Exploring the future of vegetable oils

Oil crop implications – Fats, forests, forecasts, and futures

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INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Contents

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An intensive production landscape growing three dominant vegetable oil crops – corn, sunflower, and soy, by ArtSvitlyna, 2019, Adobe Stock.

Key insights

There is no good or bad oil crop.
There are only good and bad practices.

Key actions

Good practices

Planning and growing all oil crops **to minimise harm and maximise benefits to people and the planet**.

Good choices

Empowered by clear and reliable information on the impact of oil crops, consumers can make **informed choices that benefit themselves, the environment, and global communities**. Governments, producers, traders, and retailers all have a role to play **in providing the transparency consumers need to make informed choices**.

Key takeaways

Global significance

Key insights

Oil crops use ~37% of all agricultural land. Thus, their future significantly influences global land use, prosperity, health, climate, and the environment. Demand for oil is growing, and thus the pressure of land for growing oil crops.

Considerations

Governments, businesses, and investors should make vegetable oils a crucial policy, cross-cutting food, energy, agriculture, land use, and biodiversity consideration. They must ensure that vegetable oil demand is met on existing agricultural land and respect human rights.

Practices matter

Key insights

No vegetable oil crop is intrinsically good or bad. Whether a crop is good, bad, better, or worse, depends on how and where they are produced, financed, traded, speculated upon, and consumed.

Considerations

Consumers and investors should demand a rights-based approach, transparency, and accountability. Where expansion is needed, it should not happen in natural ecosystems or negatively impact people. Preferences and culinary traditions need to be acknowledged.

Transparency for informed decisions

Key insights

Objective guidance for oil consumers and investors is lacking. Improving traceability and transparency enables informed decision-making and helps hold producers, investors, and buyers accountable.

Considerations

There has to be more transparency in vegetable oil systems. This includes making issues that are often overlooked more transparent and disseminating a more nuanced view of impacts from vegetable oil systems.

Responsible governance for sustainability

Key insights

Responsible governance in oil crop production requires a combination of legislation and Voluntary Sustainability Standards (VSS) to reduce harm.

Considerations

Strong auditing and assurance systems are important for both mandatory and voluntary governance systems.

Foreword

The future of vegetable oils

Jon Paul Rodríguez, Chair of IUCN Species Survival Commission

Kristen Walker, Chair of IUCN Commission on Environmental, Economic and Social Policy

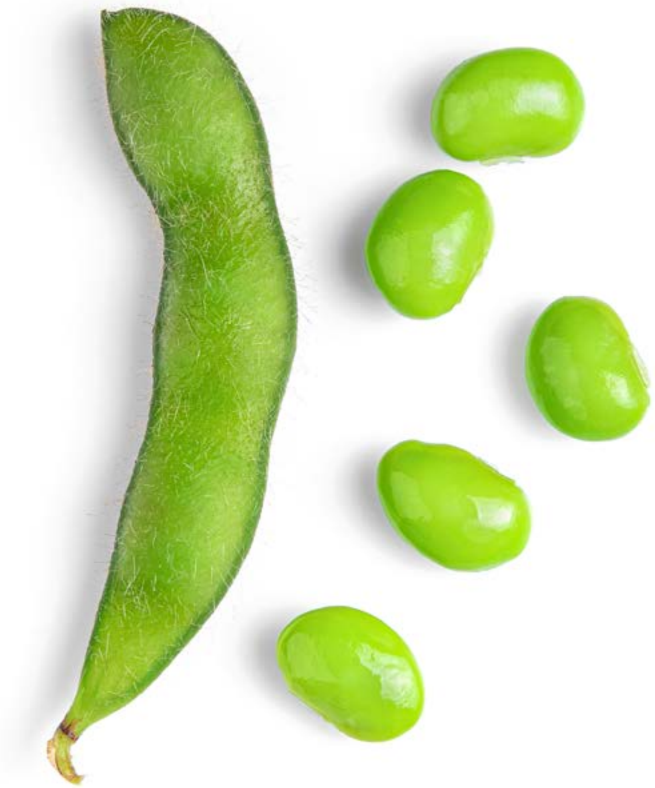
Angela Andrade, Chair of IUCN Commission on Ecosystem Management

This report explores what we need to do to improve the environmental, socio-economic, and nutritional outcomes of vegetable oil production. Most vegetable oils are extracted from plant seeds and fruits, constituting a distinct group of commodities with wide-ranging applications, including cooking oils, cosmetics, and biofuels. Soybean, palm, sunflower, rapeseed, and coconut oils are the most widely used globally, but many other oils are in local use in different parts of the world (Figure 1). This report discusses the production, trade, and consumption of vegetable oils, which are associated with various concerns and challenges.

Globally, vegetable oil crops account for over one-third of all agricultural lands and the current production value of vegetable oils is estimated at over US$ 265 billion, annually. To support growing demand, the areas allocated for oil crops continue to expand. While this expansion appears necessary to sustain our growing global population, it also drives biodiversity decline and climate change. Although there are major economic benefits, the social impacts from vegetable oil production are profound. There are serious concerns around human rights and livelihoods in production environments. Respecting rights, feeding people, and sustaining a biodiverse, productive, and liveable environment is the challenge we face.

Humans need fats. Fats constitute 25–35% of adult daily energy needs, and also provide essential fatty acids and fat-soluble vitamins. Nearly 800 million people (10% of the global population) do not get enough fat to satisfy their daily needs – a concerning 'fat gap' (see Glossary). Closing this gap is a vital global task. Simultaneously, among many wealthier consumers, obesity and related health concerns are increasing, in part due to overconsumption of fats. These divergent situations require distinct solutions.

Few oil crops are solely used to produce vegetable oil. For example, soy and maize are predominantly used for food and animal feed, while rapeseed and palm oil are common feedstock for biofuel production. Any forecasts of future needs and impacts need to consider these different uses and their alternatives for a comprehensive assessment.



⟶ *Soybeans, prized for their high oil content, yield seeds that can be extracted to produce soybean oil, a widely used cooking oil and essential ingredient in various food products,* by watkung, 2019, Adobe Stock.

⟶ *Palm oil, derived from the fruit of the oil palm, is a versatile and widely used vegetable oil but negative media coverage has resulted in mixed perceptions from consumers on its use and application,* by alenthien, 2019, Adobe Stock.

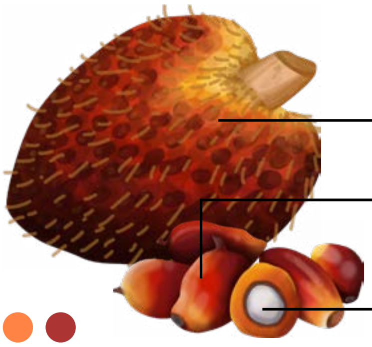
Perceptions of vegetable oils reported in scientific literature and global media are primarily shaped by international trade and Western consumption patterns, with a focus on globally dominant crops like oil palm, soybean, rapeseed, and sunflower. However, to fully inform inclusive policies, other oil crops must also be considered. These other oil crops are often neglected in global analyses and tend to be less well known with many remaining overlooked, yet continue to play significant roles in local diets, cultures, and economies.

To improve the environmental, socio-economic, and nutritional outcomes of vegetable oils, a comprehensive approach is necessary, considering the multiple values associated with lands that produce these oils. Concentrating solely on individual crops and their oil production provides a narrow perspective that overlooks the larger context of the vegetable oil industry. No crop is good or bad in and of itself, and much depends on the contexts, including where and how it is planted, owned, managed, traded and consumed. The production and consumption of vegetable oils occur within distinct systems that are defined more by factors, such as production scale, trade, consumption patterns, and the specific landscape within which these systems operate, rather than the particular crops within them.

Lastly, it is important to set goals. The future of vegetable oil crops should align with the United Nations Sustainable Development Goals, the goals and targets set by the Convention on Biological Diversity, human rights frameworks, and other relevant global sustainability pursuits. Important decisions lie ahead for the future of these vegetable oil systems, encompassing their complexities and wider relationships. While we, in the IUCN, may not have all the answers, we possess valuable knowledge. By seeking commonalities, identifying pitfalls to avoid, and exploring options, we can inform people and organisations that are addressing the challenge of meeting global vegetable oil demands.

A visual guide to the world of vegetable oils

Vegetable oils come in a diverse array of shapes and colours, each favoured for its distinct flavour profiles, nutritional attributes, and culinary applications across various regions that reflect the cultural preferences and traditions they are cherished in.



● ●

PALM OIL (INCL. PALM KERNEL OIL)

Palm oil stands as the most widely consumed vegetable oil globally, with Indonesia, Malaysia, Thailand, and Nigeria being its biggest producers. It also plays an important role in many traditional African cuisines.

●

SOYBEAN OIL

As the second most consumed vegetable oil, soybean oil is known for its neutral taste and widespread use in processed foods.

Global distribution of vegetable oils

Note: the icon placements provide a general sense of their locations on the map rather than pinpointing specific parts of the countries.

●

RAPESEED OIL

Versatile rapeseed (canola) oil ranks third, valued for its heart-healthy qualities and mild flavour.

●

SUNFLOWER OIL

Celebrated for its light taste and vitamin E, shines as a prime option for culinary creations.

●

OLIVE OIL

Highly valued in Mediterranean cultures for its rich flavour and health benefits.

●

COTTONSEED OIL

With its neutral flavour, it is commonly used in processed foods due to its stability and affordability.

Figure 1 The world's main oil crops – A visual guide to the world of vegetable oils. Source: Data compiled by the report editors.

●

GROUNDNUT OIL

Its distinctive nutty taste makes it a popular choice for stir-fries and deep-frying applications.

●

MAIZE OIL

Has a mild flavour and is often used in cooking and baking, making it a versatile option.

●

COCONUT OIL

Cherished for its tropical sweetness, adds a unique flavour and aroma to cooking.

●

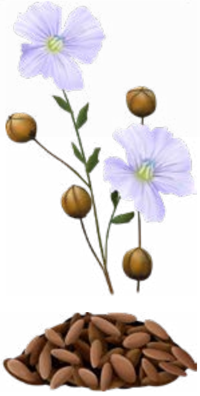
SESAME OIL

With its rich nutty taste, it is a staple in Asian cooking as a touch to enhance flavours.

●

SAFFLOWER OIL

Its high smoke point is valued for frying and sautéing while maintaining the dish’s flavours.



●

LINSEED OIL

Rich in omega-3 fatty acids, it is typically used as a dietary supplement.

⟶ *Field of flax flowers, the source of linseed, which is used to produce linseed oil, in Wiltshire, UK,* by Ruud Morijn, 2020, Shutterstock.

Foreword

The role of vegetable oils in sustainable nutrition

Professor Ranaan Shamir, Chair of the Sustainable Nutrition Scientific Board

This report makes an important contribution to understanding the meaning and implications of sustainable nutrition, a powerful concept at the heart of our scientific board's mission. We study this topic at the nexus of food production, the environment in which this occurs, the people in that environment, and the nutritional and health impacts on consumers through the lens of Big Data and Artificial Intelligence. By pulling together relevant information from socio-economic, environmental, nutritional, and social perception angles, the current report identifies key unknowns that can become important focal points for our Artificial Intelligence and Big Data studies.

The concept of sustainable nutrition aims to be a driving force for healthy, nutritious, and sustainable food solutions. Humanity is facing a 'quadrilemma': to produce more food, ensure its nutritional adequacy, avoid negative social impacts, and avoid the expansion of cultivated lands at the expense of natural environments. These complex issues cannot be solved in isolation. The need for a new approach is evident: one that optimises health and nutritional outcomes, while effectively restoring the key ecosystems and farming livelihoods on which humanity depends. Solving this problem could make an important contribution to help fix our global food system.

The recognition in this report that oils and fats are essential in healthy diets, and that many people in the world experience a fat gap, is important. We know that the global population is increasing and, therefore, fat gaps will continue to grow unless more fats can be produced and brought to those most vulnerable to undernutrition. At the same, overconsumption of fats, especially in ultra-processed foods, is a growing societal problem that needs to be addressed. In this tricky interplay between increasing production for some consumers and reducing consumption by others, the current report finds broad patterns of how this can be achieved while minimising negative environmental and social impacts.

One significant concern identified by this report is the inadequate state of nutritional and health science related to vegetable oils, both as products and ingredients. This deficiency renders the resulting health guidelines of limited utility. The only viable solution in this context would be the establishment of a comprehensive, globally-shared database and the exploration of innovative methods, leveraging artificial intelligence, to effectively discern the most relevant markers for labelling food components. This initiative should not only encompass macro-level considerations but also delve into the finer details of chemical components and metabolites, focusing on their nutritional and health implications. Such an undertaking should be a collaborative endeavour involving multiple countries to facilitate the requisite correlations.

→ *Edible oils, such as olive oil, are a source of dietary fats, which are an essential nutritional component of a balanced diet,* by Africa Studio, 2014, Adobe Stock.

Global consumer choices in vegetable oils

Different countries around the world exhibit distinct culinary traditions and dietary preferences, which is reflected in their diverse use of vegetable oils. Global consumer choices reflect only the internationally traded oils and fats and overlook hundreds of oils that are produced and consumed locally.

by Arkadiusz Fajer, 2021, Adobe Stock

SUNFLOWER OIL
A key component of Russian cuisine due to its neutral flavour, high smoke point, and high domestic production.

by Ezume Images, 2019, Adobe Stock

PALM OIL
A staple in many African countries, where it is used for frying, cooking, and flavouring traditional dishes. In its refined form it is used in thousands of products.

by M.studio, 2021, Adobe Stock

SOYBEAN OIL
A prominent cooking medium in India, celebrated for its affordability and high smoke point.

by artitwpd, 2016, Adobe Stock

GROUNDNUT OIL
An important staple in African and Asian cuisines with a distinct aroma.

Figure 2 What oils and fats are consumed in different countries? Priority consumer choices in vegetable oils, by country.
Source: Data compiled by the report editors.

by airborne77, 2016, Adobe Stock

RAPESEED OIL

Also known as canola oil, a staple in Canadian cuisine for its light flavour and perceived benefits for cardiovascular health.

by BRAD, 2016, Adobe Stock

SOYBEAN OIL

A prevalent choice in the US, valued for its neutral taste and diverse applications, from sautéing and frying to baking and salad dressings.

by Orion Media Group, 2019, Adobe Stock

COCONUT OIL

The traditional edible oil in most Pacific nations.

by Gustavo, 2021, Adobe Stock

SOYBEAN OIL

Extensively utilised in Brazil, playing a central role in cooking and frying due to its affordability and versatility in various regional dishes.

- ● Palm oil
- ● Palm kernel oil
- ● Soybean oil
- ● Rapeseed oil
- ● Sunflower oil
- ● Olive oil
- ● Cottonseed oil
- ● Groundnut oil
- ● Maize oil
- ● Coconut oil
- ● Others

Main narratives

Our analysis raises various questions and provides insights that translate into the following key narratives regarding the future of vegetable oils.

→ Scale of opportunity

Oil crops play a crucial role in human health and well being, as well as for the global environment. Covering a substantial portion of the Earth's surface, oil crops occupy around 543 million hectares (mha), accounting for ~37% of the total land area dedicated to agricultural crop production. Notably, the expansion of land allocated to vegetable oil crops has outpaced that of other commodities. Moreover, unless there are major policy changes vegetable oils will continue to be cultivated as a by-product of animal feed production for meat animals, as well as for biofuel, surfactant, and other purposes, even if the production of edible oils meets global fat demands. Acting in vegetable oil production areas represents 2% of the total global opportunity for reducing species extinction risk through abating threats to species in their current habitats and 5% of the opportunity from habitat restoration.

→ Values and interests

The challenges in vegetable oil production, trade, and consumption go beyond the technical aspects and touch on numerous sociocultural aspects. Therefore, solutions must be holistic, addressing diverse interests and values. In our study, recognising and aligning our values is crucial. This means navigating conflicts between economic efficiency and equity and rights in complex global systems. Efficiency optimises resource use, while equity ensures just distribution of benefits and costs. The transformation of vegetable oil systems must uphold human rights and align with the Sustainable Development Goals (SDG) and the Kunming-Montreal Global Biodiversity Framework.

→ Nutritional contexts

The nutritional significance of edible oils remains a significant blind spot, with numerous uncertainties. While affordable edible oil has played a crucial role in meeting our nutritional requirements, it is also linked to the sometimes-unhealthy consumption of processed foods and a reduction in the intake of vegetables, fruits, and pulses. Furthermore, perceptions around vegetable oils are marred by misinformation and a lack of transparency regarding their nutritional value. These perceptions and culinary traditions determine which oils people prefer to consume (Figure 2). There is a need to shift the focus towards access to high-quality food and its overall nutritional quality rather than individual components.

→ Environmental, social, and economic impacts

Oil crop production can often have significant negative environmental, social, and economic impacts, especially when pursued on industrial scales and in areas with poor governance and regulatory frameworks. Deforestation and losses of other natural ecosystems are a key environmental concern in vegetable oil production. While timing has varied, globally threatened ecosystems have been replaced by industrial oil crop systems for cotton, rapeseed, coconut and sunflower cultivation, broadening the perspective beyond terrestrial biodiversity impacts associated with oil palm and soybean.

The most prominent social impacts are those related to land rights, inappropriate and excessive use of chemicals, and economic exploitation. On the other hand, as a global source of energy and nutrition, many vegetable oils offer a less land-hungry alternative to animal products (although oil crops and animal feed are closely related), and oil crops are often a key driver of development in rural areas, and, under the right conditions, bring income and other benefits to local people. Local ecological knowledge, practice, governance, and social contexts, along with the food systems in which a crop is embedded, are crucial when assessing the impacts of oil crops, as well as the efforts to mitigate the risks associated with their production.

While social and environmental impact assessment is an ongoing process, scientists are trying to transition from singular crop impact evaluation to adopting a systemic perspective, exploring alternative metrics beyond mere impact and yield averages. Different food systems coexist, yielding diverse effects. For example, impacts vary widely with production scales and levels of mechanisation. This suggests that it makes more sense to not focus on crop impacts as such, but rather on the impacts of typical systems, and how they can be improved. With systems we mean the way by which these crops are produced, traded, and consumed and the socio-economic context in which these value chains are embedded.

Perennial production systems generally offer environmental advantages, including lower fertiliser and pesticide requirements, and promoting biodiversity and healthier soils. However, their longer production cycles and higher upfront costs limit flexibility. Mixed cropping, mosaic landscapes, and agroforestry present promising opportunities for vegetable oil production, showcasing environmental and social resilience while achieving comparable yields to monocultural systems.

Analysing the social and economic impacts of vegetable oil production demands distinct approaches – such as rights-based methodologies, economic assessments, and value chain perspectives – whether considering these impacts together or separately. Structuring discussions around both the positive and negative impacts require careful attention, posing an ongoing challenge. To comprehend rights violations, it is vital to grasp contextual conditions, including the role of value chains in generating broader impacts, be they positive or negative. Product differentiation becomes fundamental for addressing aspects like quality, governance, and production and trade systems.

Economic exploitation remains poorly assessed in large regions of the world, necessitating a clear separation between value chain analyses and the social outcomes they entail. Large-scale production emerges as a notable contributor to exploitation, warranting a more responsible approach. Smallholder production offers benefits for both people and nature compared to large-scale production. Furthermore, smallholder crop systems achieve more Sustainable Development Goals outcomes than their industrial counterparts.

Deforestation and related social and environmental impacts in tropical forest regions are a major political issue in the Global North, whereas impacts in their own regions are often overlooked. Non-governmental organisation campaigns influence social media, and the framing that governs many viewpoints. For example, palm oil has been vilified but production of other oils, even the beloved olive oil, has severe environmental impacts when industrially produced. Figure 3 indicates a great degree of variation of different environmental impacts between and within different vegetable oil crops.

The environmental impacts of oil crops

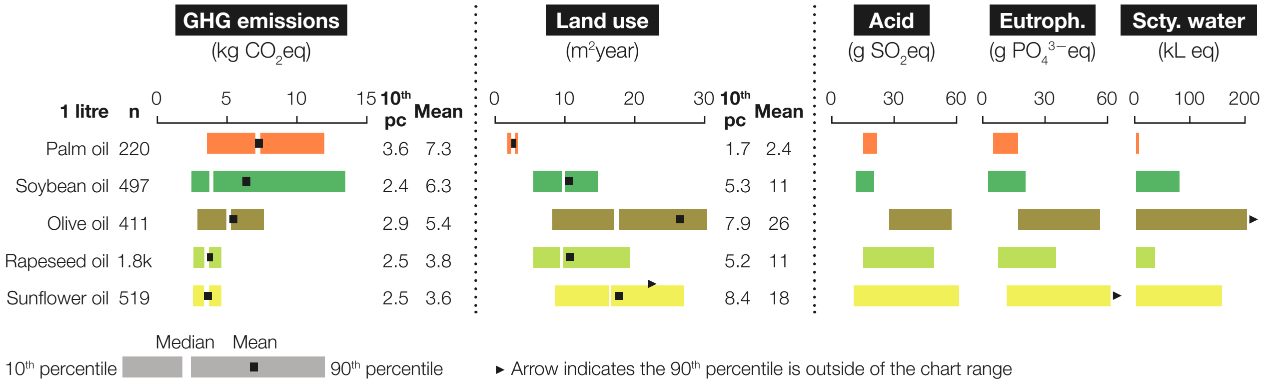


Figure 3 The environmental impacts of five important vegetable oils. Global variation in greenhouse gas (GHG) emissions, land use, terrestrial acidification, eutrophication, and scarcity-weighted freshwater withdrawals, within and between five oils. Source: Prepared by the report editors based on Poore & Nemecek (2018) [1].

⟶ *Olive oil production requires far greater land use per annum than other vegetable oils,* by T photography, 2009, Shutterstock.

Value chain and power in food systems

The globalised and industrialised nature of edible oil production and trade has led to inequities, with most benefits staying at corporate levels, and those that reach the local level favouring landowners and wealthy farmers. Disadvantaged groups, including Indigenous peoples, women, and the rural poor, receive fewer benefits, and are subject to exploitation and other rights violations. Agrifood companies and traders from industrialised nations benefit the most from the vegetable oil industry, even if production occurs elsewhere. However, the similarity of most edible oils for many uses contributes to flexible and resilient food systems in industrialised nations. Shorter value chains, involving a reduced number of economic operators, benefit local producers, manufacturers, and consumers. Entrenched powers impede food system transparency and transformation.

Climate change

There are two different aspects to the relationship between climate change and vegetable oil production. Firstly, in addition to emissions related to production and transportation, the expansion of vegetable oil crops into natural environments is a major contributor to climate change through forest clearance, natural grassland conversion and peatland drainage, emitting significant carbon dioxide and potentially releasing methane and nitrous oxide. Converting natural ecosystems to oil crops causes microclimate shifts, temperature increases, and reduces rainfall, which in turn reduces yields, thus driving further expansion. On the other hand, climate change also affects oil crops. Extreme weather events are projected to become significantly more frequent, leading to substantial reductions in oil crop production, with potential impacts such as a loss of agriculture-based employment, resource disputes, and mass migration, but also expansion of crops into new climatic zones. Improved growing conditions might occur at higher latitudes that are currently not suitable for oil crops.

Best practice

Many people have ill-informed views about vegetable oils through exposure to polarised and biased media. Our analysis shows that there are no good or bad oil crops, and the impacts of any oil crops vary widely depending on production, trade, and consumption scales, as well as the respective governance and regulatory contexts. This insight invites a more nuanced appreciation of best practice.

While impact assessment is an ongoing process in business, this report recommends efforts to transition from individual crop impact evaluation to adopting a systemic approach that explores alternative metrics beyond mere impact and yield averages that better captures co-benefits and multiple values in food systems.

Tailoring strategies for best practices in global value chains to local contexts is essential, and there is also an important role to be played by universally agreed standards, principles and criteria for production, processing, and trade. This parallel need has been partly addressed in initiatives like the roundtables for soy or palm oil.

A novel perspective is emerging, highlighting that comprehensive governance demands a balanced blend of mandatory and voluntary tools. This adaptable approach caters to diverse scenarios, spanning from local landscapes to worldwide systems. Achieving effective governance and ensuring the future resilience of oils necessitates the synergy of various elements. These encompass customary governance structures, governmental policies and regulations, expansive landscape-level measures, such as jurisdictional land use planning, and valuable voluntary tools like standardised systems or attractive financial incentives for producers. This combined approach has the potential to optimise governance effectiveness and cultivate sustainable outcomes, in line with the Sustainable Development Goals and other international standards.

To provide consumers with more informed choice, new technologies are emerging to improve transparency of vegetable oil value chains, which exposes impacts and improves the opportunities for rewarding good practice and related improvements.

There is considerable scope for improving agricultural practices that offer better environmental outcomes, including improved soil health and biodiversity conservation, and reduce negative social impacts. Mixed cropping and agroforestry, for example, present promising opportunities for vegetable oil production, but the products, values, costs, and benefits derived are perceived differently at the local and regional scales and depending on who is asked. Furthermore, the interchangeability of edible oils, driven by the desire to maintain low prices, poses challenges for the development of alternative agriculture. Comprehensive regulations and safeguards are necessary for all oils due to the ease of interchangeability.

Finally, increasing the proportion of small-scale local food production can yield positive outcomes for both the individuals who currently rely on such systems and the larger global production landscape. Cooperation between industrial and smallholder production can support innovation exchange and multiple values in landscapes.

→ Voluntary standards

Tailored combinations of governance tools are essential to effectively address the social and environmental risks posed by vegetable oils, promoting sustainable practices. While robust voluntary standards can be instrumental, their efficacy relies heavily on effective auditing. Unfortunately, the direct payment of auditors by assessed companies can create incentives for underreporting non-compliance. Despite financial links, auditor experience, certification protocols, unannounced audits, and peer review quality can also influence underreporting. This issue is notably documented in palm oil certification systems and potentially extends to other vegetable oils.

Instituting institutional reforms that mitigate such risks is crucial for the credibility of these systems. For instance, the Rainforest Alliance's new cocoa certification in Ghana adopts a risk and competence-based allocation approach, avoiding direct financial links. Instead, it assigns certification bodies to certificate holders based on risk and competence, aiming to address the challenge without severing the financial connection.

Future scenarios

Perceptions about vegetable oils are often polarised and poorly informed. In consequence decisions too are poorly informed. Partly, to 'counter' these often polarised views, we draw some cartoon scenarios that capture and exaggerate aspects that may help inform future trends. We do not know the future. No one does. The objective of these future scenarios is not prediction but insight into different societal options and their possible consequences. We use extreme scenarios to force our thinking to suggest clear implications of the wide-ranging scenarios and alternative futures. These extreme options provide food for further introspection about these complex systems. A fuller account is presented in the main report.

What if?

SCENARIO 1

What if all food oil were produced by algae or other microbial processes?

High-tech oils will require a lot of feed stock (the microbes need nutrients) and energy. We do not expect major volumes in the next decade, but the technologies are advancing rapidly and who knows in the longer term? If these systems do become cheap and productive at a sufficiently large scale it will transform food oil with major knocks on oil monopoly and impacts on land use.

SCENARIO 2

What if monoculture is the only culture?

A lot of people would lose their livelihoods and their food cultures, but consumers could have cheaper food and spare land for biodiversity and carbon only over the short term. Over the long term, monocultures pose significant risks to diversified food systems.

SCENARIO 3

What if we all became vegetarian?

It would benefit global biodiversity, climate, and the majority of people, though we have concerns for pastoralists, fishers and hunter-gatherers. A reduction in meat consumption in industrial countries would reduce pressure on land and related resources.

SCENARIO 4

What if we ran the world on vegetable oils for biofuel?

At present a staggering amount of additional land would be needed, or 10 times the currently planted oil palm area. This would have major knock on impacts on land-use and users.

Figure 4 What if? Possible outcomes from some extreme assumptions about the world of vegetable oils.
Source: Prepared by the report editors.

SCENARIO 10

What if more financial institutions invested in smallholder agriculture?

There is a huge credit gap so far, but investment at scale accompanied by digital innovation has the potential to revolutionise smallholder agriculture.

SCENARIO 9

To simplify regulation needs, can one oil do it all?

This is probably a bad idea because it will involve over-use of one type of ecosystem suited to that oil crop (for example, tropical humid areas for oil palm). Consumers can no longer access their favourite oils, but palm and soy can meet most global needs. For maximum production by area palm wins compared to other crop oils.

SCENARIO 8

Climate change hits 4.4°C?

Maintaining oil crops will not be the main concern.

SCENARIO 7

The climate wild card – A temperature rise of 2.4°C?

Climate instability will hit edible oils hard. While many of us will have bigger problems, production areas will shift and there will be marked challenges in sustaining sufficient production.

SCENARIO 6

Can countries achieve self-sufficiency through domestic production?

Probably a bad idea. In the next 10 years, Europe would have a massive fat gap (short fall in availability).

SCENARIO 5

What if there were no tariff barriers and regulations at production or consumption levels?

In a neoliberal world, big business would gain but many workers, smallholders and much biodiversity would likely lose.

Executive summary

This report is a collaboration between the IUCN Oil Crops Task Force and the Sustainable Nutrition Scientific Board.

The former group was set up in 2017 by three International Union for Conservation of Nature (IUCN) Commissions with the goal of generating a more solid scientific basis for discussions about, initially, the biodiversity impact of palm oil production and, later, more generally the socio-economic and environmental context of vegetable oil production. The Sustainable Nutrition Scientific Board carries out independent research on the sustainability of nutrition, primarily through complex sciences and Big Data approaches and a specific focus on the nutritional and health context of vegetable oils.

The current study is unique in its comprehensive assessment of an important group of crops that occupy 37% of all agricultural crop land and the impacts of this production. We reviewed the scientific and grey literature and consulted 25 vegetable oil experts working in government, private sector, non-government, and research sectors. Results of our initial data gathering were discussed during a one-week workshop in June 2023, when the main structure of the report was decided, as well as key narratives. Following internal reviews by the members of the IUCN Oil Crops Task Force and Sustainable Nutrition Scientific Board, the report was revised. The final draft was reviewed by three external reviewers through a double-blind review process managed by IUCN's Chief Scientist. The review comments and our responses are publicly available on the Oil Crops Task Force website.

By analysing social and environmental impacts it becomes clear that these impacts occur across all production systems but are especially severe when large areas of natural environments are converted for crop expansion, and in areas of poor governance. Impacts also vary widely with production scales and levels of mechanisation, with negative impacts tending to be greatest for large-scale monoculture production, especially where it involves the heavy use of chemicals and a high level of mechanisation. This suggests that while the different oil crops each have specific characteristics, some of which affect their impacts, it is more important methodologically not to focus on crop impacts as such, but rather on the impacts of the food systems in which these crops are produced, traded, and consumed, and how these systems can be improved.

The best food systems appear to be those that add value in producing countries and are generally associated with local and regional economic growth, lower environmental impacts (such as reduced agrochemicals use, more heterogenous landscapes), and less concentration of power. Such systems often operate alongside larger scale industrial production systems that have the resources to develop production-related infrastructure, research novel production methods, and invest in sustainable practices. The system transitions required to minimise negative future impacts of meeting the growing oil demand should be safeguarded by aligning new approaches with the Sustainable Development Goals, the requirements under the goals and targets of the CBD's global biodiversity framework, and international human rights frameworks.

As a society concerned about the negative impacts of agricultural production on society, our planet, and our health, we need to move beyond the debate about 'good' and 'bad' crops, and towards the debate between bad and better production, processing, trade, and consumption. By providing science-based insights, the authors of this report hope to contribute to a better future for vegetable oils.

Recommendations

→ For influencers

The report targets influencers (such as those that influence media, debates, and policies) and highlights the numerous positive outcomes that can be achieved through improving vegetable oil systems. These benefits include improved well-being, reduced poverty, increased biodiversity, and the effective mitigation of the impacts of climate change.

It also highlights the need to address the many negative outcomes in large-scale industrial production, especially human rights violations, agrochemical pollution, and habitat loss. These negative aspects must be acknowledged and addressed in any efforts to promote sustainable practices. The intended audience includes governments, traders, farmers associations, and processors, who all play a crucial role in the realisation of sustainable oil systems.

The report emphasises the importance of respecting the rights of and supporting smallholder and local oil production systems due to their positive socio-economic outcomes and contribution to food security. While these local production and consumption systems alone may not feed the world, they have the potential to make much greater contributions to doing so in the future, and play vital roles in their respective communities.

The report acknowledges that within each vegetable oil system, there are both good and bad actors and outcomes, and urges for a nuanced perspective. A systemic approach is recommended to effectively address various challenges. The report underscores the significance of considering food systems and contexts as they influence the impacts that arise. Having diverse systems is seen as beneficial for increasing societal resilience.

→ For researchers

We identify several key knowledge gaps that require attention, noting that it is crucial to use research findings to inform and influence effective policy decisions. Firstly, there is a need for a more comprehensive incorporation of social factors into environmental analyses and vice versa. Secondly, research on vegetable oils has strongly focused on internationally traded oils and overlooked those in local value chains, which are often of considerable nutritional and cultural importance.

Research must prioritise rights-based approaches, as rights are non-negotiable. Secondly, more research on transitioning to mixed cropping systems, perennial crops, intercropping, and regenerative agriculture is needed to explore sustainable alternatives. Thirdly, research should investigate new finance mechanisms that consider the holistic value of oil systems, beyond just yields and profits.

Scientists need to acknowledge and clarify the myths, gaps, and biases in available knowledge on vegetable oil, paying special attention to how scientific opinions have evolved over time. This requires greater transparency and requires addressing the issue of ‘invisibles’, the often-overlooked aspects of the food industry. Invisibles are the blind spots in systems that occur because of underrepresented voices and methodologies which bias some factors and perspectives from others. The report has identified the need for approaches that explore broader positive and negative outcomes of vegetable oil systems, as well as using alternative metrics that are better able to capture co-benefits and multiple values, beyond mere yield and impact averages.

Big Data analysis, complex systems and Artificial Intelligence will play an increasing role in analysing complex system outcomes but need to overcome challenges of data quality and bias (e.g. severe underrepresentation of local oil production and consumption systems in international science).

→ For financial institutions

There is a need for financial institutions to address the risks associated with current investment strategies in the industry. Financial institutions can help to uphold suitable governance mechanisms at company, value chain and jurisdictional levels, through their investment policies. Engaging in discussions with shareholders and investment funds for responsible investment is vital. Divestment is the easy option and better is to explore means of conditioning investment on verified sustainable production. This includes promoting positive examples, such as the disinvestment by Norwegian funds from non-compliant palm oil companies, which can encourage responsible practices. Financial institutions should sign up to international standards for sustainable vegetable oil value chains. Expanding ethical consumption into major consumer markets such as China and India should be a priority to foster responsible and sustainable practices globally.

> "Expanding ethical consumption into major consumer markets such as China and India should be a priority to foster responsible and sustainable practices globally."

Greater investment and other forms of financial support should also be available for small-scale production, including regenerative agriculture, perennial crops, and other agricultural systems that require time to develop. For instance, investments in tree crops that may not generate profits for the initial 20 years can lead to sustainable outcomes.

The value of crops should not solely be defined by yield per crop but also their social, environmental, and cultural aspects. New forms of financing and markets should be explored for crops and food systems that provide multiple values.

→ *Intensive agriculture, characterised by vast areas of monoculture, is often associated with negative social and environmental outcomes*, by Roger de la Harpe, 2020, Adobe Stock.

→ For business and governments

The vegetable oil market has expanded tremendously through policies and actions between governments and businesses. Ensuring the future resilience of vegetable oil trade chains, landscapes, and their various uses requires proactive measures, also between governments and businesses. Establishing a high degree of transparency regarding impacts and mitigation strategies is pivotal. Effective hybrid governance strategies that uphold transparency and respect for rights are essential. The report highlights that policies and safeguards can only be upheld when governments and businesses work together with a rights-based approach.

This includes robust safeguards, encompassing both mandatory global and regional instruments, including the United Nations Human Rights Instruments, the International Labour Organization Conventions, and EU regulations as well as national legislative requirements, and voluntary measures, such as the UN Guiding Principles on Business and Human Rights, the OECD Guidelines for Multinational Enterprises and the Accountability Framework Initiative, and Roundtable standards, jurisdictional programmes, and financial incentives. Positive investment in conservation and poverty reduction beyond legal requirements, particularly in critical biodiversity areas, and the promotion of agroecological production systems also play a significant role.

As we look into the future, the human population will increase, especially in Africa, and closing the fat gap will become more challenging. At the same time, there will also be major advances in farm technology, automation and robotics that could boost vegetable oil production. Yet, climate change will impact the production and resilience of supply chains. Given the challenging future ahead, this report highlights the need for diverse food systems, and the need for actors in those systems to cooperate, in particular industrial and small-scale systems. Collaboration between food systems can enhance innovation through technology exchange but can also build resilience through landscapes with multiple values. Smallholder agriculture plays a critical role in such multi-functional landscapes. To strengthen innovation and resilience in globally connected oils value chains, governments and businesses will need to work proactively together and focus on multiple values, rather than only on, for example, feeding the world, climate change or energy security.

→ For consumers

Consumers deserve reliable information. Beyond just differing perspectives, disputes can arise from conflicting claims and perceptions related to factual matters that can be resolved through empirical evidence. In a world currently marked by polarisation and susceptible to misinformation, transparency and objectivity become crucial to steer policymaking and trade.

Informed consumer choices require measures and standards that are equally applicable to producers in Borneo, Belgium and Barbados. Enhancing the widespread availability of accurate information concerning vegetable oil production and its food system context could guide consumers in making well-informed decisions about oil use. Such decisions should factor in the diverse spatial, temporal, cultural, and power-related ethical considerations. Effectively capturing these considerations in product labelling and other product information should equip consumers with better information for decision making that reflects their values.

→ For social media

Social media tends to amplify the polarised views about vegetable oils – ‘good’ oils are made better, and ‘bad’ ones are made worse. There is a need to work with social media influencers to reduce this dichotomy between good and bad by providing them with access to more nuanced views. This would provide one way to break through the global myths around oils that appear to be driven strongly by western views on oils which overlook non-western perspectives.

> “The report highlights that policies and safeguards can only be upheld when governments and businesses work together with a rights-based approach.”

⟶ *Effective management of existing production landscapes is essential to mitigate the costs of expansion while addressing the growing global demand for vegetable oils,* by 2seven9, 2017, Shutterstock.

Using influencers from non-western backgrounds may be one way to strengthen accurate views on the relative costs and benefits of different vegetable oils. The important closure of the fat gap might be one angle to address how important it is to get things right towards future oil production and consumption.

→ For growing producer and consumer countries

Together, Brazil, China, India and South-East Asian and African-producing countries yield and consume a substantial and growing amount of global vegetable oil. As major consumers of the oils themselves, certain countries with rapidly growing populations and concomitant increasing oil demand play important roles in the evolving cultivation, production, and processing standards, and only if their people and politicians support these activities can key sustainability concerns be met. As major producers, these countries aspire to be self-reliant with the potential to provide direct benefits to their people and minimise social, economic and ecological harms. However, the ambition to earn export revenues from vegetable oils can often sideline other values. This report recommends more nuanced, fact-based discourse on policies for oils, more multi-livelihood value-based approaches, focused regulatory standards for production and processing, and better understanding of current and future risks, especially as these countries are at the intersection of production and consumption.

This report also emphasises that countries with major fat gaps should aim for more self-reliance. In particular, Africa should become more self-reliant with regards to oil production to meet growing local demand, reducing dependence on imported oils. Stimulating existing food systems of smallholders for oil production and giving support for cooperation between industrial and smallholders, for oil production is necessary to prepare for the future.

→ For Voluntary Sustainability Standards

Robust voluntary sustainability standards can have an important role among other tools in companies' (mandatory) due diligence toolboxes. Robustness concerns strong legal, social and environmental criteria, not only on deforestation, but for example also on responsible chemicals management. It is also key for standards to go beyond this towards more regenerative and agroecological practices. Crucial for standards are good quality assurance criteria and practices. As part of this, auditors should no longer be paid directly by companies, to ensure that audits are genuinely independent.

Contributors

REPORT EDITORS AND MAIN AUTHORS

Erik Meijaard, Malika Virah-Sawmy, Helen Newing, Verina Ingram, Mukhlish Jamal Musa Holle, Thijs Pasmans, Syazwan Omar, Heleen van den Hombergh, Nabillah Unus, Ariadna Fosch, Henrique Ferraz de Arruda, James Allen, Konstatinos Tsagarakis, Matthew Chidozie Ogwu, Andrea Diaz-Ismael, Jeremy Hance, Yamir Moreno, Sinéad O'Keeffe, Joanna Slavin, Maja Slingerland, Emily Mae Meijaard, Nicholas Macfarlane, Randall Jimenez, Serge Wich, Douglas Sheil

Chapter 1: Introduction

Erik Meijaard, Jeremy Hance, Matthew Chidozie Ogwu, Thina Arifin, Nabillah Unus, Rona Dennis, Syazwan Omar, Douglas Sheil

Chapter 2: Vegetable oils, their global importance and key sustainability issues

Erik Meijaard, Thijs Pasmans, Matthew Chidozie Ogwu, Douglas Sheil

Chapter 3: Food systems, value chains and transformations

Malika Virah-Sawmy, Verina Ingram, Helen Newing, Heleen van den Hombergh, Erik Meijaard

Chapter 4: Impacts and outcomes

Erik Meijaard, Helen Newing, Syazwan Omar, Mukhlish Jamal Musa Holle, Ariadna Fosch, Henrique Ferraz de Arruda, Joanne Slavin, Nabillah Unus, Safwanah Ni'mattulah, Clara Zemp, Emily Mae Meijaard, Rona Dennis, Jesse Abrams, Sinéad O'Keeffe, Nicholas Macfarlane, Randall Jimenez, Serge Wich, Douglas Sheil

Chapter 5: Global trade and governance

Thijs Pasmans, Heleen van den Hombergh, Helen Newing, James Allen, Malika Virah-Sawmy, Emily Meijaard, Andrea Diaz-Ismael, Maja Slingerland

Chapter 6: Key future developments

Malika Virah-Sawmy, Ariadna Fosch, Henrique Ferraz de Arruda, James Allen, Douglas Sheil, Erik Meijaard

Chapter 7: Scenarios, unknowns and choices

Meijaard, E. Virah-Sawmy, M., Helen Newing, Verina Ingram, Thijs Pasmans, Heleen van den Hombergh, Yamir Moreno, Douglas Sheil

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Conflict of interest disclosure

IUCN's Code of Conduct for Commission Members requires that "any authors receiving any payment of special consideration from persons or organisations whose purpose is to influence the decisions, policies or actions of the IUCN", declare a potential conflict of interest.

Erik Meijaard and Joanne Slavin are independent members of the Sustainable Nutrition Scientific Board. The Sustainable Nutrition Scientific Board research is carried out independently thanks to the financial support of Soremartec SA and Soremartec Italia, Ferrero Group. The funder has no role in study design, data collection and analysis, decision to publish, or preparation of any manuscript. The Scientific Board brings high-level competences and warrants network with the most respected and known associations.

Through a Memorandum of Collaboration between the Sustainable Nutrition Scientific Board and Borneo Futures Sdn Bhd, the host organisation for the IUCN Oil Crops Task Force, signed on 2 April 2023 in Brunei Darussalam, it was agreed that on behalf of the Sustainable Nutrition Scientific Board (SNSB), Borneo Futures would coordinate the research and reviews needed to develop the study. Borneo Futures, as well as any SNSB member, agreed that any study carried out within the scientific field would be conducted in an independent, honest, ethical, and professional manner.

Malika Virah-Sawmy, Heleen van den Hombergh, Douglas Sheil, Nicholas Macfarlane, Serge Wich, and Erik Meijaard are members of the IUCN Oil Crops Task Force. Douglas Sheil and Serge Wich have facilitated student research in palm oil concessions. Heleen van den Hombergh works for IUCN NL on vegetable oil issues.

None of the remaining authors have declared a conflict of interest.

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Glossary

TERM	DESCRIPTION
Biobased economy	The bioeconomy encompasses the production and use of renewable biological resources from land and sea, like crops, forests, fish, animals and microorganisms to produce food, feed, materials and energy.
C-number in lipids	The numbers in a lipid name are used to describe the fatty acid chains on the lipid. The numbers are generally presented in the format (number of carbons in fatty acid chain) : (number of double bonds in fatty acid chain), for example, 16:0 would be 16 carbons in the fatty acid chain with zero double bonds, or the numeric representation of palmitic acid.
Circular economy	A model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible, thereby extending the life cycle of products. It implies minimising waste. When a product reaches the end of its life, its materials are kept within the economy wherever possible.
Convention on Biological Diversity	The Convention on Biological Diversity (CBD) is a multilateral treaty. The Convention has three main goals: the conservation of biological diversity (or biodiversity); the sustainable use of its components; and the fair and equitable sharing of benefits arising from genetic resources. Its objective is to develop national strategies for the conservation and sustainable use of biological diversity, and it is often seen as the key document regarding sustainable development.
Customary lands	Lands, territories, and resources that are governed by Indigenous peoples and local communities according to their established collective system of ‘customary’ rules and norms.
Domestic disappearance	Domestic disappearance refers to the use of a commodity in a certain country. It includes a broader scope of ‘disappearance’ such as processing into new products, final ingredients as well as direct consumption of that commodity. Domestic disappearance is, however, not equal to final consumption by consumers of that country as processed products and ingredients could be exported (or imported) to other countries as well. In this report, domestic disappearance is based on FAOSTAT data and calculated by combining production and import, minus the export of the commodity (oil) concerned.
Downstream	Downstream in a value chain refers to activities after processing and manufacturing, getting the finished goods to the end consumer(s).
Environmental human rights defenders	“individuals and groups who, in their personal or professional capacity and in a peaceful manner, strive to protect and promote human rights relating to the environment, including water, air, land, flora and fauna”. UN General Assembly (2016). A/71/281. [2]
Family farm	“An agricultural holding which is managed and operated by a household and where farm labour is largely supplied by that household”.[3]
FAO	Food and Agriculture Organization of the United Nations is a specialised agency of the United Nations that leads international efforts to eliminate hunger.
Fat gap	This is a measure of how much more fat would need to be produced and consumed in the world to bring all regions to within the recommendations of a healthy diet, requiring that fats meet 27.5% of energy intake. [4]
Fats and oils	Fats and oils are lipids. They are important energy stores in animals and plants. Fats are solid at room temperature whereas oils are liquids.
Food security	“All people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets people’s dietary needs and food preferences for an active and healthy life”. [5]
Food system	A sustainable food system is one that delivers food security and equitable nutrition without compromising the socio-economic and environmental well-being of future generations. This means that it is profitable, has broad-based benefits for society, and a positive or neutral impact on the natural resource environment.
Human rights	Human rights are rights that are inherent to all human beings. They are protected in international law by a set of global human rights treaties and protocols. Rights are defined as universal, Inalienable, indivisible, and non-discriminatory. [6] As well as individual rights, international law also recognises certain collective rights, including the collective rights of indigenous people. [7]
Indigenous peoples	There is no single definition of Indigenous peoples, because such a definition may not be workable in all contexts. However, Indigenous peoples have unique and distinctive cultures, languages, legal systems and histories, and most have a strong connection to the environment and their traditional lands and territories. They also often share experiences of discrimination and marginalisation. Self-identification is a key criterion for indigeneity. [8]

Kunming-Montreal Global Biodiversity Framework	The Kunming-Montreal Global Biodiversity Framework (GBF) is an outcome of the 2022 United Nations Biodiversity Conference. The GBF was adopted by the 15th Conference of Parties (COP15) to the Convention on Biological Diversity (CBD) on 19 December 2022. It has been promoted as a 'Paris Agreement for Nature'. It is one of a handful of agreements under the auspices of the CBD, and it is the most significant to date.
Lipids	Any of a diverse group of organic compounds including fats and oils, that are grouped together because they do not interact appreciably with water.
Local communities	Non-Indigenous traditional communities, including Afro-descendant communities and others who have collective customary systems of land tenure and social organisation. This term is commonly used in this sense in international law and policy.
Mha	Million hectares (1 million hectares = 2.47 million acres = ca. the size of Jamaica, Lebanon, Gambia or Cyprus.
Mt	Million metric tonnes. One metric tonne = 1,000 kg. To give an idea of the magnitude of this metric, one million metric tonnes weighs about the same as 20 times the weight of the *RMS Titanic*.
Peasants	"A peasant is a man or woman of the land, who has a direct and special relationship with the land and nature through the production of food or other agricultural products. Peasants work the land themselves and rely above all on family labour and other small-scale forms of organising labour. Peasants are traditionally embedded in their local communities, and they take care of local landscapes and of agro-ecological systems. The term peasant can apply to any person engaged in agriculture, cattle-raising, pastoralism, handicrafts related to agriculture or a similar occupation in a rural area. This includes Indigenous people working on the land. The term peasant also applies to the landless. [9]
Planetary boundaries	The basic idea of the Planetary Boundaries framework is that maintaining the observed resilience of the Earth system in the Holocene is a precondition for humanity's pursuit of long-term social and economic development. The framework described nine 'planetary life support systems' essential for maintaining a 'desired Holocene state', and attempted to quantify how far seven of these systems had been pushed already. Boundaries are defined to help define a 'safe space for human development'. [10]
Rights-based approach	A rights-based approach consists of two complementary strategies to meet the overall aim of fulfilment of rights, in line with international law and standards. It involves supporting rights-holders to claim and fulfil their rights, and at the same time working to ensure that 'duty-bearers' meet their obligations to respect, protect and fulfil rights. Governments are the primary duty-bearers (they hold the primary obligations), but businesses, non-governmental organisations and others are also duty-bearers.
RSPO	Roundtable on Sustainable Palm Oil is a member-based organisation established in 2004 with the objective of promoting the growth and use of sustainable palm oil products through global standards and multistakeholder governance.
Smallholders	Farmers who rely principally on family labour, lack formal corporate management structures, and typically, grow a mixture of crops for home consumption and for markets. Generally, they own less than 2 ha of land, although definitions differ between countries and organisations (see Chapter 4.2).
Substitution	This refers to the ability to swap one type of oil for another due to similar chemical properties and functionality, such as using rapeseed oil or palm oil as biofuels
Supply chain	The network of all the individuals, organisations, resources, activities, and technology involved in the creation and sale of a product, from the delivery of source materials from the supplier to the manufacturer, through to its eventual delivery to the end user. The management and logistics of getting a product from A to B.
Sustainable Development Goals (SDGs)	The Sustainable Development Goals (SDGs) are a collection of 17 interlinked objectives designed to serve as a "shared blueprint for peace and prosperity for people and the planet, now and into the future". The SDGs are: no poverty; zero hunger; good health and well-being; quality education; gender equality; clean water and sanitation; affordable and clean energy; decent work and economic growth; industry, innovation and infrastructure; reduced inequalities; sustainable cities and communities; responsible consumption and production; climate action; life below water; life on land; peace, justice, and strong institutions; and partnerships for the goals. The SDGs emphasise the interconnected environmental, social, and economic aspects of sustainable development by putting sustainability at their centre.
Transesterification	Transesterification is the general term used to describe an important class of organic reactions where an ester is transformed into another one, resulting in a vegetable oil product with different characteristics.
Upstream	Upstream in a value chain refers to activities related to sourcing and transportation of raw materials needed in a manufacturing process
Value chain	The processes, inputs, outputs, and stakeholders involved in creating and adding value to a product, from the plant-based raw material, through processing and production, to delivery to final consumers, and ultimately its disposal.
Vegetable oils	Vegetable oils, or vegetable fats, from the seeds, nuts, or fruits of plants.

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An aerial perspective captures a coconut tree plantation in Ratchaburi, Thailand,
by AUUSanAKUL+, 2019, Adobe Stock.

1

Introduction

1.1 The IUCN Oil Crops Task Force

The IUCN Oil Palm Task Force was established to implement the IUCN Resolution 61: “Mitigating the impacts of oil palm expansion and operations on biodiversity”, adopted at the IUCN World Conservation Congress in Hawai‘i, in September 2016. The Resolution requested key deliverables for the Task Force, “building upon existing studies focused on the impacts of palm oil expansion and operations on biodiversity, land use planning and best practices”. Following the publication of its high-impact study on Oil Palm and Biodiversity in 2018 [11], the group was renamed the ‘Oil Crops Task Force’, recognising the need to examine oil crops more broadly. With this name change, the Task Force also took on a broader mandate of looking at other impacts in addition to those on biodiversity.

Using the latest scientific information, the Oil Crops Task Force will give guidance to the IUCN and others concerning vegetable oils. Making use of IUCN’s extensive knowledge base, the Task Force also seeks to comprehensively guide thinking on the complex issues of agro-industrial and smallholder vegetable oils production, trade, and consumption.

The Task Force seeks to inform and foster inclusive decision-making processes that fully engage Indigenous peoples, local communities, and other stakeholders. It also provides technical guidance to strategies for appropriate land-use planning at landscape, national, and regional levels, while considering environmental, regulatory, and local rights concerns.

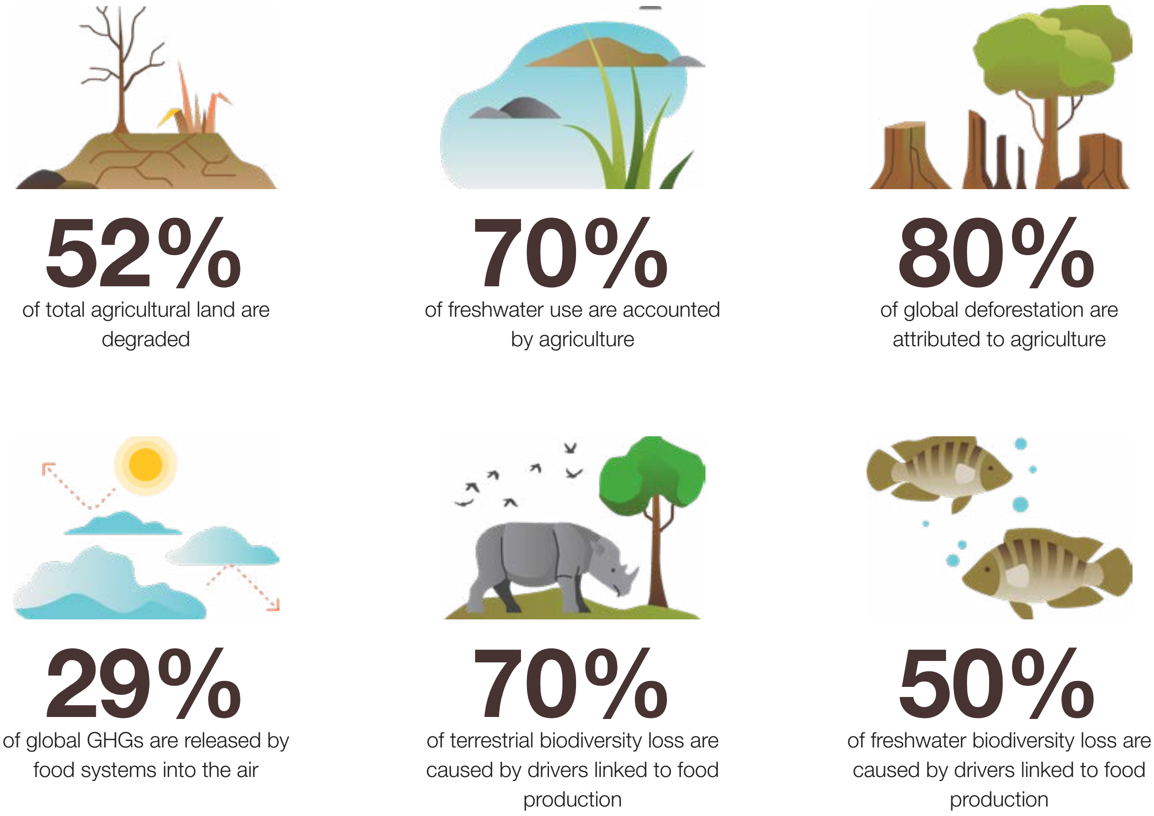
In 2021, the Terms of Reference for the Oil Crops Task Force were updated to balance biodiversity concerns with other social, economic and environmental impacts. This required the consideration of the Sustainable Development Goals and other relevant international standards, such as those related to human rights. This revised mandate expanded on the key objectives of Resolution 61 to include all major oil-producing crops and identifying conditions for sustainable and responsible production of all major oil crops.

1.2 The Sustainable Nutrition Scientific Board

The Sustainable Nutrition Scientific Board is a research team brought together to investigate sustainable nutrition. Composed of international scientific experts from different disciplines, the group has a broad science-based perspective. Its members are leaders in the environmental, nutritional, health, and epidemiological sciences, who collaborate in the fields of health, environment, nutrition, big data and artificial intelligence.

> “The Oil Crops Task Force Force also seeks to comprehensively guide thinking on the complex issues of agro-industrial and smallholder vegetable oils production, trade, and consumption.”

The environmental impacts of food production



52% of total agricultural land are degraded

70% of freshwater use are accounted by agriculture

80% of global deforestation are attributed to agriculture

29% of global GHGs are released by food systems into the air

70% of terrestrial biodiversity loss are caused by drivers linked to food production

50% of freshwater biodiversity loss are caused by drivers linked to food production

Figure 5 Current impacts of all food production on nature. Source: Prepared by the report editors, adapted from UNCCD (2022) [12].

1.3 The impact and importance of vegetable oils: a comprehensive analysis

Agricultural expansion is a major driver of biodiversity loss and climate change (Figure 5), but remains necessary for food production and numerous other goods and services. We focus here on vegetable oils (Box 1), an important component of both agricultural expansion and a source of nutrition, industrial feedstocks, and fuel. Steering future vegetable oil production, trade, processing, and consumption into a direction that causes fewer negative social, environmental, and health impacts represents an important contribution towards goals for human rights, biodiversity, climate, chemical use, and sustainable development. Our current study has limitations. For example, we are missing many local and small-scale production systems. These include, for example, subsistence systems that have not been the subject of in-depth investigation.

Box 1

What are vegetable oil crops?

Supplies and consumption of oils and fats are generally described in terms of seventeen commodity oils. Of these, four derive from livestock (animals) while 13 derive from plants. Here we focus on plant-derived oils and fats (referred to as ‘vegetable oils’). This selection excludes cocoa butter with an annual production of around 1.7 million tonnes, which is used nearly exclusively in making chocolate. Nor does it include oils consumed in the form of nuts (such as tung nuts, almond, walnut) or grains. Production and trade data relate primarily to crops grown and harvested for the oils that they contain (such as palm, rape, and sunflower) or for which oils represent a significant byproduct (such as cottonseed, soybean, and maize/corn).

Nonetheless, our research indicates various patterns. For example, many oil crops are associated with high usage of fertiliser, pesticides, fungicides, and herbicides, the use of which has implications for both the environment and human health. Another example is the prevalence of negative social impacts on rural communities in contexts where governance is weak and industrial-scale systems concentrate power in the hands of a few.

We identified the socio-economic, environmental, and health impacts of different vegetable oil crops and sought commonalities and differences. We focused primarily on oil palm, soybean, rapeseed, and sunflower, but also looked at groundnut, maize, cotton, coconut, linseed, and sesame, as well as oils that are increasingly seen in global markets such as shea.

Our analysis has revealed recurrent patterns which are often more related to the scale and type of vegetable oil systems rather than the crops used in these systems. For example, the impacts of industrial-scale oil palm and soybean are more alike than industrial-scale oil palm in Southeast Asia and subsistence oil palm in West Africa.

There are no inherently good or bad crops, but there are better and worse ways to produce, trade, or use them. Recognising this, we focus more on systems of production (Figure 6), rather than the crops.

For the different systems, we synthesise what is known and what we need to know for a better future. Where the data are clear, we summarise what to avoid, what to seek, and where better solutions may occur.

Vegetable oil systems

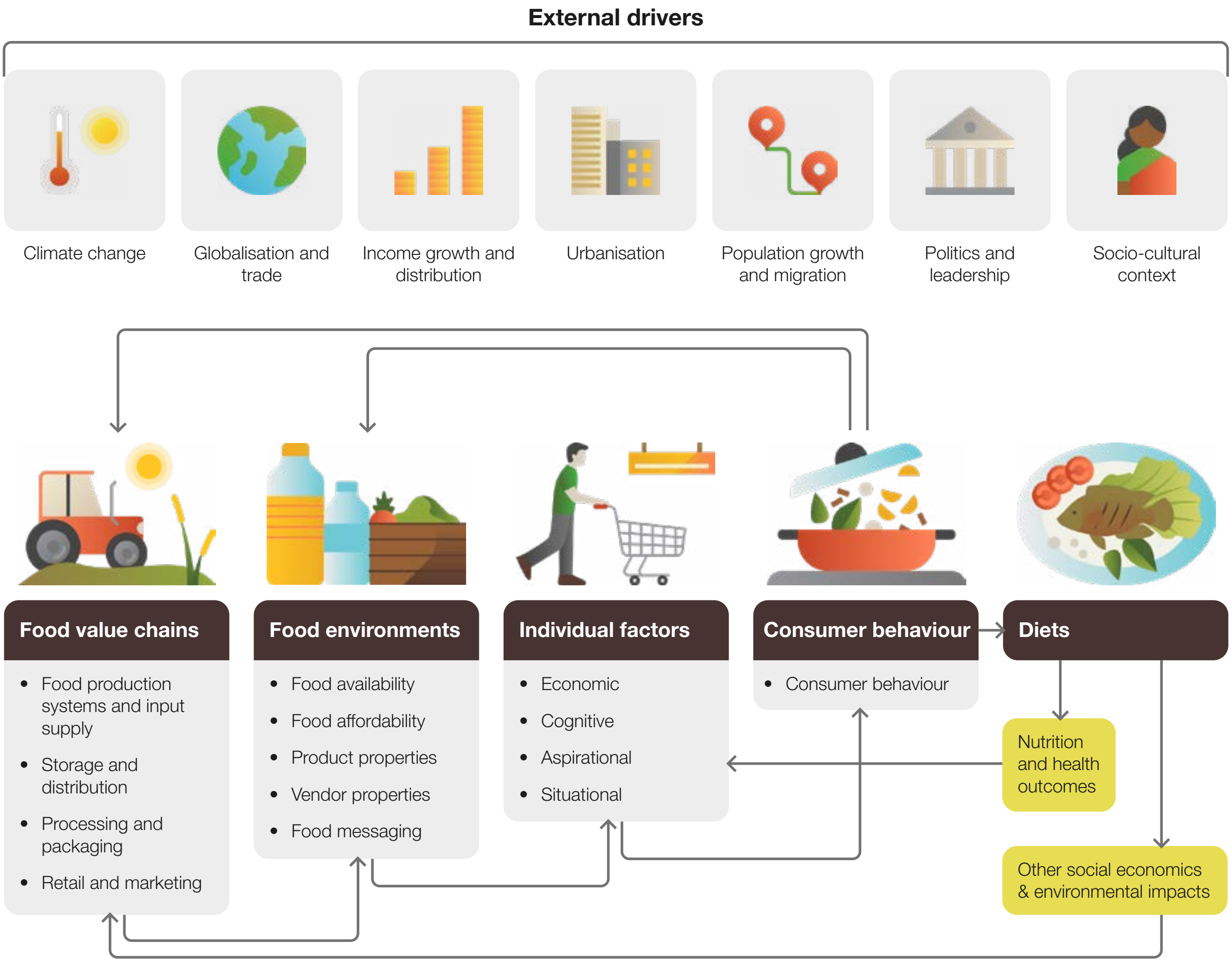


Figure 6 A conceptual framework for vegetable oil systems. Source: Prepared by the report editors, adapted from Marshall et al. (2021) [13].

1.4 Vegetable oils and international agreements

This report was developed in the context of global governance frameworks across fine thematic areas: biodiversity, climate change, human rights, sustainable development, and responsible use of chemicals. Considering the pressing challenges posed by biodiversity loss and climate change, the fundamental frameworks established to address these issues serve as essential pillars. To ensure the future resilience of global vegetable oil production, it is imperative to align governance strategies with the principles outlined in these agreements. Recognising the inherent interconnectedness between climate and biodiversity goals, a 'twinning' approach is needed within the realm of effective governance, fostering synergies between efforts aimed at both aspects.

Furthermore, the preservation of human rights and socio-economic well-being emerges as a pivotal concern that demands attention. An awareness of international legal requirements on human rights is essential. These are set out by the UN and the International Labour Organization (ILO) in various Declarations and Conventions developed since 1948. An exploration of voluntary standards is also warranted, including the UN Guiding Principles on Business and Human Rights and the Sustainable Development Goals (SDGs), as these frameworks encompass critical dimensions that must be addressed in the pursuit of holistic governance.

A central point of convergence across these considerations is the responsible utilisation of chemicals in agriculture. The judicious use of chemicals holds significant implications for sustainable practices across climate, biodiversity, and human rights fronts.

THE KUNMING-MONTREAL GLOBAL BIODIVERSITY FRAMEWORK. At the end of 2022 this framework was adopted with major goals for curbing biodiversity loss towards 2030 and 2050. Among these goals is that biodiversity should be sustainably used and managed while maintaining and enhancing nature's value to people. It also includes a '30/30 target': by 2030, 30% of the Earth's surface of land and sea should be protected.

> "Recognising the inherent interconnectedness between climate and biodiversity goals, a 'twinning' approach is needed within the realm of effective governance, fostering synergies between efforts aimed at both aspects."

THE PARIS AGREEMENT, established on 12 December, 2015, during the UN Climate Change Conference (COP21) in Paris, is a legally binding international treaty designed to combat climate change. It gained enforcement on 4 November, 2016, with participation from 196 Parties. The primary objective is to cap the global temperature rise at under 2°C above pre-industrial levels and strive for 1.5°C. To achieve this target, global emissions must peak by 2025 and decrease by 43% by 2030. The Paris Agreement is notable for uniting nations and focusing on adapting to climate effects, necessitating transformations rooted in scientific knowledge.

THE UN GUIDING PRINCIPLES ON BUSINESS AND HUMAN RIGHTS are grounded in the recognition of:

- A States' existing obligations to respect, protect and fulfil human rights and fundamental freedoms;
- B The responsibility of business enterprises as specialised organs of society performing specialised functions, required to comply with all applicable laws and to respect human rights; and
- C The need for rights and obligations to be matched to appropriate and effective remedies when breached.

These Guiding Principles apply to all States and to all business enterprises, both transnational and others, regardless of their size, sector, location, ownership and structure. They are underpinned by existing international and national laws on protecting human rights. In the case of vegetable oils, they should translate into respect for local laws, for the rights of landowners and land users, surrounding communities, plantation and farm workers, and workers further upstream in the value chain. Mandatory as well as voluntary standards should take all these issues onboard.

THE SUSTAINABLE DEVELOPMENT GOALS (SDGS) are 17 United Nations-defined societal-environmental, social, and economic goals that should ideally be targeted in combination. However, they are prone to competing objectives and are not mandatory, which can lead to poor compliance. Vegetable oils are important for achieving no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), and, in the form of biofuels, may play a role for clean energy (SDG 7). Furthermore, the sustainable management of vegetable oil production is important for decent work and economic growth (SDG 8), responsible consumption and production (SDG 12), all the biospheric SDGs (6, 13, 14, 15), and the equality related SDGs (5 and 10). The SDGs can, therefore, serve as a checklist for vegetable oils policy rather than a framework.

CHEMICALS TREATIES: MONTREAL, STOCKHOLM, AND ROTTERDAM CONVENTIONS. Hazardous pesticides have far-reaching environmental and health implications, impacting biodiversity and leaving food tainted with residues that endanger consumers. These threats extend to farming and nearby communities. Global governance of these chemicals is guided by three key treaties: the 1987 Montreal Protocol, the 1998 Rotterdam Convention, and the 2001 Stockholm Convention. The Montreal Protocol and Stockholm Convention prohibit the production, use, and trade of listed pesticides. In contrast, the Rotterdam Convention operates a ‘prior informed consent’ procedure, allowing parties to decline imports of pesticides under the treaty.

⟶ *A Congolese woman processing palm oil for food consumption and soap manufacturing,* by MONUSCO Photos, 2015, Flickr.

→ *Photos from the one-week workshop where key narratives of the report were decided,* by Abiyasa, 2023.

1.5 Methodology

A team of experts selected for their geographic or thematic knowledge on vegetable oils were invited to be lead authors. This core team drew on their networks of contacts to bring in additional expertise to join or contribute to the fact finding and writing. Authorship of the full report or individual chapters was decided based on the amount of input provided.

Between January and November 2023, we reviewed available publications and literature related to vegetable oils. Because of the complex nature of the topic and the often-qualitative nature of the claims and evidence, we used a non-systematic literature review with narrative synthesis to generate insights about vegetable oils [14]. More details on the analyses conducted for the current study are provided in the Appendix.

We consulted 25 vegetable oil experts working in government, private sector, non-government, and research sectors. Initial results from the literature review and expert consultation were discussed during a one-week workshop in June 2023, when key narratives and the structure of the report were decided. At the workshop, we also developed draft infographics for facilitating interpretation of key concepts in the text. Our illustrator and designer was closely involved from the start of the writing process and present at the workshop.

The draft report underwent rigorous review processes before publication, facilitated by the IUCN Secretariat. Internal reviews were initially conducted by members of the Task Force and the Sustainable Nutrition Scientific Board to ensure that the report's findings were accurate and aligned with the Task Force's mandate. Additionally, the final draft was subjected to external double-blind peer review by three experts who provided valuable feedback. The authors' responses to this feedback are publicly available on the Oil Crops Task Force's website.

⟶

Oils and fats are essential to most food preparations, by U2M Brand, 2020, Adobe Stock.

2

Vegetable oils, their global importance and key sustainability issues

⟶ *Culinary traditions across the globe use oils and fats to enhance the flavour and texture of dishes*, by Mahi, 2020, Adobe Stock.

