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Estimating sustainable palm oil potentials

Working paper of the project "Consumption orientated approaches for a sustainable supply of palm oil" supported by the German Federal Environment Agency (Umweltbundesamt)

prepared by

Uwe R. Fritsche & Ulrike Eppler

IINAS - International Institute for Sustainability Analysis and Strategy

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Table of Content

List of Figures

List of Tables

Acronyms

BAU	business-as-usual
CIFOR	Center for International Forestry Research
EC	European Commission
EJ	ExaJoules
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
ffb	fresh fruit bunches
GBEP	Global Bioenergy Partnership
ICRAF	International Centre for Research in Agroforestry (World Agroforestry Centre)
IEA	International Energy Agency
IEA Bio	International Energy Agency Bioenergy Technology Collaboration Program
IIASA	International Institute for Applied System Analysis
IINAS	International Institute for Sustainability Analysis and Strategy
IUCN	International Union for the Conservation of Nature and Natural Resources
LHV	lower heating value
Mha	million hectares
Mt	million tonnes
Mtoe	million tonnes of oil equivalent
OECD	Organization for Economic Co-operation and Development
NZE	net zero emission
PJ	PetaJoule
PV	photovoltaics
SDG	Sustainable Development Goals
SUS	sustainability
UBA	Umweltbundesamt (German Environment Agency)
UN	United Nations
WWF	World-wide Fund for Nature

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Any error or omission remain the sole responsibility of the authors.

Introduction and Overview

The research project **Consumption-orientated approaches for a sustainable supply of palm oil**[1] develops action options and starting points for measures that can reduce demand of non-certified palm oil, use sustainable alternatives, or effectively facilitate more sustainable supply of palm oil along its supply chains. This transdisciplinary project focuses on Germany but involves European and international actors.

Globally, oil palm plantations cover about 29 million hectares (Mha)[2] in 2020, supplying 35% of the world's growing demand for vegetable oils, and is the most important supplier of vegetable oil (WWF & IINAS 2020). Oil palms are land-efficient plants with potential for biodiversity and soil-carbon-oriented cultivation.

However, palm oil - along with e.g., soy - is currently one of the main drivers of deforestation, land conflicts, human rights violations, and greenhouse gas emissions in parts of the world (WWF & IINAS 2021).

Given this context, this paper presents first estimates for a global supply potential of sustainable palm oil and compared this with estimates of possible future palm oil demands.

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[1] For more info see http://iinas.org/palm_en.html

[2] See Table 5 in the Annex for detailed information

1 Definitions of sustainability in the palm oil context

Already in the early 1970s, sustainability became an issue of the international discussions around environment, economic and social development, and trade (Sachs 2015). The United Nations Conference on Environment and Development (UN 1992) coined the term *sustainable development,* and the Rio+20 Conference (UN 2012) decided to develop a set of *Sustainable Development Goals* (SDGs) which were adopted as part of the *2030 Agenda* by the UN General Assembly in 2015 (UN 2015).

The SDGs are increasingly considered an appropriate *normative framework* for the sustainability of biomass (Blair et al. 2021; Fritsche 2019; Zeug et al. 2019) and, thus, could be used also to define "sustainable" palm oil (Meijaard et al. 2020), although the SDGs do not explicitly refer to "biomass", nor "palm oil".

Much scientific work is available on the sustainability of palm oil, mostly with a focus on biodiversity, greenhouse gas (GHG) emissions, and social aspects (e.g., employment, income, and land tenure)[3].

Based on this, the simplified sustainability considerations for the analysis of a "sustainable palm oil potential" in this paper use those thematic foci[4] to derive quantitative estimates for the potential "sustainable" supply of palm oil.

The paper uses high-biodiversity and protected areas as proxies for biodiversity conservation, forest land and peatland as proxies for GHG emissions, and smallholder production as a proxy for rural employment, and income.

Given the global scope of this paper, no regional or national detail on the definitions of "sustainable" palm oil can be given.

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[3] See e.g., Meijaard et al. (2020); Mohd Hanafiah et al. (2021); Naidu & Moorthy (2021); Pye et al. (2021); Qaim et al. (2020); Tang & Al Qahtani (2020); WWF & IINAS (2021).

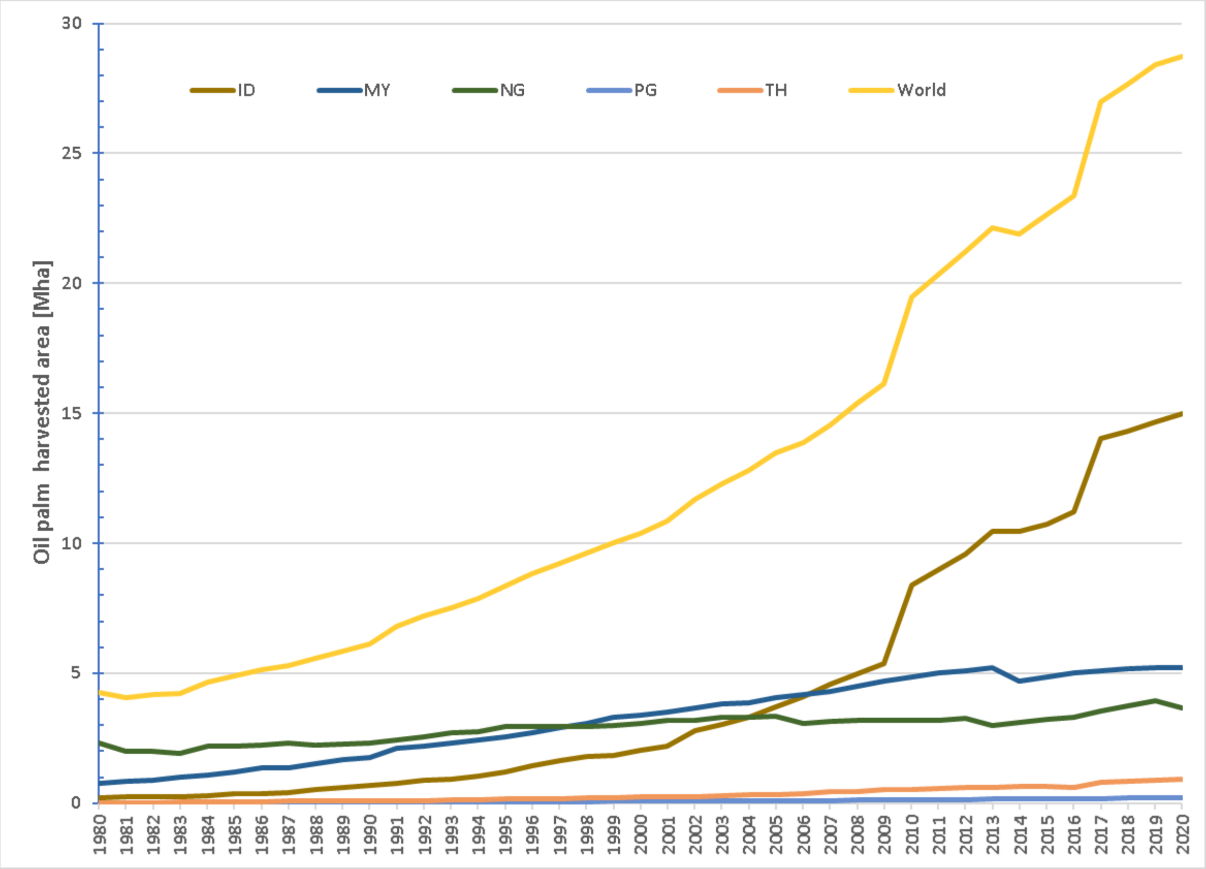
[4] Note that "sustainable palm oil" is not just an issue of appropriate metrics (criteria and indicators) and respective measurements, but also depends on how those are defined, implemented, and by whom.

