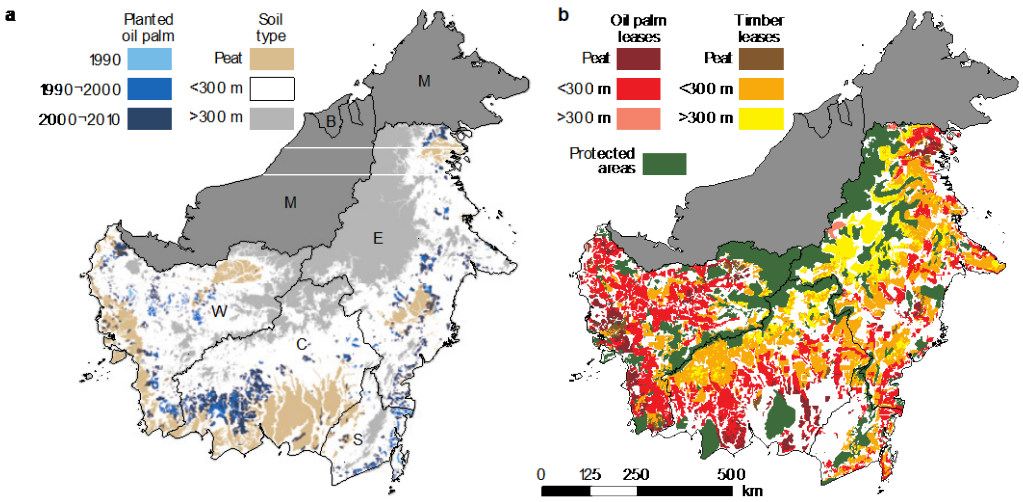


Figure 45: Planted oil palm, oil palm leases, timber leases and protected areas in Kalimantan.

Notes (from the authors its original source): Malaysian Federated States of Sarawak and Sabah (M) and Brunei (B) are dark grey. Mineral soils are distributed among elevation classes <300 m a.s.l. and >300 m a.s.l.; >99% of peat soils are <300 m a.s.l. **a)** From 1990 to 2010, oil palm expanded from 903 km2 to 31,640 km2, occupying 9% of lowlands (<300 m a.s.l) outside of protected areas, distributed among West (W; 28%), Central (C; 40%), South (S; 8%) and East (E; 23%) Kalimantan provinces. **b)** In 2010, 64% of Kalimantan's lowland area was allocated as follows: planted oil palm and awarded plantation leases (30%); logging concessions and pulp and paper plantations (Timber Leases, 24%); protected areas (10%). Residual lands, depicted in white, comprise only 31% of Kalimantan's total land area.

Source: Carlson *et al*. (2013).

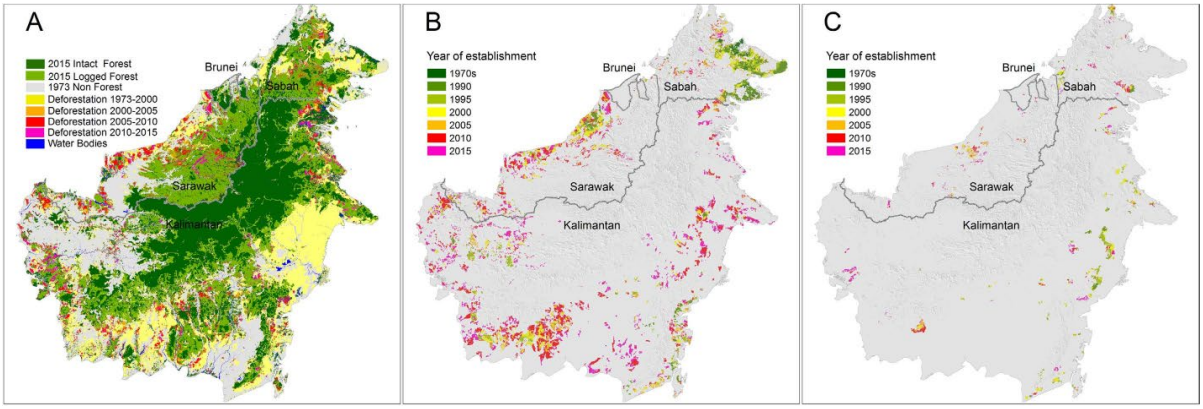


Figure 46: Land use and land cover change in Borneo (1973-2015).

Note (from the authors of original source): (A) Total deforestation (18.7 Mha) and remaining old-growth and selectively logged forest in December 2015; (B) The expansion of industrial oil-palm plantations (7.8 Mha); (C) The expansion of industrial pulpwood plantations (1.3 Mha).

Source: Gaveau *et al*. (2016)

The OECD & FAO (2017) have projected a reduction in the growth of oil palm plantation area with increasing policies to prevent deforestation and other harmful land use change. Palm oil production is expected to continue to increase, although at a slower rate of 2% per year relative to the average 7% annual growth in the 10 years prior to 2017. Wicke *et al*. (2011) estimate that there is potential for oil palm expansion on degraded land (i.e. without deforestation) in Indonesia. Oil palm expansion in Sumatra would likely occur with little deforestation because the available suitable land is predominantly (90%) in areas without forests. However, deforestation will remain more problematic in Kalimantan, where in the central and eastern parts the majority of suitable remaining area is covered by forest (Austin *et al.*, 2017).

2.4.2 Malaysia

Malaysia is the 66th largest country with a territory of 33 Mha of which about 32.9 Mha are land area. Figure 47 shows the trends in land use change since 1990. The majority of the land area in Malaysia is forested, although only a relatively small proportion of this remains as primary forest, still much above most developed nations, many of them without any remaining primary forest.

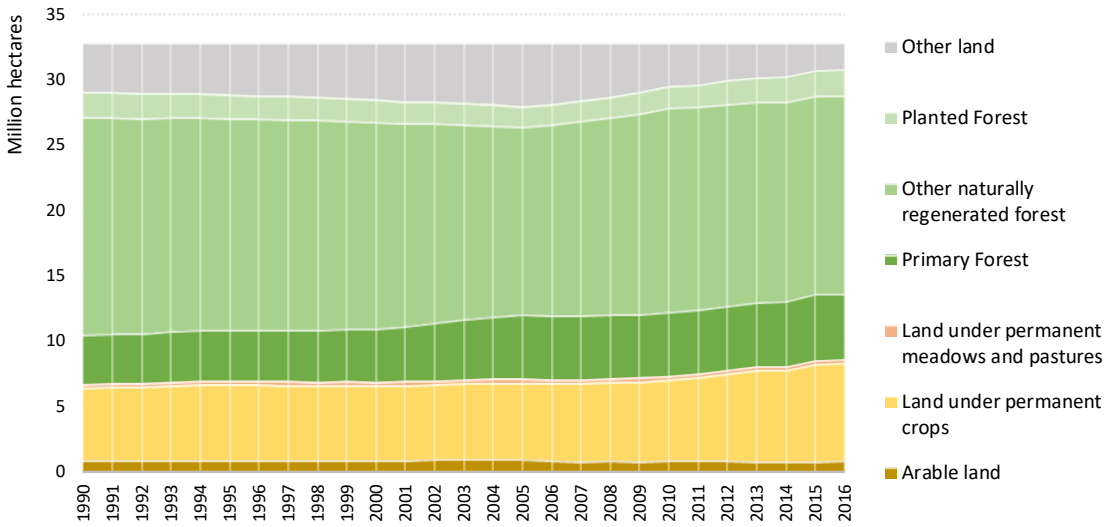


Figure 47: Land use in Malaysia.

Source: prepared by the authors, using data from FAO (2018).

Forestlands in Malaysia have been relatively stable since 2010, recovering from what seemed to be a deforestation trend until 2005 (Figure 48). On the other hand, oil palm has substantially expanded (almost linearly), while also affecting the expansion of total cropland (potentially displacing other crops) and apparently expanding over other land too (see land use definitions in Annex).

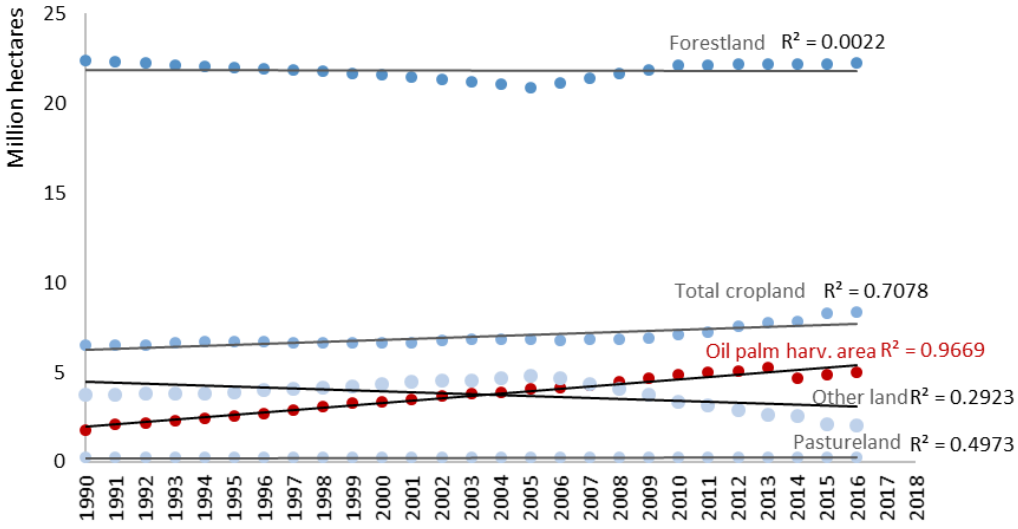


Figure 48: Dynamics of productive land use and forestlands in Malaysia, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

Malaysia is the second largest producer of palm oil globally. In 2015, production reached an estimated 17.7 Mt, or 30% of global production (USDA-FAS, 2018). As Indonesia, both production and harvested

area have increased considerable in recent decades (Figure 49). The national harvested plantation area reached an estimated 4.86 Mha in 2015 (FAOSTAT, 2018). Note that Gunarso *et al*. (2013) estimate 5.2 Mha in 2010, and this difference may be linked in part to the additional immature area (this was roughly 0.4 Mha in 2005 and 0.78 Mha in 2015 – Wicke *et al.* (2011) and MPOB (2018)). Figure 49 also shows that, based on OECD & FAO (2017) forecast and assuming that the crop yield may keep increasing linearly, the required area may not need to keep increasing in the coming decades.

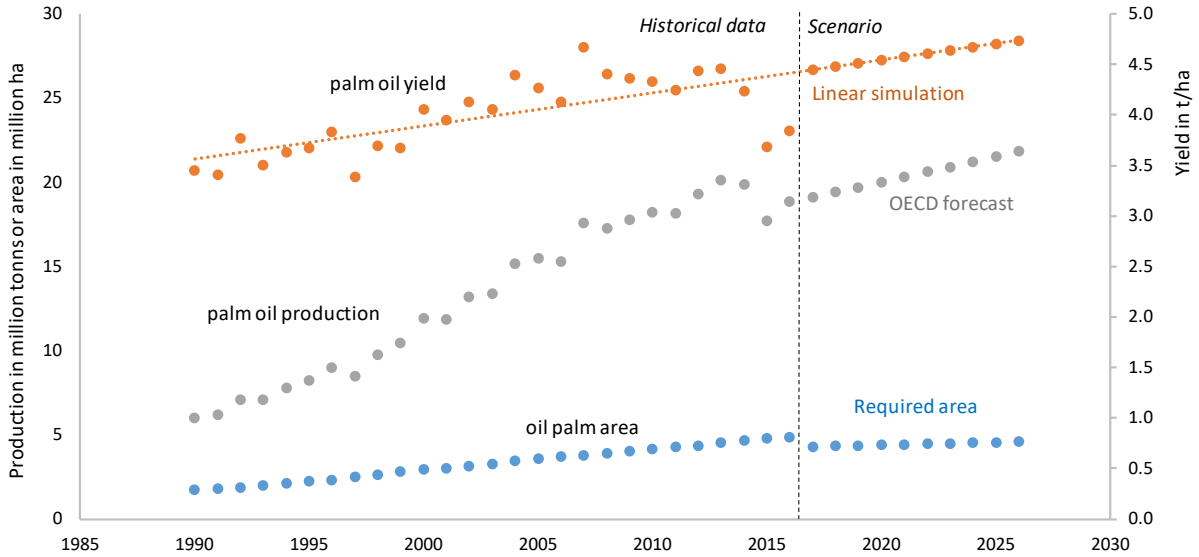


Figure 49: *Oil palm production, yield and area in Malaysia, and future simulations.*

Source: prepared by the authors, based on historical data from USDA (2018) and OECD & FAO (2017) forecast for oil palm production.

The production of palm oil is expected to continue to increase in Malaysia. Annual production growth has been projected at 1.5% between 2017-2026, whereas average linear growth was 1.2% in the prior 10-year period (OECD & FAO, 2017). The Malaysian government anticipates that yield increases will meet the growing demand for palm oil and has set an average oil yield target of 6 t/ha/yr by 2020 (Ministry of Natural Resources and Environment Malaysia, 2015). Previous average yields for Malaysia have been reported at roughly 4.5 t/ha/yr (Sayer *et al*., 2012; USDA-FAS, 2018). If increased production leads to an expansion of plantation area, there appears to be only limited potential for expansion on degraded land without problematic land use change (Wicke *et al*., 2011; Sayer *et al*., 2012).

The majority of Malaysia's oil palm plantation area is located in the region of Peninsular Malaysia, followed by Sabah and Sarawak (Table 13).

Table 13: Distribution of oil palm plantations in Malaysia.

(Mature) harvested area of oil palm plantations (ha)			
	Peninsular Malaysia	Sabah	Sarawak
2013	2,234,193	1,330,039	961,857
2014	2,275,572	1,355,541	1,058,208
2015	2,315,261	1,375,229	1,168,907
2016	2,349,387	1,383,109	1,268,942

Source: Data from the Malaysian Palm Oil Board (MPOB, 2018).