2.1 Background

2.1.1 Why use oils and fats?

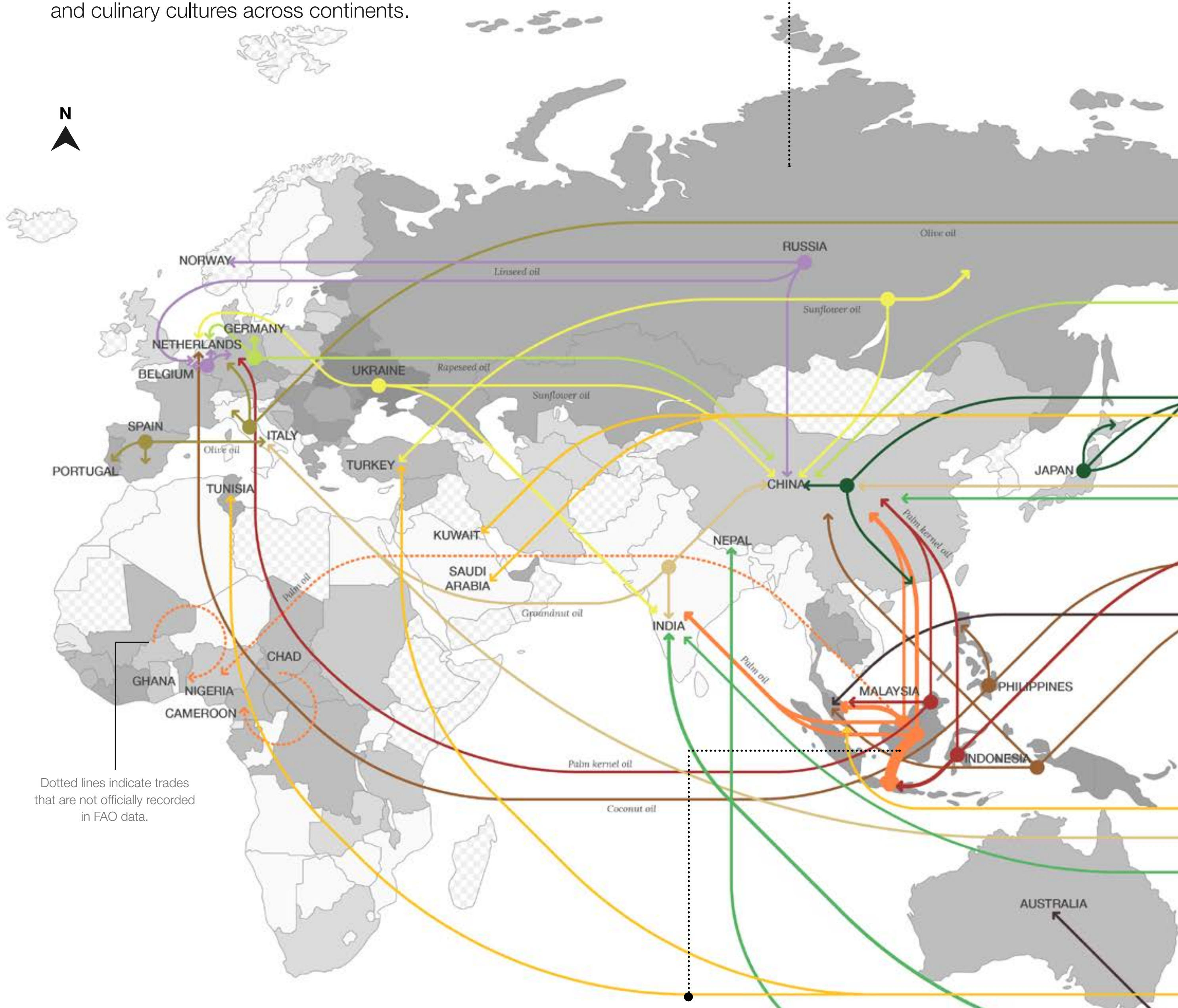
Oils and fats play an important role in our daily lives. They are present in a wide range of food and non-food products, including cosmetics, animal feed, and biofuels. The global demand for oils and fats is facilitated by advancements in extraction, refrigeration, and preservation techniques, enabling the widespread trade of oilseeds and kernels (Figure 7). Soybeans, for example, surpassed wheat as the most valuable traded agricultural commodity in 2002, while palm oil's export value ranks third and is steadily approaching wheat's level. Consequently, the decisions made by oils and fats traders and food manufacturers regarding the choice of oil are not solely based on domestic factors such as production, demand, or income. Instead, these decisions are influenced by myriad factors, including consumer preferences, food culture, trade policies, global price fluctuations, desired product attributes, and the possibilities of modification. To comprehend the social and environmental impact of oils and fats, it is essential to understand their characteristics, applications, and interconnectedness. This chapter delves into the basics, exploring the nature and functions of oils and fats.

Global oil trade routes: imports and exports

Vegetable oils traverse the globe in a complex dance of export and import, linking agricultural landscapes and culinary cultures across continents.

by Pixel-Shot, 2020, Adobe Stock

RUSSIA
The leading exporter of sunflower oil.



Dotted lines indicate trades that are not officially recorded in FAO data.

Import and export routes

Note: the line thickness provides a rough indicator of export volumes, with Indonesia leading as the largest vegetable oil exporter with palm oil, followed by Brazil with soybean oil.

- ▬ Palm oil
- ▬ Palm kernel oil
- ▬ Soybean oil
- ▬ Rapeseed oil
- ▬ Sunflower oil
- ▬ Olive oil
- ▬ Cottonseed oil
- ▬ Groundnut oil
- ▬ Maize oil
- ▬ Coconut oil
- ▬ Sesame oil
- ▬ Linseed oil

by nelzajamal, 2017, Adobe Stock

INDONESIA & MALAYSIA
The two biggest export markets of palm oil, specialising in crude palm oil and palm kernel oil production.

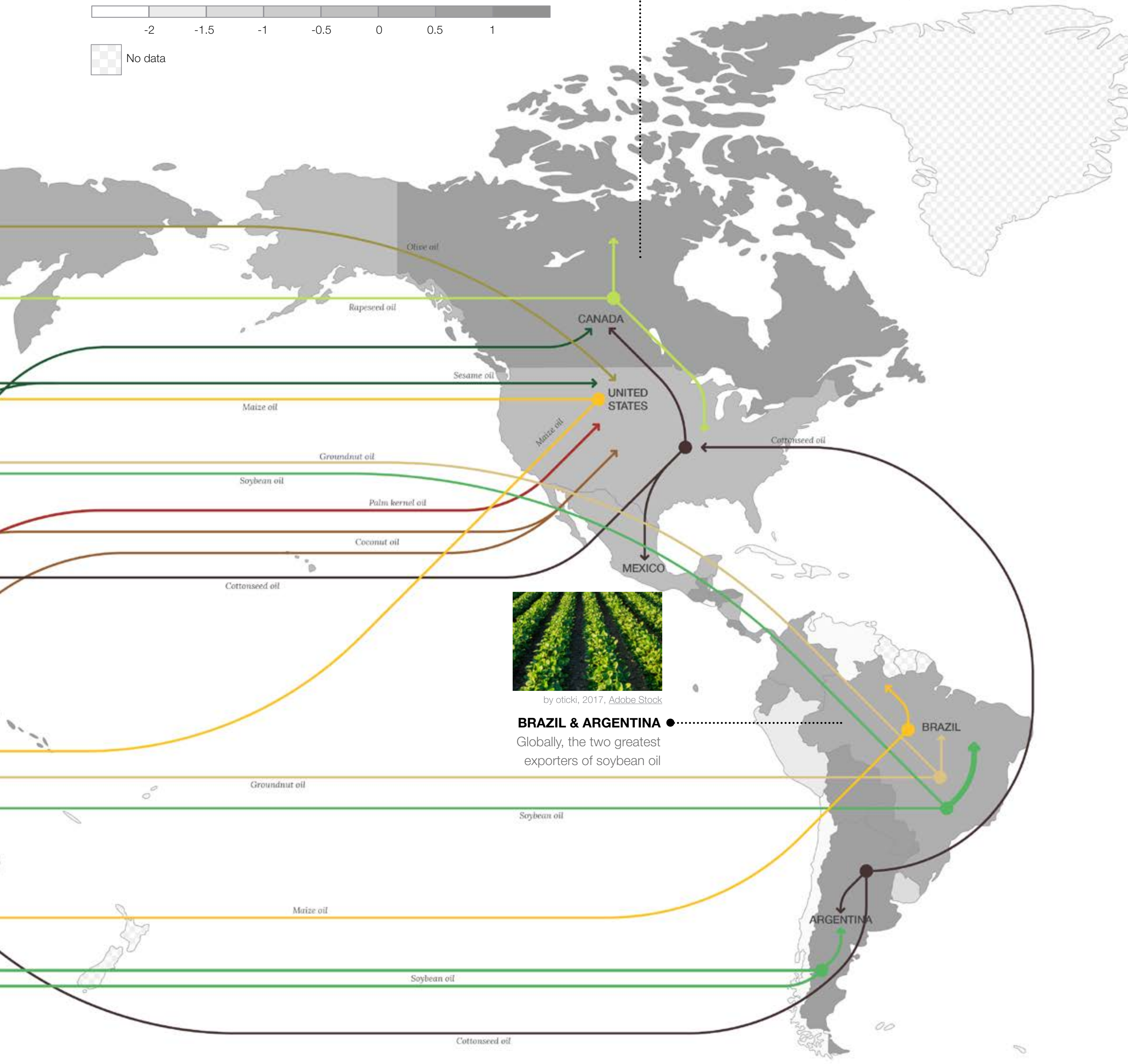
Figure 7 The global trade in vegetable oils in 2023. Source: Data compiled by the report editors from [15]; for details see Appendix.

Domestic disappearance

Countries with values approaching 1 represent major oil producers focused primarily on export markets. Those with values near 0.5 are also active exporters but allocate a significant portion of their production to meet domestic demand, approximately half. Countries around the 0 mark match their production closely to domestic consumption. Conversely, nations with values below -1 stand as net importers, needing to bring in more oils than they produce to satisfy their domestic needs.

by doris oberfrank-list, 2018, Adobe Stock

CANADA
The dominant exporter of rapeseed oil.



by oticki, 2017, Adobe Stock

BRAZIL & ARGENTINA
Globally, the two greatest
exporters of soybean oil

2.1.2 Defining oils and fats

All vegetable oils and fat molecules share the same structure (Box 2). By combining different types of fatty acids, multiple varieties of oils and fats can be created, each possessing properties suited for various applications. While food technology allows for the interchangeability of oils and fats, certain uses rely on specific oils. For example, cocoa butter equivalents need to mimic cocoa butter's rapid melting and cooling sensation in the mouth without melting when held in hand, a property found in coconut, palm kernel oil, or certain palm oil fractions.

Different types of fatty acids in oils and fats are not limited to specific oil crops. They can be found across various origins, such as beans, seeds, or fruits, with different densities [16]. This presents opportunities for interchangeability and diverse sourcing options. However, no single vegetable oil or fat can fulfil all desired properties for food or non-food applications. To achieve oils and fats with specific fatty acid profiles, blending different vegetable oils and fats is a common practice [17]. For instance, in the production of potato chips through deep frying, the stability of saturated fatty acids is advantageous, but consumer preferences lean towards unsaturated fats. Combining more saturated palm oil with unsaturated canola oil in a 1:1 ratio creates a stable blend with improved nutritional value, outperforming individual oils [18]. Consequently, potato processing companies in Europe source domestically produced canola while also relying on imported palm oil.

Box 2

Triglycerides: the oils and fats molecules

Every plant contains oils and fats that exist either as 'liquid' oils or 'solid' fats based on room temperature. Fatty acids bound in triglycerides are the dominant components of vegetable oils, while other substances like mono- and diglycerides, free fatty acids, phosphatides, sterols, fatty alcohols, and fat-soluble vitamins contribute to oil quality in smaller quantities.

Triglycerides are energy-storage molecules (especially in seeds and fruits). Oils and fats contain a higher proportion of energy-rich carbon-hydrogen bonds – 9.1 kilo calories (kcal) per gram compared to 3.8 kcal per gram of carbohydrate and 3.1 kcal per gram of protein [19].

The organisation and nature of triglyceride molecules gives rise to unique chemical and physical properties, including melting points, smoke points, and oxidative stability. This wide range of fatty acid compositions makes oils and fats highly versatile and desirable for various food and non-food applications.

2.1.3 The history of oil production and use

Vegetable oils have a long history. Ancient Egyptians used castor oil and sesame oil for cooking and as a cosmetic [20], palm oil use dates back to at least 8,000 years ago in West Africa [21], olive oil was used in the Middle East around the same time [22], and Sumerian sources from 2100 BC referred to the use of cedar oil [23]. During the Middle Ages, vegetable oils became more widely used in Europe, increasingly replacing animal fats, particularly in the Mediterranean region where olive oil became a staple [24].

With the expansion of trade and colonisation after the 17th century, new sources of vegetable oils became available to consumers in Europe and the U.S., such as palm oil from West Africa and coconut oil from Southeast Asia.

⟶ *Ancient Egyptians utilised castor oil, derived from castor beans, for culinary and cosmetic purposes,* by sommai, 2015, Adobe Stock.

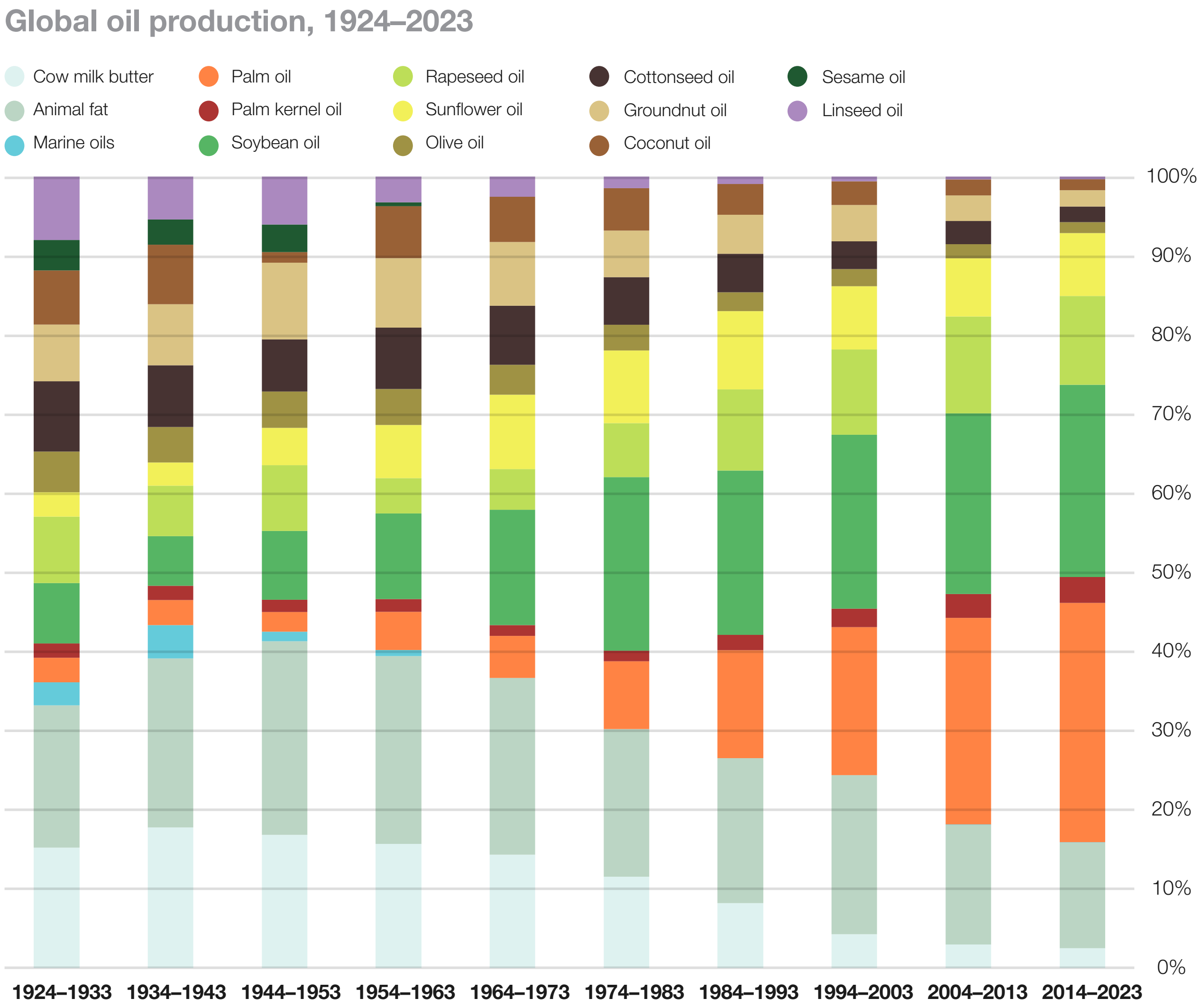


Figure 8 Relative contribution of different oils and fat sources to total global production over the past 100 years. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

For example, in the 1930s, groundnut for oil production in Europe and the U.S. accounted for two-thirds of Senegal's agricultural exports and 100% of Gambia's, while two-thirds of Nigeria's export consisted of palm oil nuts, and half of Manchuria's export was soybean [25]. The Industrial Revolution in the 18th and 19th centuries brought about new methods of extracting vegetable oils, such as solvent extraction and hydraulic pressing. These methods increased the efficiency of oil extraction and made it possible to extract oils from a wider range of crops, such as soybean, rapeseed, and sunflower. These vegetable oils increasingly replaced animal fats (such as lard and tallow) and marine oils (such as whale oil), ultimately resulting in the current domination of palm oil and soybean oil (Figure 8).

Our ancestors were dubbed 'fat hunters' [26] for good reason. We need fat. About 25–35% of adult daily energy needs in a normal modern healthy diet comes from fats [27-29]. Nearly 80% of the fats produced for human consumption are derived from oil crops, for which global production is currently around 208 megatonnes (Mt) of oil [30]. The remaining fat production derives from animal fats, of which dairy accounted for 46 million tonnes in 2019 [31], with the production of additional animal fats from lard and tallow amounting to 6 and 7.3 million tonnes, respectively [15]. Due to the high energetic costs of transforming plant material into animal material, more land is needed to produce animal fat than the same amount directly from plants, also because many domestic animals feed on oil crops (see Chapter 2.3.2). Animals do not only eat oil crops, but also consume plants such as grasses not normally eaten by people. There is a debate around the extent and conditions under which the production of animal fats and vegetable oils compete, with much depending on the particular production systems compared [32]. This debate is important because it concerns large areas of land (Figure 9).

These crops serve multiple purposes beyond oil production, and their respective oils have various applications. Soybean oil finds its primary use in the food industry for cooking, frying, and baking, but is also used in biodiesel production. Palm oil has the highest production volumes globally of all vegetable oils and features in a wide range of food products, including margarine, chocolate, instant noodles, and baked goods, while also being used in soaps, detergents, personal care items, and biodiesel. Canola, known for its neutral flavour and high smoke point, is popular for cooking and baking and is also utilised in biodiesel production. Sunflower oil is a common cooking oil and is employed in the production of margarine, other food products, and biodiesel. Olive oil, a traditional Mediterranean cooking oil, now enjoys global use as a premium culinary oil and is utilised in the production of cosmetics and soaps. Corn oil is mainly used in the food industry for frying and baking, as well as in biodiesel production. Alongside these primary vegetable oil crops, there are other crops like cottonseed and coconut, which produce smaller amounts of vegetable oil, but there are hundreds of other plant species that produce oils, which are often harvested and consumed locally only (for some examples, see Table 1). Each type of vegetable oil boasts unique properties and applications, making them indispensable components of the global economy, local cultures, and modern society.

Global land use for vegetable oil crops

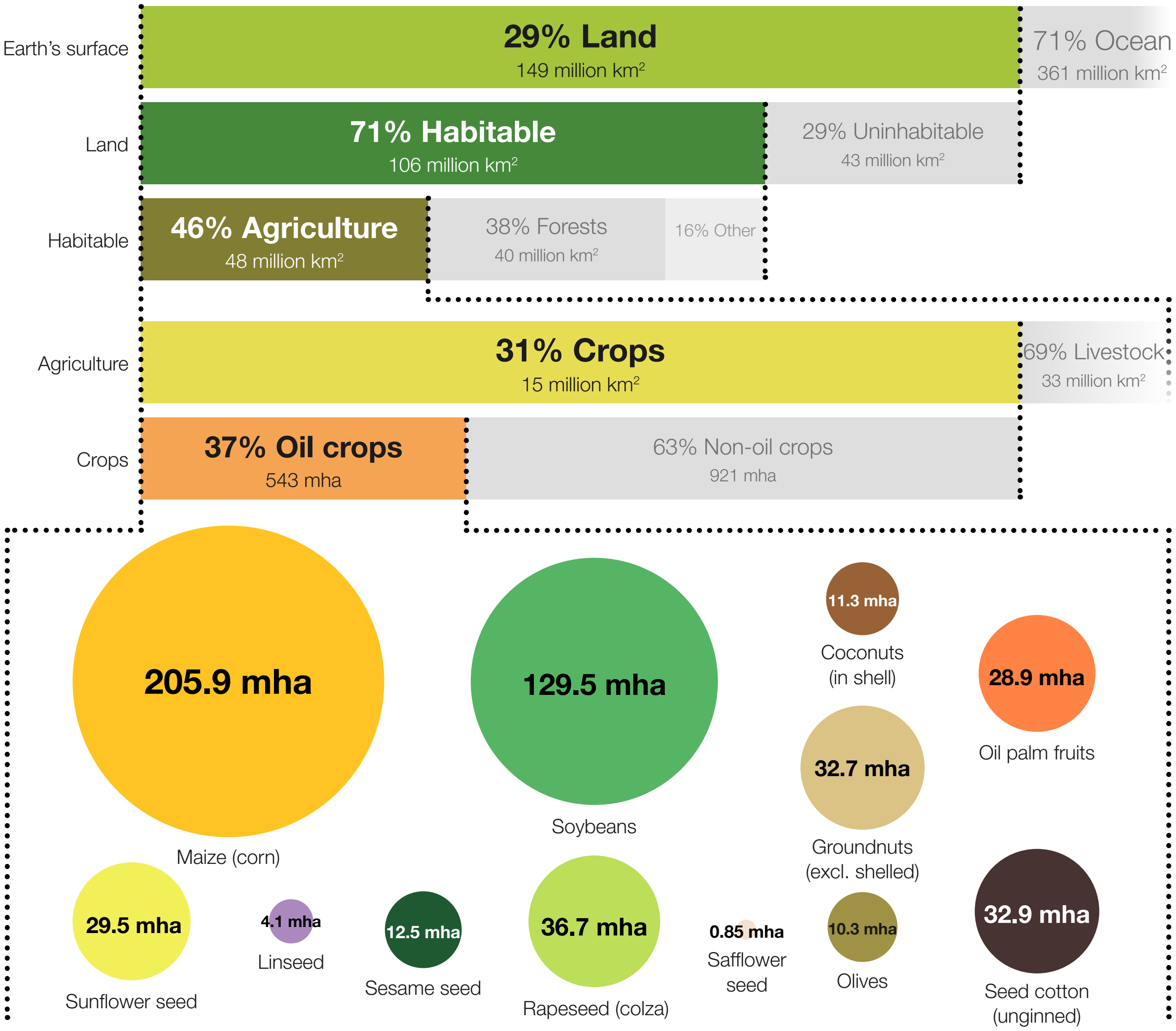


Figure 9 Allocation of global land to agricultural, cropland, and major oil crops. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

2.2 Oil crop fundamentals

2.2.1 Ecology of oil crops

There are important differences between oil producing plants. These plants have different forms and growth characteristics which influence sustainability. For example, peanut and soybean plants are nitrogen fixing, which means that growing them brings nitrogen into the soil, contributing to soil fertility (Table 1). Other oil crops are perennial trees, of which some, such as the Bornean *Shorea stenoptera* (tengkawang nut), are long-lived forest trees, while olive and walnut can grow for centuries in more open landscapes [33]. Such long-lived trees provide ecological functions in landscapes, for example, nesting holes for birds, and stands of such trees would generally be classified as 'forest', although olive groves are not (Box 3). Other oil crops include palms, some of which can be long-lived (at least up to 180 years in oil palm [34]) and provide more diverse ecological structure in landscapes than annual crops do.

Table 1 Different growth forms and plant characteristics of selected oil producing plants and whether these would be defined as 'forest' according to the FAO in their most common production context (for example, naturally occurring, plantation). For FAO forest definition see Box 3.

Perennial			**Annual**	
Tree (dicotyledon)	**Palm (monocotyledon)**	**Shrub or climber**	**Nitrogen-fixing**	**Not nitrogen-fixing**
Normally included in FAO forest definition		• Cotton/*Gossypium* spp. • Grapeseed/*Vitis vinifera* L.	• Peanut/*Arachis hypogaea* L. • Soybean/*Glycine max* (L.) Merr.	• Canola/rapeseed/*Brassica napus* L. • Castor/*Ricinus communis* L. • Corn/*Zea mays* L. • Safflower/*Carthamus tinctorius* L. • Sesame/*Sesamum indicum* L. • Sunflower/*Helianthus annuus* L.
• *Allanblackia* spp. • Brazil nut/*Bertholletia excelsa* Bonpl. • Shea/*Vitellaria paradoxia* • Illipe/*Shorea stenoptera* Burck • Walnut/*Juglans regia* L.	• Açaí/*Euterpe oleracea* Mart. • Buriti/*Mauritia flexuosa* L.f. • Tucumã/*Astrocaryum vulgare* Mart			
Normally not included in FAO forest definition				
• Olive/*Olea europaea* L. • Cocoa/*Theobroma cacao* L. • Avocado/*Persea americana* Mill.	• Oil palm/*Elaeis guineensis* Jacq. • Coconut/*Cocos nucifera* L.			

Source: Data compiled by the report editors.

Box 3

Why oil palm plantations and olive orchards are not forests

The Food and Agricultural Organization of the United Nations (FAO) defines forest as "land spanning more than 0.5 ha with trees higher than five metres and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use." [35] The definition's explanatory notes [35] clarify that forests include abandoned shifting cultivation land, areas with mangroves in tidal zones, rubber-wood, cork oak, and Christmas tree plantations. The forest definition also includes areas with bamboo and palms if the land use, height, and canopy cover criteria are met. It specifically excludes areas of trees in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards, and agroforestry systems when crops are grown under tree cover. While FAO provides a foundational definition of 'forest', there have been calls for better definitions that are purpose-built and contextualise the social and ecological aspects of forests [36, 37]. A level playing field – a situation that is fair for everyone – requires that we can all agree on what makes a forest [37, 38]. Such clarity is needed for zero deforestation commitments and the protection of natural ecosystems from conversion [39], even though the exact definition may depend on its purpose or target group, conservationists, foresters, or agroforesters may also have different views. An internationally agreed taxonomy of oil crops with regard to the FAO forest definition, based on their growth contexts (for example, wild vs plantation oil palm), would be helpful.

Annuals are sown, grown, and harvested within a year or sometimes several times per year, leaving bare soil intervals. The different growth forms and life cycles of oil crops have important ecological consequences as they determine the extent to which crops provide wildlife feeding, nesting, or dispersal habitat.

Whether oils are extracted from perennial or annual crops also has socio-economic implications. Palm or tree crops need to be planted and matured before harvesting. This means farmers need to wait several (sometimes many) years before they see a return on their investment, and may face high replanting costs when trees pass their productive lifespan. This is different from that of farmers of annual crops such as rapeseed, sunflower, or linseed, where decisions to plant the oilseed crop are based on shorter term agronomic and economic factors.

2.2.2 Where are oil crops grown?

The world's dominant oil crops have different distributions reflecting their requirements (Table 2). There is considerable uncertainty, however, about the areas producing oil crops. Only oil palm and coconut have been mapped at high resolution globally [40,41], although even those maps do not include mixed smallholder systems or subsistence production of these crops. Monoculture oil palm in 2019 was estimated at 21.00 ± 0.42 mha (72.7% industrial and 27.3% smallholder plantations) [40], while in 2020 coconut was estimated at 12.31 ± 3.83 x 106 ha for dense open- and closed-canopy coconut, but the estimate was three times larger (36.72 ± 7.62 x 106 ha) when sparse coconut (for example, between one and four coconut trees within the 20-metre pixel) was included in the area estimation [41]. These estimates are quite different from FAO statistics, and it is likely that growing areas for other oil crops also require revision. The areas provided in Table 2 should therefore be considered a rough estimation and unreliable. Estimating global cropland areas is notoriously difficult, especially for annual crops that are rotated, and FAO's reliance on national-level reporting is a known source of inaccuracies [42,43]. Figure 10 shows that the main growing areas of the vegetable oil crops with the largest production volumes (Figure 11) are concentrated in key growing regions: Central Plains of North America and southern Brazil and northern Argentina for soy, maize, and rapeseed; West Asia and Europe for sunflower, olive, and rapeseed; and South, East and South-East Asia for cottonseed, soybean, and oil palm.

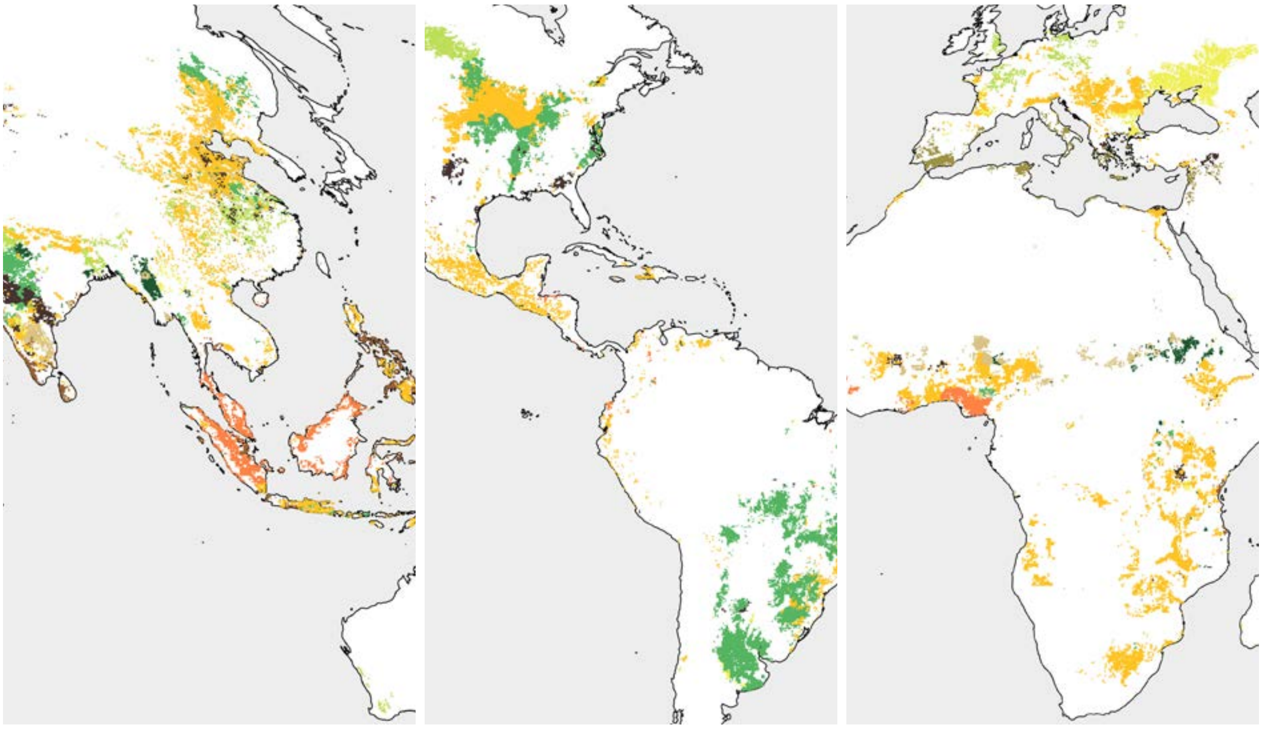
Oil palm and soybean produce by far the most seed (Figure 11) among all major oil crops in terms of production volumes, with cotton seed, rapeseed, coconut, sunflower, and groundnuts lagging well behind. Thus, most of the world's vegetable oil is produced in the tropics and subtropics.

Table 2 Main growing regions and climatic zones where the major oil crops are grown

Crop	Harvested area 2021 (ha) [15]	Main producer nations and region	Latitude	Climate
Maize	205,870,016	United States, China, Brazil	45° N to 45° S	Temperate & Sub-tropical
Soybean	129,523,964	United States, Brazil, Argentina	30° N to 45° S	Temperate
Rapeseed	36,773,580	Canada, China, Europe	30° N to 60° N	Boreal
Cottonseed	32,876,370	United States, India, China	30° N to 35° N	Tropical & Sub-tropical
Groundnut	32,720,960	India, China, United States	40° N to 40° S	Tropical & Sub-tropical
Sunflower	29,531,998	Russia, Ukraine, Europe	50° N to 45° S	Temperate
Oil palm	28,909,789	Indonesia, Malaysia, West Africa	2.5° N to 6° S	Tropical
Sesame seed	12,507,504	India, China, Sudan	35° N to 20° S	Tropical & Sub-tropical
Coconut	11,307,699	Southeast Asia, Pacific Islands, Africa, South America	35° N to 35° S	Tropical
Olive	10,338,179	Mediterranean Basin	30° N to 45° N	Mediterranean
Linseed	4,142,449	Europe, Canada, China	30° N to 60° N	Temperate

Source: Data compiled by the report editors.

Global distribution of main oil producing crops



Majority oil crop per 10 km² grid cell (crop coverage of >500 ha)

● Oil palm
● Soybean
● Rapeseed
● Sunflower
● Olive
● Cottonseed
● Groundnut
● Maize
● Coconut
● Sesame
● Linseed

Data sources: Global Spatially-Disaggregated Crop Production Statistics Data for 2010 version 2.0; Spatial Production Allocation Model (SPAM) 2010; International Food Policy Research Institute (IFPRI).

Figure 10 The global distribution of the main oil producing crops mapped at 10*10 km resolution and displaying the majority oil crop per grid cell. Source: Data compiled by the report editors. Crop data based on FAO and MapSpam statistics [44]. For methods see Appendix.

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Global production of oil crop seeds and fruits, 2020

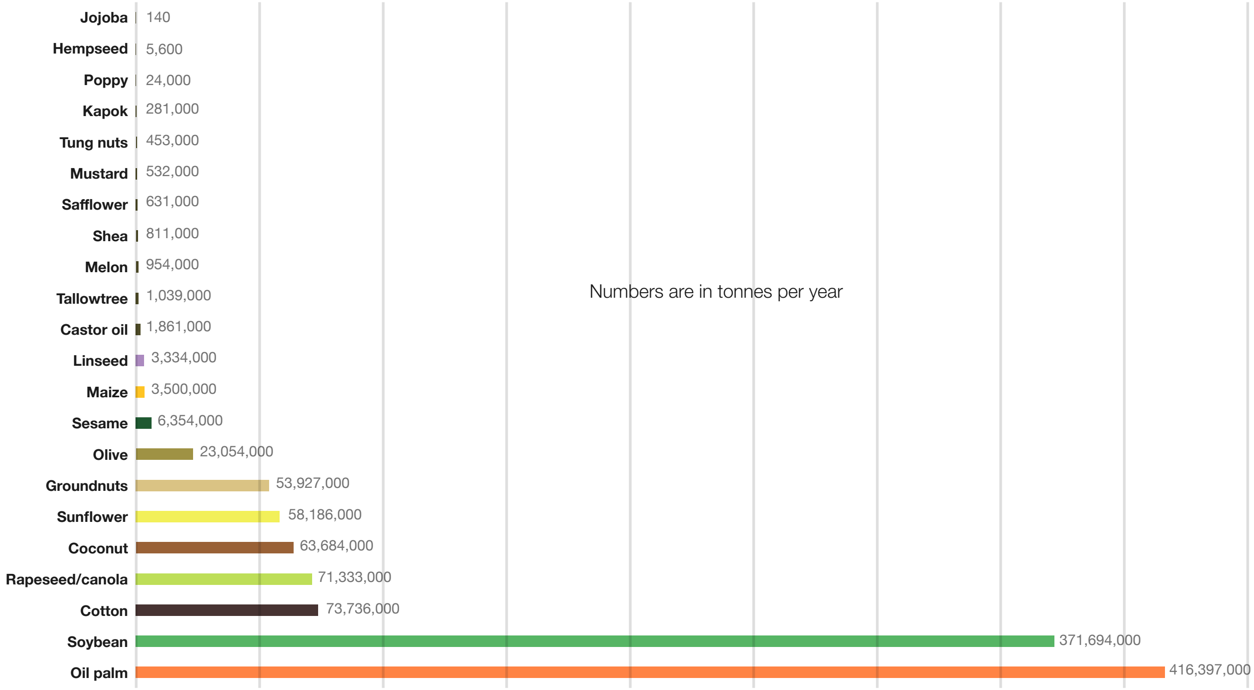


Figure 11 Global production of oil crop seeds and fruits in 2020. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

2.2.3 What were the major expansion phases of different oil crops?

There have been major shifts in global oil use and production in the past century (Figure 8). Animal fats have become less important, and several (such as whale oil) have largely disappeared. Coconut, groundnut, and cottonseed were important in the beginning of the 20th century but have become less dominant. In recent years, palm oil has become dominant, while soybean oil has also shown considerable growth. Other booms are not well reflected in global datasets such as FAOSTAT. Shea, for example, has long been locally produced and consumed in the Sudo-Sahelian savanna region of Africa [45], but the extent to which these local value chains are captured in international production and trade statistics is unknown. Similarly, chia, which is rich in omega-3 fatty acids, was a key component of both the Aztec and the Mayan diets but was subsequently largely forgotten until its recent rediscovery [46]. It is available as chia oil, but no publicly available trade statistics exist, either locally or internationally. This is a recurring theme. We know a lot about the oil produced for and traded on the international markets, but much less about locally produced and consumed oils that often play important roles in local food security, medicine, and more.

Historic production changes mean that each oil crop has had a different period of major expansion, with peanut and cottonseed plantations expanding earlier than other oil crops, possibly in the 18th century. The peanut is a legume native to South America that was extensively cultivated in tropical and subtropical regions of the Americas before European expansion into the New World. Indigenous peoples in the Americas were cultivating peanuts prior to the arrival of the Spanish and Portuguese colonists, who later brought the crop to Europe, Africa, Asia, and the Pacific Islands [47].

Discovering new oil crops was historically very important. A reported olive shortage in Europe in 1709 resulted in a search for new oil-producing crops, initially focusing on linseed and rapeseed produced in eastern Europe, but production and trade in other oil crops quickly followed [48]. In the early 20th century, France dominated the import of groundnut from its African colonies, Denmark was a major importer of soybean, England dominated the linseed market, and the Netherlands was the largest importer of coconut [48]. In the early 21st century, linseed and groundnut oils were the dominant oils in Europe (Figure 12), while linseed oil is currently of negligible importance (Figures 11 and 12).

The U.S. shows a slightly different pattern to Europe. Cottonseed oil has been used in the United States since 1768. Originally, it provided a substitute for whale oil in lamps, and as a machinery lubricant, rather than an edible oil. However, as the mid-1800s approached, cottonseed oil production began to increase. After the Civil War, the expansion of cotton cultivation led to a significant surge in cottonseed oil production, which eventually replaced lard as a common ingredient

Oil export value in the Netherlands

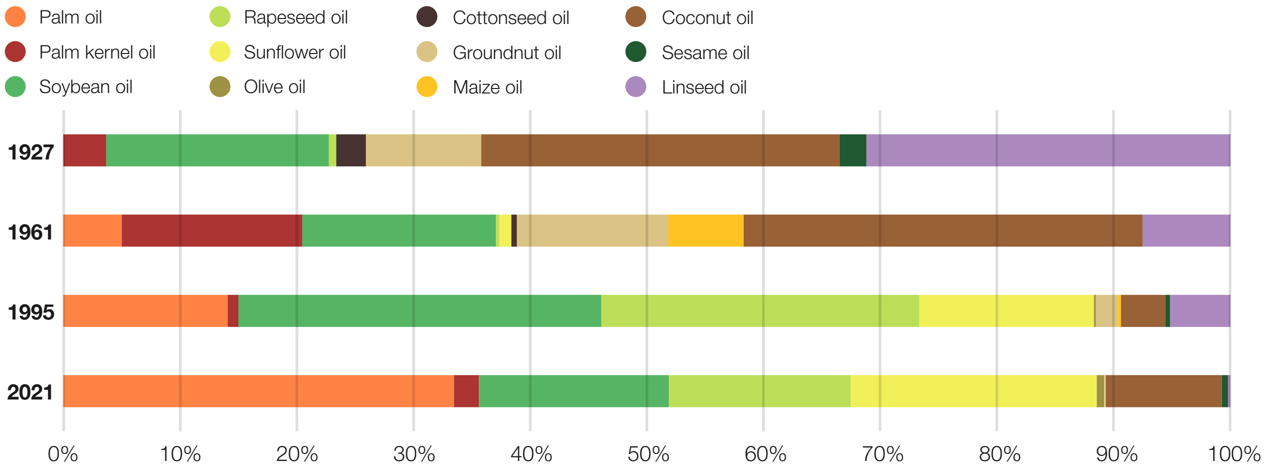


Figure 12 Export value of oils from the Netherlands in four different years as percentage of the total traded value in each year. Source: Data compiled by the report editors; 1927 data from [48] and 1961, 1995 and 2021 from [15].

in baking and frying. By 1911, cottonseed oil was commercially produced, and it became the dominant edible oil in the US by the 1950s.

In Southeast Asia and the Pacific, coconut has been a significant crop for a prolonged period and is essential to the local economy and culture. It has been claimed that coconut was the most dominant economic force in recent Oceanic history [49]. This is not only true for major producers such as the Philippines, India, and Indonesia but also for smallholders in the Pacific Islands, where coconut palms are important parts of their livelihoods. Coconut products became significantly important in the 19th century and large areas of tropical land, especially on islands, were opened up for coconut production, gaining the name 'the Coconut Zone' [50]. Coconut's recent rediscovery as an alleged health product has again boosted its production. The Asia-Pacific region is still responsible for producing about 90% of the world's coconut supply [51], but consumption in the region has switched from coconut to palm oil [52].

Major expansion of most oil crops started in the 1950s, coinciding with a global rise in vegetable oil demand. Quickly, oil palm and soybean dominated the market (Figure 12). Early industrialisation of oil palm started in Africa in the late 19th and early 20th century [53]. Until the 1960s, Africa cultivated more than 95% of the world's oil palm. From the mid-1970s onwards, there has been a notable surge in oil palm output, propelled by a growing demand for vegetable oils, especially in Southeast Asia. Conversely, the growth of oil palm cultivation in Africa has been restricted due to political instability and inadequate support from governments and private stakeholders [54].

Soybean, the second-largest oil crop, originated in China and is the world's largest source of protein for animal feed and second largest vegetable oil source after oil palm. In 2021, the global production of soybeans was double that of 2000 and over four times more than in 1980. Over 50% of the world's soybean production is currently located in South America, with Brazil and Argentina observing a 160% and 57% increase in harvested soybean areas since 2000, respectively [55]. Rising trade tensions between the United States and China are anticipated to drive China towards the South American market for imports, which could encourage further deforestation. Across South America, the land sources of the soybean expansion, either from cropland, primary forest, non-primary forest, or pasture/grassland, vary across biomes, but soybean expansion generally takes places in areas of high biodiversity value [56].

⟶ *Coconut oil is a key component of Fijian cuisine and cultural practices*, by Orion Media Group, 2019, Adobe Stock.

Box 4

India taking off as major palm oil consumer and increasingly producer

India is a significant player in the production, consumption, and import of edible vegetable oils, and is the second-largest consumer of palm oil after Indonesia [57]. However, palm oil production in India remains relatively low, forcing the nation to rely on export markets to satisfy national demand. During the COVID-19 pandemic, major trade disruptions, such as Indonesia's decision to halt palm oil exports to address its domestic oil crisis, coupled with issues like conflicts and crop failures in other major producing countries, led the Indian government to rethink its reliance on external sources of palm oil.

Recognising the vulnerability of depending on external sources, India swiftly identified the pressing need to establish self-reliance in the field of edible oils. This prompted a strategic plan to transform the northeast Indian region into a thriving 'hub of oil palm', backed by a substantial government budget of US$ 1.4 billion [58]. Despite its potential benefits, this move has ignited debates and controversies within the region. Northeast India, known as a global biodiversity hotspot, holds one third of India's rainforest and is home to diverse tribal communities, who depend on the natural resources for their survival, such that oil palm is likely to limit or reduce their access to traditional resources. Incidentally, this region has been grappling with rapid deforestation due to unsustainable agricultural practices and poorly regulated developmental projects [59].

Despite the ecological and socio-economic concerns, several states in the region are rushing to implement the 'National Edible Oil Mission-Oil Palm' [60]. The urgency of achieving self-sufficiency in oil production is driving these actions, often without considering the potential repercussions.

In the context of Indian agriculture, oil crops play a crucial role. For instance, in 2022, India produced 11 million tonnes of rape oilseed, contributing to 12.5% of global production that year. Similarly, 12 million tonnes of soybean and 10 million tonnes of cotton oilseed were produced, with the latter constituting 25% of global cotton oilseed production. Despite this importance, the Indian government's support for oil crop production has been limited. Unlike the substantial policies governing cereal production and trade, oil crops lack similar attention and regulatory support. For instance, policies like minimum pricing and subsidised storage facilities are in place for cereals, but no such measures exist for oil crops.

One of the underlying reasons for this disparity is the fluctuating popularity of certain commodities. Government attention tends to gravitate towards sectors like vegetables, meat, and wheat due to their immediate impact on consumers. In contrast, the prices of vegetable oils tend to remain relatively stable. Additionally, diplomatic ties between India and palm oil-producing countries like Indonesia and Malaysia have favoured the import of palm oil in exchange for exporting cereals. The distribution of free cereals during political election campaigns further emphasises the prioritisation of cereals over oil crops [61].

The oil crop sector in India, largely managed by smallholders, has the potential for more sustainable practices. However, the lack of corporate support and willingness to invest in sustainability hinders progress, even though these entities reap most of the profits from the value chain. Furthermore, insufficient mills underpin the lack of palm oil processing capacity while climatic conditions for oil palm are sub-optimal [57].

A shift in consumer consciousness towards health, particularly following the COVID-19 pandemic, has led to a growing willingness to pay for cold-pressed rapeseed oil. The perceived health benefits of cold pressing, which retains essential minerals and vitamins, have driven this demand. This trend has the potential to bolster local milling and processing activities. Consequently, two distinct food systems are coexisting in parallel, highlighting the evolving dynamics in the Indian food landscape.

Sunflower, which was domesticated in North America approximately 5,000 years ago, experienced its peak production there during the late 1970s before declining in the 1980s [62]. Ukraine, Russia, Turkey, and Argentina produce the majority of sunflower oil, with production in the region prior to Russia's invasion of Ukraine reaching 59% of total global production. However, the ongoing Russia-Ukraine conflict has had a significant impact on sunflower production, with production levels in Ukraine observing a 10% decrease within the first year [63].

Rapeseed was another crop that benefited from growing oil demand. Canola and rapeseed (Box 5) belong to one of the most widespread families of cultivated plants, the Brassicaceae (or Cruciferae). Rapeseed is an annual or biennial herb growing in relatively cool and humid temperate climates [64]. In 2008, rapeseed accounted for 79% of all feedstock crops used for biodiesel production in Europe.

Finally, olive oil demand is a recent phenomenon. The expansion of industrial monoculture olive emerged in the 1950s in major producing countries such as Spain [66]. Used for millennia [65] in parts of the Mediterranean, such as the Greek island of Crete, olive cultivation waxed and waned through history depending on cultural preferences, with olive grove dominance comparable to today becoming established in the late 19th century [67].

There are also many forms of oil that are locally important, have a long tradition of local use and trade but are not well known in global trade and are thus often overlooked. For example, in tropical Africa, several wild growing tree species in the forest tree genus *Allanblackia* are used locally for their fat-rich seeds which can be eaten or processed to provide oil. The seeds of *Allanblackia parviflora* A.Chev. found in West Africa are currently being commercialised by Unilever partners [68]. While in East Africa, *Allanblackia stuhlmannii* Engl. seeds have been traded for some decades, with local domestication of the wild tree observed [69]. The recent appearance in western markets of *Allanblackia* butter foretells a future of increasing international trade and intensification of local production. What this means for social and environmental impacts remains unknown.

Box 5

The difference between canola oil and rapeseed oil

Although going by different names – canola and rapeseed – these crops are derived from the same plant species. Rapeseed oil has a distinctive flavour and a high content of erucic acid, which can be harmful when consumed in large amounts. Canola oil is a modified form of rapeseed oil that is low in erucic acid, which makes it safer for human consumption than traditional rapeseed oil. Canola oil is typically refined, which removes some of the flavour and aroma, making it more neutral in taste and odour than rapeseed oil. The name 'canola' is a combination of 'Canada' and 'ola', which means oil.

→ *Both canola and rapeseed oils are extracted from the seeds of the same plant species, rapeseed,* by Jacek Fulawka, 2018, Shutterstock.

2.2.4 Crop yields, field sizes and land requirements

Figure 13 illustrates that oil palm yields can surpass five tonnes per ha, while other common oil crops average less than two tonnes per ha. As opposed to most other oil crops, oil palm is primarily used to produce oil, so all inputs (land, labour, fertiliser, etc.) are converted into oil, whereas for many other oil crops, oil is a by-product. The differences between crops in oil yields per area of land means that relatively more land is allocated to low yielding crops, such as soybean and rapeseed, compared to high yielding crops such as oil palm (Figure 14). After maize (205 mha), soybean uses the most land, with approximately 130 mha.

Oil crop yield variation from ten largest producer countries

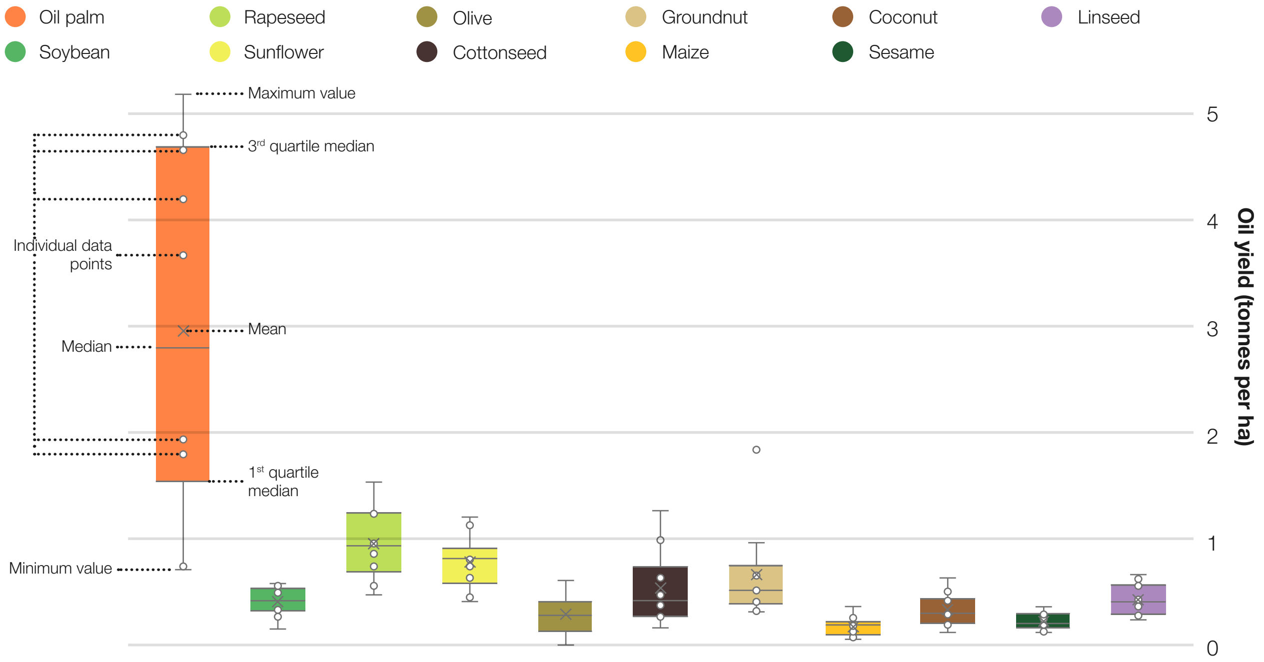


Figure 13 Variation in average oil yields per country for the 10 largest producer countries. Source: Data compiled by the report editors, based on FAO (n.d.) [15]. The middle line of the box represents the median. The X in the box represents the mean. The bottom line of the box represents the median of the 1st quartile. The top line of the box represents the median of the 3rd quartile. The whiskers (vertical lines) extend from the ends of the box to the minimum value and maximum value. Circles show individual data points for countries.

Land allocation to oil crops, 1961–2021

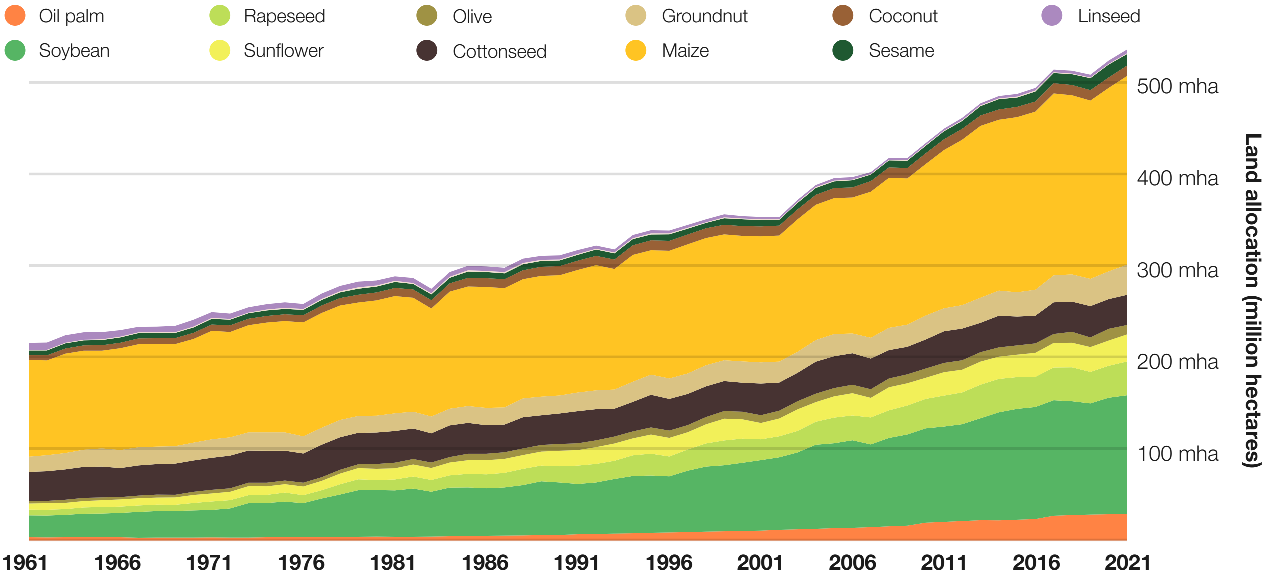


Figure 14 Land globally allocated to different oil crops between 1961 and 2021. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

Figure 15 displays variations in field sizes among different oil crops, influenced by various factors. Sunflower, soybean, and rapeseed may require larger field sizes due to their growth characteristics, cultivation practices, and planting densities. Conversely, crops like cotton, sesame, groundnut, and coconut have smaller field sizes, likely influenced by their management and planting practices and domination by smallholder growers.

Figure 15 also shows variation in field size within crops. For example, the size of soybean farms in the Cerrado, a vast ecoregion of tropical savanna in Central-Western Brazil, are much larger than soybean from southern Brazil. This has high implications for biodiversity and shifts in microclimate, and higher social impacts (local displacement, power concentration, accessibility) [70].

Field size variations for oil crops

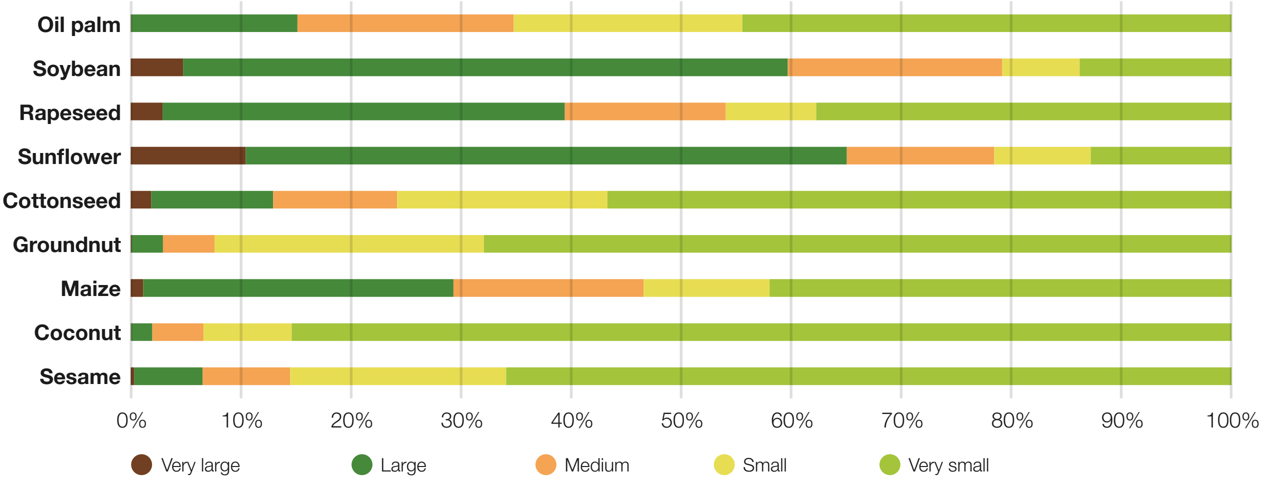
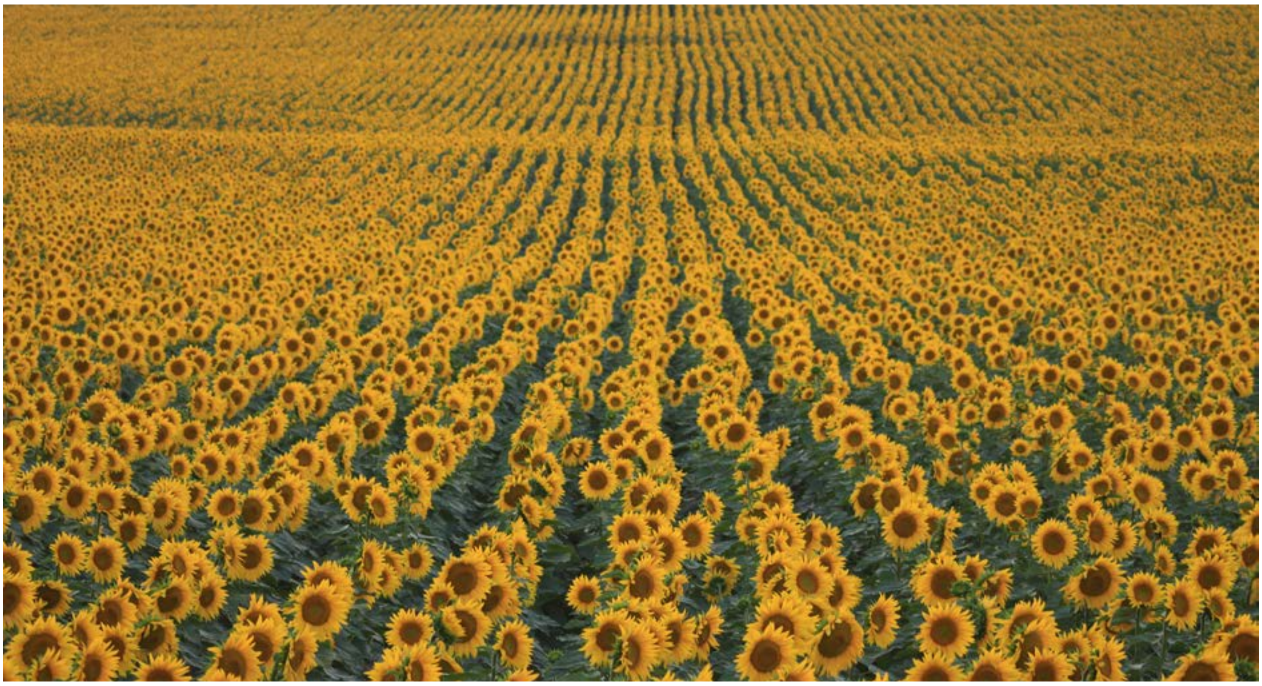


Figure 15 Main oil producing crops and average field sizes. Source: Data compiled by the report editors, based on Lesiv et al. (2019) [71]. The study defined fields as enclosed agricultural areas, including annual and perennial crops, and also included pastures, hayfields and fallow. Individual fields were determined as fields separated by roads, permanent paths, trees, or shrub shelterbelts. Very large fields have an area of >100 ha; large fields between 16 and 100 ha; medium fields between 2.56 and 16 ha; small fields between 0.64 and 2.56 ha; and very small fields <0.64 ha [71]. Note that the study identified individual fields as separated by roads, so in an oil palm or coconut plantations with planting blocks, these blocks would provide the measure of field size.



⟶ *Sunflower crops may require larger field sizes due to their growth characteristics, cultivation practices, and planting densities*, by Meriç Tuna, 2018, Unsplash.

2.3 Vegetable oil use and demand

2.3.1 Edible oil characteristics

About 72% of global vegetable oil production is for food, with biofuel attributing 16% of production, 7% for oleochemical purposes (mostly soaps, cosmetics etc.), and 5% for animal feed (Figure 16, for data sources and methods see Appendix). These percentages vary for different oil types. For example, rapeseed and palm oil have higher biofuel uses. The current study focuses mostly on the use of vegetable oils in food, their typical characteristics, and how these can be altered through food technology (Box 6).

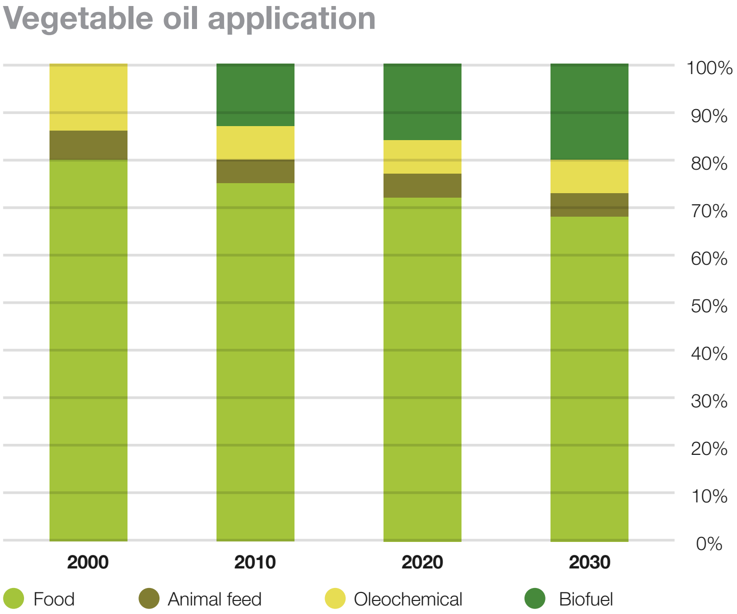


Figure 16 Trends in vegetable oil application in percentages of total. Source: Data compiled by the report editors, based on FAO (n.d.) [15]. For additional information see Appendix.

Box 6

The role of food technology in oils and fats

Late 19th-century chemistry in France and Germany laid the groundwork for food technology advancements in oils and fats. In the 20th century, food technologists developed processes to overcome physical and chemical challenges, through altering the properties of oils and fats. Three key developments greatly influenced oil and fat selection for specific applications.

Extraction and refining

Conventional grinding methods for extracting vegetable oils from plants result in rapid degradation (oils becoming rancid) due to heat, sunlight, or moisture exposure, making the oils unfit for human consumption. Consequently, the range of vegetable oil sources was limited to mostly saturated oils like coconut, palm, and olive oil, while other vegetable oils were mainly used for mechanical (lubrication) purposes. Animal fats, such as lard and tallow, found greater application in the food industry, including margarine production.

The introduction of chemical extraction using the low toxicity solvent hexane, addition of antioxidants, such as tocopherols and citric acids [72], and improvements in storage techniques like refrigeration increased oil stability and expanded possibilities for utilising a broader range of vegetable oil sources in food. Refining, bleaching, and deodorising processes effectively purified the oils, removing free fatty acids, impurities, odours, colours, and flavours, making them more suitable for various food uses [72].

Hydrogenation

Hydrogenation is a process that adds hydrogen to oils, improving the stability of polyunsaturated fatty acids and rendering them suitable for baking and long-distance trading. This stability is achieved by eliminating unsaturated double carbon bonds through hydrogen addition, subsequently raising the oil's melting point to a solid or semi-solid state at room temperature [73]. However, incomplete hydrogenation results in the formation of trans-fatty acids, which have been shown to be detrimental to human health [74].

Fractionation

Fractionation is a procedure that divides oils into liquid and solid components, with palm oil being a prominent illustration easily separated into solid (stearin) and liquid (olein). Further fractionation can produce unsaturated or saturated fractions, broadening the applications of palm oil. These fractionated palm oil products are traded and blended diversely. Palm oil stearin is a key ingredient in European margarine for imparting solidity, whereas olein finds use primarily for cooking oil production.

Lipid profiles of vegetable oils

Figure 17 Typical lipid profiles of different vegetable oils. For definition of lipids and lipid C-number, see Glossary. Source: Data compiled by the report editors, based on Parsons et al. (2020) [73].

Different vegetable oils have different chemical properties (Figure 17). For example, palm oil is widely used due to its unique lipid profile. Its fatty acid composition, with a nearly equal ratio of C16 and C18 saturated and unsaturated fatty acids, is unmatched by few other vegetable oils [73]. These chemical properties determine the melting point of oils, their smoke point (the temperature at which the oil begins to smoke and produce visible fumes, indicating that it is breaking down), their taste and also their texture or mouthfeel. Oils with a higher smoke point are more suitable for high-heat cooking methods, such as frying and sautéing, because they are less likely to break down and release harmful compounds.

Despite the developments which have enhanced the application potential of vegetable oils, there remain several limitations to the chemical processes that are used to change the characteristics of oils. For example, full hydrogenation of oils is possible, and the resulting fat contains little, if any, trans-fatty acids or unsaturated fatty acids, but this leads to melting points above body temperature (>50°C), giving poor mouth-feel and texture for food applications [75]. To overcome this limitation, producers introduce a blend of liquid oils, such as rapeseed, sunflower or soy, or blend the hydrogenated liquid oil with a fat such as coconut oil [75].

Taste and smell are also important (Table 3). Edible oils are mostly refined before their consumption so that the resulting taste is sensorially neutral. Even very small traces of volatile products may be perceived by the consumer. Unlike refined oils, virgin olive oils, and certain other virgin oils, contain minute quantities of volatile oxidation products.

> "In the U.S. and many European countries, consumers prefer oils without any flavour, while in some European, Asian and African countries, weak natural oily, nutty or buttery flavour notes are tolerable."

Table 3 Flavour characteristics and common uses of vegetable oils in food.

Classification	Edible oil seed	Flavour when unrefined	Common uses in food
Oils with high saturated values	Palm oil	Strong savoury (but usually refined and then neutral)	Commercial food production, such as bakery and confectionary
	Palm kernel oil	Subtle and nutty	Commercial cooking
	Coconut oil	Neutral flavour, mild and sweet	Common in baked goods, pastries, sautés, snack foods
	Shea butter	Neutral	As a cooking oil in West Africa and confectionary products
	Cocoa butter	Cocoa flavour and aroma	Chocolate
Oils with high poly-unsaturated values	Soybean oil	Usually refined with neutral flavour	Food manufacturing
	Cottonseed oil	Mild taste	Food manufacturing and sometimes as a frying oil
	Corn (maize) oil	Neutral flavour	Frying, baking
	Sunflower oil	Neutral flavour, hint of walnut	Shallow frying, light salad dressings, food manufacturing
	Safflower oil	Mild, sweet nutty	Cold pressed: salads and dressings
Oils with high mono-unsaturated values	Groundnut oil	Nutty/peanut	Often used in Asian cuisine
	Rapeseed oil	Subtle, neutral taste, can be slightly grassy or nutty	Mixed use, depending on level of refinement
	Olive oil	Mild and fruity to robust, distinctively herbal and peppery	Unrefined: marinades, dressings. Refined: shallow frying
	Sesame oil	Toasted seeds have distinctive nutty aroma and taste	From raw seeds: as a cooking oil. Toasted seeds for flavouring in Asian cuisine

Source: Data compiled by the report editors. Oil seed classification based on Aransiola et al. (2019) [76]. Adapted from Forum for the Future (2021) [77].

Figure 18 *Traditional palm oil extraction in Guinea: the oil palm fruit is first boiled then crushed by hand and immediately used in local dishes such as Egusi soup*, by Uzabiaga, 2017, Wikimedia Commons.

These compounds contribute a distinctive flavour to olive oil or a subtle walnut scent to sunflower oil [72]. In the U.S. and many European countries, consumers prefer oils without any flavour, while in some European, Asian and African countries, weak natural oily, nutty or buttery flavour notes are tolerable. For example, unrefined red palm oil in western Africa is part of the traditional cuisine (Figure 18; see also Box 24).

2.3.2 Other oil uses and the role of meal

For several oil crops, meal for feeding livestock is a major by-product in the oil extraction and refining process (Figure 19), or rather oil is the by-product of animal feed production and thus meat production. The meal that remains after pressing is used as a high-protein animal feed.

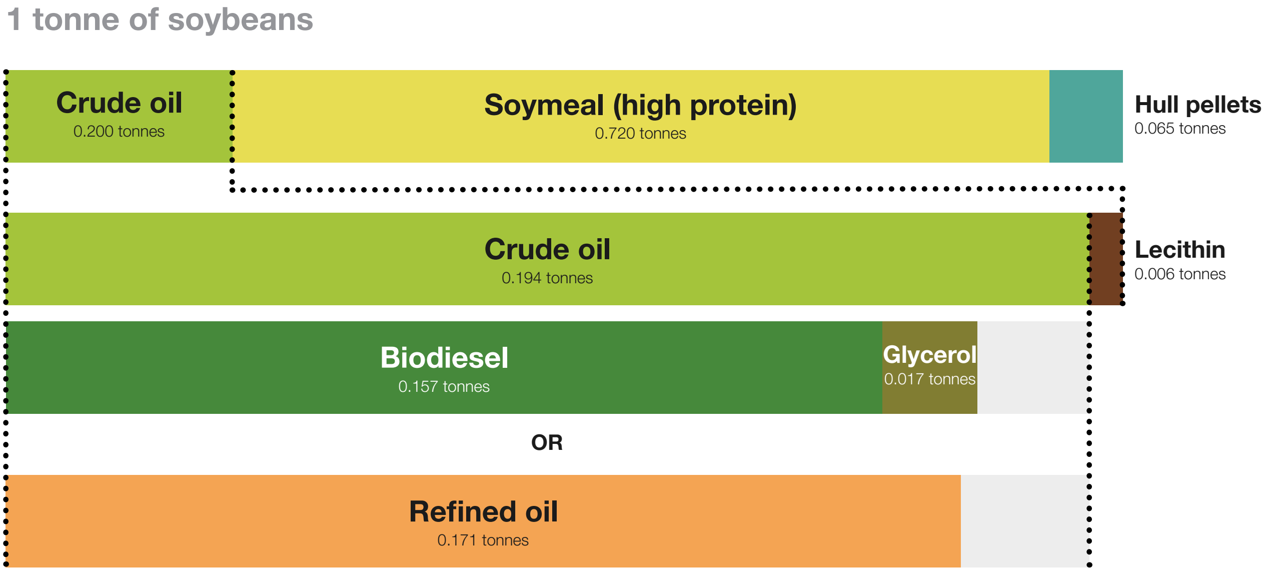


Figure 19 Soy products derived from processing. Source: Prepared by the report editors. Reproduced from 'Soybean conversion' [79].