2 Sustainable land potential for oil palm cultivation

2.1 Land potential for sustainable oil palm cultivation

Oil palm plantations exist in 47 tropical countries, but South-East Asia – especially Indonesia and Malaysia - dominates with approx. 90 % of global land use for palm oil (Figure 1).

Figure 1 Development of land use for oil palm cultivation 1980 to 2020



Source: http://www.fao.org/faostat/; ID = Indonesia; MY = Malaysia; NG = Nigeria; TH = Thailand; for data and details on other countries see Table 5 (Annex)

The age distribution of oil palm plantation implies that until 2050, all existing plantations would have to be re-planted. This opens the possibility to re-use existing sites by applying more sustainable practices (e.g., Luke et al. 2020) and other management systems (e.g., agroforestry)[5]. Furthermore, land with oil palm plantations in areas with high biodiversity and on peatlands should be restored and the plantations converted to shift away from industrialized monoculture. No new plantations should be established in such areas[6]. In consequence, the first step of the sustainable land potential estimate is to reduce the current area for oil palm cultivation by 35% to exclude existing high-biodiversity and protected areas, forests, and peatlands[7]. The global area under oil palm recorded by FAO for 2020 of about 29 million hectares (Mha) would be reduced by these restrictions to a global potential area under oil palm cultivation of about 19 Mha by 2050. This also opens the possibility of shifting existing plantations away from peatlands in the coming decades[8].

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[5] See Section 2.3 for a brief discussion of yields.

[6] Afriyanti, Kroeze & Saad (2016) have worked out such a strategy for Indonesia. Van Noordwijk et al. (2017) discussed this for the Tropics, and Quezada et al. (2019) developed such a strategy for the Neotropics.

[7] See Tapia, Doliente & Samsatli (2021) for a spatially explicit approach to determine the sustainable palm oil land potential for Indonesia and Malaysia. The assumed reduction of palm oil cultivation land follows the proposed UN CBD post-2020 global biodiversity framework target of achieving 30% share of land and sea being protected globally (UN CBD 2021).

[8] For Indonesia and Malaysia alone, Tapia, Doliente & Samsatli (2021) identified 4.5 Mha of available land for plantations **outside** of forests, peatland, and protected areas. Yet, accessibility may be restricted due to fragmentation or lack of transport infrastructure.

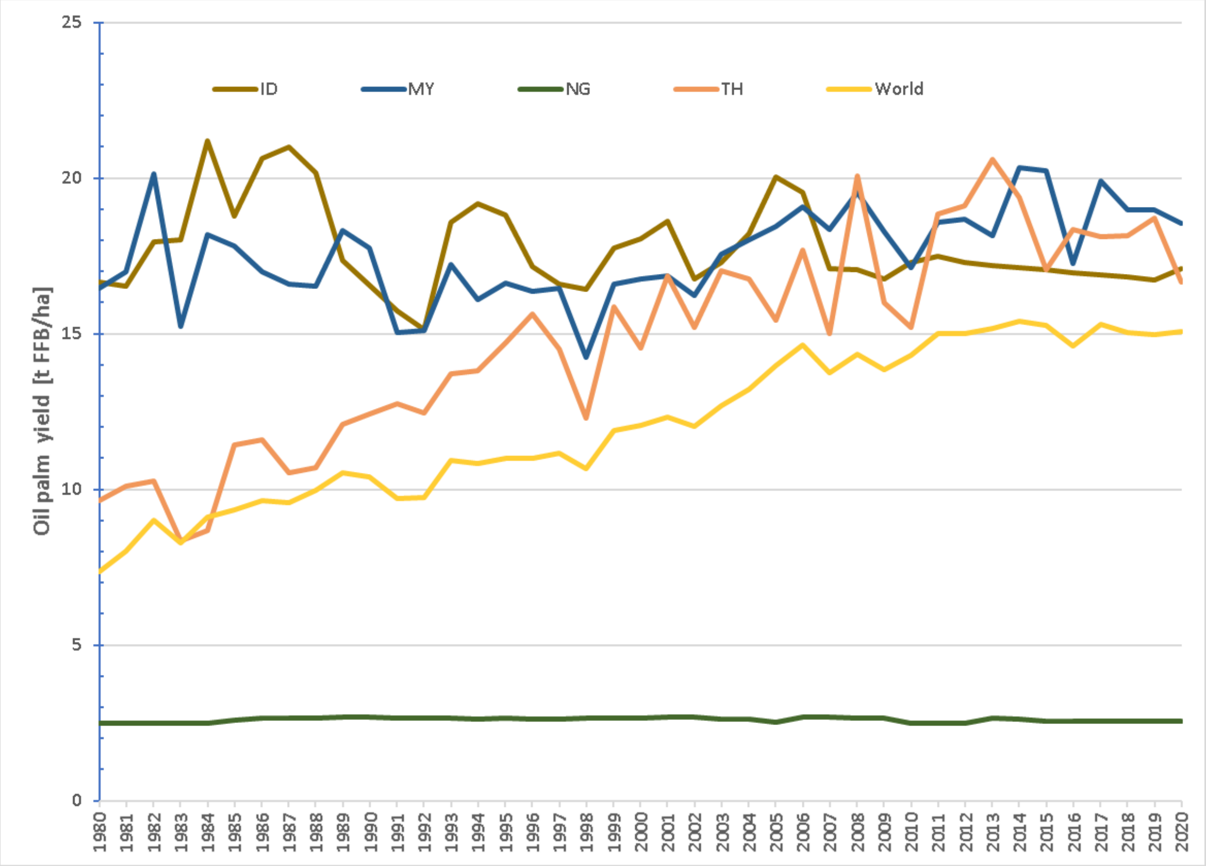
2.2 Sustainable cultivation on degraded land

In addition, a potential for sustainable oil palm cultivation exists on degraded lands, especially those covered by invasive grasses (e.g., *Imperata cylindrica*) which accounts for some 8.5 Mha in Indonesia alone (Garrity et al. 1996)[9]. Various sources have estimated a global total of 2,000 Mha of degraded land (Fritsche et al. 2017), much located in Brazil, China, India, Indonesia[10], and Sub-Saharan Africa (IRENA 2017). From this we conservatively estimate that by 2050, degraded land could be used for oil palm cultivation in Southeast Asia (5 Mha), Latin America (2.5 Mha) and Sub-Saharan Africa (2.5 Mha), i.e., a total of 10 Mha. Making use of this potential could be a promising environmental policy to give the palm oil industry responsibility to restore these areas following the UN decade on restoration[11].

