



Environmental impact of avocado production

The case of Peru and South Africa

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Environmental impact of avocado production – The case of Peru and South Africa

Miljöpåverkan av avokadoproduktion i Peru och Sydafrika

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Summary

Human activities and agricultural practices pose challenges to the environment on planet Earth. Global biodiversity faces threat to extinction because of human activities. Although, the demand for specific products, in this case avocado has increased the past decade which put pressures on the resources but creates possibilities for producers. Avocado production requires resources in terms of land, and production inputs such as water, fertilizers and pesticides.

The aim with this project was to identify and investigate environmental impacts from avocado production in Peru and South Africa. The ambition was to highlight strategies minimizing the negative effects on the environment from avocado production. Drawing on a literature review with articles from three different databases in a thorough step-by-step selection, the material was analyzed with the help of The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services' conceptual framework.

The results showed various impacts on biodiversity, ecosystems, land, soil health, climate, and water availability and quality from avocado production, due to land-use change, irrigation and use of fertilizers and pesticides. Moreover, other findings of this project highlighted potential strategies to mitigate negative impacts which included aspects of education and farmers' associations, and their importance of illustrating possibilities, development within the sector, and risks in the future.

The varied results made it difficult to highlight which driver was the greatest contributor to the negative impacts, and therefore more research is needed to answer that question. Future research should include social aspects of these environmental impacts and investigate on site ecosystems and biodiversity to better understand the direct impacts.

Keywords: Avocado, environment, biodiversity impact, ecosystem services, land-use, water, climate, sustainability, literature review

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Abbreviations

Abbreviation	Description
CF	Conceptual framework
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
GAP	Good agricultural practices
GIS	Geographic information systems
LCA	Life cycle assessment
PRISMA	The Preferred Reporting Items for Systematic Review and Meta-Analysis
SAAGA	South African Avocado Growers Association
SDGs	Sustainable Development Goals
SLR	Systematic Literature Review
SOM	Soil organic matter

1. Introduction

This chapter gives an introduction to the problems and challenges around avocado production. These are described to give the reader a knowledge about the subject in order to understand the connection to the aim, research questions, and delimitations of the project, which are presented in this chapter.

1.1 Problem background

Human activities have a major impact on the environment of planet Earth. Producers and retailers play a significant role, driven by profit gain and competitiveness. Therefore, a change towards more sustainable consumption and production is needed (Sala *et al.*, 2020). Sustainable consumption and production can be framed as value creation, using the ontological understandings of the triple bottom line (Elkington 1997). The triple bottom line rests on three important pillars: environmental, social, and financial dimensions of value creation for creating sustainable development (*ibid.*). The framework emphasizes that true progress cannot be achieved if only one dimension is considered, instead all three must work together in balance. Additionally, the Brundtland Report defined sustainability as meeting the needs of today without compromising the future generation's ability to meet their needs (United Nations World Commission on Environment and Development, 1987). This definition highlights the responsibility of current societies to manage resources wisely and ensure long-term well-being.

Environmental sustainability encompasses the preservation of natural resources, climate, ecosystems, and biodiversity, ensuring they remain healthy and resilient. Rockström *et al.* (2009) introduced the concept of planetary boundaries. The concept aims to explain the risks that human activities pose on the stability and resilience of Earth. They identify seven critical Earth system processes on which this stability and resilience depend. Some examples are “climate change”, “rate of biodiversity loss”, and “land-system change” (Rockström *et al.*, 2009). Continued studies of planetary boundaries (Steffen *et al.*, 2015; Richardson *et al.*, 2023) points to continued overuse of resources. Furthermore, the authors underline the fact that all processes are interconnected meaning a change in one of them will impact the rest of them. This illustrates how environmental processes are mutually supportive, yet at the same time capable of exerting negative impacts on one another. Moreover, updates of the planetary boundaries were released in 2023 and 2025. The update from 2023 indicated that six out of nine planetary boundaries have been exceeded (Richardson *et al.*, 2023) while the most recent update presented in 2025 shows seven out of nine planetary boundaries have been crossed (Sakschewski *et al.*, 2025).

Climate change is caused by human activities and emissions of greenhouse gases emitted by different human activities (Intergovernmental Panel on Climate Change, 2023). Unsustainable practices including unsustainable use of land, energy, land transformation, and consumption are known to negatively impact weather and climate worldwide (*ibid.*). These will also affect the environment such as soil erosion, nutrient depletion, water pollution, and wildlife and biodiversity in these regions (*ibid.*).

Given these global challenges, tackling sustainability challenges requires a systematic change, beyond individuals and single countries (United Nations, 2025). Businesses play important roles in these types of transformations, and may also lead the transition to a sustainable economy (University of Cambridge Institute for Sustainability Leadership, 2017). To contribute to this transition, businesses need to rethink how they run their business, in economic, social and environmental terms (*ibid.*; Bocken *et al.*, 2014; Boiral *et al.*, 2011; Elkington, 2018).

1.1.1 Business models for sustainable development

The development of business model concepts with a sustainability-oriented focus progressed significantly during the 2000s (Stubbs and Cocklin, 2008). Emerging sustainability challenges have compelled companies to integrate sustainable practices into their businesses. The Paris Agreement (United Nations Framework Convention on Climate Change, 2015) emphasized the need for actions that promote sustainable development. This includes aligning financial flows with the target of reducing greenhouse gas emissions and fostering the development of climate-resilient businesses (*ibid.*).

Corporate approaches to environmental responsibility may vary across contexts. Corporations tend to adjust their levels of corporate environmental responsibility in line with financial performance (Kim and Statman, 2012). Additionally, higher profitability increases the likelihood of greater future investment in environmental responsibilities.

Food retailers and other inter-connected stakeholders have power positions in value systems in questions regarding environmental concerns (Macfadyen *et al.*, 2015). They play a vital role in fostering a more resilient food supply system. Enhancing sustainable development in food production, in particular agricultural practices, requires transparency in production procedures and effects. With increased understandings of production methods, the sourcing strategy of a food retailer may support biodiversity dimensions in production, in addition to other sustainability measures (*ibid.*).

1.1.2 Food production and environmental challenges

On a global scale, the population is continuously growing causing pressure on resources on Earth. With increased demand for certain food products and more intense food production systems, comes challenges that have negative environmental impact (Myers et al., 2017; UNEP, 2016). Greater demand on availability of food products creates challenges on existing food producers, leading to extension and intensification of the agricultural systems (Farooq *et al.* 2019). Our current food system damages the environment, jeopardizes biodiversity, depletes natural resources and contributes to climate change (WWF n.d; Benton *et al.*, 2021).

Environmental challenges caused by human activities and food production include climate change, land use, water use, biodiversity loss, soil degradation, and pollution as factors impacting the environment (UNEP, 2016). Greenhouse gases from for example fossil fuel used in cultivation processes, may lead to climate change, which in turn can contribute to a rise in sea temperature, nutrient losses, and ocean acidification (Myers et al., 2017). More intensive productions may cause stress on soils and degrading the soil from its nutrients (Benton *et al.*, 2021). Furthermore, bigger yields might also require fertilizers and pesticides, causing eutrophication which in turn will lead to continuous loss of biodiversity (*ibid.*; Dymond *et al.*, 2025b).

Land and water are critical resources for agricultural activities (UNEP, 2016). Land transformation because of food production may have direct impact on biodiversity, biogeochemistry, and climate (*ibid.*). Soil quality plays a vital role in maintaining soil health and ensuring sustainable agricultural production. Soil ecosystems are essential for preserving soil functions and supporting productive agriculture. Water is, in similarity to land resources, a crucial resource for food production. Water is a critical resource in many geographical areas, where the availability may differ from region to region (*ibid.*). Agricultural activities may negatively influence water quality in terms of pesticides and nutrients released into the water (Wang et al., 2023).

Moreover, one of the environmental challenges highlighted above is biodiversity impacts caused by agricultural activities (UNEP, 2016). Biodiversity is defined by the Convention on Biological Diversity (CBD) (2011, p.4) as “variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. Human actions have drastically impacted the ecosystems on Earth (Millennium Ecosystem Assessment, 2005a). Biodiversity is crucial for human life on Earth and underlies the functioning of ecosystem services, including regulatory, provisioning, supporting, and cultural

services (*ibid.*). Ecosystem services are advantages to people from nature and ecosystems which can be divided into four categories, provisioning services (e.g fresh water), regulating services (e.g climate regulation), cultural services (e.g enable tourism), and supporting services (e.g nutrient cycling) (Millennium Ecosystem Assessment, 2005b). Goods provided by ecosystems do often originate from biodiversity (*ibid.*)

Biodiversity is currently under threat and planet Earth faces a biodiversity crisis (Augustiny *et al.*, 2025). Land-use change is one of the greatest drivers of biodiversity loss (*ibid.*). Land-use and access to land are additional critical issues linked to food production, significantly affecting natural landscapes and habitats (European Environment Agency, 2025). As these environments are degraded, they face a serious threat to a wide range of species, including mammals, insects, birds, and other wildlife as well as vital microbial organisms (Benton *et al.*, 2021). European Environment Agency (EEA) (2025) underscores the current biodiversity loss and highlights the current state as the time with the most species threatened with extinction.

Chaudhary and Brooks (2019) investigated how national consumption and global trade impact biodiversity. Their findings expose the global agriculture to be responsible of a projected extinction of 276 endemic mammal, birds and amphibian species (*ibid.*, p.182). These drivers vary across regions and countries. Pastureland plays a big role on the impact in e.g. Colombia, Mexico, and Brazil, forestry is the biggest threat in e.g. Peru, Venezuela, and Tanzania whereas cropland has the biggest impact in countries of e.g. India, the Philippines, and central Africa. Regarding import and per capita consumption, Spain, South Korea, Russia, Venezuela, Canada, and Belgium are the biggest contributors to biodiversity loss. Although, USA, China, Japan, India, France, Germany, UK, and Italy have the highest impacts from import. Moreover, Chaudhary and Brooks (2019, p.183) highlight 25% of projected species extinction arises from global trade.

Avocado is a high impact commodity and a major driver of biodiversity loss (Science Based Targets Network, n.d.). In other words, some commodities have bigger impacts than others, and these commodities are more likely to negatively impact the environment (International Finance Corporation, 2013). A recent study in Mexico highlights the negative impact of avocado production in terms of deforestation, forest fragmentation, biodiversity loss, soil health degradation, water scarcity, and ecosystem carbon loss (Denvir *et al.*, 2022).

1.1.3 Environmental challenges in avocado value systems

Avocados have been a global commodity since the 1990s and is a commodity with a high demand (Denvir *et al.*, 2022, p. 152; Magrach and Sanz, 2020). The demand for avocado, outside of Mexico, has increased substantially the past 20 years (*ibid.*). Mexico is the biggest producer and produces about 40 percent of all avocados grown in the world (World Avocado Organisation, 2024; Denvir *et al.*, 2022, p. 152). Moreover, Peru is the main supplier for the European market and South Africa is another big producer, mainly supplying the European market (World Avocado Organisation, 2024; South African Government, 2020). Denvir *et al.* (2022) underscore that the increased demand, together with the resulting higher profits for producers and suppliers, has created opportunities for expansion and intensified production.