Historical expansion in plantations has led to a loss of high carbon stock forests. Estimating this impact is challenging due to the often indirect relationship between deforestation and the establishment of new

oil palm plantations (via prior logging). However, oil palm establishment has more directly driven deforestation in Malaysia than in Indonesia, where logging is a more dominant direct cause (Gunarso *et al.*, 2013). This applies for the regions of Sabah and Sarawak (Gaveau *et al.*, 2016), while deforestation in Peninsular Malaysia has been more strongly driven by the expansion of rubber and other crops (Gunarso *et al*., 2013). As for Indonesia, estimates of deforestation associated with palm oil production in Malaysia vary (Table 14). In short, the expansion of oil palm over forestlands in Malaysia has ranged from approximately 17% to 39% in recent years.

Table 14: Estimates of the contribution of oil palm plantations to deforestation in Malaysia.

Timeframe	Region	Proportion of oil palm area expansion associated with deforestation	Absolute expansion in oil palm area associated with deforestation (ha)	Study
1990-2005	Malaysia	55-59%	1,040,000 to 1,109,000	Koh *et al.* (2008)
1990-2010	Malaysia	17%	Not available	Geographical magazine (2018)
1990-2013	Malaysia	38.9%	Not available	Vijay *et al.* (2016)
1990-2010	Malaysia	42%	1,365,700	Gunarso *et al.* (2013)
1990-2010	Peninsular Malaysia	25.1%	281,000 ha	Gunarso *et al.* (2013)
1990-2010	Sabah	59.6%	689,000 ha	Gunarso *et al.* (2013)
1990-2010	Sarawak	40.5%	396,500 ha	Gunarso *et al.* (2013)

Source: prepared by the author, using references cited within the table.

Note: Gunarso *et al.* (2013) study may have excluded areas of smallholder plantations due to the satellite-based approach. This uncertainty may be considered for the other studies as well. The values here attributed to Gunarso *et al.* (2013) do not include agroforestry as deforestation.

The rate of oil palm expansion in Malaysia has declined in recent decades, but the total land in palm plantations has continued to increase. The annual growth rate dropped from 6.4% (134,926 ha) between 1990-2000 to 3.1% (141,326 ha) between 2005-2010. The conversion of previously forested areas also declined over this period, while the conversion of other land use classes increased. However, some of these land use classes may have originated on previously forested areas (Gunarso *et al*., 2013). A decline in permanent cropland has been observed since 1990 (Wicke *et al.*, 2011). There is also evidence of an increase in clearing of land by 150% in Malaysia in the last decade (Geographical magazine, January 2018).

As in Indonesia, the expansion of oil palm plantations in Malaysia has also contributed to a loss of carbon through the conversion of peatlands. Miettinen *et al*. (2012) estimate that oil palm plantations on peatlands in Malaysia expanded from 233,000 ha in 1990 to 385,000 ha in 2000, 624,000 ha in 2007 and 844,000 ha in 2010. The majority of plantations on peatlands are located in Sarawak, where expansion has been particularly high (533,000 ha in 2010 up from 727 ha in 1990, 110,000 ha in 2000 and 330,000 in 2007. Peninsular Malaysia has the second highest area of oil palm plantations on peatlands in Malaysia (264,000 ha in 2010 up from 228,000 ha in 1990, 240,000 ha in 2000 and 250,000 ha in 2007). Plantations on peatlands are more limited in Sabah (47,000 ha in 2010 up from 5,000 ha in 1990, 34,000 ha in 2000 and 45,000 ha in 2007). Gunarso *et al.* (2013) estimate that 46% (476,000 ha) of plantations in Sarawak existed on peat soils in 2010, as did 8% (215,984 ha) in Peninsular Malaysia and 2% (29,000 ha) in Sabah.

The following tables show the prior land use of all new palm oil plantation in Malaysia (Table 15), as well as in the regions of Peninsular Malaysia, Sarawak and Sabah, between 1990 and 2010, according to Gunarso *et al*. (2013). Definitions of land classifications may vary between studies. As previously discussed for Indonesia, based on this table and assuming that the land uses potentially considered as "native vegetation" are the undisturbed and disturbed upland forest and swamp forest, as well as swamp shrub

& grasslands, and bare soil, it is possible to suggest that from the total expansion over native vegetation, approximately 40% occurred in areas analogous to “tropical forest” and the other 60% in areas analogous to “wetland” (peatland), as described in Table 3, from 2006-2010.

Table 15: Prior land use of all new oil palm plantation established in all regions of Malaysia (Peninsular, Sarawak, Sabah) between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 - 2005		2006 - 2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest			0.2	0.0			0.2	0.0
Disturbed Upland Forest	744	53.3	289	26	207	27.5	1,239	38.1
Upland Shrub & Grasslands	2.6	0.0	7.2	0.7	5.5	0.7	15	0.5
Undisturbed Swamp Forest	0.5	0.0					0.5	0.0
Disturbed Swamp Forest	36	2.6	46	4.2	43	5.8	126	3.9
Swamp Shrub & Grasslands	2.9	0.2	1.3	0.1	0.7	0.1	5.0	0.2
Agroforest & Plantation	511	37	380	34.3	228	30.4	1,119	34.4
Intensive Agriculture			8.4	0.8	0.1	0.0	8.5	0.3
Bare Soil	94	6.7	371	33.5	266	35.4	731	22.5
Others	3.9	0.3	3.2	0.3	0.1	0.0	7.0	0.2
Total New Plantations	1,394		1,106		751		3,252	

Source: Gunarso *et al*. (2013)

Table 16: Prior land use of all new oil palm plantation established in Peninsular Malaysia, 1990-2010.

Aggregate Class	1990 - 2000		2001 - 2005		2006 - 2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest								
Disturbed Upland Forest	174	35.5	63	15.4	14	6.2	251	22.4
Upland Shrub & Grasslands	0	0.0	6.6	1.6	4.9	2.2	12	1.0
Undisturbed Swamp Forest								
Disturbed Swamp Forest	9.7	2.0	20	4.9	0.1	0.1	30	2.7
Swamp Shrub & Grasslands								
Agroforest & Plantation	260	53.0	125	30.8	101	46.3	487	43.6
Intensive Agriculture	-	0.0	5.9	1.4			5.9	0.5
Bare Soil	43	8.8	185	45.4	99	45.2	327	29.3
Others	3.5	0.0	1.8	0.5			5.9	0.5
Total New Plantations	491		407		219		1,118	

Source: Gunarso *et al*. (2013)

Table 17: Prior land use of all new oil palm plantation established in Sabah, between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 - 2005		2006 - 2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest	-	0.0	0	0.0	-	0.0	0	0.0
Disturbed Upland Forest	435	68.4	126	34.5	116	75.5	677	58.6
Upland Shrub & Grasslands	1.7	0.3	0.6	0.2	0.3	0.2	2.6	0.2
Undisturbed Swamp Forest	-	0.0	-	0.0	-	0.0	-	0.0
Disturbed Swamp Forest	5.0	0.8	6.2	1.7	0.6	0.4	12	1.0
Swamp Shrub & Grasslands	2.9	0.5	1.3	0.4	0.7	0.5	5.0	0.4
Agroforest & Plantation	163	25.7	125	34.2	7.8	5.1	296	25.6
Intensive Agriculture	-	0.0	0.4	0.1	-	0.0	0.4	0.0
Bare Soil	28	4.4	106	28.8	28	18.4	162	14.0
Others			0.4	0.1	-	0.0	0.4	0.0
Total New Plantations	636		366		153		1,155	

Source: Gunarso *et al*. (2013)

Table 18: Prior land use of all new oil palm plantation established in Sarawak, between 1990 and 2010.

Aggregate Class	1990 - 2000		2001 - 2005		2006 - 2010		1990 - 2010	
	10^3 ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%
Undisturbed Upland Forest	0.0	0.0	-	0.0	-	0.0	0	0.0
Disturbed Upland Forest	135	50	100	30.0	78	20	312	31.8
Upland Shrub & Grasslands	0.7	0.3	-	0.0	0.3	0.1	1.0	0.1
Undisturbed Swamp Forest	0.5	0.2	-	0.0	-	0	0.5	0.1
Disturbed Swamp Forest	21	7.8	20	6.2	43	11.3	84	8.6
Swamp Shrub & Grasslands	-	0	-	0.0	-	0.0	-	0.0
Agroforest & Plantation	87	33	129	38.9	120	31.4	336	34.3
Intensive Agriculture	-	0	2	0.6	-	0.0	2.1	0.2
Bare Soil	23	9	80	24.2	140	36.8	243	24.8
Others	0.4	0.2	0.7	0.2	0.0	0.0	1.2	0.1
Total New Plantations	267		333		381		981	

Source: Gunarso *et al*. (2013)

In regard to Malaysia more broadly, the annual expansion of oil palm was approximately 70 kha between 2007 and 2016, based on data from FAO (2018). As previously discussed, from 5% to 39% of this expansion has occurred over native vegetation in recent years, and therefore the expansion of palm over critical areas was approximately between 3 and 27 kha per year, respectively. Considering the carbon stocks associated with forestlands, for both above ground vegetation and soil C, as previously described in Table 3, it is possible to estimate the carbon footprint for this yearly expansion in critical areas. Assuming that the oil palm area has approximately 70% of the carbon amount stated for “tropical forest” (on average) and that its expansion occurred a half over areas with a carbon amount similar to “tropical forestland” (on average) and the other half over peatlands (assumed analogous to “wetlands”, on average), the palm expansion over native vegetation has emitted (including changes in soil C) between 4 and 29 $MtCO_2eq$ per year.

Regarding the GHG emissions in total AFOLU, data from FAO (2018) shows some abrupt changes in land use CO_2 emissions and forestland emissions (Figure 50), possibly due to changes in methodology for the assessment.

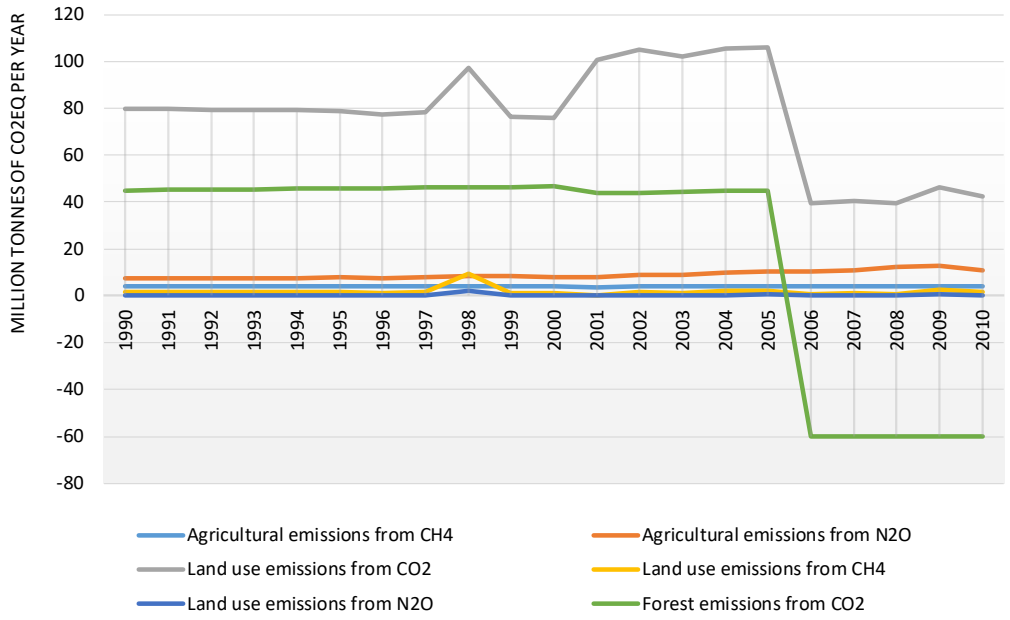


Figure 50: GHG emissions for the AFOLU sector in Malaysia.

Source: prepared by the authors, using FAO (2018).

Note: Abrupt changes in emissions may result from changes in reporting protocols.

Different values are shown in the Malaysian government report. Here the emissions associated with LULUCF have roughly stabilised since 1995 (Ministry of Natural Resources and Environment Malaysia, 2015), see Figure 51. This sector has contributed a considerable proportion of Malaysia's GHG emissions (World Resource Institute Report, 2017).

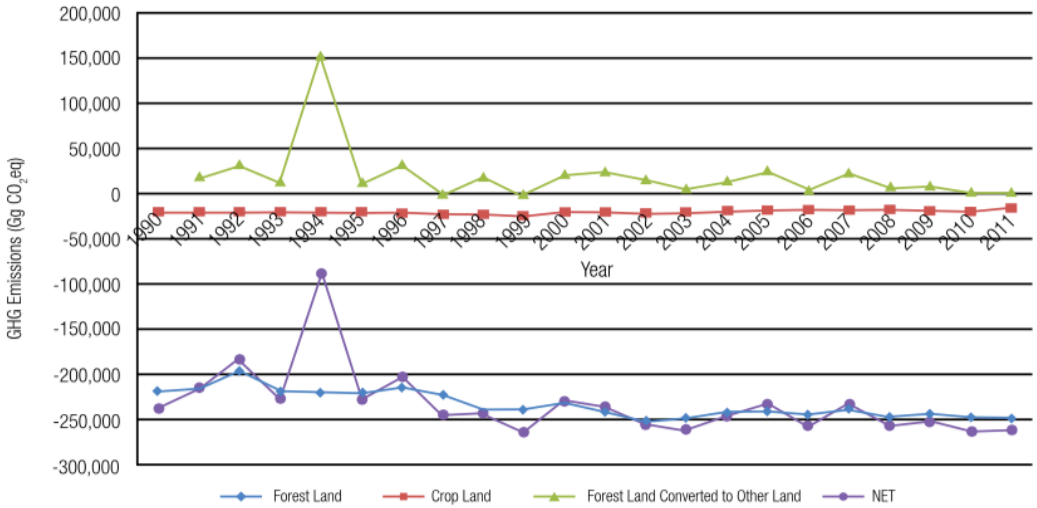


Figure 51: Emissions timeseries from 1990 to 2011 for LULUCF sector in Malaysia.

Source: Malaysia UNFCCC Biennial Update Report 2015 (Ministry of Natural Resources and Environment of Malaysia, 2015).