2.3 Sustainable oil palm yield potential

Since the 1980ies, oil palm plantation yields have increased in most production countries (except the noteworthy case of Nigeria), resulting in significant rise of chemical and fertilizer inputs as well as large-scale monocultures.

Figure 2 Development of oil palm yield 1980 to 2020



Source: http://www.fao.org/faostat/ ; ID = Indonesia; MY = Malaysia; NG = Nigeria; TH = Thailand; for data and details on other countries see Table 6 (Annex)

Bessou et al. (2017) list more sustainable cultivation practices, including agroforestry (e.g., Luke et al. 2020), riparian buffers, and understory vegetation to reduce pollution loads for soil, water, and workers while improving biodiversity – yet often with a yield trade-off. However, pilot projects in Brazil and Indonesia demonstrated that agroforestry and biodiversity-oriented practices can avoid lower yields[12].

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[9] However, the data situation here is difficult. Tolkamp et al. (2001) even speak of 20 Mha in Indonesia only. The data on degraded land should be updated and confirmed by remote sensing (e.g., through satellites), and ground truthing.

[10] Jaung et al. (2018) estimated 3.5 Mha of degraded land in Indonesia suitable for oil crop cultivation.

[11] https://www.decadeonrestoration.org

[12] See e.g., Budiadi et al. (2019); Darras et al. (2019); Gérard et al. (2017); Lorenz (2018); Purwanto et al. (2020); Suranti et al. (2021); Teuschner et al. (2016).

To reflect this and increased shares of lower yielding smallholder plantations (Monzon et al. 2021) to improve social impacts such as rural employment and income, the yield of fresh fruit bunches is set to 15 t_{ffb}/ha which reflects the current global average[13].

For degraded land, the yield is reduced to 5 t_{ffb}/ha to reflect less favorable climate and soil conditions.

2.4 Sustainable palm oil supply potential

In a nutshell, the assumptions for determining the sustainable palm oil supply potentials are as followings:

- Current cultivation area for oil palm cultivation: 29 Mha in 2020
- Reduction by 35% to exclude existing high-biodiversity and protected areas, forests, and peatlands = global sustainable potential area under oil palm of about 19 Mha
- Conservative estimate of degraded land available for oil palm in Southeast Asia (5 Mha), Latin America (2.5 Mha) and Sub-Saharan Africa (2.5 Mha) = total of 10 Mha
- Reduced yield of fresh fruit bunches to global average of 15 t_{ffb}/ha and for degraded land, the yield is reduced to 5 t_{ffb}/ha.
- Average conversion efficiency of fresh fruit bunches to palm oil is slightly raised from today's 21% to 25% in 2050 by assuming state-of-the-art extraction and milling technology.

In combining the sustainably available land for oil palm cultivation with the yield and conversion efficiency data gives the estimated sustainable palm oil supply potential shown in the following table.

Table 1 Global sustainable palm oil supply potential

Palm oil supply [Mt]	**2050**
…from reduced cultivation area	71
…from cultivation on degraded land	13
Total	**83**

Source: IINAS calculation; rounded data

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[13] For comparison: A test farm for improved smallholder palm oil cultivation practices in Malaysia sponsored by FONAP and carried out by WWF and Wild Asia yielded 30 t_{FFB}/ha (see https://www.wwf.de/themen-projekte/landwirtschaft/produkte-aus-der-landwirtschaft/palmoel/artenvielfalt-bringt-hoehere-ertraege) .

3 Future demand estimates for palm oil

3.1 Palm oil demand estimates

This paper estimates possible future demands up to 2050 from the following factors:

- Shares of palm oil for biofuels in aviation, maritime and road transport[14]
- Global estimates for palm oil demand from food and feed for business-as-usual (BAU) and a "sustainable food system" dynamic (SUS) [15]
- Global estimate for palm oil demands for chemicals and cosmetics.

Section 3.5 then summarizes the demand estimates.

3.2 Bioenergy demand: the key role of biofuels in palm oil demand

Biomass use for energy increased globally during the last decades (REN21 2021), and the World Energy Outlook projects a continuing increase in the next (IEA 2020) similar as in other scenarios such as IPCC (2019), the IEA "Net Zero 2050" roadmap (IEA 2021), and IRENA's 1.5 °C scenario (IRENA 2021).

Yet, none of these scenarios explicitly consider future palm oil use which is not only a function of demand for biofuels but also of demand dynamics and patterns of food and feed, chemicals, and cosmetics, i.e., of the overall bioeconomy. For the future bioenergy – and especially biofuel[16] – demand, the IEA Net Zero 2050 scenario (IEA 2021) was used which considers sustainability constraints in biomass supply, and alternative (non-energy) uses of biomass in the bioeconomy.

For the BAU case, twice the amount of IEA NZE scenario 2030 is used, assuming a less drastic substitution of biodiesel in road transport to reflect mid-term blending targets of countries such as Indonesia. For 2050, the amount of palm oil for air and marine transport in BAU is reduced by 25% halved compared to 2030 to reflect growing shares of non-palm oil biofuels (e.g., from 2nd generation ethanol, waste-based diesel, biomethane) as well as increased contributions from ammonia, electricity, and H_2. As competition with electricity in road transport is as assumed to be more significant, the 2050 demand is derived by reducing the 2030 value by 35%.

Table 2 Development of global palm oil demand for biofuels in the BAU Scenario

		BAU	
Palm-based biofuels [PJ]	**2020**	**2030**	**2050**
in aviation	0	282	211
in marine	0	94	70
in road[17]	1287	1126	732
total	**1287**	**1502**	**1014**
total [Mt]	**35**	**41**	**28**

Source: IINAS calculation based on IEA (2021) and own estimates (see text); conversion to metric tonnes using LHV of 36.5 GJ/t

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[14] The global share of palm oil used for electricity generation and heating is small and will be phased-out due to far more cost-competitive generation from other renewables, especially solar PV and wind. There may be a very minor role for palm oil use in diesel backup generation in renewable mini-grids but prices dynamics of batteries will out-compete this option after 2030. Therefore, non-transport energy use of palm oil is neglected in this analysis.