Soybean meal is globally the main animal feed crop in weight, with global output in 2020 amounting to 252 million tonnes, followed by rapeseed meal at around 39 million tonnes [78]. Although this report does not focus on meal, we recognise that production, trade, and prices of meal are closely related to those of oils. For example, world meat consumption is growing strongly, requiring the production of more animal feed, with implications for oil crops.

In addition to their uses in food and feed industries, vegetable oils are used in various industrial applications, including biofuels (see next page), lubricants, soaps, cosmetics, pharmaceuticals, and bioplastics (Box 7). The use of vegetable oils in these applications is increasing due to their renewable and biodegradable nature. While the percentage of global vegetable oil production for industrial applications is relatively small compared to those of food and biofuel, the annual growth in industrial uses has been much higher between 2018 and 2023 (0–8%) than the growth in vegetable oil consumption for food (-1–3%) [80].

Box 7

Vegetable oils in bioplastics

During recent decades, the global production of plastic waste has grown exponentially and reached 275 million tonnes per year, while the recycling rate is only 13–15% [81]. This is a growing environmental and health concern. Most plastics are currently made from petroleum-based polymers, but these building blocks can also be derived from vegetable oils. Rapeseed, for example, is increasingly used for producing bioplastics, but other vegetable oils are suitable too [82]. Bioplastics are biodegradable, and therefore reduce environmental impacts associated with waste and microplastics. Currently, some 4% of globally produced vegetable oils, including waste oils, are used for the production of bioplastics and this is likely to grow [83].

⟶ *Vegetable oil is one of the feedstocks commonly used in the production of certain types of bioplastics*, by Rebecca, 2008, Flickr.

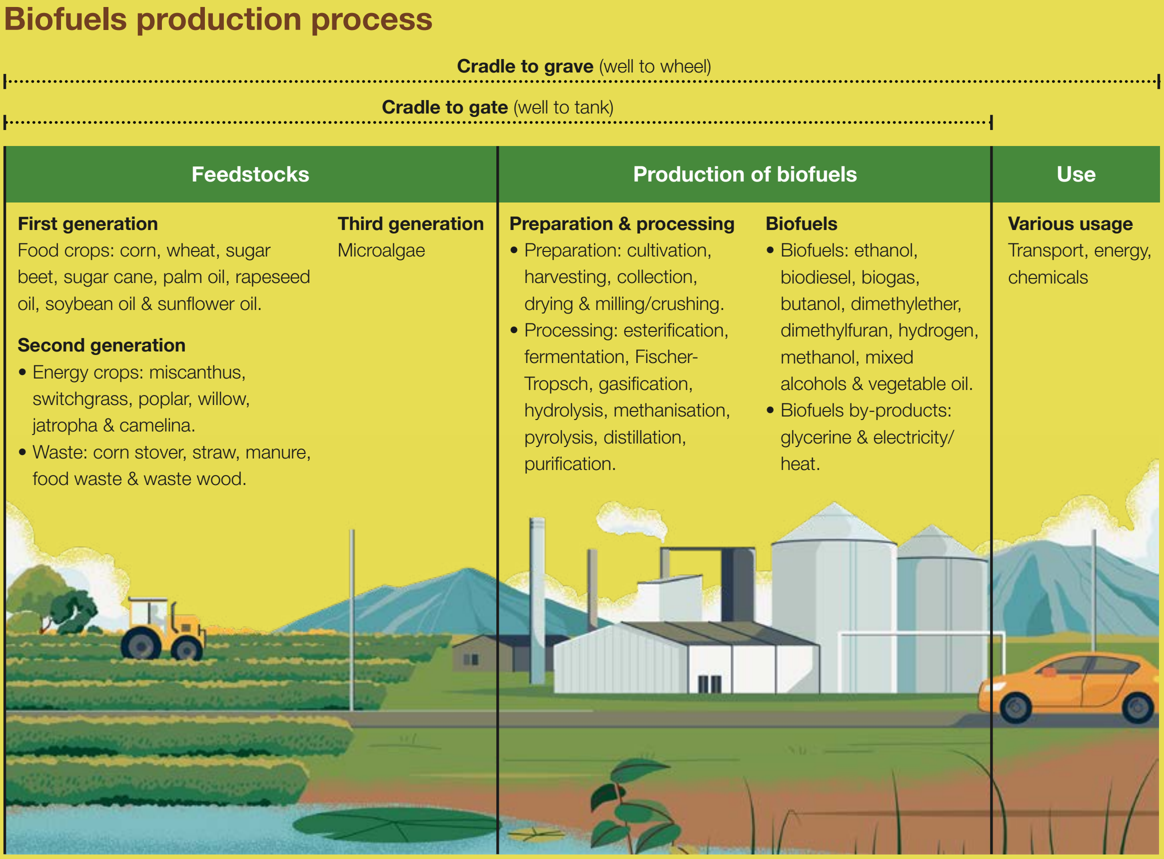
2.3.3 Biofuels

Vegetable oils can be converted into biofuels, such as biodiesel, which can be used as a substitute for petroleum-based diesel fuel. The production of biodiesel from vegetable oils has increased in recent years due to environmental concerns and efforts to reduce dependence on fossil fuels. Most countries in Europe, the Americas and, increasingly, Asia, now have national or sub-national biofuel blending mandates [84]. Predictions are that vegetable oils will increasingly be used for biofuel, reaching 20% of the total production volume by 2030 (Figure 16). Most of the biodiesel from vegetable oil is sourced from first generation feedstocks (Box 8 and Figure 20), such as maize and soybean, with smaller volumes being sourced from oil palm and rapeseed [85].

Box 8

Typology of biofuels

Various definitions exist for types of biofuel. One commonly used typology is ‘first, second and third generation’. First-generation biofuels are produced from food or animal feed crops using well-established technologies like fermentation and transesterification, making them conventional biofuels (Figure 20). Second-generation biofuels, on the other hand, are derived from non-food feedstocks such as dedicated energy crops, agricultural residues, forest residues, and waste materials like used cooking oils and municipal solid waste. Third-generation biofuels are produced from microalgae through conventional transesterification or hydro-treatment of algal oil. Second- and third-generation biofuels are sometimes called ‘advanced biofuels’ as their production techniques or pathways are still under development [86].



Feedstocks		Production of biofuels		Use
First generation Food crops: corn, wheat, sugar beet, sugar cane, palm oil, rapeseed oil, soybean oil & sunflower oil. **Second generation** • Energy crops: miscanthus, switchgrass, poplar, willow, jatropha & camelina. • Waste: corn stover, straw, manure, food waste & waste wood.	**Third generation** Microalgae	**Preparation & processing** • Preparation: cultivation, harvesting, collection, drying & milling/crushing. • Processing: esterification, fermentation, Fischer-Tropsch, gasification, hydrolysis, methanisation, pyrolysis, distillation, purification.	**Biofuels** • Biofuels: ethanol, biodiesel, biogas, butanol, dimethylether, dimethylfuran, hydrogen, methanol, mixed alcohols & vegetable oil. • Biofuels by-products: glycerine & electricity/heat.	**Various usage** Transport, energy, chemicals

Figure 20 An overview of feedstocks and production processes for different biofuels, also showing the life cycle of fuels from cradle to gate (well to tank) and cradle to grave (well to wheel). Source: Prepared by the report editors, adapted from Jeswani et al. (2020) [86].

The pros of using vegetable oils for biofuels include their biodegradability, which reduces environmental impacts, and their ability to be continually grown and replenished. Additionally, vegetable oils offer a higher energy content than ethanol, providing better fuel efficiency and reducing overall fuel consumption. However, the use of vegetable oils as biofuels also comes with challenges and limitations. One major concern is the competition with food production [87], potentially leading to higher food prices and local food insecurity. Additionally, the large-scale cultivation of crops for biofuel production can lead to habitat conversion and the loss of biodiversity [88], but also profit for farmers. In addition, the chemical processes to make biofuel from vegetable oils can be energy-intensive and biofuels may require additional refining steps to meet fuel quality standards, thereby increasing the overall production costs.

Useful principles exist that address the concerns about biofuels [88]:

1. Biofuel development should not be at the expense of people's rights and livelihoods;
2. Biofuels should be environmentally sustainable;
3. Biofuels should contribute to the net reduction of total greenhouse gas emissions and not exacerbate global climate change;
4. Biofuels should recognise the rights of people to just reward; and
5. Costs and benefits of biofuels should be distributed in an equitable way.

> "Additionally, the large-scale cultivation of crops for biofuel production can lead to habitat conversion and the loss of biodiversity, but also profit for farmers."

2.3.4 Interchangeability between different oils

Oils are largely interchangeable and substitutable. However, a range of factors influence interchangeability. Cultural and societal acceptance, scientific knowledge relating to health, technical aspects for specific uses, availability as a domestic or secondary product, market prices, environmental and land use effects, regulatory or company policies, and geopolitical tensions all play significant roles [73,77]. Examples include:

- Low European demand for palm oil in food but a growing interest in shea butter;
- Health concerns resulting in palm oil replacing trans-fats in Europe, and increased use of coconut oil;
- Chemical properties of soy, rapeseed, and palm oil allow relatively easy mutual substitution for use in biofuels;
- Local culinary cultures, such as unrefined palm oil, playing an important role in West African cuisines;
- The local availability of oils as a domestic or second product, such as soy oil, after extracting meal for feed in China, or palm oil for food in Indonesia;
- Market price of oils, with palm oil being relatively cheap compared to coconut or shea butter;
- Environmental, land use, and land use change effects associated with feedstocks;
- Regulatory biofuels blending policies affecting palm oil and soy in Europe;
- Geopolitical tensions, such as the Russia-Ukraine war affecting sunflower oil availability, the US-China trade war causing growing soy imports in China from Brazil, or Indonesia shifting to more palm oil for domestic biofuels fuelled by their resistance to European policies.

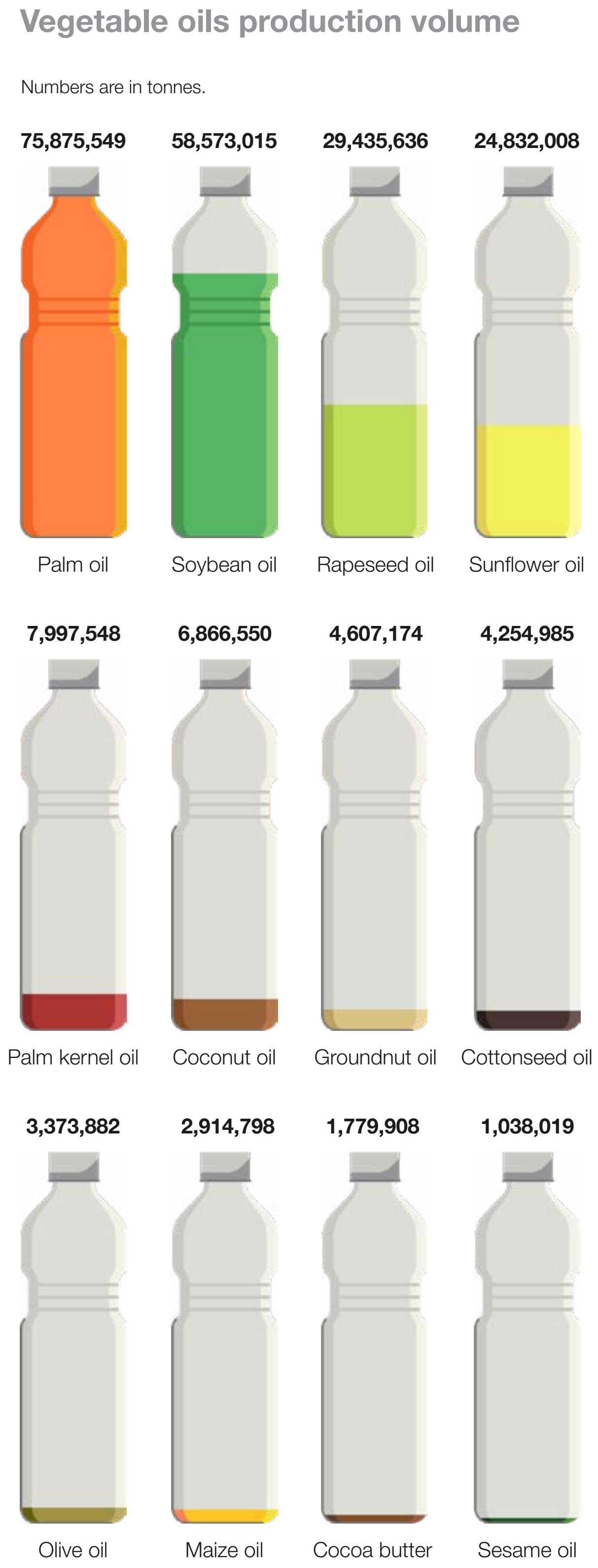


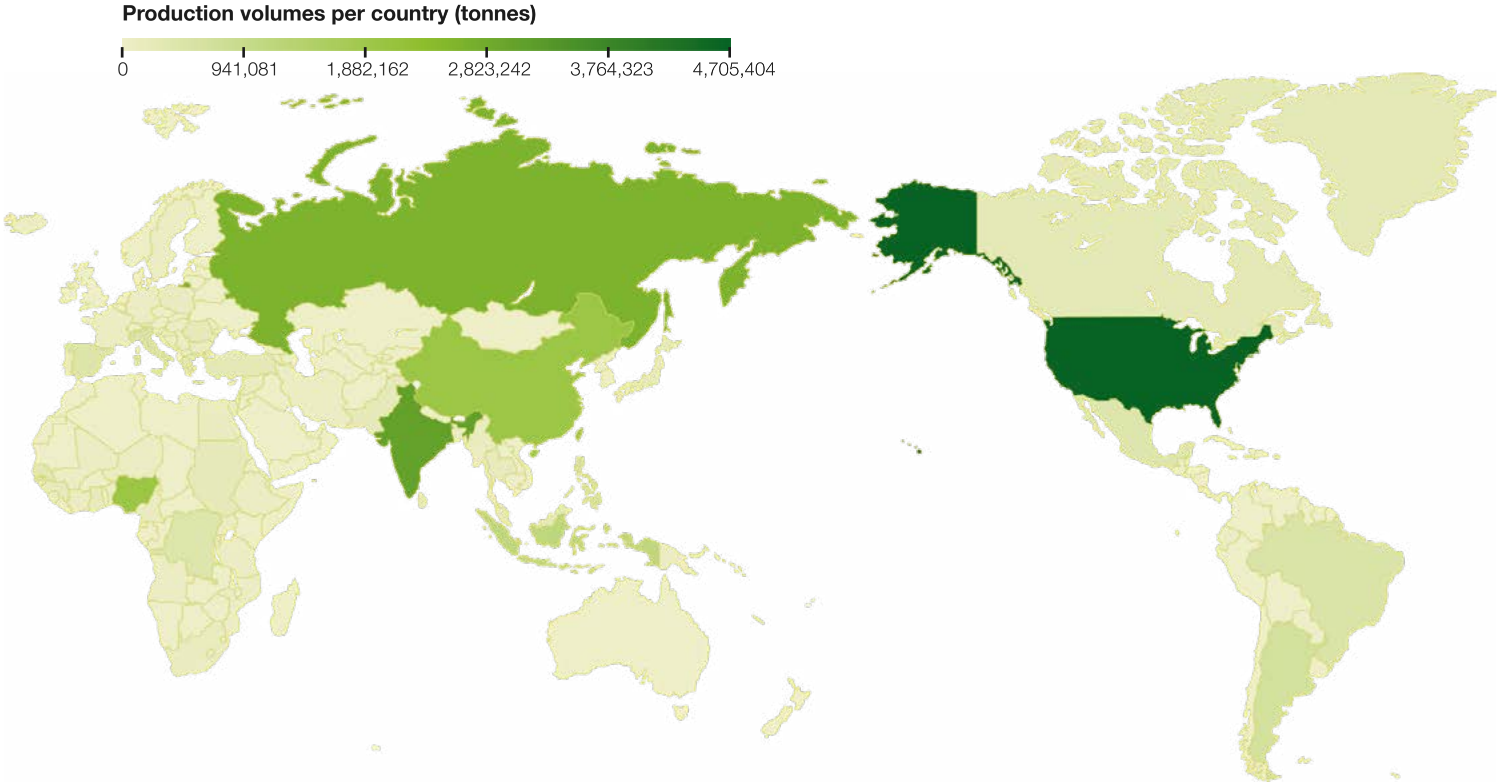
Figure 21 Production of major vegetable oils in 2021. Cocoa butter data are from 2020. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

2.3.5 Growth in vegetable oil demand

Global vegetable oil production has increased nine-fold from around 26.6 million tonnes of oil per year in 1961 to 252 million tonnes in 2021 [15], while in the same period the world population ‘only’ surged from 3 to 8 billion. Production growth has been especially strong in tropical countries, but also relates to a gradual switch from animal fats to vegetable oils [89]. In 1961, the United States of America was the main producer of vegetable oils in the world, followed by India, China, the former USSR, Colombia, and Nigeria [15]. Sixty years later, Indonesia and Brazil were the leading vegetable oil producers (through oil palm and soybean, respectively), with Malaysia also appearing in the top five producing countries [15]. Palm oil and soybean oil are by far the dominant vegetable oils, with the production of cotton, rapeseed, coconut, sunflower, maize, linseed, groundnut, and sesame seed and oil being much lower (Figure 21).

The major geopolitical shift in vegetable oil production in the late 1980s, was driven by a wave of private capital, often from foreign sources, to develop new supply chains, especially during the commodity boom from 2007 to 2014 [90]. National development banks also made state capital available, often subsidised, to the vegetable oil sector. With easy access to land and capital, as well as productive technologies, oil crops became highly profitable and their expansion was promoted [90]. The integration of global trade liberalisation brought together the supply and demand sides. As countries joined the newly created World Trade Organization, imports of soybeans and vegetable oils were liberalised, leading to an explosion in trade [90]. This resulted in producers in exporting countries being linked to distant consumers and rapidly emerging new industries by investments in infrastructure, such as roads, ports, and large ships, that facilitated trade at relatively low costs. China and India underwent the most dramatic changes, with China becoming the world’s largest importer of soybeans, primarily from Brazil, and India becoming the world’s largest importer of vegetable oils, mostly from Indonesia. The remarkable success of palm oil and soybeans was due to a massive substitution of these products for traditional sources of vegetable oil and livestock feed. For instance, palm oil replaced nearly all the coconut oil used in food in Indonesia, while soybean meal replaced the waste materials and by-products used as animal feed in China [90].

Oil crop production volumes per country, 1961



Oil crop production volumes per country, 2021

Total global oil crop production

Figure 22 Global maps showing oil crop production volumes in tonnes per year per country in 1961 and 2021. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

The Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO) make regular predictions about vegetable oil demand and production. In their latest forecast for 2021–2030, the respective organisations predicted that the global demand for vegetable oil will expand by 33 million tonnes by 2030, with food use accounting for 68% of total demand [91]. This growing demand will mostly be met by the expansion of soy, with soybean production expected to increase by 1.1% annually, through the increase of harvested area, which accounts for about a quarter of global output growth [91]. The two countries dominating soybean production and exports are Brazil and the United States, which account for approximately two-thirds of world soybean production and more than 80% of global soybean exports. Production growth incentives for other oilseeds will be curbed by stagnating demand for rapeseed oil as a feedstock in European biodiesel production and increasing competition by cereals for limited arable land in China and the European Union [91].

Indonesia and Malaysia, the world's leading suppliers of palm oil, are projected to account for 83% of global palm oil production and 34% of global vegetable oil production by 2030 [91]. Further production growth in these countries is projected to be limited (although we note Indonesia's plan to transition to 100% biodiesel, requiring 100 million tonnes of palm oil per year by 2040, and a doubling of the current plantation area). Indonesia's expected increase in domestic biodiesel production will lower its export growth of crude palm oil in the medium-term. Indonesia and Malaysia will continue to dominate the vegetable oil trade, exporting over 70% of their combined production and jointly accounting for nearly 60% of global exports [91]. India, the world's biggest importer of vegetable oil, is projected to maintain its high import growth due to growing domestic demand and limited production growth opportunities (see Box 4 for a contextual view). Over the next decade, growth in the world exports of soybeans is expected to slow down considerably due to a projected slower growth in soybean imports by China.

⟶ *Soybean planting in Central Illinois*, by James Baltz, 2022, Unsplash.

The forecasts from the OECD and FAO align closely with those of other experts, except for the projection of palm oil market dominance. Some in the business sector, such as LMC International, anticipate a stagnation in the palm oil industry due to limited expansion opportunities and reduced yields [92]. The decline in palm oil yields typically begins 10–15 years after planting [93], necessitating costly tree replacement. Our unpublished global oil palm age layer reveals that 22% of Malaysian oil palm plantations and 18% in Indonesia are over 20 years old, indicating probable yield declines in large oil palm areas.

While oil palm yield growth has plateaued, soybean yields have nearly doubled from 1.1–2.3 tonnes/ha in 1978 to 2.0–3.5 tonnes/ha in 2019 [92]. Similar growth has been observed in sunflower and rapeseed yields [92]. The anticipated demand growth for major vegetable oils is projected to be just under 2.5% in the next 15 years, with soybean increasing at over 3.5% annually, and other oils growing between 1% and 2% [92]. This places soybean ahead of oil palm in total oil output, potentially leading to higher oil prices due to increased land use pressure in South America [92].

2.3.6 Why are most vegetable oils so cheap?

Compared to many other food categories, oils and fats are generally cheap. This is important for poorer people. For example, among people in Africa, 12.3% cannot afford an energy-sufficient diet, 56.4% a nutrient-adequate diet, and 80% a healthy diet [94]. Globally, over 3 billion people in 2020 could not afford a healthy diet [94]. Because oils and fats are cheap (Figure 23), they contribute 4% of the average global costs of a healthy diet based on 2017 US$ values [94].

The production of many oils and fats is highly efficient due to advancements in agricultural practices and extraction methods. The use of modern machinery, improved crop varieties, and optimised refining processes have increased yields and reduced production costs, contributing to lower prices. Oil and fat production often generates by-products such as oilseed meals, animal feed, and glycerine. These by-products can be utilised in various industries, thereby reducing waste and generating additional revenue. The utilisation of by-products helps offset production costs and keeps the overall prices of oils and fats relatively low.

Daily cost per person by food group and region, 2017

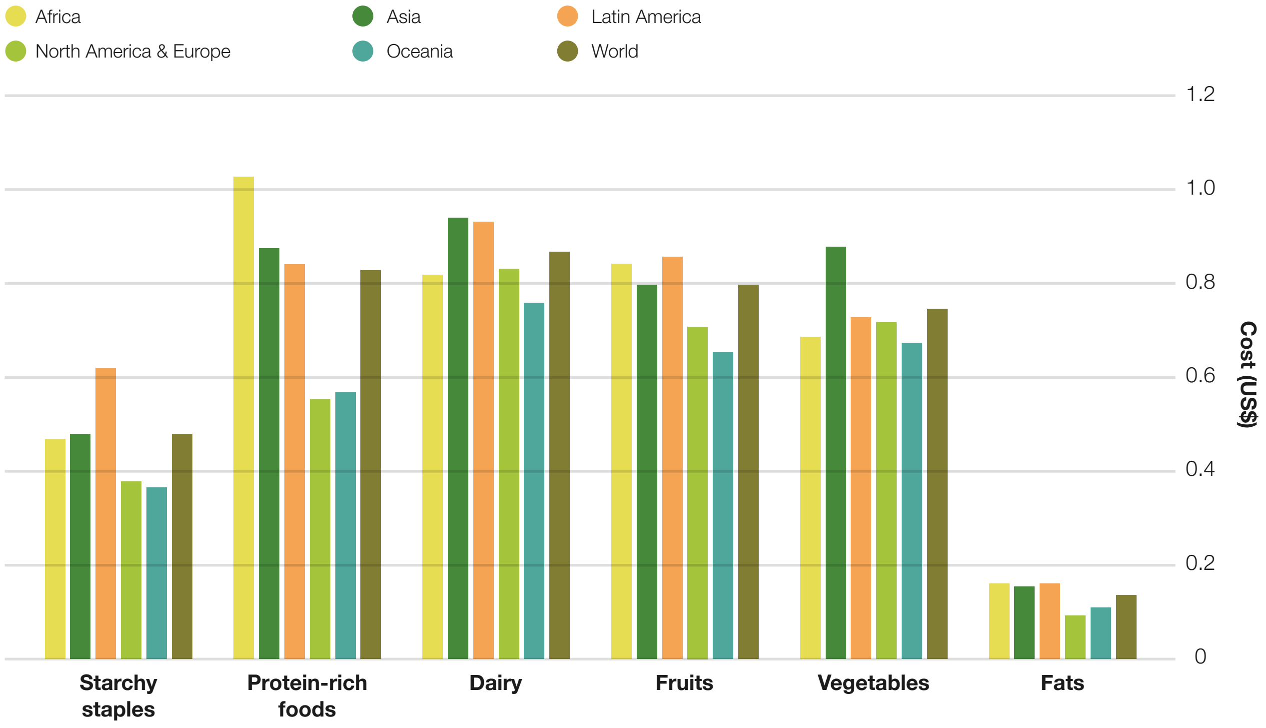


Figure 23 Cost per person per day by food group and region for a healthy diet. Source: Data compiled by the report editors, based on Herforth et al. (2020) [94].

Vegetable oil prices, 1991–2021

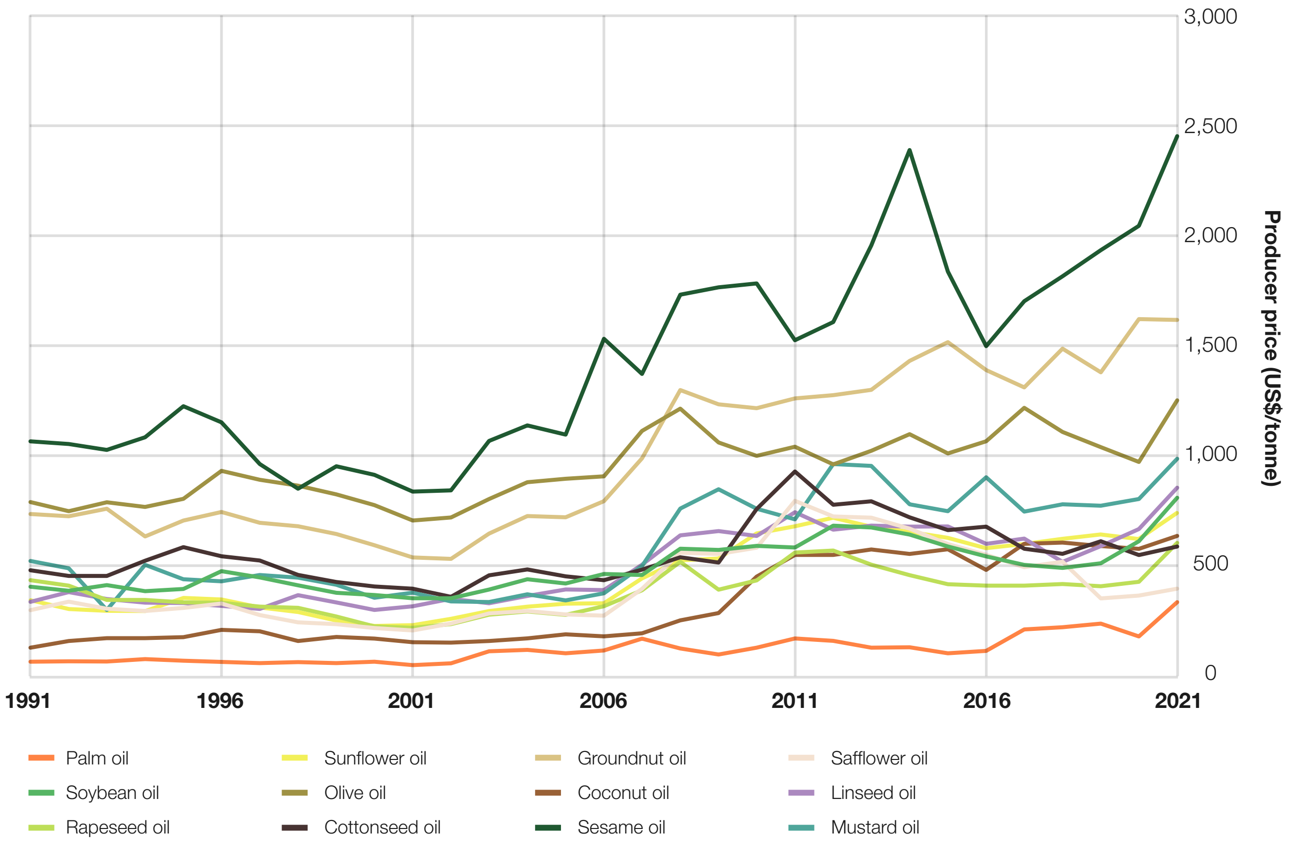


Figure 24 Variation in vegetable oil prices between 1991 and 2021. Prices represent annual values of producer prices (US$/tonne) at national level averaged per year to obtain an annual global price. Source: Data compiled by the report editors, based on FAO (n.d.) [15].

The market is also highly competitive. This competition drives efficiency, innovation, and cost optimisation in the industry. Finally, there is the role of government subsidies or incentives for producing certain oils and fats, which lower production costs and result in more affordable prices for consumers.

Indeed, governments are often in favour of cheaper food through industrial agriculture as it enhances food accessibility – one of the four dimensions of food security [95] – but also because politicians know that low (or reduced) food prices increase their political popularity and security. Inversely, there is often social unrest when the price of food goes up [95]. This economic model is encouraged by most governments through subsidies in industrial agriculture as it allows more money for people to spend on other goods, driving economic growth [95].

There are significant differences in the prices of oils from different crops (Figure 24), with the most expensive oil in this graph, sesame oil, being on average 12 times more expensive than the cheapest, palm oil [15]. With an average production cost of US$ 2,454 per tonne [15], sesame is expensive to produce, while oil extraction processes are even more costly [96]. Palm oil is cheap due to yield per unit land (see Chapter 2.2.4). Furthermore, the production of soybean and palm oils rests on the fundamentals of cheap labour and land [97], associated with high externalities such as human rights issues and deforestation (see Chapter 4.2). Indeed, thinkers such as David Harvey and Jason Moore have described how the agricultural revolution was made possible mainly by a single condition – the exploitation of cheap agricultural labour [98-100].

⟶

A vegetable oil silo factory in Japan,
by Phaendin, Shutterstock.

3

Food systems, value chains and transformations

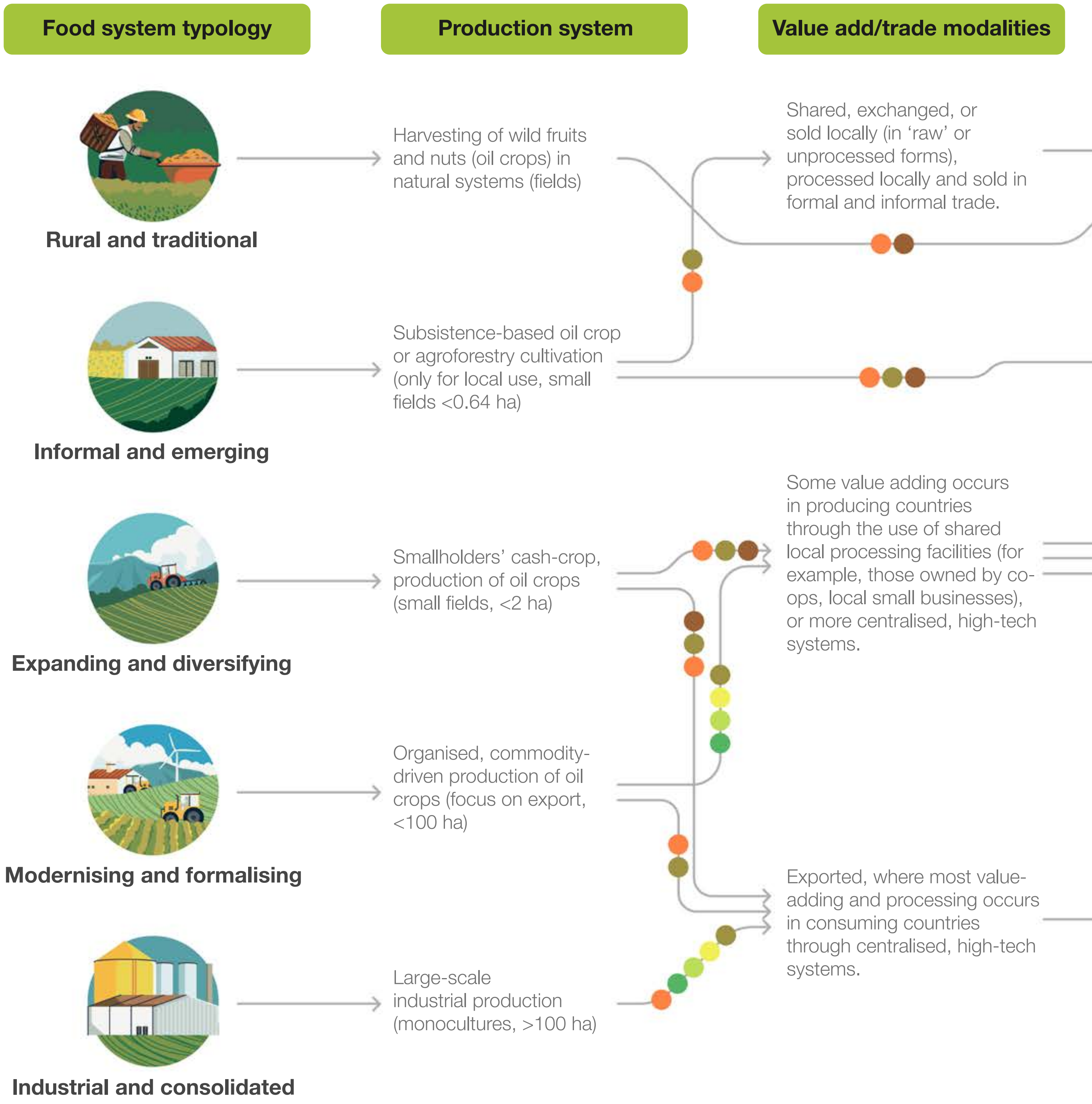
3.1 Production, trade, and consumption modalities inherent in vegetable oils

When considering vegetable oils, it is more meaningful to examine systems rather than individual crops. The quality of a crop species is not inherently good or bad—it is contingent upon how it is produced and used. The production and consumption of all oil crops have impacts (see Chapter 4) and the way these oils are produced and processed matters. Most oils are produced in a variety of ways, which feed into different kinds of value chains, each with different social, environmental, and health implications. A vegetable oil system encompasses all aspects of production, value-added (such as the difference between the market value of an oil product, and the sum value of its constituents), distribution and trading, and consumption, along with the associated social, economic, and environmental dimensions (Figure 6).

The importance of such food systems is gaining significant recognition [13,101,102]. Their impacts on nutrition, economic growth, and environmental sustainability mean they are increasingly seen as a focus for development. For example, the United Nations' food summit considered food systems as a useful way of transforming the way the world produces, consumes, and thinks about food [103]. Path dependencies in food systems, for example, between crop varieties and production or consumption systems, lead to particular social, economic, and environmental outcomes. We illustrate this path dependency with the use of genetically modified crops that are glyphosate-resistant, which dominate global soy production. This form of production represents the most intensive, large-scale system of all, involving greater automation and more reliance on chemical inputs. It has led to much higher production rates per hectare as well as in the increase of social and environmental harms from pollution and pesticide poisoning, and reduced local economic benefits because of lower labour requirements.

We adopted and refined an existing national level food systems typology[13], which proposes indicators for five ways to classify food systems: i) rural and traditional; ii) informal and expanding; iii) emerging and diversifying; iv) modernising and formalising; and v) industrial and consolidated (for details, see Appendix). Application of this approach shows that oil crops are produced in a diversity of production systems ranging from wild harvest and home consumption, such as the illipe nut (*Shorea* spp.) in the Bornean rainforest [104], to subsistence and smallholder cultivation, such as coconut grown on some Pacific islands [105], to crops such as soybean, rapeseed (canola), and sunflower grown mostly in intensive, industrial monoculture systems at a medium-to-large scale (up to and over 200,000 ha) [106]. Some oil crops are traded and processed locally or regionally, while others are grown primarily for international trade. There are multiple pathways between systems of production, value-addition, and consumption (Figure 25).

Food systems and value chains of six major vegetable oils



Food system typology

Production system

Value add/trade modalities

Rural and traditional

Harvesting of wild fruits and nuts (oil crops) in natural systems (fields)

Shared, exchanged, or sold locally (in 'raw' or unprocessed forms), processed locally and sold in formal and informal trade.

Informal and emerging

Subsistence-based oil crop or agroforestry cultivation (only for local use, small fields <0.64 ha)

Expanding and diversifying

Smallholders' cash-crop, production of oil crops (small fields, <2 ha)

Some value adding occurs in producing countries through the use of shared local processing facilities (for example, those owned by co-ops, local small businesses), or more centralised, high-tech systems.

Modernising and formalising

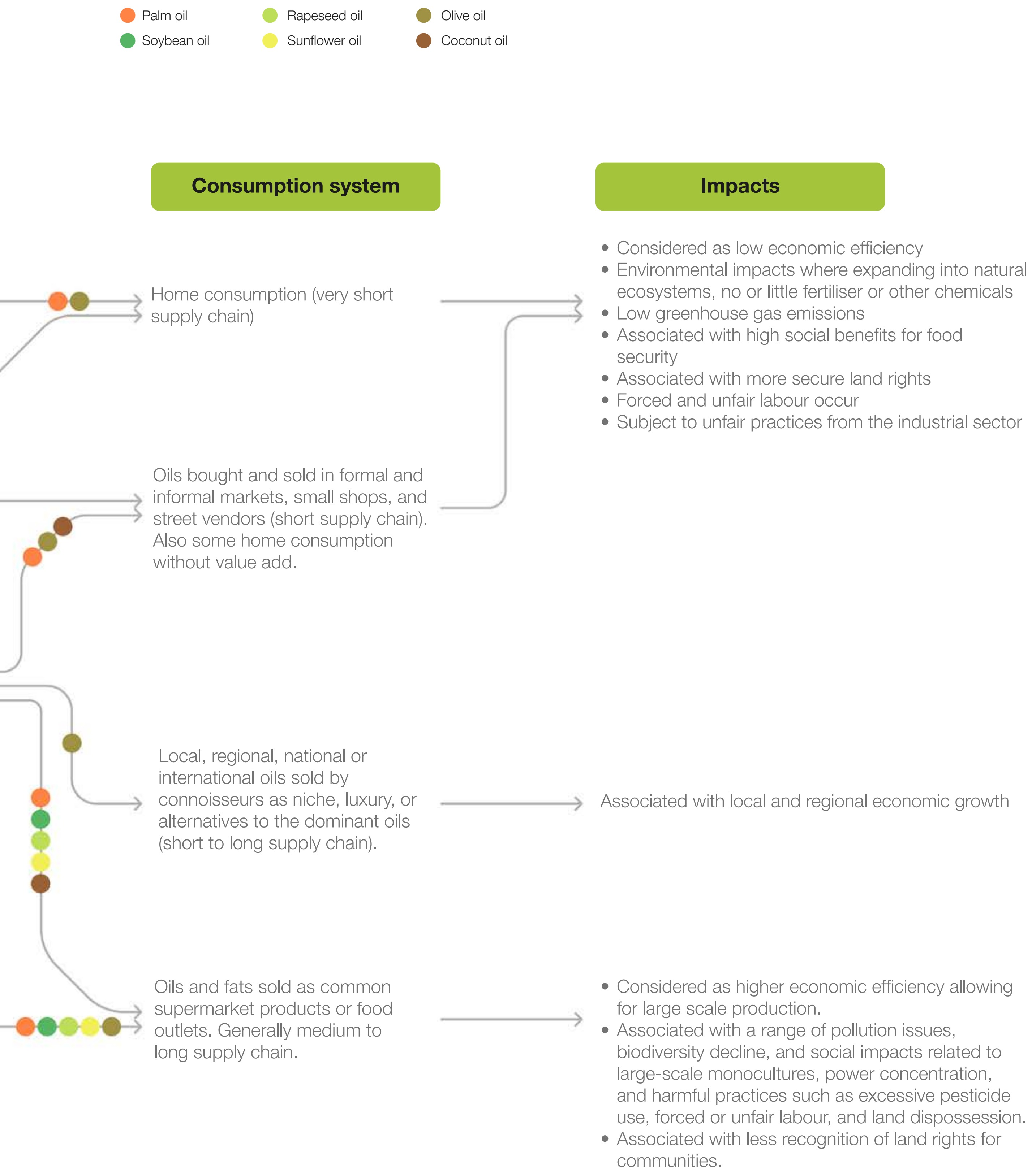
Organised, commodity-driven production of oil crops (focus on export, <100 ha)

Exported, where most value-adding and processing occurs in consuming countries through centralised, high-tech systems.

Industrial and consolidated

Large-scale industrial production (monocultures, >100 ha)

Figure 25 Food systems and value chains of six major vegetable oils. The oils were chosen based on our expertise and supply chain data available in the scientific literature. The figure is meant to offer a more conceptual way of considering the food (vegetable oil) system based on limited data rather than a robust data-led representation of all oil systems and value chains. Source: Prepared by the report editors.



● Palm oil
● Soybean oil
● Rapeseed oil
● Sunflower oil
● Olive oil
● Coconut oil

Consumption system	**Impacts**
Home consumption (very short supply chain)	• Considered as low economic efficiency • Environmental impacts where expanding into natural ecosystems, no or little fertiliser or other chemicals • Low greenhouse gas emissions • Associated with high social benefits for food security • Associated with more secure land rights • Forced and unfair labour occur • Subject to unfair practices from the industrial sector
Oils bought and sold in formal and informal markets, small shops, and street vendors (short supply chain). Also some home consumption without value add.	
Local, regional, national or international oils sold by connoisseurs as niche, luxury, or alternatives to the dominant oils (short to long supply chain).	Associated with local and regional economic growth
Oils and fats sold as common supermarket products or food outlets. Generally medium to long supply chain.	• Considered as higher economic efficiency allowing for large scale production. • Associated with a range of pollution issues, biodiversity decline, and social impacts related to large-scale monocultures, power concentration, and harmful practices such as excessive pesticide use, forced or unfair labour, and land dispossession. • Associated with less recognition of land rights for communities.

While the Food and Agriculture Organization of the United Nations compiles data on the international trade of various commodities including oil crops, information on how oils are processed and retailed locally or regionally is often deficient or inconsistent. Value addition for many oil crops occurs in industrialised countries, with production in top-oil producing countries being almost exclusively destined for export trade and extremely centralised, with a few countries accounting for the majority of global production and exports [107].

Trade modalities (such as formulas, targets, or specific measures used to accomplish objectives in trade negotiations) are also diverse. Data on oils that are traditionally processed and locally traded, often on small scales, such as olive oil in Mediterranean countries, or shea and palm oil in West and Central Africa, are seldom captured in trade statistics but are significant locally and probably globally. For example, 60.3% of a sample of Greek households in 2020 used olive oil produced by themselves or by their extended family or friends [108].

⟶ *Old olive oil pressing machinery in Panagia, a village on the island of Thasos in northern Greece*, by Ronald Saunders, 2011, Flickr.

3.2 Value chains

A key aspect of food systems are value chains (see Glossary), referring to a specific product or group of products and the activities and actors involved in creating value as a product moves from raw material to consumers. This includes all processes, inputs, outputs, and stakeholders involved in creating a product from the crop, through processing and production, to delivery to final consumers and ultimately, its disposal. The term value chain is used in preference to supply chain (see Glossary), as it emphasises how the series of operations and transactions adds value (or utility) to a product to enhance customer and/or societal value. Value refers to the economic, monetary value of a product, which is generally increased by the processes within a value chain. For example, the price of one unit of refined oil sold to a consumer is usually higher than the same unit of unprocessed beans or nuts. Value is also socially, culturally, and environmentally defined. It is the regard for which a product and the food system it originates from is held in, its importance, worth, or usefulness. Value can be intrinsic – the value of something in and for itself, irrespective of its utility for someone else. An example is the price that people are willing to pay for a certain brand or label (such as organic or certified oils), irrespective of how the oil is used (for example, for its functionality or performance). Using the term 'value' emphasises not just its price, but also its externalities: the price of things not included in many market values, such as the costs of not paying a decent wage, or environmental costs such as loss of natural vegetation or pollution from pesticides used in cultivation.

> "Using the term 'value' emphasises not just its price, but also its externalities: the price of things not included in many market values..."

A crop grown, or plant harvested from the wild, in a food system can produce multiple products involving multiple value chains. However, products too can have multiple uses (Figure 26). For example, oil palm derivative products include oil extracted from the kernel and fruit for food use. The oil is also used as an ingredient in many industrial, cosmetic, and pharmaceutical products, and the crushed kernel is used as feed for livestock and pellets and biofuel, its stem sap is used to make wine, empty fruit bunches for composting, while the trunk and leaves are sometimes used in construction. With respect to the soybean, it is used to produce edible oil and under industrial uses, bean residues are used as livestock feed, and beans are also used as sprouts and to make milk, tofu and tempeh and as ingredients in many foods. From the coconut palm, oil is extracted from copra and is an ingredient in foods, industrial and cosmetic products, flowers, coconut milk and water, husk, and others. The shell, stem and leaves of coconut palm are also ingredients in many other products (see Chapter 2).

⟶ *Coconut oil, derived from copra, is used in food, cosmetics, and various other products, including coconut milk, water, and husk,* by Pixel-Shot, 2016, Adobe Stock.

Global oils food system & value chains

Direct actors

Global value chains for vegetable oils are intricate networks involving the cultivation, processing, and distribution of various oils. These chains link various direct actors and activities, such as farmers, transporters, manufacturers, processors, retailers, and consumers worldwide, shaping modern diets and industries.

Indirect actors

The flow chart below shows the indirect actors who wield substantial influence and have meaningful impacts within this particular food system and its associated value chain, spanning both national and international spheres.

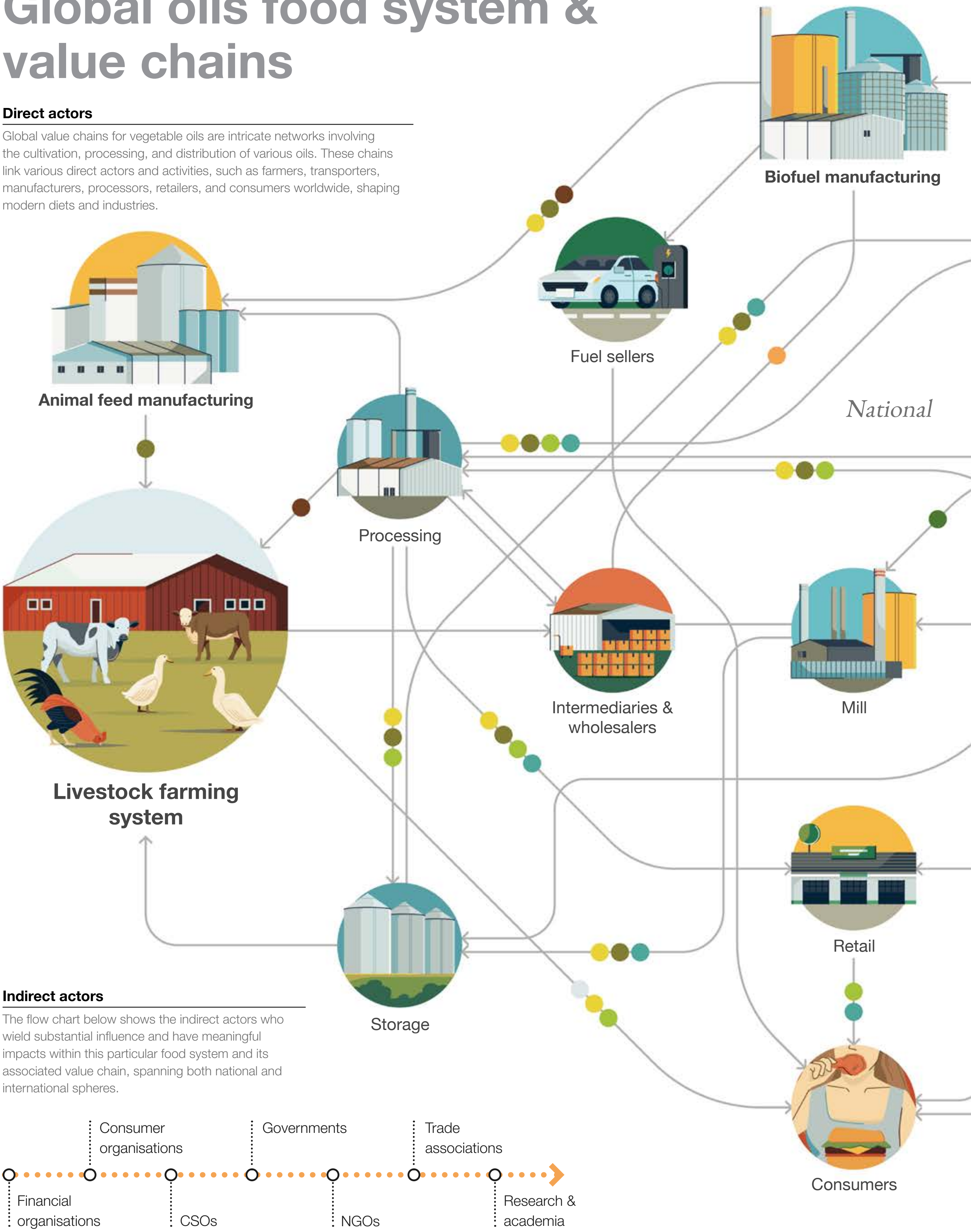
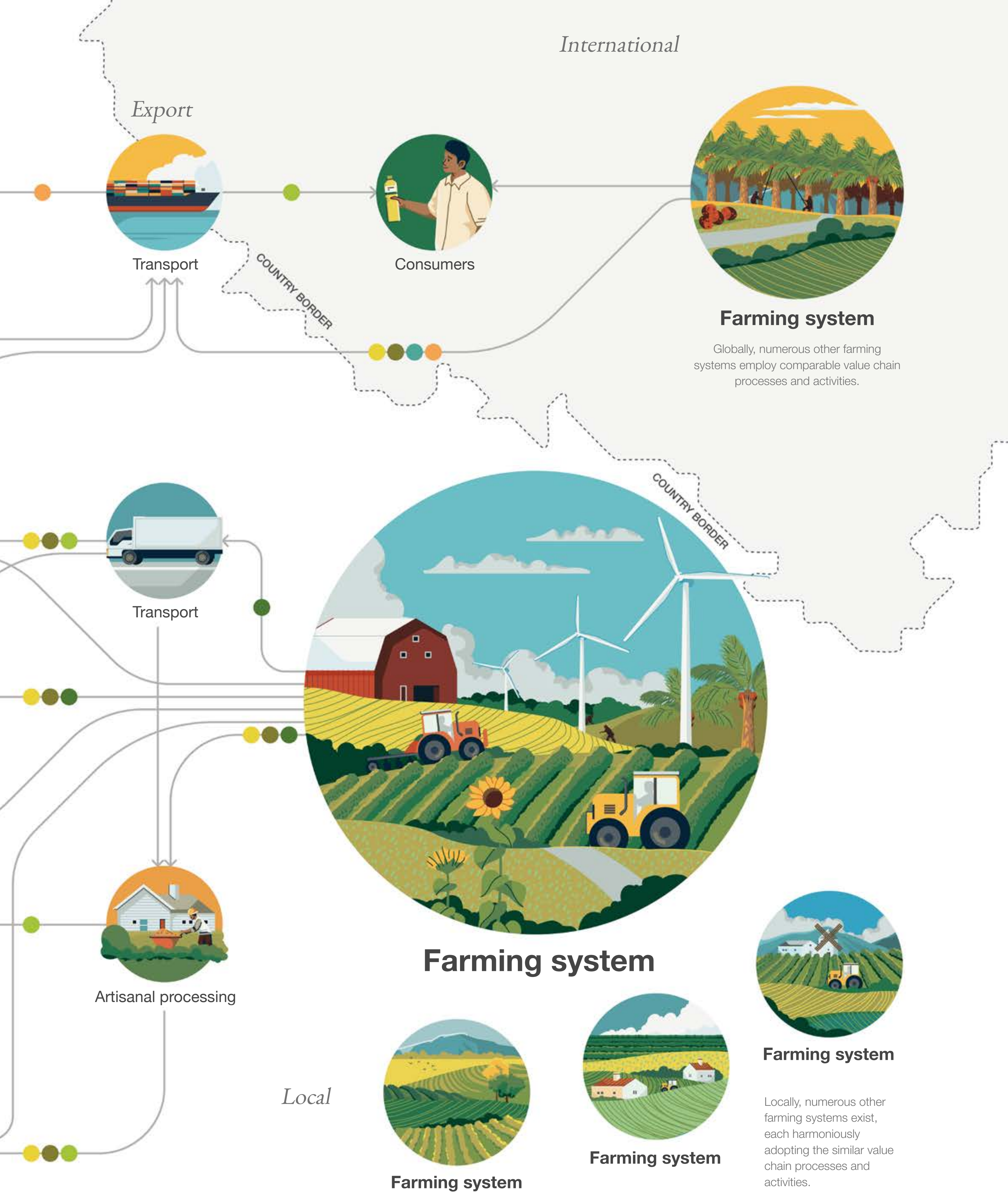


Figure 26 Generic value chain for vegetable oils. Source: Prepared by the report editors.



Globally, numerous other farming systems employ comparable value chain processes and activities.

Locally, numerous other farming systems exist, each harmoniously adopting the similar value chain processes and activities.

- ● Livestock & dairy
- ● Oils & fats
- ● Meal
- ● Seeds & fruits
- ● Cake
- ● Processed oils (edible)
- ● Processed oils (industrial, cosmetic, etc.)
- ● Processed oils (fuel)

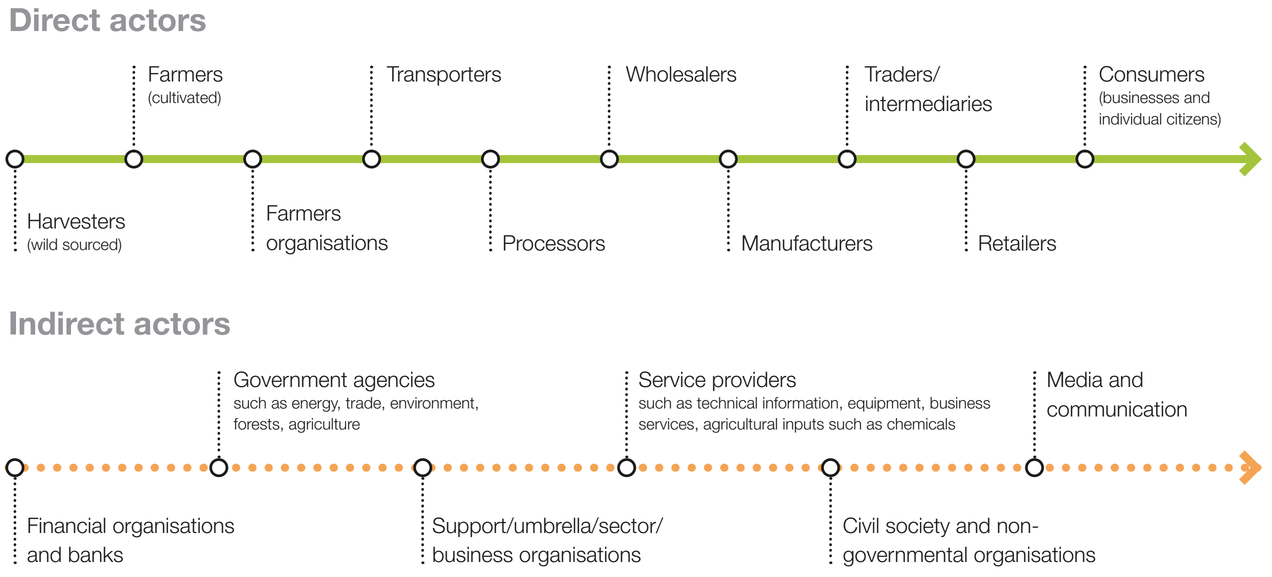


Figure 27 Actors in value chains. Source: Prepared by the report editors.

The processes in a vegetable oil value chain generally involve processing to extract oil, and range from simple, artisanal processes such as boiling and crushing to high-tech extraction and refining processes (see Chapter 2). Inputs into the value chain include energy, finance, equipment, technology, information and knowledge, labour and outputs include material products and organic waste materials (such as seed and nut residues), which can be used to generate other products (also known as by-products) like sunflower husks used for animal feed.

Stakeholders in value chains can be individuals, peoples or organisations. Direct stakeholders, shown in Figure 27, are directly involved in the processes in a chain. Indirect stakeholders have an influence, interest, or are affected in the activities and impacts of the chain through, for example, its governance, regulation, supply of goods and services, or by exerting other economic, environmental and socio-cultural forces on the chain. Stakeholders may be involved in many different activities in a chain. For example, cocoa farmers may transport, process and retail products made from cocoa, which reduces the length of the value chain as the chain extends directly from farmer to consumer. Considerably long and complex chains also occur, particularly internationally, with numerous actors involved in different activities (such as refining packaging transport storage and marketing). Thus, depending on their role and activities, impacts will vary. Internationally connected value chains, such as global soy and palm, interlink production, and consumption systems via value adding and trade and generate often distant impacts as supply or demand in one place has consequences in another [109].

Many factors affect supply and demand, including costs of production, prices, consumers preferences, and perceptions of the product and its value(s) (see Chapter 4.4), the substitutability of one oil for another (see Chapter 2.3.5), purchasing power, economic cycles, weather and the market landscape. Asymmetries in the number of consumers and sellers and their relationships create power imbalances. For example, a small number of producers, processors, buyers, or retailers means power is concentrated at certain parts of a value chain and can decrease the power of other stakeholders to negotiate prices and terms of business and determine control over land [110]. In the cocoa value chain, there are millions of cocoa farmers and they sell approximately 90% of total production to six major trading, grinding, and processing companies [111]. Control over land, crop supply, and inputs also affect prices and production systems (for example, herbicides affecting herbicide resistant crops), and resulting economic benefits. Control over outputs – such as the size of a farm, volume produced, whether stakeholders join in associations or unions, and the level of dependence upon a crop to provide income for a farmer, business, or country – all affect the producers' ability to control selling price [110,111]. For example, with cocoa, most farmers are price takers and have little power to affect selling prices.

Box 9

Hard choices optimising all Sustainable Development Goals

Policy makers should identify and favour resilient, environmentally-friendly, and socially-beneficial oil production methods. This is tricky as interventions in the oil food system can have varied outcomes across different dimensions. Palm oil exemplifies this complexity, criticised for deforestation and human rights violations, while holding local and national socio-economic importance.

Assessing overall impacts involves considering multiple factors. Diverse production systems – industrial vs. smallholder – add intricacy due to size, productivity, and labour intensity differences.

A recent Sumatra-focused study [117] found that the industrial vs. smallholder choice strongly affects intervention impacts. In unproductive lands, smallholder replanting is associated with reduced poverty, improved access to healthcare and primary education, and better forest conservation outcomes (SDGs 1, 3, 4, 15). Industrial-scale replanting can aid poverty reduction and primary education but has fewer benefits than the smallholder replanting (Figure 11). Smallholder expansion excelled across SDGs, albeit with trade-offs.

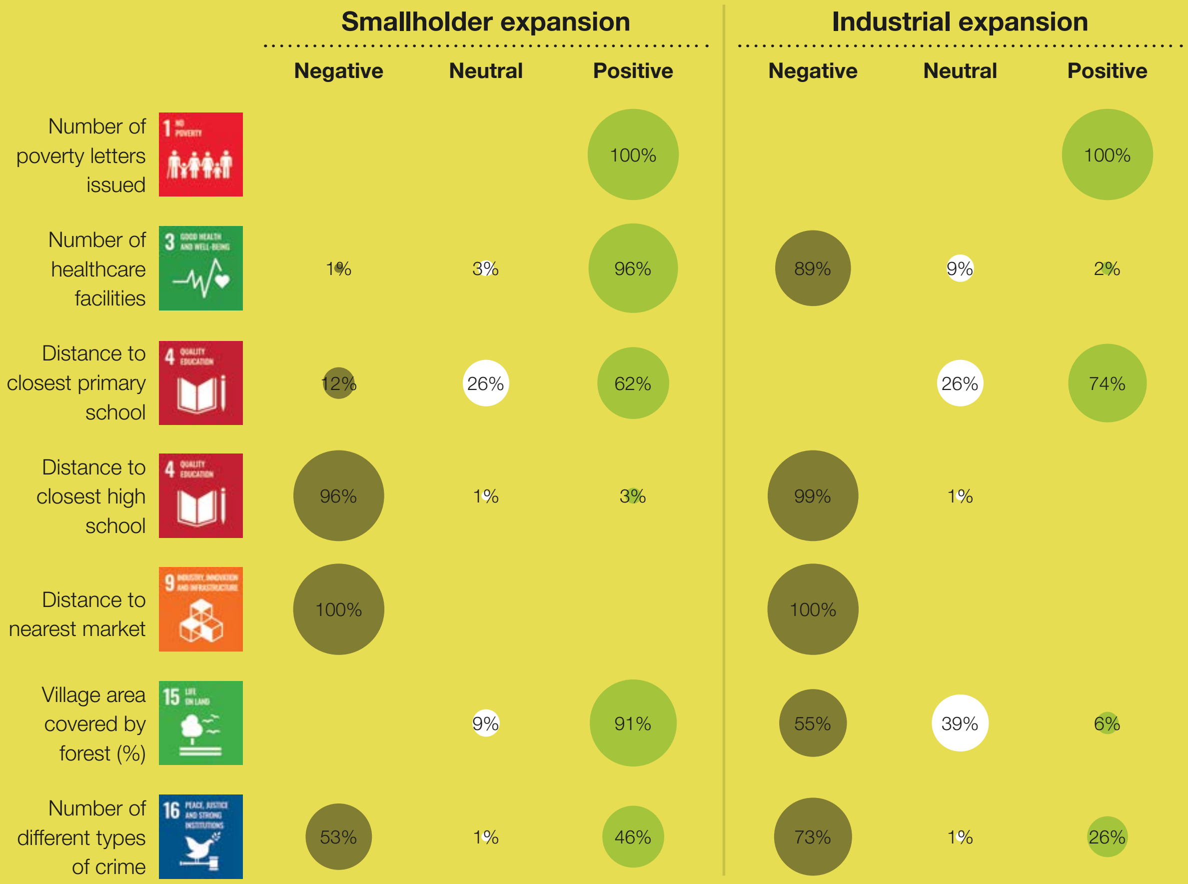


Figure 28 Evaluation of the potential impacts of unproductive palm oil replanting in Sumatra. Percentage of villages where replanting unproductive plantations through a smallholder profile or an industrial one was associated with a change in Sustainable Development Goals (SDGs). If the intervention results in more villages being positively affected than negatively affected, then the intervention is considered compatible with SDG progress (synergy); while if the intervention mostly has negative effects, then it is considered a trade-off effect. Source: Prepared by the report editors, adapted from Fosch et al. (2023) [117]. Disclaimer: The SDG icons are the property of the United Nations, reprinted for informational purposes [118].

Control over how products flow in a chain, such as warehousing and processing, and control over markets, through setting quality or production standards or introducing taxes and tariffs, also affect prices and profits of different stakeholders. Power and relationships therefore strongly influence how a chain is governed (see Chapter 5), who is included or excluded, and, in turn, which stakeholders benefit.

Value chains often involve or embody inequity and inequality. These uneven relationships have been noted in global oil value chains [112]. The disparity of interests, power, and values in oil product chains means that acknowledging, identifying, and making explicit power, and the diverse and multiple values (not just economic value) are important. For example, olive trees and oil have significant cultural values across the Mediterranean [113,114]. Being aware of the power issues within oil value chains is particularly relevant for building resilient, future scenarios, policymaking for those directly and indirectly involved, and ensuring that trade-offs are considered. Trade-offs occur on different scales, such as between global sustainable development goals (Box 9) and a personal level (such as access to cheap but nutritious oils). The decisions concerning the future of oil production, processing, and distribution, as well as the inclusivity or exclusivity of participants in these decision-making processes, significantly impact the results within the oil value chains. These outcomes encompass the distribution of wealth, prosperity, and costs among stakeholders in the value chain, and the rationale behind these allocations. [115,116]

The activities and stakeholders in value chains can both generate benefits for producers and consumers, revenues, and employment, and undesirable and unintended economic, social and environmental impacts. and national socio-economic importance.

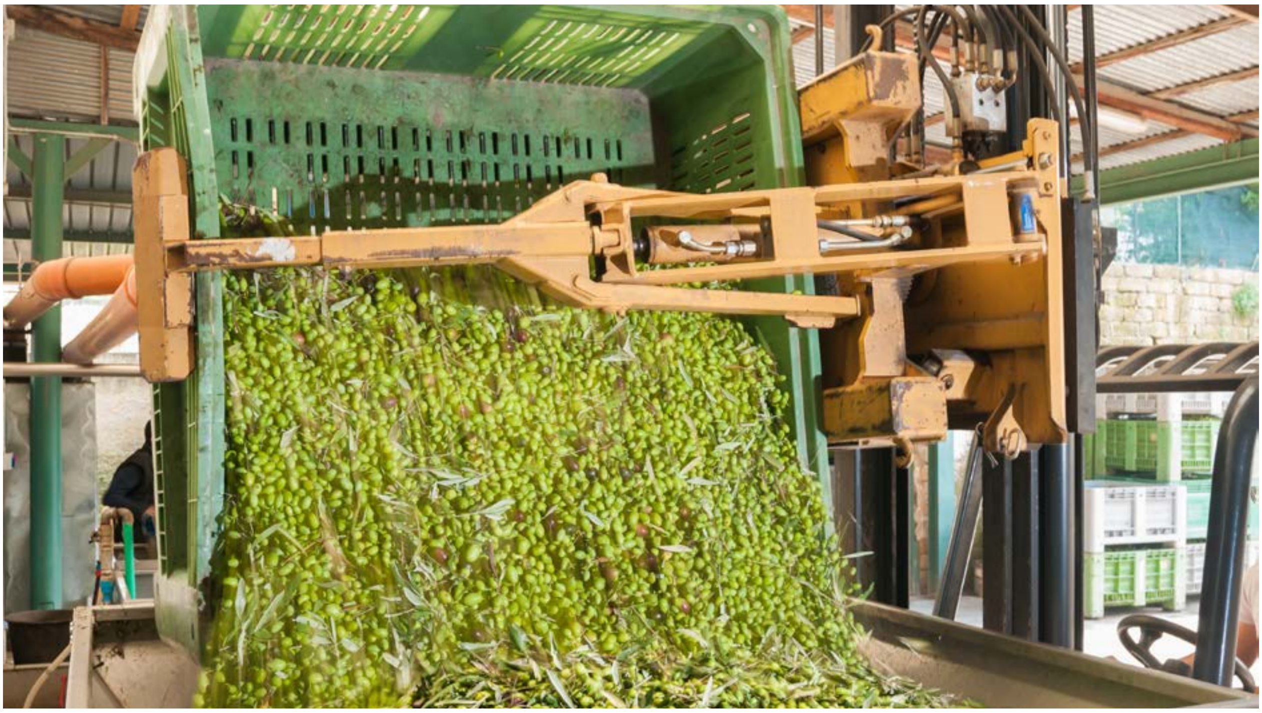
3.3 Transitioning towards resilient vegetable oil systems

In the past, decision making in oil food systems primarily prioritised low-cost calorie production without due consideration for the environment, livelihoods, and nutrition (Table 4). However, for the future transformation of oil food systems, decisions should focus on a range of outcomes, including health, sustainability, resilience, inclusivity, and equity and rights, both in the short and long term. Instead of favouring food system globalisation without risk management policies, future decision-making should emphasise creating co-benefits through a portfolio of actions that mitigate risks and enable positive impacts. Past decisions were often made in isolated silos, neglecting potential benefits and risks across the entire food system, while future decision-making should engage representatives of rightsholders, stakeholders, sectors, and institutions with a vested interest in the outcome, including those from government, civil society and the private sector. Additionally, decisions in the past did not involve those affected by the issues. However, future decisions should incorporate the experiences, knowledge, and rights of these individuals, communities and peoples. We reiterate the key points about decision-making in oil food systems (Table 4).

Table 4 A different way of making decisions in oil food systems.

Decision making in the past	Decision making needed for future oil food systems transformation
Decisions focused on short term and favoured productivity of low-cost calories over environment, livelihoods, and nutrition	Decisions that consider the range of food systems outcomes, such as producing enough calories and income, while being healthy, sustainable, resilient, inclusive, and equitable. This requires explicit consideration of trade-offs and synergies, over short- and long terms.
Decisions favoured food systems globalisation without complementary policies to manage the risks	Decision making focused on creating co-benefits with a portfolio of complementary actions to mitigate risks and enable impact
Decisions made in siloed spaces about single issues with little consideration for benefits and risks elsewhere in food systems	Decision making that engages the stakeholders, sectors, and institutions with a stake in the outcome
Decisions made without inclusion of people affected by the problem	Decisions that incorporate the experience, knowledge, and rights of those affected

Source: Prepared by the report editors, adapted from [119].



⟶ *Olives are processed into oil before being distributed to wholesalers and retailers*, by Marco Ossino, Shutterstock.

Learning from the above system and value chain contexts, we identify several factors relevant to the transition towards more resilient vegetable oil food systems. Resilience refers to the capacity of a food system and its units at multiple levels to sustain sufficient, appropriate, and accessible food to all [120]. Overall, the goal is that oils continue to provide nutritious food and other products for all, while protecting and enhancing biodiversity, reducing negative climate impacts, and respecting human rights and socio-economic contributions [4,121]. Transitioning towards resilient oil food systems involves considerations that extend beyond the scope of individual farms and companies. These factors operate at various scales, ranging from biome-wide and landscape considerations to country-wide production, sourcing, and purchasing policies. For effective implementation, transparency is crucial (Box 10).

