Climate change impacts on global food production, international trade and food security in the EU

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This study addresses the question how climate change will impact global food production and international trade in food and agricultural commodities, and what consequences these shifts can have for food security in the EU. Climate impacts are leading to regional shifts in crop and livestock productions in the EU but climate change does not threaten the availability of important food crops in the EU. Agrifood products that the EU mainly imports (such as oilseeds and tropical products) are likely to become more expensive. Adaptive strategies to reduce EU's import dependencies include policies promoting more efficient (re-)use of raw materials, establishing differentiated trade relations and supporting local production in import-sourcing regions in climate adaptation and mitigation strategies.

Key words: Climate change, food security, food production, trade, EU

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Contents

Preface

Recent findings by the IPCC suggest that the impact of climate change on global food security is more severe than previously expected, partly due to a rapidly increasing pace. Climate change and climate variability are expected to have a significant impact on food production worldwide. The European and Dutch food systems are also already experiencing consequences of climate change and will likely experience them even more in the future, directly through consequences for production within their own borders but also indirectly through reduced security of access to necessary imports because production and exports from trading partners are disappointing due to climate change.

This study is an exploratory literature review-based report that outlines the consequences of climate change on food production in the world and considers the consequences of shifting production zones for the EU's trade relations.

The study was conducted to provide the Ministry of Agriculture, Fisheries, Food Security and Nature (LVVN) with insight into shifting global production zones as a result of climate change are necessary in order to provide perspectives for action for international policy on food security.

The research was supervised by a steering committee consisting of representatives from the Ministry of LVVN. We thank all those involved for their constructive comments on drafts of the report.

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Summary

S.1 Key findings

Climate change impacts on agriculture in the EU are less severe than elsewhere in the world, yet with regional differences
Europe is currently least affected by climate change and will be according to IPCC's future long-term assessment of climate change (2021-2100). Climate impacts in Europe are causing shifts in crop production from south to north, as the south experiences higher temperatures and more irregular precipitation, while the growing season in the north is extended. In large parts of southern Europe, an increased risk of reduced livestock production is projected as drought may reduce grassland productivity and animal health. In northern Europe, the projected increase in rainfall could negatively impact livestock productivity, while wider spread of pathogens poses challenges to livestock production across Europe.

Climate change does not threaten the availability of important food crops in the EU
Studies analysing climate impacts on production and use of cereals and soy globally indicate that climate change does not threaten the availability of major food crops in the EU. Prices of food crops and animal products will increase and vary considerably between Member States, but at the same time they will not have a negative impact on the demand for and use of the products included in the analysis at EU level as a whole. This also suggests that climate change will have little to no impact on access to and affordability of food in the EU. However, for certain Member States and certain (less affluent) population groups, price effects may have consequences for access to food. Further research is needed to clarify this and the possible impacts of climate change on food use (i.e., food consumption patterns) in the longer term.

EU food security depends on some imports but dependency can be managed through adaptation strategies
The European food system relies largely on imports of protein-rich crops (including oilseeds) and tropical products (including coffee, cocoa, fruit) that are imported from a relatively small group of countries. Climate change can increase this dependency while climate change also may increase international prices for agricultural commodities imported by the EU. Examples of European policies that can reduce dependency on and prices of its main agrifood imports are innovation-promoting policies that encourage a more efficient use of raw materials and circularity, and agricultural policies that stimulate the production of protein-rich and oilseed crops. Other policy strategies are to conclude trade agreements to gain and guarantee access to as many markets as possible outside the EU (a continuation of EU's current trade agenda) and to support regions vulnerable to climate change help implementing adaptation and mitigation strategies to reduce climate change impacts on local agricultural and food production.

S.2 Background

Recent findings suggest that the impact of climate change on global food security is more severe than previously anticipated, partly due to its rapidly increasing pace. Climate change and climate variability are expected to have a significant impact on food production, both on yields and the suitability of production areas around the world.

The European/Dutch food systems are part of the global food system via imports and exports of food and related commodities. Securing long-term global food security requires understanding the climate change impacts, needed reforms in the food system and the interconnectedness of producing and consuming countries or regions. Better and more reliable risk assessments on shifting production zones due to climate change are needed to provide action perspectives for the Netherlands' international policy related to sustainable and equitable development and food security and the position of Dutch agribusiness worldwide.

S.3 Objective of the study

This study assesses what the effect will be of (future) climate change on global food production and international trade in food and agricultural commodities, and the consequences it may have for food security. Climate change particularly affects the economically less developed areas in the world exposing the population to acute food insecurity and water scarcity. However, in this study we look at the effects of climate change on food security in Europe. The EU is a net exporter of agrifood products, but also imports substantial amounts of s food products and commodities. Food security in the EU may thus be affected by climate change indirectly through its trade relations: when climate change impacts food production elsewhere in the world, this may have potentially significant consequences for international trade flows, negatively affecting the security of supply of EU imports.

S.4 Approach to the study

This research is based on desk research, analysing available trade data for the EU and the Netherlands and reviewing scientific literature about the effects of climate change on agrifood production globally and in the EU. Based on these findings, conclusions are drawn on the effects of climate change on EU’s trade relationships, and policy adaptation recommendations are suggested. Food security is mainly assessed from a climate angle in this report, whereas geopolitical factors have not been taken into account nor relevant policy developments.

Samenvatting

S.1 Belangrijkste bevindingen

De landbouw in de EU ondervindt gevolgen van klimaatverandering maar deze zijn minder ernstig dan elders in de wereld. Wel zijn er regionale verschillen in de EU
Europa is tot nu toe het minst getroffen door klimaatverandering en zal dat ook zijn volgens de lange termijn projectie (2021-2100) van het IPCC. Klimaatverandering in Europa zorgt voor verschuivingen in de gewasproductie van zuid naar noord, omdat in het zuiden de temperaturen hoger en de neerslag onregelmatiger wordt, terwijl het groeiseizoen in het noorden langer wordt. In grote delen van Zuid-Europa wordt een afname van de veehouderijproductie voorspeld, omdat droogte de productiviteit van graslanden kan verminderen en de gezondheid van dieren verslechterd. In Noord-Europa kan de voorspelde toename van regenval in de dierlijke sector een negatieve invloed hebben op de productiviteit, terwijl een bredere verspreiding van ziekteverwekkers de veeteelt in heel Europa bedreigt.

Klimaatverandering bedreigt de beschikbaarheid van belangrijke voedselgewassen in de EU niet
Volgens studies die de klimaateffecten op de productie en het gebruik van granen en soja analyseren, zal klimaatverandering de beschikbaarheid van deze belangrijke voedselgewassen in de EU niet bedreigen. Wel zullen prijzen van voedselgewassen en dierlijke producten en deze kunnen aanzienlijk variëren tussen lidstaten. Tegelijkertijd zullen de prijsstijgingen de vraag in de EU naar en het gebruik van de landbouwproducten die in de analyse zijn opgenomen niet doen verminderen. Dit suggereert dat klimaatverandering weinig tot geen impact zal hebben op de toegang tot en betaalbaarheid van voedsel in de EU. In de minder welvarende EU-lidstaten en dan met name voor de minstverdienende bevolkingsgroepen kunnen hogere prijzen echter wel gevolgen hebben voor de toegang tot voedsel. Er is verder onderzoek nodig om dit en de mogelijke effecten van klimaatverandering op voedselconsumptiepatronen op de langere termijn te analyseren.

De voedselzekerheid van de EU is afhankelijk van sommige importen, maar die afhankelijkheid kan worden verminderd door aanpassingsstrategieën
Het Europese voedselsysteem is voor een belangrijk deel afhankelijk van eiwitrijke gewassen (waaronder oliehoudende zaden) en tropische producten (zoals koffie, cacao, fruit) die worden geïmporteerd uit een relatief kleine groep landen. Door klimaatverandering kan deze afhankelijkheid toenemen, terwijl door klimaatverandering ook de prijzen voor door de EU geimporteerde landbouwproducten zullen toenemen. Voorbeelden van Europees beleid dat de afhankelijkheid van en de prijzen van de belangrijkste agrarische importen kan verminderen, zijn innovatiebeleid waarmee efficiënter gebruik van grondstoffen en circulariteit wordt aangemoedigd, en landbouwbeleid dat de productie van eiwitrijke en oliehoudende gewassen in de EU zelf stimuleert. Andere beleidsstrategieën zijn het sluiten van handelsovereenkomsten om toegang tot afzetmarkten en grondstoffen van buiten de EU te garanderen (dit is een voortzetting van de huidige handelsagenda van de EU), en door regio's die kwetsbaar zijn voor klimaatverandering te helpen met de implementatie van aanpassings- en mitigatiestrategieën om de gevolgen van klimaatverandering op de lokale landbouw- en voedselproductie tel verminderen.