Agricultural intensification and expansion come with environmental costs (Cho *et al.*, 2021; De La Vega-Rivera and Merino-Pérez, 2021). Mexico faces severe challenges related to deforestation, land-transformation, water and soil pollution (De La Vega-Rivera and Merino-Pérez, 2021). As a result, biodiversity - including both flora and fauna - is under threat, and many species face an increased risk of extinction (*ibid.*). Furthermore, the production is highly water intensive, and the fruits are often grown in geographical areas where the access to water is limited, and therefore dependent on irrigation (Caro *et al.*, 2021, pp.6).

The issues observed in Mexico illustrate the broader environmental challenges associated with avocado cultivation worldwide. As demand continues to rise, production has expanded to other regions supplying international markets, including Europe. The European market is supplied by different countries worldwide (Sommaruga and Eldridge, 2021). However, the Swedish food group Axfood buys avocados from Peru and South Africa among other countries. Given that this project was commissioned by Axfood, the assessment specifically concentrates on the environmental impacts of avocado production in South Africa and Peru, which represent key sourcing regions for the company. In this project, avocado systems refer to processes related to the production, i.e the cultivation practices, the environment and environmental conditions, resource use, and the land in which production takes place.

1.2 Aim and research questions

The aim of the project was to identify environmental impacts of avocado production by determining the hot spots in the production system with negative impacts. The literature review explored scientific articles on two countries with avocado production to assess what specific environmental challenges they face, including

biodiversity, ecosystems services, land-use and soil health, water, and climate. With this information, this study contributes to the identification of strategies that may mitigate risks for environmental damage.

Research questions of particular interest relate to the environmental impact and procurement strategies minimizing environmental impact.

- What are the negative environmental impacts on ecosystems, biodiversity, land-use, water, and climate in avocado production in Peru and South Africa?
- What strategies or policy interventions could effectively reduce the negative impacts from avocado production in Peru and South Africa?

1.3 Delimitations

In this sub-chapter the delimitations of the thesis are presented. Recognizing these delimitations is essential to ensure that the findings of this thesis are interpreted within their intended scope.

1.3.1 Empirical delimitations

The study focused on avocado production in Peru and South Africa. These countries were selected because they are two main suppliers providing avocados to the retailer Axfood, which is the commissioning company for the project. However, these limitations had an impact on the number of available articles in the field. Moreover, restricting the scope to production of the avocados, not including distribution and consumption, may have overlooked important environmental drivers.

1.3.2 Theoretical delimitations

The theoretical base for this literature review relies on The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (**IPBES**) Conceptual Framework (**CF**). This choice of CF resulted in a theoretical perspective more steered towards ecosystems services than environmental impact in general. The sixth element (Good quality of life) of the CF was excluded because it was not covered by the research question nor the literature study. The IPBES model is further presented in chapter 3.2.

1.3.3 Method delimitations

This project was based on a literature review, meaning the findings are dependent on available studies. In addition, three well established academic databases were chosen which may have limited the search results and the selection of articles included in this thesis.

Language is considered another delimitation for this investigation. The inclusion of only English papers excluded articles written in other languages.

2. Method

In this chapter the method used in the study is described and discussed. The chapter provides a detailed examination of the method and other choices related to the project, and the chapter presents research design, search strategy, quality assurance and ethical considerations of the project.

2.1 Research design

This literature review identifies research on the topic of environmental impacts from avocado production and potential strategies to mitigate these risks. The literature review was inspired by the method of a systematic literature review (SLR) approach although it did not follow the approach strictly. To collect data without exposing the risk of bias and to ensure transparency, the predefined protocol SLR approach was used for inspiration (Mengist et al, 2020).

Peru and South Africa were countries exclusively selected for the study. These countries are the main avocado suppliers for Axfood, among other countries. Since this project was commissioned by Axfood, this was an important inclusion criterion in the research design.

2.2 Search Strategy

The protocol The Preferred Reporting Items for Systematic Review and Meta-Analysis (**PRISMA**) is a protocol working as a guideline for conducting systematic reviews and meta-analysis (Moher *et al.*, 2009). This project drew inspiration from the modified SLR protocol by Page *et al.* (2021), which was used as a guiding framework for structuring the literature review. Since this project is not a SLR, it did not strictly adhere to the methodological procedures of a SLR.

The project followed an inductive approach, meaning themes and patterns were identified through an iterative process during the data collection and finalized when all data we found analyzed (Clark *et al.*, 2021). The collected material was systematically examined through a content and thematic analysis, which highlighted the identification and development of themes and patterns relevant to the research aim (Vaismoradi *et al.*, 2013).

The chosen articles for the literature review were found in the scientific databases Web of Science Core Collection, Scopus, and Web of Science CAB Abstract. The search for the academic publications was conducted between 19th of September and 6th of November. The inclusion criteria were: (1) academic articles published

in journals (2) in English, and (3) between 2005-2025. Articles published from 2005 onward were included based on that this marks the year the Millennium Ecosystem Assessment was released, an important milestone in ecosystem research (Millennium Ecosystem Assessment, 2005a). Any article that did not meet all of the inclusion criteria were excluded. The final search string for the data collection was: ((Avocado* OR “persea americana”) AND (Peru OR “South Africa”) AND (biodiversit* OR environment* OR ecologic* OR biologic*)). The outcome of article inclusion and exclusion procedure is presented in the results chapter 5.1 *Search Strategy* and in Appendix 1.

Between 2005 and 2025, 170 articles were identified in the search string in three databases Web of Science Core Collection, Scopus, and Web of Science CAB Abstracts (Figure 1). When reviewing the articles, 40 duplicates were identified and excluded. The next step included title evaluation which led to the exclusion of 76 irrelevant articles. These were removed because their primary focus fell outside the scope of this review, such as titles including words like pathogens, pests, robotic systems etc. Thereafter, 54 abstracts were evaluated and resulted in the exclusion of 27 articles. These exclusion criteria were divided into categories, “out of scope” (e.g pathogens, pests), “not related to environmental impacts”, “wrong method or material”, and “wrong part of the value chain”.

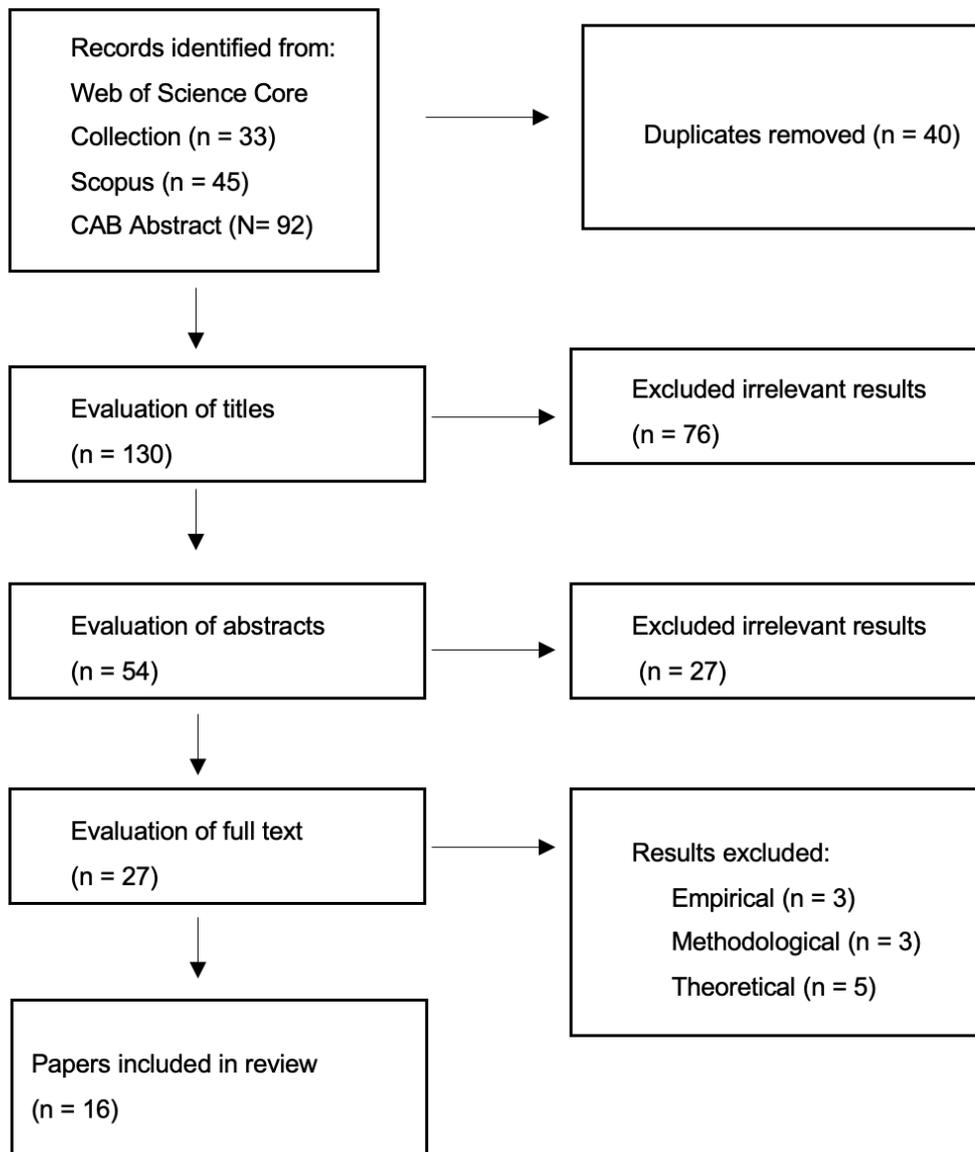


Figure 1. Flowchart of the literature review process with the number of articles excluded in the different stages and the final articles for analysis.

The last step was to read the full text of 27 articles, which led to exclusion of another 11 articles. There were various reasons to exclusion, some examples were Spanish language, not accessible article, review article, and missing focus on environmental impacts. Review articles were excluded to avoid duplication of findings and to ensure that the data used in the project was primary evidence rather than secondary interpretations.

One last evaluation of the articles was made to ensure that all articles were peer-reviewed, all of the included articles were peer-reviewed and therefore included. To answer the research questions the 16 articles were reviewed.

2.3 Quality assurance and ethical aspects

This sub-chapter addresses quality assurance strategies taken into account and ethical considerations for the project.

2.3.1 Quality assurance

The articles included in the literature review are published in peer-reviewed journals. This type of quality assurance strengthens the project since the articles have been evaluated and verified before being published (Mckenzie, 2024). Moreover, the search strategy and the inclusion of only English written articles most likely have lead to the exclusion of relevant articles written in other languages.