[15] The SUS scenario assumes a transformation of the global food system towards sustainability, i.e., diets primarily consist of plant-based proteins and low-processed (fresh) foods to avoid food losses and wastes. It postulates that the Sustainable Development Goals 2 and 12 are achieved by 2030 and continued until 2050. This estimate does *not include* possible impacts of climate change on the food system – it is assumed that achieving the 1.5 °C Paris target will imply that these impacts will remain low.

[16] Note that the IEA NZE assumes no role for biodiesel in rail transport: Here, electricity and fuel cells (using H_2) will be the key decarbonization options for a massively growing share of rail transport, both for person and freight.

[17] Even in Indonesia where the government aims at a palm oil based diesel share of up to 50% (B50) scientist recommend to change to lower shares, as the future potential of biofuel demand is highly uncertain due to the rapid development of alternative technologies (Adiatma et al. 2021).

To contrast BAU, the NZE scenario is much more ambitious in transport after 2030, with the focus on using bioenergy for decarbonization where few alternative options exist:

- Aviation is expected to make significant use of palm oil for jet fuel (kerosene) up to 2030, but afterwards, more competitive synthetic fuels and "green" hydrogen will reduce the use of palm oil.
- In maritime transport, palm-based biodiesel follows a similar logic – here, "green" ammonia and hydrogen are projected to replace much after 2030.
- For road transport, the introduction of battery and fuel-cell electric vehicles as well as increasing shares of biomethane (for buses and trucks) will replace most of current palm oil use, together with advanced (2nd generation) biodiesel from lignocellulosic wastes.

In the Annex (Figures 4-6 and Tables 7-9), some detail is given to the overall energy system dynamics, on demand for biofuels, and competing alternatives in the NZE scenario[18].

Table 3 Development of global palm oil demand for biofuels in the IEA NZE Scenario

Palm-based biofuels [PJ]	**2020**	**2030**	**2050**
in aviation	0	282	32
in marine	0	94	12
in road	1287	563	5
total	**1287**	**938**	**49**
total [Mt]	**35**	**26**	**1**

Source: IINAS calculation based on IEA (2021); conversion to metric tonnes using LHV of 36.5 GJ/t

For aviation and shipping, the 2050 palm oil demand in the NZE scenario is approx. 95% lower than in BAU while for road transport, the demand is about 99% lower in NZE than in BAU. The overall reduction of palm oil use for transport in 2050 is 95% lower in the NZE scenario than in BAU. With that, the NZE scenario represents nearly a phase-out of palm-oil-based biofuels in transport[19].

3.3 Food and feed demand: From BAU to SUS

There is, unfortunately, little detail on the global use of palm oil for food and feed – a breakdown is provided only for few countries, and even less data is available on future dynamics (e.g., Purnomo et al. 2020). It is estimated here that 80% of non-energy use of palm oil (excluding palm kernel oil) is used for food and the remaining 20% for feed.

For food and feed, the BAU scenario assumes a global increase of 10% by 2030, followed by another 20% growth until 2050, both reflecting population dynamics. This implies that global palm oil demand for food and feed will rise from 41 Mt in 2020 to 45 Mt in 2030, and to 54 Mt in 2050, respectively. It should be noted that others have estimated global palm oil demand for food and feed at much higher levels, though[20].

For the SUS scenario, a 10 % reduction of palm oil use for food and feed (compared to BAU) is assumed for 2030, rising to a 25% reduction for food and 33% for feed by 2050. This assumes that palm oil ingredients in processed food are increasingly avoided due to shifts towards unprocessed food (more "fresh" products) and increasing shares of organic farming reduce palm oil use for feed.

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[18] Note that the NZE scenario also includes carbon capture and storage (CCS) and new nuclear electricity generation as mitigation options. It is outside of this paper to critically reflect on this.

[19] For less optimistic projections of palm oil demand for biofuels in selected countries up to 2030 under a business-as-usual logic see http://www.agri-outlook.org/data/

[20] Byerlee, Falcon & Naylor (2017) estimated that by 2050, palm oil use for food and feed could increase up to 140 Mt, i.e., nearly threefold the amount estimated here. Meijaard (2021) gave a range of 50 – 200 Mt of palm oil use for 2050, matching the estimate made here for the lower range.

In total, palm oil demand for food and feed in the SUS scenario reaches 40 Mt in 2030, and 39 Mt in 2050, respectively. Compared to BAU, this is a reduction of nearly 30% by 2050, and a small reduction compared to 2020.

3.4 Demand for Chemicals and Cosmetics

Similar to food and feed there is little data on current and future global demands for palm oil use for chemicals, and cosmetics. These industrial applications mainly use palm kernel oil.

IEA (2018) and de Jong et al. (2020) project a small increase in future use of vegetable oils for chemicals, but do not give detail on palm oil. Purnomo et al. (2020) qualitatively discuss palm oil for chemicals and cosmetics in Indonesia, and Spekreijse et al. (2021) argue that compared to sugar and starch-based value chains, palm oil is less competitive due to higher feedstock cost. From this it is estimated that BAU demand will slightly increase by 10% until 2030, and by another 20% by 2050.

In the SUS case, demand in 2030 is reduced by 10% to reflect higher cost of certified palm kernel oil, and by 50% until 2050 due to competition from other bio-based and chemicals and “green” H_2.

3.5 Summary of the demand estimate

The results of the brief discussion of future demand estimates for the BAU and SUS scenarios are given in the following table.

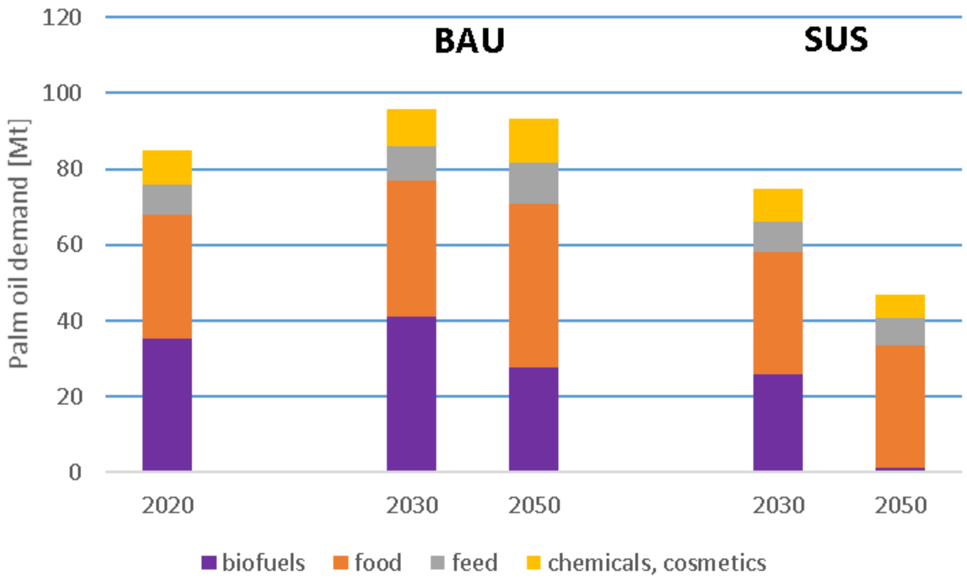
Table 4 Development of global palm oil demand in the BAU and SUS scenarios