S.2 Achtergrond

Recente bevindingen suggereren dat de gevolgen van klimaatverandering voor de wereldwijde voedselzekerheid ernstiger zijn dan eerder werd verwacht, deels doordat het tempo van klimaatverandering snel toeneemt. Klimaatverandering en klimaatvariabiliteit zullen naar verwachting aanzienlijke gevolgen hebben voor de voedselproductie, zowel op de opbrengsten als op de geschiktheid van landbouwproductiegebieden over de hele wereld.

Het Europese en Nederlandse voedselsysteem maken deel uit van het wereldwijde voedselsysteem via import en export van voedsel en aanverwante grondstoffen. Om de wereldwijde voedselzekerheid op de lange termijn veilig te stellen, is inzicht nodig in de gevolgen van klimaatverandering, in hervormingen in het voedselsysteem nodig zijn om met deze gevolgen om te gaan en in de onderlinge verbondenheid van producerende en consumerende landen of regio’s. Betere en betrouwbaardere risicobeoordelingen van verschuivende productiezones als gevolg van klimaatverandering zijn nodig om handelingsperspectieven te bieden voor het internationale beleid van Nederland met betrekking tot duurzame en eerlijke ontwikkeling en voedselzekerheid en de positie van de Nederlandse agro-industrie wereldwijd.

S.3 Doelstelling van de studie

Deze studie analyseert wat het effect zal zijn van (toekomstige) klimaatverandering op de wereldwijde voedselproductie en internationale handel in voedsel en agrarische grondstoffen, en welke gevolgen dit kan hebben voor voedselzekerheid. Klimaatverandering treft met name de economisch minder ontwikkelde gebieden in de wereld, waar de bevolking wordt blootgesteld aan acute voedselonzekerheid en waterschaarste. In deze studie kijken we echter naar de effecten van klimaatverandering op voedselzekerheid in Europa. De EU is een netto-exporteur van agrovoedingsproducten, maar importeert ook aanzienlijke hoeveelheden voedselproducten en grondstoffen. Voedselzekerheid in de EU kan dus indirect worden beïnvloed door klimaatverandering via haar handelsrelaties: wanneer klimaatverandering invloed heeft op voedselproductie elders in de wereld, kan dit potentieel aanzienlijke gevolgen hebben voor internationale handelsstromen, met mogelijk negatieve effecten op de leveringszekerheid van EU-import.

S.4 Aanpak van het onderzoek

Dit onderzoek is gebaseerd op deskresearch, waarbij beschikbare handelsgegevens voor de EU en Nederland en wetenschappelijke literatuur over de effecten van klimaatverandering op de agrovoedingsproductie wereldwijd en in de EU is geanalyseerd. Op basis van de conclusies over de effecten van klimaatverandering op de handelsrelaties van de EU worden enkele handelingsperspectieven aangegeven. Voedselzekerheid wordt in dit rapport voornamelijk beoordeeld vanuit een klimaatperspectief, terwijl in deze studie geen rekening wordt gehouden met de mogelijke invloed van geopolitieke factoren en/of andere relevante beleidsontwikkelingen als reactie op de gevolgen van klimaatverandering voor handelsstromen in voedsel en landbouwproducten.

1 Introduction

1.1 Background

The latest IPCC ARC6 report concludes that changes in the climate are happening rapidly, with average temperatures increasing and weather extremes occurring more frequently and more widely (IPCC, 2023). Even more alarming is that the IPCC finds that the projected impacts of measures to reduce emissions by 2030 as included in nationally determined contributions (NDCs) to combat climate change are not enough and that the consequences of man-made climate change will intensify. That will impact in particular the approximately 3.5 billion people living in areas that are highly vulnerable to climate change. These are mainly the economically less developed areas. Increasing extreme weather events have exposed millions of people to acute food insecurity and reduced water security, with the largest adverse impacts observed in many locations and/or communities in Africa, Asia, Central and South America, LDCs, Small Islands and the Arctic, and globally for Indigenous Peoples, small-scale food producers and low-income households (IPCC, 2023, SPM A2.2).

So far, Europe is least affected by climate change and will be according to IPCC's future projections. However, when we look in more detail, significant impacts do emerge in some of the regions within Europe in the form of yield decreases and shifts in agricultural production areas (Blanco et al., 2017; Hristov et al., 2024). In addition to direct impacts of climate change on food production, food security in the European Union (EU) will be affected by climate change indirectly through its trade relations. When climate change impacts food production elsewhere in the world and changes the balance between food demand and supply locally, this may have potentially significant consequences for international trade flows, by disrupting existing trade networks (in the short run) and/or shifting trade relations (in the longer run). As the EU is highly integrated in global food trade networks, climate change impacts on global agricultural production will most likely affect EU's imports *and* exports opportunities (EC, 2023). A particular concern is to what extent climate change and the resulting shifts in food production zones and trade flows may affect the security of supply of EU imports (EC, 2021; Loi et al., 2024).

1.2 Research questions and approach

This report analyses how climate change will impact global food production and international trade in food and agricultural commodities, and what consequences these shifts can have for food security (with a focus only on the availability of and access to food)[1] in Europe. More specifically, the research question is elaborated into two sub-questions as follows:

Question 1: How does climate change impact global agricultural production? This first step provides an overview of the potential effects of climate change on agriculture via a literature review. The analysis will show what countries/regions will be most affected by climate change (up to 2050), including possible shifts in agricultural production zones for a selected number of crops and livestock products. To answer this question, the research team will make use of the Agro-Ecological Zones (AEZ) modelling framework and databases, developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The AEZ framework provides information on current and future agricultural production risks and opportunities, climate change impacts and adoption options. Such information may facilitate planning decisions about future crop production.[2]

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[1] The four pillars of food and nutrition security are availability, access, utilization and stability (FAO, 1996; GSF/FAO, 2014).

Question 2: How will climate change impact the EU’s trade position, trade relationships, security of supply and prices of agricultural products and inputs? Based on the outcomes from research question 1, the analysis of the impacts of possible global shifts in production zones on trade in agricultural and food products will focus on the potential implications for Europe, in particular from the perspective of securing imports. Some regions may be more affected by climate change than others and depending on EU’s trade relationship with these regions, EU’s trade and food situation may be impacted. Question 2 will be elaborated based on available literature quantifying agricultural production and trade effects in the EU. The analysis will be supported by a few case studies on products imported into the EU mainly from outside the EU.

The structure of the report is as follows. Chapter 2 presents EU’s key trade facts and figures, showing EU’s trade position (both exports and imports) in agricultural and food products to provide context for assessing the impact of climate change on global agricultural production for food security in the EU. We also present the Dutch trade position in agricultural and food products, highlighting its main imports and sources of imports from outside the EU. Import dependencies can provide indications of potential risks of climate change for sufficient the sourcing of Dutch imports. Chapter 3 provides insights into how the impact of climate change on global agricultural production already manifested and potentially will under future scenarios, with impacts described per continent in several subsections. Trade implications of future climate change scenarios are analysed in Chapter 4, including case studies where we further develop the implications for key EU imports. Chapter 5 concludes by summarising major findings of the study and presents several policy adaptation strategies to combat climate change impacts in the EU.