Reliability of the project is an important aspect of the quality assurance. Therefore, this project presents the search string and every step of the evaluation of the articles in chapter 2.2 *Search strategy* and 5.1 *Search strategy*. This enables other project managers and researchers to conduct the same process and get the same results (Segal and Coolidge, 2018).

Validity is another key term of quality assurance. The relevance of this concept is to create assurance that the project investigates what it is supposed to investigate (Segal and Coolidge, 2018). This was assured by following the conceptual framework of choice in order to enable the obligatory possibilities to answer the research questions of the project. Moreover, the PRISMA protocol (Paige *et al.*, 2021) was used as a guidance instrument throughout the process, although it was not followed strictly.

2.3.2 Ethical considerations

Ethical considerations in this project include correct article usage and transparency with the ambition to interpret data objectively. Since the data from the articles already is produced, there were no considerations to take into account regarding approvals, participants or observations (Suri, 2020). Although, the project aimed to interpret and use the data objectivley and correctly in order to avoid misinterpretations (*ibid.*). Articles and data used in the project are transparently presented in the literature review.

3. Theory

This chapter presents the theoretical foundation of the thesis. It introduces theoretical perspectives relevant to the research questions and explains the rationale for selecting the conceptual framework that guides the study. The chosen theory is discussed in relation to environmental impacts. By establishing a conceptual orientation of the thesis, the chapter clarifies how the study interprets sustainability challenges and connects the theoretical discussion to the subsequent literature analysis.

3.1 Assessing sustainability

An assessment of sustainable development in avocado production would examine how production systems balance environmental, economic, and social dimensions of sustainability (Elkington, 1997). Such an evaluation considers indicators related to water use, land management, biodiversity conservation, carbon emissions, and local livelihoods (Majumdar & McLaren, 2023; Ramírez *et al.*, 2024). However, this project focuses on the environmental aspects with a particular interest in biodiversity measures.

Life cycle assessment (LCA) studies can be applied to identify environmental impacts (van der Werf *et al.*, 2020; Water Footprint & Sustainability Study, 2024). LCA is an assessment to identify and compare different environmental impact from different products or production methods (van der Werf *et al.*, 2020). The assessment focuses on different impact categories causing environmental impact, for example climate change, acidification, eutrophication, land use, and water use (European Union, 2023). However, some environmental issues of particular concern for agri-food systems, such as land degradation, biodiversity loss, and pesticide effects, are more difficult to highlight by conducting a LCA study (van der Werf *et al.*, 2020).

3.2 A conceptual framework

The analysis in the thesis is based on the conceptual approach (Figure 2) by Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Conceptual Framework (Díaz *et al.*, 2015). The conceptual framework was developed by IPBES, an intergovernmental body comprising more than 130 member states. The primary objective of IPBES is to deliver scientifically robust and policy-relevant assessments of the status of global biodiversity, ecosystems, and the benefits they provide to human societies (IPBES, 2019).

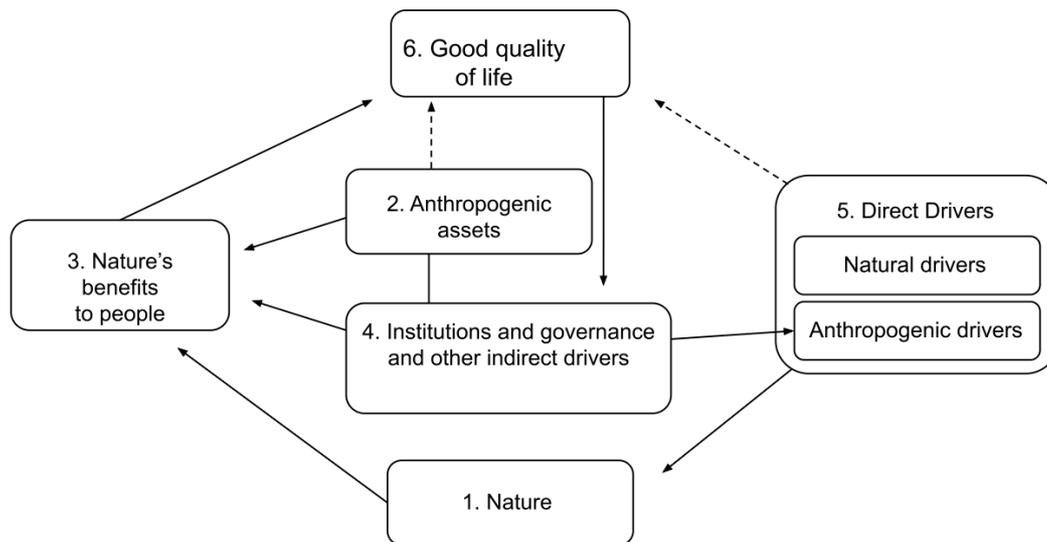


Figure 2. The Conceptual Framework (CF) developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and their interconnections within the framework, with illustrational inspiration from Díaz *et al.* (2015, p.5).

The framework of this thesis is chosen because of the framework's ability to address a broader perspective than only the ecological perspective. The research questions tackle more than only environmental impacts, it aimed to investigate potential strategies to mitigate the impact too. The IPBES CF is an interdisciplinary framework, addressing the question from different lenses. Focusing on nature in terms of direct and indirect impact on ecosystems services and biodiversity, social aspects in terms of governance, and human well-being and governance (see Figure 2). The CF is suitable for analyzing the environmental impacts of avocado production and exploring strategies to reduce these risks in both Peru and South Africa.

Additionally, the IPBES CF is used successfully in many research projects (Vilá and Arzamendia, 2020; Foudi *et al.*, 2023). One study used the framework to investigate interactions between man-made infrastructure, in this case multipurpose dams, and nature (Foudi *et al.*, 2023). The study's findings show that altering rivers for benefits like flood regulation and hydropower creates trade-offs with traditional contributions to livelihoods, unevenly affecting communities and potentially leading to conflicts. Environmental factors, such as water or biodiversity, are intimately connected to other dimensions of sustainable development.

3.2.1 The Conceptual Framework

This framework focuses on biodiversity and ecosystem services in order to strengthen the conservation and sustainable use of these. The conceptual framework by IPBES describes the relationship between people and nature (Díaz *et al.*, 2015). The CF focuses on guiding research, assessing biodiversity and ecosystems, supporting policymaking, and building capacity to address biodiversity challenges. In addition, the CF acts as a map that illustrates interconnections between nature, people, and governance.

Key elements of the CF are nature, human benefits from nature, and good quality of life. The element of nature considers biodiversity and ecosystems, also described as intrinsic values. Nature's benefits to people include ecosystem goods and services, useful for human activities. Good quality of life addresses human wellbeing, highlighting a balance with nature and Mother Earth. Additionally, three further elements play an important role in the relationship between nature and people. These are anthropogenic assets, institutions and governance systems and other indirect drivers of change, and direct drivers of change (Díaz *et al.*, 2015).

To finalize, Díaz *et al.* (2019) highlight the importance of understanding the simplification of the links between society and nature, through a conceptual framework. Although, it is argued that this simplification is justified because of the interdisciplinary and multicultural approach and the need to map out perspectives and information in different fields to spread the words (*ibid.*).

3.2.2 Six elements of the Conceptual Framework

The interconnected six elements of the IPBES conceptual framework are further presented below.

1. Nature

The term pertains to the diversity of living organisms and their interactions within their environment and with their environment (Díaz *et al.*, 2015). Ecosystems, biodiversity, the organization of ecosystems and their dynamics, the evolution, the biosphere and living natural resources. Non-living natural resources, e.g. minerals or fossil reserves, that enhance human activities and eventually support a good quality of life are included in the element nature. Although, their direct impacts are not the primary focus of IPBES CF. Nature is considered to hold intrinsic value in its own right and additionally, according to CF nature does also provide practical and relational benefits to people.

As an analytical instrument in this master thesis, the element of nature helps to understand what parts of the environment are being negatively affected by avocado production.

2. Anthropogenic assets

This highlights human built infrastructure, health facilities, knowledge and education, technology, finance, etc. (Díaz *et al.*, 2015). Human made assets are emphasized to show that a good life depends on the joint production of benefits that arise from both nature and resources, systems, and infrastructure created by people. To include anthropogenic assets in the CF is of interest because the value of many of nature's benefits to people varies depending on the availability of, and preference for, alternative ways of obtaining those benefits. The value of the vegetation and soils of watersheds for filtering drinking water is more valuable when built alternatives are non-existing.

As a tool for the analysis of this master thesis, this element helps to understand what man-made assets that may be beneficial or may not be needed for the production.

3. Nature's benefit to people

Benefits to people from nature includes all benefits that humanity obtains from ecosystem goods and services (Díaz *et al.*, 2015). These include for example biodiversity, and nutrient cycling. Moreover, most of these benefits are related to the element's nature, and anthropogenic assets. The classification of what is beneficial or not, depends on the perspective of various societies, groups, and even individuals.

In terms of addressing the research questions of this thesis, this element helps to analyze ecosystem services impacted negatively by avocado production in Peru and South Africa.

4. Institutions and governance systems and other indirect drivers of change

These systems are central in the CF because of the impacts on the relationship between nature and people (Díaz *et al.*, 2015). This element in itself describes the structures of how people and societies arrange themselves and their interactions with nature. Their impacts are regarded as indirect, as these systems primarily aim to influence human actions, which in turn may affect nature and ecosystems. Moreover, these may be beneficial for nature, although they can be both positive and negative.

This element enhances the possibility to analyze what potential strategies and policy interventions are useful for decreasing the negative impact on the environment.

5. Direct drivers

This element considers non-human activities among with anthropogenic drivers that affect nature directly (Díaz *et al.*, 2015). Natural climate, weather patterns, and extreme events are included together with the impact of human activities with direct impacts on nature. Some examples of direct anthropogenic drivers are degradation, intensification or abandonment, climate change, and pollution of soil.

As a tool for the analysis, this element helps to pinpoint specific stages or parts of the avocado production causing direct impact on the environment.

6. Good quality of life

Access to food, water, shelter, health along others are multiple factors that could be considered crucial in a “Good quality of life” (Díaz *et al.*, 2015). The CF of IPBES goes beyond just economics and includes sustainable use of nature and ethical values. Human well-being, living in harmony with nature, and living in balance and harmony with Mother Earth are the three perspectives in the CF. These perspectives underline relational and holistic understandings of well-being that highlight the interdependence between humans and ecosystems. Furthermore, it underscores the importance of linking biodiversity conservation with human well-being.

This element is excluded because it is not covered by the research questions.

4. Empirical background

This chapter positions the thesis within the context of existing research in the field related to human activities and environmental impacts. To provide background for the subject under investigation, this chapter presents an introduction to biodiversity and environmental impacts, and avocado production in Peru and South Africa. Biodiversity is particularly explored, as the topic tends to be overlooked in sustainability research and the commissioning company's strong interest in the topic. To give more insight on subjects related to the research questions of this project, the last two sections present research on other global examples of avocado production and cultivation processes.