		BAU		SUS	
Palm as feedstock [Mt]	**2020**	**2030**	**2050**	**2030**	**2050**
Food	33	36	43	32	32
Feed	8	9	11	8	7
chemicals, cosmetics	9	10	12	9	6
total material use	**50**	**55**	**66**	**49**	**45**
total biofuel use	35	41	28	26	1
total demand	**85**	**96**	**93**	**75**	**47**

Source: IINAS calculation; BAU = business-as-usual; SUS = sustainability

Under BAU, global palm oil demand would be about 10 % higher in 2050 than in 2020, while in the SUS scenario, a reduction of nearly 50% compared to the 2020 level would be possible.

Figure 3 Development of global palm oil demand in the BAU and SUS scenarios



Source: IINAS calculation; BAU = business-as-usual; SUS = sustainability

4 Comparing global sustainable palm oil supply potential with projected demand

The estimated global sustainable palm oil supply potential of approx. 83 Mt compares well with the estimation for a sustainable scenario (SUS) which gives a demand approx. 47 Mt by 2050.

This indicates that the sustainable oil palm cultivation without degraded land (i.e., 66 Mt) could be more than enough to meet (the significantly reduced) demand in the SUS scenario by 2050.

For the BAU case, the 2050 demand of approx. 93 Mt is higher than the sustainable supply potential estimated here, including degraded lands. Given the significant uncertainty in the demand projections, this indicates the need for transformation not only on the supply but also on the demand side, as required by SDG 12 (sustainable consumption and production) of the UN Agenda 2030.

5. Conclusions and limitations

This estimation of the global sustainable palm oil supply potential and of respective demand scenarios indicated that for the BAU case, demand in 2050 may well be in the same other as today, i.e., no increase might be possible. Yet, the estimated sustainable palm oil potential would not be high enough to meet the BAU demand.

In the SUS scenario, demand by 2050 might be reduced to about 50% of today so that the estimated sustainable palm oil potential would be more than sufficient for the SUS case. As indicated in Table 4 and Figure 3, biofuels for transport as drivers for global palm oil use will be reduced to approx. 50% of today’s demand by 2050 in the BAU case, while in the SUS scenario, palm oil for biofuels could be phased-out.

This means that the focus of the discussion on the sustainability of future palm oil demand will shift towards food and feed and respective climate change mitigation (IPCC 2019). In this, the use of palm oil for pre-processed food and – to a lesser degree – for feed depends not only on population dynamics but on food choices of people, i.e., their diets, and the way the food system supplies respective demands:

- On the one hand, less animal-based protein demand implies less feed for animals and, thus, less palm oil demand even under BAU supply assumptions.
- On the other, eating more unprocessed (fresh) food would reduce palm oil use in the food industry and, given lower prices of fresh food compared to industrial food provision, imply higher food security.

As with biofuels, the food-feed links of palm oil are not just an issue of consumer’s choice, though: The food system is subject to policy framing, and diets have cultural contexts such as traditions. As the opportunities to transform the transport system towards more sustainable levels and modes have been analyzed and discussed in the last decades and clearly resulted in the call to shift away from palm oil for biofuels, the respective scientific work and societal discussion on sustainable supply and use of palm oil in the broader bioeconomy has just started.

Given the quite limited amount of data, literature, and studies on potential future sustainable palm oil supply and demand, the indicative results presented here should be considered only as a first orientation which needs further substantiation through further work.