Central to these considerations is the concept of production within planetary limits [122]. This includes accounting for factors, such as food production, conservation requirements, and the prevention of exceeding environmental and social boundaries. Optimal resource utilisation is a critical consideration in this, aiming to achieve the highest productivity amidst conflicting demands for land use. This involves addressing both food production and environmental conservation, extending to non-land-based sources like single-cell oils (see Chapter 6.1). All this requires comprehensive land use planning at a biome or landscape scale that considers conflicting interests and the promotion of landscape connectivity.

Good practices matter greatly for that and should include soil organic carbon enhancement, efficient water and pest control methods, and creating favourable conditions for wildlife through improved undergrowth management. It also involves adopting regenerative and agro-ecological approaches. Such practices should ensure respect for human rights, in line with international law and standards. These include the rights of Indigenous peoples, local communities, workers, and others. They also extend to responsible and respectful social relations with workers and surrounding communities, including respecting labour and land rights while maintaining respectful relations between consumer and producer countries. Fairness in production and consumption is crucial and involves ensuring fair prices, wages, and sustainability incentives for producers. This supports sustainability requirements and resilient land use models in producing countries. In essence, achieving resilient vegetable oil systems requires a comprehensive and integrated approach that considers these diverse factors at multiple scales.

Box 10

Transparency in value chains of oils

Transparency is important to understand and clarify the social and environmental impacts of oils. Transparency in oil value chains is bound with positive connotations. More transparency is better for the sustainability of chains, and the empowerment of specific stakeholders within chains who generally hold less power like farmers, consumers, and civil society. As a greater level of importance is attributed to local to global transparency within oil value chains, it may become an object of power and if not addressed may increase existing struggles between the private sector, states, consumers, and civil society organisations rather than promote partnerships.

A unified and standard global oil value chain transparency index could help understand local and regional differences of globally marketed commodities. Transparency can be a normative criterion related to democracy, participation, accountability, and right-to-know. Transparency can empower weaker participants and hold more powerful accountable by reducing imbalances in information, enabling more equal participation in controversial situations, and enhancing accountability. Therefore, transparency should not only assume a top-down or bottom-up outlook but a linked network and reciprocal feedback process. Transparency is also about politics and disclosure of practices that are currently blind spots, cloudy, secretive, or invisible (see Chapter 7.2) and are generally related to improved sustainability and governance, for example on:

- **Nutritional aspects:** the properties of oils which are beneficial or harmful to human health
- **Profits:** who gains what and how much at different stages in a value chain
- **Environmental impacts:** such as previous land use and ecological consequences of oil value chains
- **Social responsibility:** such as wages and incomes of workers compared to decent wage or living income benchmarks
- **Accountability and responsibility and risk management** by value chain actors
- **Consumer trust:** confidence and awareness of consumers in oil products
- **Quality control** of oil products
- **Responsible sourcing** of raw materials
- **Regulatory compliance:** documentation, compliance, traceability, and ethical practices
- **Market access and benefit sharing:** access to broader range of customers for smallholder farmers and other less powerful stakeholders

The Accountability Framework [123] is an example of new transparency frameworks. It is a practical guide for ethical supply chains in agriculture and forestry. Intended for companies, financial institutions, and others, it comprises 12 core principles and operational guidance. The Framework addresses issues like deforestation, land conversion, and human rights, as well as operational aspects including due diligence, traceability, supply chain management, and monitoring. Published in 2019 after a global consultation involving various stakeholders, the document has evolved since. The Accountability Framework Initiative has developed a standardised Methodology to assess progress towards deforestation-free supply chains, which could widely enhance corporate disclosure platforms and reporting. Other examples of transparency initiatives in vegetable oil systems include TRASE [124], SPOTT [125], the European Union Corporate Sustainability Reporting Directive (CSRD), Taskforce on Nature-related Financial Disclosures (TNFD) [126].

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Smallholder coconut farmers and workers in the rural Mekong Delta, South Vietnam,
by xuanhuongho, 2015, Shutterstock.

4

Impacts and outcomes

To determine the environmental impact of vegetable oils, we searched the recent scientific literature on key topics. Where possible, we used data from lifecycle analysis, which quantify the greenhouse gas emissions, energy use, and water consumption of products rather than environmental impacts like of just production. We mapped spatial patterns to highlight important points. Detailed methods can be found in the Appendix.

4.1 The environmental outcomes

4.1.1 Crops and loss of natural ecosystems and their services

Oil crops make up 37% (543 mha) of the land allocated to crop production globally, of which 206 mha is maize. In total these oil crops expanded their area (41%) more than the croplands average between 2003 and 2019 [15]. Expanding agriculture is the principal cause of global biodiversity decline [127], a major contributor to nitrogen and phosphorus pollution [128], land degradation [129] and freshwater depletion [130]. From 2003 to 2019, global cropland areas increased by 9%, with a near doubling of the annual expansion rate, primarily due to agricultural expansion in Africa and South America [131]. Forty-nine percent of the new cropland area replaced natural vegetation, indicating a conflict between the global framework goals (see Chapter 1.5) of producing food and protecting terrestrial ecosystems [131]. Such expansion risks incurring lasting damage to the habitability of the planet [122]. The discussion on ecosystem and ecosystem services impacts from expanding oil crops has focused especially on tropical forests and the role of oil palm and soybean expansion in driving deforestation [132-134]. All oil crops, however, have replaced natural ecosystems, although some more recently than others (Box 11). The biomes that are most threatened by agricultural expansion and other factors are: i) Temperate Grasslands, Savannas and Shrublands and ii) Mediterranean Forests, Woodlands and Scrub – of which 45.8% and 41.4% respectively, had been converted in 2005 with only 4.6% and 5.0% of these biomes protected [135].

Box 11

Different temporal contexts of biodiversity loss and oil crops

The ecological impact of vegetable oils on biodiversity can be categorised into two temporal scenarios: contemporary and historical. In the contemporary scenario, ongoing alterations in land cover are exerting negative effects on biodiversity. Worldwide, natural land cover is being displaced by vegetable oil crops, at the detriment of biodiversity. The primary strategy to mitigate biodiversity loss associated with oil crop expansion is to curtail the encroachment of these crops into natural habitats. Emphasis should be placed on developing oil crops on land already affected or enhancing yields within existing oil crop systems. In situations where development is inevitable, adopting a land-sparing approach along with yield enhancements appears to be the most effective strategy in terms of overall biodiversity impact, particularly for species reliant on extensive contiguous habitat [136]. However, it is crucial to note that an in-depth analysis encompassing various global crop species indicated that simplified landscapes generally have a negative influence on crop yields due to the loss of pollinators and natural pest control [137]. Recent expansion of crops, particularly maize and soybean, on marginal lands in the United States has led to lower crop yields compared to the national average while also adversely impacting local wildlife and plant populations [138].

In the historical scenario, past impacts on biodiversity have shaped the current status of oil crop areas, which tend to exhibit low biodiversity. In such regions, opportunities exist for enhancing biodiversity. This can be achieved through transitions from large-scale industrial monoculture systems to mixed cropping approaches, or by incorporating practices that promote biodiversity within expansive industrial food systems, all the while minimising potential yield losses [139].

Table 5 Relative presence of oil crops based on Mapspam [44] in threatened ecosystems. Also, see criteria for IUCN Red List of Ecosystems [143]

Oil crops	Ecosystems reduced to 20% of original size and less than 17% protection	Ecosystems reduced to 50% of original size and less than 17% protection	Ecosystems reduced to 70% of original size and less than 30% protection	Oil crops within the crisis ecosystem	Oil crops outside the crisis ecosystem
Cotton	25.1%	17.0%	1.8%	43.9%	56.1%
Rapeseed	18.8%	13.5%	9.3%	41.6%	58.4%
Sunflower	17.4%	11.6%	10.9%	39.9%	60.1%
Soybean	16.1%	22.2%	8.7%	47.0%	53.0%
Groundnut	12.8%	12.1%	2.9%	27.8%	72.2%
Sesame	12.0%	12.4%	1.9%	26.4%	73.6%
Maize	11.8%	16.5%	11.6%	39.9%	60.1%
Olives	9.6%	19.6%	2.8%	32.0%	68.0%
Coconut	4.9%	11.9%	13.9%	30.7%	69.3%
Linseed	0.2%	0.1%	0.0%	0.3%	99.7%
Oil palm	0.0%	23.0%	14.8%	37.8%	62.2%

Source: Data compiled by the report editors, based on Meijaard et al. (2021) [144].

While a specific study directly examining the biodiversity impacts of vegetable oils and their corresponding food systems is lacking, a comprehensive meta-analysis investigating the broader consequences of agriculture on biodiversity in tropical regions has uncovered patterns that hold relevance for vegetable oils as well [140]. The researchers identified a trend where crops cultivated in large, uniform landscapes tend to exhibit lower biodiversity than crops grown in agroforests or shaded plantations. Similarly, a study conducted in Canada, with a focus on bird diversity within mixed agricultural landscapes, observed a general decline in overall biodiversity compared to natural ecosystems [141].

A global study specifically centred on potential biofuel crops and their impact on biodiversity revealed noteworthy findings. Among the various vegetable oil crops examined, cotton and soybean were identified as having the most substantial negative impact on species richness of plants and animals. This was followed by maize and oil palm, while rapeseed exhibited the lowest negative impact [142]. However, it is essential to highlight that this study did not differentiate between the various food systems or production scales and methods of these crops.

Table 5 shows that the growing areas of cotton, soybean, rapeseed, sunflower and maize are associated with the globally most threatened terrestrial ecosystems. Linseed, coconut and oil palm are grown in areas that are less critically threatened, with 99.7% of linseed being grown outside crisis ecosystems.

Table 5 provides a different way of looking at the relative threats of different vegetable oil crops to global biodiversity and ecosystems. The focus from the public, media and researchers is on immediate impacts of oil crop development on species diversity and natural ecosystems, with oil palm impacts being most frequently noted [145.] The negative biodiversity impacts of oil palm development are well studied and clear. Clearing tropical forests for oil palm results in strong local and regional biodiversity declines [11,54,146,147]. Oil palm is commonly produced in monocultures and, compared to the forests that they replace, these monocultures are far less structurally complex; that is, they have only one canopy layer instead of multiple forest strata, they lack a complex and rich understory vegetation, and they are almost devoid of leaf litter and woody debris, all of which are needed to support the high biodiversity of tropical forests [53]. In addition, pesticides, chemical fertilisers, and frequent human disturbance make oil palm plantations inhospitable for most forest species. Popular examples of species incompatible with plantations include the critically endangered orangutans and tigers [148]. Equally at risk are certain birds [149], amphibians [150], fishes [151], plants [152], insects [153], soil fungi [154,155] and soil fauna [156].

Box 12

Oil crops threatening high diversity grassland

The La Plata basin, home to the main grassland area in South America and the Pampas ecoregions in Argentina, is critical for biodiversity, hosting over 550 grass species and approximately 500 bird species [161]. Unfortunately, anthropogenic activities such as livestock grazing and soy croplands have led to the reduction of the once vast 750,000 km^2 area of grasslands in the La Plata basin [161]. Specifically, the Pampas grasslands in Argentina have been greatly reduced, with only around 30% remaining in natural or semi-natural condition and just 1% being formally protected [161]. The speed of agricultural expansion, particularly in soybean production, over the last 40 years has played a significant role in this decline.

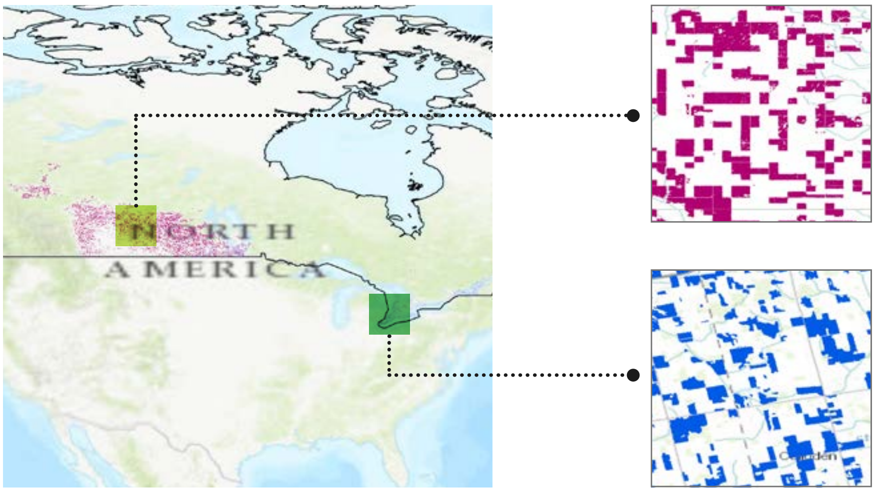
What is often left unmentioned in the discussion about the impacts of oil crops on natural ecosystems is that all oil crops have low biodiversity compared to the natural ecosystems they replaced. This is even more the case for annual crops (such as soybean, rapeseed) than perennial crops (such as oil palm and coconut) (see Table 1 and next section). Crops like maize, rapeseed and soybean are often grown in areas of previously species-rich grasslands, resulting in, for example, major decreases in North American bird diversity and abundance [157]. Similar conversions of grassland ecosystems are taking place in South America (Box 12). The frequently encountered argument on social media, suggesting that the losses of natural ecosystems in regions such as North America, Europe, India, Australia, or West Asia are of lesser significance due to their historical nature, compared to more recent losses in countries like Indonesia, Malaysia, or Brazil, fails to acknowledge the ongoing degradation of natural ecosystems in the former regions [158-160] (Figure 29). Moreover, it neglects the precarious state of the remaining ecosystems in these areas, which are frequently under severe threat and require ecological restoration.

⟶ *North American farmland birds, such as the Eastern Meadowlark, have experienced population declines due to agricultural intensification,*
by Andy Morffew, 2013, Flickr.

Canadian rapeseed and soybean expansion into deforested areas

Total forest loss in Canada, 2001–2022

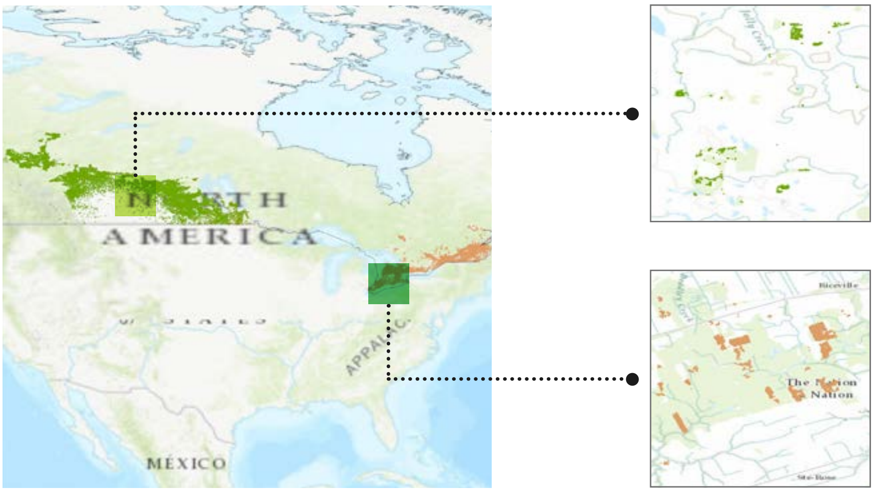
Rapeseed & soybean total areas, 2021



Rapeseed (2021)
Total area = 28,449,005 ha

Soybean (2021)
Total area = 2,411,499 ha

Rapeseed & soybean forest loss, 2001–2022



Rapeseed-forest loss (2001–2022)
Total area = 136,721 ha

Soybean-forest loss (2001–2022)
Total area = 16,011 ha

Data sources:
1. Government of Canada (2021). Annual Crop Inventory [online dataset]. Agriculture and Agri-Food Canada; Science and Technology Branch.
2. Hansen/UMD/Google/USGS/NASA. Global Forest Change, 2000-2022

Figure 29 Canadian rapeseed and soybean expansion into areas that were deforested between 2001 and 2022. In that period, Canada lost 48.9 mha of its tree cover. Source: Data compiled by the report editors, from [162].

4.1.2 Biodiversity threat abatement and ecological restoration

In this analysis (for methods, see Appendix), we used the Species Threat Abatement and Restoration (STAR) metric [163] to quantify the relative opportunity for reducing global species extinction risk through acting in the footprints of twelve different oil crops. Oil crop footprints are not just abstract production zones but can also overlap with important habitat for threatened species. Overall, acting in these footprints represents 2% of the total global opportunity for reducing species extinction risk through abating threats to species in their current habitats and 5% of the opportunity from habitat restoration. Looking at the global footprints of individual oil crops (Figure 30), maize, coconut and oil palm represent the greatest opportunities for threat abatement, and maize, coconut and soybean represent the greatest opportunities for restoration when considering the entire footprints. The size of this opportunity is driven both by the locations of the production zones and the threatened species that occur there, as well as the overall area of the footprint. Looking not across the entire footprint but considering the average conservation opportunity in a given 100 km^2, we find that coconut has the highest threat abatement value, followed by oil palm and maize. For restoration opportunity, coconut once again has the highest value, followed by maize, and then oil palm (Figure 30).

Considering the set of potential conservation gains that can be achieved by acting within oil crop production zones, Figure 31 shows the relative opportunity for conservation that comes from acting in the global footprint of each crop. Abating threats to species in maize production zones represents 53.90% of the global opportunity, driven both by the fact that it covers the largest area, as well as the number and type of threatened species that are found in those places.

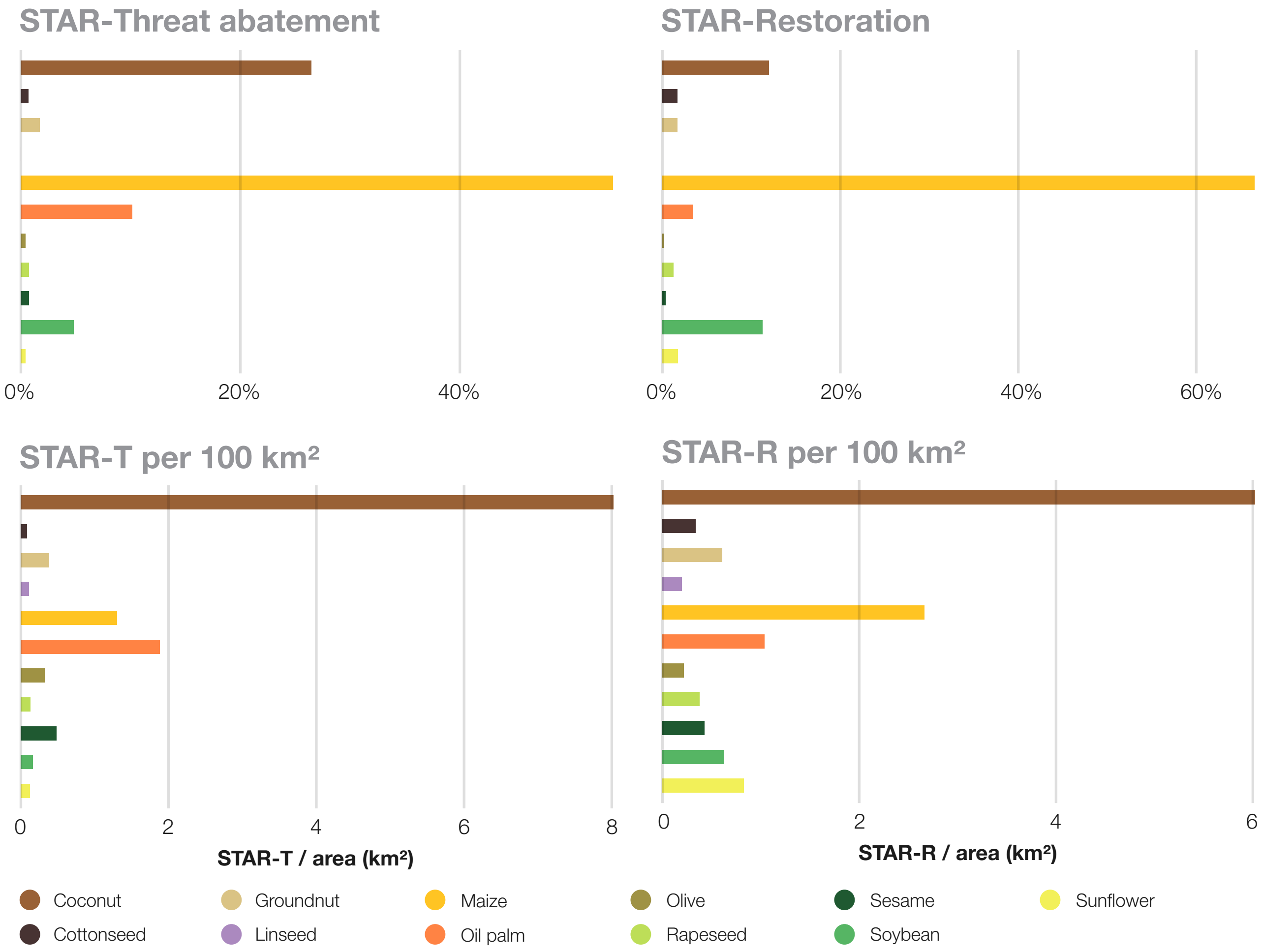


Figure 30 Opportunity for reducing species extinction risk through threat abatement or restoration actions across the global footprints of different oil crops. Sorted by STAR threat abatement value per 100 km^2. Source: Data compiled by the report editors. Bottom right figure shows the STAR score relative to total crop area (km^2). For methods, see Appendix.

Relative STAR Threat Abatement opportunity

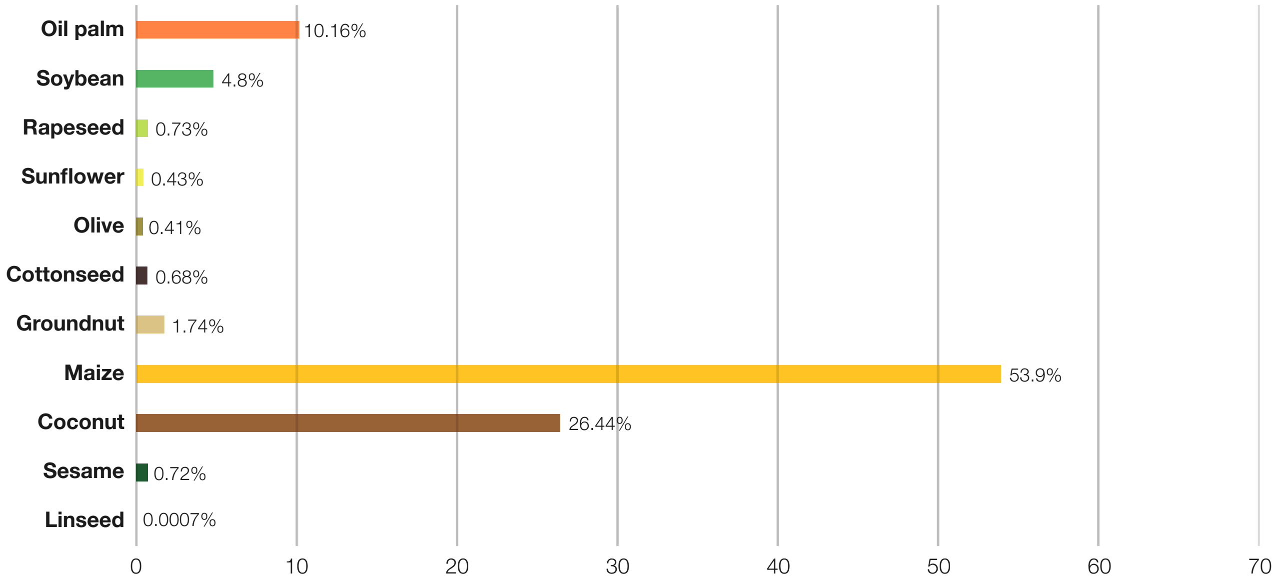


Figure 31 The relative percentage of the total opportunity for reducing global species extinction risk through threat abatement in all oil crop footprints that could be achieved by acting in each individual oil crop. Source: Data compiled by the report editors.

Relative STAR Restoration opportunity

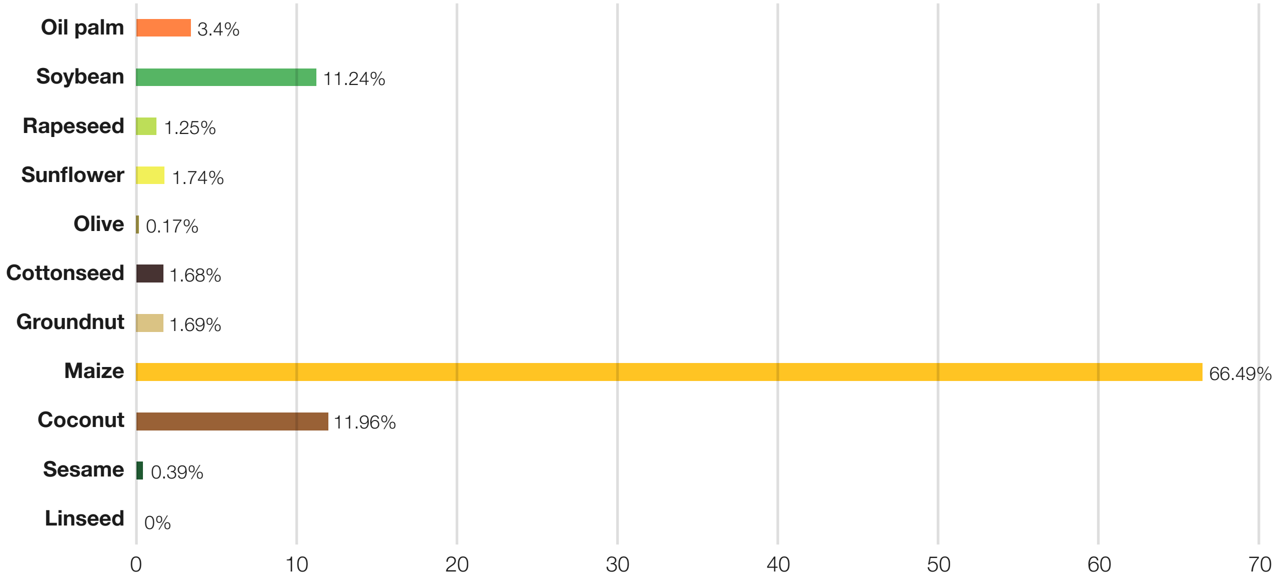


Figure 32 The relative percentage of the total opportunity for reducing global species extinction risk through restoration actions in all oil crop footprints that could be achieved by acting in each individual oil crop. Source: Data compiled by the report editors.

Likewise, Figure 32 shows the relative opportunity for restoration that comes from acting in the global footprint of each crop. Restoration in historical habitat that occurs in maize production zones represents 66.49% of the opportunity.

Overall, oil crop production zones have a critical role to play in helping deliver the Kunming-Montreal Global Biodiversity Framework. This stems both from addressing threats to species from the production itself, as well as threats that are not necessarily driven by the production but occur in production zones. At a global level, there is large variability across different oil crops, with coconut, oil palm, and maize emerging as ones that might deserve special attention, and there will also be large variability within individual footprints based on the species and threats present locally, and the type of oil crop production.

4.1.3 Agricultural intensification and annual and perennials oil crops

Agricultural intensity pertains to the proportion of resources invested in relation to the agricultural yield, whether on a large or small scale of farmland. Numerous studies have demonstrated a direct link between the intensification of agriculture and a decline in biodiversity. The introduction of fertilisers and pesticides into agricultural systems has adverse consequences for ecosystems. For instance, one study spanning 38 years revealed a noteworthy reduction in amphibian populations within pond habitats due to such intensification [164]. Another study showed that over a six-year period, grassland and insectivorous birds in the U.S. declined annually by 4% and 3%, respectively, because of exposure to neonicotinoids which impairs the biological functions of these bird species [165]. Similarly, bird populations in the United Kingdom declined with increasing use of pesticides such as glyphosate and metaldehyde [166]. Agrochemical pollution also extends to freshwater and marine ecosystems, and water quality is compromised as pollution levels surge [167].

All oil crops negatively impact biodiversity when compared to the natural ecosystems they displace (as depicted in Table 5). Nevertheless, the way these crops are managed can significantly influence the diversity and abundance of species within these cultivated areas (as indicated in Table 6). Perennial crops like olives, with their enduring root systems, help preserve soil biodiversity and mitigate erosion. Conversely, annual oil crops, such as soybeans, sunflowers, or maize, tend to degrade soil health, necessitating the application of external chemicals to enhance yield. Similarly, coconut tree farming contributes to soil degradation as the palms' productivity diminishes with age, prompting increased fertiliser usage [168].

A consistent pattern emerges from these studies: the more intensive the crop management (including monoculture practices, irrigation, and the absence of nearby natural vegetation), the lower the biodiversity. This pattern appears to hold true for all oil crops, underscoring the importance of adopting improved crop management and the protection of natural ecosystems within and around cultivated areas, whether terrestrial or freshwater, to achieve positive biodiversity outcomes.

Table 6 Examples of different management types of vegetable oil crops and impacts on biodiversity, ecosystem services and yields.

Crop	Production system comparison	Biodiversity outcome	Ref
Canola	Monocultures vs intercropping	Higher insect abundance in intercropping	169
Olive oil	Traditional vs intensive plantation	Higher biodiversity in traditional systems but lower yields	170,171
	Organic vs conventional	40% higher plant species richness in organic settings	172
	Intensified olive plantation	The more intensified, the greater the negative impact on wintering bird species	173
	Irrigated olive vs rainfed olive and annual crops	Irrigated olive groves had negative impacts on birds	174
	Traditional vs intensive vs super-intensive orchards	Bird species richness declined significantly with intensity of management	175
Sunflower	Fields with or without woody or non-woody margin	Avian species richness was almost double when there was woody vegetation and reduced damage from moths	176
	Fields with or without wildflower strips	Pollinator abundance and yield increase in areas with wildflower strips	177
Oil palm	Plantations with or without small forest patches	Forest patches increased above and underground species diversity and maintained similar yields	139,178
Soybean	Interspersing strips of prairie vegetation with corn and soybean	Prairie strips increase pollinator abundance as well as bird species richness and abundance	179
	Tilled vs no-till fields	No-till had higher bird densities as well as nesting density	180
Maize	Pure maize vs maize intercropped with beans	Intercropped areas had higher bumblebee and honeybee activity and bee species richness, but not higher for carabid beetles	181
	With vs without wildflower strips	Increases flower and pollinator diversity but reduced yields	182

Source: Data compiled by the report editors.

Box 13

Two key concepts for biodiversity and vegetable oils: biodiversity values of different landscapes, and the benefits of land sparing vs sharing

Wildlife diversity and abundance is higher in natural and undisturbed areas compared to human-modified landscapes and those dominated by agriculture. For example, oil palm plantations contain lower species diversity and abundance for most taxonomic groups when compared to natural forest [183,184]. Plant diversity in some plantations is less than 1% of that in natural forests [183]. Recorded mammal diversity in oil palm is 47–90% lower than in natural forest [185,186], and strongly depends on the proximity of natural forests. Oil palm plantations generally exclude forest specialist species [187,188], which are often those species of greatest conservation importance. For example, forest-dependent gibbons (Hylobatidae) cannot survive in stands of monocultural oil palm, but can make use of interspersed forest fragments within an oil palm matrix [183].

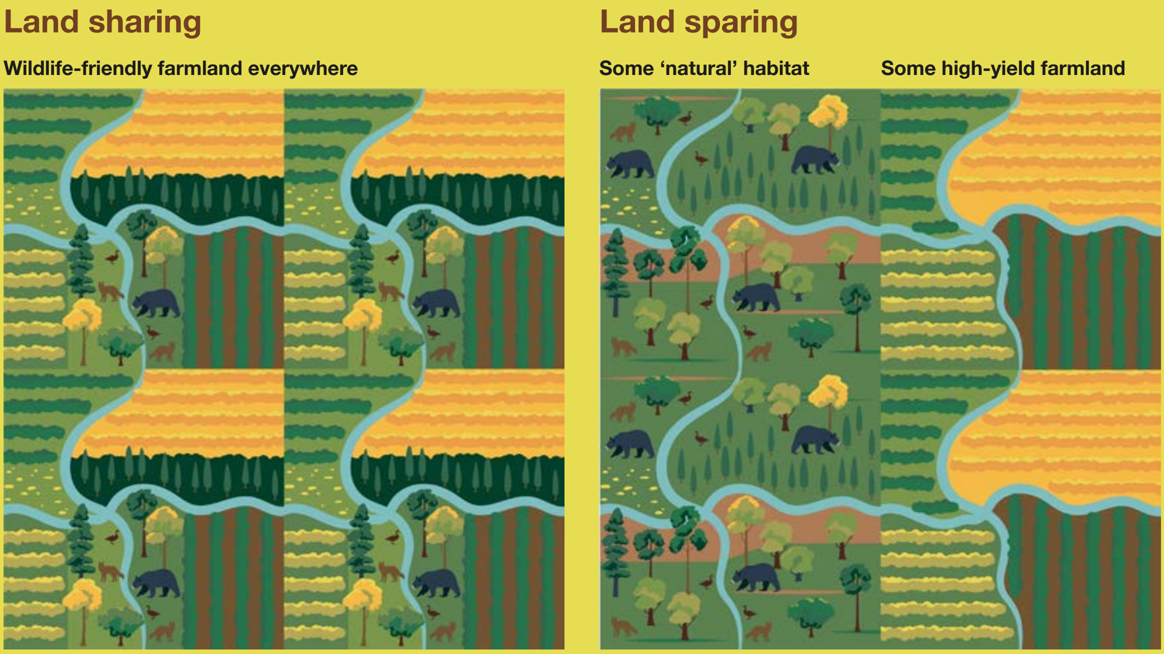
The other dimension determining biodiversity values is the intensity of land management. Monocultures of oil crops have lower diversity than more heterogeneous landscapes with oil crops, and areas of natural vegetation. Much depends though on the quality of management, and, for example, oil palm plantations with effectively protected conservation areas maintain a high diversity of animal species in oil palm areas [189,190]. Factors that are likely to positively influence biodiversity values in both industrial-scale and smallholder plantations include higher landscape heterogeneity, the presence of large forest patches or other natural ecosystems and connectivity among these [191], and the plant diversity and structure of undergrowth vegetation. For example, in palm areas where there are systematic cattle grazing, bird and dung beetle abundance and diversity increase [192,193].

Because oil palm is perennial, associated plant diversity may exceed that of annual oil crops. One study found 298 plant species in the oil palm undergrowth [194], and another found 16 species of fern on oil palm trunks [195],

⟶ *Forest-dependent gibbons, such as the white-handed gibbon, cannot survive in stands of monocultural oil palm, but can make use of interspersed forest fragments within an oil palm matrix*, by KongkhamWichit, 2013, Wikimedia Commons.

while a meta-analysis of plant diversity in a range of annual crops, including oil crops, found between one and 15 associated plant species [196]. Similarly, some vertebrate species will utilise plantations. For instance, planted oil palm in Malaysian Borneo supported 22 of the 63 mammal species found in forest habitats [185], 31 of 130 bird species [197], and most of them are relatively common species. Still, it is important to emphasise that no vegetable crop areas can achieve the same wildlife diversity and abundance of natural ecosystems, and conserving these ecosystems therefore remains essential.

This need for conservation is an important part of the debate on land sharing versus land sparing [136,187,198]. Land sparing aims to set aside large tracts of land for exclusive wildlife use while intensifying agriculture on existing farmland to keep people and wildlife apart (Figure 33). Land sharing seeks coexistence between agricultural land use and biodiversity through small-scale eco-friendly farming and sustainable forest management in patchworks of low-intensity agriculture. Empirical evaluations suggest that land sparing results in better outcomes for wildlife diversity and abundance, at least in the time frames and contexts measured [187,199,200]. However, there are long-term concerns about how to ensure land is spared in practice, and over the long term viability of isolated protected areas within intensive agricultural matrices [201]. The offsite impacts of intensive agriculture, such as the use of fertilisers, herbicides, fungicides, and pesticides [127,202], can also be harmful to wildlife [203]. Research suggests that intensification may be necessary but not sufficient for land sparing [204,205]. So, land sparing is the modelled best approach for biodiversity conservation, but yield increases do not guarantee that land will be spared for nature. The reality for wildlife conservation in vegetable oil production areas is likely to remain a mixed sharing and sparing model, where parts of the land will need to be included in protected areas, because certain conservation objectives simply cannot be achieved in agricultural landscapes.

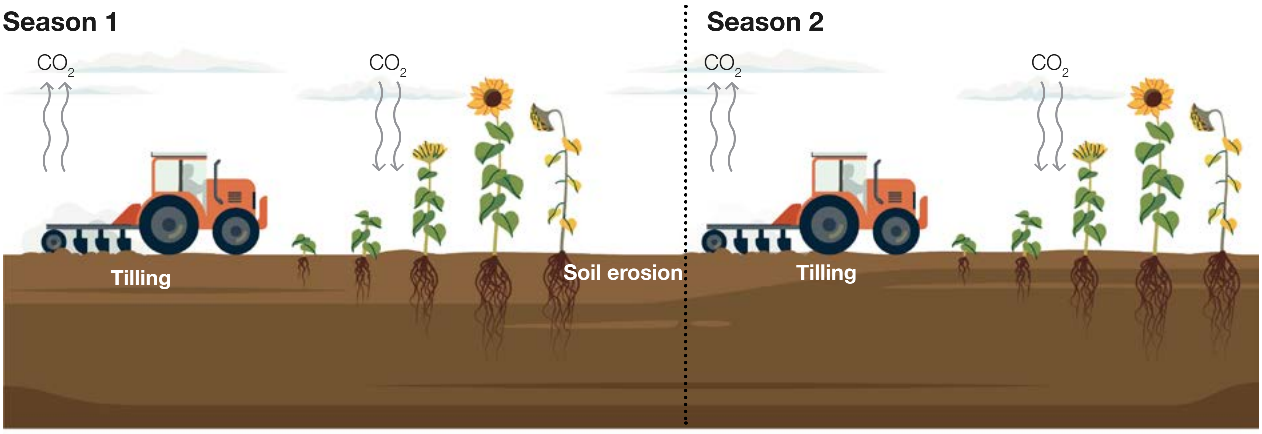


Entire region managed as **wildlife-friendly** farmland, which *shares* the function of food production & biodiversity conservation. To maintain overall food production, there is no room for natural habitat.

High-yield farmland delivers food production over a smaller area, so land elsewhere in the region can be *spared* as natural habitat.

Figure 33 Two options for achieving both food production and biodiversity conservation objectives. Source: Prepared by the report editors, adapted from avleveri (2020) [206].

Annual crop



Perennial crop

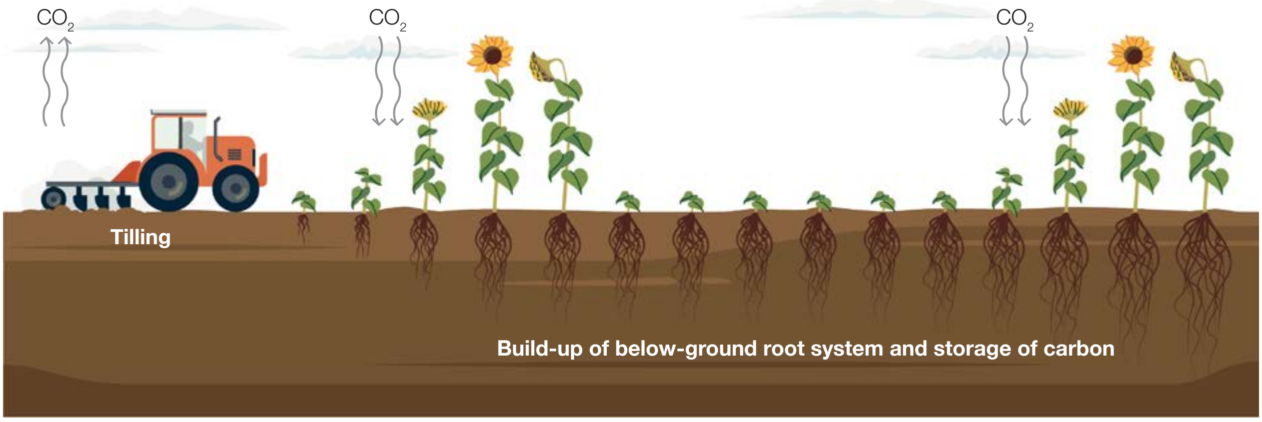


Figure 34 The difference between annual and perennial crops. **(A)** Annual crops have a single growth season with annual cultivation generally dependent on machines for tilling and sowing. Tillage disrupts soil aggregates, exposing the previously protected organic matter to microbes resulting in elevated respiration and losses of CO$_2$ to the atmosphere. **(B)** Perennial crops need tilling and sowing only in the first year and thereafter are viable for several seasons. Source: Prepared by the report editors, adapted from Chapman et al. (2020) [210].

There are numerous studies that advocate for the use of perennial rather than annual crops. Annual crops constitute 60–80% of global cropland and about 75% of calorie consumption [207]. Perennial staple crops, however, constitute a small but growing proportion of cropland, regardless of being in an industry where short-term returns and continuous increases in yields are favoured [208]. A comprehensive study [209] highlighted the transformative potential of perennial crops in addressing the pressing challenges of global food security and environmental sustainability. Perennial crops offer a promising solution to feeding a growing population while conserving vital natural resources and wildlife habitats. Their extensive root systems (Figure 34) contribute to mitigating environmental challenges such as nitrogen leaching and soil erosion [209], while supporting pollinators and other beneficial insects [209].

> “Perennial crops offer a promising solution to feeding a growing population while conserving vital natural resources and wildlife habitats.”

Table 7 Examples of perennial oil crops and their key characteristics

Crop	Crop cycle or tree age	Time until initial production	Other benefits or drawbacks	Ref
Perennial sunflower (*Helianthus annuus × Helianthus tuberosus*)	10 years	2 years	Can tolerate drought and poor soils	209
Oil palm (*Elaeis guineensis*)	>25 years	3 years	High oil yield per unit area, but requires large amounts of water and fertiliser	216
Olive (*Olea europaea*)	500 years	3–5 years	Can tolerate drought and poor soils, but susceptible to pests and diseases	217
Coconut (*Cocos nucifera*)	60–100 years	3–8 years	High economic value and can be used for a wide range of products, but requires large amounts of water and is susceptible to pests and diseases	218,219
Perennial maize (*Zea mays × Tripsacum dactyloides*)	40 years	2–3 years	Tolerant to drought and poor soils, but lower yields than annual maize	209 ,210,220
Perennial maize (*Zea diploperennis*)	20 years	3–4 years	Highly resistant to many diseases and pests, but lower yields than annual maize	209,220

Source: Data compiled by the report editors.

Perennial oil crops include a wide range of plant species [210] (Table 7). In addition to the impact of production systems on biodiversity, there are likely also significant differences between crop types (Table 1). Perennial crops have potential advantages in minimising the loss of the natural ecosystem and biodiversity while maintaining their long-term production, as they can be grown in polyculture while allowing complex vegetation to develop over time [209,211]. On the other hand, unlike perennial crops, annual crops require regular replanting, which promotes soil disturbance and soil organic matter loss [212]. Shorter rooting systems make annual crops less able to store water and nutrients than perennials [213].

> "Despite their potential benefits, perennial crops present challenges to food security as they have slower initial growth compared to annual crops, which delays the onset of yields."

Perennial plants play a pivotal role in maintaining the quality of habitats within the agricultural landscape matrix. They facilitate improved organism movement between habitat patches (such as orangutans in oil palm landscapes with forest patches [214]) and can function as primary habitat patches themselves [215]. Other services that are better supplied by perennial than annual crops include soil carbon sequestration, pollination support, regulation of pests, maintenance of water quality, and prevention of soil erosion [211].

Despite their potential benefits, perennial crops present challenges to food security as they have slower initial growth compared to annual crops, which delays the onset of yields (Table 7). This poses a problem to farmers who require immediate or short-term returns on their investments. The nature of perennial crops also complicates crop rotation, as the slower rotation pace can lead to heightened pathogen, pest, or weed build-up during the perennial phase. Hydrologically, perennial crops can lower water tables and reduce surface flow, impacting water availability. Longer lifespan of perennial crops limits the flexibility of the crops as they are harder to adapt to changing market demands or new varieties. Additionally, the transition from a conventional annual crop to perennial systems may involve significant upfront costs and adjustments in farming practices. Thus, while there are obvious benefits from a switch from annual to perennial crops, there are also costs.

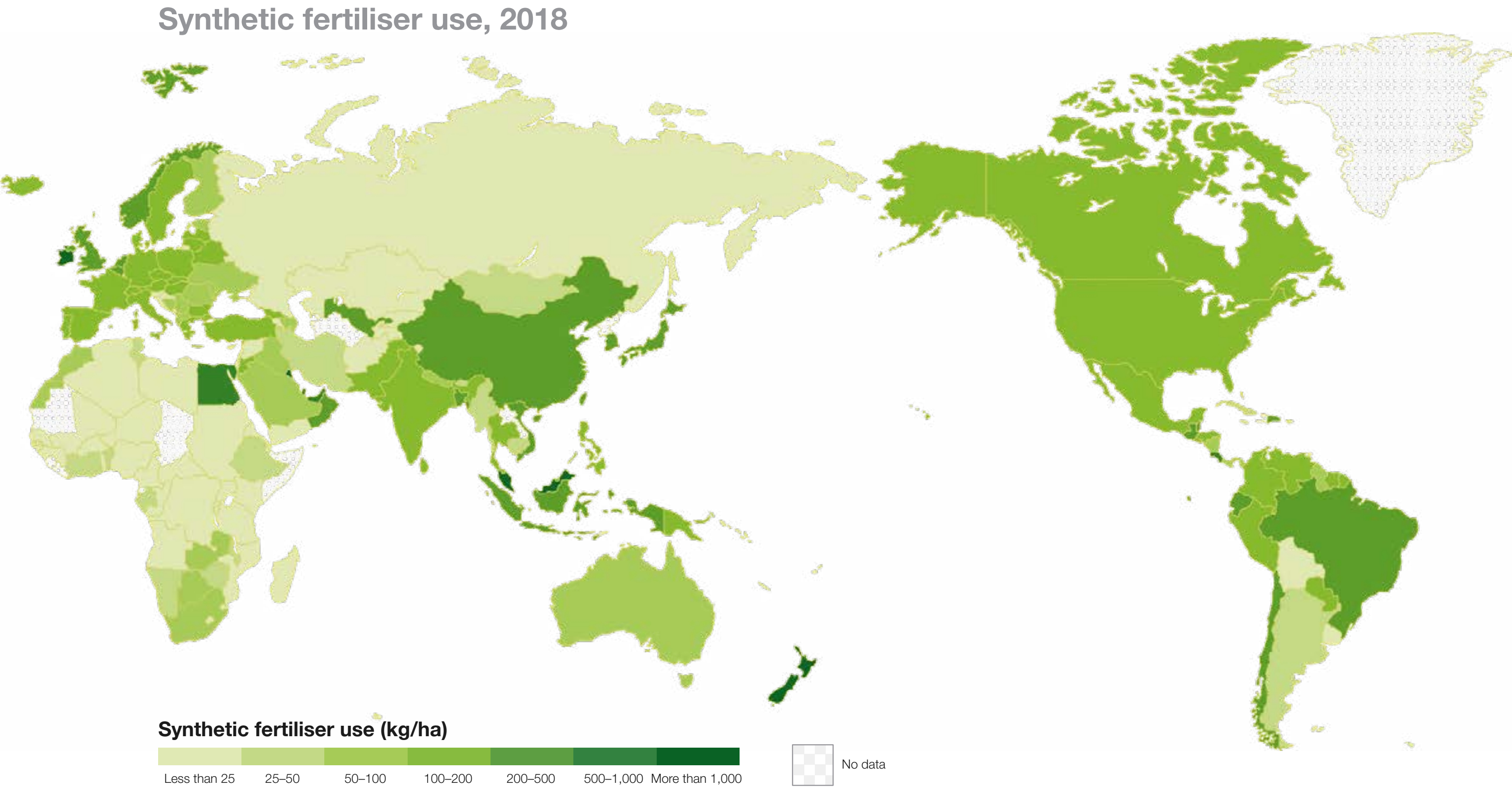


Figure 35 Synthetic fertiliser use in 2018 (kilograms per hectare of arable land). Source: Data compiled by the report editors, based on Viglione (2022) [225].

4.1.4 Fertiliser needs

Fertilisers are important for maintaining current agricultural production levels, but they are also associated with a wide range of problems. Global fertiliser consumption reached approximately 191 million tonnes in 2022, with nitrogen fertilisers accounting for approximately 56% of the total consumption [221]. Fertiliser production currently accounts for 2% of the energy used on Earth and is associated with nitrogen and phosphorus losses from agricultural land as well as ammonia (NH_3) volatilisation that exceed planetary boundaries [122,222]. Nitrogen fertilisers alone are responsible for more greenhouse gas emissions than commercial aviation (~2.1% of the global total [223]), because of their production and that more than half of the nitrogen applied is not taken up by the plants and converted to nitrous oxide, which has a warming potential about 265 times that of carbon dioxide [224]. Fertiliser application rates are high across the globe, except for much of Africa (Figure 35).

Among major oil crops, maize requires the highest fertiliser application, primarily in the form of nitrogen followed by cottonseed, soybean, rapeseed, and oil palm (Figure 36). Maize is typically cultivated in well-drained soils with multiple planting cycles, making them susceptible to nutrient leaching. Consequently, additional fertiliser application is common to ensure an adequate nutrient supply. Soybean, being a legume crop, benefits from its ability to fix atmospheric nitrogen, which reduces the reliance on synthetic fertilisers and enhances overall efficiency. On the other hand, oil palm requires the least amount of fertiliser to produce a tonne of oil (Figure 36). The fertiliser efficiency for other oil crops, including cottonseed, rapeseed, sunflower, linseed, sesame seed, groundnut, and olive, varies depending on specific crop requirements and agronomic practices.

By-products of oil production are increasingly used as organic fertiliser, for example, in rapeseed [226], soybean [227], oil palm [228], or sunflower [229]. This reduces the need for chemical fertilisers and benefits soil structure and biodiversity [230,231], and can be a major cost saver for producers, especially when prices of chemical fertilisers are high, where fertilisers in general represent a substantial share of management costs [232].

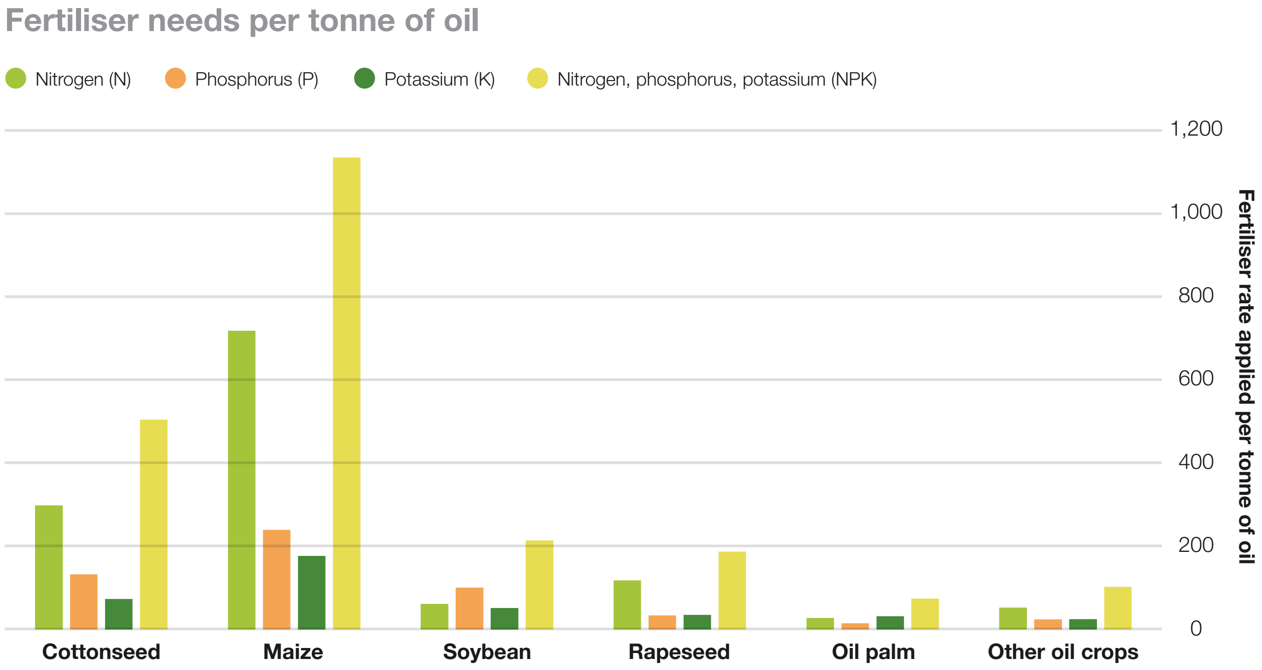


Figure 36 Fertiliser needs per tonne of oil produced. Source: Data compiled by the report editors, based on FAO (n.d.) [15]. For details on methods, see Appendix.

4.1.5 Soil health

Soil health is a critical component of sustainable agriculture, as healthy soils are essential for producing high-quality crops with minimal environmental impact. Soil organic matter (SOM) and soil biochemical properties are the most widely accepted indicators of soil quality [233]. Increased SOM leads to improved nutrient cycling, cation exchange capacity, buffering capacity, crop yield, and increased microbial biomass and resulting respiration. Proper soil management in agriculture can enhance soil quality. Because different vegetable oil crops are managed differently, impacts on soil health also vary, depending on factors, such as crop rotation, tillage practices, and nutrient management. Overall, soil health is, therefore, a critical factor to consider when selecting vegetable oil crops for cultivation. By using practices, such as diversified crop rotations, reduced tillage, and nutrient management, it is possible to improve soil health and promote the long-term sustainability of vegetable oil crop production. So-called ‘service crops’ that are grown simultaneously in mixtures with oil crops can also provide biological regulation and reduce the use of pesticides [234].

The excessive use of chemicals to fertilise soil and eliminate pests has deteriorated the soil health in many vegetable oil crop growing areas. Maintaining soil health can reduce operational costs [235], increase yield and crop quality [235], promote resistance to plant disease [236], and reduce soil erosion and surface run-off [237]. Practices such as incorporating high-crop-residue-producing crops with an intensive rooting system, for example wheat in crop rotations can be more effective to improve soil health than low-crop-residue-producing shallow-rooted crops, like rapeseed [238]. However, increasing the frequency of soybean in crop rotations may negatively impact crop productivity and soil health due to a greater risk of disease and loss of soil organic carbon. A study conducted in Wisconsin, U.S. found that soybean yields increased when grown one year out of three in three-crop rotations (such as corn-soybean-wheat) compared to being grown every other year in corn-soybean rotations [239]. Some studies [240,241] have found that crop rotations with a high frequency of soybean have led to decreased soil organic carbon storage due to low residue input by soybean. Soybean yield was reduced when it was grown continuously, but it was greater when grown in rotation with cereal crops. This suggests that reducing the frequency of soybean in rotations results in improved soil organic carbon storage, microbial activity, and increased crop yields. Furthermore, the negative impacts of soybean on soil health can be mitigated by including cereal crops in rotation [242].

There are several other ways to reduce the negative impacts of oil crops on soil health. Mulching in a smallholder oil palm plantation with empty fruit bunches increases yields by up to 39% while increasing 19% soil organic carbon content [243], although benefits vary with soil type [228]. Mixing inorganic and organic fertilisers [244], the use of polycultures [245], and the use of cover crops, such as the fern *Nephrolepis biserrata*, can also maintain soil health and decrease surface run-off and soil erosion [237]. Recent experiments show that oil palm agroforestry and the retention of natural forest patches within oil palm benefit soil health in planted oil palm areas (see Chapter 4.1.9).

Organic techniques involve the application of organic manure in combination with inorganic fertilisers, which has been found to be beneficial to soil health. This practice increases the available and total soil organic carbon, macro, secondary, and micro-nutrient status and improves soil microbial growth, thus enhancing soil fertility [246]. Adding organic matter to the soil through compost or manure improves soil fertility and structure. Using organic and inorganic fertilisers together as part of proper crop and soil management practices can increase soil microbial and enzyme activity, leading to improved soil health and higher seed yields for crops such as sunflowers.

Reduced tillage is another practice that minimises soil disturbance during planting and other operations to reduce erosion and maintain soil structure. Intensive tillage has long been recognised as detrimental to soil health, leading to a significant decline in environmental quality, biodiversity, and agricultural production [247,248,249].

4.1.6 Invasive species

Invasive species have gained significant attention due to their ecological and economic impacts [250]. A recent structured method evaluated the risk of species incursion and included some of the oil crops assessed in this study [250]. This approach assigns values to these categories to generate a simple scoring system for assessing the overall risk of a species becoming invasive and causing ecological disruptions, while describing the localities in which these oil crops are considered invasive (Table 8).

Coconut is generally overlooked in discussions about vegetable oil impacts and not many see this palm as a threat to biodiversity. It has a high-risk rating with a global invasiveness risk score of 28.8. The species possesses traits that contribute to its invasive potential, notably its capacity for natural dispersal, with its nuts capable of floating in seawater for up to 120 days before landing and germinating on new shores, which allows it to spread extensively without direct human intervention. Upon establishment in new coastal regions, the coconut palm can form dense, monospecific thickets, impacting local ecosystems [252]. A recent study identified coconut as a potential threat to tropical species, many of which are highly threatened and restricted to tropical islands where coconut is extensively grown [253]. In some of these islands, coconut is considered an invasive species that drives near-complete ecosystem state change when it becomes dominant [254].

Table 8 Oil crops and their associated Global Risk Score and Level

Oil crops	Species	Global risk score	Global risk level
Oil palm	*Elaeis guineensis*	4.32	Low
Coconut	*Cocos nucifera*	28.80	High
Olive	*Olea europaea*	26.88	High
Rapeseed/canola	*Brassica napus*	19.20	High
Soy	*Glycine max*	13.44	Medium
Cottonseed	*Gossypium hirsutum*	8.96	Low
Groundnut/peanut	*Arachis hypogaea*	17.92	High
Maize/corn	*Zea mays*	17.92	High
Sesame	*Sesamum indicum*	4.80	Low

Source: Data compiled by the report editors, based on Randall (2017) [251].

⟶ *In Hawaii, the African olive tree is considered invasive, threatening endangered native vegetation communities*, by Forest and Kim Starr, 2001, Flickr.

The olive tree, and specifically the African olive tree *Olea europaea cuspidata*, is invasive in drier woodlands, riverine environments, coastal headlands, and dune systems [255], threatening endangered native vegetation communities in, for example, Australia [256] and Hawaii [257]. The species has a high global risk score of 26.88, signifying its potential to disrupt ecosystems across different continents (Table 8). Oil palm is considered a potentially invasive species in the Atlantic Forest in Brazil and a high-risk invasive species on several islands in the Pacific, although its global rating is not that high (Table 8). Oil palm, however, is often associated with cover crops and nitrogen fixing green fertilisers, such as *Mucuna bracteata* DC. Ex Kurz, *Axonopus compressus* P.Beauv., *Calopogonium caeruleum* (Benth,) Hemsl., and *Centrosema pubescens* Benth., which can all be invasive, especially *M. bracteata*. The invasiveness of species associated with oil palm and other oil crops is often unclear. This includes the African oil palm weevil (*Elaeidobius kamerunicus*), which is introduced as a pollinator of oil palm, and species such as barn owls (*Tyto alba*), which are not endemic to Borneo, Sulawesi, and Papua, but the species are often being introduced into plantations there to control rodent pests [11].

⟶ *In Indonesia, barn owls are often introduced to plantations as a natural means of controlling rodent pests*, by 32847342, 2023, Pixabay.

4.1.7 Water needs and impacts

Water is a vital and increasingly scarce resource globally [258]. In the context of agriculture, blue (lakes, rivers, and reservoirs) and green (root-zone soil moisture) water are terminologies commonly used to describe different water sources for crop production. Water plays a critical role in domestic, industrial, agricultural, and food uses, with agriculture and food production accounting for around 70% of total global blue water withdrawals [259]. Striking a balance between blue and green water resources is essential for sustainable agriculture and water management, enabling optimised crop growth while conserving water resources.

The water footprints of various oil crops and their water requirements for producing a tonne of oil vary by an order of magnitude [260], with the highest water footprint found in olive groves at 14,500 m^3, followed by linseed, groundnut, and sunflower. Cottonseed, soybean, rapeseed, coconut, and palm oil required amounts ranging from 3,800 to 5,000 m^3. Maize and sesame exhibited the lowest water requirements for oil production, ranging from 1,800 to 2,600 m^3 (Table 9).

Table 9 The water required to produce a tonne of oil for each oil crop.

Crops	Water consumption per tonne of oil production (m^3/t)
Maize	2,600 [260]
Cottonseed	3,800 [260]
Soybean	4,200 [260]
Rapeseed	4,300 [260]
Palm oil	5,000 [260]
Sunflower	6,800 [260]
Groundnut	7,500 [260]
Linseed	9,400 [260]
Olive	14,500 [260]
Sesame	1,800 [261]
Coconut	4,490 [262]

Source: Data compiled by the report editors, based on Mekonnen & Hoekstra (2010) [260].

Water usage sustainability varies depending on a crop's geographic region and climatic conditions. Crops grown in tropical regions with high rainfall generally face few challenges in sustainable water resource utilisation, although there is some drought sensitivity in oil palm [263], and oil palms are proving marginal in seasonal monsoon areas in Thailand and Cambodia. Conversely, crops cultivated in hot and arid conditions, such as olive, maize, cottonseed, and rapeseed, have high water demands, necessitating careful management of water withdrawal and supply ratios. Supplementary irrigation is essential for optimal yields during the critical growth stages of these water-intensive crops, especially in areas with limited rainfall. Oil palm, due to large-scale cultivation practices, also requires substantial water, with water demand increasing as the oil palm trees mature but decreasing during the rainy season [264]. Olive trees, typically grown in the Mediterranean region, are considered relatively drought-tolerant crops [265], although olive oil production was much reduced in Europe and Spain during the hot summers of 2022 and 2023 resulting in price increases of 47% in the United Kingdom [266]. Soybeans, sunflower, and linseed are categorised as moderate water-consuming crops. While sunflower and linseed exhibit higher tolerance to drier conditions, appropriate irrigation is crucial for optimal growth and seed production. Sunflower cultivation in the Ukraine, for example, has a high environmental water stress index, because sunflower oil production in this country is responsible for 70% of the total blue water footprint of the product [267]. Sesame is known for its drought tolerance and is considered water-efficient, requiring minimal water compared to other oil crops [268,269]. Coconut, known as a coastal crop, exhibits tolerance to coastal conditions and drought periods [270], relying on sufficient rainfall, but irrigation is required in dry regions or during specific growth stages.

Water scarcity is an increasing risk for oil crops under climate change. Even in crops that do not necessarily utilise a lot of water, the effects of extensive monocultures on local evapotranspiration have now led to shifts in rain and climate patterns, which are already affecting yields and harvests. That is true for soy in the Cerrado, with regions becoming unsuitable for growing due to lack of rain, and for corn in the U.S., where farmers report reduced flexibility for spring planting [271-273]. Similarly, in Borneo, deforestation has reduced rainfall by 800 mm over 30 years, making some parts of the island unsuitable for oil palm [274].

Table 10 Relative water scarcity for different oil crops based on global analysis. BWS = blue water scarcity, GWS = green water scarcity, EWS = economic water scarcity, and NWS = no water scarcity. Note that the BWS, GWS, and EWS categories can spatially overlap. Also refer to Figure 37.

Crops	BWS (%)	GWS (%)	EWS (%)	NWS (%)
Linseed	100	100	0.0	0.0
Olives	47.4	99.9	8.3	0.1
Cotton	71.1	95.7	2.6	4.2
Sunflower	12.4	94.3	29.3	5.5
Rapeseed	27.5	85.0	10.3	14.8
Groundnut	41.7	82.8	10.2	16.8
Sesame	34.4	81.5	10.5	17.6
Maize	26.1	70.2	5.5	29.4
Soybean	13.2	66.3	3.1	33.7
Coconut	13.2	34.6	2.8	65.3
Oil palm	1.2	25.6	17.5	73.9

Source: Data compiled by the report editors, based on Rosa et al. (2020) [275].

Global agricultural water scarcity

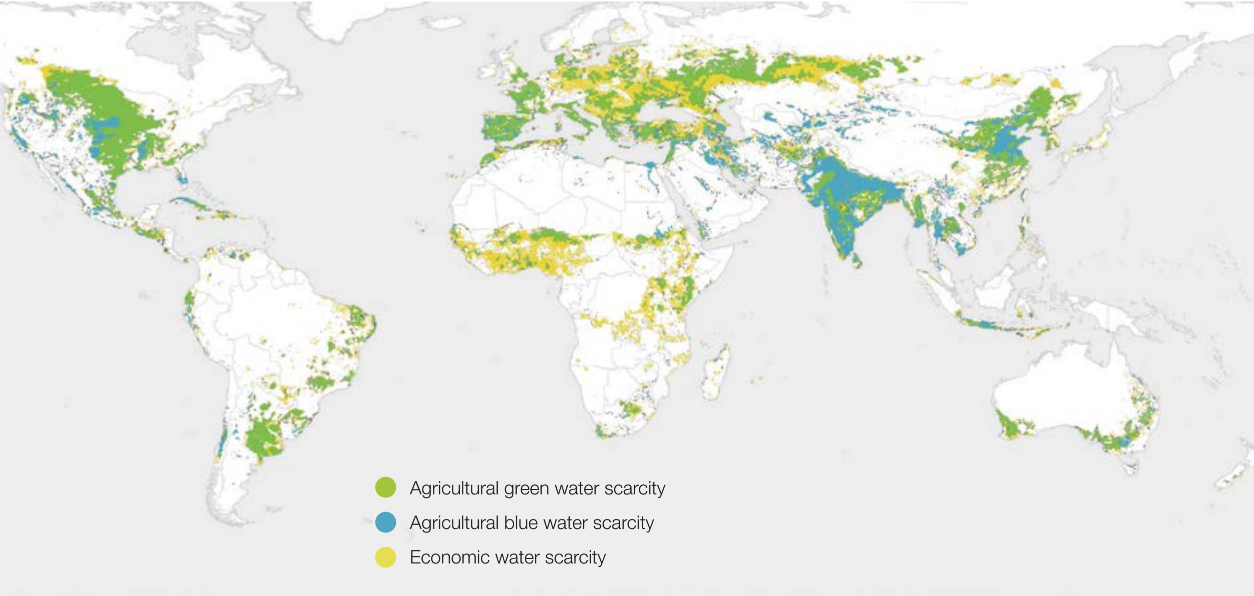


Figure 37 The geography of global agricultural water scarcity. The map shows the global distribution of agricultural green water scarcity (GWS), blue water scarcity (BWS), and (economic water scarcity) EWS across global croplands. EWS is defined as the condition in which renewable blue water resources are physically available but a lack of economic and institutional capacity limit societal ability to use that water. In the map, shown are croplands facing at least 1 month of water scarcity per year. Source: Data compiled by the report editors, based on Rosa et al. (2020) [275].

Linseed, olive, cotton and sunflower are the crops with the highest water scarcity, while soybean, coconut and oil palm have the lowest water scarcity (Table 10). Geographically, blue and green water shortages are especially prominent in the central plains of North America and large parts of Canada and southern Brazil, the Mediterranean, India and northern China (Figure 37). Finally, sub-Saharan area and west and central Asia have significant areas of economic water shortages, likely impacting oil palm, sunflower, maize, and rapeseed (Figure 37).

Oil crop cultivation can also affect regional water quality, mainly through the excess application of fertilisers that cause nitrate pollution [276], and the redistribution of water flows that may cause periodic water scarcity in villages surrounding oil palm estates [277] or flooding [278]. In addition, the mill effluent that remains after crushing and processing —a polluted mix of crushed shells, water, and fat residues—are returned each year by some of the mills to watercourses without treatment [276]. We discuss these pollution impacts further in Section 5.2.

Finally, a key issue related to water use is the downstream impacts of oil production on water pollution (also see Chapter 4.2). Many waterways in the corn belt of North America, for example, suffer from high levels of nutrient pollution linked to excessive use of agricultural fertilisers that run off farm fields. Excessive fertiliser in streams, rivers and lakes can also contaminate local drinking water and contribute to 'dead zones', or areas devoid of life. Corn and soybean production in the Mississippi River Basin contributes over 50% of the nitrogen pollution that enters the Gulf of Mexico, creating a massive seasonal dead zone with highly damaging effects on ecosystems and economic consequences [279].

4.1.8 Oil crops and their climate impacts

Among the oil crops, the impact of oil palm expansion on climate change has probably received most attention. The clearance of forests and drainage of peatlands for oil palm emits substantial carbon dioxide [280], and generates local climate change [274]. Oil palms can maintain high rates of carbon uptake [281] and their oil can potentially be used to substitute fossil fuels, yet, biofuel from oil palm cannot offset the carbon released when forests are cleared and peatlands drained over short or medium time-scales (<100 years) [282]. Moreover, the carbon opportunity cost of oil palm, which reflects the land's opportunity to store carbon if it is not used for agriculture, does not differ significantly from annual vegetable oil crops [282] (Table 11).

Oil palm plantations, and the production of palm oil, can also be sources of methane [283] and nitrous oxide [284], both potent greenhouse gases that contribute further to climate change [285]. Other emissions associated with oil palm development include elevated isoprene production by palm trees, which influences atmospheric chemistry, cloud cover and rainfall, although how this affects the environment remains unclear [286].

> "Many waterways in the corn belt of North America, for example, suffer from high levels of nutrient pollution linked to excessive use of agricultural fertilisers that run off farm fields."

Table 11 Main oil crops and their carbon emission, which include carbon opportunity costs and production emissions [282].

Crops	Kg CO_2e/MJ [282]
Oil palm	1.2
Soybean	1.3
Rapeseed	1.2
Cotton	1.2
Groundnut	1.5
Sunflower	1.0
Coconut	n/a
Maize	0.7
Olive	n/a

Source: Data compiled by the report editors.