4.1 Biodiversity – connections to ecosystem services, environment and sustainability

The concept of biodiversity emerged from biological diversity that was explored by several scientists in ecology and biology in the 1980s (Ali, 2023). Biodiversity constitutes the basis for a sustainable food system (World Health Organization, 2025). Biodiversity has an impact on the nutritional value and the availability of food because of its important functions. Furthermore, farming, crop resistance towards pests and diseases, and in general agricultural productivity and resilience is dependent on biodiversity. Ecosystem services are supported by biodiversity, and without biodiversity, services like soil fertility, natural pest control, pollination, and water regulation will not function (*ibid.*). Unsustainable practices may result in biodiversity degradation from activities like overuse of irrigation, pesticides, and fertilizers (*ibid.*).

Biodiversity is essential for ecosystem services which provide resources and benefits, such as pollination, nutrient cycling, and climate regulation, that humans depend on (Niesenbaum, 2019). Additionally, ecosystem services and biodiversity is closely linked to sustainable development, including economic, social, and environmental dimensions of sustainability (CBD, 2018).

According to Cabernard et al. (2024), agricultural production is responsible for more than 90% of global biodiversity loss associated with land-use. Furthermore, their analysis highlights that the dominant drivers of these impacts are highly heterogeneous across different nations and commodities.

Another study assesses biodiversity loss as a result of global agriculture, pasture, and forest land-use from two different perspectives, consumption and production

(Chaudhary *et al.*, 2016). The assessment was made through calculating species loss and combining high-resolution land-use data with countryside species area relationship for mammals, birds, amphibians, and reptiles (Chaudhary *et al.*, 2016).

Ran *et al.* (2024) highlight the biodiversity aspect as underrepresented in terms of investigating the environmental impact in food consumption and diets. Therefore biodiversity is considered an important factor in this project.

Moreover, a study conducted by Crenna *et al.* (2019) investigated and assessed biodiversity impacts as a result of food consumption in the European Union. The authors assessed different commodities and their production impact on biodiversity. The comparison aimed to find out what caused the most negative impact on biodiversity loss by looking at drivers' impact and the potential effect on biodiversity. The results showed meat and dairy products to have the biggest impact on the environment across all impact categories (*ibid.*). Beef and pork are considered the greatest contributors to species loss from transformation of natural land and cultivation of feed-plants (Crenna *et al.*, 2019). However, the authors mentioned that the use of LCA for biodiversity impact tool should be used with caution.

There are different agricultural strategies used in practice that might have different impacts on biodiversity conservation. One study investigated land sharing and land sparing and their potential on biodiversity conservation (Augustiny *et al.*, 2025). The definitions of the concepts may differ in the literature (*ibid.*). Land sparing could be defined in a way of letting land be untouched, and therefore separating biodiversity protection from agricultural activities (*ibid.*). Land sharing could be defined as intergrating biodiversity preservation together with agricultural land (*ibid.*). The authors compared land sparing strategies to land sharing strategies and assessed the impacts on biodiversity. The results pinpoint the lack of information on the actual effects on biodiversity in empirical evidence. Furthermore, the study could not find significant results to conclude if any of them is better than the other. Although, they did find that a combination of both strategies may enhance biodiversity conservation in some scenarios. Moreover, their conclusions emphasize the importance of a synergistic approach, taking it all into consideration, to integrate environmentally sustainable agriculture, to enhance ecosystem services, and care for the conservation of natural habitats. This type of approach minimizes the trade-offs between agricultural production and biodiversity (Augustiny *et al.*, 2025).

Moreover, soil health and soil fertility can be seen as an important tool in order to make soil to function as an important ecosystem (Lekberg *et al.*, 2024). Strategies

including regenerative practices may increase soil health. Regenerative agricultural practices may include crop rotation, cover cropping, livestock integration, use of manure or compost instead of chemically produced fertilizers and decrease the usage of synthetic pesticides (Lekberg *et al.*, 2024). Conversion to regenerative may enhance healthier soils, including soil organic matter (**SOM**), aggregate stability and microbial biomass (*ibid.*). SOM is used as an indicator of soil health, and improvement of SOM can strengthen aggregate stability and improve the soil's ability to hold water and nutrients, as well as raise soil fertility and microbial biomass (*ibid.*). Incorporating management for regenerative practices in avocado production may enhance increases in SOM over the years, which in turn may have a positive impact on microbial biomass (*ibid.*). Additionally, bacterial and fungal diversity may not change in some cases (*ibid.*).

4.2 Agriculture in Peru

Peru is a major producer of agricultural commodities, a position facilitated by its diverse and vital agricultural landscape (Raihan and Tuspekova, 2022). The agricultural sector contributes approximately 13% to the national GDP and remains important to the labor market, accounting for 30% of the country's workforce (*ibid.*, p. 2). Peru produces various commodities, and one of the biggest producing countries in the production of avocado, blueberry, artichoke, and asparagus in the world (Raihan and Tuspekova, 2022). Additionally, Peru is considered a big producer in the production of potato, pineapple, grapes, sugarcane, rice, bananas, maize, and cassava (*ibid.*). The topography in Peru is complex and contributes to climate variations (International Institute for Sustainable Development, 2013). Historically, the climate phenomenon El Niño and El Niña have been two great impact factors affecting the climate variability (*ibid.*). El Niño is the typical driver of droughts in the southern and central highlands as well as, to some extent, the Amazon (International Institute for Sustainable Development, 2013). Moreover, floods occur in the rainy season and during El Niño, it may reach the northern areas as well.

Changes in climate are observed and affect rainfall trends, which are more varied (International Institute for Sustainable Development, 2013). Some areas have experienced increases in annual average precipitation (*ibid.*). In contrast, annual precipitation in the northern Amazon has decreased (*ibid.*). In similarity to the global sustainability issues, Peru faces agricultural challenges regarding biodiversity loss and ecosystem depletion (*ibid.*). The agricultural sector is important for economic growth in the country but negatively affects environmental degradation (Raihan and Tuspekova, 2022). Additionally, agricultural expansion is one of the drivers of deforestation in the country (International Institute for Sustainable Development, 2013). Deforestation for agricultural expansion is

common in many countries even though forests are home to many species (Jayathilake *et al.*, 2020). Moreover, the study by Jayathilake *et al.* (2020) studied drivers for deforestations in Africa, Asia and America (i.e. Peru and Bolivia) and found agricultural expansions to be the greatest driver alongside reasons of settlement expansion, infrastructure development, and forest fires. Rice, rubber, and cassava were the commodity drivers for deforestation, and more specifically rice was the greatest driver in South Americana (*ibid.*).

The Andean region and the Low rainforest region are two regions found to contribute less to deforestation because of topographical reasons in the primary mentioned region and transport networks in the latter (Móstiga *et al.*, 2024). Deforestation in the High Rainforest region has been found to be caused by agroindustrial and agricultural livelihood systems, and the production of rice, cocoa, coffee, and palm oil (*ibid.*). Alongside deforestation, the country faces issues related to unsustainable use of natural resources such as land and water (International Institute for Sustainable Development, 2013).

4.3 Avocado production in Peru

Avocados are mostly grown along the desert coast in Peru, in regions of Lima and La Libertad (USDA, 2021). Avocado production in Peru is concentrated around three areas in the country, the hyper-arid coast, Andean shrubland, and the Amazon basin (Elorrieta-Mendoza *et al.*, 2025). These areas differ in terms of how the cultivation processes of avocado occur, where the hyper-arid coast tend to produce in avocados in mono-culture agricultural land (*ibid.*). In the Andean shrubland areas, the avocado trees are mostly grown together with other fruit trees and often dependent on surface water for irrigation (*ibid.*). Lastly, avocado orchards tend to be integrated in agroforestry systems and rely on rainfall for irrigation in the Amazon basin (*ibid.*).

The increased global demand for avocados made the avocado production in Peru triple, compared to the previous decade to a total of 550,000 tons in 2020 (USDA, 2021, p. 5). The two most common avocado varieties are Hass and Fuerte (*ibid.*). During a period of five years, from 2018 to 2022 Peru managed to increase their production because of beneficial weather and successful investments for production expansion (FAO, 2023).

4.4 Agriculture in South Africa

South Africa is a country with diverse landscapes and climate. There are mainly two regions where rainfall naturally occurs and these are important for e.g. wheat and maize production (Strauss *et al.*, 2021). Continuous climate change will most

likely affect natural rainfall patterns in different regions and eventually negatively impact water availability and have a significant impact on agriculture (Davis *et al.*, 2017).

South Africa faces severe and various challenges related to agriculture. Climate change puts pressure on water access, agriculture, ecosystem services, and biodiversity (Davis *et al.*, 2017). Droughts, because of climate change and climate variability, are dispersed phenomenon in South Africa affecting agriculture (Calzadilla *et al.*, 2014). Moreover, South Africa is a country who differs from other countries when it comes to precipitation. South Africa's annual rainfall is lower than the average global precipitation (Orimoloye *et al.*, 2022). The varied climate in the country and uneven precipitation contribute to substantial water losses through evaporation, which in some areas may even exceed actual rainfall (*ibid.*). These factors intensify water scarcity and make the country at risk to drought conditions and water stress (*ibid.*). Rising temperatures combined with water stress exacerbate agricultural losses (*ibid.*).

A study from 2000 looking into soil degradation found that the region of KwaZulu-Natal, the Northern Province, and the Eastern Cape suffer from great soil degradation (Hoffman and Todd, 2000). More recent research indicates that farmers in South Africa, including industrial to small-scale and household farmers, continue to face challenges related to soil fertility (Rusere *et al.*, 2020). Farmers report using strategies such as animal manure, crop residues, and compost to mitigate soil degradation (*ibid.*). However, socio-economic and technical factors hinder the widespread adoption of these practices (*ibid.*).

4.5 Avocado production in South Africa

South African avocado orchards and plantations are mainly concentrated in the province of Limpopo and Mpumalanga (South African Government, 2020). These are regions with subtropical climate, beneficial for avocado production. Additionally, some orchards are growing in the provinces of KwaZulu-Natal and Cape. The most grown avocado varieties are Hass and Fuerte, followed by Ryan and Pinkerton. The climatic variabilities between regions of avocado production enable an extended growing period. Avocados are produced between February and November, with the main growing period from February to September (South African Government, 2020).

4.6 Avocado production and environmental impacts – global examples

Agricultural activities may have a direct impact on land-use change (Baca-Patiño *et al.*, 2024). Focusing on avocado orchards and land-use change in Michoacán, Mexico, these types of land transformations for agriculture disrupts the natural balances of nutrients, which have an impact on how soil microorganisms access carbon and phosphorus in soils (*ibid.*).