2.4.3 Summary for oil palm

Both oil palm production and plantation area have increased considerably in recent decades, with roughly 84% of global production in 2015 coming from Indonesia (55%) and Malaysia (29%). Estimating the impact of this expansion on land use change is a challenge due to the variation in estimates of plantation area, deforestation and other land use transitions. In addition, oil palm plantations often become established only after other primary drivers have driven land conversion, which complicates this link. However, several studies have estimated the association between oil palm and deforestation, peatland conversion and other transitions using independent satellite data. These indicate that oil palm expansion in both Indonesia and Malaysia have caused considerable impacts over high carbon lands in recent decades. Table 19 provides an overview on the potential relationship between oil palm and their potential impacts on high carbon stock areas. It is worth noting that the range, especially for Malaysia, may be underestimated, due to the uncertainties related the definition of "other land", which is not considered as forestlands, but which may (or may not) include some peatlands and bare soils. Regarding the rest of the world, palm oil production has not substantially varied in recent years when compared to Indonesia and Malaysia, as previously shown in Figure 32. Regarding the adopted reference value, it was assumed 80% of the range average, rounded-down to one representative figure (for uncertainty reasons), given that the ranges include values back from 1990's, when deforestation rates were much higher than recently.

Table 19: Oil palm producing countries and risks associated with high carbon stock lands.

Country	Forestland dynamics	Total palm oil production (Mt of oil)	Share of global production	Approximate range of recent oil palm expansion over forestlands	Adopted reference value
Indonesia	Net deforestation	36.0	55%	18% - 63%	30%
Malaysia	Net deforestation	18.9	29%	17% - 39%	20%
Other nations	-	10.4	16%	-	-
WORLD	**Net deforestation**	**65.3**	**100%**	**18% - 55%**	**29%**

Source: prepared by the authors.

Note: total palm oil production as in 2016 base-year (USDA, 2018). Approximate range estimated by the authors, based on literature review (see Table 6 and Table 14). World range assumes a weighted average of the situation occurred in Indonesia and Malaysia alone i.e. excluding other nations. The chosen reference value was assumed 80% of the range average, rounded-down to one representative figure, given that the range includes values back from 1990's, whereas recent deforestation rates have occurred in a slower pace.

Whether these trends continue in the future as palm oil production increases will depend on the efficacy of policies to prevent deforestation and other problematic land use change as well as progress in enhancing yields. In an analysis of yield gaps for oil palm, Woittiez *et al*. (2017) state that actual yields lag far behind potential levels. While global palm oil yields are estimated at roughly 3 t ha^{-1}, yields as high as 12 t per ha^{-1} have been recorded in small plantations. In addition, the maximum theoretical yield has been estimated at 18.5 t ha^{-1}. However, achieving such yields in practice is challenging, and oil palm yields have increased slowly in recent decades (USDA-FAS, 2018). If future yield increases are unable to absorb the expansion in palm oil production and policies are unable to adequately prevent the conversion of high carbon stock land, oil palm may continue to contribute to problematic land use change in Malaysia and Indonesia. However, if Malaysia and Indonesia limit such land use change in the future, the risk remains of oil palm expansion in other regions such as central Africa and South America that have high levels of vulnerable forest areas (Vijay *et al*., 2016).

Besides the future land use risks of oil palm expansion in critical areas, Table 20 summarises its average annual carbon footprint observed in the recent years (2007-2016). The values shown in this table were

estimated based on the approximate share of palm expansion over native vegetation (Table 19) and the previous estimates for the GHG emissions associated with their conversion into oil-palm land (see further explanations in Sections 2.4.1 and 2.4.2, especially Table 7 and Table 15). As previously shown in Table 3 (with data from IPCC, 2000), carbon stocks including above ground vegetation and soil carbon in tropical forests are approximately 243 tC ha^{-1}. In wetlands the total carbon stocks are about 686 tC ha^{-1}, whereas in oil palm land the carbon stock is on average about 170 tC ha^{-1} (assumed around 70% of the carbon stocks in tropical forest, including soil C). Thus, considering that the oil palm area that expanded over natural vegetation occurred over both tropical forest and wetlands (including peat and bare soils) at different rates for Indonesia (50% over forest and 50% over wetland) and Malaysia (40% over forest and 60% over wetland), it is possible to estimate the changes in carbon stocks associated with this expansion. Hence, once converting this natural vegetation area into oil palm land, the difference in total carbon stocks is 481 tC ha^{-1} for Indonesia and 339 tC ha^{-1} for Malaysia, which in terms of carbon dioxide emission means 1080 and 1242 tCO_2 ha^{-1} respectively (note: 1 tC equals 3.67 tCO_2). It is important to point out that, differently to soy oil which is a co-product from the meal chain, representing approximately 20% of the total grain mass, palm oil is the dominant product and locally processed. Our GHG emission calculations were made directly considering the oil amount and, therefore, the total emissions associated with the vegetable oil are 169 $MtCO_2eq$ y^{-1} for Indonesia and 21 $MtCO_2eq$ y^{-1} for Malaysia. Soil carbon change is also included in these values (1m depth).

Table 20: Annual GHG emissions due to oil palm expansion over native vegetation.

Country	Oil palm expansion kha y^{-1}	Oil palm expansion over natural vegetation kha y^{-1}	Assumed type of natural vegetation converted	Carbon stock in natural vegetation tC ha^{-1}		Carbon stock in oil palm land tC ha^{-1}	Emission factor tCO_2 ha^{-1}	GHG emissions from the conversion of natural vegetation for oil production $MtCO_2eq$ y^{-1}
Indonesia	522	157	50% tropical forest	243	464	170	1080	169
			50% wetland (incl. peatland)	686				
Malaysia	84	17	40% tropical forest	243	509	170	1242	21
			60% wetland (incl. bare soil)	686				
Total	**606**	**173**					**1095**	**190**

Source: prepared by the authors.

Note: Annual oil palm expansion from 2006-2016 (FAO, 2018). Annual palm expansion over native vegetation based on estimates described in the report (Table 19). Emission factor estimated from IPCC (2000), including both above ground vegetation and soil carbon changes (Table 3). One tonne of Carbon (C) is equivalent to 3.67 tonnes of Carbon Dioxide (CO_2). Oil palm plantations are assumed to contain 70% of the carbon content of an average tropical forests. Values include emissions from above ground vegetation and soil C (1m depth).

The carbon dynamics related to land use change for oil palm plantation involves some other variables not here accounted. For example, oil palm takes about 4-5 years for its first fruit production and the tree remains productive until about its 25th year (MAPA, 2015). We are not making projections in the present calculations, but using consolidated values for a standard mature palm oil plantation. Values from past years (e.g. 10 or 20 years ago) may also have carbon sequestration from older palm plantations (e.g. trees planted 25 years ago) still influencing the more recent historical values of carbon accumulation. Besides, the carbon accumulation in a palm tree growth is not linear over time, instead, it usually occurs as a S shape curve.

2.5 Oilseed rape (OSR)

The production of rapeseed oil also has a concentrated market, with Canada, China and EU28[6] dominating the global production with about 78% of the global production (Figure 52). Including India and the United States, this total share increases to 90%, with all other nations representing only 10% of global production. The main producing countries of rapeseed oil in the European Union are France, Germany, Poland, the United Kingdom, Czech Republic and Romania, accounting for 81% of its total production (Figure 53).

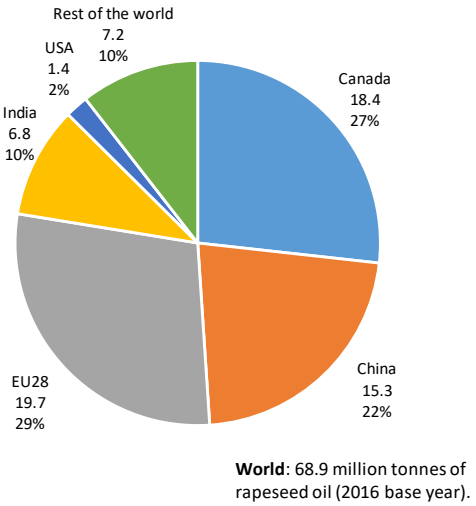


Figure 52: Rapeseed oil, in million tonnes of veg. oil.

Source: Prepared by the authors, using data from FAO (2018).

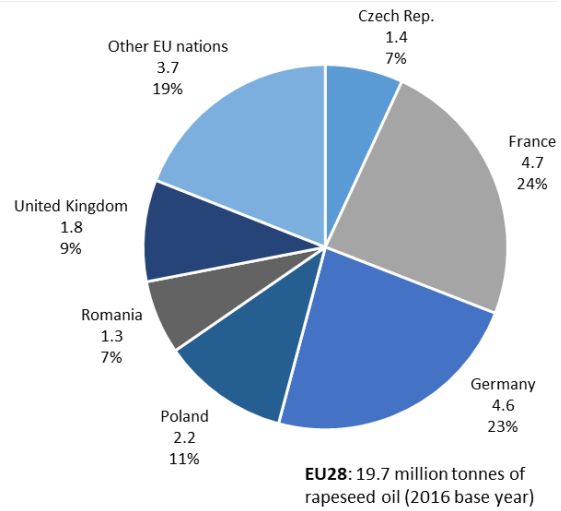


Figure 53: Rapeseed oil, in million tonnes of veg. oil.

Source: Prepared by the authors, using data from FAO (2018).

Oilseed rape (*Brassica napus*) is also known as rapeseed, rape or colza. Canola is originally a brand name created in Canada in the 70's to distinguish cultivars of oilseed rape presenting low content of erucic acid at a time when the selection had not yet eliminated this fatty acid from all rapeseed cultivated (which is the case nowadays), currently the term is often used as a synonym of oilseed rape more broadly. It is a crop relatively resistant to cold temperatures, and largely produced in temperate zones. In contrast, soybean is more favourable to tropical and subtropical zones, whereas oil palm to humid equatorial areas. The global production of rapeseed oil has substantially increased in the past decades, especially in Canada, China and European nations (Figure 54).

[6] EU28 – the European Union's 28-member countries as of December 2018: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

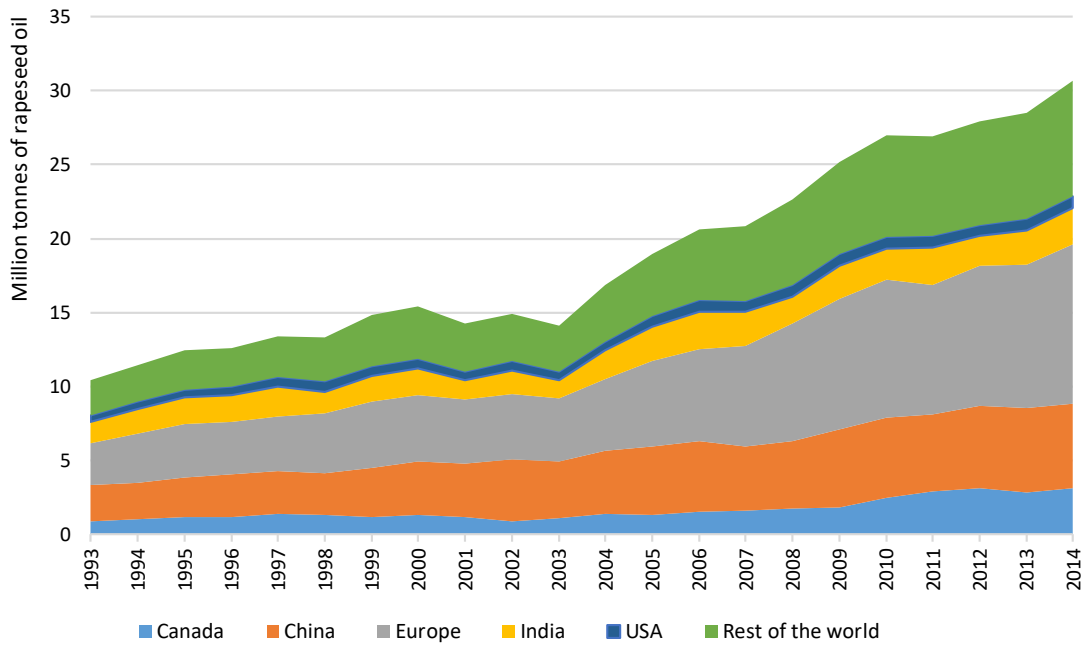


Figure 54: World production of rapeseed oil, in tonnes of vegetable oil.

Source: prepared by the authors, using data from FAO (2018).

Europe has achieved a substantial progress in the production and consumption of biodiesel from rapeseed oil. Although the agronomical potentials to expand the domestic production at larger scales are still high, Europe also has substantial land use constraints and legal barriers. On the other, rapeseed production has apparently stagnated and there is no substantial consumption increase expected neither for food nor for biofuel use in the coming years. Since 2015, crop-based biofuels are capped at 7% of the road and rail energy, whereas from 2021 the cap is expected to be based on the 2020 level of consumption for each EU Member State, more specifically 2020 level + 1 point, without exceeding 7% anyway. The importation of vegetable oils (mostly palm oil) or grains (e.g. soybean or OSR) to be processed locally have attracted interest for business making, whilst also calling the attention of NGOs and governments, including at the European Commission level, about the risks associated. The main concern is the possible negative environmental impacts outside Europe, particularly in terms of deforestation and biodiversity conservation (especially regarding oil palm from Indonesia and Malaysia), land and carbon footprint.

2.5.1 EU28

The EU28 land use patterns have slightly changed over the past decades (Figure 55). Total agricultural lands, including both croplands and pasturelands, have substantially decreased as opposed to global trends of growing productive lands. Other lands, which includes ice covers and deserts, has increased, particularly due to the expansion of urban areas and infrastructure (e.g. road, railways, energy plants, ports, factories).