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Data annex

Table 5 Development of land use for palm oil cultivation 1980 to 2020

	BR	CM	CO	CI	CD	EC	GH	GN	HN	ID	MY	NG	PG	TH	subtotal	World
1980	0.01	0.04	0.03	0.09	0.18	0.03	0.15	0.23	0.02	0.20	0.78	2.30	0.01	0.01	4.06	4.28
1981	0.01	0.04	0.03	0.09	0.19	0.03	0.14	0.23	0.02	0.23	0.85	2.00	0.02	0.02	3.87	4.08
1982	0.01	0.04	0.03	0.09	0.20	0.03	0.14	0.23	0.02	0.24	0.89	2.00	0.03	0.02	3.96	4.19
1983	0.01	0.03	0.04	0.09	0.20	0.03	0.14	0.23	0.02	0.26	1.01	1.90	0.03	0.04	4.01	4.23
1984	0.01	0.05	0.04	0.09	0.21	0.03	0.12	0.23	0.02	0.30	1.07	2.20	0.04	0.05	4.44	4.67
1985	0.01	0.05	0.04	0.09	0.21	0.03	0.10	0.23	0.02	0.35	1.20	2.20	0.04	0.05	4.62	4.90
1986	0.01	0.05	0.05	0.09	0.22	0.04	0.10	0.23	0.02	0.37	1.36	2.22	0.04	0.06	4.86	5.15
1987	0.02	0.05	0.05	0.09	0.22	0.05	0.10	0.23	0.02	0.42	1.37	2.30	0.04	0.07	5.02	5.30
1988	0.02	0.05	0.06	0.10	0.23	0.05	0.11	0.23	0.02	0.54	1.53	2.25	0.03	0.08	5.30	5.58
1989	0.03	0.06	0.08	0.10	0.23	0.06	0.13	0.24	0.02	0.59	1.67	2.26	0.04	0.09	5.59	5.86
1990	0.03	0.06	0.09	0.12	0.23	0.06	0.13	0.25	0.02	0.67	1.75	2.30	0.05	0.10	5.85	6.12
1991	0.07	0.05	0.10	0.13	0.23	0.06	0.13	0.26	0.03	0.77	2.09	2.45	0.05	0.10	6.52	6.80
1992	0.08	0.05	0.11	0.13	0.24	0.07	0.14	0.29	0.03	0.88	2.20	2.55	0.05	0.11	6.91	7.20
1993	0.07	0.05	0.11	0.13	0.24	0.07	0.14	0.30	0.02	0.92	2.31	2.70	0.06	0.13	7.23	7.53
1994	0.07	0.05	0.11	0.13	0.24	0.09	0.14	0.30	0.03	1.05	2.41	2.75	0.06	0.14	7.55	7.86
1995	0.07	0.05	0.11	0.13	0.24	0.09	0.14	0.30	0.03	1.19	2.54	2.94	0.06	0.15	8.05	8.36
1996	0.07	0.05	0.12	0.13	0.24	0.09	0.15	0.31	0.03	1.43	2.69	2.95	0.06	0.17	8.50	8.82
1997	0.08	0.05	0.12	0.13	0.22	0.10	0.15	0.31	0.03	1.62	2.89	2.95	0.06	0.18	8.90	9.23
1998	0.08	0.05	0.12	0.15	0.21	0.10	0.16	0.31	0.03	1.80	3.08	2.95	0.06	0.21	9.30	9.64
1999	0.08	0.06	0.13	0.16	0.20	0.09	0.16	0.31	0.03	1.85	3.31	3.00	0.07	0.22	9.66	10.00
2000	0.08	0.06	0.13	0.16	0.20	0.11	0.16	0.31	0.03	2.01	3.38	3.08	0.07	0.23	10.02	10.39
2001	0.08	0.06	0.14	0.16	0.18	0.13	0.18	0.31	0.05	2.20	3.50	3.18	0.08	0.24	10.48	10.86
2002	0.08	0.06	0.15	0.18	0.17	0.15	0.18	0.31	0.06	2.79	3.67	3.18	0.08	0.26	11.30	11.68
2003	0.09	0.06	0.15	0.17	0.16	0.15	0.24	0.31	0.06	3.04	3.80	3.30	0.08	0.29	11.90	12.28
2004	0.09	0.06	0.16	0.20	0.16	0.12	0.32	0.31	0.07	3.32	3.88	3.32	0.09	0.31	12.39	12.80
2005	0.09	0.07	0.17	0.20	0.16	0.14	0.33	0.31	0.08	3.69	4.05	3.35	0.09	0.32	13.04	13.46
2006	0.10	0.07	0.17	0.22	0.17	0.14	0.33	0.31	0.08	4.11	4.17	3.08	0.09	0.38	13.41	13.86
2007	0.10	0.07	0.17	0.20	0.17	0.15	0.30	0.31	0.09	4.56	4.30	3.15	0.10	0.43	14.09	14.57
2008	0.10	0.08	0.17	0.22	0.18	0.15	0.34	0.31	0.09	4.98	4.49	3.20	0.12	0.46	14.87	15.37
2009	0.10	0.10	0.17	0.25	0.18	0.20	0.35	0.31	0.10	5.37	4.69	3.20	0.12	0.51	15.64	16.16
2010	0.11	0.11	0.20	0.26	0.18	0.19	0.36	0.31	0.11	8.39	4.85	3.20	0.14	0.54	18.94	19.48
2011	0.11	0.12	0.23	0.27	0.18	0.20	0.35	0.31	0.11	8.99	5.00	3.20	0.14	0.57	19.79	20.37
2012	0.11	0.13	0.24	0.27	0.22	0.20	0.39	0.31	0.12	9.57	5.08	3.25	0.15	0.59	20.62	21.24
2013	0.11	0.14	0.25	0.27	0.27	0.22	0.32	0.31	0.13	10.47	5.23	3.00	0.15	0.60	21.46	22.13
2014	0.13	0.12	0.28	0.27	0.27	0.27	0.35	0.31	0.13	10.47	4.69	3.11	0.16	0.64	21.21	21.90
2015	0.14	0.14	0.33	0.27	0.28	0.29	0.35	0.32	0.16	10.75	4.86	3.23	0.17	0.65	21.94	22.66
2016	0.14	0.15	0.31	0.32	0.27	0.26	0.35	0.32	0.18	11.20	5.00	3.32	0.18	0.62	22.60	23.36
2017	0.12	0.15	0.46	0.35	0.28	0.26	0.36	0.32	0.18	14.05	5.11	3.56	0.18	0.80	26.16	26.97
2018	0.16	0.15	0.49	0.33	0.28	0.22	0.38	0.32	0.19	14.33	5.19	3.76	0.19	0.86	26.85	27.68
2019	0.18	0.16	0.50	0.32	0.28	0.20	0.37	0.32	0.20	14.68	5.22	3.93	0.20	0.90	27.45	28.31
2020	0.20	0.17	0.56	0.36	0.33	0.19	0.36	0.32	0.21	15.00	5.23	3.68	0.22	0.94	27.76	28.74

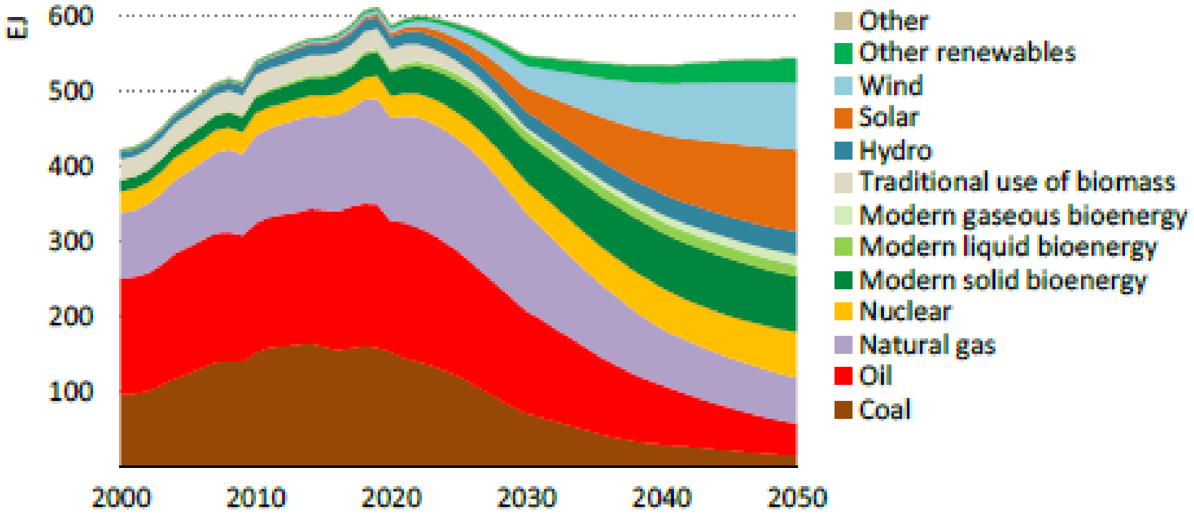
Source: http://www.fao.org/faostat/; data given in Mha of harvested area; BR = Brazil; CM = Cameroon; CO = Colombia; CI = Cote d'Ivoir; CD = Dem. Rep. of Congo; EC = Ecuador; GH = Ghana; GN = Guinea; HN =Honduras; ID = Indonesia; MY = Malaysia; NG = Nigeria; PG = Papua New Guinea; TH = Thailand