Our research findings concerning soy production in the Brazilian Cerrado reveal an annual emission of around 52 million tonnes of CO_2. This emission is primarily attributed to changes in land use, accounting for 42% of the total. Greenhouse gas emissions from road transportation in Cerrado soy production account for 26% of the entire emission footprint. The impact of deforestation-induced microclimate changes is evident, with local temperatures rising by up to 3.5 degrees Celsius following forest clearing and a 44% reduction in evapotranspiration within converted areas [273,287]}. These shifts potentially led to a 12% decrease in soy yield, resulting in an annual loss of US$ 99 per ha. These circumstances further intensify the pressure for more land clearance or unsustainable intensification practices.

4.1.9 Examples of improved oil crop management

> "Oil palm agroforestry is one promising approach for achieving sustainable agricultural development while conserving biodiversity and ecosystem services in tropical regions."

Because of the major pressure on the palm oil industry, there has been much focus on improving production practices [232], arguably more so than in other oil crops that have received less public scrutiny. Oil palm agroforestry is one promising approach for achieving sustainable agricultural development while conserving biodiversity and ecosystem services in tropical regions. The agroforestry method is widely recognised for its economic, social, and environmental advantages [288] and has the potential to mitigate some of the negative impacts of agriculture [289]. Agroforestry practices promote biodiversity, enhance soil health, and offer additional income sources for farmers. It also induces ecological benefits by planting nitrogen-fixing species, which reduce nutrient leaching and water run-off [290], increase biological pest control, and create a more favourable microclimate [291]. However, the association of agroforestry with the palm oil industry is relatively new. Successful implementation of oil palm agroforestry requires novel partnerships between the government, private sector, and local communities. Two successful oil palm agroforestry cases in Pará, Brazil and Jambi, Indonesia provide insights about the realistic benefits of these new practices.

Good examples of oil palm agroforestry include the SAF Dendê project (Figure 38), where researchers have shown that oil palm agroforestry can deliver competitive financial returns. At the start in 2008, there were six hectares of trial farms. After 11 years the yield volume of fruit bunches – from which palm oil is extracted – was 180 kg a plant, compared to 139 kg a plant in monocultures of the same age [292]. Fresh fruit bunch yields in agroforestry outperformed those in monocultures [293].

Figure 38 *Oil palm agroforestry in Tomé Açu, Pará, Brazil*, by Jimi Amaral, 2022, CIFOR-ICRAF.

A recent study in Indonesia shows that maintaining natural forest stands in oil palm also has important ecological benefits. In 2013, 52 tree islands were embedded on 140 ha of a conventional oil palm plantation, with islands varying in area (25–1,600 m^2) (Figure 39) and in planted tree diversity (zero, one, two, three, and six tree species) [294]. The six planted species were native and locally used for fruits, wood, or latex [295]. In 2016–2018, multidimensional ecological restoration benefits were quantified using 10 indicators of biodiversity, including bacteria, fungi, plants, and animals, and 19 indicators of ecosystem functioning representing primary productivity, resistance to invasion, pollination, soil quality, predation and herbivory, nutrient and carbon cycling, and water and climate regulation [139]. Overall, results indicated that enriching oil palm-dominated landscapes with tree islands is a promising ecological restoration strategy, with multidiversity and multifunctionality increasing by a factor of 1.5 and 2 compared with conventional oil palm monocultures. Although per area oil palm yield declined within the tree islands, this was compensated by a per palm yield gain directly adjacent to the islands resulting from oil palm thinning within the islands [139,296]. Therefore, tree enrichment did not decrease landscape-scale oil palm yield five years after planting [139].

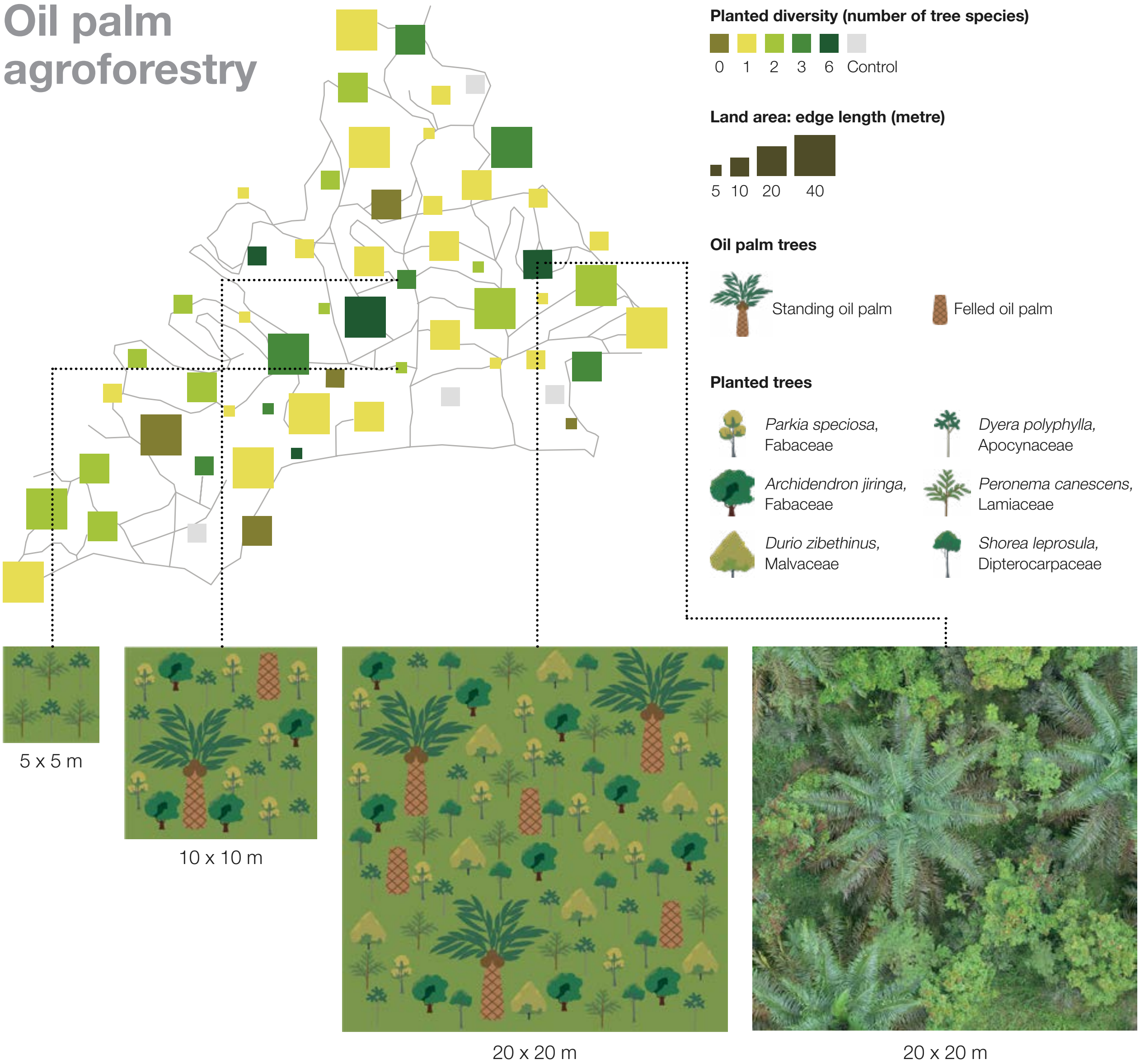


Figure 39 Experimental design that tests the ecological restoration outcomes of tree island establishment in oil palm-dominated landscapes. Tree islands vary in area (25–1,600 m^2) and planted tree diversity (0–6 species), with a total of 52 tree islands established in an industrial oil palm plantation in Jambi, Indonesia. Control plots (ctrl) represent conventionally managed oil palm monocultures. Note that the islands in the map are not at scale. Source: Data compiled by the report editors, based on Zemp et al. (2023) [139].

Another area of improvement is better pest management. Ideally, the application of chemical control for diseases and pests should be carried out as part of an integrated pest management strategy, with the application of agrochemicals as a last resort [297] (Figure 40).

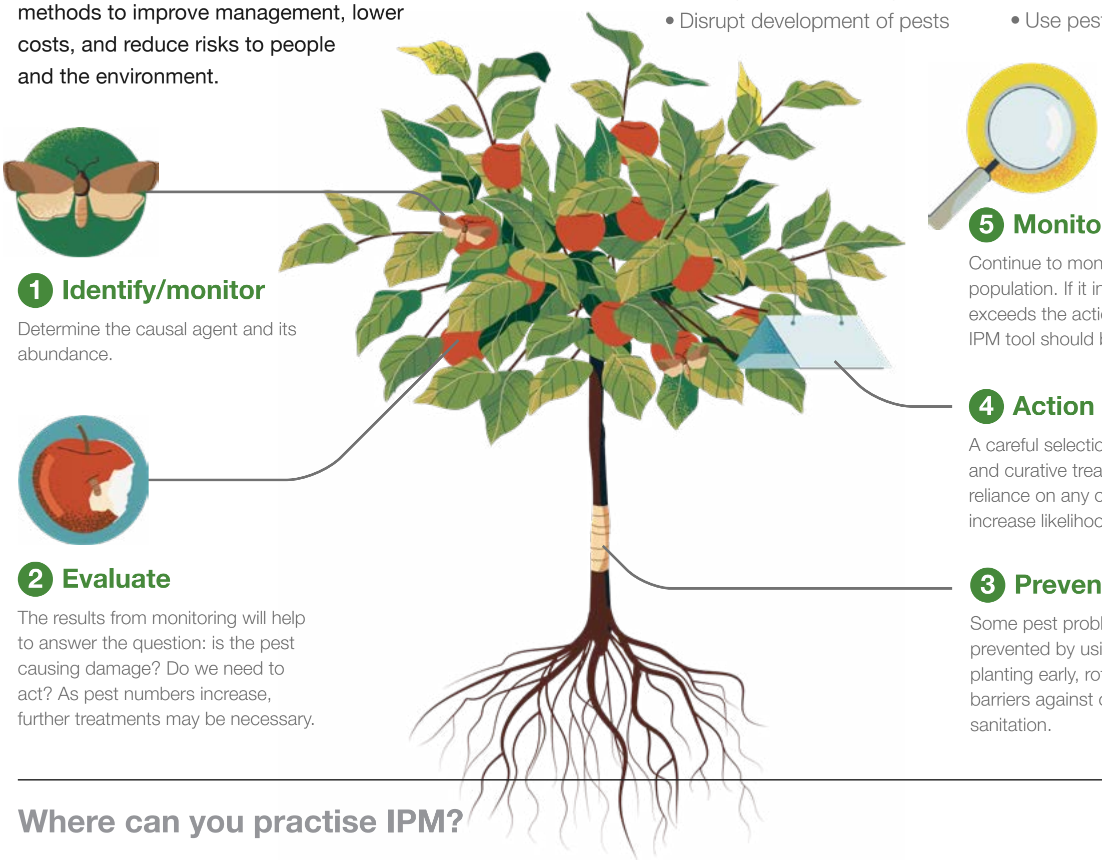
Integrated pest management is not always implemented and many of the food, environmental and health safety issues we are currently facing within the oil cropping systems are due to the misuses and excessive use of agrochemical application. There are many reasons for this misuse of agrochemicals, such as farmers' lack of knowledge concerning the health and safety risks of pesticides [298], and lack of integrated pest management promotion and support by governments and agricultural agencies, among many others. Thus, there is increasing widespread agreement that integrated pest management needs to be implemented and supported by international recommendations and enforcement, as well as national policies which ensure better education and transfer of knowledge to farmers about the appropriate use of pesticides within an integrated pest management strategy. This will result in minimising the impact of agrochemicals, while ensuring sustainable food production, food security and healthy agricultural communities [297,299,300].

Integrated Pest Management

Integrated Pest Management is a science-based approach that combines a variety of techniques. By studying their life cycles and how pests interact with the environment, IPM professionals can manage pests with the most current methods to improve management, lower costs, and reduce risks to people and the environment.

IPM tools

- Alter surroundings
- Add beneficial insects/organisms
- Grow plants that resist pests
- Disrupt development of pests
- Prevention of pest problem developing
- Disrupt insect behaviours
- Use pesticides



1 Identify/monitor

Determine the causal agent and its abundance.

2 Evaluate

The results from monitoring will help to answer the question: is the pest causing damage? Do we need to act? As pest numbers increase, further treatments may be necessary.

3 Prevent

Some pest problems can be prevented by using resistant plants, planting early, rotating crops, using barriers against climbing pests, and sanitation.

4 Action

A careful selection of preventive and curative treatments will reduce reliance on any one tactic and increase likelihood of success.

5 Monitor

Continue to monitor the pest population. If it increases and exceeds the action threshold, another IPM tool should be used.

Where can you practise IPM?

Buildings and homes

Inspect, identify pests, keep pests out, clean to deny pests food and water, vacuum, trap, or use low-risk pesticides.

Farms

Regularly check for pests, accurately identify, choose pest-resistant plants, encourage beneficial insects, practice early planting, and use low-risk pesticides, if necessary.

Managed natural systems

Identify the pest and use management options that have minimal risks to pollinators, humans, and pets.

Figure 40 Integrated Pest Management fact sheet by the Entomological Society of America. Source: Prepared by the report editors.

4.1.10 Conclusions on environmental outcomes

Our review shows that all oil crops can have negative environmental impacts through the displacement of natural ecosystems and associated wildlife (forests, savannas, grasslands), poor soil management, overuse of fertilisers and pesticides, inappropriate water use, and emission of greenhouse and other gases. Important considerations are the total areas used by different crops, and when and how much natural ecosystems these areas displace as oil crop preferences evolve. Figure 3 illustrates that oil palm is associated with relatively high greenhouse gas emissions, but low land use, acidification, eutrophication, and scarcity-weighted freshwater withdrawals. Olive oil has high land and water needs, while sunflower is associated with high levels of acidification and eutrophication. Maize, having the largest crop area, also has the greatest role to play in biodiversity threat abatement and restoration.

In addition to variation between crops, there is a major variation within each crop in terms of environmental impacts. Therefore, in evaluating impacts, how crops are managed must be considered, where they have been developed, and the scale in which they were developed. A large monocultural oil palm or soybean estate in areas that were, until recently, covered in natural forest or savanna has an entirely different environmental impact to these same crops managed in subsistence or smallholder settings in areas that were converted to agriculture many centuries ago. From an environmental point of view, talking about 'better' or 'worse' crops does not make sense, as this depends on which environmental context is highlighted and how crops are managed.

“From an environmental point of view, talking about 'better' or 'worse' crops does not make sense, as this depends on which environmental context is highlighted and how crops are managed.”

⟶ *Orangutans have suffered greatly from habitat loss and fragmentation caused by oil palm plantations in Southeast Asia*, by e-smile, 2019, Pixabay.

4.2 The social impacts of oil crop production

4.2.1 Introduction

This section provides an overview of the social impacts of vegetable oils crops. Until recently, social impacts have received far less attention than environmental impacts, reflecting greater international concern for environmental issues [301]. There has been a lot of progress in documenting the social impacts of oil palm and soy, especially on those living and working in production areas, but information on the social impacts of other oil crops and at other stages of value chains remains limited and fragmented. Here, we summarise the most widely reported types of social impacts identified through searches of the academic and non-academic literature.

Our primary focus is on the impacts of vegetable oil production on human rights, including Indigenous peoples' rights, because respecting, protecting, and fulfilling rights are requirements under international law (Box 14). As a secondary focus, we also explore the impacts on livelihoods and poverty, reflecting the central place of poverty reduction in the United Nations Sustainable Development Goals (SDGs). Finally, equity, including gender equity, is treated as a cross-cutting issue.

Internationally agreed standards and legal requirements relating to human rights are set out in an extensive framework of global treaties, conventions, and other instruments. Respect for rights is enshrined in Article 1 of the United Nations Charter and is integral to the UN 2030 Agenda for Sustainable Development, the UN Convention on Biological Diversity's Kunming-Montreal Global Biodiversity Framework, and implementation measures under the UN Framework Convention on Climate Change. It is also embedded in leading voluntary environmental and social sustainability standards and methodologies, including the UN Guiding Principles on Business and Human Rights, and the OECD Guidelines for Multinational Enterprises, the Accountability Framework Initiative, and others.

Box 14

What are human rights?

Human rights are rights that apply equally to all human beings, regardless of their gender, ethnicity, religion, or other personal characteristics. They include the right to life, liberty, and security of person, the right to freedom from slavery, torture, and arbitrary arrest, and the right to freedom of opinion and expression, among others. They are protected in international law by a set of global human rights treaties and protocols, and are recognised as having the following characteristics:

- They apply equally to everyone (they are universal and non-discriminatory)
- They cannot be given or taken away (they are inherent and therefore inalienable)
- They are unconditional (they do not depend on behaviour or context)
- They are interdependent and indivisible: one set of rights cannot be fully enjoyed without the others and, therefore, they cannot be treated separately.

In addition to individual rights, certain collective rights are recognised in international law, including cultural rights. The collective rights of Indigenous and tribal peoples are the specific focus of several international instruments, including Convention 169 of the International Labour Organization (ILO) [302] and the UN Declaration on the Rights of Indigenous Peoples [303]. These rights include the right to ownership and possession of their traditional lands, the right to consultation, participation, and free, prior and informed consent (FPIC), and the right to decide their own priorities (self-determination).

⟶ *Geometrical scars on land caused by large-scale agricultural activities, including sugar cane and soybean plantations, in Mato Grosso, Brazil*, by Riccardo Pravettoni, 2014, GRID-Arendal.

According to these standards, governments have obligations to respect, protect and fulfil rights in their role as the 'primary duty-bearers', and other institutions such as businesses and non-governmental organisations (and all individuals) also have an obligation to respect rights. Respecting rights means refraining from any activities that cause or contribute to rights violations and addressing past rights (commonly referred to as 'do no harm'). Protecting rights means preventing rights violations by others, and fulfilling rights means taking positive action to enable people to claim or enjoy their rights.

The social impacts of the vegetable oil industry are substantial, complex, and multidimensional, including both positives and negatives. The net effects on rights and livelihoods vary widely, both geographically and within local communities. The most commonly reported impacts include violations of the collective rights of Indigenous peoples (especially related to land loss and land conversion), impacts of agrochemicals on health, impacts on the local economy and livelihoods, and violations of labour rights.

Impacts of land conversion are of particular concern for crops that are grown in industrial-scale plantations in countries and regions with weak rule of law, especially where there are Indigenous peoples and other traditional peoples with customary rights. Violations of land rights, the right of consultation and the right to give or withhold free, prior, informed consent are well-documented for palm oil throughout its range, for soy in Latin America, and for coconut. Land dispossession, especially where it involves forced violent evictions and persecution of environmental human rights defenders, causes severe social and cultural disruption, and is associated with deteriorations in mental and physical health and economic destitution, especially for those who were previously dependent on local natural resources for their subsistence. Vegetation clearance causes further effects on health and well-being, including through the deterioration of air and water quality and destabilisation of soil systems, which can lead to respiratory ailments and food and water insecurity.

Social impacts of vegetable oil production

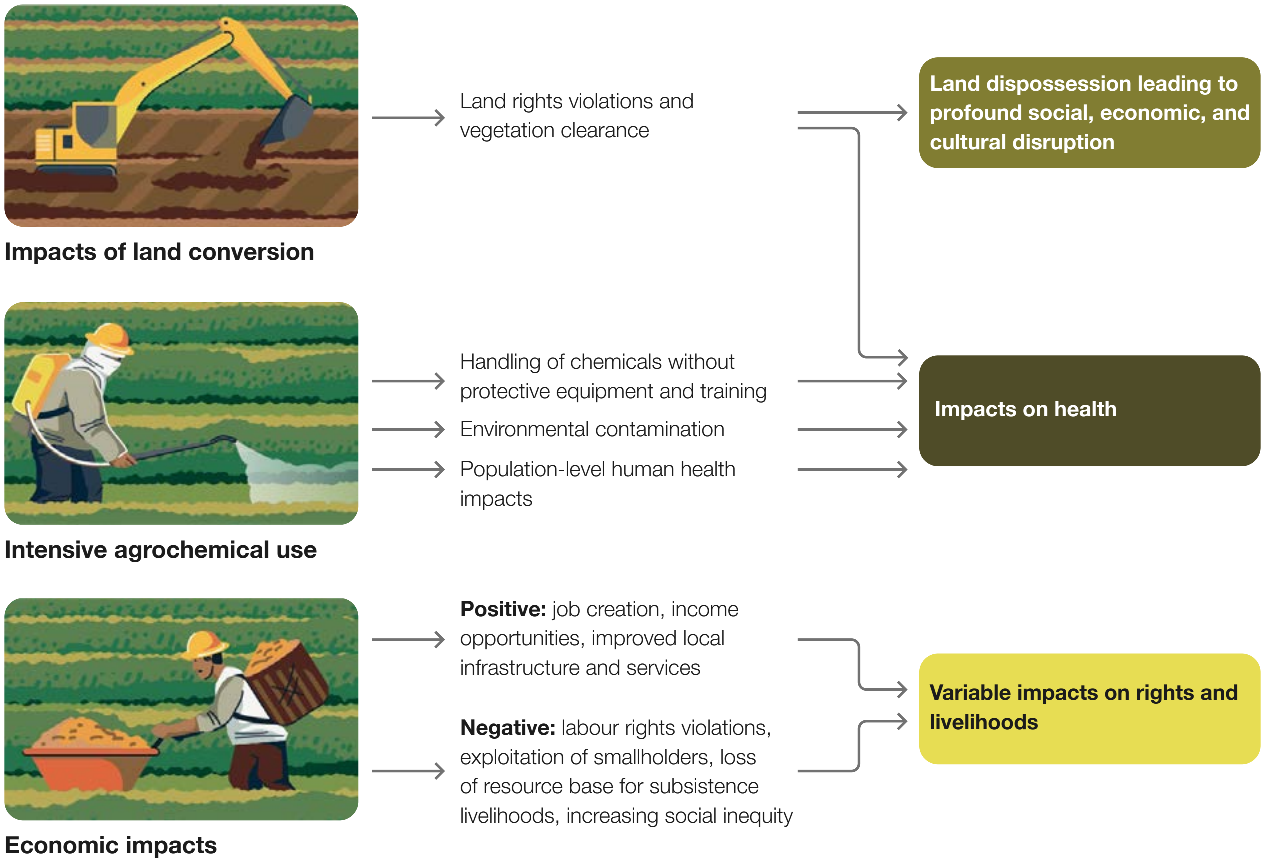


Figure 41 The social impacts of vegetable oil production. Source: Prepared by the report editors.

Impacts of agrochemical use on health include direct impacts on farmers and farm workers who work with chemicals, often without appropriate protective equipment, and wider impacts, especially on those who live in or near production areas, but also ultimately on consumers. These impacts are of concern for all vegetable oil crops, but they are particularly severe for soybean production in Latin America, where the adoption of genetically-modified glyphosate-resistant seed varieties has led to a steep rise in the rate of application of herbicides, with far-reaching environmental and social consequences [304,305].

Impacts on livelihoods and poverty include both positives and negatives, and the net impacts vary greatly, both spatially and within local communities. Vegetable oils make significant contributions to poverty reduction in several producer countries and regions, through the creation of jobs and new sources of income for farmers, farm workers and others, and through improvements to local infrastructures and services. However, jobs are often poorly paid and labour rights violations are widely reported in plantation-based production. For palm oil, soy, sunflower, and coconut, there are also barriers to entry and profitable production for many smallholders, including a lack of land or land tenure security, limited knowledge and capital, and poor access to markets. Furthermore, there are well-documented rights violations connected to exploitative contractual arrangements for smallholders, and to discrimination, including against Indigenous peoples and women.

In summary, the impacts of vegetable oils on rights and livelihoods and poverty vary widely, both spatially and within local communities. Understanding the patterns of variation and the drivers underlying them is important in thinking through how the positive economic impacts can be increased and the negative impacts decreased. The types of impacts summarised above are shown in Figure 41 and described in more detail in the following sections.

4.2.2 Impacts of land conversion

Land conversion for plantation production is a major driver of the human rights impacts of vegetable oils, including violations of Indigenous peoples' collective land rights and right to give or withhold free, prior informed consent. Based on a set of 16 case studies from seven countries in Asia, the Pacific and Africa, Colchester and Chao [301] demonstrated that lack of respect for rights, including customary collective land rights, remained a major concern for certified palm oil under the Roundtable on Sustainable Palm Oil. Other oil crops also overlap with land managed by Indigenous peoples (Figure 42), and in these areas of overlap there is a risk of violations of their collective rights. Common forms of rights violations include forced, violent evictions; the granting of permits without consultation or free, prior and informed consent ('land grabs'); threats, violence, and persecution of environmental human rights defenders; and the use of bribes, deception and coercion to secure signatures on land acquisition agreements [301,306]. Land rights violations of these kinds are most widespread for oil crop production in countries where there are high levels of customary or informal land ownership, inadequate recognition and protection of Indigenous and customary rights in national law, poor governance, and a high level of financialisation of the land investment sector [306,307]. They are therefore most relevant for the oil crops that are widely grown in corporate-controlled plantations in these regions, which are oil palm, soybeans and coconuts [308,309].

The impacts of evictions and land dispossession are particularly severe for many Indigenous peoples, because of the close ties that exist between their lands and their identities, cultures, and livelihoods. Profound impacts on traditional knowledge systems, belief systems, health systems, farming systems, and livelihoods have been reported when access to customary lands is lost and forests are cleared for soybean [307] and oil palm production [306], as well as damage to sites of critical cultural importance in the landscape, including sacred forests, rivers, or mountains as well as man-made features, such as graves, shrines, and monuments. More insidious cultural impacts include the weakening of traditional institutions and the loss of community cohesion due to increasing inequities and social conflict [310].

Indigenous peoples and oil crop production areas

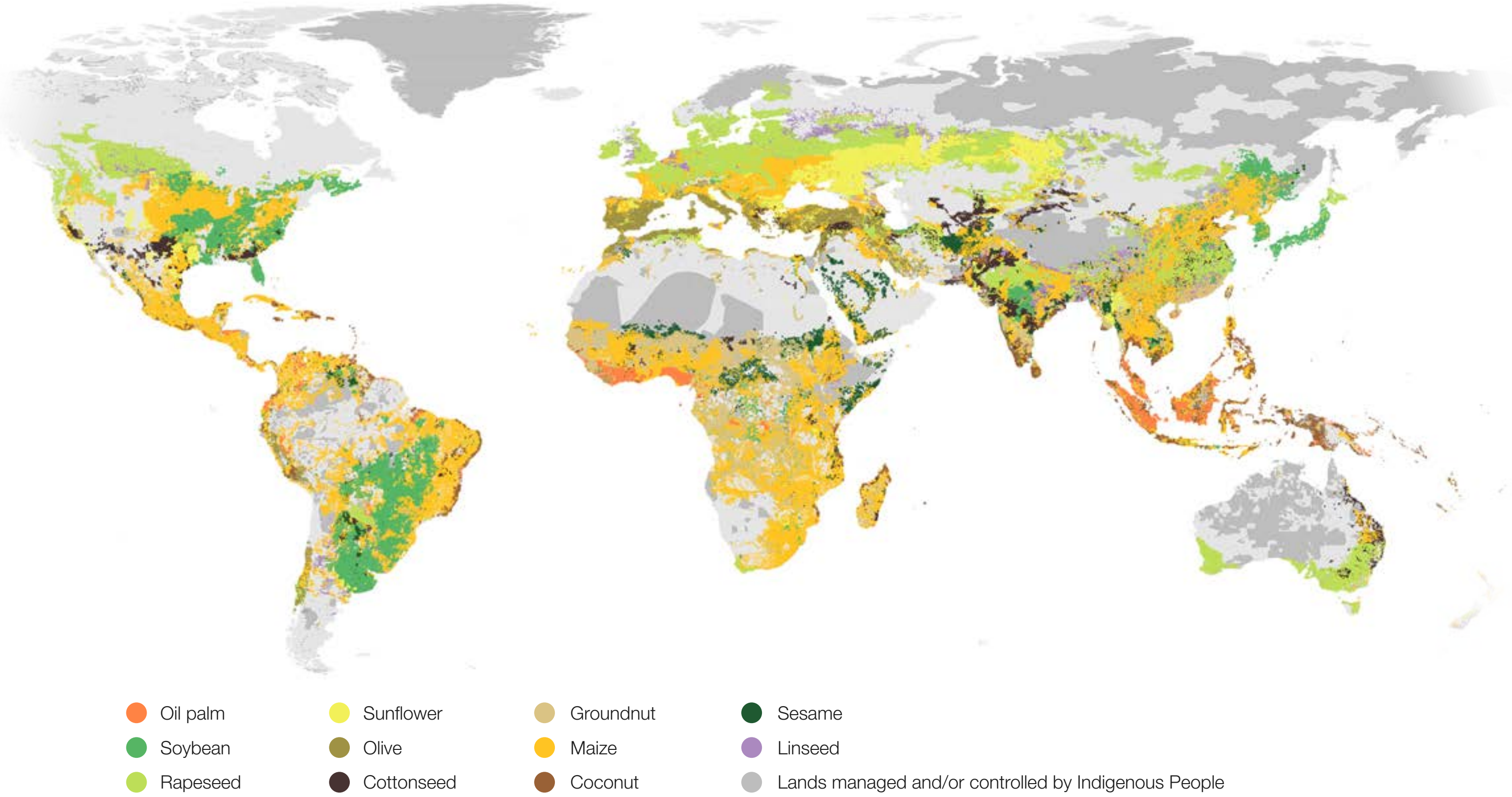


Figure 42 Indigenous peoples and oil crop production areas. Source: Prepared by the report editors.

For communities who previously depended on wild resources for their food, fuel, medicines, and other household needs, land dispossession and clearance can cause a major shock to livelihoods and well-being, especially where market goods are not readily available or affordable, and these impacts affect women disproportionately where they bear the main responsibility for food and water provisioning and for household budgeting [311]; for example, they may have to walk further to collect forest resources and clean water [306].

These kinds of impacts are well-documented for oil palm [306] and for soy [307]. Documented cases related to oil palm are numerous, especially in Southeast Asia; for example, from 2016 to 2017, oil palm was the largest single source of reported land conflicts in Indonesia [306]. Similarly, land rights violations related to soybean production are well-documented in Argentina, Paraguay and Brazil and in Central America, and have increased sharply since the introduction of roundup-resistant genetically-modified varieties in the 1990s [304,307,312]. By 2013, there were 224 land conflicts in the northern Argentinian Chaco alone, covering 2.8 mha and affecting nearly 18,000 Indigenous and peasant families [304]. Land rights violations from large-scale commercial plantations of oil palm and other food and biofuel crops are also well-documented in Africa [313-315].

A second group of social impacts of land conversion is related to large-scale vegetation clearance. For example, poor air quality following forest burning for oil palm development in southeast Asia has been linked to respiratory diseases, child mortality, asthma, lung damage, low birth weights, miscarriages, and impaired cognitive developments [306]. Land clearance and the infrastructural construction can destabilise soil and water systems, increasing the risk of floods and water shortages and impacting food and water supplies.

> “From 2016 to 2017, oil palm was the largest single source of reported land conflicts in Indonesia.”

⟶ *Conversion of a rainforest to palm oil plantations in Sumatra, Indonesia*, by Peter Prokosch, 2014, GRID-Arendal.

4.2.3 Impacts of agrochemical use

Oil crop diseases and pests can result in yield reductions and crop mortality and thus, can have knock on effects on the economics, as well as food security of these production systems. Those particularly vulnerable to these shocks are those dependent on oil crops for their livelihoods [299,300]. This is why agrochemicals are prevalently used in the production of all the major vegetable oil crops. The use of agrochemicals within oil crop systems is complex, coupling issues of food security, food safety, the health of the environment and human health [299].

In the cropping systems assessed here, many of the agrochemicals found to be applied are classified as Highly Hazardous (HHPs). Direct impacts include acute toxicity (occurring within hours of exposure), as well as a range of longer-term effects, including an increased risk of cancer, neurological disorders and endocrine disorders, among others (Table S2 in Appendix). Indirect impacts are caused by persistence of chemicals in soils and surface water, and contamination of groundwater. These ‘ecotoxic’ impacts can affect drinking water and bathing water as well as contaminating food crops, fish, and other wild food resources, and can also reduce subsequent crop yields [306].

The misuse of agrochemicals and thus, the associated pollution and related health impacts, are particularly acute for soy production, 74% of which is of genetically modified strains that were developed for resistance to the herbicide glyphosate. Glyphosate is now one of the most widely used agrochemicals worldwide, with a global market value in 2020 of US$ 7.8 billion [316], and soy and maize account for the greatest volume of use. Recorded incidents of acute poisoning and other health effects of glyphosate have increased in line with the expansion of genetically modified soy. Drift from spraying of genetically modified soy with glyphosate is a significant cause of acute toxicity, including fatalities, in all three major producer countries in Latin America (Brazil, Argentina, and Paraguay) [317,318]. Glyphosate is classified by the World Health Organization as probably carcinogenic. It is also a potential contaminant of groundwater, and has been directly linked to increased rates of miscarriages and birth defects [319].

Many of the health impacts of agrochemicals affect Indigenous families, the poor, and women and children disproportionately [319]. Small-scale farmers in lower- and middle-income countries are particularly vulnerable, because of the cost of protective equipment and other mitigation measures, a lack of access to information on responsible use, the impracticality of setting up buffer zones in small, tightly packed landholdings, and weak regulation and enforcement [316]. Labourers can also suffer severe health impacts from the use of hazardous chemicals without appropriate equipment and training, as well as work-related accidents, demanding workloads, and inadequate health care provision [320]. Gender-disaggregated data on health impacts of agrochemicals used in vegetable oil production are not available, but women are more vulnerable than men to health impacts, for several reasons. Physiologically, women are more vulnerable due to higher body fat, higher hormone sensitivity, and risk of breast cancer, endometriosis, birth defects, and neonatal deaths. They are also socially more vulnerable in many contexts because of lower literacy levels and because they often work as sprayers in agricultural areas and are exposed while spraying, mixing, and loading pesticides without personal protective equipment (PPE). They can also be exposed while weeding and harvesting and during household chores [316].

Brazil uses a greater volume of agrochemicals than any other country in the world, both because of its large agricultural area and because of a move towards genetically modified crop varieties and chemical-intensive farming [305]. In 2015, a total of 899 million litres were used, of which soybean production accounted for 63%. It was estimated that each Brazilian was ingesting 7.3 litres of agrochemicals a year, principally through contamination of water supplies [321]. In 2017, 4,003 cases of pesticide poisoning were recorded nationally, including

> “The misuse of agrochemicals and thus, the associated pollution and related health impacts, are particularly acute for soy production.”

148 deaths [321]. However only about one in 50 cases of acute poisoning were reported, partly due to reprisals against communities and individuals who speak out against spraying [322] and harassment of municipal governments [305]. The actual figure of acute poisoning in the country has been estimated to be around 200,000 [305].

Several studies have documented spatial correlations between high agrochemical use and reported incidences of health problems. For example, in one analysis of government health indicators for the state of Mato Grosso, which had the highest level of agrochemical use in Brazil and the largest area planted with crops (63% of which were for soybeans), positive correlations were reported between the mean volume of pesticides used per hectare and the reported incidences of acute poisoning, foetal abnormalities, and childhood cancer mortality, which is the second highest cause of child mortality in Brazil [305,324.] Glyphosate was the most frequently used chemical.

There have also been several acute cases of contamination. In 2006, the municipality of Lucas do Rio Verde in Mato Grosso suffered toxic rains, following fumigation of soy with paraquat to dry the crop before harvest. Subsequently, glyphosate, pyrethroids and organochlorines were found in 100% of samples of women's breast milk (n=62) and in the urine and blood of 88% of teachers tested (n=79) [321]. In 2013, insecticides were sprayed directly over a school surrounded by soy and maize plantations for 20 minutes and dozens of teachers and children were hospitalised [316]. In another incident reported in the Brazilian national press in 2019, one soy company – *Fazenda Luta*

> “Brazil uses a greater volume of agrochemicals than any other country in the world, both because of its large agricultural area and because of a move towards genetically modified crop varieties and chemical-intensive farming.”

Figure 43 *Aerial agrochemical application is indiscriminate and can have negative consequences for nearby ecosystems* [331], by Eric Brehm, 2022, Unsplash.

– was reported to have repeatedly sprayed the lands of Indigenous and peasant communities who had resisted eviction with agrochemicals, until the livestock and trees were poisoned, the rivers were contaminated, and the people were suffering from increasingly severe health problems, so that they were left with no choice but to leave [325].

Legal regulations are in place in Brazil, Paraguay and Argentina to reduce the effects of spray drift, such as leaving 'green walls' along roadsides and respecting no-spray buffer zones near waterways, roads, and settlements. However, regulations are often less stringent than in industrialised countries. The limit on glyphosate in drinking water in Brazil is 500 micrograms per litre, which is 5,000 times higher than the limit in the EU (0.1 micrograms per litre), but currently under EU law European countries are still permitted to export agrochemicals that are classified as highly hazardous and banned for domestic use on health and safety grounds, for use elsewhere [316]. In addition, in all three countries, government monitoring and enforcement of regulations is ineffective, and non-compliance is common [318,319,321]. This has driven some community groups to set up their own monitoring programmes and protest groups [326], and the severity of the problem is evident in the nature and scale of protests that have emerged. In Argentina, residents of sprayed towns across the affected region have joined a 'stop spraying' campaign, in Paraguay, a national protest has adopted the slogan '*la soja mata*' (soy kills), and in Brazil, the '*Campanha Nacional Permanente contra os Agrotóxicos e Pela Vida*' was launched in 2011 under the slogan 'agrotoxins kill' [317]. However, rural people have continued to be exposed to spraying, and in Brazil this has been attributed at least partly to intimidation and physical violence against farmers, communities, and anti-spraying activists by large landowners [327].

"Legal regulations are in place in Brazil, Paraguay and Argentina to reduce the effects of spray drift, such as leaving 'green walls' along roadsides and respecting no-spray buffer zones near waterways, roads, and settlements."

Health impacts related to glyphosate use on soy are also recorded in the U.S., where they may be less severe than in Latin America because of more stringent regulations and greater adherence to good practice in agrochemical use [328,329]. However, there is evidence that glyphosate and other active ingredients can rise into the air and spread over distances of up to 1,000 kilometres making it very difficult to control against environmental and health impacts. The health impacts of direct inhalation of airborne agrochemicals are still largely unknown [316].

As a result of the development of genetically modified crops, the agrochemical business has been combined with the seed business and control has become concentrated in the hands of just four companies (Syngenta, Bayer, Corteva Agriscience and BASF), which in 2018 controlled 70% of the global agrochemicals market, worth about US$ 85 billion per year, and 57% of the global seed market. Despite glyphosate probably being carcinogenic [330], it is still approved for use by the EU. This has been attributed to corporate interests in maintaining high levels of agrochemical use and lobbying within the EU policy processes. The EU is reported to have relied entirely on manufacturers' own studies in assessing the evidence for carcinogenic effects of glyphosate, whereas the WHO evaluated the more impartial evidence provided by extensive independent studies [316].

Meanwhile, the long-term effectiveness of glyphosate is uncertain. Over 50 weed species have developed resistance to glyphosate since 2000 [316], meaning that ever-increasing levels of glyphosate application are needed, together with increasing use of more toxic herbicides, including paraquat, 2, 4-D, dicamba, atrazine, and endosulfan [326]. While we focus here on agrochemical use in industrial-scale soybean production, all oil crops and the people working with them are exposed to different chemicals with different use intensity. Health impacts and impacts on surrounding natural ecosystems in relation to chemical use in oil crops remains poorly studied. We highlight some key issues in Table S2.

⟶ *Smallholder coconut farmers and workers in the Mekong Delta, Vietnam*, by xuanhuongho, 2015, Shutterstock.

4.2.4 Impacts on poverty and livelihoods

Vegetable oils make highly significant contributions to poverty reduction in several producer countries, both through the creation of jobs and new sources of income for farmers, farm workers, and others, and through improvements to local infrastructures and social services. It has been estimated that 2.6 million rural Indonesians were lifted out of poverty by palm oil development between 2000 and 2010, and Indonesian villages with significant oil palm cultivation are reported to have better schools, roads, incomes, access to electricity, and access to health facilities than others [331]. According to another study in Indonesia, a 10% increase in the land area under oil palm cultivation between 2001 and 2009 led to a 2.4% increase in district-level GDP and a 10% reduction in poverty rates [332]. Similarly, increased soybean production in some regions of Brazil, Argentina and Paraguay is correlated with an increase in average incomes, improved education levels, increased life expectancy and a fall in poverty levels [307]. Sunflower oil production has been promoted as a tool for poverty reduction in Africa since the 1990s, and it has transformed the local economy in some districts of Tanzania. The coconut industry is an important source of local livelihoods for millions of small farmers, including some 3.5 million small farmers in the Philippines and 6.6 million in Indonesia [335].

Box 15

Who are smallholders?

The standard definition, used by the FAO, describes smallholdings as those farms under two ha. However, the definition of smallholders varies greatly across commodities, regions, and countries. The RSPO uses 50 ha as the default size limit for palm oil smallholdings, with smaller or larger figures in some national interpretations.

Smallholders are also often described according to the nature of their farming systems. Typically, they rely mainly on family members for labour and operate informally, without corporate management structures. Many smallholders grow a mixture of crops for home consumption and for markets. Smallholders may be Indigenous or local families, or they may be recent settlers from elsewhere.

The impacts on livelihoods and poverty vary widely, both spatially and within local communities, Many farmers and labourers involved in vegetable oil production remain poor. Understanding the patterns of variation and the drivers underlying them is important in thinking through how the positive economic impacts can be increased and the negative impacts decreased. Recognition and protection of rights, including customary land rights, is an underlying enabling factor for positive impacts, as is apparent from earlier sections of this chapter. Other contributing factors include: the size of landholdings and the nature of production systems [336]; the remoteness of the site and the nature of the local economy prior to oil crop development [331,337,338]; and contractual arrangements for smallholders (Box 15).

With regard to landholdings and production systems, Choi and Kim [336] analysed Brazilian government socio-economic and agricultural data at two administrative levels (states and municipalities) for the period from 1976 to 2013 to explore the impacts of soybean cultivation on poverty. They showed that nationally, increased soy acreage significantly increased poverty and worsened inequality. This was driven by expansion in regions in the north, where soy was grown mainly in large, highly-mechanised plantations. In the south, where production is mainly on small-scale mixed family farms, the opposite effect was found, and soy expansion decreased poverty. Based on more detailed analysis at the local level, the authors concluded that this difference was due to the different farming systems: soybean relieved poverty when it was produced on family farms, but not when it was produced on large, industrialised plantations.

Studies of oil palm have also indicated that smallholder production provides greater benefits for local people than employment in plantation production, provided that contractual arrangements and other conditions are favourable. For example, a simulation of stakeholder benefits in Sarawak, Malaysia found that returns to local people were many times higher per hectare from state-run smallholder schemes than from company concessions, even though the total economic returns across the supply chain were lower [339]. In West Kalimantan, Indonesia, independent smallholders with oil palm plots of six ha or more were reported to be far more prosperous than plantation workers (or tied smallholders [340]).

There are specific barriers to oil palm smallholder development in the main producer countries in southeast Asia, because of the predominance of large mills with specialised equipment, which give economies of scale. The need for fresh fruit bunches to be processed within 48 hours of harvest means that this favours intensive production within the catchment area of a large mill, and that individual mills often have a monopoly on smallholders within this area [341]. Therefore, smallholders have very little bargaining power and are particularly vulnerable to exploitation. In Africa and Thailand, small-scale processing facilities are more common, giving smallholders more power to choose where to take their produce and providing them with an important source of off-farm employment [341]. Similarly, the introduction of herbicide-resistant varieties of genetically modified soy has decreased labour requirements and increased economies of scale. It has therefore been an important factor in the trend towards production in highly mechanised mega-plantations, making it difficult for smallholders to compete.

A second important factor driving spatial variations in impacts on poverty is the pre-existing state of the local economy. Several studies have shown that where smallholders are already integrated into markets, they can increase their profits substantially by switching to oil palm from other crops, such as rice, sorghum, and maize [341]. However, where market access is poor, smallholders may still increase their cash incomes by adopting palm oil, but the overall livelihoods benefits are likely to be greatest when they also continue to grow food crops so that they have a secure source of food [331] (Box 16).

Box 16

The impacts of vegetable oil production on food security

The FAO identifies four dimensions to food security (for definition see Glossary and Figure 44): food availability, access to food, food utilisation (including food preparation, diets, and distribution of food within the household), and stability of the above over time. The concept of food security is also evolving to include two additional dimensions: agency (the extent to which people can make their own decisions about food and engage in relevant policy processes) and sustainability across generations [5].

The impacts of vegetable oil production on local food security are varied. They can contribute directly to local diets, increasing edible oil intake [343], and increase the accessibility of market foods where they boost local incomes sufficiently to enable people to buy enough good quality food to offset the loss of pre-existing food supplies [344]. Several studies in Southeast Asia and Africa have reported that food security is better for smallholders who grow oil palm than those who do not. Another study in Jambi Province, Indonesia, reported that adoption of oil palm was correlated with a 13% increase in per capita calorie consumption and a 22% increase in calories from nutritious foods [345]. However, the transition to vegetable oil production can also harm food and nutritional security. Cash crop cultivation takes time and land away from the cultivation of subsistence crops, decreasing food production, and on the longer term, intensive agricultural practices can impoverish soils, reducing food crop yields [307]. It can also cause a substantial increase in food prices [346], which may outweigh increases in incomes and decrease accessibility of purchased foods, especially for the poorest households. Increased reliance on purchased foods can also negatively affect food quality, decreasing consumption of fresh produce

Four pillars of food security

Availability

Ensured when there is a reliable supply of food of sufficient quantity and quality.

Dependent on:
- Domestic production
- Food stocks
- Imports
- Food aid

Access

Ensured when individuals & households have adequate resources to obtain appropriate food.

Dependent on:
- Political, economic, social factors
- Equitable distribution
- Markets/infrastructure
- Affordability
- Purchasing power

Food security

Exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Stability

Ensured when there is permanent and durable access to food.

Dependent on:
- Maintenance of all three pillars over time
- No risk of loss of supply due to economic, political or environmental factors

Utilisation

Ensured when food is nutritious and can be adequately metabolised and used by the body.

Dependent on:
- Food safety
- Food quality
- Nutritional knowledge
- Proper preparation
- Clean water/sanitation/healthcare

Figure 44 The four pillars of food security. Source: Prepared by the report editors, from [342].

and impacting nutrition and health [306]. The transition may also have lasting impacts on social systems. For example, as local economies transition from subsistence towards more market-oriented economies, control of household budgets may shift from women to men, worsening gender inequalities [331].

An emphasis on growing vegetable oils for biofuels or for export can also negatively affect food security [331]. For example in Indonesia, acute shortages of cooking oil and rocketing domestic prices of palm oil were reported from October 2021, and were attributed to prioritisation of biofuel by the palm oil industry and to price-fixing by a cartel of dominant companies [347]. The sunflower oil industry in Tanzania, which has been strongly supported by national and international development funding for decades because of its value for poverty reduction, is currently threatened by cheaper palm oil imports, as is coconut production in South India [348]. In Brazil, increased demand for soybeans from China has led to a shift in some regions from cultivation of maize as the main crop to cultivation of soy, with maize as a secondary crop planted later in the year. Although this has increased average cash incomes, it has reportedly reduced food security, because the later planting has made maize more vulnerable to droughts [349]. Mixed planting systems that provide a range of crops for markets and for home consumption provide greater long-term food security than monocropping, especially in remote areas with limited market integration [331]. Continuing to grow food crops provides a buffer against volatile commodity prices and diversifies income sources, enabling people to buy their food when cash crops fail or when local market conditions change [341, 331].

⟶ *The palm oil sector in Kalimantan, Indonesia, can have positive impacts for the local economy through providing employment opportunities*, by Icaro Cooke Vieira, 2017, CIFOR.

Several other studies in Indonesia have also shown that the impacts of oil palm on local livelihoods differ between areas where the market economy is well-developed and areas with a subsistence-based economy, and where people rely directly on local forest resources for their livelihoods. For example, according to one study in Papua, Indonesia, less than 15% of profits from palm oil plantation development were captured locally, and the overall net economic impact on local people over a 25-year period was negative, because of the destruction of forests, which were the source of their livelihoods [350]. The authors concluded that oil palm was more likely to contribute positively to local livelihoods and poverty reduction as part of a broader development package based on mixed farming systems retaining food crops. However, a study in Riau, Indonesia, reported much greater local economic benefits. Riau has a much more developed local economy, and this allowed most inputs to the palm oil industry to be sourced locally. Also, 84% of the income generated was spent locally, generating economic multiplier effects [351]. An analysis of village-level socio-economic data across Kalimantan, Indonesia, reported a similar pattern of variation: in remote forest regions where people lived largely by subsistence, there was an initial increase in economic welfare following oil palm development, but this effect was outweighed by broader negative socio-ecological impacts, and decreased dramatically after 9–11 years. However, where villages were already integrated into the market economy, the overall impacts on livelihoods after 9–11 years were positive [338].

> “Several other studies in Indonesia have also shown that the impacts of oil palm on local livelihoods differ between areas where the market economy is well-developed and areas with a subsistence-based economy.”

4.2.5 Impacts on local equity

For both palm oil and soy, several studies show that the economic benefits of production that are captured locally often go to those who are already advantaged, increasing local social inequities and in some cases worsening the situation of poorer households and disadvantaged groups, including Indigenous peoples. One report calculated that wealthier smallholders earned at least 50% more

Box 17

Sunflower oil production in Tanzania: some unexpected impacts on equity

Figure 45 *Sunflower oil production in Tanzania is widely promoted as a successful means of poverty reduction*, by Hailey Tucker, 2017, One Acre Fund.

Almost 95% of sunflower production in Tanzania is by smallholders with holdings of up to 2 ha (Figure 45). Sunflower production has been widely promoted as a tool for poverty reduction and, in some regions, this has had transformative benefits for the local economy. For example, in the Singida region, increased sunflower production, processing and commercialisation have brought about major improvements in local livelihoods and living standards. The number of farmers growing sunflowers has almost doubled since 2000, and the income generated has enabled them to diversify crops and business enterprise, which has led to add-on benefits. There have also been some limited benefits in terms of equity. Large livestock owners have had to share livestock care with poorer neighbours, and while this does not address inequities in land ownership and wealth, it has improved access for the poor to milk, manure, oxen and agricultural extension services.

However, these changes have also had some unforeseen negative impacts on equity, including on gender relations. New technologies, the shift away from home processing, and the need to access credit have shifted control for processing and marketing from women to men, which means that many women no longer have direct access to cash income from the industry. For these reasons, overall, women (especially female-headed households) benefit less from commercial sunflower production than men do [333,334,356,357].

from palm oil than the smallholder average [352]. Leguizamón [317] reported the main local beneficiaries of genetically modified soy in Argentina to be the local elite, including medium to large-scale farmers, landowners, and businessmen.

However, several factors can limit the adoption and profitability of vegetable oil crops by less wealthy or otherwise disadvantaged households, including: the lack of available land and secure land rights; a lack of capital to cover high setup costs and, for tree crops, replanting costs; long lead-in times to first harvest; limited technical skills and access to equipment and processing facilities; poor access to markets and supply chains; and discrimination, including against Indigenous peoples [306]. Barriers to entry are often lower for domestic markets, because of lower quality control requirements, greater compatibility with existing farming and cultural practices, and shorter supply chains, which have lower transaction costs and are often more accessible to producers. Thus, while the overall profits may be greater from export markets, they are not always the best option for local farmers [353]. On the other hand, export production is more easily tracked than production for domestic markets or for home consumption (see Chapter 3.1), and therefore there may be greater transparency and accountability. Longer supply chains also typically create more jobs and income opportunities for processors, traders, and others.

There are additional barriers to participation and capture of benefits by women. For example, in the palm oil industry, cases have been documented where women are not recognised as legitimate landowners, preventing them in taking part in negotiations or signing contracts over land and land use [306]. They are also sometimes excluded from negotiations with processors and traders; for example, in Borno State, Nigeria, returns from soybean production were found to be about 20% lower for female-headed households than male-headed households even though yields were similar, and this was attributed to discrimination that limited their access to markets [354,355]. There can also be unexpected impacts on gender dynamics within the household; for example, in Tanzania, sunflower production has brought about substantial improvements in local livelihoods and living standards in some districts, but it has resulted in a shift in control away from women towards men (Box 17). Similar changes are seen in other oil crops that were primarily used in traditional contexts but for which growing international demand is creating social tensions (Box 18).

Box 18

Dilemma of local to global system transition: Blessing or a social curse?

Within rural communities from Western to Eastern Africa, many people's livelihoods depend on natural resources including Indigenous oil crops like shea, African locust beans, castor oil, egusi, sesame, and others [1,2]. The gathering and local processing of these Indigenous underutilised oil crops has many social impacts tied to local cultures, traditions, and customs [3,4]. These oil crops contribute towards gender equity and livelihood security in the regions' largely patriarchal societies. Women and children dominate the plant gathering and local processing industries, but these activities are facing increasing threats from ongoing globalisation [5]. If unchecked, women's social groups like Sunkpa Shea Women's Cooperative (Ghana) would be replaced with larger multinational cooperatives like Bidco Africa [6], and not only will the vital traditional ecological knowledge and practices be lost, but the livelihoods of many families could be threatened. Furthermore, such transitions can also have ecological impacts. In the case of shea, its current overexploitation and competition from other cash crops is driving the trees deeper into the African savannah and making them scarcer to find compared to a few decades ago. Reportedly, women and children now travel longer distances only to find much fewer shea nuts [358].

4.2.6 Impacts of different forms of smallholder organisations and support on rights and livelihoods

There are many different arrangements for smallholder organisation and integration into supply chains, that have important implications for the social costs and benefits of production. Smallholders may operate completely independently, or they may enter into contracts with plantation companies, processors, and traders to grow or supply produce, or to lease their lands for plantation development by companies. Each of these arrangements has implications for rights, livelihoods, and equity.

Independent smallholders, or subsistence-based producers, retain the greatest control over their lands and land use, including the crops they plant, how they are grown, and who they sell the products to (Box 19). However, their productivity and profits may be limited by a lack of resources, credit, and technical knowledge on vegetable oil cultivation, as well as by poor access to processing facilities and markets, and weak bargaining power. Independent smallholders also bear the full costs of setup and production and the full risk of crop failure [337].

Contracted farmers are tied to a specific buyer, guaranteeing them a market. Contracts often include transfer of some degree of control over their lands and land use in return for financial loans and technical support. Alternatively, farmers, landowners or communities may sign contracts to lease land to companies or government bodies, who then manage their land for palm oil plantations. However, the terms of both of these kinds of contracts usually vary and are often unfavourable to the farmers. In the case of palm oil, independent smallholdings have been reported to be more profitable than contractual arrangements, which often provide incomes that are insufficient to cover costs and basic needs [331]. Farmers may also be coerced

> “Independent smallholders, or subsistence-based producers, retain the greatest control over their lands and land use, including the crops they plant, how they are grown, and who they sell the products to.”

Box 19

Independent babassu oil producers

The babassu palm, native to the Amazon region in northeastern Brazil, holds significant economic and socio-cultural importance. It is linked to traditional women known as ‘quebradeiras de coco’, who extract oil-rich seeds from the fruit [359]. This palm grows up to 30 metres and produces hard shell nuts containing babassu oil. The extraction of babassu oil involves pressing, a labour-intensive process. Despite the challenges, it provides jobs and income, particularly through organisations like the ‘Cooperative Interestadual das Mulhere Quebradeiras de Coco Babaçu’ (CIMQCB). The organisation brought over 130 women from 26 producer groups together in 2016 [360]. Apart from economic benefits, the babassu palm serves various purposes, providing food, tools, fuel, building materials, and soil fertilisers. Its oil, known for its moisturising effect and therapeutic properties, is utilised in the cosmetic industry [361]. Studies also indicate its healing effects on skin wounds [362]. Thus, this babassu community connects the subsistence activity of breaking babassu palm tree nuts with local and global value chains (GVCs) in the cosmetics industry [363]. The babassu palm can grow in dense forests and acts as a pioneer species in colonising degraded areas, aiding in reforestation efforts. The *quebradeiras* have developed organisational activities that address persistent social, economic, and environmental challenges [363]. Babassu has been suggested as a replacement for palm oil [364], but yields are low.

into signing agreements, or the terms may not be explained clearly in advance, and there may be little transparency once agreements are in place. In the worst cases, the prices paid are insufficient to cover basic needs and loan repayments, and farmers fall into permanent debt. This applies to many oil palm smallholders [301,306,353,365]. Similarly, in Davao Oriental province in the Philippines, most coconut farmers are trapped in situations of debt-bondage that ultimately force many to sell off their lands [366].

Alternatively, farmers may come together in farmer groups and cooperatives. Potential advantages of doing so include increased access to loans, technical support, processing facilities and markets, and greater control over all aspects of production and sale of produce. However, in some cases, individual farmers do not receive records of the loans they have taken out or of their repayments, making them vulnerable to economic exploitation. They may also be unaware of government purchase prices and have little say in negotiations over sales [367].

4.2.7 Impacts on labour rights

Where local people agree to the establishment of plantations on their lands, it is often in the expectation of jobs. However, the jobs that become available to local people may be few and poorly paid. Large soybean farms are estimated to need only one worker per 167 to 200 ha. In Argentina and Brazil, for example, soybean development has led to high unemployment rates and outmigration, rather than boosting local incomes [368]. Oil palm production is more labour-intensive. For example in Indonesia, it has been estimated to provide one job per six to eight hectares – and the total number of jobs created through oil palm development can be considerable. In East Kalimantan Province, Indonesia, for example, oil palm has created between 220,000 and 120,000 employment opportunities [369]. However, local people may be disadvantaged when they apply for jobs, either because of relatively low levels of skills and experience or because of discrimination, or both. In such cases, companies rather frequently bring in migrant workers to fill a perceived shortage of skills instead of investing in training and upskilling,

International labour standards and legal requirements are set out in the conventions and recommendations of the International Labour Organization (ILO), which was created in 1919 following the end of World War I (Box 20). These standards have been developed through negotiations between governments, employers and workers' representatives across the ILO's 187 Member States and therefore have wide application. However, labour rights violations are common in the edible oils industries, and include forced or bonded labour, child labour, poor renumeration, poor living and working conditions, and lack of recognition of workers' rights to freedom of association and

Box 20

Fundamental Principles and Conventions under the International Labour Organization [370]

Fundamental Principles:

- Freedom of association and the effective recognition of the right to collective bargaining;
- The elimination of all forms of forced or compulsory labour;
- The effective abolition of child labour;
- The elimination of discrimination in respect of employment and occupation.

Fundamental Conventions:

- The Freedom of Association and Protection of the Right to Organise Convention, 1948 (No. 87)
- The Right to Organise and Collective Bargaining Convention, 1949 (No. 98)
- The Forced Labour Convention, 1930 (No. 29) (and its 2014 Protocol)
- The Abolition of Forced Labour Convention, 1957 (No. 105)
- The Minimum Age Convention, 1973 (No. 138)
- The Worst Forms of Child Labour Convention, 1999 (No. 182)
- The Equal Remuneration Convention, 1951 (No. 100)
- The Discrimination (Employment and Occupation) Convention, 1958 (No. 111)

collective bargaining. Rights violations connected to agrochemical use and the impacts on the health of workers have been described above.

Migrant workers often arrive illegally and are therefore particularly vulnerable to exploitation; many cases have been documented where they are living and working in conditions of modern slavery. There can also be severe impacts on their families, who may be left behind without an adequate means of making a living. Women workers are also especially vulnerable to exploitation [371]. Typically, they are paid less than men, and in some cases, forced to work without pay in support of their husbands. Women often get no maternity leave, and they are sometimes dismissed from their jobs when they become pregnant. For women, time is rarely allowed to attend prenatal check-ups and for childcare. As described earlier in the report, they are also particularly vulnerable to agrochemical poisoning during spraying and other activities. As regards the hiring of migrant male workers in oil palm plantations, and the resulting influx of outsiders, that has been linked to increased alcohol abuse and sexual violence against women, especially, but not only, those who seek work on plantations.

Much employment in the palm oil industry is insecure and poorly paid. However, the wages of those who have secure, permanent employment on plantations tend to be higher and more regular than the cash income that smallholders gain from vegetable oils production [344].

> “Migrant workers often arrive illegally and are therefore particularly vulnerable to exploitation; many cases have been documented where they are living and working in conditions of modern slavery.”

⟶ *In Nuporanga, Brazil, a worker uses a machine to assist in dumping harvested soybean seeds*, by Alf Ribeiro, 2013, Shutterstock.

4.3 Nutritional and health contexts

We briefly review the literature on the nutritional and health contexts of vegetable oils, broadly reiterating certain findings in some of the authors' previous review studies [121,343,372].

4.3.1 Oils and fats as part of a healthy diet

Fats or lipids are essential components of cellular membranes and serve as a source of energy [373] (Box 21). From 1991 to 2011, vegetable oils accounted for ~25% of the increase in calorie consumption globally [90]. Increased consumption of fats, which are concentrated calorie sources, are linked to adverse health outcomes such as increased risk of cardiovascular disease. Since the 1950s, consumers have been told to avoid fats as they make them fat, increase their risk of cardiovascular disease, and may even increase their risk of cancer. Yet avoiding dietary fats because of their concentrated calories without decreasing calories from other sources, especially refined carbohydrates and alcohol, is now known to be a losing dietary strategy.

Dietary guidance has evolved to emphasise dietary patterns over nutrients with an emphasis on a plant-based diet that prioritises consumption of vegetables, fruits, legumes, and whole grains, such as the Mediterranean diet [374]. These dietary patterns have implications beyond cardiovascular disease though, with new emphasis on brain health, gut health, and weight management. The types of fatty acids and quality of fat in diets are also recognised as more important than just the saturated fat content to which much health guidance refers [375,376]. High-fat diets may be protective in cardiometabolic disease, with some studies suggesting that a higher consumption of saturated fat may be associated with a lower risk of stroke [376]. A balanced diet that includes recommended foods and high-quality fats is essential for maintaining optimal health [377].

Box 21

Fats are an essential part of healthy diets

Fats provide essential fatty acids and facilitate the absorption of fat-soluble vitamins such as A, D, E, and K [378]. Some fats, such as alpha-linolenic acid, an omega-3 fatty acid, and linoleic acid, an omega-6 fatty acid, are essential, meaning that the body cannot synthesise these fats and must, therefore, be consumed as part of a balanced diet. Alpha-linolenic acid is particularly abundant in walnuts, rapeseed, legumes, flaxseed, and dark leafy vegetables [379], while linoleic acid is an important component of breast milk and is present in nuts, cereals, legumes, some meats, eggs, and dairy products [380]. Some minor components, such as found in olive oil (hydrocarbons, aliphatic and aromatic alcohols, phenols, sterols, tocopherols, fat-soluble vitamins, volatile organic compounds, aldehydes, triterpenic acids, etc.) also play important nutritional and biological roles [381], although health benefits beyond what could be expected from the fatty acid composition of olive oil remain unclear.

Cholesterol, primarily found in animal fats, is essential for human life as a component of the cell membrane, a precursor molecule in the synthesis of vitamin D, and steroid and sex hormones [382]. It also plays a role in the absorption of fat-soluble vitamins. The effects of dietary fats on cardiovascular disease risk have traditionally been estimated from their effects on serum cholesterol, although the thinking about health implications of high cholesterol levels is changing [376,383]. There is also ongoing debate about the optimal intake ratios of various omega 3, 6, and 9 fatty acids.

4.3.2 Impacts on food security, nutritional quality, and obesity

While in parts of the world there is an excessive intake of calories (overnourishment), an estimated 691 to 783 million people in the world faced hunger in 2022 [5,384]. Fat is an efficient, healthy, and tasty way to take in energy and nutrition, especially for undernourished populations. A recent study estimated that 45 million tonnes of additional dietary fat per year are required to reach recommended levels of fat consumption to reduce this 'fat gap' [4] (Box 22). The fat gap exists in places, such as Southeast Asia, South Asia and much of Africa (see Figure 46). If this fat gap is projected up to 2050, an additional 88–139 million tonnes of oils and fats will be required [4].

Most nutritional and health studies have evaluated the role of different fats on people in high income countries, often in relation to the 1.9 billion adults worldwide who are overweight due to the relatively high energy density of fats [385]. Fat contains 9 kcal/g vs. 4 kcal/g for carbohydrates and protein, which can pose a risk to overweight individuals but can play an important role in providing nutrition to those who are underweight. Geographically, undernourishment and food insecurity are concentrated in sub-Saharan Africa, parts of Asia and the Caribbean (Figure 1). The 'depth of the food deficit', i.e. a measure providing an estimate of the number of additional calories the average individual needs to achieve adequate nutrition, is especially high in countries such as Haiti (530 kcal per person per day), or the Central African Republic (380 kcal per person per day) [386]. Countries with high food deficits coincide with parts of the world with large fat gaps: Eastern, Northern, Central and Western Africa; East, Southeast and South Asia, and the Caribbean [4]. Understanding fats in diets of undernourished people is important, as irreversible health impacts can start at a young age, with fat consumption affecting the quality of breast milk of future mothers and, consequently, their infant's health and life-expectancy [387]. However, regional studies in South America note that feeding energy-rich, micronutrient-poor foods to undernourished people can promote obesity [388]. The extent to which fats can contribute to closing the food deficit without generating obesity remains unclear, although dietary fats will likely play some role in increasing energy intake among undernourished people.

Box 22

Fat gap estimates may miss important local oil production and consumption

The fat gap measure proposed by Bajželj et al. [4] was calculated using the FAO's Food Balance statistics, which are based on food supply at the retail or market level. It therefore misses oil that is locally produced and consumed, which may concern large volumes. For example, in Benin, Cameroon and Nigeria, about 50% of the palm oil consumed is produced in the traditional way, while in Ghana and Sierra Leone, it is about 70% and 90% [389]. Areas of these unaccounted traditional African oil palm plantations were estimated in 2013 to be 6,665,000 ha [390], and even at low yields these trees could produce some 6.7 million tonnes of palm oil per year. The fat gap could therefore be smaller than predicted in parts of West, Central and East Africa that have subsistence palm oil. This indicates the importance of mapping the traditional plantations and understanding how they contribute to local fat consumption.

> "Geographically, undernourishment and food insecurity are concentrated in sub-Saharan Africa, parts of Asia and the Caribbean."

Fats are important nutrients during growth and development, providing more than 50% of the calories in breast milk. Dietary guidance supports higher intakes of fats when calorie needs are high, during growth and development. The Acceptable Macronutrient Distribution Range (AMDR) for fat is 30–40% of energy for ages 1 to three years old and 25–35% of energy for ages four to 18 years old. Linoleic acid and linolenic acid are two essential fatty acids that are needed in higher concentrations during pregnancy and lactation. Usual recommendations are to limit intakes of trans fatty acids and increase intakes of omega-3 fatty acids over omega-6 fatty acids, while reducing intakes of saturated fatty acids. Yet these recommendations are conflicting as shorter chain saturated fatty acids are not linked to increased risk of cardiovascular disease in cohort prospective studies.

Addressing the food deficit requires affordability and availability of nutrition [94]. Compared to other food groups, fats are cheap. With a cost per person per day of less than US$ 0.20, fats contribute about 4% to the average global cost of a healthy diet. In comparison, the cost is around US$ 0.40 for starch staples, US$ 0.60–1.00 for protein-rich foods, and around US$ 0.70 for dairy, fruits, and vegetables [94]. Compare these costs to the international poverty line for low-income countries of US$ 1.90 per day [391]. Fat prices vary with type and origin. Generally, affordability favours local production. Transport and logistics costs in tropical America and the Caribbean, for example, made up 20% of the cost of food products [392]. Figure 1 shows that crops such as peanut and palm oil in central Africa and palm oil in South-East Asia could play important roles in the local supply of affordable fats.

While malnutrition remains a significant problem, with growing affluence, people consume more fat, resulting in overconsumption especially in Europe, North America, and Oceania (Figure 46). Drenowski and Popkin [89] showed that the initial phase of the nutrition transition involves a significant rise in domestic production and imports of oilseeds and vegetable oils. This leads to increased consumption of animal-based foods and processed items. The transition is also characterised by a surge in food consumed away from home, like street and fast food, coupled with insufficient intake of high-fibre foods, such as tubers, pulses, fruits, and vegetables [393].

Waste-adjusted consumption of fats per person by region

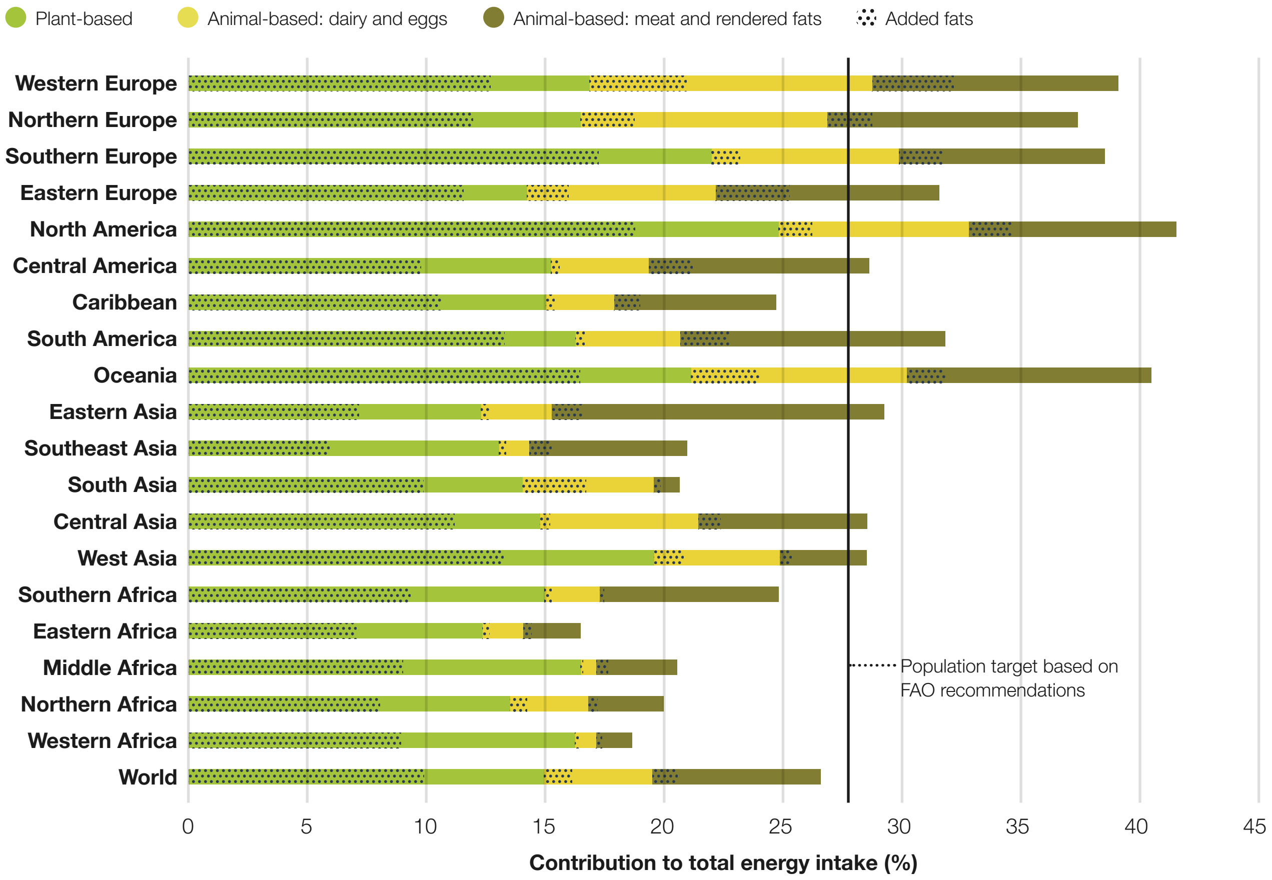


Figure 46 Waste-adjusted average consumption of plant, dairy, and meat fats per person by region in 2018. Source: Prepared by the report editors, based on data from Food and Agriculture Organization of the United Nations and figure from Bajželj et al. (2021) [4].