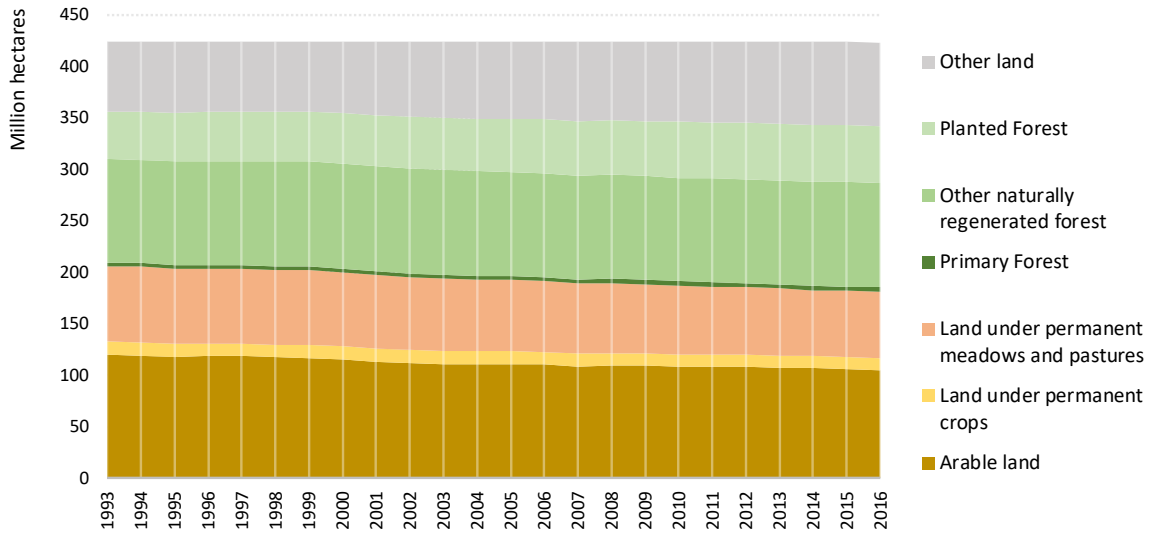


Figure 55: EU28 land use change.

Source: Prepared by the authors, using data from FAO (2018)

While looking at trendlines for land use change, EU28 has shown linear changes for all its broad land use categories (Figure 56), apart from some oscillations in the oilseed rape harvested area. Despite the gradual increase in forestlands and decrease in total cropland may be seen as something positive in terms of carbon mitigation, it also shows that the European agriculture has progressively abandoned less productive lands due to low profit margins which poses regional and social problem accompanying the rural abandonment. The recent reductions in agricultural subsidies and governmental support for farmers have aggravated this situation, even though Europe remains competitive in many agricultural areas, especially because of its historical knowhow, technological advances, efficient infrastructure and logistics. The EU agricultural policy is very complex and not the subject of this report but, in general, there is a coexistence of two types of agriculture: a highly competitive agriculture, and a social type meant to keep a rural development landscapes and tourism. In contrast, the European population has a growing demand for food (including meat), which has to be met either by increasing agricultural productivity or land expansion; otherwise, the EU28 would have to increase food imports with consequential land and carbon footprints outside Europe (Strapasson *et al.*, 2016). Thus, the production of OSR must be seen in this broad European context.

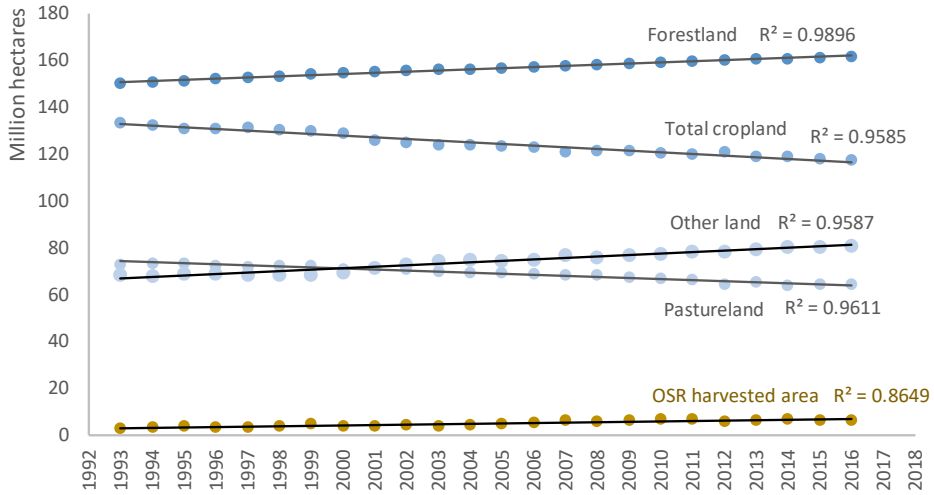


Figure 56: Changes in land use patterns in EU28, including linear regressions.

Source: Prepared by the authors, using data from FAO (2018)

The European production of oilseed rape increased from 2004 to 2009; however, it has not significantly grown since then, apart from some oscillations over the years (Figure 57). The same effect occurred for European OSR crushing volumes, which also includes processing imported OSR grains. The EU is a net importer of OSR, although it meets most of its domestic demand with local production.

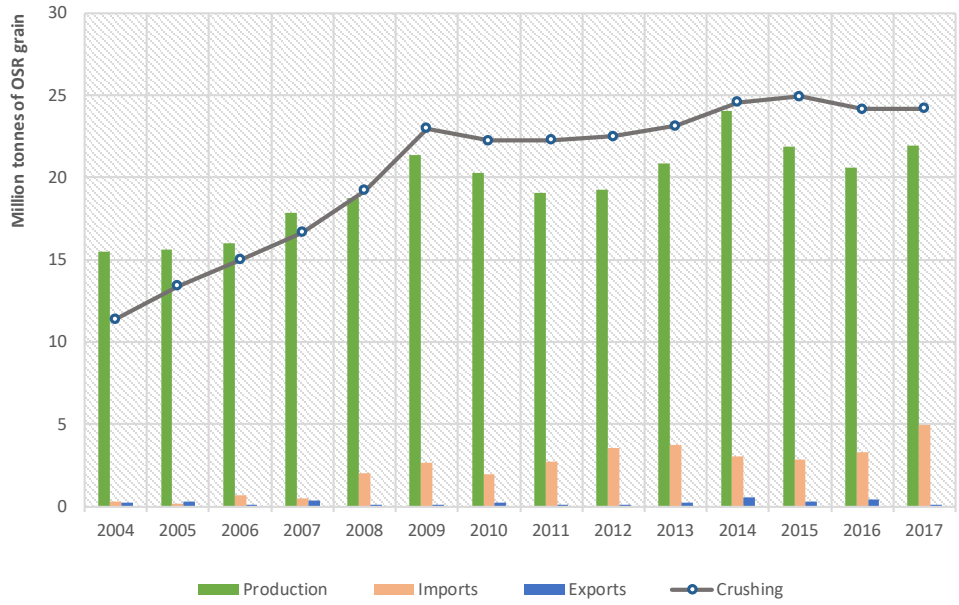


Figure 57: EU28's OSR production, imports, exports and crushing amount.

Source: prepared by the authors, using data from Eurostat (2018).

From the total processed OSR, Europe produces both rapeseed meal and oil, and consumes approximately all of their productions domestically. Imports and exports of both products are small. Therefore, this is a market for Europe and within Europe. The meal is used as an animal feed. Domestic production has nearly doubled since 2004, but remained relatively stable from 2009 to 2017, as shown in Figure 58.

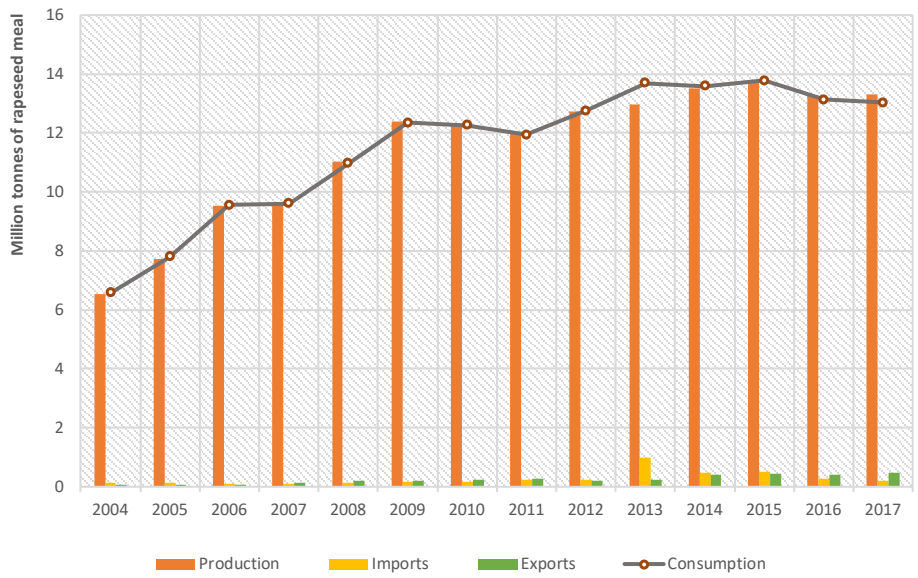


Figure 58: EU28 production of rapeseed meal.

Source: prepared by the authors, using data from Eurostat (2018).

As a co-product of the rapeseed-meal production, the production of oil has also been increasing in the EU28 in past decades (Figure 59). OSR crushing results in approximately 42-44% of vegetable oil and 56-58% of meal. These two markets are intrinsically interlinked, but some small variations are observed due to variations in oil content within the grains and industrial process yields. As noted for the meal, the European rapeseed oil consumption is aligned with its domestic production, without significant international trade.

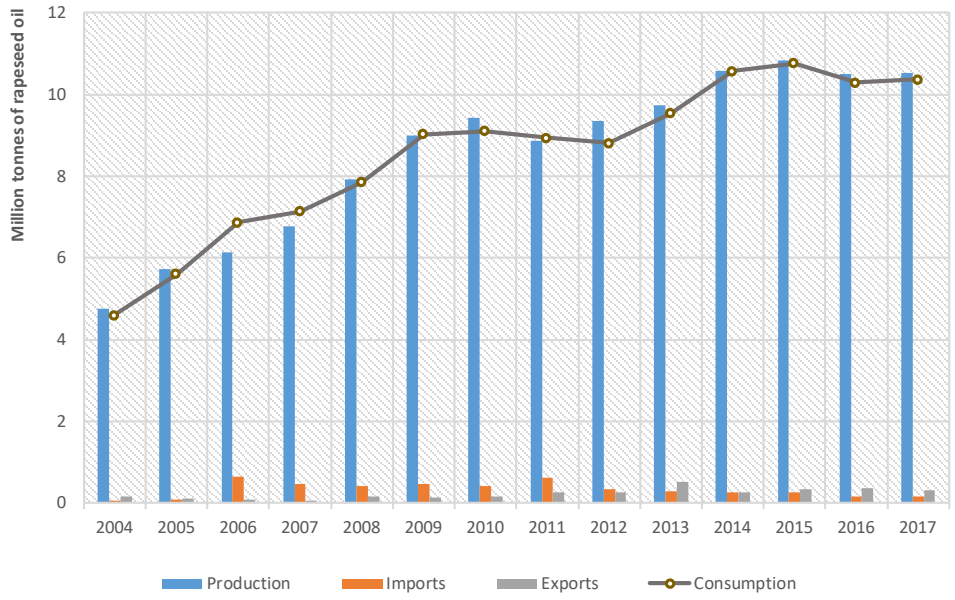


Figure 59: EU28 production of rapeseed oil.

Source: prepared by the authors, using data from Eurostat (2018).

In order to keep increasing the EU28 domestic production of OSR grains, as well as rapeseed meal and oil, the EU Member States would have to increase its production area and/or its productivity. By productivity is meant not only crop yields (production of grains per harvested area), but also the increase in harvested

area without necessarily expanding the physical land area over other uses. This is technically possible to be done via land 'multi-use', i.e. by intensifying the use of land resources, harvesting more crops in same area per year (e.g. double cropping using winter and summer crops), which can be represented by a multiple-cropping index (MCI)[7]. However, the EU rapeseed is a winter crop usually planted in the end of summer season and harvested around July and, hence, the possibilities for multiple-cropping in the same year are not applicable, given that double-cropping is already the norm. Spring rape exists (as in Canada) but yields are usually lower and the European climate is less favourable for this crop variety, currently only grown in the far north of Europe. In contrast, some producing countries of vegetable oil worldwide can still expand part of (if not all) their production by increasing crop yields and maximising the use of their lands. Some tropical nations (e.g. Brazil, Paraguay) can have triple-cropping a year, for example, no-tillage rotation of maize and soybean, i.e. alternating Gramineae and Leguminosae crops.

However, depending on the level of additional biofuel demand in the Europe, an area expansion would be hypothetically necessary to meet the market, potentially expanding (or not) over forestlands, either directly or indirectly, for example, by stimulating the expansion of another crop or livestock over forestlands somewhere else in order to re-equilibrate the vegetable oil market at global level. Santeramo (2017) and Searle (2017), for example, demonstrated that biodiesel from rapeseed and soybean may drive oil palm expansion. However, it is unlikely that the EU rapeseed production due to biodiesel consumption will substantially increase. Contrary to the global supply and demand of palm and soybean, the trend for European rapeseed is to prevent its production to decrease, given that the European food vegetable oil market is not expected to increase and that its biodiesel consumption is bound to decrease, due to regulatory caps for first generation biofuels.

In regard to greenhouse gas emissions from agriculture, forest and other land uses, Figure 60 summarises the changes in historical data for the EU28.

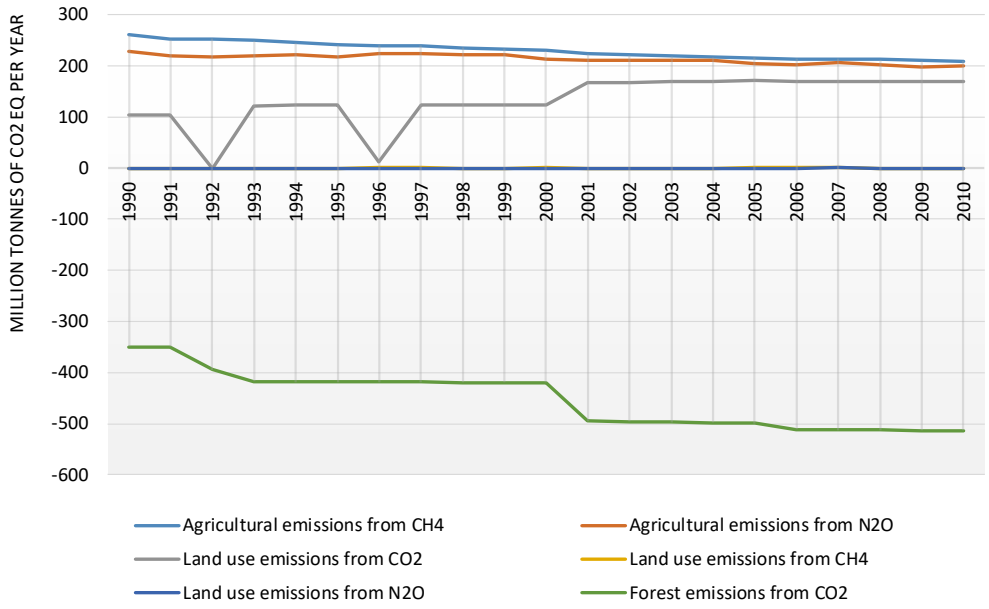


Figure 60: EU28's GHG emission in the AFOLU sector.
Source: prepared by the authors, using FAO (2018).
Note: Abrupt changes in emissions may result from changes in reporting protocols.