2 Trade relationship between the EU and the Netherlands with other parts of the world

Eurostat (COMEXT) trade data show that, since 2013, the EU is a net exporter of agricultural and food products, with a total surplus of EUR 70 billion in 2023 (Figure 2.1 below). Trade figures (in nominal terms) show a gradual increase over the years until and including 2019, whereas the more recent years illustrate among others the distortive impacts of the Covid pandemic and the Ukraine-Russia war on international markets. In 2021-2023, the EU exported EUR 225-230 billion and imported EUR 160, 200 and 185 billion, respectively. The strong increase in 2021 compared to previous years is a catch-up effect of Covid, whereas Brexit gave a boost to EU's export figures in particular.[3] The increase in international world market prices also played a role in 2021. This is also reflected in the sharp increase in both export and import values in 2022. In 2023, world market prices remained relatively high, but this applied more to products that the EU exports than to the products the EU imports.

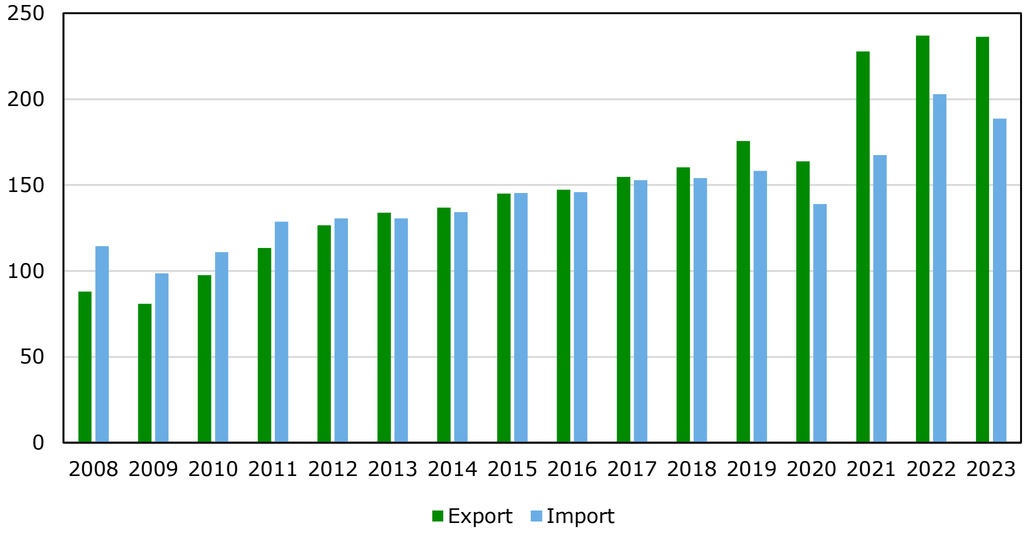

Figure 2.1 *EU agrifood trade (in €bn)*

EU's trading positions varies by agricultural product group. Figure 2.2 demonstrates that the EU is a significant exporter of meat, dairy, cocoa products, preparations of cereals, vegetable & fruits, miscellaneous edible foods (ingredients), beverages and tobacco. Typically, the EU imports fish, fruits & nuts, coffee/tea, oilseeds (e.g., soya beans and rapeseed), fats & oils (e.g., palm oil) and residues/waste of food industries (e.g., meal of soya beans). However, within these groups, the EU sometimes has contrasting net trade positions. For example, the EU exports many cocoa products, but the raw materials for these (cocoa beans and cocoa butter) are imported. This also holds for cereals, an important food staple product group: EU's trade position for this group is rather balanced in value terms, while in volume terms the EU is a net exporter of wheat and a net importer of maize/corn and rice. This indicates that when analysing the impacts of shifting production zones due to climate change on trade and food security, we need to look at a more detailed product level than just the 2-digit trade classifications of food product groups in Eurostat.[4]

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[3] As of 31 January 2020, the UK left the EU, making the UK a 'foreign market'. The UK has been a net importer of agricultural and food products from the rest of the EU. EU's 2021 trade figures are the first full year reflecting the new trade relationship between the EU and the UK since Brexit.

[4] See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Extra-EU_trade_in_agricultural_goods.

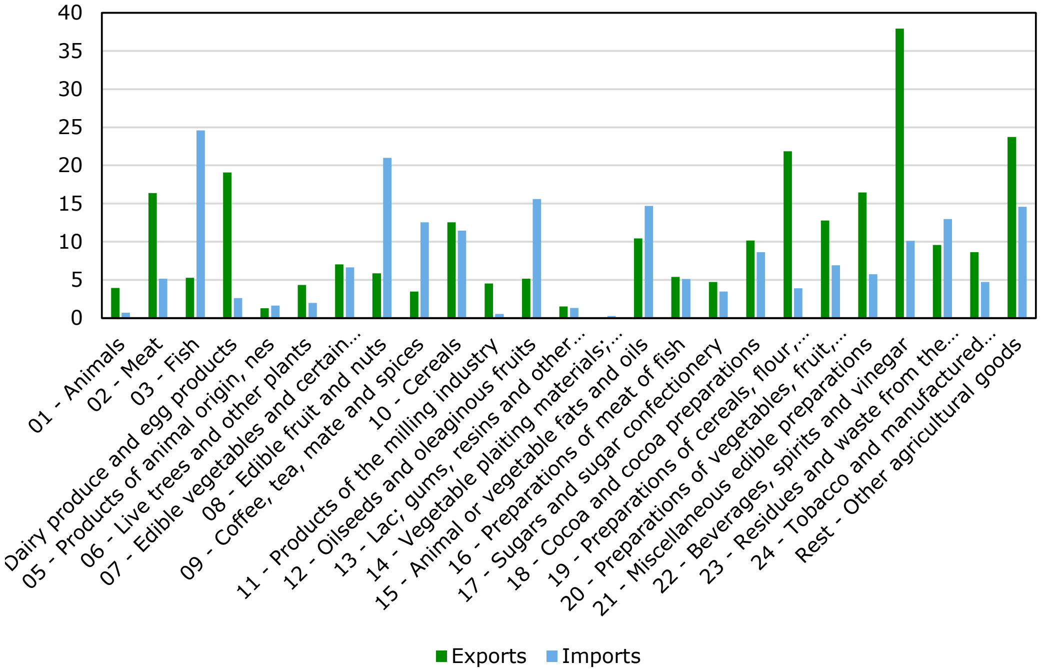

Figure 2.2 *EU-27 imports and exports of agricultural and food products (2023, in €bn)*
Note: The category 'Rest – other agricultural products' includes products in HS29-53 (e.g. rubber, wood and cotton).

Figure 2.3 below shows that the EU's major export markets are rather concentrated, with over 50% shipped to the six most important destinations (UK, USA, China, Switzerland, Japan and Russia). On the import side, main trade partners are Brazil, UK, Ukraine, USA, China and Norway. More detailed trade data show that EU imports from 30 countries amount to EUR 1 billion or more, which demonstrates the great diversification of the origins of EU's agricultural and food imports. But once again, if we zoom in on a product that (as a share of total EU use) is mainly imported from outside the EU, the concentration of suppliers of this product can be high. For example, almost half of EU's imports oils and fats are sourced from Indonesia, Malaysia (palm oil) and Ukraine (sunflower oil) (see Figure 2.4).[5]

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[5] Both pie charts are from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Extra-EU_trade_in_agricultural_goods#Main_trading_partners_for_agricultural_products.