Table 6 Development of palm oil yield 1980 to 2020

	BR	CM	CO	CI	CD	EC	GH	GN	HN	ID	MY	NG	PG	TH	World
1980	10.5	15.3	15.0	12.3	5.7	9.5	6.3	2.7	3.4	16.7	16.5	2.5	15.9	9.6	7.0
1981	10.6	15.4	15.0	10.0	5.7	11.5	6.2	2.7	4.2	16.5	17.0	2.5	13.6	10.1	7.6
1982	10.5	15.3	15.2	10.5	5.3	11.5	6.2	2.7	7.7	17.9	20.1	2.5	14.3	10.3	8.5
1983	10.5	15.2	16.4	10.7	4.9	12.4	6.2	2.7	8.3	18.0	15.2	2.5	15.4	8.4	7.9
1984	10.5	14.7	16.6	10.7	5.0	12.8	6.2	2.7	12.6	21.2	18.2	2.5	12.7	8.7	8.7
1985	10.7	15.6	16.8	10.1	4.9	13.4	6.6	2.7	14.0	18.8	17.8	2.6	14.6	11.4	8.8
1986	10.7	16.2	15.4	12.5	4.7	14.9	6.4	2.7	14.3	20.6	17.0	2.7	13.6	11.6	9.1
1987	10.8	16.0	16.7	13.3	4.3	14.3	6.4	2.7	14.7	21.0	16.6	2.7	13.2	10.5	9.1
1988	11.0	16.1	19.4	10.3	4.6	12.8	6.4	2.7	13.9	20.2	16.5	2.7	14.5	10.7	9.5
1989	10.7	19.3	16.3	10.2	4.4	16.3	6.6	2.6	14.1	17.3	18.3	2.7	14.0	12.1	10.0
1990	9.9	19.1	15.6	11.1	4.4	14.3	6.5	2.6	14.0	16.6	17.8	2.7	14.5	12.4	10.0
1991	7.6	17.9	16.6	10.5	4.4	9.6	6.5	2.7	12.8	15.7	15.0	2.7	17.1	12.7	9.3
1992	8.1	17.7	15.6	11.1	4.4	13.8	6.4	2.2	13.4	15.1	15.1	2.7	17.8	12.4	9.4
1993	9.4	19.8	15.4	11.2	4.4	14.5	6.4	2.6	17.9	18.6	17.2	2.7	17.9	13.7	10.5
1994	9.8	19.4	15.6	11.4	4.4	12.5	6.5	2.7	13.3	19.2	16.1	2.6	16.8	13.8	10.4
1995	10.0	20.0	16.3	10.9	4.5	11.0	6.4	2.7	15.0	18.8	16.6	2.7	15.9	14.7	10.6
1996	10.2	19.6	16.2	12.4	4.5	12.1	6.6	2.7	16.0	17.1	16.4	2.6	16.3	15.6	10.6
1997	9.8	20.2	17.0	7.5	5.0	11.9	6.4	2.7	17.4	16.6	16.5	2.6	14.7	14.5	10.8
1998	9.5	20.2	16.7	8.4	5.5	15.7	6.4	2.7	20.0	16.4	14.2	2.6	16.4	12.3	10.3
1999	8.5	20.0	18.7	8.4	5.5	10.6	6.4	2.7	18.5	17.7	16.6	2.7	16.3	15.9	11.5
2000	8.3	19.6	18.3	7.1	5.6	11.8	6.7	2.7	18.2	18.1	16.8	2.7	17.3	14.5	11.6
2001	9.1	20.9	18.8	6.1	6.0	11.4	6.1	2.7	13.1	18.6	16.8	2.7	16.2	16.9	11.9
2002	9.2	20.5	17.9	6.6	6.2	11.3	6.1	2.7	14.2	16.8	16.2	2.7	14.9	15.2	11.6
2003	10.4	21.1	17.2	6.0	6.7	10.4	6.7	2.7	15.2	17.3	17.6	2.6	14.5	17.0	12.3
2004	10.4	21.1	19.7	6.5	6.8	15.0	6.2	2.7	13.8	18.2	18.0	2.6	14.7	16.8	12.8
2005	10.3	20.7	19.3	6.2	6.8	11.1	6.2	2.7	13.0	20.1	18.5	2.5	14.8	15.4	13.6
2006	12.5	20.8	19.4	6.1	6.5	11.7	6.3	2.7	17.8	19.5	19.1	2.7	14.7	17.7	14.2
2007	10.5	21.3	19.4	6.7	6.5	12.5	5.6	2.7	16.6	17.1	18.4	2.7	14.6	15.0	13.3
2008	10.6	19.9	19.4	6.6	6.5	14.7	5.6	2.7	15.4	17.1	19.6	2.7	14.5	20.1	13.9
2009	10.8	15.7	19.4	7.1	6.5	11.4	6.0	2.7	15.8	16.8	18.3	2.7	14.5	16.0	13.4
2010	12.1	19.6	19.6	6.0	6.5	14.7	5.6	2.7	16.8	17.3	17.1	2.5	13.7	15.2	13.9
2011	11.9	19.7	20.0	6.2	6.6	10.3	6.0	2.7	17.0	17.5	18.6	2.5	14.0	18.9	14.6
2012	11.0	19.5	19.9	6.9	6.6	13.3	5.7	2.7	17.0	17.3	18.7	2.5	14.0	19.1	14.6
2013	11.5	18.1	20.0	6.5	6.6	10.6	7.3	2.7	15.4	17.2	18.1	2.7	14.0	20.6	14.7
2014	11.0	16.8	19.5	6.4	6.6	12.8	7.0	2.7	14.4	17.1	20.3	2.6	13.8	19.4	14.9
2015	11.3	14.7	18.8	6.6	6.6	14.4	7.0	2.7	12.6	17.0	20.2	2.6	13.7	17.1	14.8
2016	12.0	13.8	18.2	6.4	6.6	11.8	7.0	2.7	11.7	17.0	17.3	2.6	13.7	18.3	14.1
2017	14.7	14.3	17.4	6.4	6.6	12.6	6.8	2.7	13.4	16.9	19.9	2.6	13.7	18.1	14.8
2018	13.9	14.2	17.0	6.5	6.5	12.4	6.9	2.7	13.1	16.8	19.0	2.6	13.6	18.1	14.6
2019	14.6	14.0	16.6	6.5	6.5	11.3	7.1	2.7	11.7	16.7	19.0	2.5	13.5	18.7	14.5
2020	14.2	14.7	12.8	6.5	6.5	13.0	6.9	2.7	11.2	17.1	18.5	2.6	13.1	16.7	15.1