[7] See more about MCI calculations for all EU28 nations in Strapasson *et al.* (2016).

The following sub-sections show further descriptions on the most important OSR producing countries in the EU28, namely France, Germany, Poland, United Kingdom, Czech Republic and Romania.

France

Land use change in France has gradually changed over the past decades, particularly forestlands and pasturelands (Figure 61). The country has no remaining primary forest, but presents a growing amount of naturally regenerated forests. Approximately half of its total territory is comprised of productive lands, let alone the sustainable management of natural forests.

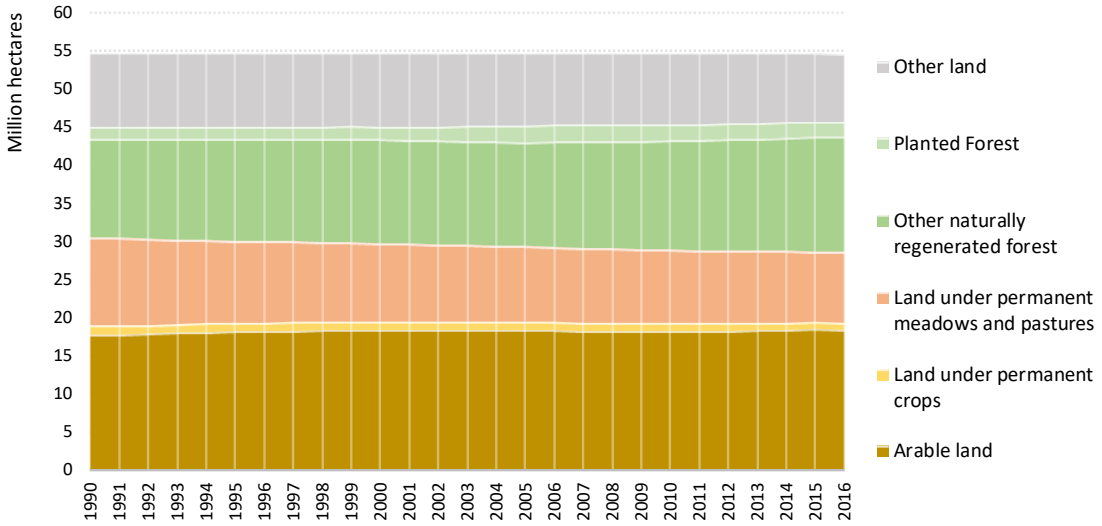


Figure 61: Land use distribution in France

Source: prepared by the authors, based data from FAO (2018)

France is the largest producer of OSR in Europe, slightly ahead of Germany. It occupies the fourth position globally, after Canada, China and India. As shown in Figure 62, its harvested area has increased almost linearly in the past decades with some oscillations over time (although relatively stable since 2008), whereas total cropland has been approximately stable in the same period. On the other hand, forestland have been substantially increasing, whilst pasturelands and other lands decreased. Therefore, the expansion of OSR plantations in France is not directly associated with deforestation within its country.

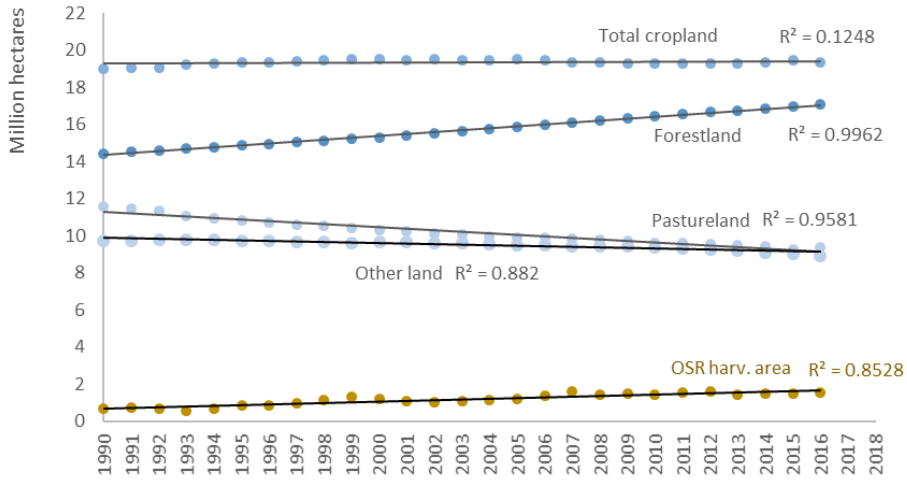


Figure 62: Changes in land use patterns in France, including linear regressions.
Source: prepared by the authors, based data from FAO (2018)

Germany

Land use in Germany has not substantially changed in the past decades for the categories shown in Figure 63. Approximately a third of the German territory is comprised of arable lands. Like in France, Germany has no remaining primary forests. On the other hand, while total forest area in France has increased, in Germany they have not. The German population is well distributed all over the country's territory, and not very concentrated in a few cites as observed in many other nations worldwide. Apart from the German reunification in 1990, land use patterns have not substantially varied to date for the broad categories assessed here.

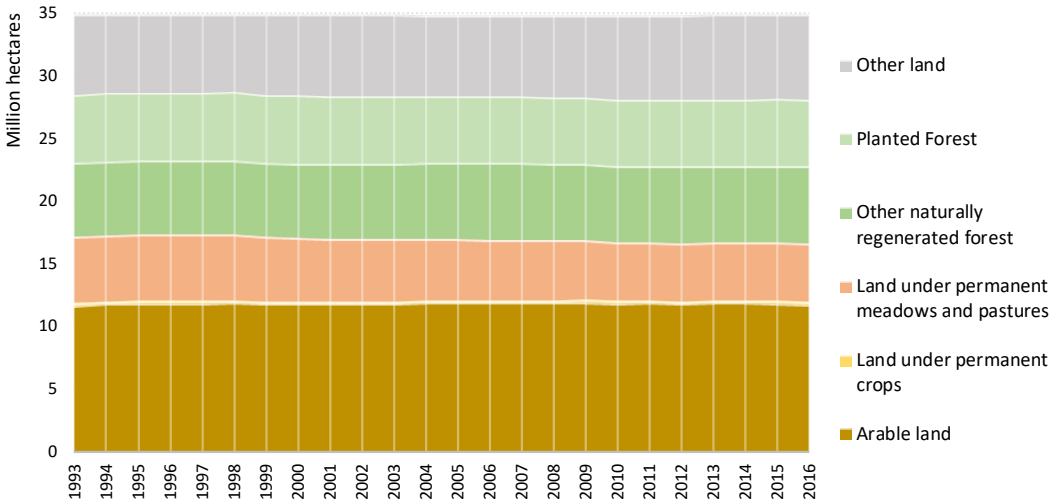


Figure 63: Land use change in Germany.

Source: prepared by the authors, using data from FAO (2018)

The harvested area of OSR has increased in Germany in the past decades, but remained approximately stable since 2008; whereas pastureland significantly reduced over time at a nearly linear change (Figure 64). Given that forestlands and total cropland have not varied significantly, the presented dynamics suggest that OSR has not directly affected forestlands in Germany.

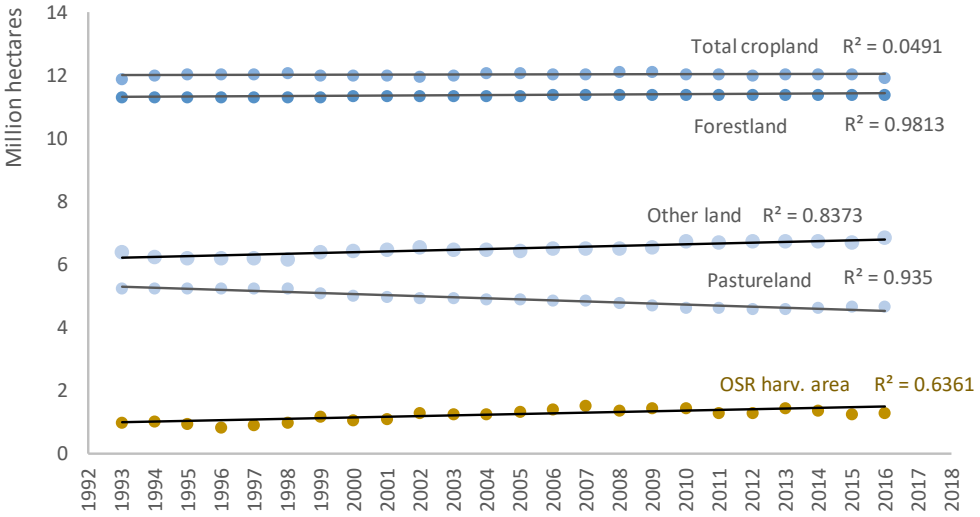


Figure 64: Changes in land use patterns in Germany, including linear regressions

Source: prepared by the authors, using data from FAO (2018)

United Kingdom

The land use pattern in the UK is quite different to France and Germany, whereas the country also has no primary forest, its naturally regenerated forests are small and pastureland occupies a much larger share of its total territory (Figure 65). In terms of land use ranking, pastureland is first followed by arable land, then by 'other land' (incl. settlements and infrastructure, see definitions in annex). Only after this comes forestlands, which are mostly comprised of planted forests (silviculture).

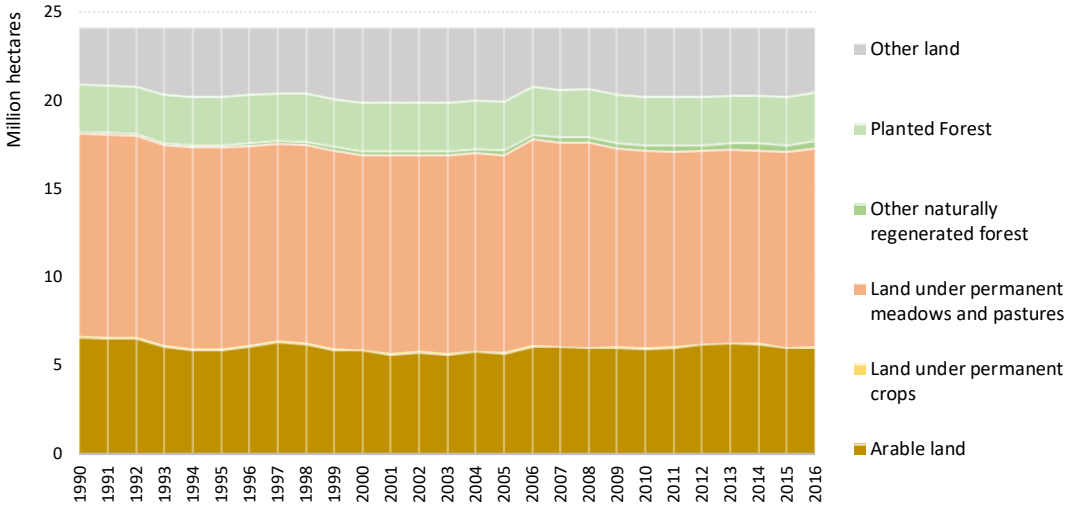


Figure 65: Land use change in the United Kingdom.

Source: prepared by the authors, using data from FAO (2018)

Pastureland and total cropland have slightly decreased, whilst forestland has increased slightly. The harvested area of oilseed rape has also increased, but the total area remains small and without major changes since 2008. Thus, it is unlikely that OSR has affected the dynamics of forestlands within the UK.

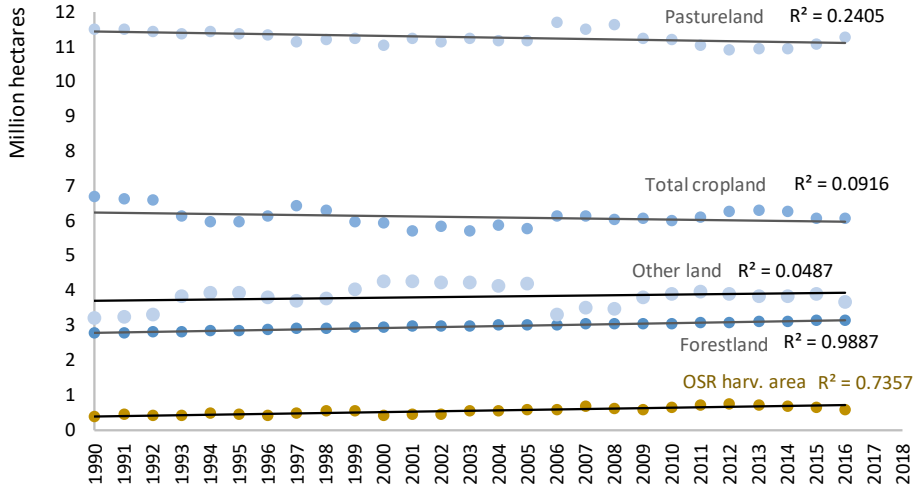


Figure 66: Changes in land use patterns in the United Kingdom, including linear regressions.

Source: prepared by the authors, using data from FAO (2018)

Czech Republic

The Czech Republic is substantially smaller than the other countries in this report. The Czech Republic has had no significant changes of land use patterns since its establishment as a separate nation, apart from an abrupt reduction in total arable land from 2012 to 2013, apparently due to a change in data reporting (Figure 67).