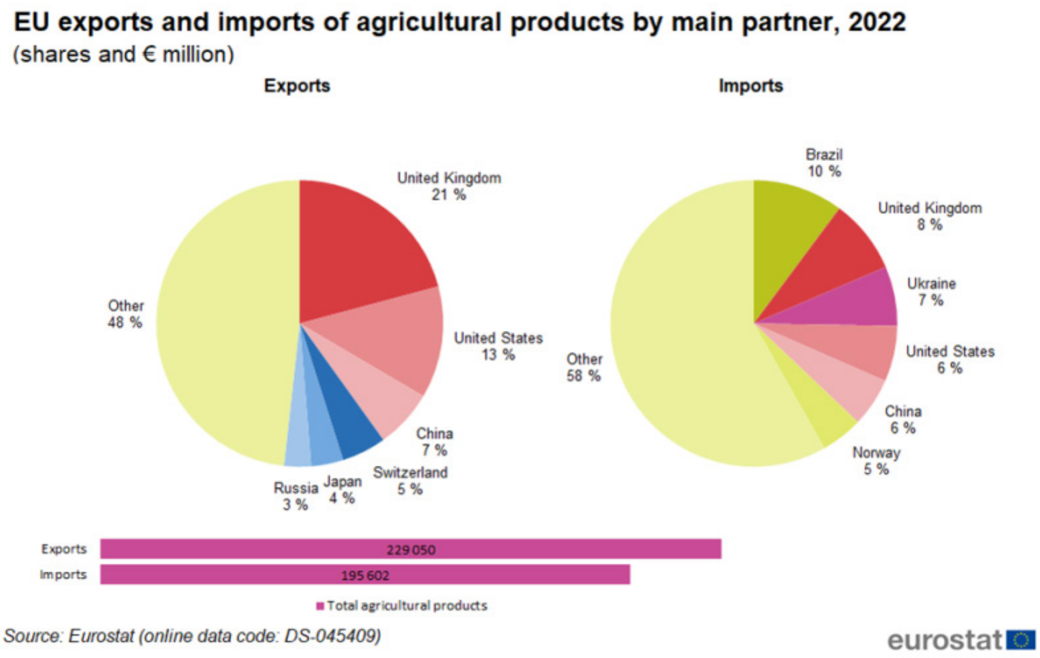

Figure 2.3 *EU exports and imports of agricultural products by main partner, 2022*
Source: Eurostat.

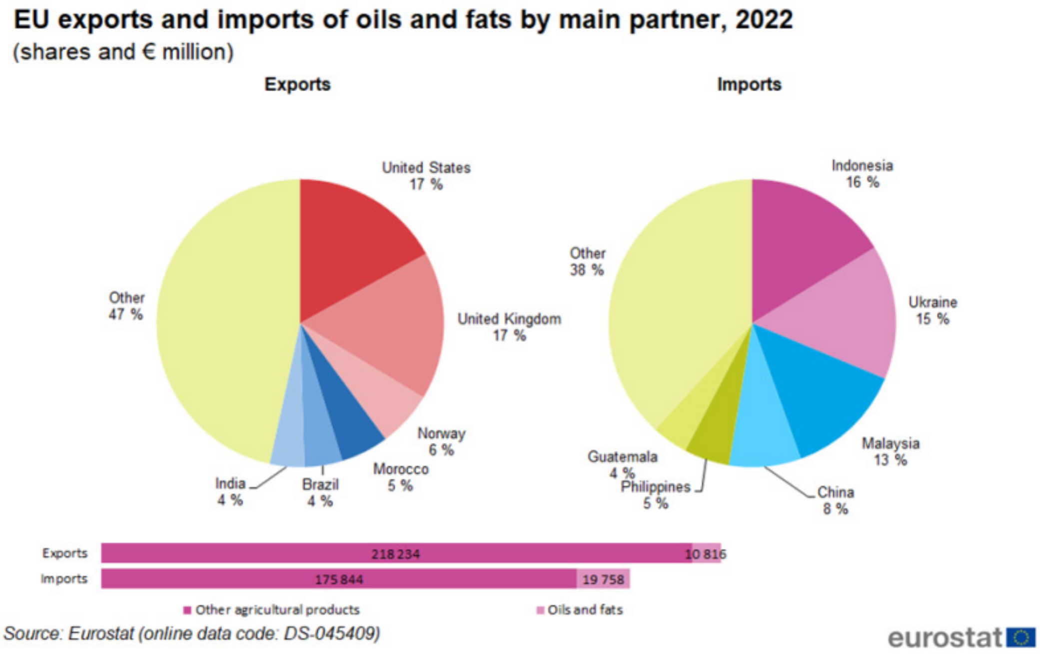

Figure 2.4 *EU exports and imports of oils and fats by main partner, 2022*
Source: Eurostat.

We also present the Dutch trade position in agricultural and food products, highlighting its main imports and sources of imports from outside the EU, as import dependencies may indicate potential risks of climate change for the sufficient sourcing of Dutch imports. Table 2.1 presents the Dutch trade positions with the EU Member States on the one hand and its trade position with countries outside the EU on the other. A first observation is that Dutch export markets are mainly in other EU Member States: 72% of all agricultural exports find their destination in other EU countries. Agricultural imports are more equally obtained from EU and non-EU countries, with 56% from other EU Member States and 44% from countries outside the EU. In its trade with non-EU countries, the Netherlands has a net-import position for fish, fruits, coffee/tea etc., cereals, oilseeds, oils and fats, cocoa and 'other agricultural goods'. The Dutch overall trade balance for fish and cocoa products is positive, though, due to a significant net-export position in its trade with other EU countries.

Table 2.1 *Exports and imports of the Netherlands with EU and non-EU countries, and trade balances (coloured negative figures = net-import position; in € million)*

Product group	**Export to EU**	**Import from EU**	**Trade balance with EU**	**Export to countries outside EU**	**Import from countries outside EU**	**Trade balance with non-EU**
01 - Animals	1,777	1,535	242	511	86	425
02 – Meat	8,653	3,816	4,838	3,026	1,987	1,039
03 – Fish	4,049	1,375	2,674	1,097	2,841	-1,744
04 - Dairy produce	9,031	5,462	3,569	2,936	222	2,714
05 - Products of animal origin, nes	465	249	216	251	277	-26
06 - Live trees and other plants	8,639	1,091	7,548	3,317	1,567	1,750
07 - Edible vegetables	6,494	2,559	3,935	2,464	946	1,518
08 - Edible fruit	8,130	2,247	5,883	1,040	7,230	-6,190
09 - Coffee, tea, mate and spices	1,401	1,009	392	369	1,131	-763
10 - Cereals	680	2,853	-2,173	41	1,044	-1,003
11 - Products of the milling industry	640	1,115	-475	580	76	504
12 - Oilseeds	2,428	1,375	1,053	1,521	3,814	-2,294
13 – Lac	117	131	-15	57	168	-110
14 - Vegetable plaiting materials	34	20	14	14	56	-41
15 - Animal or vegetable fats and oils	5,787	3,960	1,827	1,317	4,078	-2,760
16 - Preparations of meat, fish	2,195	1,197	997	363	897	-535
17 - Sugars and sugar confectionery	1,724	1,274	450	578	323	255
18 - Cocoa and cocoa preparations	4,303	1,723	2,580	2,096	3,341	-1,244
19 - Preparations of cereals, flour, starch or milk	3,232	3,084	148	3,456	646	2,810
20 - Preparations of vegetables, fruit, etc	5,382	2,041	3,341	2,238	1,993	245
21 - Miscellaneous edible preparations	4,104	2,625	1,479	2,795	1,290	1,505
22 - Beverages, spirits and vinegar	5,580	4,586	995	3,657	2,022	1,634
23 - Residues and waste from the food industries; prepared animal fodder	5,171	2,384	2,787	1,426	1,824	-399
24 - Tobacco	2,082	968	1,114	683	523	160
Rest - Other agricultural goods	3,632	3,266	366	1,546	2,826	-1,280
Totals	95,730	51,944	43,786	37,379	41,208	-3,829

Source: Eurostat COMEXT. Note: ‘other agricultural goods’ include products in product groups with HS code 29, 33, 35, 38, 40, 41, 43-45 and 50-53.

Looking more closely at the products, the Netherlands is a net importer from countries outside the EU. The countries of origin from which the Netherlands mainly sources its imports are listed in Table 2.2.

Table 2.2 *Main non-EU countries of origin of products for which the Netherlands has a net-import position*

Product group	**Main countries of origin outside the EU from which the Netherlands imports**
Fish	Norway, Iceland, USA
Fruits	USA, South Africa
Coffee, tea	Brazil, Columbia, Vietnam (coffee); Sri Lanka, India, China (tea)
Cereals	Ukraine, USA
Oilseeds	Brazil, USA
Oils and fats	Ukraine, Philippines, Indonesia
Cocoa	Cote d’Ivoire, Ghana

Source: EurostatCOMEXT.