Source: http://www.fao.org/faostat/; data given in t fresh fruit bunches per harvested ha; BR = Brazil; CM = Cameroon; CO = Colombia; CI = Cote d'Ivoir; CD = Dem. Rep. of Congo; EC = Ecuador; GH = Ghana; GN = Guinea; HN =Honduras; ID = Indonesia; MY = Malaysia; NG = Nigeria; PG = Papua New Guinea; TH = Thailand

Figure 4 Global energy supply in the IEA NZE scenario



Source: IEA (2021)

Table 7 Global renewable energy supply in the IEA NZE scenario

	2019	2020	2030	2050
Total energy supply [EJ]	**612**	**587**	**547**	**543**
Renewables	67	69	167	362
Solar	4	5	32	109
Wind	5	6	29	89
Hydro	15	16	21	30
Modern solid bioenergy	31	32	54	73
Modern liquid bioenergy	4	3	12	15
Modern gaseous bioenergy	2	2	5	14
Other renewables	4	5	13	32
Traditional use of biomass	25	25	-	-

Source: IINAS compilation based on IEA (2021)

Table 8 Global biomass supply for energy use in the IEA NZE scenario

Biomass source/feedstock [EJ]	2020	2030	2050
Conventional bioenergy crops	8	11	3
Traditional use of biomass	25	0	0
Organic waste streams	6	33	43
Forest and wood residues	7	13	20
Short-rotation woody crops	4	7	25
Forestry plantings	13	9	12
Total biomass	**63**	**72**	**102**

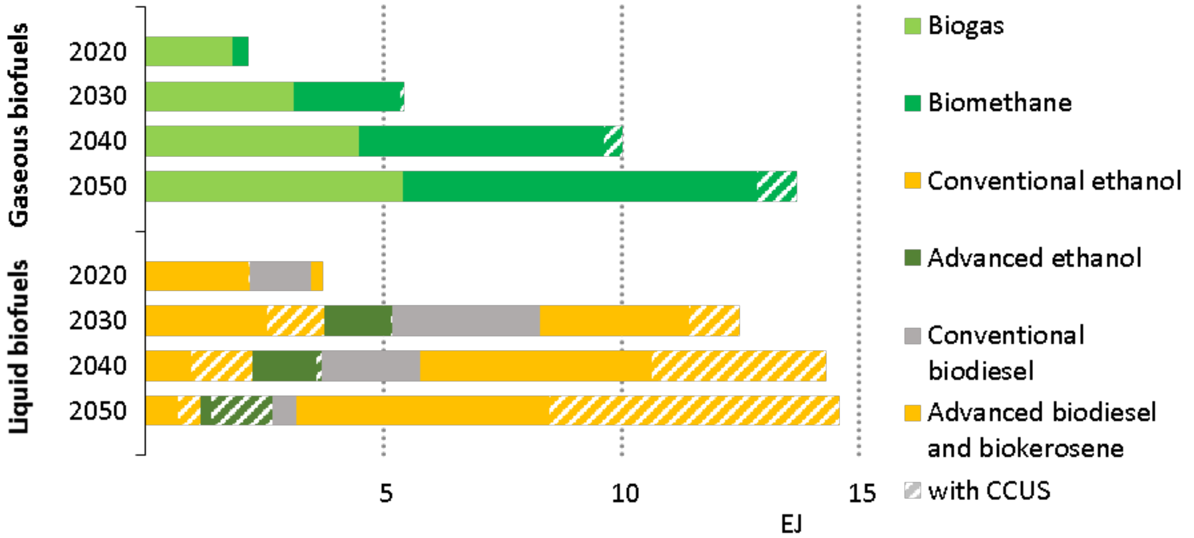
Source: IINAS compilation based on IEA (2021)

Table 9 Global biofuel supply in the IEA NZE scenario

Liquid biofuels for transport [EJ]	**2020**	**2030**	**2050**
Conventional ethanol	2,2	2,6	0,7
Conventional ethanol with CCUS	0,0	1,2	0,5
Advanced ethanol	0,0	1,4	0,2
Advanced ethanol with CCUS	0,0	0,0	1,3
Conventional biodiesel	1,3	3,1	0,5
Advanced biodiesel and biokerosene	0,3	3,1	5,3
Adv. Biodiesel and biokerosene with CCUS	0,0	1,1	6,1
Total	**3,7**	**12,5**	**14,6**

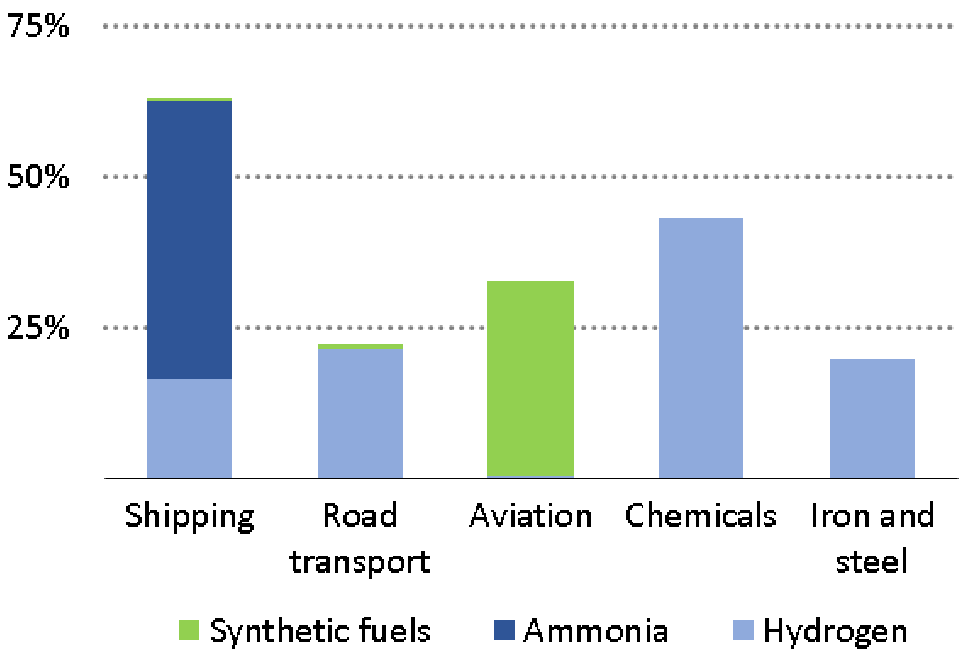
Source: IINAS compilation based on IEA (2021); CCUS = carbon capture, use and storage

Figure 5 Global biofuel supply in the IEA NZE scenario



Source: IEA (2021); CCUS = carbon capture, use and storage

Figure 6 Global shares of hydrogen fuel in 2050 by sector in the IEA NZE scenario



Source: IEA (2021)