Table 12 Change in calorie intake in developing, industrialised countries, and China.

Change in four decades (1963 to 2003)	% change Meat	% change Sugar	% change Vegetable oils	% change Rice	% change Roots and tubers	% change Pulses
Developed countries	119	127	199	13	-13	-41
Industrialised countries	15	-6	105	-19	-23	-7.5
China	349	305	680	24	-31	-88

Source: Data compiled by the report editors, based on FAO (n.d.) [15], and adapted from Kearney (2010) [393].

Analysing calorie intake per capita from 1963 to 2003 reveals a notable shift in developing countries, industrial nations, and China. These regions moved from carbohydrate-rich staples (such as cereals, roots, and tubers) to a higher consumption of vegetable oils, animal products (meat and dairy), and sugar (Table 12). Notably, vegetable oil consumption experienced the most pronounced increase: a 105% rise in industrialised countries; 199% surge in developing nations; and 680% in China alone (Table 12).

The transition to a high-fat diet can be attributed to several factors. Rising incomes have made fatty foods more affordable, while urbanisation has led to the proliferation of supermarkets, predominantly dominated by multinational corporations [394]. These corporations have facilitated the integration of imports into the food supply, resulting in easily accessible and cheaper oils. Vegetable oils have become widespread due to their interchangeability in cooking (see Chapter 2.3.5), except for culturally significant options like olive oil in Europe and palm oil in Africa. Unfortunately, this increased consumption of vegetable oils has also been linked to unhealthy dietary trends, often tied to the consumption of ultra-processed foods and their components [4,395].

Supermarkets and multinational food companies play a significant role in promoting ultra-processed food consumption, which utilise vegetable oils extensively. These ultra-processed foods, often high in fats, salt, and sugar, cater to consumers' desires for hyper-palatable products. Advertising also plays a role in driving consumption of high-fat foods and sugary drinks. Even within developed

→ *Classic Chinese cuisine, rich in meat, sugar, and vegetable oils*, by M.studio, 2020, Adobe Stock.

⟶ *Ultra-processed foods, easily found in convenience stores at affordable prices*, by Martin Lewison, 2014, Flickr.

nations, lower-income households find it easier and more affordable to access processed foods and meat compared to fresh vegetables. This phenomenon is often referred to as 'food deserts' [396,397,398].

Food processing is critical to food safety and food economics, so we must be respectful to differences in food access and food costs before suggesting that ultra-processed foods must be deemed unhealthy and banned or limited. Food waste is linked to lack of food preparation facilities or food storage facilities, so a one size approach to ultra-processed foods will not improve public health.

Before moving forward with ultra-processed foods (UPF) research, we must agree on definitions of ultra-processed foods in research trials. In a recent proof of concept study, it was found that menus containing popular foods in the United States scored high on the Healthy Eating Index (HEI), despite all foods coming from UPFs [399]. Appropriate food processing systems are dependent on access to processing facilities and cultural cooking practices. Labelling all UPFs foods as unhealthy will lead us to a similar place as labelling all saturated fats as unhealthy when we have only observational trials to support our hypothesis and no intervention trials based on biological mechanisms to add to the body of evidence.

Cheaper and more affordable fat has contributed to food security, but low food price is only one aspect of food security in relation to access to food. Another aspect of food security concerns availability, which is determined by the quantity of domestic food production and utilisation for an adequate nutritious diet [400]. Lastly, stability, which examines whether vulnerable households or individuals have access to food at all times is also important [400]. For example, the global fat gap could be reduced through the expansion of oil palm plantations in Africa, but there are concerns that most of the new plantations would be developed by big international companies with narrow trickle-down benefits to the local economy and low-income populations. Furthermore, if the process is not well conceived and implemented, as has often been the case in the past, it can exacerbate rural poverty through reduced access to land for local communities brought about by the large-scale concession acquisitions and the associated land expropriation (see Chapter 4.2). For example, in India, the globalisation of vegetable oils has been accompanied with the eradication of local rural businesses producing domestic oilseeds, and traditional farms and methods of oil processing [401].

In summary, several aspects of food security have been worsened by the globalisation of vegetation oils, with less land and business opportunities for local production, especially for the poorest households that are dependent on agriculture as their primary source of income [401].

4.3.3 Food nutrition labelling

In response to public concerns about the adverse impacts of vegetable oils, there has been an increase in food labelling that provides specific information about the type of oils used in foods. Food labelling has a long history dating back to ancient civilisations. The Babylonians, for instance, used cuneiform scripts on clay tablets to record trade information about food and wine, although this was probably only accessed by the few that could read [402]. Modern food labelling as we know it today has its roots in the late 19th and early 20th centuries. In the United States, the Pure Food and Drug Act of 1906 was the first such law that required food products to be accurately labelled [403].

Today, food labelling is a complex and highly regulated field, with requirements varying from country to country. For example, the U.S. Food and Drug Administration (FDA) defines a wide range of labelling terms such as the source of fat (such as ‘beef fat’ or ‘cottonseed oil’). Additionally, terms related to production standards, such as ‘all-natural’, country of origin labelling, and nutritional claims, such as ‘low fat’, are clearly defined. Other terms, such as ‘good source of Omega-3S’, are likely prohibited because there is no FDA-established nutrient guidance which those claims refer to [404]. Similar food labelling requirements exist within the European Union [405], with the Nutri-Score playing an important role in providing consumers with information about nutritional and other impacts (Box 23).

> “Today, food labelling is a complex and highly regulated field, with requirements varying from country to country.”

Food labelling regulations provide specific guidance for the principal display panel where the name of the food is shown. The ‘information panel labelling’ refers to the label statements that are generally required to be placed together, without any intervening material, on the information panel, if such labelling does not appear on the Principal Display Panel (PDP). These label statements include the name and address of the manufacturer, packer or distributor, the ingredient list, nutrition labelling and any required allergy labelling [406]. Manufacturers are relatively free to make claims about the benefits of their products (Figure 47), although there are regulations. Psychological studies show that clear and short messages about product benefits are most effective in changing the perceptions of buyers [407]. A study in Japan indicated that conventional health claims such as ‘low in saturated fat’ are valued more by buyers than the relatively newer claims, such as ‘high in oleic acid’. Similarly, consumers did not prefer oil with genetically modified ingredients or oil that is not domestically produced, but they were willing to pay extra for ‘organic’ or ‘functional food’ features [408]. It seems that product information that claims to not contain a particular oil, such as ‘contains no palm oil’ labels, are powerful marketing tools that capitalise on perceptions of which oils are ‘clean’, ‘healthy’, or ‘environmentally-friendly’ [409].

Figure 47 Examples of products making specific claims about palm oil. **A)** The label states “We never use palm oil”; **B)** Mother Africa is a well-known Nigerian brand; **C)** The Dutch text on the right says “100% Vegetable. Cook, bake, or fry without palm oil. With shea.” Source: Prepared by the report editors.

Box 23

Nutri-Score

Nutri-Score is one of the most used nutrition labels in the European Union. The Nutri-Score uses nutritional information, including energy and saturated fat content, the ratio of saturated fat to overall lipids, and the presence of fruits, vegetables, nuts, and specific oils (such as colza, walnut, and olive) to assign foods a ‘health’ or nutrition value score between A (highest) and E (lowest).

Numerous studies have highlighted the value of the Nutri-Score system as a tool to help individuals enhance the overall quality of their dietary choices [410,411]. However, one review study noted that there is insufficient evidence to support a health claim based on the Nutri-Score system, since a cause-and-effect relationship could not be established [412].

While Nutri-Score has garnered recognition for its positive aspects, it is important to acknowledge that there is still room for refinement. The system’s dependence on arbitrary cut-offs can lead to abrupt score changes for certain foods, even with minor variations in component values. For example, rapeseed oils in the Open Food Facts database can either be rated B, C, or D and it is not clear what generates this variation. This highlights a potential limitation of using Nutri-Score for specific products containing nutrient amounts close to the cut-offs. Addressing this challenge remains an opportunity for future enhancements, which also includes combining health scores of foods with their ecological and social impacts [413]. The new Eco-Score, which is now used alongside Nutri-Score, tries to address this by scoring the environmental impact of food [414]. We note that the Eco-Score automatically deducts 10 points for any products containing palm oil for its association with deforestation.

The EU recently updated its Nutri-Scores for cooking oils with those with low levels of saturated fatty acids (rapeseed, walnut, olive oil) reaching the B class (Figure 48). Other fats, such as coconut and butter, remain as E. Nutri-Score is controversial with some claiming that the system “introduces distortions” that can mislead consumers [416].

Nutri-Scores for vegetable oils and butter

Figure 48 Nutri-Scores for fats were recently updated by the European Scientific Committee Nutri-Score. Other oils and fats not depicted rated as follows: palm oil (D), lard (D), linseed (D), and argan (D). Source: Prepared by the report editors, European Scientific Committee of Nutri-Score (2022) [415].

4.3.4 Conclusions on nutritional and health contexts

The subject is dynamic (despite a remarkable lack of progress in the last three decades) and much uncertainty remains. Fats play an important role in the transition to sustainable diets as they are a concentrated energy source that are needed for future food security. Past dietary guidance that recommended carbohydrates in exchange for fats have not been associated with improvements in health outcomes. Fats are a concentrated source of calories, and caution must be taken when introducing them into diets, despite their importance to food security in developing countries. Best practices would be to respect local customs and food production and refrain from banning sources of fats that are crucial to local income and culture.

With regard to vegetable oil crops, palm oil is an important oil for cultural and price reasons in large parts of South-East Asia and Central Africa, and its alleged negative health impacts because of high saturated fat content are increasingly questioned [417,418]. Among the oil crops, palm oil is the most land-efficient fat where efficiency could be further improved, especially through mechanised harvesting and better chemical management, as well as providing access to improved planting stock, and avoiding deforestation to protect biodiversity and carbon stocks [54]. Peanut provides a healthy and cheap oil, and improved peanut production could reduce fat gaps in key regions of human population growth (for example, in Africa and South Asia). Because both palm oil and peanut oil are relatively cheap, they will remain important for many people. Peanut improves soils through nitrogen-fixing, but impacts from aflatoxin contamination on health remain a concern [419]. Coconut, another crop of tropical regions, is an important source of fat to many poor people. Impacts on health remain debated [420], and differ for different types of coconut oil [421]. Furthermore, there are concerns about coconut's environmental impacts, especially on tropical islands with high species endemism, where coconut-driven losses of natural ecosystems threaten biodiversity [253]. Olive and rapeseed oil are often used for their alleged health benefits [377,381,422,423], although given the high variation in effective compounds in these oils, much remains to be learned about actual health impacts [372].

> "Fats play an important role in the transition to sustainable diets as they are a concentrated energy source that are needed for future food security."

Soybean oil, as the largest oil crop in global area, will likely remain a leading source of oil and animal feedstock. Reducing pork and poultry production can lead to reduction in soybean oil production and spare land in regions of high deforestation such as South America. There are concerns about negative health impacts related to the lipid profile of sunflower oil, especially its very high omega-6 to omega-3 ratio [4], but it is difficult to generalise about this, also because there are different types of sunflower oil that vary significantly in their oleic, linoleic (omega-6) and stearic acid content. Finally, the nutritional and culinary roles of hundreds of locally produced and consumed vegetable oils remain poorly known, unless increasingly traded internationally (such as shea, *Allanblackia* spp., or argan *Argania spinosa* L. [424-426]).

⟶ *Peanut provides a healthy and affordable oil, and could address the fat gap in low and middle-income countries*, by alter_photo, 2019, Adobe Stock.

4.4 Perceptions of oils and their impacts

Perceptions of food have always been shaped by availability, taste, and culture. In the modern age, they are also shaped by other concerns: price and, increasingly, environmental, climate, and social concerns. Our recent surveys (unpublished data) have found that olive oil is the most beloved edible oil in the world with consumers, in general, feeling most negatively about palm oil. Other oils did not elicit such extreme feelings. According to a recent survey of 694 people across five continents (our unpublished data) – olive oil elicited the fewest negative perceptions. Only in India did negative perceptions of olive oil exceed 10% of those surveyed. The generally positive perception of olive oil in Europe and North America (a mere 1% and 3%, respectively, viewed the oil negatively) is likely due to several factors.

A YouGov survey of 25,000 people around the world found that the world's most popular and beloved cuisine is Italian [427], to which olive oil is an integral component. There is not another edible oil that is often served naked on a plate for dipping. Olive oil is almost universally considered by consumers to have beneficial properties for health due to a high unsaturated fat and antioxidant content. A 2022 survey by Cargill dubbed FATitudes found that 62% of Americans believed olive oil was good for you (Figure 49).

While olive oil comes with environmental impacts – pesticides, impacts on nesting birds, habitat loss and desertification [429]– these have not gained as much public attention as, say, the impacts of palm oil.

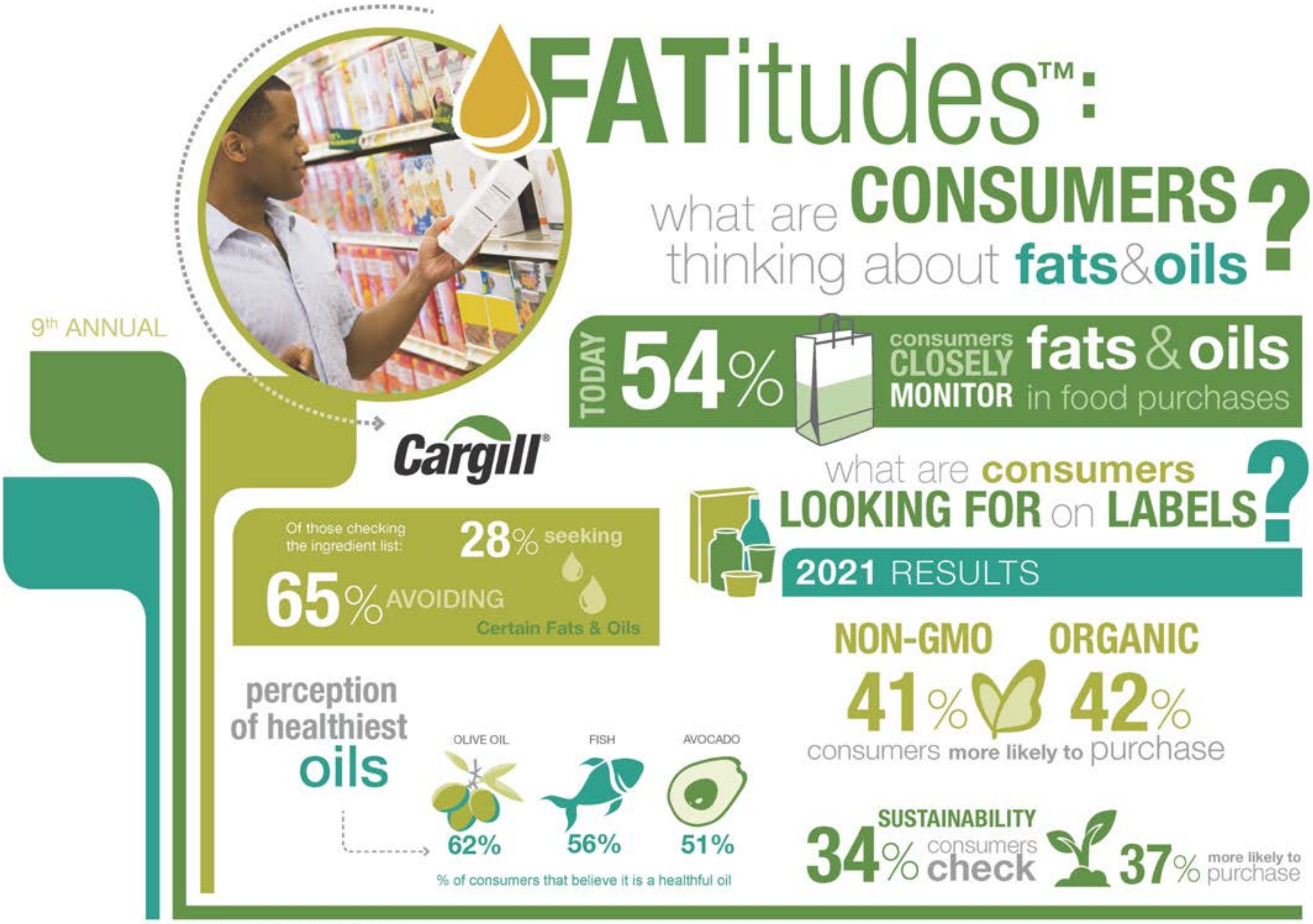


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Figure 49 Cargill's proprietary FATitudes™ research provides an understanding of consumer awareness, perceptions and stated behaviours around types of oils in packaged foods. It includes a year-over-year comparison of these measures as well as how different demographic groups (age, gender, region of the US and income) differ in their oil attitudes and usage. Source: Cargill (2023) [428].

It is possible that the overall love for olive oil may buffer it from environmental criticism, although the high mortality of roosting birds during night harvests of olives [430] did get attention in global media.

On the other side of the spectrum is palm oil. We analysed data from a 2022 survey by Kantar of 1,000 respondents in 18 countries (unpublished data), none of which were from Southeast Asia, where palm oil is largely produced. The survey found that 55% of respondents were aware of palm oil, with the majority of responders who were aware of palm oil expressing negative perceptions of the oil. Over the whole survey, 28% of respondents believed it had a negative impact on the environment, 27% thought palm oil was bad for one's health, and 21% believed it negatively impacted society. Negative views rose to their highest point in European countries. For example, half of the Austrians surveyed said palm oil was bad for the environment.

This is echoed in the above-mentioned more globally-focused survey, which included people from Asia and Africa (our unpublished data). This survey found that 69% of European respondents said they avoid palm oil when they have a choice. Interestingly, even 9% of Indonesians say they also avoid palm oil, even though Indonesia is the world's largest producer of palm oil. In contrast, only 6% of Indonesians avoid olive oil where possible. No other edible oil in this survey – which asked respondents about nine different edible oils – elicited such a negative response.

Similar perception differences are reflected on social media. A recent analysis of 20 million tweets about vegetable oils, posted between 2006 and 2021, showed that three oils dominated: coconut, olive, and palm oil [431]. Tweets about coconut and olive oils primarily focused on health, beauty, and food, while palm oil tweets drew attention to environmental concerns. A sentiment analysis showed that palm oil was often associated with negative sentiments, which became more prevalent over time, compared to olive and coconut oils that had more neutral and positive comments throughout the study period (Figure 50).

What has given palm oil this reputation? Firstly, deforestation (and orangutans). Oil palm plantations grow best in the lowland tropics, often destroying rainforest and carbon super-rich peatlands [54]. Deforestation concerns have clearly reached a large audience, especially in Europe. Nearly half of all Austrian, French, and Spanish respondents had a negative view of palm oil due to its environmental impact, according to the Kantar survey (see above). Negative views are less common in other countries, such as Brazil and the US, where only 9% and 6%, respectively, had negative views on the environmental impact of palm oil. It should be noted that these nations were also much less aware of palm oil overall.

It would be interesting to contrast these results, however, with even bigger drivers of rainforest destruction. For example, beef and soy are more significant contributors to tropical forests than palm oil [432], while crops like maize and rice, which have globally much larger tropical production areas than oil palm, are often overlooked in deforestation debates [433]. We are not aware of any comparative perception studies that include all these commodities.

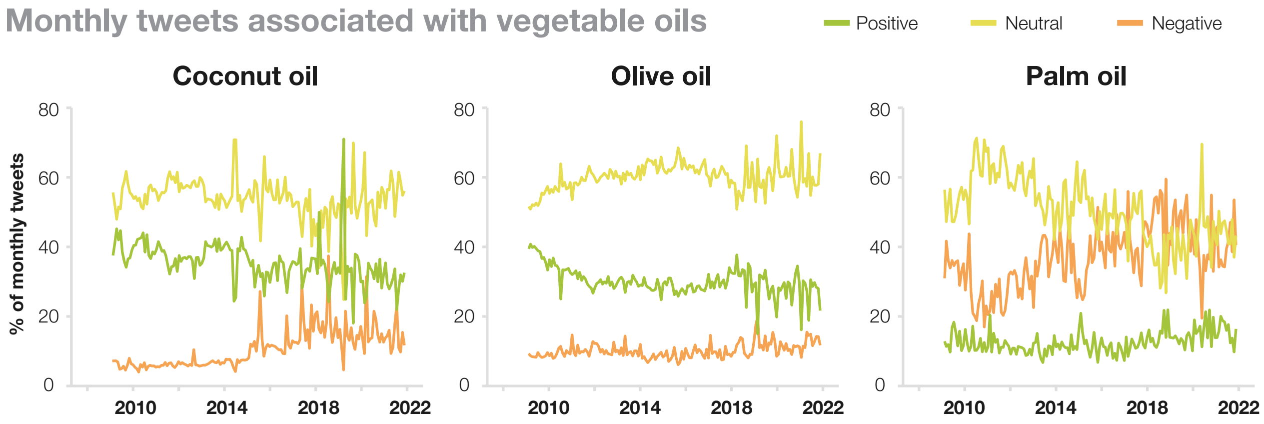


Figure 50 Evolution of the percentage of monthly tweets associated with each sentiment. Analysis performed using English-language tweets. Source: Prepared by the report editors, based on Candellone et al. (2023) [431].

Environment was not at the top of mind for all respondents. In Russia – which has the highest awareness of palm oil (73%) of those surveyed by Kantar – the overriding concern was health impacts. Russia is an interesting case: it is the 13th largest consumer of palm oil, consuming over a million metric tonnes in 2020 [434]. This makes it a larger consumer of palm oil per capita than the US, China, and Nigeria. Still, 60% of respondents in Russia viewed palm oil as damaging to their health, while only 28% of Russians were concerned about potential environmental impact.

Additionally, palm oil's reputation has been a negative view of its impact on society. Across the Kantar research, 21% of respondents cited social impacts, mostly poor working conditions. Indeed, some palm oil companies have been accused of using forced and even child labour in both Malaysia and Indonesia (see Chapter 4.2). Then again, these negative perceptions about palm oil are not shared by everyone (Box 24).

In response to the criticism of the palm oil industry, stakeholders, including environmental groups, launched the Roundtable on Sustainable Palm Oil (RSPO) in 2004. The group certifies palm oil based on sustainability and labour standards. The Kantar survey found that most respondents, however, did not know about the drive for a more sustainable palm oil. Across all the countries surveyed, only 7% were aware of the RSPO with the highest percentage in the Netherlands (17%). Raising awareness of the initiative being taken by actors within the industry to promote more sustainable and equitable palm oil production could be instrumental to changing consumer perceptions and ensuring that producers abide by regulatory standards to remain relevant in a competitive market.

Box 24

Palm oil perceptions from the perspective of a Nigerian cook

The BBC GoodFood Podcast explores the stories behind food by interviewing cooks about their cooking journey, with a narrative focused on their favourite dishes.

In an episode released on 15 August 2023, chef Mallika Basu, who was born and raised in Kolkata, India, interviewed Lerato Umah-Shaylor, a Nigerian chef and cookbook author, championing African cooking and its importance in world history. The interview is light-hearted and friendly but takes a turn when Lerato introduces her favourite dish and its defining ingredient – palm oil. While the interviewer appears open-minded, the reaction to and singling out of palm oil tinges the conversation with a sense of judgement.

The following excerpt serves as a poignant illustration of the polarised nature of the ongoing debate surrounding the utilisation of various cooking oils. It highlights the contrasting perspectives held by both the interviewer and interviewee, which can be expanded to the larger global population, shedding light on the complexities and sensitivities involved in discussions about palm oil and its cultural significance.

**BBC GoodFood Podcast,
15 August 2023 (partial transcript)**

**Interviewer: Mallika Basu,
Interviewee: Lerato Umah-Shaylor**

L: You cook it simply in a dish we call *Agoyin*. It's a dish that was brought into Nigeria by the neighbouring tribes in Benin, so they are a mix of the Yoruba and neighbouring Beninese tribes. So, they brought that dish in and it's very popular in Lagos now. The women walk down the streets with these big pots on their heads yelling 'Agoyin, agoyin!'

MB: I love that!

L: As a child, I would hear them and run outside with my plates. The beans were plainly cooked, with lashings of palm oil.

MB: I love that! But I heard you mention palm oil a couple of times. I have never actually

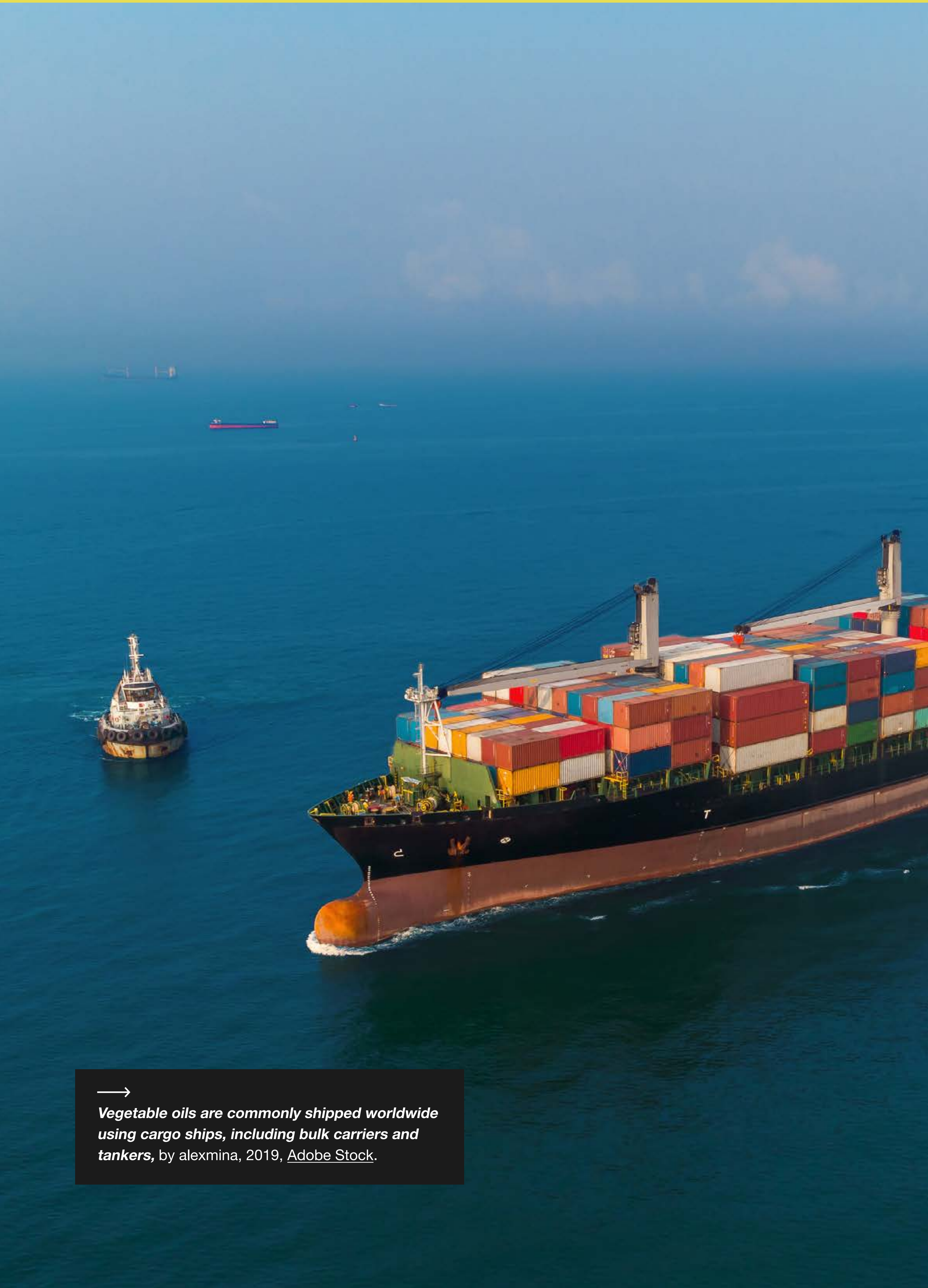
Figure 51 *Lerato's Mum's Melon Seed Soup with Pounded Yam cooked with palm oil,* by Tara Fisher, 2021, Africana: Treasured Recipes and stories from across the continent.

cooked with palm oil. What does one need to know about using and buying palm oil?

L: Well people say – and I say this with caution – 'responsible', 'sustainable' palm oil. I think we, individually, need to do our own research. Because it's an ingredient of my culture, I'm not afraid of it. I know that the orangutans aren't being killed in Nigeria [laughs]. It's difficult. People have identified a problem in a particular location and have sort of washed that across the world. We don't all have the same problems. That's not saying that there isn't unsustainable palm oil in Africa, but I say do your own research. Find companies that you are assured, by the evidence, are sustainable. A lot of these companies share their process and the origins. I buy palm oil from my local stores where the palm oil has [emphasis] *come from Nigeria*. There are some companies that have advertised and are very transparent about their origins, but I'd say don't just jump on the bandwagon and say 'oh, palm oil is destroying the rainforest'. It is, in some parts of the world, and in some parts of the world it is part and parcel of the culture and the economy. I have seen them processing palm oil in Nigeria. It's literally done by just people, you know, with their hands.

MB: Wow. I have heard that it's also culturally very significant. It's a sign of prosperity, happiness.

L: Yes, yes! We use it, especially, when there's the yam festival. During the yam festival, when they cook the new yam, it's a way to thank the gods for another year of harvest and prosperity. The yams are cooked in palm oil and shared amongst the community. So, it's a very strong sense of identity and culture for us. It's really hurtful when people say 'oh, don't use it! Don't use it' when they don't know anything about people who use it – why [they use it], where they get it from. Some time we should educate ourselves and learn. Not be blinded by the media.



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Vegetable oils are commonly shipped worldwide using cargo ships, including bulk carriers and tankers, by alexmina, 2019, Adobe Stock.

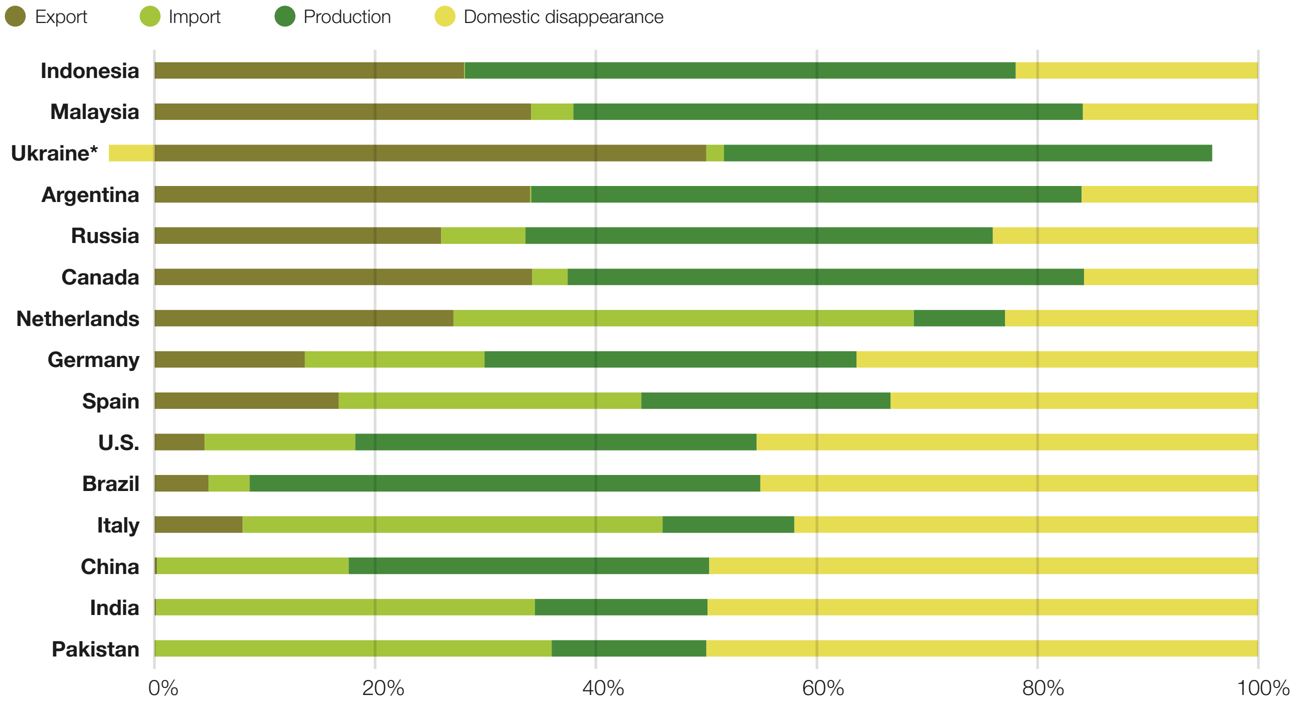
5

Global trade and governance

5.1 Global trade

Vegetable oils are among the most internationally traded agricultural commodities with 56% percent of locally produced oils being traded into other countries [1]. Because oil meal is a key product in oilseeds, such as soybean, sunflower, and canola, oils and fats figures should be combined with oilseed figures to create a complete picture of trade dynamics. For example, the import of soybeans into China to supply feed to its domestic livestock industry explains why China is also a major consumer of soybean oil (without importing it directly). On the other side of the globe, differences in trade tariff policy between Brazil and Argentina explain why Brazil is a large exporter of beans but is less dominant in meal and oil trade, whereas Argentina is a relatively larger meal and oil exporter compared to beans. Similarly, Malaysian and Indonesian tax tariff changes can influence traders' decisions to export crude or refined palm oil products.

Relative contribution of vegetable oil trades per country, 2020



*Ukraine shows a negative domestic disappearance due to higher exports than production and imports. This could be attributed to fluctuating stocks and export volumes.

Figure 52 Relative contribution of export, import, production and domestic disappearance (see Glossary) of vegetable oils per country: main players (2020). Source: Data compiled by the report editors, based on FAO (n.d.) [15].

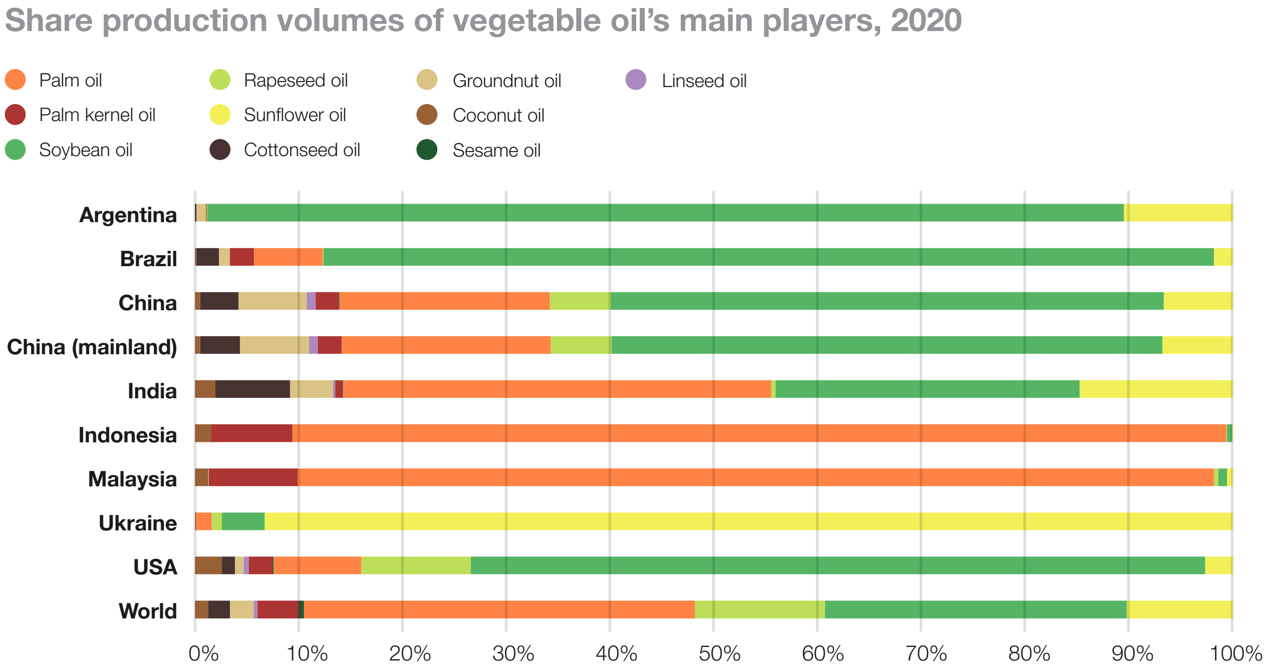


Figure 53 Relative production volumes of vegetable oils for main producer and consumer countries and global figures (2020). Source: Data compiled by the report editors [15].

Through looking at the world from an oilseed, and oils and fats perspective we can distinguish four types of countries: 1) Importers (such as China, India, Pakistan) that bring in oil and oilseeds for local processing and/or consumption; 2) Exporters with a modest domestic market (like Malaysia, Argentina, Ukraine) that centre production on exports; 3) Exporters with a substantial domestic market (including Brazil, Indonesia, the U.S.) that balance production for both domestic consumption and export; and 4) Traders (exemplified by the Netherlands and Germany) who import, process, and subsequently re-export oils and oilseeds (Figure 52).

Certain oils are primarily produced and traded by specific countries, such as soybean oil in Argentina, palm oil in Indonesia and Malaysia, and sunflower oil in Ukraine. A network of traders facilitates the local, regional, and global movement of seeds and oils, often playing important roles as intermediaries who help finance deals (Box 25).

Box 25

Insights into the role of a palm oil trader

The key points from an interview with a global trader in palm oil are listed here:

Palm oil is a highly sought-after commodity. This precious oil has permeated nearly every sector of the commodity market. Trading is far from straightforward. In our conversations with industry insiders, especially the traders, who serve as the crucial link between producers and consumers, we gained insights into the intricate and challenging world of global palm oil trade.

Palm oil traders typically work with multiple producers simultaneously, forging relationships built on trust that can span generations. Through a process known as 'market scanning', traders seek out producers who are eager to expand their sales and export opportunities. This search enables traders to develop a deep understanding of producers' needs, preferences, and capabilities. These close relationships facilitate the creation of tailored and personalised trading arrangements.

Additionally, as traders often engage in the trade of other commodities, such as chemicals, they approach potential sellers with comprehensive offers that encompass established logistical frameworks and a profound understanding of market dynamics.

While the specific agreements between traders and producers may vary, the fundamental role of a trader in relation to producers remains constant, facilitating the expansion of a seller's trade network while mitigating risks associated with finances, documentation, and logistics. As traders operate within extensive networks, they possess access to unique opportunities and insights, including relationships with specific banks that specialise in financing palm oil trade—a privilege that most producers would not have. Once a trade relationship is established, additional benefits for producers may arise, such as expedited or waived quality inspections at the origin.

However, traders are not solely concerned with sellers; they function as intermediaries. The relationship between a trader and a buyer is equally important and involves similar interactions. Setting up and maintaining a trade deal is a lengthy and arduous process that necessitates a series of agreements and checks between buyer(s) and supplier(s), sometimes extending to laws and trade agreements to govern the trade. In practice, it is the trader who handles these negotiations, with minimal direct contact between the buyer and the supplier. Successful trade agreements are often cemented through the trader's establishment of price fixes, securing long-term contracts that maximise benefits for both parties.

⟶ *Local palm oil traders operating in East Kalimantan province, Indonesia*, by Mohammad Reza Fauzi, 2021, Shutterstock.

5.2 The role of power and vested interests in trade

> “A 1% increase in the amount of wealth held by high-net-worth individuals, can lead to the long-term expansion of the share of crops area of up to 2.4–10%.”

Governments employ various methods, such as subsidies, taxes, credit assurances, food assistance, and market enhancement initiatives, to incentivise the production and export of vegetable oils [89,401]. This results in the development of highly globalised and concentrated supply chains, primarily overseen by multinational agrifood corporations [300,401], a dominance that is more pronounced compared to other commodity markets. For instance, in the Brazilian soybean sector, the top five trading companies (ADM, Bungee, Cargill, Louis Dreyfus, and Amaggi) collectively control 66% of the trade [435], exercising significant influence over all aspects of production, processing, and trading and thereby wielding considerable power within the global food systems (Table 13). Furthermore, a recent study [436] showed that wealth concentration among the super-rich can have striking environmental consequences. A 1% increase in the amount of wealth held by high-net-worth individuals (individuals with assets worth US$ 1 million or more), can lead to the long-term expansion of the share of crop area of up to 2.4–10%. It also finds that as global inequality rises, and with it the amount of wealth in the hands of high-net-worth individuals, foreign investments in agriculture become increasingly dominated by a financial logic [436].

Table 13 Influential factors that contribute to the concentration of trade and power among agrifood traders [437].

Factors	Description
Price-setting	Because they deal in high volumes, trading companies have significant leverage in terms of setting the purchase price, particularly with farmers with whom they contract directly, as well as with the vegetable oil processors and refineries. The companies often own the processor and refineries themselves.
Market power	Traders play a central role in the decisions that producers make about what to grow, where, how, in what quantities, and for which markets. They do this by providing inputs and other services directly to farmers, and by securing the sale of those products to traders at harvest. For example, Clapp [439] shows that in the U.S. it is “is becoming increasingly difficult for farmers to access non-transgenic varieties of seeds, as the big firms with more market share can exert influence over product availability and incentivise distributors to focus on sales of genetically modified versions of seeds that deliver higher profits and the sale of other products, such as associated herbicides”.
Transportation, storage, and logistics	The large commodity traders own and operate global storage and delivery systems that are indispensable to the global grain trade. They also have huge storage facilities. In the cereal sector, these physical stocks can have an important impact on grain prices.
Financial speculation	Trading companies profit from other activities that surround and relate to agricultural trade, such as financial speculation on agricultural commodity markets and index funds, transportation, and storage.
Asset management	The big commodity traders are also actively involved in asset management activities, not all of which are related to food and agriculture, and they all sell these sorts of services to professional or accredited investors.
Influence on regulation	The large commodities trading firms can exert considerable control and influence over the regulatory context within the agri-food sector. They do this by direct lobbying with governments, or placing former staff in key decision-making roles in government and/or hiring former government officials to lobby on their behalf [437]. The companies spend a lot of time and money on influencing public and political debate on trade, production, and investment regulations at the domestic and international levels. Clapp [439] states that “In 2019, for example, Corteva Agriscience spent over US$ 3 million and BASF and Syngenta each spent over US$ 1 million on lobbying activities in the U.S. Bayer AG spent US$ 9 million in the same year—a year after it purchased Monsanto and the same year the U.S. was reviewing whether to re-register glyphosate”.

Source: Compiled by report editors.

Box 26

The hourglass shape of global food systems

The hierarchy of food systems can be visualised as a narrow hourglass, dominated in the middle by a few agrifood companies that control the supply chain between farmers and consumers (Figure 54). Since 2018, after the most recent mergers, the top four trade firms controlled around 70% of the global pesticides market and around 60% of the global seed market [439]. Concentration at these levels can increase seed prices through weakened competition but there are relatively few studies that examine this question empirically in the sector, given the difficulties in accessing data that are held behind paywalls by the private sector.

It is not just economic power that the agri-food corporations monopolise. Boundaries between politics and business are complex as companies often have access to regulators behind the scenes. This allows them to exert considerable control and influence over the regulatory context within the agri-food sector or in political campaigns. Research by Murphy et al. [437] shows that they do so through direct lobbying with governments or placing former staff in key decision-making roles in government, or hiring former government officials to lobby on their behalf (see Table 13). This means fewer people are making decisions about how oils are produced and what we eat, and these few people tend to be those from agri-food corporations. For example, antitrust laws in the U.S., which are regulations that encourage competition by limiting the market power of any particular firm, have been reinterpreted by regulators, in part as a result of the influence by agri-food corporations to allow for mergers [441].

Many agri-food corporations are still benefitting from indirect subsidies that allow them to operate at scale. For example, a government may promote road and port infrastructure development to support large volume trading. Research into large industrial monocultures, such as new crop varieties or genetically modified organisms, is another form of indirect subsidy paid for by the public for large agrifood operations. More direct subsidies are also benefitting these firms, for example, tax breaks, or subsidies on machinery. Smallholders are often in a difficult position. They are too isolated for their products to enter the competitive market. Special programmes to support their productive and sustainability needs are, therefore, indispensable.

Concentration in food and agricultural markets

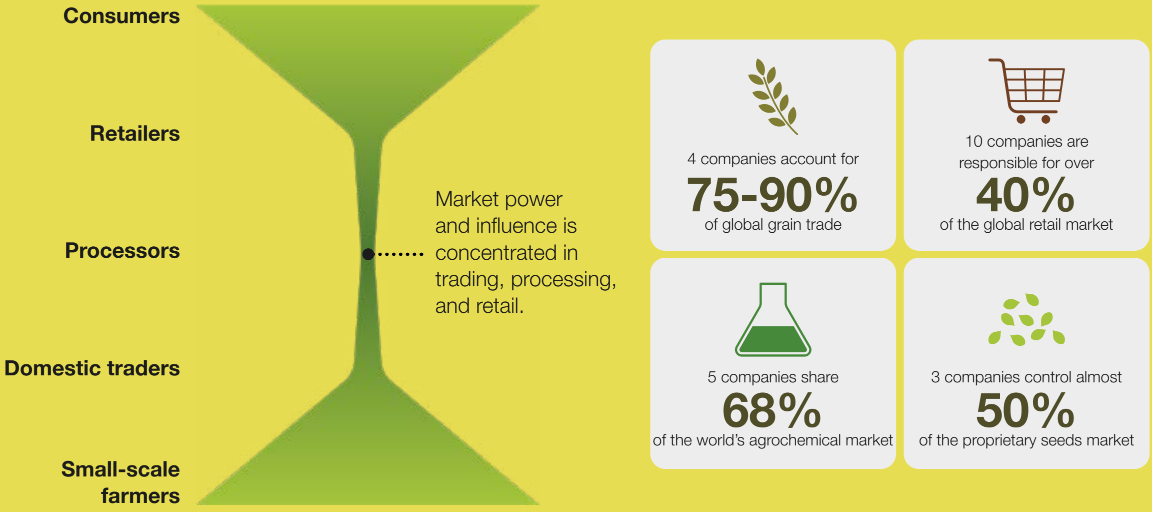


Figure 54 Concentration in food and agricultural markets. Source: Prepared by the report editors, adapted from Horstink (2017) [440].

The trends observed in the soybean sector are comparable to those within the cocoa and palm oil sectors. For example, Cargill owns plantations in Indonesia and accounts for around 11% of the value of the country's exports of palm oil [437]. Another of the largest plantation owners is the Wilmar Group, a Singapore-based conglomerate with a market capitalisation of US$ 18.5 billion [438], that owns more than 235,000 ha of palm oil operations in Indonesia and Malaysia, as well as fertiliser and shipping interests [437]. Wilmar is also the world's largest palm oil trader controlling an estimated 45% of traded crude palm oil.

A study of trends in oil crop production and trade between 1986 and 2016 shows that while the number of major net importing countries has increased over time, leading export countries have reduced to only a handful, with only two to seven countries accounting for 60% of global production and net export [107]. A reason for this is that, once the trade infrastructure is in place, countries can capture large flows of different goods [107]. Such trade infrastructure is put into place by large trading companies, often subsidised by governments (Box 26).

Centralising agricultural flows within a context of expanding trade has implied rapidly growing infrastructural requirements, which involves heavy investments that only rich or rapidly developing countries can afford. One consequence is that countries with the highest re-export scores – high levels of import and processed export – are among the most industrialised and these countries centralise more re-exports today than in the early 1990s [107].

A study on the palm oil value chain shows that while smallholders from countries, such as Indonesia, are struggling to make a profit, downstream actors like food manufacturers and consumer goods companies and retail from industrialised nations generate 66% of the gross profits on palm oil [442]. Similarly, at the global level, palm oil had a value of US$ 282 billion in 2020, but smallholders only generated US$ 17 billion, or 6% of the value in the entire chain because of low levels of processing [443] (the 6% does not include the 'invisible' subsistence production of palm oil). Developing countries still have limited presence in re-exports and value chains [107]. Centralised agricultural flows have thus led to reduced global equity between industrialised and developed countries, but also for smallholder farmers. In addition, centralisation and power concentration decreases resilience of the food system as shocks in the international marketplace and supply chains are transmitted quicker than previously [444]. As a result, global food supply is becoming more vulnerable to, for example, climate change, wars, or price volatility.

There are, however, benefits to centralisation and the vertical integration of trade and processing, for example on the roll out of sustainability requirements. Large companies have had important influences on attaining large quantities of certified sustainable palm oil. Important trading countries wield significant influence over sustainability standards, as evidenced by the Roundtable on Sustainable Palm and the Round Table on Responsible Soy in the Netherlands. Although trade through Dutch harbours has not directly enhanced European sustainability requirements, Dutch engagement has spurred sector-wide voluntary sustainability guidelines for soy through the European Feed Manufacturers' Federation (FEFAC) Soy Sourcing Guidelines [445]. This influence has also fostered collaboration between European soy sustainability initiatives, involving the UK, Denmark, France, and others, and ensured that 40% of European soy trade adheres to a sustainability standard [446]. The impact is even more pronounced in the case of palm oil, where 86% of European palm oil consumption is now certified as sustainable [447].

> "Centralising agricultural flows within a context of expanding trade has implied rapidly growing infrastructural requirements, which involves heavy investments that only rich or rapidly developing countries can afford."

5.3 The role of finance

Estimates for the global market value of vegetable oils vary. One estimate of the global market in 2022 for edible oils alone was US$ 211.7 billion [448], while another estimate for the global vegetable oil market was US$ 318 billion in 2022 [449]. We do not know why these estimates vary but for the purpose of this report, we shall use the average of US$ 265 billion.

Leading creditors in the vegetable oil markets for soybean and palm oil are Banco do Brasil, which finances soybean producers and traders as well as palm oil, Bradesco, Itai Unibanco, and Rabobank. Among those, Banco do Brasil is by far the biggest investor with estimated 2022 investments of US$ 81.7 billion (Figure 55). Investment groups also provide finance to the vegetable oil markets, with groups such as the Malaysia-based Employees Provident Fund that funds major oil palm companies, Blackrock and Vanguard providing most investments (Figure 56).

Top creditors in soybean and palm oil markets, 2022

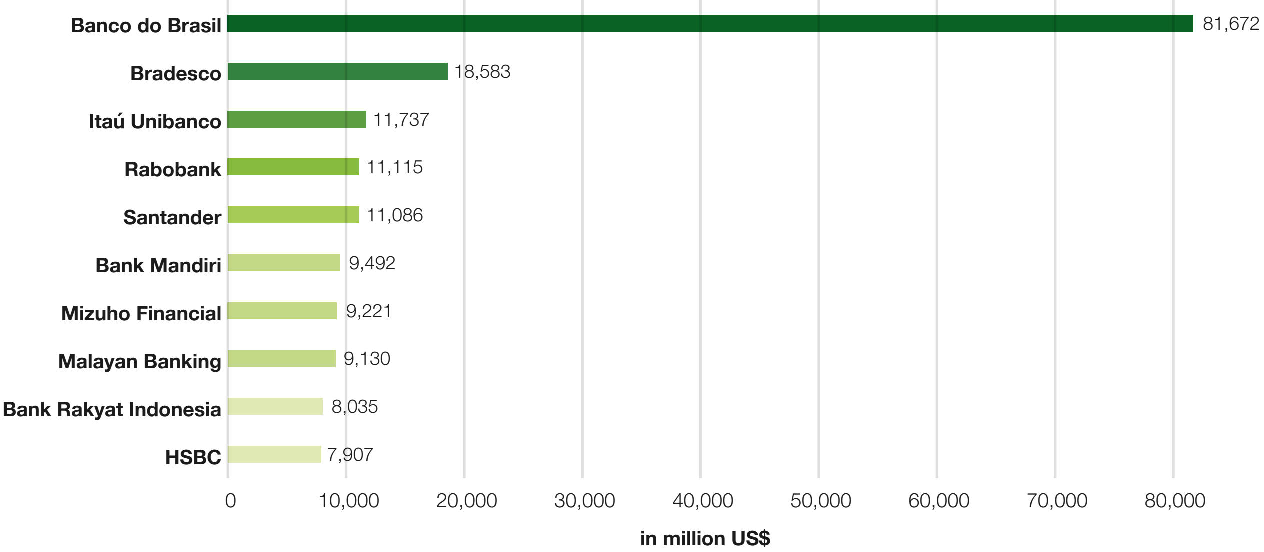


Figure 55 Top 10 creditors in soybean and palm oil markets in 2022. Source: Data compiled by the report editors, based on Forest & Finance (2023) [450].

Top investors in soybean and palm oil markets, 2022

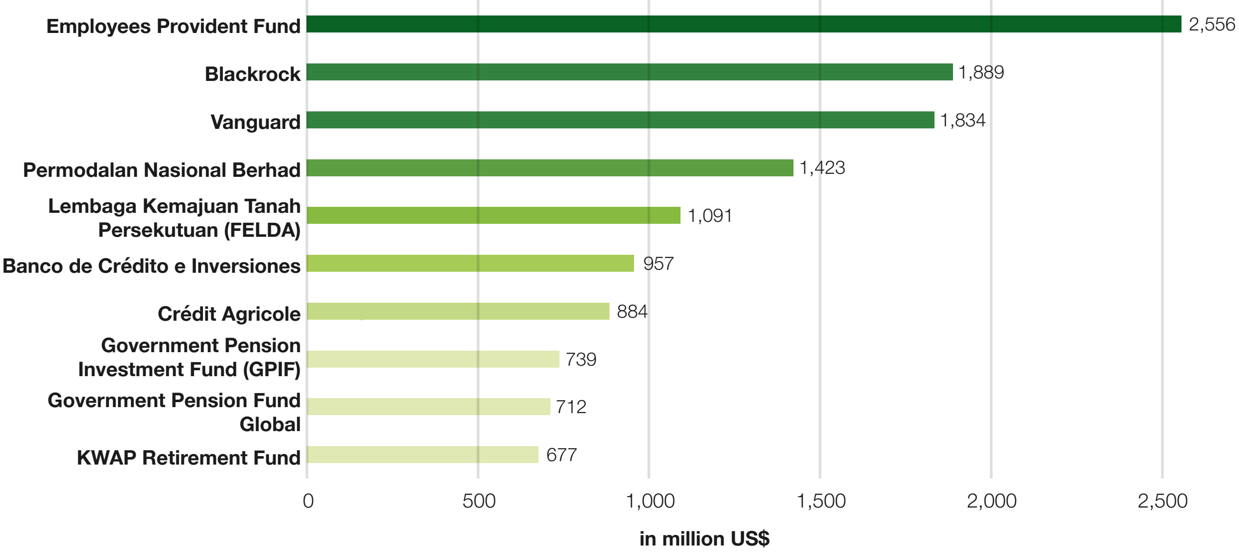


Figure 56 Top 10 investors in soybean and palm oil markets in 2022. Source: Data compiled by the report editors, based on Forest & Finance (2023) [450].

Most of these financial institutions lack environmental, social and governance (ESG) policies to adequately address the material impacts and risks inherent in their investment [450]. Investments include infrastructures associated with production, processing, and trading, such as mills and refineries. Sadly, a staggering 59% of financial institutions scored less than one out of 10 in 2023, in the quality and robustness of their financing and investment policies involved in financing, or investing in, forest-risk commodity sectors in tropical regions (Southeast Asia, Central Africa and South America). In other words, their investment is associated with high impacts and risks with deforestation and rights violation [450].

It is becoming clear that financial institutions play one of the most critical roles in facilitating the reallocation of capital toward low-impact activities while also financing transition activities. This represents a big opportunity for developing new business. Banks that embed environmental, social and governance policies across their business model are predicted to become better positioned to understand and engage with clients on their own impact risks and sustainable transformations and secure their business relationships with those clients as a result [451,452].

Indeed, sustainable investing, also called responsible investing, is becoming more common in the finance sector. It covers environmental, social, and governance factors that influence their strategy and investment decisions [453]. IISD classified investment strategies as negative and positive screening, environmental, social and governance investing, and impact investing. The first seeks to avoid situations that harm society or the environment affecting the reputation of companies, while positive screening is used to select situations that may provide an advantage over competitors. Environmental, social and governance investing strategy integrates a minimum set of criteria to inform decisions. Impact investments support and promote solutions towards positive social and environmental impacts.

Investing in agriculture could be seen as low-risk from a financial point of view as the demand for food increases globally, however, there are socio-ecological challenges that might translate into risks. Those risks are related to market, reputation, regulations, operations, litigations, resilience, nature conservation, among others. For example, despite the risks and concerns regarding the palm oil sector, investing in oil palm is attractive due to its high productivity and versatility. Many investors consider Voluntary Sustainability Standards (VSS) a strong tool to support positive impacts and reduce environmental, social, and governance risks through compliance with criteria and monitoring. For instance, investments in smallholder oil palm producers can provide important development benefit potential to regions where food security and employment opportunities are lacking, while VSS provide criteria on avoiding potential associated deforestation and labour rights infringements.

Among investors and creditors in the vegetable oil markets, there are major differences in how their environmental, social and governance policies stack up. The Forest & Finance scoring system, for example, gives the highest score to the Norwegian Government Pension Fund Global (score of 7.5), and Netherlands-based Rabobank and ABN Amro (7.4 and 7.2, respectively). Some of the major investors and creditors in the vegetable oil market (Figures 55 and 56) do not score that well: Banco do Brasil (4.4) and Bradesco (1.0), indicating significant differences in views on sustainable investing. This has consequences for where vegetable oil producers and traders can source funding. For example, in 2019, Norway's Government Pension Fund Global (GPFG) sold stakes in more than 60 companies, including 33 firms involved in palm oil, due to deforestation [454].

The policies that distinguish sustainable investment by Rabobank, for example, compared to other traditional financers include their tight sustainability standards that encourages customers to achieve higher standards, which can result in cheaper loan pricing [455]. Rabobank also promotes best farming practices, which are generally seen favourably by its customers, as these practices also lead to higher economic value. In addition, non-compliance with Rabobank's sustainability policy can threaten the relationship with the bank, unless damages are repaired and compensated within a reasonable time frame. Such policies are transforming the financial landscape between agrifood companies, farmers, and financial institutions.

5.4 An overview of key international standards, policies, and regulations

Five main global frameworks underpin the current study and set pathways for a better future of vegetable oil systems (Chapter 1.5). Adhering to these frameworks requires that vegetable oils respond to needs for resource efficiency (scale of production and consumption, lowering pressure on land use), biodiversity – and climate-resilience, legal and socially responsible ways of producing, and robust governance from biome-wide to plantation level scales. Adherence, in this regard, includes avoiding High Conservation Value and High Carbon Stock loss [456], investing in production methods that enhance CO_2 storage and biodiversity, protecting rights, and optimising value for the most vulnerable actors in value chains and landscapes.

At the local level, customary systems of governance may also be important. For example, palm oil and shea butter in West Africa are only subject to formal international regulatory standards when exported. The same is true for many domestically used vegetable oils elsewhere, such as palm oil in Indonesia or soy biodiesel in the U.S., although national level regulations and standards may apply (Indonesian Sustainable Palm Oil, ISPO in Indonesia, or the Renewable Fuels Directive in the U.S.).

Table 14 Overview over the most relevant policies for the vegetable oils

	Public	Multi-stakeholder	Private
Worldwide	The major frameworks (see Chapter 1.4): • Paris Agreement • Kunming-Montreal Global Biodiversity Framework • UN and ILO Declarations and Conventions on Human Rights • Chemicals agreements and treaties • Sustainable Development Goals	Major Roundtable and other global voluntary standards relevant for the oils, including: • The High Conservation Value (HCV) methodology • The High Carbon Stock Approach (HCSA) • The UN Guiding Principles on business and human rights [457]; • OECD Guidelines for Multinational Enterprises on Responsible Business Conduct [458]; • The Accountability Framework for ethical supply chains [123]; • The Task Force for Nature-related Disclosure (TFND) guidelines for businesses and financial institutions [459]	Global company zero deforestation policies + actions [39]
Producing regions	Regional rights law, including the American Convention on Human Rights and the African Charter on Human and Peoples' Rights; national policies, such as those of Brazil, Argentina, Indonesia, Colombia, and France	Influential national voluntary sustainability schemes such as the Indonesian (ISPO) and Malaysian (MSPO) Sustainable Palm Oil Multi stakeholder landscape, jurisdictional initiatives (for example, by Initiative for Sustainable Trade in Brazil or Indonesia [460])	Private sector schemes and initiatives, such as No-deforestation, No-peat and No-exploitation (NDPE) agreements since 2013
Import/consuming regions	European Union Renewable Energy Directive (EU RED), European Union Deforestation Regulation (EUDR) U.S. Renewable Fuel Directive Other major users/importers China, India, Indonesia	European national platforms on sustainable soy and palm oil that make agreements on collective sourcing policies (such as UK, Denmark, France, Netherlands) [461]	Private sector schemes and initiatives

Source: Prepared by the report editors.

5.5 Multi-stakeholder Voluntary Sustainability Standards – Limitations and opportunities

5.5.1 Voluntary standards in relation to mandatory standards and government control

Voluntary and mandatory sustainability criteria for some vegetable oils have been around for about 15 years. Voluntary criteria include the multi-stakeholder governed standards that were created and updated after roundtable dialogues and public consultations: the Roundtable on Sustainable Palm Oil (RSPO) for palm oil (2007); the Roundtable Responsible Soy (RTRS) for soy (2010); and the Roundtable for Sustainable Biomaterials (RSB) for all biofuels and biomass feedstocks (2010) [462]. Table 15 provides an overview of additional voluntary standards.

Mandatory criteria include legal frameworks in producing countries, but also, for example, the basic sustainability criteria related to biodiesel, such as in the European Union Renewable Energy Directive (EU RED) (since 2009) [463]. The EU RED has been the only international mandatory framework to control the sustainability of soy, palm oil, rapeseed, and sunflower, until palm oil and soy became subject to the new EU Deforestation Regulation (2023).

Buyers and producers of vegetable oils are increasingly adopting sustainable practices [464]. Voluntary Sustainability Standards (VSS) provide a means to certify these practices, thus playing an important role in the control of social and environmental risks. Voluntary Sustainability Standards have paved the way to defining, implementing, and controlling good governance at plantation and supply chain level, where governments often fail.

Table 15 Some voluntary sustainability standards relevant for the vegetable oils.

Standard	Main characteristics	Practical application in vegetable oils	Potential
ISEAL – a standard setter of quality	Defines, evaluates and promotes the use of quality criteria and processes in certification	ISEAL member standards include those for palm oil (RSPO, Rainforest Alliance), soy (RTRS and Proterra), and Fairtrade [465]	Together the ISEAL member standards can cover all vegetable oils
European biodiesel standards allow 15 voluntary standards [466]	Control on mandatory criteria: 60 % GHG savings, High Biodiversity Value area and HIGH Carbon Stocks to be protected after 2008	Mostly used for soy, palm oil, sunflower and rapeseed	Already applied 100%, however quality of applied standards (especially for soy) could improve
Roundtable on Sustainable Palm Oil (RSPO)	Best in class standard on environmental and social criteria [467,468]	Hardly applied in biofuels, but major one for food, 19% of all palm oil production is covered by RSPO	High, but implementation of assurance in the field needs improvement [467]
Roundtable Responsible Soy, ProTerra, Donau Soja	Best in class, in part ISEAL recognised standards on environmental and social criteria in soy [469] NB: Pro Terra can also certify palm oil, coconut, peanut, rapeseed, sunflower	All have non-genetically modified (GM) applications, but RTRS is mainly applied to GM soy in practice, which is used as feed, biofuel, and also used as food oil in non-European countries. In Europe, Pro Terra and Donau soy are key for providing non-GM soy.	High but chemical use is hard to lower.
ISCC EU for biodiesel and ISCC + for feed and food applications	Strong standard on environmental criteria if all its add-on modules are applied [470]; aligned with Sustainable Agriculture Initiative (SAI) Platform silver level	ISCC has mainly energy applications: palm, rapeseed, sunflower, and soy oil	High, but transparency on which criteria are included in the claim is key.
Rainforest Alliance	ISEAL recognised standard to tackle social as well as environmental criteria applicable to various crops	Can be applied to soy, palm oil, peanut, coconut, rapeseed, and sunflower	Certification is open ended and relatively open for interpretation.
GLOBALG.A.P.	A farm assurance standard	In principle, applicable to palm oil, coconut, peanut sunflower, rapeseed	Widely used farm-level certification system

Standard	Main characteristics	Practical application in vegetable oils	Potential
Fair trade, IFOAM organic	Fairtrade is an ISEAL-recognised standard to tackle social and some environmental criteria. IFOAM certifies organic cultivation (for example, soil criteria applicable to various crops).	Integrated and organic standards often (and best) used in combination to tackle all criteria Fair Trade: palm oil, peanut IFOAM: palm oil, peanut, coconut, rapeseed, and sunflower	
The coconut partnership	Sustained by a charter with goals on smallholder income and livelihoods, supply chain traceability and prevention of deforestation.	Coconut	Relatively new, but with potential to develop better production practices.

Source: Prepared by the report editors.

However, they need support from private and public policies to be effective at scales beyond the plantation level. Voluntary Sustainability Standards, as a series of principles and criteria at farm, supply chain, or company level, are often insufficient to mitigate risk and create impact. Standards that are independent from companies, and are multi-stakeholder governed, tend to score stronger on environmental, social and assurance (field control) criteria (but see Box 27). What is required therefore is better integration of mandatory and voluntary tools – for example, hybrid governance – to achieve more effective governance and greater resilience in vegetable oils.

Particularly in regions where managing land and resources presents challenges, a paradox emerges: implementing a sustainability standard is simultaneously a remedy and a complication. This holds true especially when auditors lack independence, and issues like deforestation, ecosystem conversion, child labour, land disputes, inequality, and corruption persist and resist resolution. In this context, the certification of 28% of palm oil in Colombia (RSPO along with other standards) and 19% in Indonesia (RSPO) is noteworthy. However, these standards on their own cannot revolutionise the entire agricultural sector, reshape power dynamics, or address governance variations and limitations in any nation.

5.5.2 Relative benefits of Voluntary Sustainability Standards

Voluntary Sustainability Standards play an important role in the evolution and monitoring of positive and negative impacts (see Chapter 4). These issues led to a global call for improved practice, in turn driving public and private sector initiatives at national and international levels, to address them.

Table 16 Voluntary Sustainability Standards that are linked to soybean, oil palm, peanut, coconut (fresh), rapeseed, or sunflower

Standard	Product					
	Soybean	Oil palm	Groundnut	Coconut	Rapeseed	Sunflower
RTRS Soy	✓					
RSPO		✓				
Rainforest Alliance		✓	✓	✓		✓
Global GAP (Crops)	✓	✓	✓	✓	✓	✓
Fairtrade International		✓	✓			
ProTerra Foundation	✓	✓	✓	✓	✓	
IFOAM – Organics	✓	✓	✓	✓	✓	✓

Source: Data compiled by the report editors, based on the ITC Standards Map [471].

In response to consumer concerns around economic, social, and environmental dimensions, producers are progressively adapting good sustainable practices. Controversy, criticism, credibility, and transparency are key factors that have been associated with the production of vegetable oil crops [464], contributing to the expansion of certification standards. The impact of these Voluntary Sustainability Standards on the vegetable oil value chain and production areas is supported by some scientific evidence. One study on the impact of RSPO-certification in oil palm areas, for example, revealed minor reduced deforestation compared with non-certified oil palm concessions [472]. Nonetheless, many consumers remain critical about the value of certification, undermining their ability to influence practices.

Viewing certification as a comprehensive solution for addressing large-scale deforestation or ecosystem conversion within a landscape or biome is unrealistic for several reasons. Firstly, voluntary sustainability standards cannot exert control over uncertified plantations. Secondly, when certification expenses are high, particularly during periods of high commodity prices, the premium prices associated with conversion-free voluntary sustainability standards might not adequately cover the costs of refraining from ecosystem conversion, especially if national policies permit or endorse such activities. There are also other issues that are not sufficiently addressed in many voluntary schemes. The environmental benefits from voluntary sustainability standards can be increased by providing incentives in addition to the deterrent of the standard itself. One example are farmers in Brazil's Cerrado or Argentina's Chaco regions, who seek compensation for conserving forests and savannah vegetation that could potentially be lawfully converted. Initiatives involving loans supported by the private sector, contingent on no conversion activities, have shown promise in Brazil [478]. This combined approach, coupled with governmental regulations and policies, holds significance for achieving legality and conversion-free status in both international (such as EU) and domestic (such as biodiesel) applications of soy.