A land-use change analysis in Chile found expansion of avocado orchards to be the main cause of very critical local landscape transformation and also the greatest change in land use and land cover (Duran-Llacer *et al.*, 2025). In addition, native vegetation was identified as diminished in size whereas avocado plantations had increased in size (*ibid.*).

On the same note, pollinators in avocado orchards were investigated in the critical biodiversity hotspot Aconcagua River basin in Central Chile (Lavín *et al.*, 2024). Areas high in native vegetation tend to have more bees present in the area (*ibid.*). Avocado trees in the basin area were surrounded by mainly degraded vegetation, which may describe the reason for the low occurrence of pollinators (*ibid.*). The authors highlight the importance of restoring natural habitats to support pollinator populations and enable food production in agroecosystems (Lavín *et al.*, 2024).

In terms of sharing land, agroforestry strategies may be applied. From a smallholder's perspective in the southern highlands of Ethiopia, avocado production integrated in agroforest systems may increase the efficiency of production (Biazin *et al.*, 2016). Their findings present an increase in yield in kg per tree and per year tree when using a coffee-based agroforestry or enset-based (a type of banana plant) agroforestry compared with the yield from individual trees around homes. However, group discussions in the study concluded that the agroforestry strategy decreases the productivity of the other crop (*ibid.*).

In contrast to agroforestry, avocado monoculture may cause threat to species in the environment (Sáenz-Ceja and Pérez-Salicrup, 2025). Increasing areas for avocado monoculture may negatively impact closeby areas, such as Monarch Butterfly Biosphere Reserve in central Mexico (*ibid.*). The direct impacts may not be very harmful although the indirect impacts from pesticides and unsustainable practices may cause threat to the butterflies and biodiversity in the area (*ibid.*). Intense use of pesticides and unsustainable practices from conventional avocado production can negatively impact pollinators and other varieties of crops in the nearby areas (*ibid.*). Research has shown that proximity to natural habitats enhances pollinator diversity and ecosystem services in avocado orchards, underlining the ecological value of landscape conservation (Dymond *et al.*, 2025a).

One study in Peru investigated avocado production and habitat loss (Elorrieta-Mendoza *et al.*, 2025). The results showed regional differences and the lowest impacts were observed in the Coastal desert area for both of the varieties Hass and Fuerte. Although, the region with the highest negative impacts on biodiversity was identified in the Yunga ecoregion. The reason was mentioned to be “its indirect proportional relationship with the yield” (*ibid.*, p.18). Moreover, the Yunga ecoregion is a high species-habitat and a part of the lowland Amazon in Peru which increases the negative impact compared to other regions (*ibid.*). Regarding the organic *versus* conventional production systems, they did not present the differences on biodiversity impact (*ibid.*).

In similar terms, studies from Tanzania and Mexico highlighted that while avocado production can improve rural livelihoods, it may also pose risks to biodiversity and water resources if not properly managed (Boniphace, Kadigi, & Kangile, 2023; Ramírez *et al.*, 2024). Integrating quantitative data on resource use in avocado production with qualitative insights from producers provides a comprehensive understanding of context bound sustainability performance and supports transitions towards more resilient and equitable avocado value chains aligned with long-term development goals (Boniphace *et al.*, 2023; Dymond *et al.*, 2025a).

Another study conducted in Colombia, investigated the avocado value chain (Pérez and Gómez, 2022). The study looked into challenges and policies applied in the coffee sector in the 1900s and identified similar challenges in the avocado sector. The sector of coffee overcame difficulties like negative environmental impacts, and inadequate welfare system for workers. In order to defeat these challenges in the avocado sector, Pérez and Gómez (2022) highlighted integration and collaboration between large avocado businesses, and small and medium size growers in order to for example minimize export costs. Regarding environmental challenges, the study emphasize the importance of using resources more efficiently and to protect biodiversity (*ibid.*). Implementing a mixed production system is highlighted by the authors to broaden their income to successfully deal with market risks. Additionally, focus on improvement of services which collect toxic waste, and managing inputs in the production to minimize the outcomes on water quality are impacts needed to decrease the environmental impacts (*ibid.*).

4.7 Avocado production – common cultivation practice and the hazard to ecosystems and biodiversity

According to research conducted on avocado productions in the Michoacán region in Mexico, pesticide use consisted of 55 percent insecticides, 33 percent fungicides,

and 11 percent herbicides (Merlo-Reyes *et al.*, 2024). The study presented some pesticides used in Mexico which are banned internationally (*ibid.*). Glyphosate, imidacloprid, and benomyl were the most frequently reported pesticides. Glyphosate may cause adverse effects on soil macrofauna and pollinators, imidacloprid and glyphosate are highly toxic to bees and other insects, and benomyl pose a high risk to aquatic ecosystems. Moreover, paraquat, 2,4-D, and copper sulphates were also frequently mentioned. Copper sulphate is considered a pesticide in the US and Europe with a very high risk of toxicity of aquatic life and paraquat and 2,4-D are extremely toxic to humans and animals (*ibid.*). Moreover, a study from Turkiye investigated pesticide usage among avocado farmers (Sarica and Aydemir, 2024). Copper were reported by 96% to be used as a fungicide through drip irrigation (*ibid.*). Pesticide usage for treating aphids were reported by 10.7 % and for slugs 6.7 %, both by using a backpack sprayer (*ibid.* p. 851). Interestingly, 48 % of the growers used pesticides even though they had not observed any diseases and pests (*ibid.* p. 852).

Application of pesticides depend on various factors, including country varieties, the age of the tree, what pests are found in the field, and economic status (Merlo-Reyes *et al.*, 2024). Application intervals of fertilizers and insecticides every two weeks are common for plants that recently were planted (*ibid.*). Over time, when the trees have become more mature many make changes in application towards monthly application intervals or applications every second or third month (*ibid.*). To ensure high yields, application of fertilizers with all necessary nutrients, i.e phosphorus and micronutrients, is essential throughout the year (Silber *et al.*, 2018). Moreover, extra attention is needed to quantify water and nutrient requirements throughout the flowering and early fruit-development stages (*ibid.*).

Common pests in avocado production are called ‘red spider mite’ and ‘avocado thrip’ pests. The frequency rate of application may depend on economic budget and if they face challenges with a pest at that moment. The amount of applied dose depends on what pesticide is used and on which crop it is applied (Merlo-Reyes *et al.*, 2024). Regarding fertilizers, timing and amount are two important factors for application (Silber *et al.*, 2018). The usage strategies such as analyzing methods of leaves and inflorescence might help to find a precise fertilizing schedule and design (*ibid.*). However, when the researchers conducted an environmental risk assessment in Mexico the results showed the measured concentrations to seem safe for aquatic life, although the accumulation of these chemicals in organisms could still threaten the broader ecosystem, including land species such as pollinators (Merlo-Reyes *et al.*, 2024).

Another study conducted in Peru looked into water consumption for irrigation in avocado production systems and found that they tend to vary depending on season and availability (Elorrieta-Mendoza *et al.*, 2025). Moreover, the water demand may

vary depending on the variety of avocado, location (Coastal vs Andean areas) and also cultivation strategy, i.e conventional and organic (*ibid.*). Beyá-Marshall et al. (2022) researched optimal irrigation strategies for avocado production and identified that avocado producing trees tolerated mild stress through reduced irrigation by 29 % without decreasing the yield amount and yield quality.

In Colombia, Forero *et al.* (2025) found different important prioritations done by farmers within the avocado sector, depending on area of production and farm size. In their study they looked at the producer's capacity to adopt Good agricultural practices (**GAP**), systems to enhance traceability, and effective resource management. Export orientation, certifications, and institutional support were the focus in four regions whilst smallholders focused on fragmentation, and resource-efficient production in three other regions (*ibid.*, p. 11). Moreover, certifications for export might increase the prediction of using chemical fertilizers while usage of biostimulants increased the possibilities of adapting organic fertilizers (Forero *et al.*, 2025). Certifications like Export, GAP, or Global G.A.P showed positive outcomes for soil and nutrient management practices. However, geographical factors such as isolation, and socioeconomic variables were impacting the choice to adopt sustainable technology (*ibid.*).

4.8 Certifications within the avocado sector

One study conducted in Uganda found almost 90% of avocado farmers express that they did not achieve advice regarding food safety standards, GAP, or regulatory threshold values defining the highest acceptable concentrations of pesticide residues in food (Sseruwagi *et al.*, 2025, p.9). In this case, farm and field size was reported as positively affecting the advisory services, whereas age of farmer, age of orchard, location, and membership of a farmer organization did not enable advisory services (*ibid.*). Moreover, the study highlighted 12 % of the farmers to have a certification, such as Global G.A.P, Organic, or Rainforest Alliance (*ibid.*, p.11). Important to notice was the results that pinpointed that the holding of a certification was not significantly associated with field size, farmer age, or being a member in a farmer organization.

The avocado production and value chain in Colombia could benefit from strong social and environmental certification systems (Pérez and Gómez, 2022). Although certification efforts are predominantly administered by private actors, public policy interventions that enable small and medium growers to comply with global quality and sustainability standards remain fundamental for strengthening the country's export capacity (*ibid.*). Even with the government's limited capacity, producer guilds, associations, and cooperatives can play an important role by guiding and supporting growers as they navigate certification requirements (*ibid.*).

Regarding the initial stages of avocado production, Bugudole *et al.* (2025) investigated attitudes and knowledge on seedling processes and certified seeds in Tanzania. The advantages of certified seedling processes, are the possibilities of high-quality plantations, genetically similar, high yields, resilience towards some biotic and abiotic stresses, longer shelf-life, and the overall avocado tree productivity (*ibid.*, p. 2). The Tanzanian organization Tanzania Official Seed Certification Institute and the included standards were not identified as well-known by the farmers. The barriers for achieving the standards were hindered by small-scale nurseries. Additionally, access, economy and knowledge were highlighted limitations to choosing certified seeds (*ibid.*). Moreover, the authors pinpoint farmer groups as possible solutions for accessing funding and to strengthen the support for communities in high-quality seedling production (*ibid.*).

5. Results

This chapter presents the results of the literature review. The first part includes an overview of articles and their relations to the research questions, authors included in the review and which research question are being addressed. Thereafter, the main part presents the literature review outcomes divided into categories, biodiversity, ecosystems, land-use and soil health, climate, water and lastly one category highlighting potential mitigating strategies to minimize the negative impacts.

5.1 Overview

The literature search process led to 16 included articles (Table 1). The full search strategy on the three different databases can be seen in Appendix 1.

Table 1. Results of authors addressing content related to the research questions.