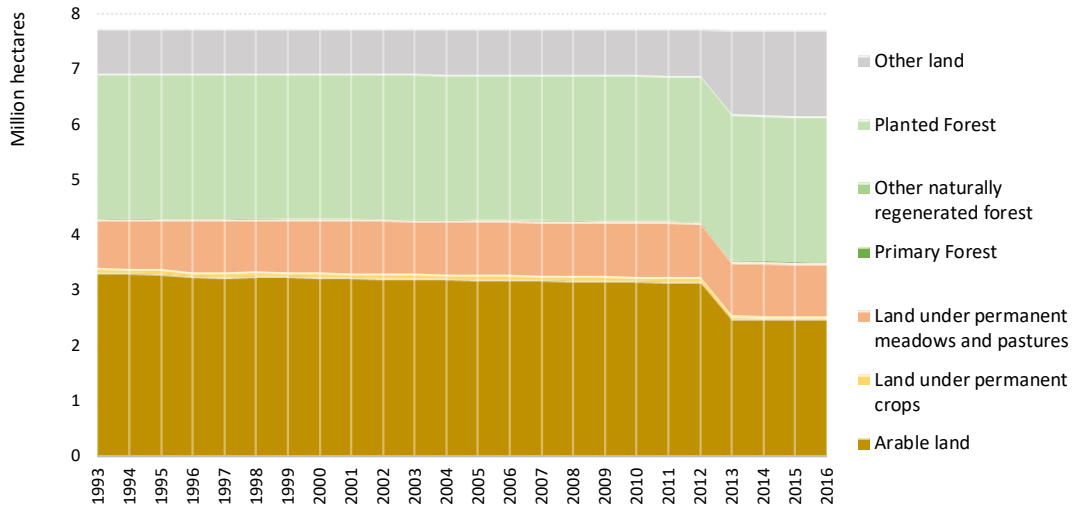


Figure 67: Land use change in Czech Republic.

Source: prepared by the authors, using data from FAO (2018)

As shown in Figure 68, the total area of forestlands in Czech Republic has been unaffected (no significant variation) over the past decades. It is mostly comprised of naturally regenerated forests. In contrast, total croplands have linearly declined, even though the harvested area of oilseed rape has increased in the same period. Given that there is no net deforestation occurring in Czech Republic, it is unlikely that the expansion of OSR harvested area has been directly affecting forestlands within the country.

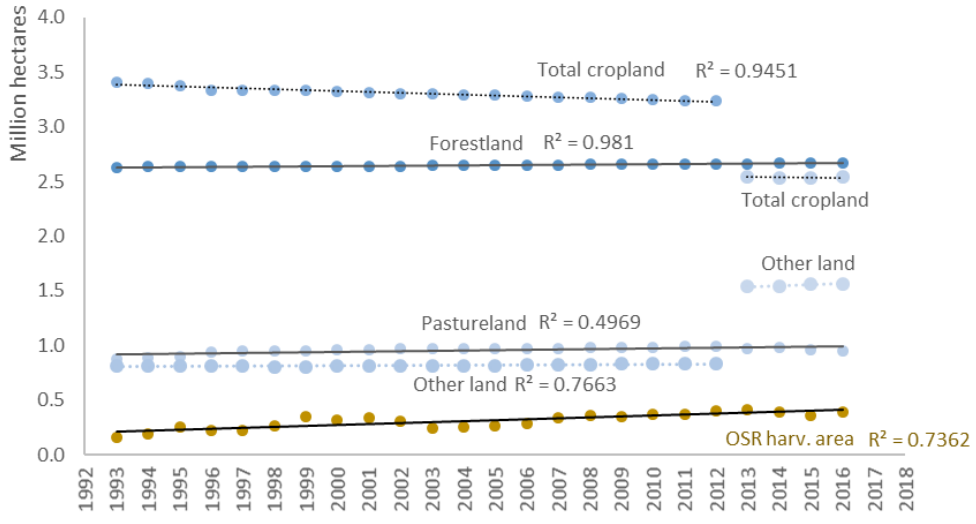


Figure 68: Changes in land use patterns in Czech Republic, including linear regressions.

Source: prepared by the authors, using data from FAO (2018)

Poland

Poland has 31 Mha of total territory, with a population of approximately 39 million inhabitants. It is one of the most forested countries in Europe, including several landscape parks, natural reserves and other protected areas. Different to the EU28's consolidated land use change patterns, Poland has shown significant variations in some land use types over the past decades, specially a reduction in total agricultural land (croplands and pasturelands), followed by an increase in other lands and forestlands (Figure 69).

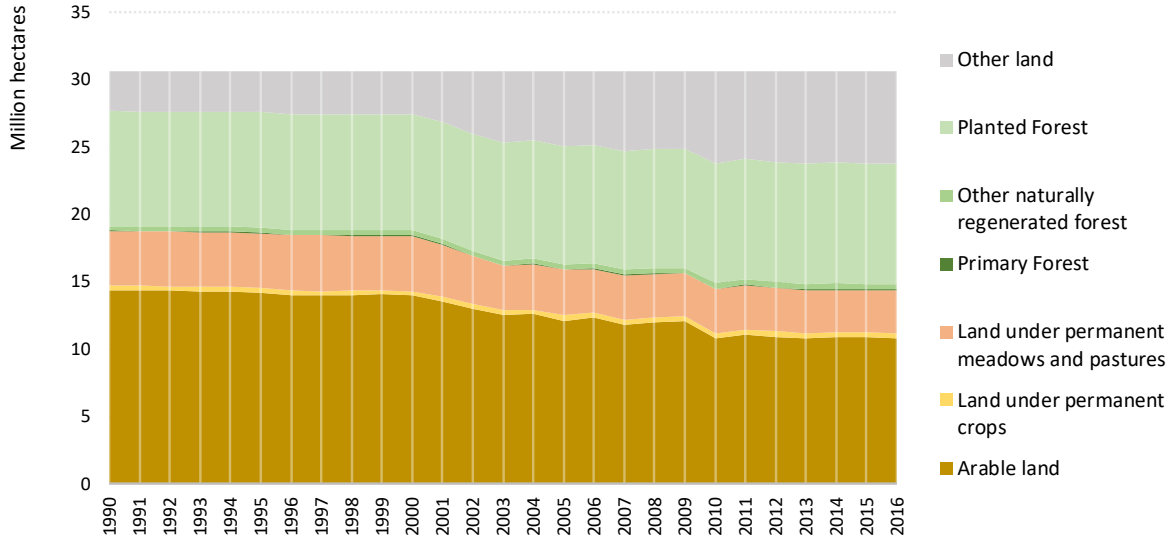


Figure 69: Land use change in Poland.

Source: prepared by the authors, using data from FAO (2018).

In the long run these land use changes show linear variations for almost all land use categories assessed here (Figure 70). Apart from the significant reduction in total cropland, the harvested area of oilseed rape has increased in the past decades, although remained relatively stable in more recent years. Poland is the third largest producer or OSR in the EU28 (behind France and Germany), accounting for 2.2 Mt of rapeseed oil, which represents 11% of the total EU28 production (19.7 Mt) as in 2016.

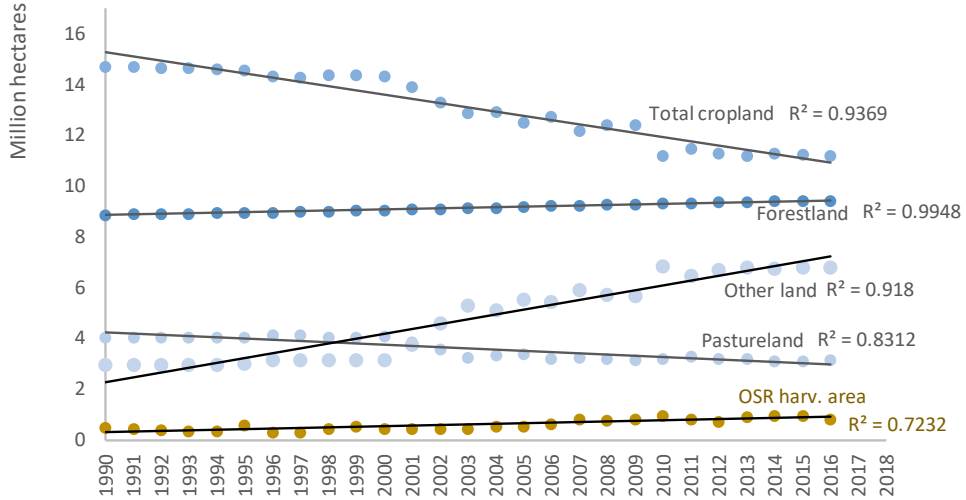


Figure 70: Changes in land use patterns in Poland, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

Romania

Land use patterns in Romania have been stable from 1990 to 2003, but have varied since then (Figure 71). Arable land is its main land use, followed by forestlands (including a small fraction of primary forest) and pasturelands. The country also holds a biodiversity-rich marshland in the delta of Danubio River, which flows into the Black Sea. Romania is in the crossroads of Central, Eastern and South-eastern Europe, and joined the EU in 2007. It has been one of the fastest growing economies in the EU.

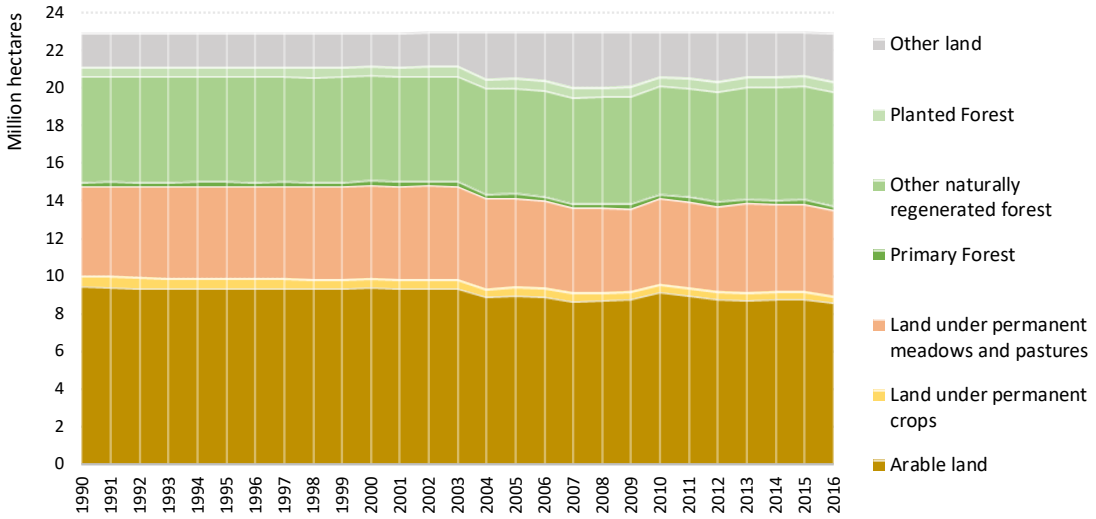


Figure 71: Land use change in Romania.

Source: prepared by the authors, using data from FAO (2018).

Total cropland in Romania has declined in past decades, although the harvested area of oilseed rape has increased in the same period (Figure 72). Pasturelands have also decreased, whereas forestland and other land increased, although presenting a volatile pattern in recent years. Thus, no significant correlation has been observed between the increase in OSR harvested area and forest dynamics within Romania's territory.

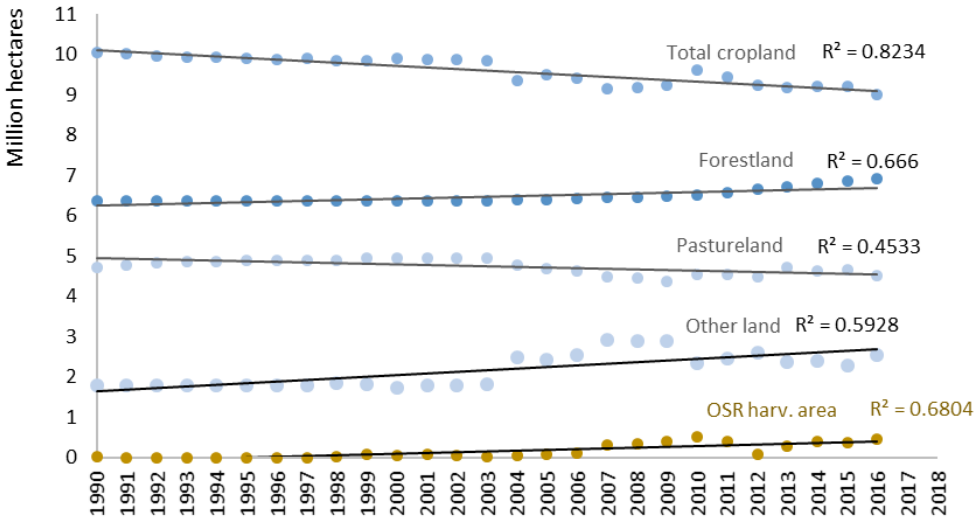


Figure 72: Changes in land use patterns in Romania, including linear regressions.

Source: prepared by the authors, using data from FAO (2018).

2.5.2 Other OSR producing nations

In addition to the EU nations already described, Canada, China, India and the United States are also relevant players in the global market of rapeseed oil. **China** and the **United States** are also important soybean producers and therefore their land use patterns and cropland dynamics (including for OSR) were already discussed in the soybean section of this report. China is the second largest producer of OSR, but consumes almost all its production internally. Thus, the following sections show a brief overview on the land use dynamics of Canada and India, with an emphasis on the production of OSR as potential feedstock for biodiesel production.

Canada

Canada is the second largest country worldwide, with 998 Mha, and a vast number of lakes containing fresh water. Most of its territory is comprised of non-commercial areas, particularly large extensions of ice covers and sheets, which are here included in the classification of other land (Figure 73). Most of the Canada's North Region is covered by ice and permafrost. Forestland is the second most important land use category, out of which more than half is comprised of primary forest, followed by naturally regenerated forest, and just a small fraction is made of planted forest. Arable land and pasturelands represent just small share of its total territory. Unlike most of other nations here assessed, Canada has not shown major land use changes in the past decades.

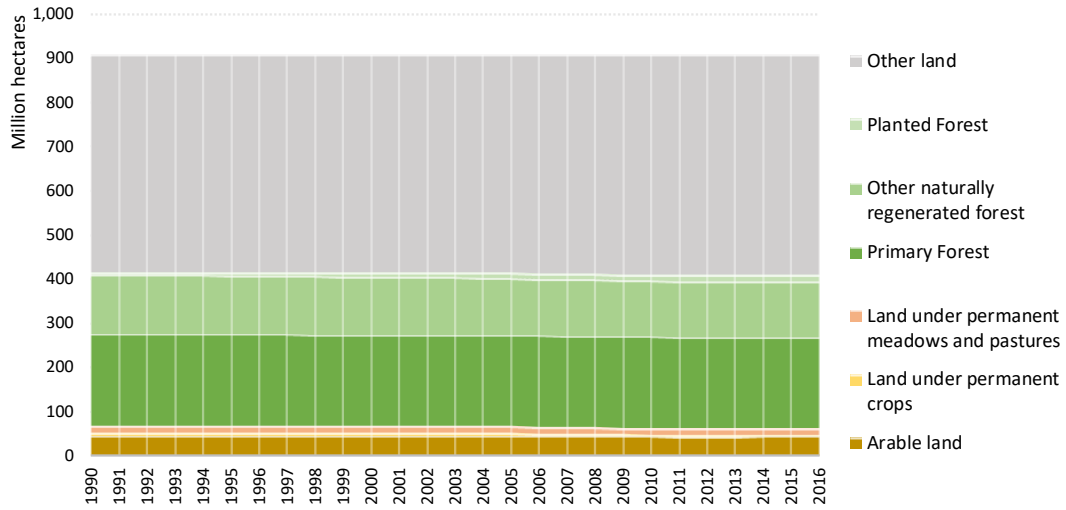


Figure 73: Land use change in Canada.