The EU’s trade figures indicate that it is a major exporter of agricultural goods to the international market, indicating a surplus of production over domestic demand that can be sold on international markets. However, the EU also imports a number of important products including protein-rich oilseeds and tropical products. Imports come from a limited number of countries. The Dutch trade profile largely matches that of the EU as a whole. In particular, the concentration of countries of origin from which imports are sourced is a potential risk if climate change negatively impacts local production in those countries, reducing their exports to international markets.

3 Climate change and shifting of agricultural production zones: current situations and future scenarios with impacts on areas and yields per hectare

3.1 Introduction: climate change affects suitability of land for food production

Climate change is projected to have a profound impact on the agricultural sector, leading to significant changes in regional crop-growing conditions and the occurrence of pests and diseases, which may disrupt supply chains. The effects of climate change, however, will be different across regions and agroecology conditions (Howden et al., 2007; Parry et al., 2004; Wheeler and von Braun, 2013).

Consequences of climate change for agricultural production depend on changes in temperature and rainfall, but also on soil suitability and other biophysical characteristics (e.g., highland and lowland) that influence crop growth. A useful notion to evaluate the interaction between climate change and agricultural land use is the concept of agro-ecological zones (AEZ). The AEZ methodology provides a framework for establishing a spatial inventory of land resources compiled from global/national environmental data sets and assembled to quantify multiple spatial characteristics required for the assessments of land productivity under location-specific agro-ecological conditions. The land resources inventory includes spatial layers of historical and future climate, soil, terrain, land cover, population density, livestock density, protected areas/areas of high biodiversity value, and administrative boundaries (Fischer, 2021).

The following figure shows how AEZs are mapped and classified across the globe. Main climate classifications are: tropics (red and purple colours in the map), sub-tropics (orange and yellow), temperate (green and teal) and cold (blue), with deserts/arid areas indicated by a (very) light yellow colour (see Figure 3.1).

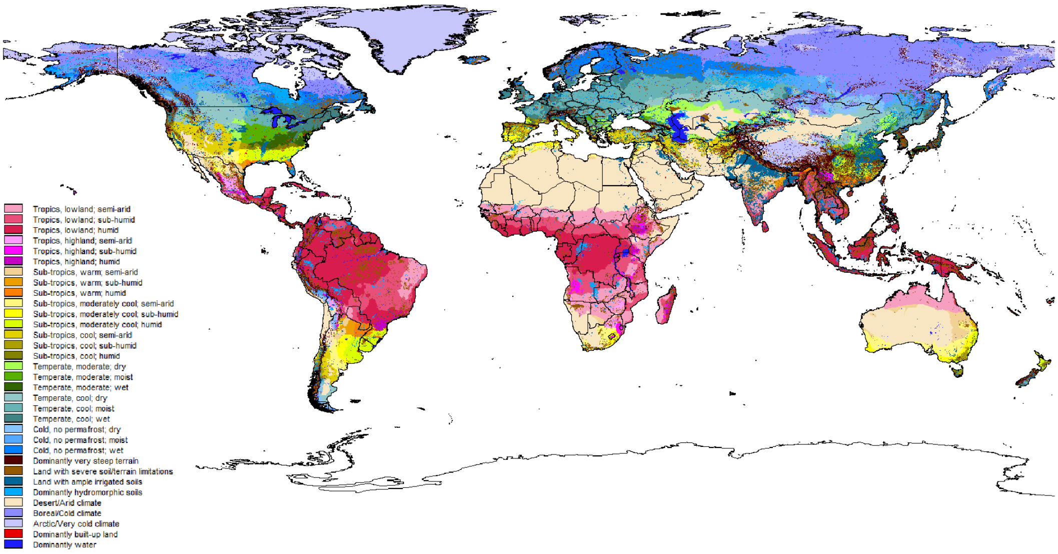

Figure 3.1 *Agroecological Zones Classes, Climate 1981-2011*
Source: Fischer (2021).

Climate change may shift AEZ boundaries as temperature and water availability change. The shift in agroecological zones due to climate change is complex and varies regionally. However, some general patterns can be observed based on projections of temperature increases, changing precipitation patterns, and other climate-related factors affecting production yields.

In the temperate regions, a northward shift is occurring for the Northern Hemisphere, as agroecological zones suitable for temperate crops move northwards in North America, Europe, and Asia, with warmer temperatures lengthening the growing season (Deryng et al., 2016; Gregory and Marshall, 2012; Parry et al., 2004; Rosenzweig et al., 2014; Yang et al., 2015). This may cause wheat production to move northwards into Canada and Russia, while maize and soya bean zones may expand in the northern United States and southern Canada. In contrast, in the tropical and subtropical regions, an expansion of arid zones is having the opposite effect. Areas like the Sahel in Africa, parts of South Asia, and Central America may see an expansion of arid and semi-arid zones due to reduced precipitation and increased temperatures, leading to more desert-like conditions. This may cause a need for crops currently grown in tropical regions, such as coffee and cocoa, to be cultivated at higher altitudes or latitudes as lower elevations become too warm or dry.

Similar effects may be observed in the Mediterranean Regions, such as Southern Europe, California, and parts of Australia, as these regions will experience more intense droughts and higher temperatures, shifting these zones towards more arid conditions. The changing conditions may require crop adaptation, as traditional crops like grapes and olives may need to be adapted or replaced with more drought-resistant varieties.

In South and Southeast Asia, shifts in the timing and intensity of monsoon rains are likely to occur, affecting rice and other monsoon-dependent crops. This could necessitate changes in crop calendars and water management practices. In contrast, coastal regions, particularly in deltas such as the Mekong, Nile, and Ganges-Brahmaputra, may face challenges from sea level rise and increased soil salinity, reducing the suitability for traditional crops.

In the next sections, a more detailed analysis is provided of how climate change may affect production yields across the various global continents by taking a few plausible emissions scenarios into consideration (RCP 4.5 is considered a main reference for a middle of the road climate change scenario – see Appendix for clarification) with a time horizon of 2040-2050.

3.2 Europe

Climate change is leading to significant alterations in weather patterns across Europe, with various impacts depending on the region. Europe faces increasing vulnerability to climate change, as warmer temperatures and more volatile weather patterns disrupt ecosystems and increase the frequency of extreme droughts, floods, heat waves, and forest fires (IPCC, 2023).

In the north of Europe, temperature increases will be milder. In contrast, the south of Europe will face a large increase in heat extremes, leading to periods of drought affecting crop growth in the region (Hannah et al., 2013; Iglesias et al., 2011; King et al., 2018; Marx et al., 2017 in Ceglar et al., 2019). Climate change is furthermore predicted to lead to major changes in water availability across Europe, due to less predictable rainfall patterns and more intense storms. The main climate change impacts on the agricultural sector across the various biogeographical regions in Europe are presented in Figure 3.2.