Research questions	Relevant articles (authors)
What are the negative environmental impacts on ecosystems, biodiversity, land-use, water, and climate in avocado production in Peru and South Africa?	Bartl <i>et al.</i> (2012) Blaauw <i>et al.</i> (2024) Van Eeden and Korsten (2013) Esteve-Llorens <i>et al.</i> (2021) Kekana <i>et al.</i> (2023) Murovhi and Materechera (2015) Mzezewa (2025) Munjonji <i>et al.</i> (2024) Wienk <i>et al.</i> (2022)
What strategies or policy interventions could effectively reduce the negative impacts from avocado production in Peru and South Africa?	Broekman <i>et al.</i> (2020) Caro <i>et al.</i> (2020) Esteve-Llorens <i>et al.</i> (2021) Jarisch <i>et al.</i> (2022) Khudzadzo <i>et al.</i> (2021) Phillimon Mohale <i>et al.</i> (2021) Sanchez-Matos <i>et al.</i> (2023) Feliciano <i>et al.</i> (2025)

Table 1 presents the included articles in relation to what research question they address.

The findings in the articles are presented below divided into categories based on their type of impact (chapter 5.2-5.6) and identified actions to mitigate the negative impact from avocado production (chapter 5.7).

5.2 Biodiversity

Out of all included articles, only two articles addressed aspects related to biodiversity. In terms of avocado production's impacts on biodiversity, one LCA study explored agricultural production of eight fresh commodities (including avocado) in the lower part of the valley Chancay-Huaral, at the Peruvian coast (Bartl *et al.*, 2012). When comparing the different impact categories, the study found total terrestrial acidification¹, driven by fertilizer use, to be the greatest contributor to species loss out of four impact categories over a year. These other three impact categories were “total freshwater eutrophication²”, “eutrophication due to regional agricultural activities”, and “acidification due to regional agricultural activities” (*ibid.*, p.9876). Bartl *et al.* (2012) emphasize the limitations of the study, since the results are based on a simplified method for the LCA study.

Kekana *et al.* (2023) studied the Groot Letaba River in South Africa in order to investigate the health of the river as a result of being exposed to nearby agricultural activities. The geographical area was dominated by commercial farming and avocado was mentioned as one of the commodities produced in the area (*ibid.*). The results highlighted continuous anthropogenic activities, like agriculture, to increase nutrient concentration in rivers and therefore lead to serious impact on biodiversity in aquatic ecosystems (Kekana *et al.*, 2023).

5.3 Ecosystems

One study made in South Africa found fertilizer use to be the main contributor leading to aquatic acidification³, aquatic eutrophication⁴, aquatic eco-toxicity⁵, and increased carbon footprint⁶ (Esteve-Llorens *et al.* 2021). Moreover, the findings presented by Kekana *et al.* (2023) did also highlight the negative impacts on ecosystems from agricultural activities on aquatic ecosystems.

Esteve-Llorens *et al.* (2021) highlighted the results of pesticide emissions to freshwater bodies, these are stated as very low compared to other conventional

¹ Terrestrial acidification is when the soil becomes more acidic than the natural state. The decline in soil pH and leaching of base ions may have negative, harmful impacts on ecosystem and lead to biodiversity loss (Lebrun *et al.*, 2025).

² Freshwater eutrophication is caused by pollution of water bodies from nutrient fertilizers which cause stress to aquatic organisms and their existence (Akinawo, 2023; Bali and Gueddari, 2019).

³ Aquatic acidification may be the result of increased amount of emissions into air that eventually deposit into water and make the pH-levels in the water low (European Union, 2023).

⁴ Aquatic eutrophication is caused by nitrogen and phosphorus released in aquatic environment and may cause algae and other plants in the environments to grow faster and consume oxygen which leaves the other life under water under oxygen stress (European Union, 2023).

⁵ Aquatic eco-toxicity is the potential toxic impacts on ecosystems in the aquatic environment which may harm species and how the ecosystem function (European Union, 2023).

⁶ Carbon footprint is the amount of carbon dioxide emissions that is caused by an activity or by a product (Liu *et al.*, 2018).

agricultural systems. The low eco-toxicity impact was referred to the hyper-arid conditions along the Peruvian coast, which made the pesticides to remain on the soil surface (Esteve-Llorens *et al.* 2021).

5.4 Land-use and soil health

Regarding land-use capacity and land-use change in South Africa, Mzezewa (2025) found arable land and avocado orchards less favorable than grassland for the the soils' water-holding capacity affecting water uptake and the need for irrigation. Air capacity was shown to be the best in grassland compared to the other land types. Air capacity means air-filled porosity and indicates soil aeration (*ibid.*) The result highlighted converting grasslands to arable land and avocado orchards increases the risks of soil degradation (Mzezewa, 2025).

Khudzadzo *et al.* (2021) used a model to explore optimal areas for production for various crops in one province in South Africa. The crop suitability of the different crops was based on several parameters, available water for irrigation purposes, agroecology, and climatic predictive parameters. The optimal setting for avocado production was set to a humid environment with high precipitation, temperatures at 20-25 degrees Celsius, soil composition of 20-40% clay, and lastly a pH value of 5.0-7.0.

The results showed the usage of an integrated Geographic Information System (GIS)-based crop suitability model to potentially increase the area possible for crop production (Khudzadzo *et al.* 2021). These results were found when precipitation and underground water resources were used as water systems, and compared to a regular GIS-based with only precipitation as water systems. It highlighted the most suitable areas for avocado production in the province, which were Vhembe and Mopane in terms of precipitation, Blouberg, Mookgopong, and Thabazimbi in terms of ground water accessibility but regarding area for production, Waterberg and Mopani showed the greatest potential for expansion of avocado production areas. The latter took irrigation, agroecology, and climatic predictive parameters into account.

On the same note, Broekman *et al.* (2020) explored crop suitability in different geoenvironmental conditions. The findings presented by the authors show the annual rainfall in the Limpopo Province to be inadequate to meet the water needed to grow avocado. Furthermore, it identifies the climatic conditions in the area as unfavorable for avocado production because of the extreme heat waves that exploit the province. Heat stress creates challenges for avocado production which makes it undesirable. In contrast, the authors highlight the Levubu-Tshakhuma district as more fitting because of its microclimate that makes it receive more rainfall, suitable

for avocado production. However, Broekman *et al.* (2020) pinpoint three municipalities with potential for avocado production in terms of annual rainfall; Thulamela, Ma-khado and Greater Tzaneen Municipality.

Soil health and soil biodiversity were also explored by Phillimon Mohale *et al.* (2021). They investigated soil health, through applying rest products from eucalyptus wood on the soil under avocado trees in two different production sites in South Africa. This was done in order to improve soil fertility. The results showed significant differences regarding compost application rates and total bacteria, total fungi, beta glucosidase, phosphate, and enzyme urease on both sites. The total amount of bacteria and fungi was found to have increased significantly. In terms of significantly increased total bacteria and fungi, the amount of compost applied was the same for both sites.

5.5 Climate

Carbon footprint concerns mainly the activities in production of fertilizers and the use of these (Esteve-Llorens *et al.* 2021). Around 20 percent of the total greenhouse gas emissions from fertilizers are related to activities on the field, mainly nitrogen but also carbon dioxide from urea (*ibid.*, p.9). Additionally, energy use for electricity and diesel production are great contributors as well (Esteve-Llorens *et al.* 2021).

In terms of land-use and carbon emissions, Munjonji *et al.* (2024) investigated carbon dioxide emissions in a comparative analysis, comparing natural systems with citrus and avocado orchards in South Africa over the seasons. Munjoini *et al.* (2014) found that an avocado orchard had lower carbon stocks compared to forest land. A weak relationship was observed between the amount of carbon dioxide emitted and soil moisture. Avocado orchards only emitted less carbon dioxide to the air during summertime because of the increased soil moisture of the natural forest. For the rest of the year, irrigated orchard systems emitted more carbon dioxide into the air. Moreover, they presented increased soil temperature to have resulted in increased soil carbon dioxide emission rates (Munjonji *et al.* 2024).

On the same note, but from another point of view Blaauw *et al.* (2024) conducted a LCA study on avocados grown in South Africa. The results showed electricity use (331 kg CO₂e per tonne of avocados) on farms as the greatest carbon footprint contributor during the farming phase and the total life cycle of farm to fork. Electricity use was followed by fuel use on farms (224 kg CO₂e per tonne of avocados) as the second greatest contributor, and lastly with significant lower impact, fertilizer and pesticide (33 kg CO₂e per tonne of avocados). Moreover, a sensitivity analysis was formed in order to investigate identified hotspots and

optimization opportunities for all the stages in the farm to fork LCA. During the farming phase, a conversion to renewable energy sources offered substantial emission reductions and possibilities to reduce carbon footprint emissions per ton avocado by 96% (*ibid.*, p. 997).

5.6 Water

Water scarcity and virtual water trade of avocado is explored by Caro *et al.* (2020). Avocado production is water demanding and the food products are often produced in countries or areas who suffer from water scarcity (*ibid.*). This makes the water flows move from countries like Mexico, Peru, and Chile to countries who do not have to deal with water related issues (*ibid.*). Caro *et al.* (2020) highlight the problems around water trade in commodities like avocado, causing even bigger water stress in these countries. Eventually that may result in challenging environmental conditions in countries that largely depend on avocado production as an important source of economic growth (*ibid.*).

Regarding water footprint in avocado production, Esteve-Llorens *et al.* (2021) found direct water consumption linked to 98% crop irrigation and the rest needed for indirect water consumption, such as fertilizer production, and generation of electricity. Moreover, water scarcity as a result of avocado and grape production in Peru was researched by Sanchez-Matos *et al.* (2023) through a comparison of old regionalized water scarcity characterization factors and an updated version produced by the authors in order to investigate water scarcity. The characterization factors represent watershed-specific measures of water scarcity using the AWARE method, quantifying the remaining water available in the environment after human use. The results showed all included watersheds experienced high levels of water scarcity, especially during June-October. Moreover, groundwater sheds showed severe pressure all year but only one groundwater shed experienced low water scarcity (Sanchez-Matos *et al.*, 2023). On another note, Kekana *et al.*'s (2023) study on the Groot Letaba River in South Africa found agricultural activities to have a negative impact on water quality.

The climate and environment provide farmers with certain benefits necessary for farming activities, although current climate changes challenge avocado farmers' ability to produce crops and commodities (Feliciano *et al.*, 2025). Feliciano *et al.* (2025) found the size of farms to be crucial for climate change adaptation, where large-scale farmers tended to better cope with these. The reasons for large-scale farmers coping better were mentioned as they had greater capacity, for example in terms of droughts they often had a reservoir or a dam to use for irrigation possibilities (*ibid.*). Moreover, their findings highlighted the location of land to have an impact, most often small-scale farmers used land that was situated in

marginal areas where water access is insecure. Additionally, Feliciano *et al.* (2025) emphasized the agricultural expansion in drier areas as a potential threat and challenge regarding the impact on water availability.

5.7 Strategies or interventions for change

Wienk *et al.* (2022) investigated genetic diversity in South African avocado cultivars. They looked into genetic variations and individuals by using single nucleotide polymorphism markers. The study used an avocado breeding population from Tzaneen, Limpopo in South Africa. The population consisted of 375 fruiting cultivar individuals with 108 individuals totally genetically unique. 326 individuals remained after exclusions were made because of different reasons, such as duplicates etc.