Regarding the social outcomes of certification, there is a mixed body of evidence. Some studies, which considered farmers' perspectives, suggested that the adoption of sustainable palm oil production practices yields more substantial economic and social benefits compared to conventional methods [479,480], although positive impacts from introducing sustainable oil palm were particularly pronounced in communities with market-based livelihoods, but not in those with subsistence livelihoods [481]. An assessment of certification systems for five different commodities in Sumatra, Indonesia, revealed that farmers often prioritise premium prices, although the most significant gains typically arise from cost reduction and enhanced production efficiency [482]. Certified smallholders frequently experience increased yields, yet the expenses associated with certification may hinder its adoption among them. One study in Ghana similarly found substantially higher oil palm, total farm, and household income in RSPO certified farms. This was due to higher yields through access to improved varietals, rather than as a result of any

Box 27

Addressing flaws in certification systems

Combinations, often tailor-made, of governance tools are needed to effectively tackle the social and environmental risks and impacts of the vegetable oils and promote sustainable practices. Robust, voluntarily developed standard systems that are strong, both in social and environmental criteria and in quality assurance, can play an important role as long as the auditing is effective. However, these systems are often compromised by the fact that auditors and assessors are paid directly by the companies being assessed, introducing incentives for underreporting of non-compliance [473,474]. Among the vegetable oils, this is best documented for palm oil certification systems [475,476], and has also recently been documented in a case study with farms certified by the Round Table for Responsible Soy in Bahia, Brazil [477]. There are also several common technical weaknesses in certification audit systems, which are often based on superficial checklist-based information on selected issues, which may not take the views of marginalised groups into account sufficiently, and are poor at dealing with complex value chains that involve widespread outsourcing and subcontracting [474].

premium [483]. Likewise in Ghana, researchers found that certified cocoa and palm oil farmers exhibited slightly better food security compared to uncertified counterparts, with 65–68% of certified farmers still classified as vulnerable to food insecurity [484]. These researchers propose a stronger focus on food security within certification standards, including support initiatives for smallholders.

Certification also yields economic advantages for businesses. A 2022 meta-survey [485] unveiled that adopting independent sustainability standards, typically governed by multiple stakeholders, furnishes businesses with early benefits. Primarily, these standards markedly enhance operational efficiency and risk management, with 80% of the sources attesting to this. Secondly, they prove advantageous in marketing, shaping market strategies for downstream firms, and enabling market access and premium pricing for upstream producers, as reported by 73% of the sources. Furthermore, these standards offer benefits in terms of stakeholder engagement (recognised by 55% of the sources surveyed), procurement, encompassing supply chain risk management and transparency traceability (mentioned by 30% of sources), and supporting broader sector-wide transformations (noted by 25% of sources). As time progresses, businesses increasingly perceive impact from improved practice as a vital long-term benefit. Reputation, sales, and cost reduction also hold significance, albeit to a somewhat lesser degree.

In summary, when considering the use of Voluntary Sustainability Standards, it is essential to acknowledge that while criteria and the level of assurance of these standards can and should be enhanced through appropriate measures, voluntary standards, by definition, cannot exert authority over uncertified plantations. Even when standards like RSPO endeavour to create a broader impact by mandating certification for all a company's plantations, they cannot govern uncertified ones. The exception is in areas with effective jurisdictional approaches (Box 28). In the soy trade, where certification rates remain notably low globally (at just 2%, except for Europe at 40%), additional measures are imperative to combat deforestation and conversion in key producing regions like Brazil and Argentina. These

Box 28

Jurisdictional approaches for vegetable oils

Jurisdictional approaches encourage governments and companies to work together alongside key landscape actors towards landscape sustainability, improving local livelihoods and maintaining forests and other natural ecosystems through coordinated strategies across sectors, including deforestation-free commodity production. This approach holds great potential to address the shortcomings of certification approaches and build more comprehensive and long-lasting solutions. However, the approach is still in early stages of development and is built on assumptions, some untested, about the needs of commodity buyers and the market information and incentives that could encourage governments and producers to work together to adopt policies and practices to halt deforestation. These assumptions, as well as questions about how best to implement the strategy, if not validated and answered, could undermine this important new approach to slowing commodity-driven deforestation. Thus, within the framework of combining multiple tools for impact, voluntarily developed standard systems can be valuable components in the toolboxes of both companies and governments. They provide crucial sustainability metrics and enable control over legal compliance, responsible plantation management, prevention of conversion, responsible handling of High Carbon Stock (HCS) and High Conservation Value Areas (HCVAs), responsible soil and water management, responsible chemical practices, and responsible labour and community relations. All these aspects are pivotal for the sector's contributions to climate, biodiversity, and social resilience [486].

measures encompass comprehensive protection initiatives at the biome and landscape levels, conversion-free sourcing policies for companies, Payments for Ecosystem Services, and bolstered local oversight to ensure legal compliance.

Whether or not farmers decide to pay the price of adopting voluntary sustainability standards depends on their vision. Where this is a choice made at the level of individual farmers, it may encompass a sustainable future for their children, market access considerations, the additional efforts and costs associated with voluntary sustainability standards compliance, for example, as well as the potential benefits in terms of cost savings and attractive premiums. In Argentina, the demand and attractive pricing of soymeal drive soy production, but the certification is primarily motivated by the appealing premiums offered for biodiesel exports to the U.S. and European Union markets, which have relatively low sustainability requirements but significantly higher premiums (currently 2–3 times more) compared to most feed certification. However, there are other incentives for producers to meet the more rigorous environmental and social criteria of standards like Roundtable Responsible Soy. As stated by Marcelo Carrasco, a producer in the Argentinean Chaco: "It forces us to maintain proper documentation, ensure efficient management both in the office and in the field, including the responsible use of chemicals. Besides the premium, it helps us save costs." Argentinean traders are now preparing to supply soy in compliance with both US biodiesel and EU-RED/EUDR requirements (see Chapter 5.6), with the latter potentially enhancing legal compliance monitoring. Incorporating additional sustainability values, such as responsible herbicide and pesticide management according to international best practices, will require special attention.

5.5.3 The importance of Voluntary Sustainability Standards for investors

Benchmarking, such as the process of measuring business performance against competitors and standards, provides important information on the suitability, specificity, and coverage of the sustainability criteria for different oil crops. According to the International Trade Centre (ITC) Standards Map [471], from a list of 326 standards, seven Voluntary Sustainability Standards are linked to the most relevant vegetable oil crops. With a total of 411 criteria summarised among the standards, the Rainforest Alliance covers 72% with 297 criteria, followed by RSPO, Fair Trade, ProTerra Foundation and RTRS-Soy covering 63% (257 criteria), 59% (244 criteria), 54% (223 criteria) and 53% (216 criteria), respectively. GlobalG.A.P. and IFOAM Organics range from 50% or below with 206 or less total number of criteria. The percentage of criteria coverage per dimension also varies across the different standards (Figure 57).

Criteria coverage by the different Voluntary Sustainability Standards

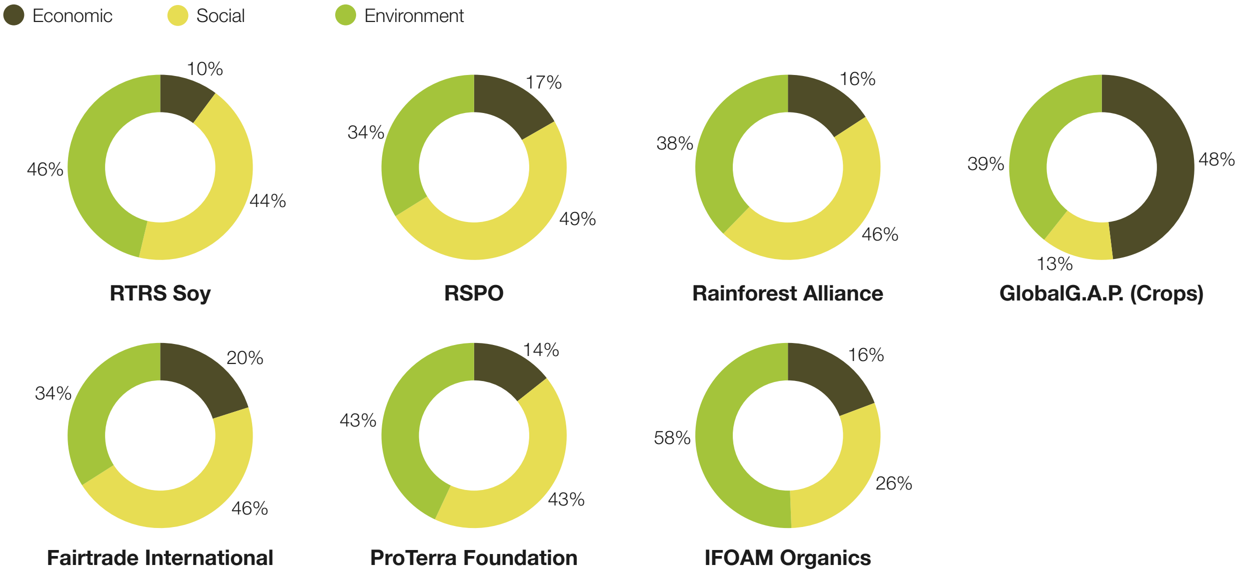
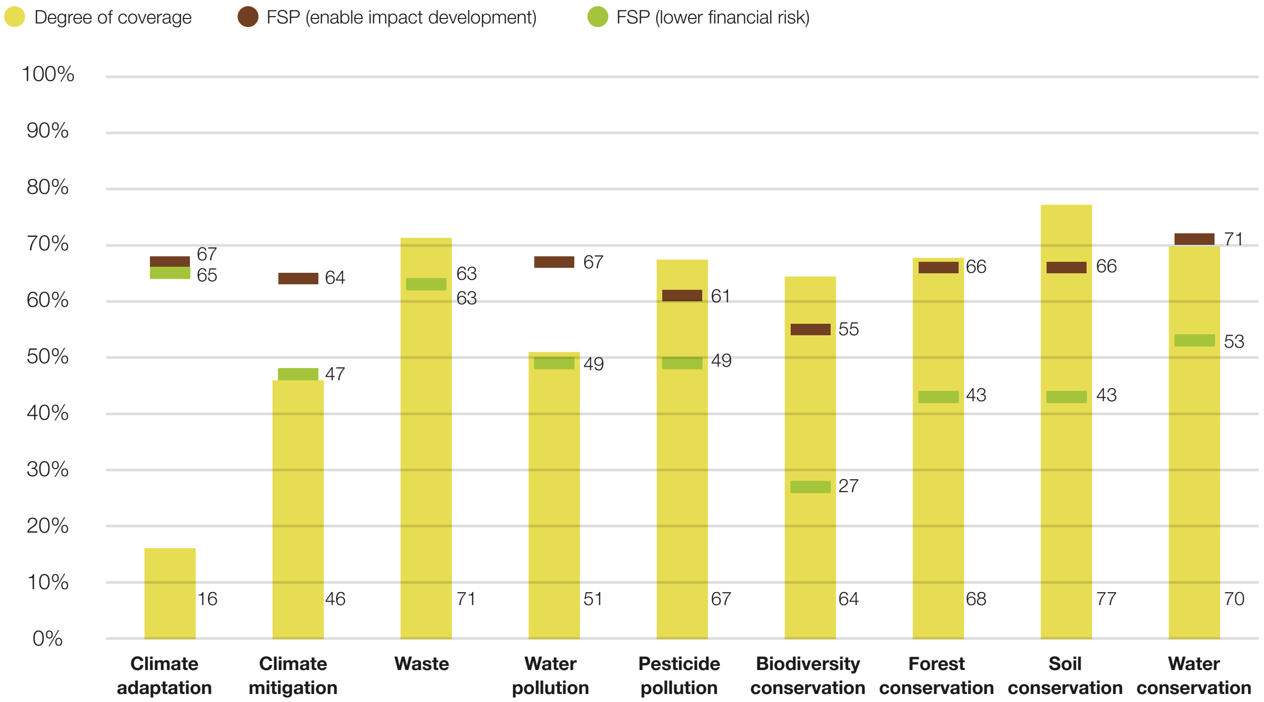


Figure 57 Criteria coverage around the economic, social and environmental dimensions by the different Voluntary Sustainability Standards that certified oil vegetable crops. Source: Data compiled by the report editors, based on the ITC Standards Map [471].

To compare between different voluntary sustainability standards, the International Institute for Sustainable Development (IISD) defined a scoring system for criteria (not implementation) [453]. Their review presents a detailed benchmarking among 13 voluntary sustainability standards, and the perception by 51 financial service providers (FSP) with regards to the importance of a suite of aspects covered by the voluntary sustainability standards to reduce investment risks and/or promote sustainable development impact. The Institute for Sustainable Development defines risk mitigating investors as those who aim to contribute to value protection, access to capital and services, enhance reputation, improve compliance with legislation, increase efficiency and productivity, and ensure the supply and loyalty. Although small in number, impact investors aim to enable development by primarily addressing issues, such as deforestation, water scarcity, labour rights, and the inclusion of environmental, social, and governance (ESG) factors. Investment strategies may include negative screening (avoiding situations that harm society and/or the environment), positive screening (selecting opportunities with superior performance), ESG investment (integrating a minimum set of ESG criteria), and impact investments (support and promote solutions towards positive social and environmental impacts).

We adapted the IISD's review by filtering the voluntary sustainability standards that are linked to vegetable oil crops. Thus, we analysed RTRS-Soy, RSPO, Rainforest Alliance, GlobalG.A.P., Fair Trade, Proterra Foundation and IFOAM Organics standards regarding the economic, social, and environmental dimensions, of which we show the environmental (Figure 58) and economic dimensions (Figure 59).

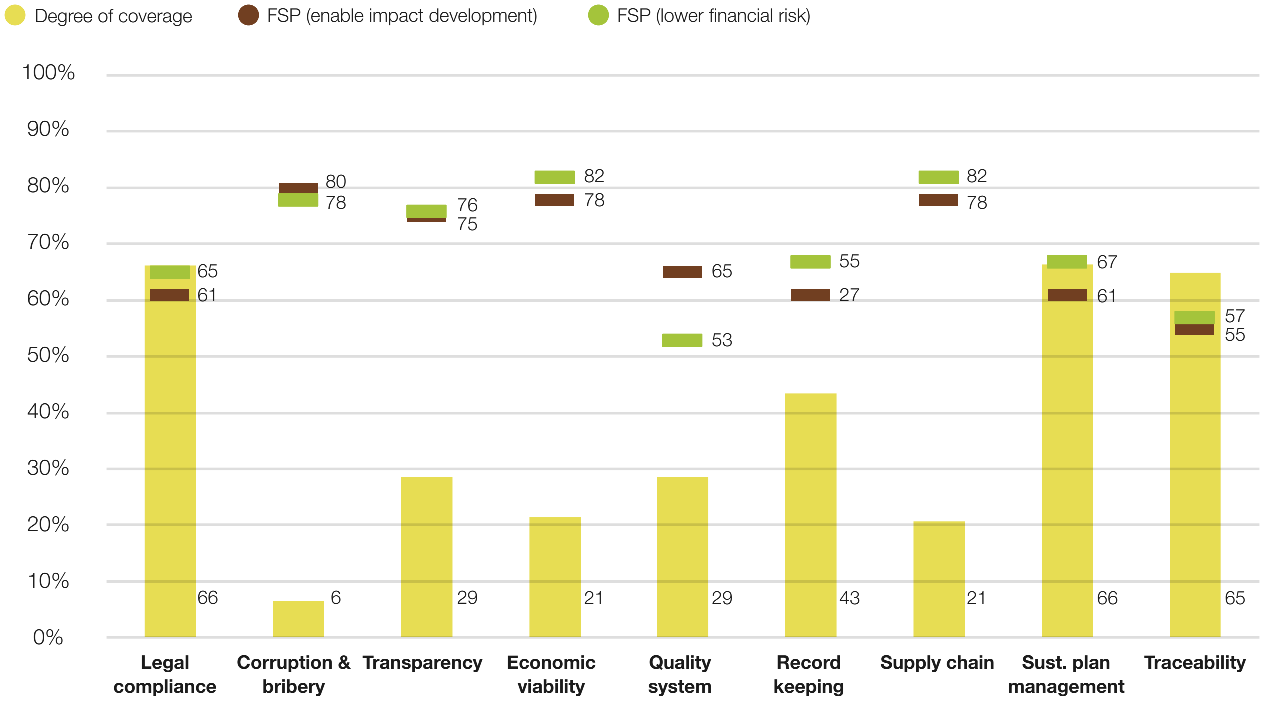
Environmental dimension



	Climate adaptation	Climate mitigation	Waste	Water pollution	Pesticide pollution	Biodiversity conservation	Forest conservation	Soil conservation	Water conservation
Soybean	20	51	69	48	64	75	67	82	76
Oil palm	16	54	65	49	69	77	73	74	68
Groundnut	16	40	77	57	73	65	55	81	74
Coconut	15	39	78	59	71	63	52	88	76
Rapeseed	9	39	78	56	75	57	36	83	80
Sunflower	11	21	76	56	70	51	36	90	75

Figure 58 Average degree of coverage of the criteria of different voluntary sustainability standards that certified different vegetable oil crops in the environmental dimension, compared with the perceived importance of these criteria by two types of financial service providers (FSP). Source: Data compiled by the report editors. Adapted from 'Standards and Investments in Sustainable Agriculture' [453].

Economic dimension



	Legal compliance	Corruption & bribery	Transparency	Economic viability	Quality system	Record keeping	Supply chain	Sust. plan management	Traceability
Soybean	66	0	17	13	22	31	0	63	73
Oil palm	66	9	30	30	27	48	29	74	64
Groundnut	66	5	25	20	40	45	25	62	84
Coconut	62	0	25	25	42	44	16	57	89
Rapeseed	55	0	17	13	45	32	0	44	96
Sunflower	50	0	25	20	50	43	21	45	89

Figure 59 Average degree of coverage of the criteria of different voluntary sustainability standards that certified different vegetable oil crops in the economic dimension, compared with the perceived importance of these criteria by two types of financial service providers (FSP). Source: Data compiled by the report editors. Adapted from 'Standards and Investments in Sustainable Agriculture' [453].

In the environmental dimension, investors attached substantially more importance to climate adaptation than covered by the voluntary sustainability standards criteria, as shown by the gap between expectations from investors and the degree of coverage in the standards (Figure 58). For investors aiming to reduce risk, all other categories were sufficiently covered by voluntary sustainability standards. Impact investors attached relatively more importance to criteria related to climate mitigation and water pollution than the coverage of voluntary sustainability standards criteria.

In the economic dimension, the criteria are related to the improvement of governance (legal compliance, preventing corruption, and facilitating transparency) and management practices (economic viability, quality system, record keeping, supply chain, plan management, and traceability). With the exception of legal compliance, sustainability plan management and traceability, the gap between the percentage of criteria and the Financial Service Providers perceptions is large. It means that while for investors criteria related to corruption are important (scores around 80%), the voluntary sustainability standards cover only around 6% of these (Figure 59).

When looking at the average for each crop, the situation might slightly change. For instance, the percentage of criteria coverage for quality system in sunflower is 50%, which is more than the 29% average (Figure 59). In this case, the VSS that certifies sunflower almost meets the expectations of financial investors.

5.6 Mandatory blending and sustainability for biodiesel

Currently ~16% of all vegetable oils in the world are used for biofuels (Figure 16). Compared to the 6.5% per year increase of vegetable oils use for biofuels recorded between 2011 and 2020 when biofuel support policies took effect, the global use of vegetable oil as feedstock for biodiesel is projected to remain stable towards 2030 [91]. The long-term viability of biofuel crops remains uncertain due to the differing motivations and strategies pursued by various countries [90]. It is expected that regional differences will be more pronounced with countries, like Indonesia, increasing biofuel blending targets based on domestic vegetable oil production, while European Union biofuel policies are reducing use of vegetable oils in biofuel [91].

In the United States, the largest biofuel producer, biofuel demand is expected to remain strong thanks to the Renewable Fuel Standard (RFS) regime. This regime, managed by the Environmental Protection Agency, has set fixed volumes for biodiesel (mainly soy-based) on 1 billion gallons per year and requires biomass-based diesel to meet a 50% lifecycle greenhouse gas reduction compared to petroleum [487]. Most requirements are met with domestic production from a mixture of feedstocks (such as soybean oil, rapeseed oil, corn oil, used cooking oil, and animal fats).

In Europe, the European Union Renewable Energy Directive (EU RED) has made the blending of biomass in transport fuels mandatory since 2009. This has promoted the increasing use of rapeseed and palm oil compared to food uses. In 2018, 65% of palm oil import into the European Union was used for energy; biodiesel (53%); and electricity and heating (12%) [488]. What is key for the vegetable oils market is that the EU RED has actively promoted the use of palm, rapeseed, sunflower, and soy oil in energy (like the U.S.), with only some basic sustainability criteria. The EU RED required biofuels and liquid biomass feedstock to reduce greenhouse gas emissions (first 30%, now 50%), and additionally meet the following sustainability requirements:

1. The biomass may not originate from an area with high biodiversity value such as primary forest, protected nature areas and grasslands with high biodiversity; and
2. The biomass may not come from lands with high carbon stock such as wetlands and permanently forested areas.

> “The global use of vegetable oil as feedstock for biodiesel is projected to remain stable towards 2030.”

However, the EU RED did promote the use of sustainability standards of voluntary origin for vegetable oils throughout Europe even if not all of the strongest quality.

Despite being subject to sustainability criteria and efforts to mitigate direct land use changes in their production, the increased policy-driven use of vegetable oils for biofuels could exert additional pressure on land resources, potentially leading to indirect deforestation and ecosystem conversion [489]. The European Commission (EC) has recognised this issue since a study highlighted the significant Indirect Land Use Change (ILUC) associated with vegetable oils, particularly palm oil due to peatland oxidation and forest and ecosystem conversion [490]. Consequently, in 2019, ILUC criteria were incorporated into the EU RED through a Delegated Regulation.

The outcome of the Delegated Regulation was the imposition of restrictions on palm oil, recognised as a high-risk biofuel with regards to Indirect Land Use Change. It was capped at usage levels observed in 2019 and mandated to be phased out as a biodiesel component, reaching 0% by December 2030. However, exceptions are made for:

1. Palm oil produced by smallholders on plots less than two hectares;
2. Palm oil cultivated on ‘unused’ land; and
3. Palm oil demonstrating exceptionally high productivity.

It is worth noting that even for these categories of 'low ILUC risk' palm oil, additional certification requirements are imposed, adding to the overall complexity of compliance. This factor of discouragement makes it highly unlikely for such palm oil to see significant practical use.

Indonesia responded to the 2019 Delegated Regulation with a World Trade Organization complaint and boosted its domestic usage of high-blend palm oil biodiesel. Consequently, Indonesia is poised to become the primary driver of increased vegetable oil use for biodiesel worldwide. Indonesian production needs to adhere to the Indonesia Sustainable Palm Oil (ISPO) standard, which is considered less stringent and has yet to attain widespread implementation, partly due to illegal land use practises [491,492].

Because of the various new regulations, it is projected that palm oil use in the European Union will drop from 23% to 9% of European Union (not global) biofuels use between 2021 and 2032, while rapeseed (in combination with some other European vegetable oils) will remain relatively stable at 50% [493]. The exact mechanism is uncertain, but palm oil might step in to address gaps left in food when rapeseed biofuel is used, as it did previously. Simply substituting palm oil in biofuels or food, without reducing the usage of all similar vegetable oils, could result in shifting impacts on biodiversity worldwide. It may also lead to palm oil replacing rapeseed or sunflower oil for other purposes. Managing Indirect Land Use Change (ILUC) within individual supply chains is obviously challenging, and the European Commission's efforts are unlikely to effectively control it. Instead, these efforts have intensified geopolitical tensions with Indonesia and Malaysia [494].

> “It is projected that palm oil use in the EU will drop from 23% to 9% of EU biofuels use between 2021 and 2032, while rapeseed will remain relatively stable at 50%.”

5.7 The EUDR lifts and lowers the bar for sustainability

Both palm oil and soy are considered 'high deforestation risk commodities' in European Union trade, along with beef, cacao, coffee, rubber, and timber/wood. As such they are subject to the new European Union Deforestation Regulation, or EUDR. This Regulation, to be applied across the whole European Union, came into force in June 2023, and enters implementation from January 2025 onwards. It requires full traceability to the production area or plot. The sometimes tens of thousands of geographic boundaries of the production plots related to each oil shipment need to be uploaded in an information system of the European Commission. It also requires a declaration that the production has happened according to national laws and without deforestation. The Due Diligence responsibility, and related declarations of compliance, lie in the hands of the traders and operators who put a product on the European market for the first time. It is a major step forward on traceability. However, the data required for traceability under the EUDR are not readily available, may be sometimes costly to produce, and in some cases conflict with data protection laws in producing countries. It could lead to the costs of organising compliance being higher than the additional market value generated [495]. The new rules require informed dialogue about the additional cost of organising information for transparency, who pays that cost, and to what effect. Non-compliance can lead to considerable fines (up to 4% of annual turnover – of a trader).

The rigid traceability modalities of EUDR have met with resistance of producing companies, of palm oil and soy, but also other commodities. It is a major practical challenge that, with every single batch put on the European Union market, the geolocations of each producing plot need to be uploaded into a database system, accompanied by a declaration that there is no or negligible risk of violations of national legislation or risk of deforestation after 31 December 2020. It leads to de facto segregation of trade streams to the European Union and elsewhere, and exclusion of non-compliant farmers. In sectors such as palm oil, getting smallholders up to speed to comply and being able to show this before 2025 is a major challenge and may lead to smallholder exclusion from the European Union market if not accompanied with a strong roadmap of implementation.

The EUDR has led to new tensions between the European Union and producing countries. Indonesia, Brazil and Argentina have filed a complaint about the EUDR to the World Trade Organization. Traders also have reacted critically to the announced measures, as full traceability in soy oil and palm oil has never been required, stating that it will lead to a high administrative and logistical burden. This will most probably affect the global vegetable oils market and prices, as well as Europe's relation with certain conversion-risk production areas, as traders are not keen on running the risk of high fines.

Because the EUDR applies to palm oil and soy, but not to rapeseed, coconut, olive oil, shea, and other oils, it may favour these latter crops, even though social and environmental impacts from their production can be significant (Chapter 5).
As sunflower oil (mainly Ukraine) is suffering from geopolitical events, rapeseed might come out as the big winner of the game in both European fuel and food [496], along with coconut and shea for food, the latter of which however has a limited replacement capacity. Soy in Europe may also be increasing, to be used as non-genetically modified food oil and feed. Soy expansion in Europe would have some space as rotation crop capturing nitrogen for its successor crops [497,498]. Major rapeseed expansion, however, might put European nature conservation and restoration goals further under pressure (along with many other factors). How this will affect sustainability of worldwide vegetable oils production in practice remains unclear.

5.8 Conclusions on global trade and governance

A few major agri-food traders exert significant control over the global vegetable oil trade, leading to various disadvantages. This concentration of power allows a handful of players to influence trade and food system conditions and can hinder progress in sustainability policies and regulations. Conversely, when robust policies are adopted, major food companies can effectively shape the standards. For instance, this has led to a significant adoption of the RSPO standard, accounting for approximately 20% of global usage and 90% in non-energy European applications.

Voluntary standards can yield positive economic, environmental, and social outcomes. However, they have limitations, as they cannot govern uncertified plantations across broader landscapes or jurisdictions. They often face challenges in governance contexts that restrict their capacity to implement standards effectively or drive wider change. Complementary measures like biome-wide policies (such as moratoria), landscape programmes, payments for ecosystem services, and strong local legislation, along with robust enforcement, play pivotal roles. Greater independence of these standards from corporate power and other interest groups is also needed.

The synergy between mandatory and voluntary governance tools is crucial but not yet fully optimised. The EU Renewable Energy Directive, for example, has led to the widespread adoption of sustainability standards for vegetable oil-based biodiesel. However, it has not consistently favoured the strongest standards and has struggled to address additional land pressure caused by vegetable oil expansion, despite recent efforts to limit vegetable oil use and regulate indirect land-use change (ILUC) factors.

In response to persistent deforestation challenges, particularly difficult for voluntary tools to address independently, the EU introduced the Deforestation Regulation. This regulation imposes stringent requirements for traceability and deforestation-free trade of certain commodities like soy and palm oil. However, it does not automatically ensure sustainable trade and might even pose a setback to the current high adoption of integrated sustainability standards (40% of soy, 90% of non-energy palm oil, and 100% of biodiesel use). This is unless the value of integrated sustainability standards, along with complementary measures mentioned earlier, is recognised, and producer countries are supported in implementing these combined measures.

Enhancing mutual recognition of the effectiveness of governance tools, both mandatory and voluntary, is essential. This recognition can lead to tailored combinations of hybrid governance measures, ensuring the resilience of the vegetable oil sector in addressing sustainability challenges.

⟶

Precision agriculture with drones allows for more accurate application of fertilisers, by Satawat, 2020, Adobe Stock.

6

Key future developments

This chapter examines pivotal developments and outcomes within the coming decade (or decades for some scenarios). We seek to shed light on the repercussions of likely trends on the supply and demand of vegetable oils. In this section, we envision the forthcoming landscape of vegetable oil and its primary uncertainties. Extreme scenarios provide a means to glimpse the nature of the trends.

6.1 Changing technology and practices in production

Technology will continue to impact commodity production and consumption. These advances aim to improve precision, reduce labour requirements, enhance efficiency, and optimise resource utilisation. For example, robots are being developed for tasks, such as planting, weeding, harvesting, and crop monitoring for crops such as oil palm.

Precision agriculture, which involves the use of technologies, such as global positioning systems, sensors, drones, and satellite imagery to gather data and make informed decisions about crop management, is expected to contribute to large-scale industrial production of oil crops. These developments are likely to continue, with more precise practices, such as targeted fertilisation, irrigation, and pest management, leading to improved resource use and higher crop yields [499]. Precision agriculture can potentially bring environmental benefits to crops, such as corn [500], associated with high use of fertilisers and pesticides.

As adoption of mechanisation and technology advances, the amount of data generated in food systems also grows. The future trend revolves around harnessing the power of data through advanced analytics and artificial intelligence algorithms [501]. Data-driven decision-making can help optimise operations and crop choices, predict crop performance, detect diseases or pests, and provide actionable insights for improved productivity and profitability. Technology might also enable production of single-cell oils in the lab, but its success will depend on feedstock production costs and relative impacts compared to traditional oil crops. The flip-side is that the Big Data approach risks marginalising local ecological knowledge and locally embedded cultural values.

Technology will significantly impact agriculture labour. Currently, agriculture employs 26% of the global population, with up to 80% in developing countries [502]. Technological advances in agriculture over the last 30 years have driven the global loss of around 200 million food production jobs [502]. Advances in technology, automation, and artificial intelligence will continue reshaping labour, possibly reducing demand for manual work and causing rural-urban migration as a consequence. Advanced technology may also concentrate power, deepening inequities between developed and developing nations, with potential socio-economic risks like instability, conflicts, and mental health issues. At the same time, future labour might involve more human-machine collaboration, emphasising creativity and complex task management, creating rural opportunities.

We assessed two scenarios for changing technology and practices and preview likely outcomes.

SCENARIO 1

What if all food oil were produced by algae or other microbial processes?

High-tech oils will require a lot of feed stock (the microbes need nutrients) and energy. We do not expect major volumes in the next decade, but the technologies are advancing rapidly and who knows in the longer term? If these systems do become cheap and productive at a sufficiently large scale, it will transform food oil with major knocks on oil monopoly and impacts on land use.

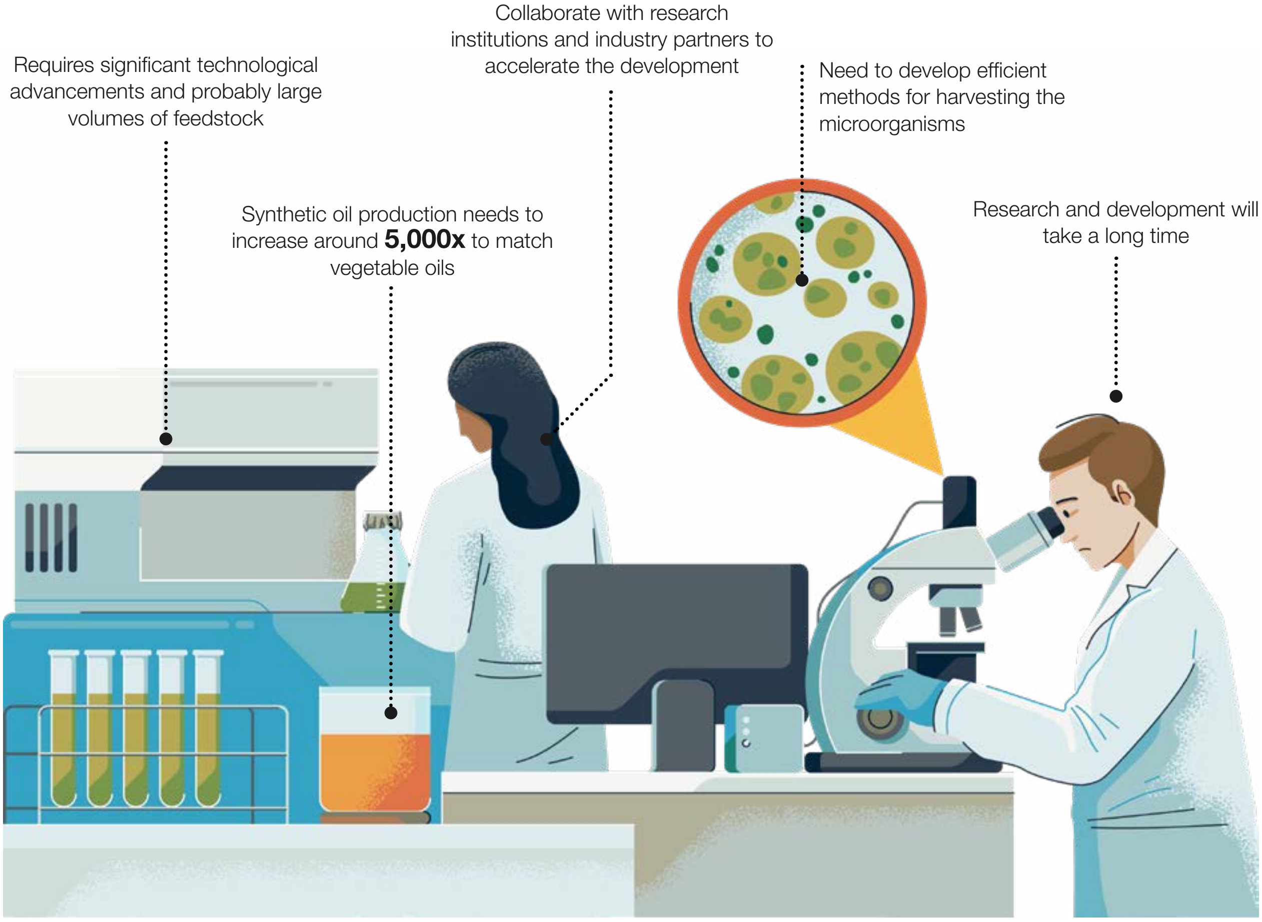


Figure 60 Future scenario: What if all food oil were produced by algae or other microbial processes? Source: Prepared by the report editors.

Some experts believe they can produce an edible oil that overall requires less land and water and produces less CO_2 than our current production methods. It even seems possible to produce food and oil producing food without agricultural inputs, using fossil fuel, biomass and food waste, or carbon captured from the atmosphere [503]. Such new methods may compete directly with palm oil on yield and shelf stability, allowing it to be used in snacks and cosmetics alike. Companies are looking primarily at making edible oils out of microorganisms, such as certain types of algae, yeast or other fungus. To date, no yeast and algae oil company has managed to break into the mainstream [504]. Despite this, several start-up companies are betting that the future of edible oils will be revolutionised using microorganisms.

Microalgae-based oil could be an option. Microalgae would require fertiliser, sugars, water, light, and CO_2. After cultivation in ponds or bioreactors, microalgae are harvested, and their cell walls broken for oil extraction. Yeast oil production, another option, resembles brewing, involving yeast growth, sugar feeding, multiplication, and harvesting with oil extraction. After growing the yeast microbes, they are put in brewing tanks and fed sugars. Feeding on the sugar, the microorganisms multiply until they are ready for harvesting. Like the microalgae, the yeast then undergoes a process to press the oil out of the cells. Currently, C16 Biosciences has produced a microbial oil from the Torula yeast for cosmetic use [505] – dubbed *Palmless Save the F***ing Rainforest Oil* – priced at US$ 45 for 4 oz (or US$ 380 per litre), or about 20 times more expensive than many of its palm oil-using competitors. But, of course, high prices are the norm for any product using new technology that has not been built to scale yet. There have been fewer attempts at crafting microalgae edible oils. A microalgae oil produced by Corbion was taken off the market in 2020 after continuing inventory-write down related losses [504]. Corbion is a good example of how this technology – and the ideas – have been around for decades, but no one has yet been able to create a microorganism edible oil that successfully competes with plant or seed oils.

Yeast and microalgae are not the only next generation edible oils with potential. Options include oils made from insects, krill, or organic waste from current crops like rice bran and corn or wheat germ [69]. Yeast, fungal, and microalgae oils appear the closest to mass production. But would these oils be more environmentally friendly? The largest input for most options is sugar. The main sugar producing crop is sugar cane, of which globally some 27.5 mha are planted – similar to the area allocated to oil palm [15], and in a similar growing region [15]. It requires a lot of water and, in some areas, this means irrigation [506]. The crop can deplete soils, leading to acidification [507]. Sugarcane processing may lead to pollution of waterways as well and if farmers practise pre-harvest burning it results in net carbon emissions [508]. Also, historically, and in many parts still today, cheap sugar production is linked to labour exploitation [100]. In the end, whether sugarcane (for oil feedstock) ends up with a better environmental performance than a crop like oil palm may well depend on where and how it is grown.

Some companies, however, are working to skirt the sugar problem by feeding food waste to their microorganisms. This could improve sustainability. For example, *No Palm Ingredients* claims its food-fed edible oils would reduce land use by 99% and greenhouse gas emissions by 90% compared to other edible oils [509]. Another consortium, *NextVegOil*, is skipping yeast altogether and instead working to make oil with *Ustilago maydis*, or corn smut, a fungus that grows on maize that can be used to produce oils from food residues with a fatty acid profile similar to palm oil [510].

The challenges for producing oils from fermentation are many. First, a product must be able to scale-up to compete with current vegetable oil production of 252 million tonnes of oil. Current global production volumes for single-cell oils were not available but the predictions are growing [511]. It remains unclear whether these oils can compete in our current economy.

Even with continued breakthroughs, some researchers believe fermentation will change little for the environment [512]. There are fears that any successful company will be swallowed up by a large multinational agriculture company, many of which have already invested in researching these approaches. This would allow current power dynamics to remain unchallenged and discourage broad consumer engagement of the new products [512]. Over time, businesses equipped with advanced technology may gain a competitive edge, allowing them to dominate the vegetable oil market. This trend mirrors the observed pattern in high-tech goods, predominantly originating from countries with advanced technologies, including the U.S., European nations, and several Asian countries like China, Korea, and Japan. Consequently, only a handful of such enterprises in the vegetable oil sector are likely to remain profitable.

Despite the barriers, change remains possible. If experts can successfully navigate these challenges, they could truly usher in a new generation of edible oils with considerably less environmental and climate impacts that may leave many farms and plantations redundant. This would affect millions of smallholders in vegetable oil plantations and contracted workers. Many of these farmers and workers will live in poverty, engage in subsistence agriculture or migrate to cities. Biodiversity may recover on abandoned land.

SCENARIO 2

What if monoculture is the only culture?

A lot of people would lose their livelihoods and their food cultures, but consumers could have cheaper food and spare land for biodiversity and carbon only over the short term. Over the long term, monocultures pose significant risks to diversified food systems.

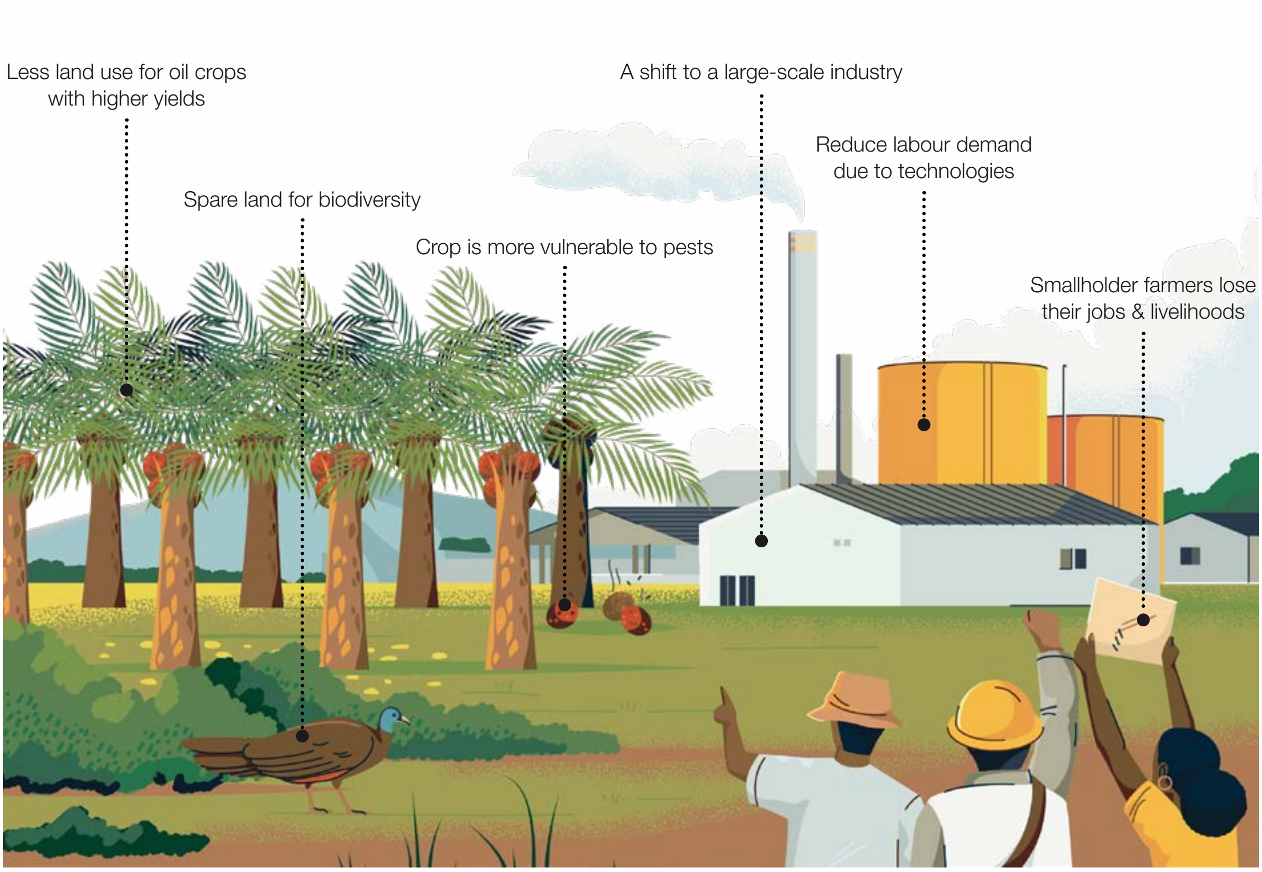


Figure 61 Future scenario: What if monoculture is the only culture? Source: Prepared by the report editors.

If all vegetable oils were produced in intensively managed monocultures, less land would be required to meet global demand, because crop yields tend to be higher in monocultures (but see Chapter 4.1.9). Industrial-scale monocultures yield between 20% and 40% more palm oil than smallholder areas do [513,514]. The influence of production scale on the yield of other oil crops is not well studied – yield variation in soybean and maize seems to be primarily determined by climatic factors [515,516]. Assuming 30% higher yields in a vegetable oil sector under industrial management alone and a current smallholder-industrial ratio of 1:1, 15% less land would be needed to produce the same volume of oil. Conversely, if current production volumes had to be achieved only on smallholder land, 21% more land would be required. The present land area allocated to vegetable oil production is 543 mha (see Chapter 4.1). Allocating all production to either industrial or smallholder plantations under the current yield difference would save 81 mha or necessitate 114 mha more land, respectively, to meet current demand. This could lead to land sparing for biodiversity and reduction of CO_2 emissions over the short term. Over the long term, monocultures present significant risks to healthy ecosystem functioning.

Encouraging innovation in smallholder agriculture provides an alternative to industrial monocultures, potentially narrowing the yield gap. For example, in China, participatory innovation between government agencies and farmers' communities has been put successfully into practice to increase yields among small farmers and to reduce environmental pollution [517,518].

Switching production scales is not just about yields. Transitioning to large-scale industrial agriculture in edible oils impacts smallholders who, globally, produce a third of palm oil and most coconut oil [40,41]. A shift to large-scale industrial agriculture means that smallholders would be integrated into larger firms. As a result, it would potentially lead to the consolidation of agricultural land, as well as concentration of power in the edible oil sector, which is likely to reduce supply chain resilience in the vegetable oil chain. There is also evidence that smallholders in the vegetable oil sector play an important role in food security and local food cultures. For example, food security is better for smallholders growing oil palm than for those who do not, but the benefits are greatest when oil palm is part of mixed cropping systems that provide a range of foods. Finally, a shift to large-scale industrial agriculture likely means more monocultures and automation in the sector. The shift towards monocultures is likely to make the crop more vulnerable to pests, diseases, and climate shocks [519].

> “The shift towards monocultures is likely to make the crop more vulnerable to pests, diseases, and climate shocks.”

In summary, a world under industrial oil crop production would mean higher yields and less land use, but less access to food, land, resources, and opportunities for smallholder farmers. Over the long term, monocultures pose significant risks to diversified food systems.

⟶ *Smallholder farmers in a palm oil plantation in East Kalimantan province, Indonesia*, by Yogie Hizkia, 2019, Shutterstock.

6.2 Future consumption

Because oils and fats are essential to people, the demand for vegetable oils will be influenced by the world's population, which is projected to continue growing, albeit at a slower pace compared to the past. The United Nations (UN) project that the global population will reach approximately 9.7 billion by 2050, up from around 7.9 billion in 2021 [520]. After 2050, the population is expected to stabilise or decline. Demographic trends vary across regions, with some countries experiencing population growth while others face stabilisation or decline, due to ageing populations. Africa is projected to experience the highest population growth, while certain European and Asian countries may see population decline. Consequently, the highest new demand for vegetable oils is likely to be in Africa.

Around 252 million tonnes of vegetable oils were produced in 2021 [15]. Assuming no more vegetable oil is redirected for biofuel and industrial use (about 28% of current global production is used for biodiesel, animal feed, and industrial applications, totalling 71 million tonnes), vegetable oil production would need to increase to 288 million tonnes just to feed the projected 9.7 billion people. Depending on the choice of crop and management system, and the extent to which the yield gaps can be closed, we estimate the range of additional land needed for a 14% increase in vegetable oil by 2030 to be between 30 and 100 mha.

A growing body of research is dedicated to understanding the future of sustainable consumption and nutrition [372,521,522]. Studies already indicate that one of the current consumption trends revolves around sustainable and ethical consumption. Other significant future consumption trends include the rise of e-commerce, which has transformed the retail landscape through greater personalisation and customisation of products and services, and increasing health consciousness, particularly in an ageing population.

New technological advances also impact the consumption of vegetable oils. Artificial Intelligence and data science tools are used to explore the composition of vegetable oils [523], and their health [524] or environment impact [343]. New discoveries can alter public perception of certain oils, indirectly affecting consumption and production patterns [525]. The use of artificial intelligence in vegetable oil research is likely to thrive even more. Currently, its performance is limited by the poor quality of available data in some research fields. However, as more technological advances are integrated into the value chain, higher-quality data sources will become available. This will enable the creation of holistic representations connecting knowledge across different disciplines such as food production, environmental preservation, nutrition, and public health. Such holistic analyses are crucial for policy makers in crafting sustainable food production policies, like the One Health initiative [526] or the Sustainable Development Goals.

In addition to informing policy makers, new technological advances could be used to directly educate consumers about the implications of oil production. Front-of-package nutrition labelling can effectively promote healthier food choices [411,527]. Therefore, we believe similar approaches could be employed to encourage sustainable production systems [528]. To achieve this, producers will need to conduct comprehensive environmental assessments at all stages of the value chain. These evaluations should extend beyond CO_2 assessments to include reporting on the social impacts of the entire production system. Presenting all this information through single-score labels is challenging. Thus, digital technologies, such as quick response (QR) codes, could complement front package labels by providing sustainability information.

Empowered consumers with objective information are more likely to modify their global perception of vegetable oils than those who are uninformed. The opinion of consumers permeates social media, where the spreading power of these platforms has resulted in highly controversial and often polarised debates [431]. Informing consumers about the environmental impacts of all oils is the first step to stop the dichotomous characterisation of oils as 'good' or 'bad'. This will transform the debate into a rich and nuanced discussion that can truly inform the future of sustainable production systems. The implicit assumption here is that educated consumer choice drives change, although currently we see that rather than drive change these consumer choices have created niche markets. The question should be posed if regulation and fiscal tools would drive wider scale changes.

SCENARIO 3

What if we all became vegetarian?

It would benefit global biodiversity, climate, and the majority of people, although we have concerns for pastoralists, fishers, and hunter-gatherers. A reduction in meat consumption in industrial countries would reduce pressure on land and related resources.

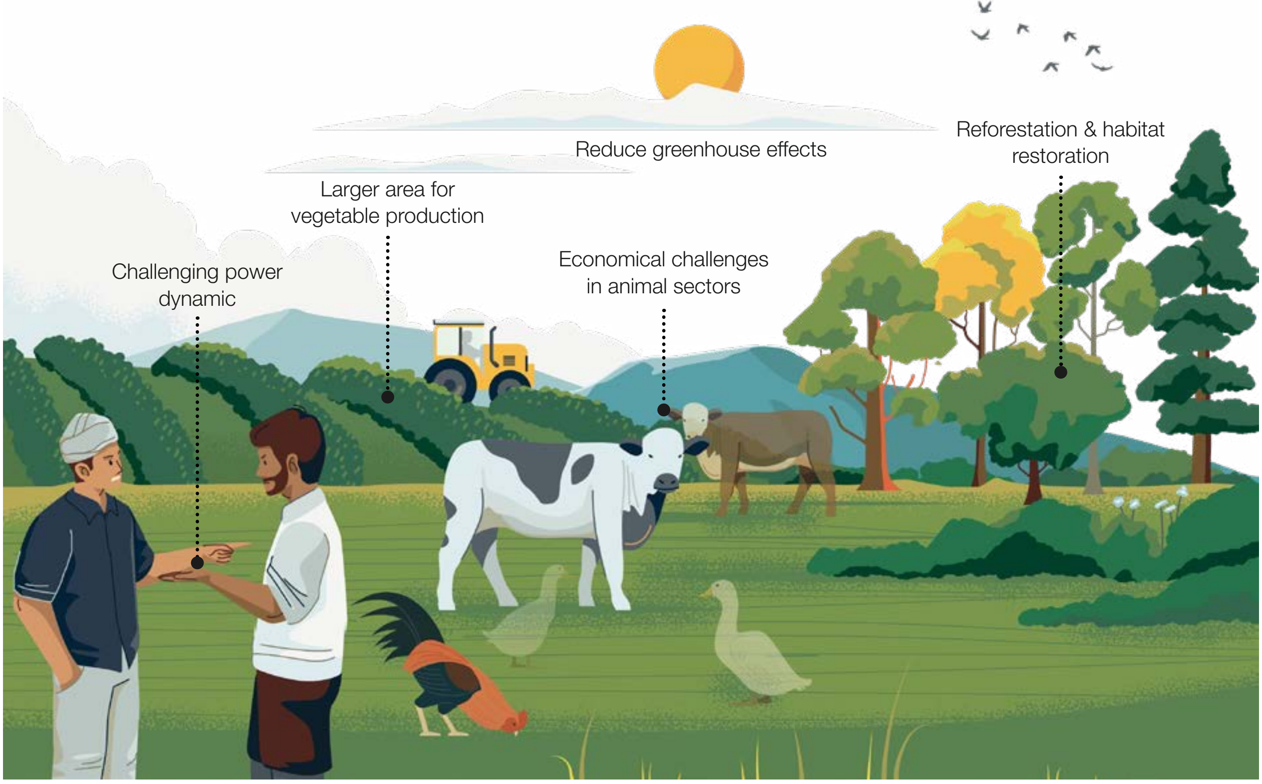


Figure 62 Future scenario: What if we all became vegetarian? Source: Prepared by the report editors.

Future consumption of meat products in developing countries is projected to increase from 29% to 35% by 2030 and 37% by 2050. In contrast, consumption is stabilising in Europe [529]. There is evidence suggesting that, at least in some countries, peak meat consumption has already occurred [530,531]. A behavioural change pattern is emerging in western diets: reduced fat and meat consumption, and an increased intake of fruits and vegetables, and less meat. In parallel, we are seeing the rising popularity of plant-based diets and. In the future, there may be more consumption of insect-based protein, due to concerns about both the environmental impact of meat production and health implications. Additionally, cultured or lab-grown meat might also influence meat consumption trends in the future. What might a world look like if we were all to adopt a plant-based diet?

A global switch to plant-based diets could save up to 8 million annual lives by 2050 [532]. It would also reduce food-related greenhouse gas emissions by two thirds, and lead to healthcare-related savings [532]. It is also estimated that such a global switch would avoid climate-related damages of US$ 1.5 trillion [532], or about 1.5% of the global gross domestic product. Furthermore, as two-thirds of agricultural land is currently dedicated to meat production, transitioning to plant-based diets would significantly free up land and water for other purposes. It is projected that a shift to plant-based diets could reduce global agricultural land use from four to one billion ha (see Figure 9). With land available for other purposes, there would be less pressure on forests and agricultural systems for food production. In the vegetable oil sector, this scenario would mean more available land for oil crop production, potentially meeting the rising demand for vegetable oils. Simultaneously, under this scenario, soybean oil availability on the market would decrease, as much of the soybean crop is used for animal feed. Oil palm might well thrive and fill the oil gap left by soybean.

A transition to plant-based foods and alternative protein sources will be accompanied by the growth of plant-based food industries and increased investment in research and development for new food technologies. However, there could be challenges related to power concentration in the agriculture sector. Additionally, severe economic challenges will arise for individuals working in the animal and animal feed sectors. Local mixed-farming, fishing, gathering, and pastoral systems would be disqualified causing wide-scale cultural disruption and loss of local ecological knowledge.

SCENARIO 4

What if we ran the world on vegetable oils for biofuel?

At present a staggering amount of additional land would be needed, or 10 times the currently planted oil palm area. This would have major knock on impacts on land-use and users.

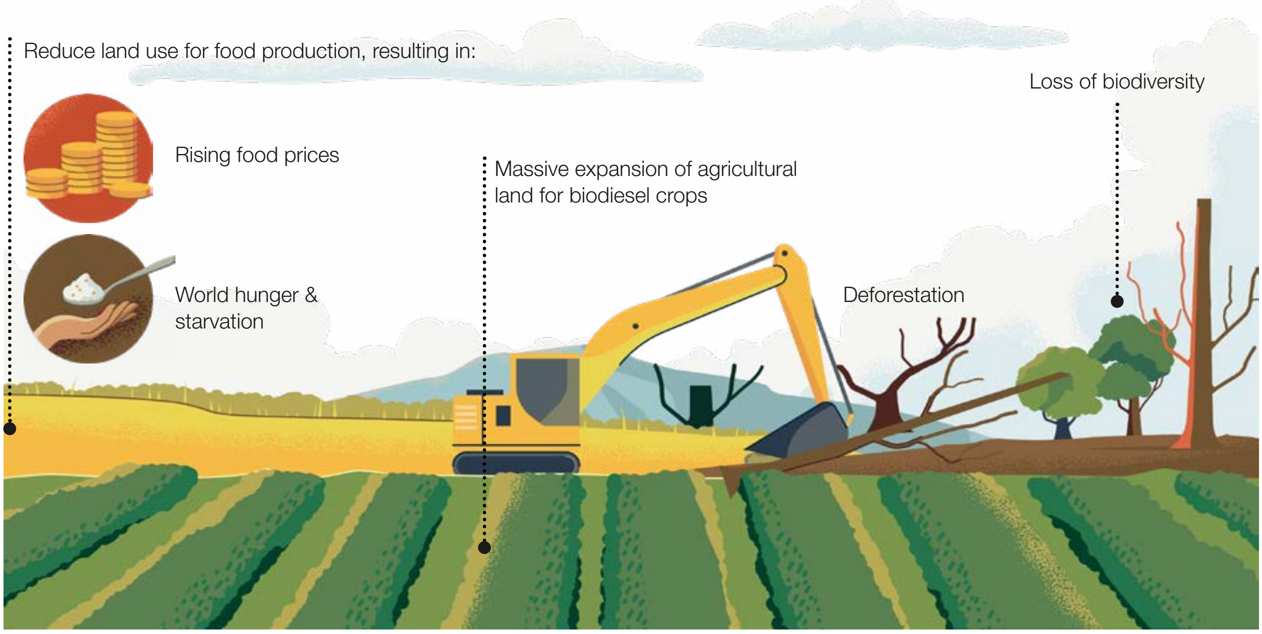


Figure 63 Future scenario: What if we ran the world on vegetable oils for biofuel? Source: Prepared by the report editors.

Trends in biodiesel will also determine demand for oil crops. First-generation biodiesel (Box 8) from vegetable oils still faces policy challenges, including concerns about land use, potential competition with food production, and the overall lifecycle environmental impact [86]. There is interest in diversifying feedstocks to reduce dependence on food crops. Non-food oilseeds, such as jatropha, camelina, and algae, as well as waste oils and fats, are already being explored as alternative feedstocks for biodiesel production.

Current fossil fuel-based diesel consumption is about 40 quadrillion British thermal units [533] or about 1 billion tonnes per year, suggesting that biodiesel production would need to reach 1 billion tonnes per year to replace all diesel. If this additional oil demand was met through palm oil only, some 250 million ha (approximately the land area of Argentina) of additional land would be needed, or 10 times the currently planted oil palm area. If on the other hand, the additional biodiesel demand was met by soybean or rapeseed, some 1.5 billion ha of land would be needed, nearly the size of Russia. Dedicating such large areas to fuel production would have major impacts on the environment, if expansion happened in natural ecosystems, or on food security, if that expansion happened on existing agricultural land. Lower energy density and the price of raw materials make biofuels more expensive than fossil fuels when producing heat. This means that the one-to-one conversion from fossil fuel to biodiesel above is unrealistic, but it also means that replacing all fossil fuels with biodiesel would significantly increase fuel prices.

⟶ *Soybean plantation in the state of Mato Grosso do Sul, Brazil*, by Ilton Rogerio, 2020, Adobe Stock.

6.3 Geopolitical trends

Geopolitical trends reflect numerous factors and are subject to unexpected events and developments. Emerging powers, such as China, India, and Brazil, may form new global alliances and economic relationships, and influence the geopolitics of trade.

With an increase in global population and consumption, competition for resources, particularly energy, water, and food, is likely to intensify. Access to and control over these resources will play a crucial role in shaping geopolitical dynamics, potentially leading to conflicts, cooperation, and new alliances. These trends will be exacerbated by the impacts of climate change and resource scarcity [534].

Regional trade blocs, the impact of protectionist policies, and the rise of economic nationalism may shape the relationships between countries and influence their geopolitical positioning. Already, the soybean market experienced profound shifts when China retaliated against U.S. trade tariffs on its electronic goods and, in turn, levied a 25% retaliatory tariff on U.S. soybean exports. That tariff shifted market preferences so that Chinese buyers, who make up a substantial share of total world consumption, favoured Brazilian soybeans [535].

> “With an increase in global population and consumption, competition for resources, particularly energy, water, and food, is likely to intensify.”

SCENARIO 5

What if there were no tariff barriers and regulations at production or consumption levels?

In a neoliberal world, big business would gain, but many workers, smallholders and much biodiversity would likely lose.

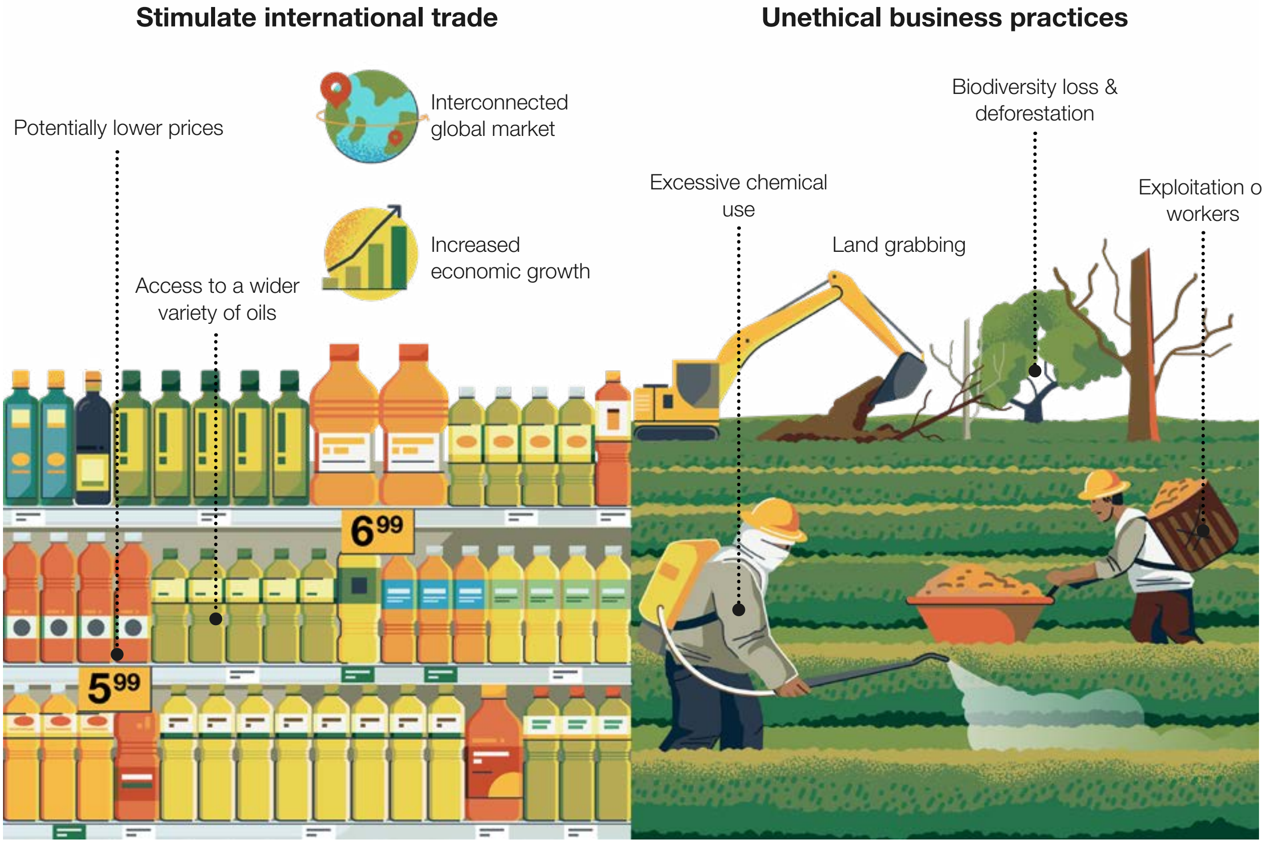


Figure 64 Future scenario: What if there were no tariff barriers and regulations at production or consumption levels? Source: Prepared by the report editors.

In recent decades, various regional trade deals have been negotiated towards lower agricultural tariffs. The EU's Common Agricultural Policy (CAP) and agreements like the North American Free Trade Agreement (NAFTA) and the Agreement between the United States of America, the United Mexican States, and Canada (USMCA) reduced tariffs among members. Despite efforts, global agricultural tariffs remain high at around 62%, unlike lower industrial product tariffs [536]. Governments use tariffs to protect domestic industries. The vegetable oil sector often benefits from relatively low inter-country tariffs. For example, Indonesia has very low export tariff rates for agriculture commodities, such as palm oil, compared to generally higher tariffs prevailing in other countries. Similarly, trade agreement between China and Brazil has meant low tariffs for the export of soybean to China.

Low tariffs have helped countries like Brazil and Indonesia specialise in commodities like palm oil and soybeans, boosting efficiency and global output. Trade liberalisation boosts conditions for transnational agrifood companies to invest in and expand markets [537]. This has helped smallholders to integrate global vegetable oil trade, such as in the case of palm or coconut oil. For consumers, removing barriers has led to more accessible vegetable oil products.

We have described how free trade leads to market efficiency, but this also creates more demand and trade in commodities and goods, and more push for free trade and export-driven agriculture. This reinforcing loop risks overlooking environmentally harmful farming practices or increasing competition between countries and competition to reduce regulatory barriers, which can undermine environmental and social regulations. In fact, common unsustainable practices like excessive chemical use, deforestation, water misuse, pollution, land grabbing, and violence against those opposing such practices are widespread in global commodity production (Chapters 4 and 5), particularly without strong state regulations or oversight.

Large transnational agrifood companies such as Nestle, ADM, Cargill, thrive under free trade conditions [537], not only because of opportunities to produce and trade large volumes, but because their capacity for market efficiency and investment outcompetes most costly local business transactions. This inevitably leads to accumulation of wealth and market power in the hands of a few in the vegetable oil sector (Chapter 5.2).

A future increase in free trade in the vegetable oil sector is expected to continue shifts towards national commodity specialisation, industrial agriculture, cheap vegetable oils, and consolidation of power in the hands of a few transnational agrifood companies. Integration of smallholders in global vegetable oil trade has not consistently taken smallholders out of poverty (Chapter 4.2).

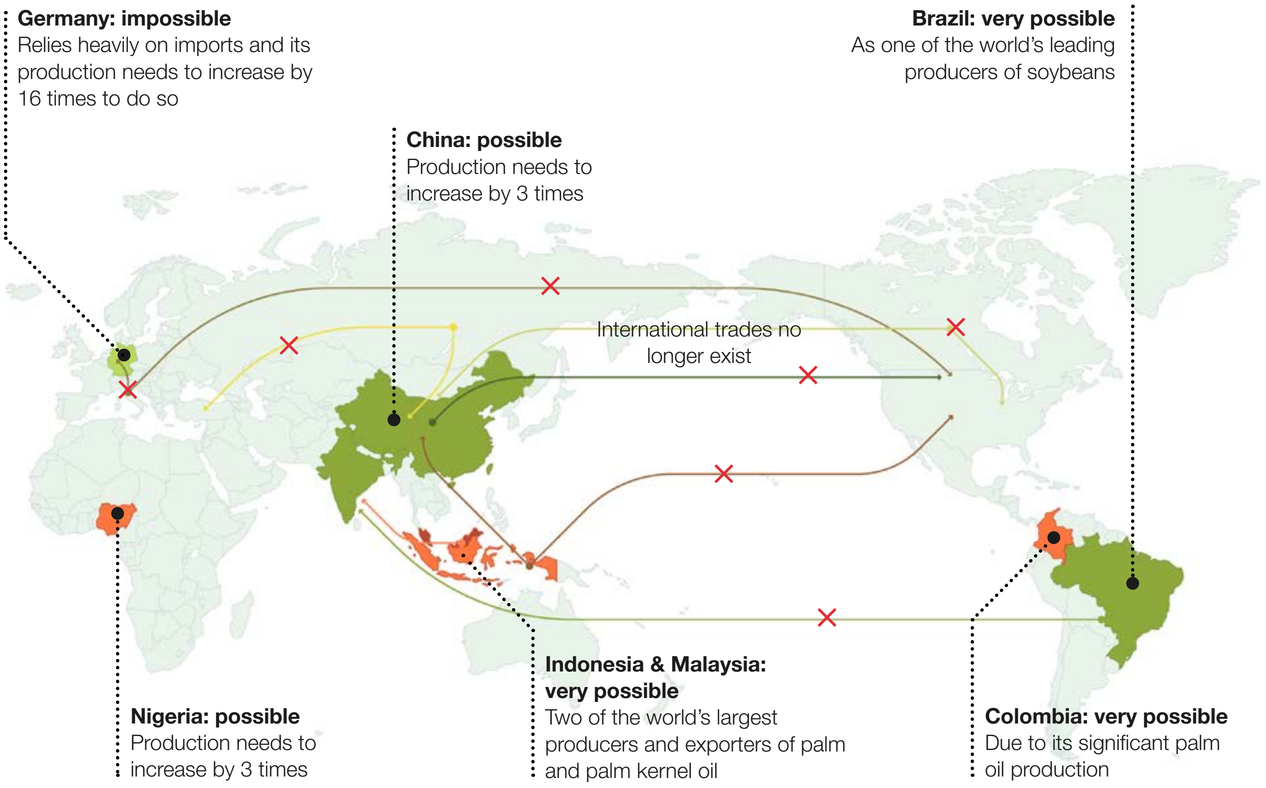
> “Common unsustainable practices like excessive chemical use, deforestation, water misuse, pollution, land grabbing, and violence against those opposing such practices are widespread in global commodity production.”

⟶ *Frequently employed in agriculture, pesticides are widely recognised for their adverse effects on both human health and the environment*, by Andrii Yalanskyi, 2021, Adobe Stock.

SCENARIO 6

Can countries achieve self-sufficiency through domestic production?

Probably a bad idea. In the next 10 years, Europe would have a massive fat gap (short fall in availability).



Germany: impossible
Relies heavily on imports and its production needs to increase by 16 times to do so

Brazil: very possible
As one of the world's leading producers of soybeans

China: possible
Production needs to increase by 3 times

Nigeria: possible
Production needs to increase by 3 times

Indonesia & Malaysia: very possible
Two of the world's largest producers and exporters of palm and palm kernel oil

Colombia: very possible
Due to its significant palm oil production

Figure 65 Future scenario: Can countries achieve self-sufficiency through domestic production? Source: Prepared by the report editors.

Would it be possible to source most vegetable oils within nations? To meet national demand, domestic production would need to triple in India and China, while in Europe production would need to increase eighteen-fold. In short, it will be impossible for Europe to eliminate vegetable oil imports, although this may be possible for China, India, and various African nations. This, however, would require more adequate technical training and capacity-building support to small farmers, better financial conditions supportive of farmers, and infrastructure, such as roads and processing facilities. Supportive policies, regulations, and governance frameworks would play a vital role in boosting smallholder agriculture.

Nonetheless, tripling oil crop production in China, India, or Africa could involve encroaching upon land already used currently for major cereal crops or involve land grabbing from communities and smallholders. For example, in India, there has been a call for expanding palm oil plantations in the more humid regions, but these would involve encroachment on already vulnerable ecosystems (Box 4).

For producing countries already specialising in global production of soybean oil, and palm oil for international trade, such as the U.S., Brazil, Malaysia, Indonesia, and Colombia, national production in vegetable oils could be easily met if export was no longer an option. Extra production could be dedicated to biodiesel to avoid abandonment of existing plantations and loss of jobs. However, governments would no longer benefit from export revenues and, therefore, the global market value might decline.

6.4 Climate change

Climate change is already impacting vegetable oil production. Climatic changes include slow-moving changes in average conditions. For example, precipitation and temperature. Climate change also implies larger, anomalous disruptions, such as floods, droughts, and extreme heat or fire hazards. Indirect changes of climate change are another factor to consider. For example, its influence on pollinators, pests, and disease.