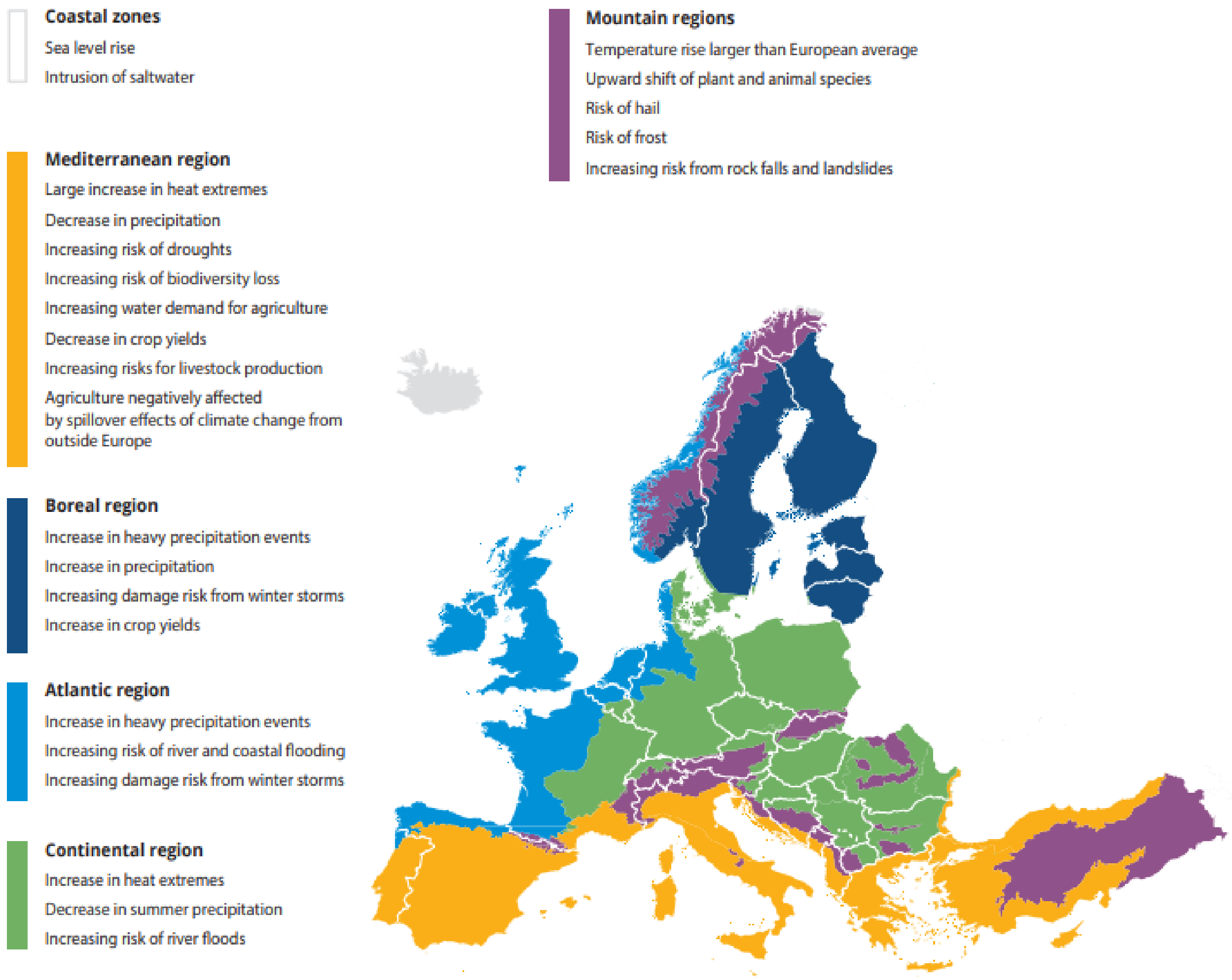

Figure 3.2 *Main climate change impacts on the agriculture sector for the main biogeographical regions in Europe*
Source: EEA (2019).

Heat stress and droughts already negatively affected European crop production compared to their yield potential for the period 1981-2010, especially in southern Europe (Webber et al., 2018). This led to wheat and maize yield reductions of over 60% in some southern European regions, and up to 30% in other European regions (Webber et al., 2018), causing substantial economic damage. A study by Bras et al. (2021) found that the severity of drought and heatwave crop losses have in fact tripled over the last five decades in Europe. Excessive rainfall can also lead to crop failures, as observed in 2016, when wheat production failure in France led to losses of up to 55% in specific regions (Nóia Júnior et al., 2023). European agriculture relies on irrigation for 5.9% on average, but this figure may rise to 30-50% locally in southern Europe (Eurostat, 2019). Agriculture is the largest net water-using sector in Europe and puts pressure on water resources (EEA, 2020). Several countries in Europe already exceed thresholds for sustainable water use (Berbel et al., 2019 in EEA, 2024).

Meanwhile, increasing temperatures have led to an extension of the growing season in the north of Europe. A well-documented example is the shift in climatic suitability for wine production, which was originally largely confined to Mediterranean, southern maritime, and Pannonian regions in Europe (Hannah et al., 2013), and which has expanded in recent years in several regions of central and western Europe (Spinoni et al., 2015 in Ceglar et al., 2019).

Global warming will further promote a northward expansion of crops adapted to warmer climates but also decrease suitability in the areas affected by increasingly higher temperatures and more frequent droughts (Hannah et al., 2013; Iglesias et al., 2011; King et al., 2018; Marx et al., 2017 in Ceglar et al., 2019). Simultaneously, increasing variability in precipitation will lead to substantial agricultural production losses in the coming decades, with different drivers across Europe – i.e., warm and dry conditions in the south and altered rainy seasons in the north. Considering the consequences of climate change-driven productivity shocks, market adjustments and trade feedbacks in 2050 compared to a baseline, losses could reach up to 10-25% for key crops like maize and wheat under low and moderate impact scenarios, even with CO_2 fertilisation effects (Bezner Kerr et al., 2022; Hristov et al., 2020).

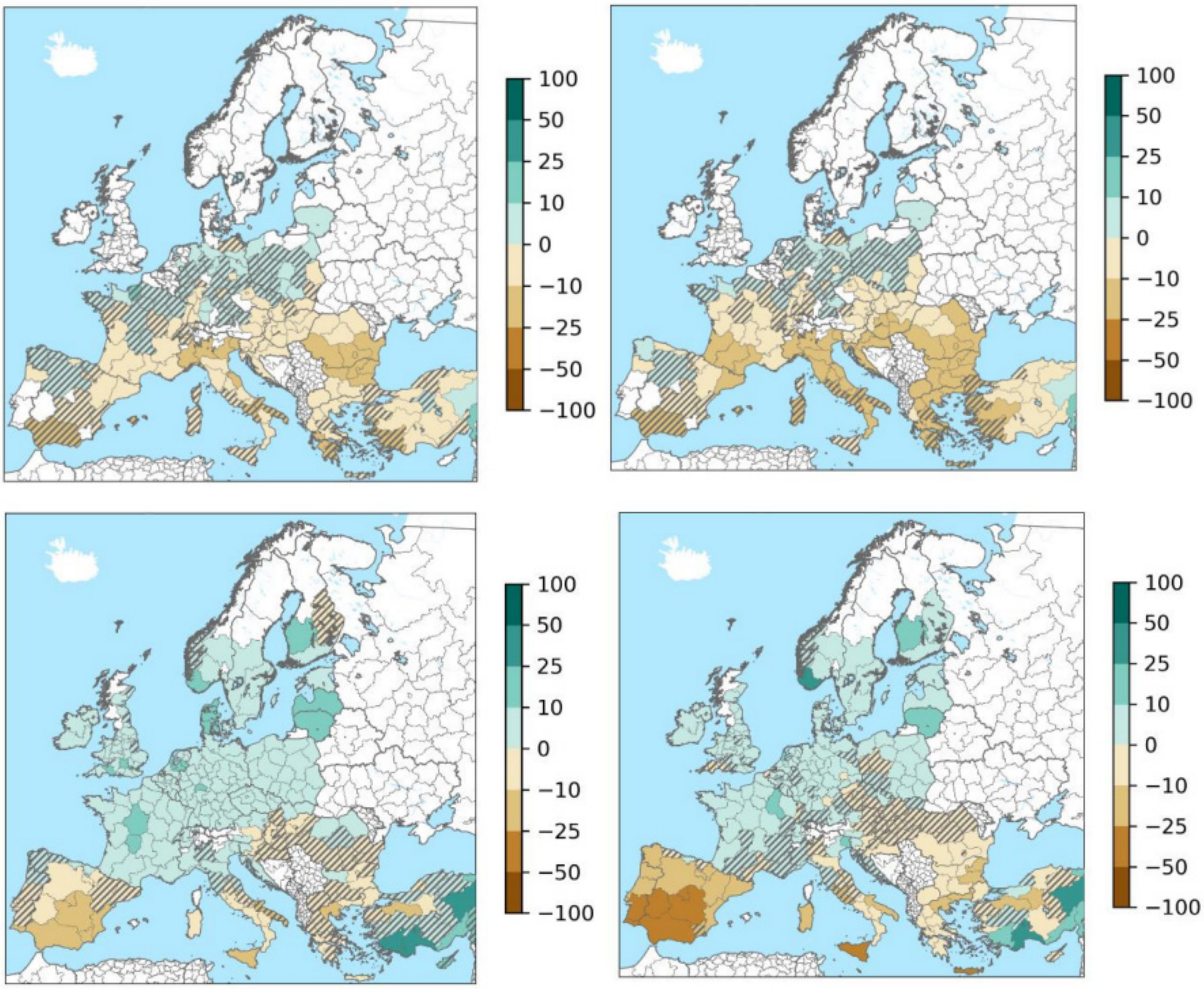

Figure 3.3 *Mean changes of grain maize yield (top) and wheat yield (bottom) (% relative to the historical period projected under RCP 8.5 for 1.5°C (left panel) and 2°C (right panel) warming conditions under irrigated conditions*
Source: JRC (2020).