The results show that the South African avocado cultivar mainly consists of a mix of the Guatemalan and Mexican varieties, caused by hybridization over time (Wienk *et al.* 2022). However, there were also several individuals with unknown horticultural varieties. Moreover, the researchers discuss different genetic varieties and their positive outcomes. Wienk *et al.* (2022) state genetic diversity to be important for species to adapt to different environmental conditions and stressors, such as pests and pathogens which could therefore be an important strategy for farmers to better cope with extreme weather events.

The study by Feliciano *et al.* (2025) identified important actors in relation to avocado production in South Africa. The study presented water advice by growers associations, such as the South African Avocado Growers Association (SAAGA) to be important in order to provide advice on water usage and to inform about the likelihood of water scarcity events (Feliciano *et al.*, 2025).

On another note, van Eeden and Korsten (2013) investigated adoption of biocontrol. The results from the interviews at 15 companies within the pesticide field found various indicators as the main issues for establishing biological control products as an option in the agricultural market (van Eeden and Korsten, 2013). Unstable environmental conditions may negatively impact the success of biological control products, farmers perceived success of using chemical disease control products, and lastly the experience of success when applying chemical disease control programs compared to the lower success rate when using biocontrol (*ibid.*).

van Eeden and Korsten (2013) results also showed the difficulties around obstacles to register a biocontrol product. The process was described as time consuming and frustrating. The average registration process of a product was described to take around two years. Furthermore, historically this has caused unregistered products

to be sold on the market which may have caused damage to the industry in the long run (*ibid.*). Moreover, van Eeden and Korsten (2013) highlighted the importance of education in terms of increasing the acceptance of biological control within the farming industry. Additionally, education was stated in the study to be important to raise awareness on technical knowledge.

The results in the study found a positive association regarding farmers who had a food safety certification and the willingness to consider biological control usage (van Eeden and Korsten, 2013). Moreover, the results showed agricultural land owners were less positive to utilize biological control products than farm managers or representatives of a community (*ibid.*). Age of the farmers showed as an impact influencing the decision making and the acceptance of biopesticides. An age over 40 reduced the willingness of farmers to explore biological control. Economic barriers to utilize biological control were noticed and mentioned by two percent of the farmers, even though they found the biocontrol to be effective (van Eeden & Korsten 2013).

Murovhi and Materechera (2015) investigated leaf litter from avocados, mangos, and litchi for small-hold farmers in order to improve soil fertility. The findings related to avocado showed that the litter released more nutrients into the soil and decomposed more quickly than the litter from litchi. Their results concluded the possibilities for soil fertility management in small-scale farmers to use leaf litter in combination with other high-nutrient fertilizers, or if applied well in advance before using the soil for planting.

Jarisch *et al.* (2022) examined how discounting⁷ of ecosystem services, meaning valuation of future ecosystem services, influences how land is optimally allocated in systems combining forestry and avocado cultivation. They integrated economic profit, carbon sequestration, and fertilizer use to evaluate how different discounting assumptions shape land-use outcomes. The authors presented four scenarios to illustrate how varying discounting assumptions influence the optimal distribution of land-use. Their results demonstrated that different approaches to valuing future ecosystem services significantly influence trade-offs between economic returns and ecological benefits. Specifically, when future ecological benefits are valued lower by discounting, the model favors short-term economic gains. Conversely, discounting only monetary values while leaving ecosystem services undiscounted can create an overly optimistic picture of sustainability (Jarisch *et al.* 2022).

⁷ Discounting could be defined as “the way in which we relate the future and the current costs and benefits in cost-benefit analyses for public policy and project evaluation.” (Zhu *et al.*, 2019, p.1). In relation to ecosystems services, this means the cost-benefit analysis has to include future scarcity of ecosystem services (*ibid.*).

6. Discussion

The literature review analysis is further developed in a discussion chapter. The results from chapter 5 are discussed with the research questions as a structure, focusing on environmental impacts from avocado production and strategies to reduce negative environmental impacts.

6.1 Environmental impacts from avocado production

The LCA study conducted by Bartl *et al.* (2012) investigated impact categories such as climate change, terrestrial acidification, and freshwater eutrophication from avocado production in Peru. In terms of connecting the interpretation of the data to the IPBES CF, as mentioned above, these could be considered direct anthropogenic drivers. Díaz *et al.* (2015) highlighted the direct anthropogenic drivers to be the outcome of human decisions and operations. Although, when interpreting the results of Bart *et al.*'s (2012) study, it is important to consider their result of how nitrogen fertilizers affect eutrophication and acidification. These findings highlight the importance of implementing policy instruments of measures in order to minimize the negative environmental risks.

In similarity, Esteve-Llorens *et al.* (2021) found fertilizer use to lead to aquatic acidification, aquatic eutrophication, aquatic eco-toxicity and carbon footprint in their LCA study. These findings do partially align with the study results from Avadí (2023), which found irrigation and negative direct in-field emissions from manure to have the biggest environmental impact in the growing phase. Although that study focused on cocoa production in Ecuador which made it difficult to compare with the results presented by Esteve-Llorens *et al.* (2021) and Bartl *et al.* (2012), it can give an indication on the negative impacts from fertilizers and irrigation.

Moreover, when interpreting data from LCA studies on biodiversity impacts it is important to consider uncertainties with these kinds of studies, which Crenna *et al.* (2019) highlighted. The authors emphasized the significance of understanding that the biodiversity impacts are very dependent on the specific investigated area which means that it may be difficult to assess the actual impacts without having the exact data on ecosystems at the site (*ibid.*).

As presented by Mzezewa (2025) and Munjonji *et al.* (2024) land-use and land transformation may have different and diverse impacts. Mzezewa (2025) findings related to land-use change in South Africa pinpointed the soils' capacity to hold water in order to manage the need for irrigation. The results highlighted arable land and avocado orchards less favorable than grassland (*ibid.*). Baca-Patiño *et al.*

(2024) pointed out the risks of these kinds of transformations and marked the results of disruption of natural nutrient balances in the soil as one challenge. On the same note, Mzezewa (2025) presented increased risks of soil degradation from converting grassland to arable land and avocado orchards. One study from Chile by Duran-Llacer *et al.* (2025) identified avocado orchards to be the main contributor to the loss of critical local landscape transformation. This indicated the risks of avocado production and land-use change. Land-use change may have negative impacts on biodiversity as well (Cabernard *et al.*, 2024).

Land-use change may have other negative impacts than soil health and biodiversity threat, as presented by Munjonji *et al.* (2024). Natural forest converted to avocado orchards may lead to more production and export, but also more carbon emissions released into the air. Munjonji *et al.* (2024) observations of avocado orchards' ability to stock carbon are lower than natural forest land. This cause more carbon dioxide to be released in the air (*ibid.*), which is contributing to climate change (Intergovernmental Panel on Climate Change, 2023). Additionally, increased temperature, resulting from climate change, may result in higher amount of carbon losses from the soil into the air (Munjonji *et al.*, 2024).

Additionally, Boniphace *et al.* (2023) and Ramírez *et al.* (2024) explain the possibilities for more rural livelihoods as a result of avocado production but they do, in similarity to the statement above, underscore the risks of threatening biodiversity and water resources.

Stated by Jarisch *et al.* (2022) are the trade-offs in terms of how land should be allocated for long-term sustainability. Ecosystem services and economic returns should both be considered to avoid short-term economic gains and in realistic ideas of sustainability. In similarity, this was discussed by Augustiny *et al.* (2025). Trade-offs between agricultural production and biodiversity could be solved by adopting a combination of both land sparing and land sharing strategies, and therefore enhance biodiversity conservation (*ibid.*).

Moreover, water scarcity is another potential outcome of avocado production (Denvir *et al.* 2022). On this note, Caro *et al.* (2020) emphasized the risks of the ongoing global trade of avocados. When already water scarce areas deal with water demanding activities such as avocado production, and avocados end up outside of the production country it moves the water from these countries (*ibid.*). This creates further pressure on the water availability in these areas (*ibid.*). Regarding avocado production, the water consumption is high for particularly crop irrigation but also the production of necessary resources such as fertilizers and generation of electricity may contribute (Esteve-Llorens *et al.* 2021). However, these challenges

are also in various sizes for different farmers. Feliciano *et al.* (2025) pinpoint that location of land, just like Khudzado *et al.* (2021), may have an impact in this case. Their findings emphasize size of farms to be crucial in terms of water access (Feliciano *et al.* 2025). Small-scale farmers tend to be facing heavier challenges than large-scale farmers in terms of water access because of economic and land limitations (*ibid.*). Interestingly, Beyá-Marshall *et al.* (2022) found that avocado trees tolerate a mild stress as a result of decreased irrigation which interestingly may contribute to less water needed in production.

6.2 Strategies or policy interventions to reduce the negative impacts

The results of potential strategies or policy interventions that aim to decrease the negative impact on biodiversity, ecosystems, land-use and soil health, climate, and water could be linked to the fourth element of the IPBES CF, Institutions and governance systems and other indirect drivers (Díaz *et al.*, 2015). The CF portrays the fourth element in a way that describe the connection between people, society, and actions that impacts nature (*ibid.*). Change is argued by the authors to play an important role in the way it impacts nature through human activities and people, which are in line with the potential solutions presented in this project related to the third research question.

The development of a resilient food supply system and the promotion of sustainable agricultural practices are in the hands of the food industry actors and affiliated stakeholders (Macfadyen *et al.*, 2015). On this subject, Feliciano *et al.* (2025) highlighted important actors in South Africa that have an influence and the ability to have an impact on the system. These types of organizations serve as production guides giving advice on water availability in terms of extreme weather events (*ibid.*). In contrast, Sseruwagi *et al.* (2025) found that being a member in a farmer organization did not give access to advisory services. Education is another important tool that may enhance development in the agricultural sector to more sustainable practices, such as using biological pest control (Eeden and Korsten, 2013). Jarisch *et al.* (2022) highlight the possibilities for policy makers to adapt to modern land management strategies and a valuable instrument for this could be multi-objective optimization. This emphasizes the importance of political power and the potential for increased negative impacts on biodiversity, climate, and water (*ibid.*).

In terms of soil health, Phillimon Mohale *et al.* (2021) and Murovhi and Materechera (2015) investigated the use of litter from both eucalyptus wood and leaf litter from different fruit trees and its potential on improving soil fertility. Phillimon Mohale *et al.* (2021) results indicated increased amount of bacteria and

fungi from application of eucalyptus wood on the soil underneath the avocado trees. These findings do not align with Lekberg *et al.* (2024) investigations on soil health from regenerative practices, more specifically cover cropping, compost additions, organic amendments, and rotational grazing. Lekberg *et al.* (2024) findings did not show improved amounts of bacteria and fungi, although it is important to separate these since Phillimon Mohale *et al.* (2021) used eucalyptus wood and Lekberg *et al.* (2024) used different practices related to regenerative agriculture.