> "Climate change also implies larger, anomalous disruptions, such as floods, droughts, and extreme heat or fire hazards."

High temperatures are already having adverse effects on the flowering and fruiting of perennial crops such as oil palm and coconut, resulting in lower yields [538]. Annuals such as soybeans are also impacted by high temperatures, droughts, and frost, all of which result in reduced growth, especially during growing phases.

Fat composition is also impacted by climate change. For example, water stress in soybean results in decreased linoleic fats and omega-6 and omega-3 polyunsaturated fats, while sunflowers grown at higher temperatures during seed development produce fewer polyunsaturated fatty acids and higher levels of monounsaturated fatty acids [539].

Some climate simulations are available for major oil crops [540], but vary in scope and consistency, making comparisons challenging. Climate change will impact production, but it will also "affect people and their ability to work" (our interviews and [541], see IPCC scenarios later).

⟶ *Aerial shot of oil palm plantations in Malacca, Malaysia flooded during the rainy season*, by Pejal745, Shutterstock.

SCENARIO 7

The climate wild card – A temperature rise of 2.4°C?

Climate instability will hit edible oils hard. While many of us will have bigger problems, production areas will shift and there will be marked challenges in sustaining sufficient production.

A 'middle of the road' scenario developed by the IPCC involves a 2.4°C mean global temperature increase by 2100. In this scenario, CO_2 emissions would hover around current levels before starting to fall mid-century, but would not reach net-zero by 2100. This scenario assumes that socio-economic factors follow historic trends, with no major shifts, while progress toward sustainability is slow, with development and income growing unevenly.

Under this scenario, extreme temperature events will likely occur 5.6 times more often, extreme precipitation will likely occur 1.7 times more often and drought episodes will likely occur 2.4 times more often. Even this moderate scenario will severely impact oil crop production, especially in sub–Saharan Africa [542]. Major hubs for oil crop production, such as Indonesia, Malaysia, and India, are also facing a reduction of 15–30% in agricultural productivity [542].

Climate change will also impact the ability of individuals to work within the agriculture sector [541], as highlighted by our interviews. However, these factors are seldom considered in climate change models. An increase in disputes concerning resource access and management is likely, as well as a rise in mass migration resulting from the collapse of food and economic systems.

Overall, predictions indicate that oil palm plantations may face the greatest climate impact among oil crops. Reductions of up to 30% in production are projected with a 2°C temperature increase, based on the moderate IPCC scenario [538,543]. Soybean yield declines are estimated at around 2.6% per decade, suggesting an approximately 20% decrease by 2100 [540]. Rapeseed yields might decline between 25–42% by 2070 in Canada [544], and face similar decreases, particularly in southern Europe [545]. Sunflower shows a 5–20% yield decline in southern European regions by 2030, contrasting with increases in France and Germany [546].

Coconut productivity is predicted to rise in much of India [547], although the impact of extreme weather events appears to have been neglected [548]. Areas suitable for the production of coconut production areas will also shift away from the equator [549].

Shortfalls in palm oil production are likely to be met by greater soybean oil production, especially in the U.S. and the Amazon-Cerrado agricultural frontier. Predictions suggest that 51% of the Amazon-Cerrado agricultural frontier will move out of the most favourable climate space for rainfed agriculture by 2030, reaching 74% by 2060 [550]. Meanwhile, more of the boreal zone may become available for farming due to a 500 to 1,200 km northward shift of the northern margin of the agricultural climate, resulting in a 5.62 million km^2 expansion of boreal agricultural land by 2050 [551]. This agricultural expansion would result in large losses of carbon stored in vegetation and soils [552].

> "Overall, predictions indicate that oil palm plantations may face the greatest climate impact among oil crops. Reductions of up to 30% in production are projected with a 2°C temperature increase, based on the moderate IPCC scenario."

SCENARIO 8

Climate change hits 4.4°C?

→ Maintaining oil crops will not be the main concern.

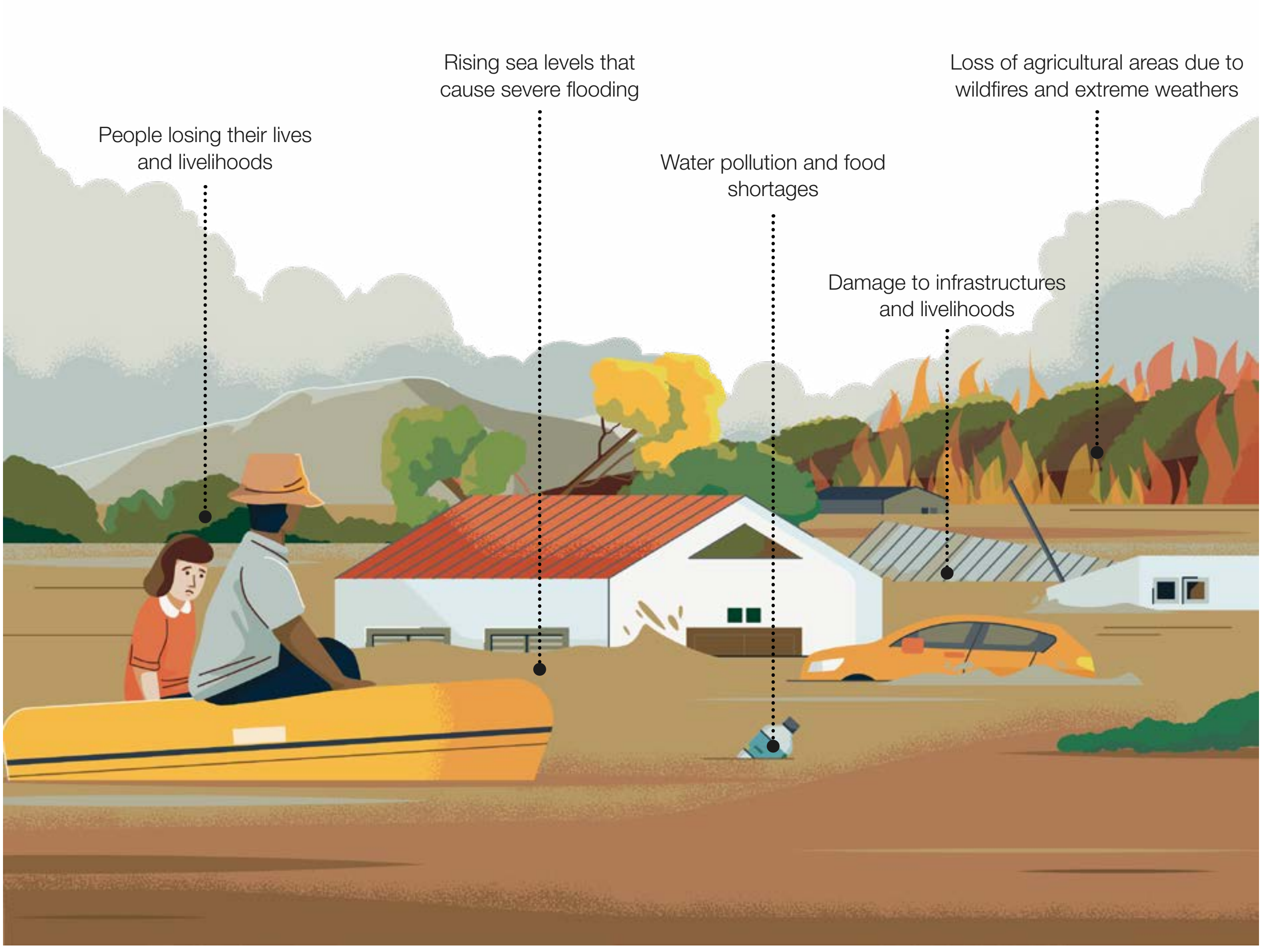


Figure 66 Future scenario: Climate change hits 4.4°C? Source: Prepared by the report editors.

The catastrophic IPCC scenario, also known as ‘avoid at all costs’ involves a 4.4°C mean rise in global temperature by 2100 [553]. In this scenario, current CO_2 emissions levels will approximately double by 2050. The global economy grows quickly, but this growth is fuelled by exploiting fossil fuels and energy-intensive lifestyles. While some food production may remain viable, many environments will be severely modified with severe negative impacts on most of the world’s people and species.

The IPCC has forecasted significant crop failures in this scenario, accompanied by a multitude of uncertainties. Critical factors influencing crop production, such as freshwater availability, impacts of sea level rise, heat waves leading to heat-related deaths, forest fires, and harvest losses, as well as damage to infrastructure and potential migration crises, remain unassessed. Consequently, drawing definitive conclusions about this scenario is challenging, but it is evident that serious challenges lie ahead.

> “Many environments will be severely modified with severe negative impacts on most of the world’s people and species.”

6.5 Regulations

Regulations can play a crucial role in influencing various aspects of vegetable oil systems, encompassing environmental protection, such as pesticide regulations, food safety, land use, labour practices, reporting on social and environmental information, and more. These regulations vary depending on the region, country, and the specific policies in place.

Regulations governing vegetable oils encompass both voluntary and mandatory sustainability criteria, with a history spanning approximately 15 years. Mandatory regulations are prevalent not only in producing countries but also extend to consuming nations. Notable instances of legislation in consuming countries aiming to enhance value-chain practices include the sustainability criteria for biodiesel outlined in the European Union Renewable Energy Directive (EU RED) and the recent enactment of the Corporate Sustainability Reporting Directive (CSRD) in the European Union (Chapter 5 and Box 10).

However, as many vegetable oils are interchangeable for their more common uses, this means that if a particular oil becomes too expensive due to more stringent regulations compared to norms or past trends, consumers and industries can switch to cheaper alternatives. For example, if soybean oil prices rise, consumers might opt for rapeseed or sunflower oil. Also, vegetable oils are often sold as blends of two or more different oils. Prices of the component oils dictate which blends are available. This both limits the impacts of regulations, as well as disincentivises more stringent regulations.

In our scenarios, we look at simplifying regulatory needs with the question, what if only one vegetable oil (for example, palm oil or soybean oil) were used to cover all demand? We also asked ourselves what if more financial institutions invested in smallholder agriculture?

⟶ *Vegetable oils are readily available in retail stores, found alongside a variety of other products*, by Daria Volkova, 2018, Unsplash.

SCENARIO 9

To simplify regulation needs, can one oil do it all?

→ This is probably a bad idea because it will involve over-use of one type of ecosystem suited to that oil crop (such as tropical humid areas for oil palm). Consumers can no longer access their favourite oils, but palm and soy can meet most global needs. For maximum production by area, palm wins compared to other crop oils.

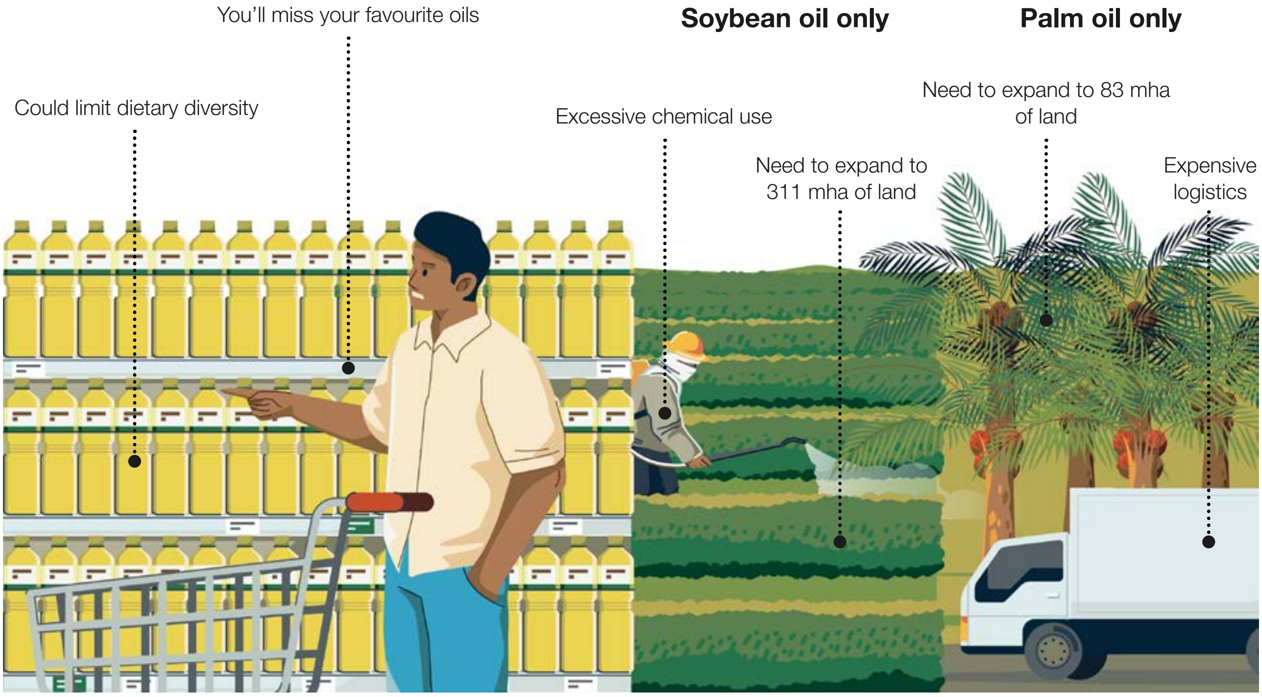


Figure 67 Future scenario: To simplify regulation needs, can one oil do it all? Source: Prepared by the report editors.

Meeting the entire demand for vegetable oil through palm oil would necessitate the allocation of further tropical land for agriculture. As of 2022, the global production of vegetable oil reached 220 million tonnes, with palm oil contributing 35% of the total output. The cultivation of palm oil occupied approximately 29 mha of land. Should palm oil satisfy the entire current supply for vegetable oil, currently standing at 252 million tonnes, the cultivation of palm oil would need to expand to encompass an estimated 83 mha of land. Consequently, an additional 54 mha of tropical land would need to be designated for this purpose.

If all vegetable oil demand was met by soybean oil, it would require 446 mha of land. That is 311 mha in addition to the current 125 mha. In sum, if only one vegetable oil fulfilled global demand, you would miss your favourite oils, but palm and soy can do a lot. For maximum production by area, palm wins.

Nonetheless, the expansion of oil palm plantations or soybean fields may be limited in Asia due to labour constraints. Expansion could occur in South America. However, labour constraints also exist in the region, as evidenced by our interviews. In Africa, both labour and land are accessible to producers. Nevertheless, the logistics of production, manufacturing, and trading are costly. The expansion of palm oil or soybean production could generate supplementary employment prospects in various parts of Africa. However, it might also intensify conflicts around land rights and the displacement of Indigenous peoples and local communities, and, in the case of soy, it would imply significant health issues related to pesticide use (Chapter 5). These concerns might be mitigated if production originates primarily from smallholders, as is the case for coconut, especially when small farmers are provided with technical and financial assistance and are better integrated in the value-chain.

SCENARIO 10

What if more financial institutions invested in smallholder agriculture?

There is a huge credit gap so far but investment at scale accompanied by digital innovation has the potential to revolutionise smallholder agriculture.

Figure 68 Future scenario: What if more financial institutions invested in smallholder agriculture? Source: Prepared by the report editors.

Over one third of global food is produced by smallholder farms on 24% of agricultural land, serving as the primary food source in both developing and developed countries [554,555]. In the U.S., 48% of farmlands are operated by small family farms, contributing to one fifth of agricultural sales but only five% of net farm income [556]. The success of small farms is vital for feeding the projected nine billion people by 2050 and is crucial for rural socio-economic development [502,518].

However, small-scale farming faces challenges like economic constraints, marketing issues, labour costs, technology gaps, production decline, climate change, limited education, and inadequate infrastructure [557].

Further, smallholder farmers have traditionally had little access to affordable long-term finance that allows them to invest in their farms, increase productivity, and align with the best agriculture practices. The credit gap for farmers in developing countries is estimated at around US$ 170 billion per year [558]. Investment has been limited due to the high logistical costs of accessing smallholders, limited understanding of smallholders, and lending risks. If these conditions could be overcome and the credit gap closed, all smallholders would have access to affordable credit with the critical associated technical support. Such funds can have a major impact on smallholders' livelihood especially when these investments are facilitated by local agriculture institutions. Examples from China demonstrate how participatory innovation and investment between government agencies and farmers communities can help overcome yield gaps among small farmers, and also reduce environmental pollution.

One Acre Fund is an example of an initiative that is delivering social and environmental goods adapted to local contexts. It has offered farmers in East Africa greater access to training, services, and products that they need to increase their crop yields and incomes. The products include seeds, fertiliser, and tools that are provided to farmers on credit that they can pay back over the course of the farming season. In 16 years, One Acre Fund has reached 3 million farmers and helped increase farmer's income by US$ 2.70 per US$ 1 invested by donor investment [559]. This combined financial and technical investment, with impact focused, has the potential to eliminate poverty and food insecurity in environmentally compatible ways.

Today, there are at least 270 million smallholder farmers in Africa, Asia, and Latin America, producing over 70–80% of the world's food supply – but due to their lack of economies of scale, low productivity, and limited know-how and means of production, the majority live in poverty [502]. More investment would lead not only to reducing social and environmental impacts but will also enhance diversified food systems, including more mixed cropping and agroforestry, for example, which present promising opportunities for vegetable oil production and biodiversity. In the future, new digital tools and services, if combined with access to finance and knowledge, have the potential to revolutionise smallholder agriculture [560,561].

⟶ *Several programmes in Africa have worked to give farmers in East Africa better access to the training, services, and products they need to increase their crop yields and incomes*, by Georgina Smith, 2016, CIAT.

→

Cottonseed, a by-product of cotton production, is one of the most widely consumed oil seed crops in the world, by Esin Deniz, 2013, Adobe Stock.

7

Scenarios, unknowns and choices

Our study indicates that vegetable oil demand will continue to grow and that production needs to increase. We find that for all oil crops in all vegetable oil systems, there are negative social and environmental impacts. Production increases therefore require changes in the way vegetable oils are produced, traded, and consumed to decrease negative impacts. The minimum requirement for good practice is respect for international agreements on human rights and the environment. Once this bottom line is in place, informed decisions are required about choices (which crops, which production scales and systems, how governed, how financed, how traded, how consumed), understanding that some of these decisions come with trade-offs. Based on the evidence presented from Chapters 1 to 6, we review these choices and their implications.

> “The future demand for vegetable oils will be influenced by the global population, projected to reach 9.7 billion by 2050. While some regions will experience growth, others will see stabilisation or decline in populations.”

7.1 Scenarios

We considered some scenarios for the future of vegetable oils. Advances in technology will persistently influence commodity production, emphasising precision, efficiency, and resource optimisation, including robotic applications in agriculture. Precision agriculture, employing Global Navigation Satellite Systems, sensors, drones, and satellite imagery, will bolster industrial oil crop production, offering environmental advantages. Technology will yield more data, enabling advanced analytics and artificial intelligence for enhanced operations and productivity. Yet, it will alter agricultural labour, potentially reducing manual work and prompting rural-urban migration, and without adequate countermeasures in place it is likely to increase the concentration of power. Of the two technological scenarios we considered, synthetic vegetable oil production faces uncertainties, while monoculture-intensive oil crop production could yield more but threaten smallholders, supply chain resilience, and food security.

The future demand for vegetable oils will be influenced by the global population, projected to reach 9.7 billion by 2050. While some regions will experience growth, others will see stabilisation or decline in populations. Africa is expected to have the highest demand for vegetable oils. Current global production levels, excluding biofuels and industrial use, are predicted to increase from 252 million tonnes to 288 million tonnes to feed this projected population. Consumer trends are shifting towards sustainable and ethical consumption, driven by e-commerce and health consciousness. Providing consumers with objective information can reshape perceptions and promote sustainability. We considered two **consumption scenarios**. A switch to plant-based diets would have significant positive health and environmental benefits, reducing emissions and freeing up land for oil crop production. However, it would pose economic challenges for those in the animal and animal feed sectors. Using vegetable oils for biofuels on a large scale could lead to environmental and food security issues due to land requirements and increased fuel prices.

Geopolitical trends will be influenced by emerging powers like China, India, Russia, Indonesia and Brazil, potentially leading to new global alliances and trade dynamics. As the global population and consumption rise, competition for resources, such as energy, water, and food, will intensify, affecting geopolitical dynamics. Climate change and resource scarcity will exacerbate these challenges. Trade policies, protectionism, and economic nationalism will shape relationships between countries. Regional trade blocs and tariff barriers will continue to impact trade dynamics. We considered two particular **geopolitical scenarios**. Reducing tariffs has led to specialisation in commodity production but can also promote unsustainable farming practices and environmental degradation. Nationalism-driven self-sufficiency in vegetable oils may not be feasible for all nations and could lead to land conflicts and encroachment on ecosystems. On the other hand, shorter supply chains and decreased transportation provides economic benefits to growers. National production would require supportive policies and infrastructure development.

Climate change is affecting vegetable oil production, with temperature fluctuations, droughts, and extreme weather events impacting crop yields. High temperatures are harming perennial and annual crops, leading to lower oil production. Additionally, climate change alters the composition of fats in crops. We considered two **climate change scenarios**. A scenario with a 2.4°C temperature increase by 2100 will result in more frequent extreme weather events, severely affecting oil crop production in regions like sub-Saharan Africa, Indonesia, Malaysia, and India. These climate impacts could lead to resource disputes, mass migration, and food system collapses. The catastrophic IPCC scenario with a 4.4°C temperature rise by 2100 would have severe negative consequences on global ecosystems and food production.

⟶ *People are increasingly embracing plant-based diets, such as this vegetarian "burger"*, by Microgen, 2019, Adobe Stock.

7.2 What we do not but should know

This report has provided some clarity about the highly complex systems in and different scales at which vegetable oils are produced, traded and consumed, and the positive and negative outcomes of these systems. Nevertheless, some critical knowledge gaps remain that require attention. We note that it is crucial to use research findings to inform and influence effective policy decisions. We also note that on the basis of what we know a lot could be actioned today.

There is not enough understanding of how to effectively control rights violations and other negative social impacts.

For some of the vegetable oils, these impacts have been well-documented over many years, but despite the existence of well-established international norms and standards on good social practice, they continue to be widespread. A better understanding is needed of how to ensure that law and policy processes are evidence-based and not unduly influenced by corporate interests, and that adequate quality control processes are in place, including in certification systems. There is also a need for more comprehensive incorporation of social factors into environmental analyses and vice versa. Research must prioritise rights-based approaches, as rights are non-negotiable. The report has identified the need for approaches that explore broader positive and negative outcomes of vegetable oil systems that better capture co-benefits and multiple values, beyond mere yield and impact averages.

We do not know enough or overlook the local value chains.

Research on vegetable oils has strongly focused on internationally traded ones and overlooked those in local value chains, which are often of considerable nutritional and cultural importance. More study is needed on the cultural, nutritional, and economic importance of these local vegetable oil value chains, and their social and environmental contexts. How can these local value chains be stimulated; what is the role of micro-finance to help its sustainable development?; what is the flow of products within these local value chains, and what is the impact on these local systems once they become international?

There is not enough information on finance mechanisms and measurement systems beyond yields and profits.

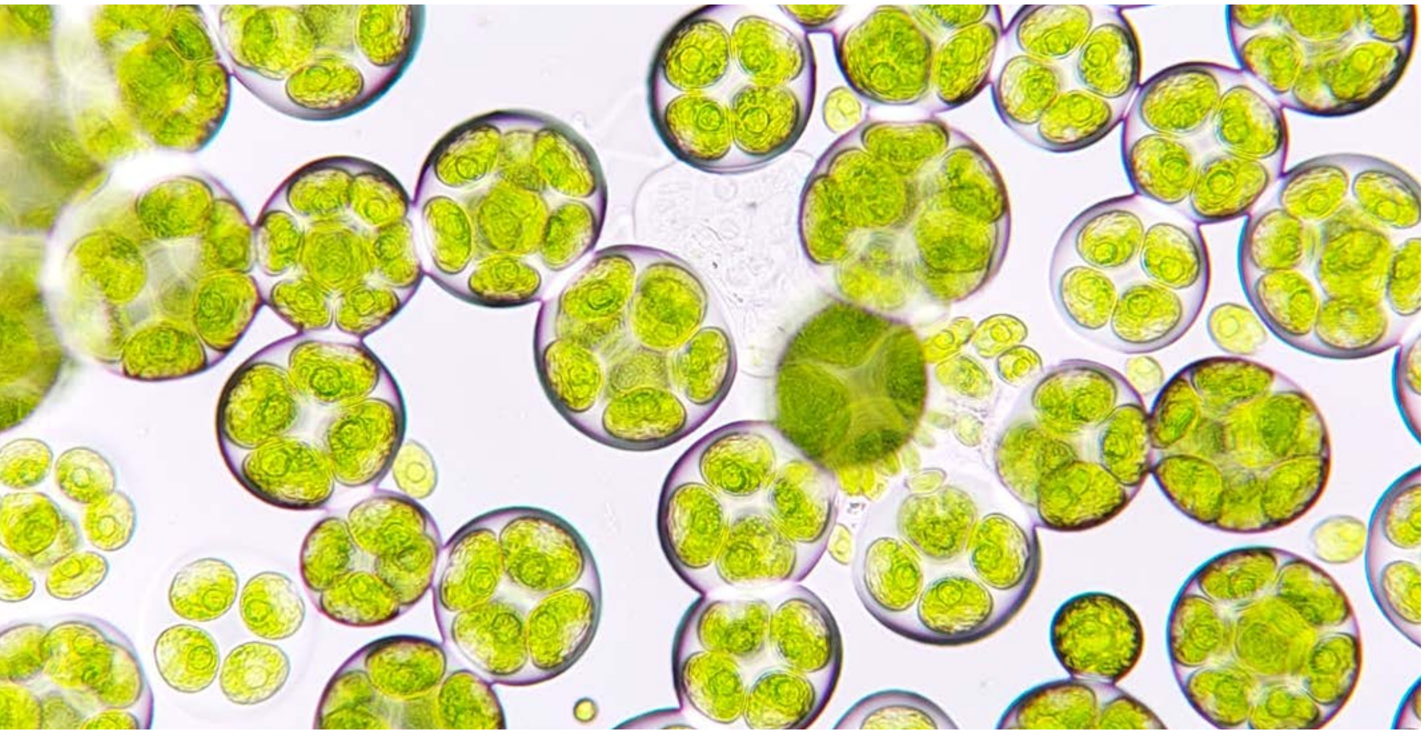
Research should investigate new finance mechanisms that consider the comprehensive values of oil systems, beyond just yield.

We do not precisely know where the major oil crops are grown, when their growing areas were established, and what drives yield variation.

This relates to the fact that it is relatively easy to map perennial crops (such as oil palm, coconut, olive), but a lot more difficult for the annual crops that can be grown in one field one year and in an adjacent one the next. This makes it difficult to determine the impacts these crops have on natural ecosystems, and how these impacts differ with varying scales of operation (such as smallholder vs industrial scale). Satellite imagery is of increasingly high resolution and analytical methods are becoming more powerful, allowing scientists to soon quantify relative impacts of crops on key environmental (and social) indicators.

There are confusing messages and scientific results on the nutritional value of different oils.

Nutritional science faces challenges in establishing causation due to observational evidence, confounding factors, and limitations of traditional epidemiological studies. To overcome these challenges, a paradigm shift is needed, incorporating complexity science and Artificial Intelligence methodologies [372]. These approaches analyse interactions and correlations within complex systems of nutrition, considering multi-scale and multi-level factors. The digital era provides vast data opportunities, but challenges persist, including data quality and integration. More efforts are needed to build networks to study food composition, health, and environmental impacts. A comprehensive analysis of nutrition and health requires better data standardisation, improved exposure assessment, and understanding social influences. Research also needs to overcome challenges of data quality and bias (such as severe underrepresentation of local oil production and consumption systems in international science).



⟶ *Algae may be used as a source of biofuel in the future*, by Ekky Ilham, 2023, Shutterstock.

→ We still do not know how to scale agriculture that is conducive for people and the planet, even when some new approaches are exciting.

There have been many attempts to reconcile agriculture with environmental and social objectives, for example through transitioning to mixed cropping systems, perennial crops, intercropping, and regenerative agriculture. The oil palm agroforestry trials in Brazil and Indonesia (see Chapter 4.1.9) are good examples of improving environmental outcomes while maintaining yield levels. Such efforts need to be rapidly scaled up, requiring investment and other support, allowing alternative approaches to vegetable oil production to displace currently dominant monocultural production systems.

→ There is a lot of media hype about the potential of single-cell oils to replace those from traditional oil crops [562].

What we should know is that progress has been slow, single-cell oils remain expensive, and their production in most cases requires crops as feedstock. Researchers should clarify what the real potential is of such new methods and whether these can indeed benefit people and the planet as is often claimed.

→ Further research is needed on the economic viability for smallholder agriculture and what is needed to strengthen it.

Research on small-scale vegetable oil production highlights several key technical issues and challenges. Conventional processing plants are economically viable only on a large scale, making small-scale processing costly. Cooperatives could benefit small-scale producers, but vested interests may hinder their development. Mechanisms are needed to give smallholders access to better prices, reduce debt, and build capital. Providing smallholders with information on oil palm management, high-yielding varieties, and protection against fraud is crucial. Additionally, research should explore economically viable agroforestry combinations for smallholders who prefer diversification.

→ We still do not know how to assess social impacts from value chains.

Analysing the social and economic impacts, whether in combination or individually, presents methodological challenges that necessitate separate assessments using rights-based methodologies and economic evaluation from a value chain perspective. Effectively organising discussions around both adverse and favourable impacts is an ongoing challenge that requires thoughtful deliberation. It is essential to comprehend the contextual factors contributing to rights violations, including a grasp of value chains and their broader implications for positive and negative consequences. There is also a need to integrate rights-related aspects into monitoring metrics and assessment methodologies. This requires study.

→ **We still have no clue on the 'invisibles', the often-overlooked aspects of the food industry.**

Scientists need to acknowledge and clarify the myths, gaps, and biases in available knowledge on vegetable oil, paying special attention to how scientific opinions have evolved over time. This requires greater transparency and requires addressing the often-overlooked aspects of the food industry. Invisibles are the blind spots in systems that occur because of underrepresented voices and methodologies, which bias some factors and perspectives from others.

> "Nevertheless, there are concerns regarding the sustainability of the global food system, because the growing concentration of commercial power due to globalisation and industrialisation is leading to increased inequality within rural communities."

7.3 Choices and recommendations

Currently, the global food system is built upon limited diversity, with almost half of calorie consumption relying on just four crops – wheat, rice, sugar, and maize [1]. The same is the case in vegetable oils, where despite oil crop diversity, global production and consumption is increasingly dominated by oil palm and soybean. The food we consume is becoming more calorie-dense and less nutrient-rich [563], leading to overconsumption in some parts of the world, while a fat gap remains in others [4]. In areas with such fat gaps, affordable prices of vegetable oils are important for poorer households, while vegetable oil production is a source of income for many.

Nevertheless, there are concerns regarding the sustainability of the global food system, because the growing concentration of commercial power due to globalisation and industrialisation is leading to increased inequality within rural communities. Reducing conversion of natural ecosystems for vegetable oil production, together with carbon sequestration in agriculture, and ecosystem restoration are among the most impactful ways to reduce greenhouse gas emissions [534]. We must reduce the impacts from crop expansion on biodiversity and natural ecosystems and depletion of groundwater. The correct balance between these different objectives is difficult to determine because ultimately many choices are value driven, although respect for and protection of rights is non-negotiable. Addressing these challenges requires a comprehensive understanding of which systems have the potential to simultaneously offer environmental, nutritional, and livelihood benefits.

RECOMMENDATION:

By building on existing local vegetable oil systems, production increases can bring socio-economic benefits and reduce the concentration of power. There are efficiencies that occur in the global trade system. To strengthen local value chains without losing the benefits of international trade, the specific production contexts and nuances of the global system must be carefully considered. There is a need for more evaluation methods that assess the environmental, nutritional, and livelihood and rights-related benefits and impacts of food systems.

As we have emphasised throughout this report, oil crop production has significant negative environmental, social, and economic impacts, especially when pursued on industrial scales and in areas with poor governance and regulatory frameworks. Deforestation, losses of natural ecosystems, agrochemical pollution, biodiversity loss and contributions to climate change are key environmental concerns in vegetable oil production. The most prominent social impacts are those related to land rights, inappropriate and excessive use of chemicals, and economic exploitation. The impacts of some of these vegetable oils have been well-documented over many years and remain widespread despite the well-established international norms and standards on good social practice. These widespread negative impacts are prevalent in vegetable oil production despite the growth of voluntary standards, which can indeed have positive economic, environmental, and social outcomes. However, they have limitations. Voluntary standards often face challenges in governance contexts that restrict their capacity to implement policies effectively or drive wider change, while insufficient independence of these standards further undermines their effectiveness. Complementary measures like biome-wide policies (for example, moratoria), landscape programmes, payments for ecosystem services, and strong local legislation, along with robust enforcement, play pivotal roles. The synergy between mandatory and voluntary governance tools is therefore crucial but not yet fully optimised, and the contexts for their lack of government and corporate partnerships to uphold rights must be made more transparent.

RECOMMENDATION:

Effective hybrid governance strategies that uphold transparency and respect for rights are essential. The report highlights that policies and safeguards can only be upheld when governments and businesses work together on a rights-based approach. Power and vested interest between corporate and governments must not remain an ‘invisible’ part of the food system and must be explored in the context of persistent right violation.

Financial institutions are showing a greater interest in upholding suitable governance mechanisms at company, value chain and jurisdictional levels, through their investment policies. Examples includes the disinvestment by Norwegian funds from non-compliant palm oil companies, which can encourage responsible practices. When financial institutions do that, much can change for the sustainable vegetable oil value chains.

RECOMMENDATION:

Financial institutions should sign up to international standards for sustainable vegetable oil value chains and make use of the guidance and standardised methodology developed by the Accountability Framework Initiative (Box 10). We need greater investment and other forms of financial support to be available for small-scale production, including regenerative agriculture, perennial crops, and other agricultural systems that require time to develop. New forms of financing and markets should be explored for crops and food systems that provide multiple values.

Our review indicates potential trade-offs and synergies of different choices. In some parts of the world, production of local, affordable fats is important, despite global recommendations calling for avoidance of fat and especially saturated fat [384]. The availability of products such as Plumpy’Nut, a peanut-based paste that consists of one-third fat and is used for treatment of severe acute malnutrition, indicates the importance of fats [343]. Fats are an essential part of people’s diet and lives, and a growing human population likely requires a growing amount of oil and fat production. In terms of planetary health, the production of plant-based fats has lower negative impacts than the production of animal fats, and in regions where it is possible, and culturally acceptable, growing crops with high oil yields is recommended as this spares land. While algal, yeast, and other microbial oils have major potential for the production of specifically designed oils that meet human health requirements, they remain relatively expensive to produce [564], and the extent to which these oil types can achieve the required production scales for meeting global demand in the coming decades remains unclear. Furthermore, the environmental impacts of such oils depend on the need for a feedstock, with the nature of feedstocks determining crop land needs for their production [565]. Policy makers, investors, and other stakeholders need to plan for the oil production needs of the coming decade, which will primarily be met through vegetable oil crops.

RECOMMENDATION:

Global efforts are needed to increase the availability of oils and fats in areas with significant fat gaps. Strengthening existing production methods in combination with introducing proven efficient and locally suitable vegetable oil systems can help meet growing demand. More robust evidence is needed on trade-offs and synergies for oils from microbial and insect sources.

Oils are produced, traded and consumed in different systems with varying negative and positive impacts on people and the environment. These impacts relate less to the oil crop type than to how the crop is grown, and the seeds harvested and the oil produced, traded and consumed. Each vegetable oil system has examples of good and bad planning and management practices, and all systems can be improved. Agroecology, conservation agriculture, integrated production systems, and organic farming [463] – all offer more environmentally friendly production methods that can increasingly approach the yields that are generated in more intensively managed systems, but scaling this up has proven challenging.

Oil production increases need to be sought first on existing agricultural or oil crop land where better production methods can increase yields and thus reduce the need for land expansion. Where such expansion is still required, this should not be done until assessments of High Conservation Value and High Carbon Stocks and associated social methods (such as free, prior and informed consent) have been completed. These tools are currently the most appropriate and extensively tested for ensuring that vegetable oil production growth is not associated with environmental or social harm.

RECOMMENDATION:

There is a pressing requirement to enhance our understanding of the effects of various vegetable oil systems. Most studies have concentrated on the impacts of crops alone, rather than considering crops in the context of their management and value chains.

Facilitation of transitions in vegetable oil systems requires collaborative efforts across various levels and stakeholders. It needs tailor-made combinations of mandatory and voluntary measures. Voluntary standards for example have many sustainability benefits but cannot govern uncertified plantations or address broader land use change or social challenges. Complementary measures like biome-wide policies and strong national legislation are crucial. Mutual recognition and synergy between such governance tools is needed. For these measures to be fair and effective, inclusive approaches are important, amplifying the voices of local expertise and vulnerable stakeholders in the decision-making processes.

RECOMMENDATION:

For vegetable oils to be resilient for the future, decision makers need to take into account in their choices limits to expansion and overconsumption, optimum productivity of the oils, landscape-wide or jurisdictional conservation planning, protecting High Conservation Value and High Carbon Stock areas, responsible agricultural practices, and biodiversity enriching management of farms and plantations, respect for rights, including the collective rights of Indigenous peoples, and responsible and respectful social relations with workers, communities and producers.

The European Union Deforestation Regulation (EUDR) require full traceability to production plots and due diligence by traders ensuring no deforestation and legal production. While it enhances traceability, it may disincentivise the use of more comprehensive integrated sustainability standards or trade relations with vulnerable areas.

To avoid negative consequences and optimise the environmental and social impact of such regulations, support measures for (small) producers are key. The overall impact on worldwide vegetable oil production sustainability of European Union laws and regulations remains uncertain; as other European Union laws, such as on biofuels have shown, it is hard to arrange for sustainability with mandatory measures from a distance alone.

RECOMMENDATION:

Decision makers can enable compliance with trade rules, such as the new European Union Deforestation Regulation, while promoting and supporting essential aspects of sustainable land use.

Consumers can play two important roles in improving the vegetable oil value chains. Firstly, by deciding which products they buy, they can influence demand. Secondly, consumers can influence policy making relevant to vegetable oils through their political votes. Consumer perceptions of edible oils like olive oil and palm oil are influenced by various factors, including taste, culture, and environmental concerns. Olive oil generally receives positive perceptions due to its association with healthy Mediterranean cuisine. In contrast, palm oil faces negative perceptions, primarily driven by environmental issues like deforestation and habitat destruction, particularly in Europe. Surveys and social media analysis show that palm oil is often associated with negative sentiments, while olive oil is seen more positively. Efforts like the Roundtable on Sustainable Palm Oil (RSPO) aim to improve palm oil's sustainability and labour standards, but awareness of such initiatives is low among consumers.

Food labels play a crucial role in conveying product information to consumers, and manufacturers often make claims about their products' benefits. Psychological studies suggest that clear and concise messages about product benefits are most effective in changing consumers' perceptions. Health-related claims like 'low in saturated fat' are valued by buyers, while labels indicating the absence of specific oils, such as 'contains no palm oil', can be powerful marketing tools, capitalising on perceptions of clean, healthy, or environmentally-friendly oils. Consumers deserve better information about the positive and negative impacts of their consumption choices, and there is a need for consumers to demand such information and for producers to provide it. One notable nutrition label is Nutri-Score, commonly used in the European Union. This does not yet provide comprehensive information on the social, environmental and health contexts of vegetable oils, and future enhancements may include combining health scores with ecological and social impact assessments.

RECOMMENDATION:

There is a need to nudge consumption patterns through new food labelling. Social and other media play a major role in shaping people's opinions about vegetable oil impacts and better informing of media influencers is needed to change media messaging.

The debate around vegetable oils has been highly politicised and strongly influenced by Western views. Scholars providing views from a non-Western or global South perspective are much needed. Scientists have insufficiently sought more nuanced analysis and debate and conducted research that largely confirmed what the public and financial sponsors wanted to hear. A Google Scholar search on 'oil palm and deforestation' results in hundreds of publication titles relevant to the topic, while a similar search on 'peanut and deforestation' results in zero titles specifically addressing this, even though there are large areas of previously forested land currently used for peanut cultivation [433].

RECOMMENDATION:

More evidence needs to be provided from the perspective of the global South and main oil-producing countries, and different value systems need to be made explicit.

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At the end of the day, oils and fats persist as an inescapable cornerstone of our daily lives, serving countless essential roles,
by Ivan Shemereko, 2022, Unsplash.

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Appendix

Methodology

Production and trade data sources

Information on vegetable oils production, trade and use in this report comes from two major sources: FAOSTAT and UN Comtrade. FAOSTAT [15], produced by the Food and Agriculture Organization of the United Nations, has a publicly available dataset with production volume, area, and national and regional import and export figures. One significant drawback of FAOSTAT data is that it excludes, possibly large volumes, of locally produced and consumed oils that are not included in national-level statistics. Trade data between countries and regions based on (Harmonised System) HS codes is publicly available via UN Comtrade [566]. They can be used as a complementary by retrieving FAOSTAT production and area figures and UN Comtrade trade figures. Both datasets cover all major oils and fat, their crop origins and related products such as oilseeds and meals. Because they are publicly available, it is easy for readers to retrieve data themselves as well as for specific or latest information. We retrieved pre-war data on vegetable oils from World Bank documents [567].

Other data sources that publish data on global production and trade of vegetable oils are USDA [80], Eurostat [568] and Oil World ISTA Mielke GmbH [569]. We did not choose to use these data because they are not publicly available, limited in product and regional scope, or did not allow us to conduct consistent analyses.

Use and application data

The use of vegetable oils can be categorised into four different applications: food, feed, oleochemical and biofuels. The term 'use' should not be confused with consumption of final products by end consumers. At a certain moment in the supply chain, vegetable oils are 'used' as an ingredient to produce different type of products. These products can be exported as ingredients or final products to be consumed elsewhere – and vice versa. We therefore speak of the term 'domestic disappearance' (production + import – export) to explain the use of vegetable oils in a certain country.

Data on the use of vegetable oil between the four major applications is not straightforward. Manufacturing destinations of oils can change throughout the supply chain and different fractions of the same batch of oil can be used for different applications (for example, palm stearin for food and palm olein for biofuel). Information that reports on the use of vegetable oils should also be carefully interpreted on scope (what oils are included?).

Based on existing literature and datasets, we combined figures to provide an estimate of the share of vegetable oils used in different applications that gives a good understanding of ratio and trend. From the 1980s until the early 2000s, the global ratio between food, feed, and oleochemical was approximately 80:6:14 [570]. With the increasing demand for biofuels, the share of non-food applications increased towards 30% in just two decades. Demand for animal feed seems to have remained constant with a reported 8–10 million tonnes of oils and fats (6–7%) used for feed in 2010 [571]. Oleochemical use might have decreased towards 7% as reported [90]. However, information on the global use of these applications was difficult to find and existing data was also difficult to compare because it was not clear what oils were included. Since these two applications represent the smallest shares, it also makes them sensitive to relative ups or downs if reported percentages differ throughout time. Any trends in these applications should be taken with caution. Note however that the absolute volumes for all of these applications have been growing during the past three decades.

Two different sources report 19% and 16% shares of vegetable oil use in biofuels in 2019. While the International Energy Agency [85] expects this share to grow up to 23% towards 2030, the OECD FAO Agricultural Outlook [91] expects a final share for biofuels of 15%. Both datasets however show a steep growth of biofuel in the 2000s and 2010s and a stabilising trend towards 2030.

Based on existing data found we have combined and averaged shares of vegetable oil use per application. These percentages were then used to calculate approximate vegetable oil volumes based on FAOSTAT data on the production of nine major vegetable oils and fats.

Food systems

To generate a workable framework for this study, our starting point was the food systems typologies, developed by Marshall et al. [13] at the national level which led to a range of indicators pointing to five types of food systems: i) rural and traditional; ii) informal and expanding; iii) emerging and diversifying; iv) modernising and formalising; and v) industrial and consolidated (Table 17). Multiple food system types coexist within a country and that disaggregated data may reveal some of this heterogeneity. To capture this heterogeneity in the vegetable oil sector, we overlaid on this broad typology a simplified set of systems at each point in the value chain: from production to value-adding and trading, and consumption systems for five major oils (coconut oil, olive oil, palm oil, rapeseed oil, and sunflower oil).

We classified five main forms of production, from i) harvesting wild fruits and nuts, ii) subsistence farming in very small field of no more than 0.64 ha; iii) small-scale farming, including in mixed intercropping systems usually in plots of no more than 2 ha; iv) to medium- and large-scale commercial farms linked to markets in plots of less than 100 ha, and v) recent phenomena of super-size, input-intensive farms in plots larger than 100 ha. Farm plot sizes were derived from Lesiv et al. [71].

In terms of value-add and trade modalities, oils can be: i) shared, exchanged or sold locally (in 'raw' or unprocessed forms); ii) processed locally and sold in formal and informal (traditional) trade, sold in local shops and markets, such as red palm oil, cotton and shea in West and Central Africa; iii) sold such that some value-adding occurs in producing countries and other value-adding processes take place in consuming countries such as soybean oil from Brazil including the use of shared local processing facilities (such as those owned by co-ops, local small businesses), or more centralised, high-tech systems; or iv) exported, where most value-adding and processing occurs in consuming countries through centralised, high-tech systems.

When describing consumption systems of vegetable oils, we identified four main systems: i) home consumption; ii) local oils bought from and sold in formal and informal markets, small shops, and street vendors; iii) local, regional, national or international oils sold as niche, luxury, or alternatives

Table 17 The five main food system typologies globally

Food system archetypes	Description
Rural and traditional	Farming mainly done by smallholders, with low agricultural yields and limited diversity. Scarce infrastructure results in seasonal variation and large food losses. Most food is sold locally in informal open markets, small shops and street vendors.
Informal and expanding	Rising incomes, formal employment and urbanisation, with demand for processed and packaged foods from locally-sourced and imported ingredients. Coexistence of informal markets (fresh food) and supermarkets (convenience foods) but limited quality standards and no regulation.
Emerging and diversifying	Increasing number of medium- and large-scale commercial farms linked to markets. Modern supply chains for fresh foods, and supermarkets expansion to smaller towns. Processed foods are common in urban and many rural areas, but fresh food continues to be acquired through informal markets.
Modernising and formalising	Higher agricultural productivity and larger farms that rely on mechanisation and input-intensive practices. More sophisticated food infrastructures result in fewer food losses. Food imports enable year-round availability of a diverse basket of foods. Public safety and quality regulation is common.
Industrialised and consolidated	Large-scale, input-intensive farms serve specialised markets. Supermarket density is high and formal food sector captures nearly all of the food intake, including fresh foods, fast food and home delivery. Food policies focus on banning trans fats and the reformulation of processed foods.

Source: Data compiled by the report editors.

to the dominant oils, with intermediaries between farmers and consumers; and iv) oils and fats sold as common supermarket product and food outlets.

Data is scarce on how vegetable oils are produced, processed and consumed locally or regionally. Much more data exists on vegetable oils that are traded internationally. Taken this caveat in consideration and based on our broad understanding of some vegetable oils, we mapped the relationships between these different productions, value-add and consumption types. The vegetable oils we overlaid on this classification include shea butter, olive oil, palm oil, rape seed, sunflower, and soybean oils.

→ Methods for vegetable oil STAR analysis

The Species Threat Abatement Restoration (STAR) metric [163,572] allows quantification of the potential contributions that species threat abatement or restoration activities can make to reducing global extinction risk. It uses The IUCN Red List of Threatened Species™ [573] data to estimate the potential reduction in species extinction risk that could be achieved at a site, across a corporate footprint, or within a country. It can also be used to set local or global species extinction risk targets, and measure progress towards those targets.

Developed as a collaboration between 55 organisations, the STAR methodology [163] draws on the Red List data to estimate the potential for species extinction risk reduction broken out over a global 5x5 km^2 global grid. For each pixel within this grid, STAR estimates the contribution of the threats affecting species present in the grid to the total value for the pixel. Values of pixels can be added up to enable assessment for larger polygons representing corporate, administrative areas, protected areas, or commodity production zones, such as the footprint of particular oil crops.

Because biodiversity is distributed unequally around the world, STAR is standardised and scalable, meaning that every grid cell or combination can be directly compared using the same objective criteria. The STAR value of a pixel or footprint is calculated using data on the distribution, threats, and extinction risk of threatened species present in the area of interest.

> "STAR estimates the contribution of two kinds of action to reduce species extinction risk – threat abatement and habitat restoration."

STAR estimates the contribution of two kinds of action to reduce species extinction risk: i) threat abatement (addressing threats to species in their current habitat); and ii) habitat restoration (restoring habitat where species used to occur). At the projection and resolution used in this analysis, the total global STAR Threat Abatement score is 1,205,282, and the total STAR Restoration score is 676,375, representing the total potential global conservation opportunity through either strategy. The version of the STAR layer used in this analysis includes terrestrial birds, mammals, and amphibians.

Widely deployed across the IUCN Union, including through the IUCN Contributions for Nature Platform [574], the STAR layer is available through the Integrated Biodiversity Assessment Tool (IBAT).

The potential for reducing global species extinction risk through threat abatement and restoration activities in the footprints of the individual oil crops was calculated through a weighted intersection with the STAR threat abatement and STAR restoration layers from Mair et al. [163]. The STAR score for each grid cell was assigned based on the proportion of the pixel that was estimated to be covered by crop production. All analyses were conducted in software [575].

To match the STAR layers and oil crop footprints based on MAPSPAM data [44], the STAR threat abatement and restoration layers were first aggregated up to a 10x10 km resolution with a STAR threat abatement and restoration value assigned to each grid cell. Then the global raster layer for each oil crop was reprojected from WGS84 to Molleweide and intersected with the STAR layer based on the grid cell IDs using a joining function. Each oil crop grid cell had a hectare value estimating the proportion of the 10x10 km cell that was covered with the crop, and this was used as a weighting function to assign a proportion of the potential STAR score for that grid cell to the oil crop. For example, if a hypothetical 10x10 km raster grid cell was 50% covered by maize, that cell would be assigned 50% of its potential STAR threat abatement or restoration value.

For each oil crop these weighted STAR threat abatement and STAR restoration values for each grid cell were summed across the entire crop footprint to determine the total STAR scores for that oil crop. The relative STAR scores for different oil crops were calculated by expressing these as a percentage of the total STAR scores for all oil crops in the analysis.

Yield data

To generate the crop yield variation data, we collected production volume and harvested area data at country level for olive, rapeseed, soybean, oil palm, sunflower, coconut, cotton seed, groundnut, linseed, maize, and sesame seed [15]. The data was organised and cleaned using Microsoft Excel, and yield extraction rates were obtained from literature (Table S1). Real yield values were calculated by multiplying the extraction rates with FAOSTAT's data, converted to tonnes per hectare. Box-and-whisker plots and scatter plots were created for each crop, and the data was analysed for distribution and outliers.

Table S1 Extraction yields of different oil crops, indicating the percentage of oil that can be obtained from each crop

Oil crop	Extraction yield (%)	Reference
Olive	20	576
Rapeseed	38–42	576
Soybean	17.1	577
Oil palm	22–28	576
Sunflower	40	576
Coconut	60–70	576
Cottonseed	0.23	576
Groundnut	47	576
Linseed	36.10	578
Maize	3.4	579
Sesame seed	42.5	580

Source: Data compiled by the report editors.

> "Real yield values were calculated by multiplying the extraction rates with FAOSTAT's data, converted to tonnes per hectare."

Fertiliser

We gathered fertiliser data from the International Fertilizer Association (IFA) and the Food and Agriculture Organization of the United Nations (FAO). Our analysis involved several steps, including calculating fertiliser application rates per hectare, creating charts to visualise nutrient distribution, integrating oil yield data, and visualising variations in fertiliser application based on oil production.

To obtain a comprehensive dataset, we focused on IFA, a trusted agricultural database, specifically targeting information on fertiliser application for major oil crops [581]. The dataset included oil crops classified by IFA, such as soybean, rapeseed, cottonseed, maize, oil palm, and other oil crops (such as coconut, sunflower, linseed, sesame seed, groundnut, and olive). We collected detailed records for each oil crop, including crop areas and the quantity of fertiliser applied in tonnes.

By dividing the total amount of fertiliser used by the corresponding crop areas, we calculated the fertiliser application per hectare. To provide a visual representation of nutrient distribution, informative charts were generated using Microsoft Excel. These charts illustrated the utilisation and distribution of nitrogen (N), phosphorus (P), and potassium (K) nutrients across the different oil crops.

To explore the fertiliser requirements associated with oil crop production, we incorporated oil yield data obtained from FAOSTAT into the analysis [15,582]. This integration allowed us to compare fertiliser application rates per tonne of oil produced among the various oil crops by comparing the fertiliser application rate from IFA with the yield of each oil crop from FAOSTAT. We generated charts to visually illustrate the variations in fertiliser application intensity across the different oil crops.

Crisis ecosystems

We acquired a dataset on crisis ecosystems from The Nature Conservancy [144]. This dataset classifies the ecosystems into three categories: Vulnerable, Endangered, and Critically Endangered, using the recently defined terrestrial World Ecosystems [583] and analysed with a modification of the IUCN's threatened ecosystem criteria. Our analysis was focused on assessing the extent to which each oil crop overlaps with the corresponding ecosystem crisis.

The final crisis ecosystem categories were as follows: Vulnerable – those ecosystems reduced to 70% of original size and less than 30% protection; Endangered – those ecosystems reduced to 50% of original size and less than 17% protection; Critically Endangered – those reduced to 20% of original size and less than 17% protection.

The datasets containing information on oil crops were obtained from two sources namely, Harvard Dataverse [584] and EarthStat [585]. Our analysis specifically focused on examining 11 different oil crops: soybean, rapeseed, cottonseed, maize, oil palm, coconut, sunflower, linseed, sesame, groundnut, and olive. We performed a spatial analysis to determine the area of intersection between oil crops and crisis ecosystems. We then calculated the percentage of the area where each of the oil crops intersected with the critical ecosystems. Furthermore, we determined the respective percentages of oil crop presence within and outside of these ecosystems. Lastly, we produced a map to visually represent the intersection between oil crops and critical ecosystems.

> "Our analysis was focused on assessing the extent to which each oil crop overlaps with the corresponding ecosystem crisis."

Agrochemicals

What kind of pesticide is used, how it is applied and how monitoring protections are enforced are country-dependent. For some countries, there is very detailed data available. However, for other countries, there is insufficient data available and therefore, we need to rely on best practice guidelines. For this study, we aimed to provide data for representative countries growing five oil crops. Data for pesticide use has been geolocated as follows: soy in Brazil, oil palm in Indonesia, rapeseed in Germany, sunflower in Tanzania, and coconut in India and Sri Lanka.

For the application of pesticides in Brazil, a short list of potential active ingredients was compiled from the comprehensive studies of Pollack (2020) [586] and Maciel et al. (2015) [587]. This list was then cross-referenced with the annual bulletins of "Production, Import, Export and Sales of Pesticides in Brazil", published by the Brazilian environmental agency (IBAMA). In Brazil, every year, actors involved in the pesticides industry (such as manufacturing) are required to report to IBAMA, the volumes they produce, import, export and sell. This provides data on the total amount of active ingredients, organised into product classes (such as herbicides, fungicides, insecticides) at both the national and state levels. For ease of calculation and keeping in line with the approach for rapeseed, we selected the active ingredients associated with each product class which contributed the greatest sales volume. We used a cutoff point of 1%, meaning that the sales of an active ingredient was greater than 1% to the total sales of all product classes, thus, forming a list of 10 active ingredients.

For Germany, the types of active ingredients being applied to rapeseed for a particular year could be determined from the Papa (pesticides) [588] database of the Julius Kuhn Institute, the federal research centre for cultivated plants. The results are based on annual survey data extrapolated to national level and provide an overview of the active ingredients for each type of pesticide associated with a particular crop for a particular year. To simplify, those active ingredients were selected per product class (such as herbicides, fungicides, insecticides), which when combined had a total weight greater than 75% of the active ingredients of that product class. In the end, this created a list of approximately 13 active ingredients.

For oil palm production, it was very difficult to determine an accurate inventory for pesticide use throughout the lifespan of the crop, from nursery phase (<1 year) up and including the plantation phase period (~ 24 years). This is because, for example, in most cases of insect or fungi infestations, the application of crop protection products will only be on a need-by-need basis (if there is an infestation) [589]. Therefore, there are no “standard applications”, which are commonly used for annual crops. This is particularly pertinent for insecticides and fungicides. The most standard crop protection product found to be applied in palm oil production systems are herbicides, and often these products are applied on an annual basis for maintenance of the site, as well as weed control [590]. Therefore, the list derived from this study comes from the study of Syafrani et al. (2022) [591], in which they surveyed pesticide application in the Indonesian provenance of Riau. This list was then cross-referenced with other studies and handbooks [589,590,592,593]. A final list of 14 pesticides was determined.

For coconut, a similar approach was taken to that of oil palm, as it was again difficult to find information for the control of pests for coconut production (life span approximately 75 years). The best available data could be found mainly for the countries of India and Sri Lanka. The list of pesticides was put together assuming best practices, which aim to use pesticides according to the principles of integrated pest management (IPM) strategies (for example, as a last resort). The main source for these best practice applications were found in Thomas et al. (2010) [594] for India. This was then further cross-referenced with Rajan et al. (2009) [595] and Liyanage (1999) [596], the latter a guidebook from Sri Lanka, which had similar strategies to India and this is why the information was used. A final list of 15 pesticides was identified. Again, like palm oil, many of these crop protection products will only be applied on a need-by-need basis (for example, if there is an infestation).

For sunflower production in Tanzania, the available literature suggests that the use of pesticides by many smallholder farmers is low (the main producers of sunflower). This is because their access to the market for pesticides is limited, or they are too expensive to use [597]. However, according to a study by Lahr et al. (2016) [598], there has been an increase in pesticide use in Tanzania, for sunflower production in some parts of southern Tanzania, there has been the use of herbicides in sunflower production. Data for agrochemical use in Tanzania is a limitation of this study.

For palm oil, coconut, and sunflower, the data quality is uncertain and this is a limitation of this current study, as it is very difficult to determine the real application of pesticides for these crops. This is a data gap that needs to be closed, if we are to truly manage the use of these chemicals effectively within the socio-ecological systems where they are applied.

We qualitatively assessed the list of pesticides for potential direct human effects and indirect human effects, using an adapted approach of [586], which used the database of the Pesticide Action network [599] and the European Chemicals Agency [600] to classify the pesticides according to the parametres outlined in Table S2.

Table S2 Agrochemicals used in five oil crops and their direct and indirect impacts

Crops[1]					Pesticide details				
Soy	**Oil palm**	**Rapeseed**	**Sunflower**	**Coconut**	**Active ingredient**	**CAS No.**	**Type**	**PAN bad actor/ HHP**	**Drift prone**
x					2,4-D	94-75-7	H	NL	Mod
x	x				Acephate	30560-19-1	I	Yes	Mod
	x				Aminopyralid potassium	566191-87-5	H	NL	NL
				x	Azadirachtin	11141-17-6	I	NL	V High
		x			Azoxystrobin	131860-33-8	F	NL	V low
		x			Boscalid	188425-85-6	F	NL	Low
	x			x	Carbaryl	63-25-2	I	Yes	Mod
x				x	Carbendazim	10605-21-7	F	Yes	V Low
				x	Carbofuran	1563-66-2	I	Yes	Low
	x			x	Carbosulfan	55285-14-8	I	Yes	NL
x					Chlorothalonil	1897-45-6	F	Yes	Mod
				x	Chlorpyrifos	2921-88-2	I	Yes	Mod
x					Copper oxychloride	1332-40-7	F	NL	V low
	x				Cypermethrin	52315-07-8,	I	Yes	V low
	x				Deltamethrin	52918-63-5	I	Yes	Low
		x			Dimethenamid	8764-68-8	H	No	NL
				x	Dimethoate	60-51-5	I	Yes	Mod
x					Diuron	330-54-1	H	Yes	Low
		x			Ethofenprox	80844-07-1	I	Yes	NL
				x	Fenthion	55-38-9	I	Yes	Mod
	x				Glufosinate	51276-47-2,	H	NL	Low
x	x	x	x	x	Glyphosate	1071-83-6	H	Yes	Low
				x	Hexaconazole	79983-71-4	F	NL	NL
x					Imidacloprid	138261-41-3	I	Yes	Low
	x				Lambda-cyhalothrin	91465-08-6	I	Yes	V Low
x	x				Mancozeb	8018-01-7,	F	Yes	V Low
		x			Mepiquat	15302-91-7	F	NL	NL
		x			Metazachlor	67129-08-2	H	NL	NL
	x				Metsulfuron-methyl	74223-64-6,	H	NL	V Low
				x	Monocrotophos	6923-22-4	I	Yes	Mod
x	x				Paraquat (dichloride)	1910-42-5	H	Yes	Low
				x	Phorate	298-02-2	I	Yes	High
		x			Propyzamide	23950-58-5	H	Yes	Low
		x			Prothioconazole	178928-70-6	F	No	V Low

Direct health effects[2]						Indirect[4]
Acute toxicity	Carcinogenic potential	Cholinesterase inhibitor	Reproductive and developmental toxicant	Endocrine disruptors	Other health effects[3]	Ecotoxicity potentials[5]
Mod	Possible	No	Ins Data	Sus	7,10,14,18	d,g
Slight	Possible	yes	Ins data	Sus	7	a,e,g
Ins Data	Not L	No	Ins data	Ins Data		b
Ins Data	Ins Data	No	Ins data	Sus	18	b
No	Not L	No	Ins Data	Ins Data	4	b,g
No	Possible	No	Ins Data	Ins Data		c,f,
Mod	Yes	Yes	Yes	Sus	7,8,12	a,b,g
Slight	Possible	No	Ins Data	Sus	15,16,17,18	b
Yes	Not L	Yes	Ins Data	Sus	1,2	a,b,g
Mod	Ins Data	Yes	Ins Data	Ins Data	1,5,18	a,b
Yes	Yes	No	Ins Data	Ins Data	1,10,12,14,18	b
Mod	Not L	Yes	Yes	Sus	5	a,b,e
Slight	Not L	No	Ins Data	Sus	7,8	b
Ins Data	Possible	No	Ins Data	Sus	4,5,9,11,14,15,16,	a,b,e
Mod	Unclass	No	Ins Data	Ins Data	4,5	a,b
Mod	Possible	No	Ins Data	Ins Data	7,8,18	b
Yes	Possible	Yes	Yes	Sus	7,9	a,e
Slight	Yes	No	Yes	Sus	7,11,12	b,e,f,g
No	Yes	No	Ins Data	Sus	19	a,b
Mod	Not L	Yes	Ins data	Sus	4,7,9,11,17	a,b,g
Slight	Ins Data	No	Ins Data	Sus	7,8,9,11,15,16	c
Slight	Yes	No	Ins Data	Ins Data	10	c,g
No	Possible	No	Ins Data	Ins Data	7,18	c,f
Mod	Not L	No	Ins Data	Ins Data	5	a,b,f,g
Mod	Not L	No	Ins Data	Sus	1,5,9	a,b
No	Yes	No	Yes	Sus	11,12,15,16,18	b,e
Slight	Not L	No	Ins Data	Ins Data	7	d
No	Susp	Ins Data	Ins Data	Ins Data	12,18	b
Slight	Not L	No	Ins data	Ins Data		b,g
Yes	Ins Data	Yes	Sus	Ins Data	1,2,6,17	a,b,e
Yes	Not L	No	Ins Data	Sus	1,5,6,10,11,14,18	b,f,g
Yes	Not L	Yes	Ins Data	Ins Data	2,3	a,b,g
Slight	Yes	No	Ins Data	Sus	12	b,f,g
No	Not L	No	Ins Data	Ins Data		b

Crops[1]					Pesticide details				
Soy	**Oil palm**	**Rapeseed**	**Sunflower**	**Coconut**	**Active ingredient**	**CAS No.**	**Type**	**PAN bad actor/ HHP**	**Drift prone**
		x			Quinmerac	90717-03-6	H	NL	NL
		x			Tau-fluvalinate	102851-06-9	I	Yes	NL
		x			Tebuconazole	107534-96-3	F	NL	Low
		x			Thiacloprid	111988-49-9	I	Yes	V Low
	x				Triadimenol	55219-65-3	F	Yes	V Low
	x				Triclopyr	55335-06-3	H	NL	Low
				x	Tridemorph	81412-43-3	F	Yes	NL

[1] Data for pesticide use has been geolocated as follows: Soy in Brazil, Oil Palm in Indonesia, Rapeseed in Germany, Sunflower in Tanzania, Coconut in India/Sri Lanka.

[2] Direct health effects short explanation can be found in appendix.

[3] Source of data provided in this column: European Chemicals Agency (ECHA).

[4] Indirect Health effects short explanation can be found in appendix.

[5] Source of data provided in this column is combined information from ECHA and PAN.

H=Herbicide; **I**=Insecticide; **F**=Fungicide; **NL**=Not listed (no data provided); **Mod**=Moderate; **Not L**=Not likely; **Ins Data**=Insufficiently studied, or insufficient data; **Sus**=Suspected

Other health effects codes: **1**-fatal if inhaled; **2**-fatal if swallowed; **3**-fatal if in contact with skin; **4**-toxic if inhaled; **5**-toxic if swallowed; **6**-toxic in contact with skin; **7**-harmful if swallowed; **8**-harmful if inhaled; **9**-harmful in contact with skin; **10**-causes serious eye irritation or damage; **11**-causes damage to organs through prolonged or repeated exposure; **12**-suspected of causing cancer; **13**-suspected of causing genetic defects; **14**-may cause respiratory irritation; **15**-may damage fertility; **16**-may damage the unborn child; **17**-may cause genetic defects; **18**-may cause or can cause an allergic skin reaction or irritation; **19**-may cause harm to breast-fed children; **20**-may cause drowsiness or dizziness

Ecotoxicity potentials codes refer to: **a**-Toxic to bees; **b**-Very toxic to aquatic life, with long lasting effects; **c**-Toxic to aquatic life, with long lasting effects; **d**-Harmful to aquatic life with long lasting effects; **e**-Potential to be a persistent pesticide, bioaccumulative and toxic substance in fresh water; **f**-Potential to be a persistent pesticide, bioaccumulative and toxic substance in soil; **g**-Potential to pollute ground water

Definitions for table:

These definitions have mostly been summarised, extracted from the PAN website [601]. For more detailed explanations and descriptions, please refer to the website.

CAS No: This is a unique ID number assigned by the Chemical Abstracts Service (US) to every chemical described in open scientific literature. It ensures that the same chemical will be referred to. across databases describing them and there can be no confusion on which chemical is being discussed.

Drift prone: “this refers to how likely the pesticide dust or droplets will move through the air at their time of application or soon after” [602].

Acute toxicity: this refers to the immediate health effects (0–7 days) after being exposed to a pesticide. Highly acute toxicity can be lethal at very low doses.

Carcinogenic potential:

Cholinesterase inhibitor: “Cholinesterase-inhibiting pesticides disable this enzyme, (potentially) resulting in symptoms of neurotoxicity – tremors, nausea, and weakness at low doses; paralysis and death at higher doses. Exposure has also been linked to impaired neurological development in the fetus and in infants, chronic fatigue syndrome, and Parkinson’s disease”.

Reproductive and developmental toxicant: “Some pesticides are known to cause reproductive

Direct health effects[2]						Indirect[4]
Acute toxicity	Carcinogenic potential	Cholinesterase inhibitor	Reproductive and developmental toxicant	Endocrine disruptors	Other health effects[3]	Ecotoxicity potentials[5]
No	Ins Data	No	Ins Data	Ins Data		d
No	Not L	No	Yes	Ins Data	7,18	b
Mod	Possible	No	Ins Data	Sus	7,15,16	b,f,g
Mod	Yes	No	Ins Data	Ins Data	5,8,12,15,16,20	b
Mod	Possible	No	Ins Data	Sus	7,15,16,19	c,f
Slight	Unclass	No	Ins Data	Ins Data	7,10,11,18	b
Mod	Ins Data	No	Ins Data	Ins Data	7,8,15,16,18	b

and developmental harm, including birth defects, infertility, sterility and impairment of normal growth and development. Many pesticides that disrupt endocrine hormone functions also cause reproductive and developmental harm, as well as other adverse effects".

Endocrine disruptor: "Many pesticides and industrial chemicals are capable of interfering with the proper functioning of estrogen, androgen and thyroid hormones in humans and animals. These "endocrine disruptors" can cause sterility or decreased fertility, impaired development, birth defects of the reproductive tract, and metabolic disorders".

PAN bad actor: This is a derived pesticide, from the Pesticide Action Network. They denote bad actors as those active ingredients which have at least one of the characteristics outlined above: carcinogenic potential, cholinesterase inhibitor, reproductive and developmental toxicant, endocrine disruptor.

HHP: "The PAN International List of Highly Hazardous Pesticides (HHPs) was initially developed by PAN Germany in 2009, in response to a need identified through participation in the FAO/WHO Joint Meeting on Pesticide Management. Listing criteria include acute toxicity, long term health effects, environmental hazards and status under global pesticide-related conventions".

Ecotoxicity potential:

Bee toxicity: "The U.S. EPA Office of Pesticide Programs, after reviewing individual toxicity or ecological effect studies for a pesticide, summarises the toxicity of each chemical to certain species groups. In developing its ecological effect characterisations for bees, the agency uses a three-step scale of toxicity categories to classify pesticides based on bee toxicity data. Based on this analysis, EPA defines a pesticide as highly toxic to bees if the LD50 (exposure level at which half the bees die) is lower than two micrograms per bee (µg/bee). All pesticides classified as 'highly toxic to bees' are listed in the PAN HHP list".

POPs: "Persistent organic pollutants, or "POPs," are chemicals that persist in the environment for years – sometimes decades. POPs travel long distances in the environment, and "bioaccumulate" in most or all living creatures, including humans. They become more concentrated as they move up the food chain, and are linked to a range of serious health effects, including birth defects, infertility and cancer. For the table presented in this report the thresholds used to define 'very persistent' were based on the EU regulations [603], which define persistence of the half -life of the chemical in fresh water as higher than 60 days and the half-life (for example, the amount of time it takes for the concentration of that substance to half) in soil is higher than 180 days.

It must be noted that even though some of the chemicals are currently not listed, for some of the effects, "the absence of a chemical on any of these lists does not necessarily mean it is not a reproductive or developmental toxicant. It may mean that it has not yet been evaluated"

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WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland, Switzerland
mail@iucn.org
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org
www.iucn.org/resources/publications