Staple crops like wheat and maize are affected significantly by climate change, with substantial differences in impacts on yield, protein content and nutritional value between climate projections, regions and crops (Hristov et al., 2020). Yield volatility is likely to increase. However, Europe is among the least negatively affected continents globally (Jägermeyr et al., 2021) but rising global demand may increasingly affect production in Europe (Hristov et al., 2020). Northward shifts of production (Franke et al., 2022) pose challenges to production and processing systems. Generally, warmer conditions are conducive to the spread of pests and diseases, but there is limited evidence for impacts on future yields.

Changes in irrigation water availability could lead to additional yield declines (Elliott et al., 2014). Under a 2 C warming scenario, increased water shortages are projected for southern Europe, particularly in Cyprus, Greece, Italy, Spain and Turkey, while central and northern Europe show an increase in annual water availability (Bisselink et al., 2018). Roughly 80-90% of these projected changes can be attributed to climate change (Bisselink et al., 2018). At the same time, many crops in Europe may benefit from CO_2 fertilisation if water and nutrients are sufficiently available, possibly overcompensating for direct climate impacts on production, but this is less the case for maize and most other crops of tropical origin (Toreti et al., 2020).

An increased risk for livestock is projected for large parts of southern Europe (EEA, 2017; EEA, 2024). An increasing drought risk in various regions in Europe is expected to reduce livestock productivity through negative impacts on grassland productivity and animal health. The increased growing season for crops and grasslands may boost livestock system production in northern Europe, but also leads to changes in the distribution of pathogens across Europe. The projected increase in rainfall in northern Europe may furthermore pose challenges for livestock grazing and harvesting grass (EEA, 2024).

The potential effects of climate change on aquaculture range from changes to production capacity in existing cultivation areas to changes in the areas themselves, which may become unsuitable for species, but also suitable for new species. Martinez Cubillo et al. (2021) demonstrate how projected temperature changes will have variable effects on fish growth and productivity in the EU aquacultural sector, depending on the species and geographic region and concluded that as a general trend across species and regions, economic uncertainty is expected to increase under all future IPCC RCP projections.

The dominant agroecological zone of Europe is the temperate zone, which reflects a mild climate, neither too hot nor too dry. The GAEZ projection for 2041-2070 under the (extreme) RCP8.5 scenario shows a significant shift northwards from the subtropical zone, which, in 2010, is still roughly marked as the northern boundary in Europe by the Bordeaux-Istanbul line on the map, but shifts northwards to the Belgian-French border and further east, demarcated by a line on the map from Munich via Belgrade to Istanbul. Subtropics are even the dominant AEZ class in some of the southern regions in Ireland and the UK in that scenario (see GAEZ v4 - Theme 1 Web App (fao.org), which allows the use of filters to navigate through the land and water resource themes of the GAEZ database).

3.3 North Africa and the Middle East

Climate change already impacts the Middle East and North Africa (MENA) region significantly and will continue to do so. North Africa (Algeria, Egypt, Libya, Morocco, Tunisia), a region with a strong population growth, is highly vulnerable due to its sensitivity to climate change exposure, its scarce water resources and low adaptive capacity (Schilling et al., 2020). Agriculture in the region is highly dependent on weather, as an estimated 70% of crops are rain fed. With annual temperatures continuing to rise, the already critically low annual water discharge is likely to worsen, with negative impacts for local food production in the region. This will likely exacerbate rural to urban migration, as the vast majority of the region’s populations rely on agriculture for livelihoods and will thus also make it harder to meet the demand for food and water in the region (Waha et al., 2017; Droogers et al., 2012). In the region, there is a general trend towards more arid conditions, less precipitation and increased scarcity of water supply due to reduced surface runoff and groundwater degradation (Schilling et al., 2020). The effects of this for specific countries and times of year are not linear, however, as some countries near the Mediterranean basin experience less water stress in certain times of the year (Alboghdady and El-Hendawy, 2016).

Regarding agricultural production, more than two thirds of all output in the region comes from Iran and Egypt. Cereals dominate staple food crop production in the region. One third of all wheat produced in the region is produced by Iran. Egypt is responsible for two thirds of rice production.[6] As a whole, the region is overly dependent on food imports for food security, as climate change is compromising domestic crop production (Woertz, 2020). The MENA region received one third of all international shipments of cereal, sheep meat and whole grains in 2019, as well as one fifth of all sugar, poultry meat, and skimmed milk imports (FAO, 2022). It is understood that benefits of increased global CO_2 on wheat and rice production will be undermined by drought and higher temperatures (Helman and Bonfil, 2022; Farooq et al., 2023). For Iran, the likelihood is that climate change will shift much of the wheat production to the northern, northwestern, and western parts of the country, which have the greatest potential for rainfed wheat production and can make use of the growing benefits of increased CO_2 (Alizadeh-Dehkordi et al., 2022). In

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[6] Home | OECD iLibrary (oecd-ilibrary.org).

Egypt, climate change is likely to negatively impact agricultural production in the Nile River Delta, due to rising temperatures, more frequent droughts, water and land scarcity, rising sea levels, and increased groundwater salinisation (Mahmoud, 2017). Overall, for key crops in MENA, climate change is creating difficult conditions for current production zones. The production zones themselves are varied, and production may shift from arid regions within countries to areas of higher precipitation. If increases in CO_2 lead to higher crop yields, this might offset the climate challenges, but it would come at a higher cost of adaptation measures (Elsherpiny, 2023; Elsadek et al., 2024).

3.4 Sub-Saharan Africa

The African continent is often considered to be the region in the world most affected by climate change (Lickley and Solomon, 2018; WMO, 2022). Effects of climate change are mainly noticeable in terms of changing weather patterns, which are becoming less favourable in many instances, increasing the volatility of crop and livestock yields (McKinsey, 2020). Given that 95% of Africa's agriculture is rainfed (Abrams, 2018), irregular rainfall patterns have a significant impact on yields and therefore on food security and livelihoods overall on the continent.

There is mounting evidence that climate change has already led to changes in agricultural crop production in Africa and has slowed down agricultural productivity growth. Ray et al. (2019) estimate that maize yields decreased by 5.8% and wheat yields by 2.3% between 1974 and 2008, on average, in Sub-Saharan Africa (SSA) due to climate change. Moreover, WMO (2022) claims that Africa's agricultural productivity growth has declined by 34% since 1961 because of climate change, which is the highest decline compared to what other regions in the world have experienced over the same period. Figure 3.3 shows the trends in cereal production in SSA over the past two decades, showing an overall decline across the respective countries.

__Figure 3.4__ Trends in cereal (including rice, millet, sorghum, maize and wheat) production in SSA over the last 20 years (2000-2020) compared to current production yields (2023)
Source: Omotoso et al. (2023).

If climate change continues its current trend, crop production in Africa may decline by an estimated 2.9% in 2030 and by 18% by 2050, according to Adom (2024). Maize, rice, wheat and soya bean yields in tropical regions (20°S–20°N) are projected to decrease by approximately 5% for every degree Celsius of global warming (Rosenzweig et al., 2014; Franke et al., 2020). Dryland agricultural areas are especially sensitive to changes in rainfall. For example, without adaptation, substantial yield declines are projected for staple crops. A meta-analysis of 56 studies indicates that, compared to 1995-2005, economic welfare in the agriculture sector in SSA is projected to decline by 5% for 2°C global warming (Moore et al., 2017).

A synthesis of projected staple crop impacts across 35 studies, covering nearly 1,040 locations and cases, shows that crop yields in Africa, on average, decrease with increasing global warming, even when accounting for CO_2 increases and adaptation measures (Hasegawa et al., 2021). For example, for maize in West Africa, compared to 2005 yield levels, median projected yields decrease by 9% at 1.5°C global warming, without adaptation. However, projected impacts across crops and regions are driven by uncertainties in crop responses to increasing CO_2 and adaptation response, especially for maize in East Africa and wheat in North Africa and East Africa.