On the same note, Murovhi and Materechera (2015) highlighted the possibilities of using leaf litter together with high-nutrient fertilizers. However, the authors pinpointed the importance of having knowledge of the nutrient in the soil because some biochemicals aggravated the release of nutrients in the soil from the litter (*ibid.*). In terms of nutrient availability, Lekberg *et al.* (2024) found the increase in SOM to likely enable nutrient holding capacity although the nutrient availability was less consistent across the researched crops.

The harm on biodiversity and pollinators may have great impact from pesticides (Merlo-Reyes *et al.* 2024). However, the results highlighted by van Eeden and Korsten (2013) presented the acceptance to use biological pest control instead of conventional pest control. Some factors, such as age on farmers, owning land vs managing the land, and representatives of communities are impacting the willingness (*ibid.*). On the same note, economic barriers acted as obstacles to adopting biological control for some of the farmers, no matter their general acceptance around biocontrol (*ibid.*). Interestingly, economic status also has an impact on the general approach of the possibilities to use pesticides and frequency of application too (Merlo-Reyes *et al.* 2024).

To successfully produce avocados and decrease the potential negative impacts on the environment, the location of the orchards may have positive and negative outcomes. Khudzadzo *et al.* (2021) highlighted the complexity around the avocado production in South Africa that depends on many different factors in the production area. Their findings show how different needs in the production, such as irrigation and land potential, may be more suitable in some areas and less suitable in other areas (*ibid.*). Connecting these findings to the IPBES CF, this would then mean that the nature's benefit to people seem greater in the areas more suitable for production.

Avocado production is extremely water intensive and often grown in areas with limited access to water (Caro *et al.* 2021). Growing avocados in these areas requires irrigation which can increase risks of water scarcity in groundwater and basins (De La Vega-Rivera and Merino-Pérez, 2021). Therefore it might be optimal to take advantage of areas that are more suitable for avocado production. In terms of

precipitation, two districts in the Limpopo Province were identified as the most suitable – Vhembe and Mopane (Khudzadzo *et al.* 2021). On the same note, did Broekman *et al.* (2020) investigate crop suitability based on geoenvironmental conditions. They found the Limpopo Province to be insufficient regarding annual precipitation which aligns partially with the results, although Broekman *et al.* (2020) does not focus only on Limpopo Province. Moreover, Broekman *et al.* (2020) underline the province of Limpopo's climatic conditions to be challenging for avocado production. On the other hand, the author underscore one district, and three municipalities as more favorable for avocado production: the Levubu-Tshakhuma district, and the municipalities of Thulamela, Ma-khado, and Greater Tzaneen (*ibid.*).

6.3 Method discussion

One limitation of this literature review is the low number of included articles in the results section. Lack of empirical data impacts the results and a higher number of included articles may have given other insights, other results, and more homogeneous findings. Although, the project had a narrow focus on two countries which may be one reason for the inclusion of only 16 articles. On the same note, articles addressing biodiversity impacts were very few. The initial idea of the project was to investigate only biodiversity impacts but since the number of articles dealing with biodiversity impacts from avocado production were so low, the plan was changed and this project looked at the environmental impacts from a larger perspective.

Methodological limitations of this project include data collection from the included articles which were included based on a subjective interpretation. Given that this project only had one author, it meant there was no second author which may have impacted the process. Two authors or more enable the quality assurance process of having more than a single person reviewing what articles should be included and excluded based on the inclusion and exclusion criteria. Another reviewer may have had another interpretation of the articles and therefore made the inclusion of articles differently. Since this was not possible in this project it can be viewed as a limitation.

The methodological choices were also impacting the voices and perspectives of the data in the review. In this case South Africa and Peru were at focus, meaning these were the only perspectives in the results section. If another country were included, the results might have been different and may have addressed other challenges or solutions. Additionally, the same idea works on language exclusion and inclusion in the project. Other languages, for example the main languages in the two countries of choice, could have added other dimensions and data to the results. Moreover,

review articles were excluded to minimize the risks of duplication of results, although this might have impacted the results negatively since this may have led to exclusion of relevant material.

On the same note, the results of the project conducted by the author are limited by the interpretation of the empirical data. This includes several aspects, in terms of chosen key words used in the search process and the framework used in the analysis. The selection criteria applied to identify articles of relevance and the analyzing process aligning with the chosen conceptual framework have impacted the interpretation and analysis of the empirical data presented. If another framework was used, the empirical data may have been interpreted in other ways and resulted in another outcome compared to the results of this project. The conceptual framework of choice for this project was presented by Díaz *et al.* (2015). Moreover, the authors highlight the importance of understanding the simplification of the links between society and the nature, through a conceptual framework (*ibid.*). Although, it is argued that this simplification is justified because of the interdisciplinary and multicultural approach and the need to map out perspectives and information in different fields to spread the words (*ibid.*).

Another limitation of the project was the dates for collecting the articles to use for the literature review. Articles published after these dates was not included. One study was found after the collection and analyzing processes, because of its publication date of late November. Therefore it was not included in the review although it was included in the empirical data to provide insights to the company of commission. The limitation might be considered a weakness of the project. Similarly, the exclusion of grey literature may have led to the omission of important aspects relevant to the research questions and overall aim.

Future research in the field could potentially help to answer the same research questions by taking another perspective into consideration. Including ecoregions and potential species losses into the analysis, such as the method presented by Chaudhary *et al.* (2016) may give more insight into the impact at a specific region. Another suggestion on future research could be to include the sixth element in the analysis, from the conceptual framework presented by Díaz *et al.* (2015). This element (Good quality of life) would give a social sustainability aspect on the subject and include people and societies into consideration.

7. Conclusions

The purpose with this chapter was to present the conclusions of the project. The outline consists of the findings divided by the different research questions, and lastly implications to the research field and suggestions for future research.

7.1 Research contributions

The findings highlight various impacts on biodiversity, ecosystems, water, and climate. Fertilizer usage was negatively impacting biodiversity, ecosystems, and climate in both South Africa and Peru. Although, results from LCA studies should be interpreted with caution because of the difficulties around applying this kind of data without taking the specific ecosystem and species at place into consideration. Moreover, irrigation and land-use change, separately and in combination, was found to negatively impact water in water scarce areas as well as the soils regarding water content and soil fertility. Converting forest, grassland, or other critical land into agricultural land for avocado production may cause threat to biodiversity and increase carbon dioxide emissions in the air. Parts of ecosystems and ecosystem services were found to be affected critically by avocado production in both countries. Nutrient runoff from agricultural land can negatively impact nearby watersheds and aquatic ecosystems. On the same note, fertilizer production and usage may increase amounts of carbon dioxide emissions into air and lead to terrestrial acidification which will impact local ecosystems and species. Moreover, the cultivation process and production of resources needed for production are very water demanding which may lead to water stress and can affect the ecosystems below water.

To reduce the negative impacts in avocado production, the results highlight different aspects. A farmers' association may provide farmers with education and time critical information where sustainable long-term solutions can be provided, and short-term information may be presented. Educational opportunities might raise awareness on the acceptance of using biocontrol over conventional pest control. However, it is important to take other aspects into account such as economic status which show to have an impact on the attitude. To decrease threats on the environment and ecosystems, the results show the importance of choosing the location based on the environmental possibilities in the area rather than depleting areas with non-suitable conditions for avocado production.

7.2 Implications and future studies

The results show various impacts on biodiversity, ecosystems, water and climate and strategies for reducing the negative impacts were highlighted. Although, the varied results made it difficult to highlight which driver is the greatest contributor to the negative impacts, and therefore more research is needed to answer that question. Moreover, the findings related to biodiversity impacts were few. More studies on the negative impacts on biodiversity are needed and maybe to include on-site ecosystems and biodiversity could help to better understand the direct impacts in certain areas of avocado production.

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Popular science summary

More people want products and commodities produced in other parts of the world which creates demand on producers and may lead to more intense production. The global food system comes with challenges since this can create stress and pressure on natural resources and the environment where food is produced.

Avocado is a high impact commodity and the production comes with challenges affecting the environment. Examples from Mexico enhance biodiversity loss, deforestation, land-transformation, water and soil pollution as environmental impacts related to the production of avocado.

This project aimed to identify environmental impacts from avocado production causing negative impact on biodiversity, ecosystems, land, soil health, water, and climate in Peru and South Africa. Another purpose with the study was to pinpoint potential solutions and strategies to reduce negative impact on the environment.

The results found different negative outcomes from avocado production but could not locate the greatest contributor out of all. Although, the results found that products used in production, such as fertilizers, pesticides, and water for irrigation were identified as negatively affecting biodiversity and ecosystems. Another finding was the negative impacts on water and soil health from land-use change and fertilizer production and usage. Regarding potential solutions for reducing the negative impacts, one study found farmer's associations to be helpful with support and knowledge for the farmers. More research is needed in order to pinpoint the biggest negative impact in avocado production.

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Appendix 1

Appendix 1. Search Strategy

The search strategy and the articles from the three databases are presented below.

Table 2. Article findings on the database Web of Science.

2025-09-19 Web of Science (Core Collection) via Clarivate		
#	Search terms	Results
1	TS=(Avocado* OR "persea americana")	8 161
2	TS=(Peru OR "South Africa")	226 760
3	#1 AND 2	173
4	TS=(biodiversit* OR environment* OR ecologic* OR biologic*)	7 276 890
5	#3 AND #4	47
filters applied	English Article 2005-2025	33

As displayed in *Table 2*, 47 articles were identified in the database Web of Science – Core Collection and thereafter turned in to 33 articles after applying the inclusion. These 33 articles were taken into the reviewing process.

Table 3. Article findings in the database Scopus.

2025-09-26 Scopus		
#	Search terms	Results
1	TS=(Avocado* OR "persea americana")	8 080
2	TS=(Peru OR "South Africa")	290 003
3	#1 AND 2	221
4	TS=(biodiversit* OR environment* OR ecolog* OR biolog*)	11 980 504
5	#3 AND #4	74
filters applied	Language: English Publication years: 2005-2025 Document types: Article	45

The search for articles in the scopus database resulted in 74 findings and after the inclusion criteria were applied 45 articles remained (*Table 3*).

Table 4. Article findings in the database CABI Abstracts through Web of Science.

2025-10-30 CABI abstracts		
#	Search terms	Results
1	TS=(Avocado* OR "persea americana")	12 558
2	TS=(Peru OR "South Africa")	131 070
3	#1 AND 2	877
4	TS=(biodiversit* OR environment* OR ecolog* OR biolog*)	4 833 519
5	#3 AND #4	293
filters applied	Language: English Publication years: 2005-2025 Document types: Article	92

As presented in *Table 4*, 293 articles were identified after applying the search string. The inclusion criterias did thereafter result in 92 articles that were further reviewed in the next step.

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