Source: Prepared by the authors, using data from FAO (2018).

The harvested area of oilseed rape has increased but shown no correlation with changes in forestlands, which have remained relatively constant over the past decades, although in the recent 10 years (2006-2016), Canada presented a net deforestation of 50 kha y^{-1}, according to data from FAO (2018). Forestland includes extensive areas of boreal forests. Total cropland and pastureland have shown no significant variations. Canada is the largest producer of oilseed rape globally. Its total production more than doubled in the past 20 years and it keeps increasing (Canola Council of Canada, 2018), surpassing its harvested area for wheat. For the first time ever, Canadian rapeseed passed the total EU production in 2018.

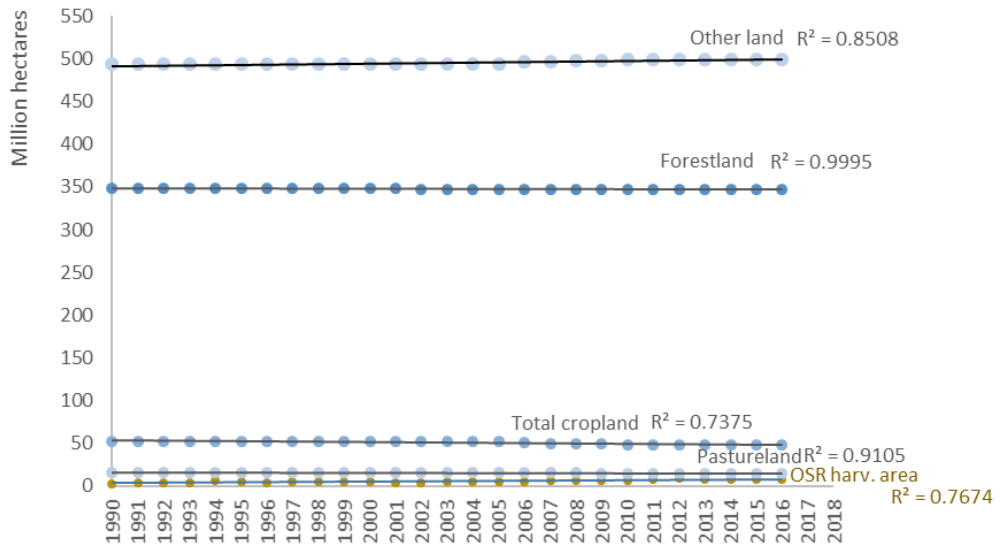


Figure 74: Changes in land use patterns in Canada, including linear regressions.

Source: Prepared by the authors, using data from FAO (2018).

In terms of AFOLU emissions, Canada has not shown significant changes over the past decades, except for the CO_2 emissions from forestland (Figure 75), which apparently have been affected by changes in the methodological approach for carbon balance and report.

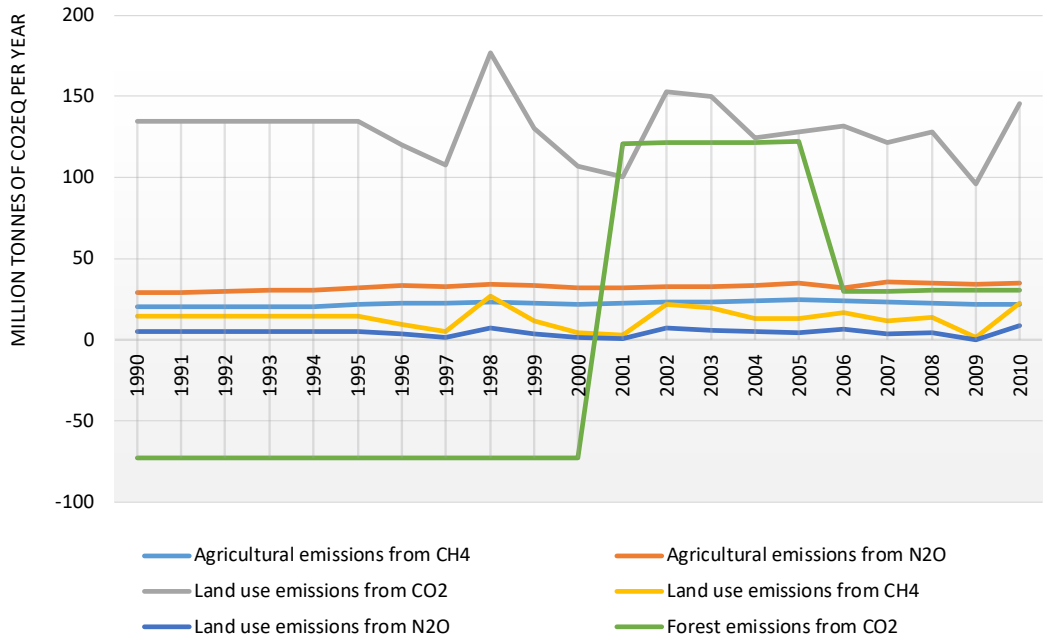


Figure 75: AFOLU emissions in Canada.

Source: prepared by the authors, based on data from FAO (2018).

Note: Abrupt changes in emissions may result from changes in reporting protocols.

India

India is the second most populated nation (about 1.2 billion inhabitants), just behind China. The population is spread all over the country's territory, which is dominated by arable lands (Figure 76). Forestlands include a small fraction of primary forest. Other land includes not only settlements and infrastructure, but also mountains, often ice covered (e.g. Himalayas), and deserts (e.g. Thar Desert). In terms of biodiversity, India is a highly diverse country, including different types of forestlands (e.g. tropical rainforest and coniferous forest), plant and animal species. Pasturelands are relatively small.

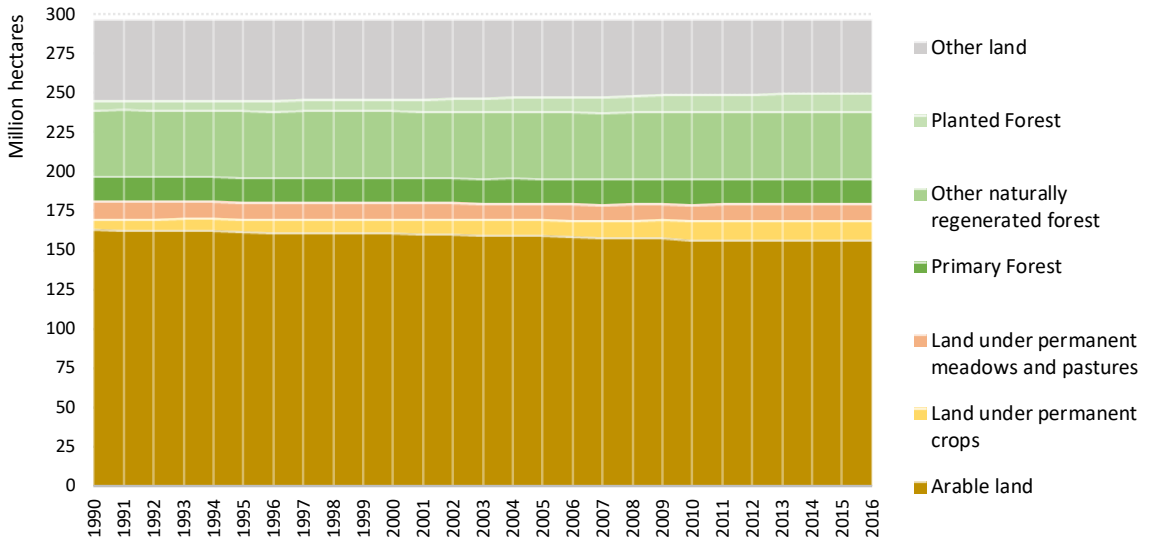


Figure 76: Land use change in India.

Source: prepared by the authors, based on data from FAO (2018).

Apart from the internal pressures on land resources in India, the country has increased its pasturelands, whilst decreasing the share of other land (Figure 77). Total cropland and the harvested area of oilseed rape have remained nearly constant in the last decades, as has pastureland. Therefore, there is no clear correlation between the dynamics of OSR harvested area and its potential impacts on high-carbon areas, such as forestlands.

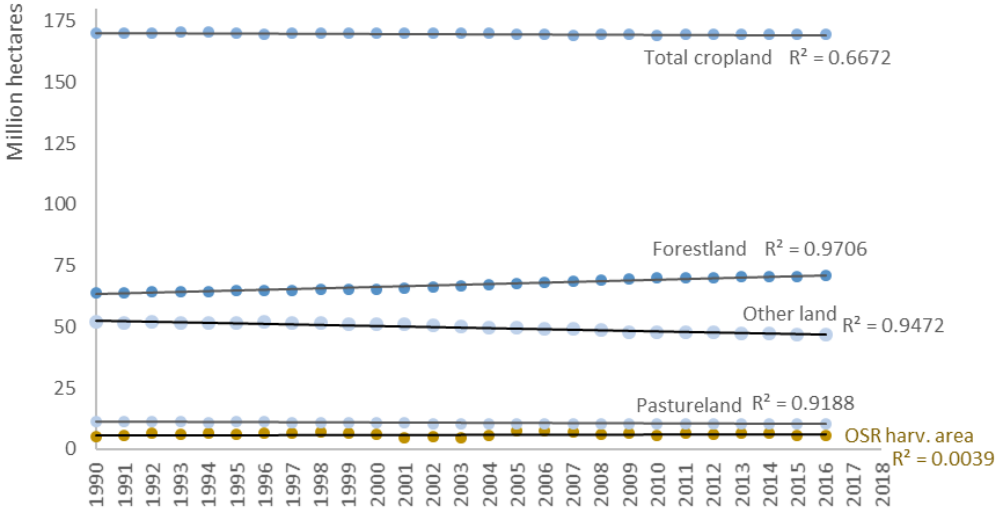


Figure 77: Changes in land use patterns in India, including linear regressions.

Source: prepared by the authors, based on data from FAO (2018).

Concerning the greenhouse gas emissions from agriculture, forestry and other land use in India, agricultural emissions of methane and nitrous oxide have gradually increased in the past decades, whereas CO_2 emissions from forestland remains negative (Figure 78). These growing emissions include impacts from agricultural intensification and higher use of nitrogen fertilisers. Methane emissions from the production of irrigated rice (paddy fields) are also a relevant in total AFOLU emissions.

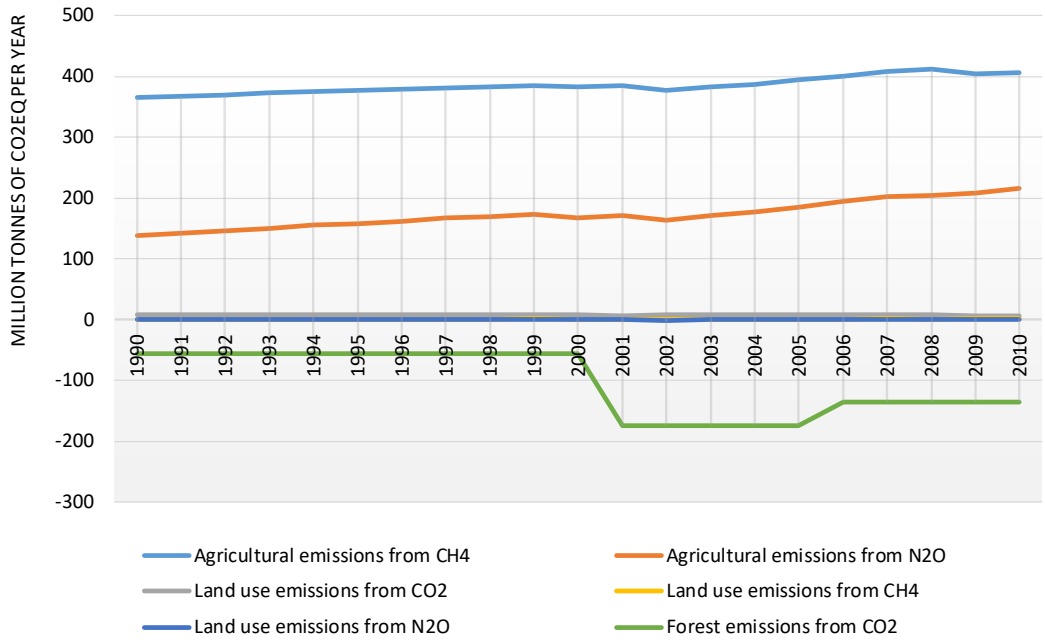


Figure 78: AFOLU greenhouse gas emissions in India.
Source: prepared by the authors, based on data from FAO (2018).
Note: Abrupt changes in emissions may result from changes in reporting protocols.

2.5.3 Summary for oilseed rape

Oilseed rape has been produced in a large number of nations, although it has more concentrated in the EU28, Canada, China, India and United States. It is third most important vegetable oil crop worldwide, behind oil palm and soybean. Its use for biodiesel production gained momentum in the EU in the past decade, particularly because it is a well-known crop, and use to be produced under rotational schemes with other crops or fodder.

All the assessed countries presented net afforestation / reforestation in the past decades (Table 21). Thus, there is no apparent correlation between the recent expansion of oilseed rape and forest dynamics. However, indirect land use effects may still occur, given that the global vegetable market is integrated in a complex manner, and that the impacts can vary overtime and region (Strapasson *et al.*, 2017; Woltjer *et al.*, 2017).

Table 21: Oilseed rape producing countries and risks associated with high carbon stock lands.

Country	Forestland dynamics	Total rapeseed oil production (Mt of oil)	Share of global production	Approximate range of OSR expansion over native vegetation
Canada	Net deforestation	18.4	27%	0%
China	Net afforestation/reforestation	15.3	22%	Not applicable
Czech Republic	Net afforestation/reforestation	1.4	2%	Not applicable
France	Net afforestation/reforestation	4.7	7%	Not applicable
Germany	Net afforestation/reforestation	4.6	7%	Not applicable
India	Net afforestation/reforestation	6.8	10%	Not applicable
Poland	Net afforestation/reforestation	2.2	3%	Not applicable
Romania	Net afforestation/reforestation	1.3	2%	Not applicable
United Kingdom	Net afforestation/reforestation	1.8	2%	Not applicable
United States	Net afforestation/reforestation	1.4	2%	Not applicable
Other nations	-	7.2	10%	-
EU28	*Net afforestation/reforest.*	*19.7*	*29%*	*Not applicable*
World	**Net deforestation**	**68.9**	**100%**	**Not applicable**

Source: prepared by the authors.

Note: total rapeseed oil production as in 2016 base-year (FAO, 2018). Risk associated with the likelihood that OSR may expand over native vegetation within the respective country, including forestlands and natural grasslands.

3 Further discussions

Table 22 shows our calculated values of the expansion ratios on high carbon stock lands, and energy intensities at the national levels, and from these we determine the global values. We see a range for palm from 20-30% for the two main producers. For soy the range is from 0% to 28%. At the level of regions within nations these variations are larger still as is seen in the main body of the report and these are used to determine the national averages. The amortised emission intensities for additional production are consistent with recent studies (for example, Valin *et al.*, 2015; Edwards *et al.*, 2014) although our values are lower. Where we differ entirely is for oilseed rape (OSR) where our methodology does not support a position that oilseed rape nationally or globally expands directly over high carbon stock lands.

Table 22: Annual CO_2 emissions from soy, palm and rapeseed expansion on lands with high carbon stocks.

Oil crop	Country	Forest area change kha y^{-1}	Production Mt y^{-1}	Oil crop expansion, harvested area, A_0 kha y^{-1}	Expansion over native land, A_1 kha y^{-1}	Expansion ratio over native land, A_1/A_0	Emission factor expansion over native land, E_m tCO_2eq ha-1	Emission factor tCO_2eq/t oil	Emission intensity, E_i gCO_2eq/MJ oil with economic allocation
Soybean (grain)	Argentina	-305	45.7	437	122	28%	415	10.3	95
	Brazil	-1252	96.3	1111	189	17%	415	5.7	52
	China	1531	12.0	-266	0	Not applicable	-	0.0	0
	USA	482	117.2	329	0	Not applicable	-	0.0	0
	ROW	-3806	50.6	-	-	-	-	-	-
	World	**-3350**	**334.9**	**1611**	**311**	**19%**	**415**	**6.2**	**56**
Palm oil (oil)	Indonesia	-685	36.0	522	157	30%	1080	4.8	126
	Malaysia	107	18.9	84	17	20%	1242	3.3	69
	ROW	-2772	10.4	-	-	-	-	-	-
	World	**-3350**	**65.3**	**606**	**174**	**29%**	**1095**	**4.3**	**108**
Oilseed Rape (oil)	Canada	-50	18.4	275	0	Not applicable	-	0.0	0
	China	1531	15.3	163	0	Not applicable	-	0.0	0
	India	274	6.8	-151	0	Not applicable	-	0.0	0
	USA	482	1.4	27	0	Not applicable	-	0.0	0
	EU28	421	19.7	107	0	Not applicable	-	0.0	0
	ROW	-5792	7.2	-	-	-	-	-	-
	World	**-3350**	**68.9**	**421**	**0**	**Not applicable**	**-**	**0.0**	**0**

Source: prepared by the authors.

Notes: **1)** Total oil crop production as in 2014 base year (FAO, 2018). **2)** Oil crop expansions over native vegetation were estimated by the authors for approximately the last ten years of historical values, based on literature review and assumptions described in this assessment report. Native vegetation includes forestlands and natural grasslands, as well as peatlands. **3)** Uncertainties involved: some peatlands may be misclassified in the assessed databases and not included as either forestlands or grasslands, but instead in the category of other lands, which includes deserts, ice covers, settlements and infrastructure. This may be particularly critical for Malaysia, which may have its potential impacts underestimated. **4)** Annual oil crop expansion from 2006-2016 (FAO, 2018). Annual oil crop expansion over native vegetation based on estimates described in the report, including assumptions for GHG emissions from IPCC (2000), and all carbon release from deforestation occurring within the same year. **5)** Although Malaysia shows a net afforestation/reforestation based on FAO (2018), it has expanded part of its oil palm area over forestland, peatland and bare soils, which may be classified as "other land" (see annex). **6)** The oil fraction yield for soybean is 20% for the calculations shown in this table. ROW – Rest of the World.

Future OECD & FAO (2017) projections suggest that the yield increases will outstrip the requirement for land use change to meet increased demand. While we recognise these studies, our work is based on the historical record rather than projections and we have not considered it in the calculations of the expansion ratios on high carbon stock lands. Table 23 is a summary of our estimates of the GHG emissions for soy and palm expansion over native vegetation (base 2006-2016).

Table 23: Annual GHG emissions due to soy and palm expansion over native vegetation (base 2006-2016).

Oil crop	Country	Crop expansion kha y^{-1}	Crop expansion over natural vegetation kha y^{-1} B_0	Assumed type of natural vegetation converted	Carbon stock in natural vegetation tC ha^{-1} D_1		Carbon stock in crop land tC ha^{-1} D_2	Carbon stock loss tC ha^{-1} $D_1 - D_2$	Emission factor t CO_2eq ha^{-1} B_1	Oil share in total crop production B_2	GHG emissions from the conversion of natural vegetation for oil production $MtCO_2eq\ y^{-1}$ $B_0 * B_1 * B_2$
Soybean	Argentina	437	122	50% Tropical Forest	243	195	82	113	415	20%	10
				50% Chaco and others	147						
	Brazil	1111	189	50% Tropical Forest	243	195	82	113	415	20%	16
				50% Cerrado and others	147						
	Total	**1548**	**311**			**195**	**82**	**113**	**415**	**20%**	**26**
Oil Palm	Indonesia	522	157	50% tropical forest	243	464	170	294	1080	100%	169
				50% wetland (incl. peatland)	686						
	Malaysia	84	17	40% tropical forest	243	509	170	339	1242	100%	21
				60% wetland (incl. bare soil)	686						
	Total	**606**	**173**			**470**	**170**	**300**	**1095**	**100%**	**190**

Source: prepared by the authors.

Note: Annual oil crop expansion from 2006-2016 (FAO, 2018). Crop expansion over natural vegetation calculated from ratio A_1/A_0 (Table 22). Emission factor estimated from IPCC (2000), including both above ground vegetation and soil carbon changes. One tonne of Carbon (C) is equivalent to 3.67 tonnes of Carbon Dioxide (CO_2). See further explanations and assumptions in Chapter 2. Conversion unit: 1 tC equals 3.67 tCO_2.

Any calculation of this sort contains a considerable uncertainty, particularly in the calculation of the expansion ratio, but also the specific prior land use. Where there is a significant range in the high carbon stock land use change, we have used the data covering the most recent period and where available the value at the lower end to reflect the increasing efforts to reduce the conversion of high carbon stock lands seen more recently. We have not considered counterfactual land use changes. This might include using otherwise abandoned cropland, where the counterfactual would be a return to a more natural landscape. This would not be consistent with an analysis based on the historical record.

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ANNEX

Table A1: Glossary of land use classifications.

Land use	Description
Agricultural land	Land used for cultivation of crops and animal husbandry. The total of areas under ''Cropland'' and ''Permanent meadows and pastures.''
Agriculture	The total of areas under “Land under temporary crops”, “Land under temporary meadows and pastures”, “Land with temporary fallow”, “Land under permanent crops”, “Land under permanent meadows and pastures”, and “Land under protective cover”. This category includes tilled and fallow land, and naturally grown permanent meadows and pastures used for grazing, animal feeding or agricultural purpose. Scattered land under farm buildings, yards and their annexes, and permanently uncultivated land, such as uncultivated patches, banks, footpaths, ditches, headlands and shoulders are traditionally included.
Arable land	The total of areas under temporary crops, temporary meadows and pastures, and land with temporary fallow. Arable land does not include land that is potentially cultivable but is not normally cultivated.
Country area	Area under national sovereignty. It is the sum of land area, inland waters and coastal waters. It excludes the exclusive economic zone.
Cropland	Land used for cultivation of crops. The total of areas under ''Arable land'' and ''Permanent crops''.
Forest land	Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 per cent, or trees able to reach these thresholds in situ. Excludes land that is predominantly under agricultural or urban land use, and land that is predominantly used for maintenance and restoration of environmental function. Explanatory notes: • Forest land is determined both by the presence of trees and by the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 metres in situ • Includes areas with young trees that have not yet reached but that are expected to reach a canopy cover of 10 per cent and tree height of 5 metres. It also includes areas that are temporarily unstocked owing to clear-cutting as part of a forest management practice or natural disasters, and that are expected to be regenerated within five years. Local conditions may, in exceptional cases, justify the use of a longer time frame • Includes forest roads, firebreaks and other small open areas • May include forest land in national parks, nature reserves and other protected areas, such as those of specific environmental, scientific, historical, cultural or spiritual interest • Includes windbreaks, shelter belts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 metres • Includes abandoned shifting cultivation land with a regeneration of trees that have, or is expected to reach, a canopy cover of 10 per cent and tree height of 5 metres • Includes areas with mangroves in tidal zones, regardless of whether this area is classified as land area or not • Includes areas with bamboo and palms provided that land use, height and canopy cover criteria are met • Some agroforestry systems such as the taungya system, where crops are grown only during the first years of the forest rotation should be classified as forest • Excludes: tree stands in agricultural production systems, such as fruit-tree plantations (→Permanent crops), oil palm plantations, rubber and Christmas trees (→Permanent crops) and agroforestry systems when crops are grown under tree cover
Forestry	Land used for forestry. Excludes land that is predominantly under agricultural or urban use.
Forestry area actually irrigated	Land area actually irrigated that is land used for Forestry.
Inland waters	Inland waters are areas corresponding to natural or artificial water courses, serving to drain natural or artificial bodies of water, including lakes, reservoirs, rivers, brooks, streams, ponds, inland canals, dams, and other land-locked waters. The banks constitute limits whether the water is present or not.
Land area	Country area excluding area under inland waters and coastal waters.
Land under perm. meadows and pastures	Land used permanently (five years or more) to grow herbaceous forage crops through cultivation or naturally (wild prairie or grazing land). Permanent meadows and pastures on which trees and shrubs are grown should be recorded under this heading only if the growing of forage crops is the most important use of the area. Measures may be taken to keep or increase productivity of the land (i.e., use of fertilizers, mowing or systematic grazing by domestic animals.) This class includes: • Grazing in wooded areas (agroforestry areas, for example) • Grazing in shrubby zones (heath, maquis, garigue) • Grassland in the plain or low mountain areas used for grazing: land crossed during transhumance where the animals spend a part of the year (approximately 100 days) without returning to the holding in the evening: mountain and subalpine meadows and similar; and steppes and dry meadows used for pasture.
Land under permanent crops	Land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee), land under trees and shrubs producing flowers (such as roses and jasmine), and nurseries (except those for forest trees, which should be classified under "Forestry"). Permanent meadows and pastures are excluded from land under permanent crops.
Land under protective cover	Land used for agriculture occupied by dwellings on farms, etc.: dwellings, operating buildings (hangars, barns, cellars, greenhouses, silos), buildings for animal production (stables, cowsheds, pig sheds, sheep pens, poultry yards), family gardens, farmyards.
Land under temp. meadows and pastures	Land temporarily cultivated with herbaceous forage crops for mowing or pasture. A period of less than five years is used to differentiate between temporary and permanent meadows and pastures.

Land under temporary crops	Land used for crops with a less-than-one-year growing cycle, which must be newly sown or planted for further production after the harvest. Some crops that remain in the field for more than one year may also be considered as temporary crops e.g., asparagus, strawberries, pineapples, bananas and sugar cane. Multiple-cropped areas are counted only once.
Land with temporary fallow	Land that is not seeded for one or more growing seasons. The maximum idle period is usually less than five years. This land may be in the form sown for the exclusive production of green manure. Land remaining fallow for too long may acquire characteristics requiring it to be reclassified, as for instance “Permanent meadows and pastures” if used for grazing or haying.
Other land	Land area not classified as "Agriculture and'' ''Forestry''. It includes SEEA categories ''Land used for aquaculture,'' ''Built-up and related areas, ''Land Use for maintenance and restoration of environmental functions," ''Other uses of land not elsewhere classified,'' and ''Land not in use.''
Other naturally regenerated forest	Naturally regenerated forest where there are clearly visible indications of human activities.Explanatory notes:1. Includes selectively logged-over areas, areas regenerating following agricultural land use, areas recovering from human-induced fires, etc.2. Includes forests where it is not possible to distinguish whether planted or naturally regenerated.3. Includes forests with a mix of naturally regenerated trees and planted/seeded trees, and where the naturally regenerated trees are expected to constitute more than 50 percent of the growing stock at stand maturity.
Perm. meadows & pastures - Cultivated	Land under ''Permanent meadows and pastures'' that is managed and cultivated.
Perm. meadows & pastures - Nat. growing	Land under ''Permanent meadows and pastures'' that is naturally growing.
Perm. meadows & pastures area actually irrig.	Agricultural land actually irrigated that is Permanent meadows and pastures.
Perm. meadows & pastures area certified organic	Permanent meadows and pastures area certified organic.
Perm. meadows & pastures area under organic agric.	Permanent meadows and pastures area certified organic and/or in-conversion to organic.
Planted Forest	Forest predominantly composed of trees established through planting and/or deliberate seeding. Explanatory notes: 1. In this context, predominantly means that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity.2. Includes coppice from trees that were originally planted or seeded.3. Includes rubberwood, cork oak and Christmas tree plantations.4. Excludes self-sown trees of introduced species.
Primary Forest	Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Explanatory note:1. Some key characteristics of primary forests are:• they show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes;• the area is large enough to maintain its natural characteristics; • there has been no known significant human intervention or the last significant human intervention was long enough ago to have allowed the natural species composition and processes to have become re-established.

Source: FAO (2018).