Rainfall in East Africa has become unpredictable, with periods of drought increasingly being interspersed with periods of excessive rainfall. Horticultural crops are particularly sensitive to climate change because of their high-water demand and strict temperature requirements. Increased or decreased rainfall and rising temperatures can result in drought or flooding, lack of water for irrigation, and outbreaks of pests and diseases, all of which can affect the suitability of areas for growing horticultural crops (Patrick et al., 2020).

Future climate change may, moreover, increase insect pest-driven losses in Africa for maize, rice and wheat (Benjamin et al., 2024). At present, roughly 10 to 35% of yield losses can be attributed to outbreaks of pest and diseases in sub-Saharan Africa (Savary et al., 2019). Rainfall pattern modifications in combination with a warming climate are considered the main cause of increased desert locust outbreaks in East Africa and other parts of the world (Subedi et al., 2023; Liu et al., 2024).

Future climate change will also have compounding impacts on livestock, including negative impacts on fodder availability and quality, availability of drinking water, direct heat stress and the prevalence of livestock diseases (Nardone et al., 2010; Rojas-Downing et al., 2017; Godde et al., 2021). The availability of fodder in terms of rangeland productivity is projected to decrease by an estimated 42% by 2050 under RCP4.5 (2°C global warming) for western sub-Saharan Africa, compared to a 2000 baseline. Similarly, rangeland productivity is projected to decline by 37% in southern Africa and both 5% in east Africa and central Africa under the same RCP scenario (Descheemaeker et al., 2018).

Climate change furthermore poses a significant threat to marine and freshwater fisheries and aquaculture in Africa, as rising sea level temperatures make fish stocks migrate towards colder waters away from equatorial latitudes (Maulu et al., 2021).

3.5 Latin America

Due to climate change Latin America is going to experience increased temperature extremes, aridity and higher risk of drought, whereas the area around the Caribbean may be affected by more frequent, more intense, cyclones and storms (Mendelsohn et al., 2012; Reyer et al., 2017). Modelling even suggests a weakening of the Intertropical Convergence Zone (ITCZ), which is a planetary-scale band of heavy precipitation close to the equator (Byrne et al., 2018). This weakening may have implications for rainfed agriculture and irrigation in the region of Latin America covered by the ITCZ. Climate change is also having a negative effect on soil quality throughout Latin America, with an estimated 68% of all soils in the region suffering soil erosion (Abeldaño Zuñiga et al., 2021). This soil erosion is made worse by severe floods, glacial lake outbursts or landslides, which are becoming more frequent due to accelerated glacial retreats and alterations to the regional water cycle.[7] The Andes mountains span the entire vertical length of the South American continent. Andean countries such as Bolivia or Peru rely on more than 80% of their water

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[7] Fighting the Impacts of Glacier Retreat in the Tropical Andes (worldbank.org).

from mountain regions (Vuille et al., 2008). Different IPCC scenarios up to 2050 suggest that warming under climate change will cause tropical glaciers to continue to retreat, and that low-lying glaciers will completely disappear within a few decades, thereby causing changes to stream flow seasonality and impacting the water buffer during dry season, while also having detrimental impacts on long-term water security in the region (Vuille et al., 2018; Vuille et al., 2008). According to inhabitants, timings and the severity of annual weather cycles are changing in the Andes. Crop yields, agricultural calendars, management practices, and the spatial distribution of crops are being affected by climate change. Brazil, Bolivia, Ecuador, Venezuela, Guyana, and Colombia will experience higher temperatures and water scarcity, leading to loss of crops such as rice. Other countries such as Peru, Argentina, Chile, Bolivia, and Uruguay will register lower temperatures, which negatively impacts yields of quinoa, potatoes and tarwi, among other crops (Saxena et al., 2016; Lozano-Povis et al., 2021).

Brazil will experience a range of weather extremes, from more precipitation in northern regions to more drought in the central regions. Ultimately, this will shift agricultural production southwards towards the sub-tropical and near sub-tropical regions of the Cerrado and Atlantic Forest biomes (Zilli et al., 2020). Soya bean is a key export crop for Brazil and is the main source of livestock feed globally. The deforestation is partially fuelled by clearing land for soya bean production, which is driving climate change in the Cerrado region by making the region hotter and drier (Hofmann et al., 2021; Aragão et al., 2022). The growing of crops such as soya bean, maize and cotton will be more difficult, due to climate change-induced precipitation loss and temperature increase. This may be offset, however, with the use of technological developments such as genetic modification and crop management techniques (Hampf et al., 2020).

Argentina’s North Patagonia is a globally important region for fruit tree cultivation. Due to climate change, this region will experience increases in temperature in certain areas, which may provide new opportunities for fruit and nut growers, to produce new species and cultivars, thus expanding the traditional growing ranges (del Barrio et al., 2021). The East and North-East regions of Argentina (Catamarca, La Rioja, San Juan, Mendoza, Neuquén) grow 98% of the grapevines in the country, and by 2050, the region could benefit from climate change by increasing the variety of grapes grown and land suitable for cultivation (Cabré and Nuñez, 2020). This would entail current grape production being shifted to the more southern and norther regions, while the current land area would be adapted to grape varieties that can tolerate higher temperatures.

Colombia is likely to experience a variable set of climate change-induced conditions of either more extreme droughts or floods.[8] The High Sierras are considered most prone to the impacts of flooding (Pardo Martínez and Alfonso, 2018). Like other Latin American countries based in the tropical Andes, Colombia is highly reliant on glacier melting for drinking water, agriculture and hydropower. Colombia could suffer major disruptions to its water supply from temperature increases and changes to the glacier melt (Bradley et al., 2006). Colombia is the world’s largest producer of Arabica coffee (Ciravegna et al., 2023). Robusta makes up 40% of the world’s coffee supply, and climate change will challenge current growing regions. Under an average warming of 2°C, the foothills around Colombia’s eastern Andean Mountain Range, the high plains of the Orinoquía region, and wet parts of the Caribbean may support Robusta coffee plantations without interrupting current Arabica coffee regions (González-Orozco et al., 2024). Colombia is ranked third in global banana exports, just behind the Philippines. Looking at the effects of climate change on bananas grown in plantations for export indicates that their current growing regions will shift when averaging 7 climate change scenarios for 2060. Colombia is likely to lose the most land suitable for export banana plantation to Mexico (Machovina and Feeley, 2013). Recent market forecasts (2023) detail that Colombian banana exports have been affected by excessive rainfall, flooding, and occurrences of tropical storms (FAO, 2023).

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[8] 15520-WB_Colombia Country Profile-WEB (3).pdf (worldbank.org).

3.6 North America

Climate change has affected growing conditions of crops in North America in various ways already too. Ray et al. (2019) find that historical trends in cropping yields of maize, soya bean, barley and wheat vary from strong increases to strong decreases and even for the same crop (e.g., > −0.5 to > +0.5 t $ha^{-}1$ yr^{-1} for maize) across North America’s agroecological regions. Other evidence shows that overall agricultural productivity in North America has decreased by 12.5% since 1961 as a result of climate change, with progressively greater losses moving south from Canada to Mexico (Ortiz-Bobea et al., 2021). A recent USDA/ERS study states that although corn and soya bean yields have doubled since the 1970s in the USA, damaging effects of extreme weather events such as droughts and floods have slowed yield growth (Beckman et al., 2023). Climate change is projected to further reduce overall yield growth of important North American crops (e.g., wheat, maize, soya beans) in the future.

Figure 3.4 show diverging paths projected for corn and soya bean production in the USA. While U.S. corn yields are projected to increase with 3.1%by 2036, U.S. soya bean yields are projected to reverse their growth trend and decrease 3.0% due to the vulnerability of the crop to changing weather patterns. Whereas some States are expected to feel the effects of climate change on yields more profoundly than others, with declines in productivity mainly being concentrated in central States (Beckman et al., 2023).

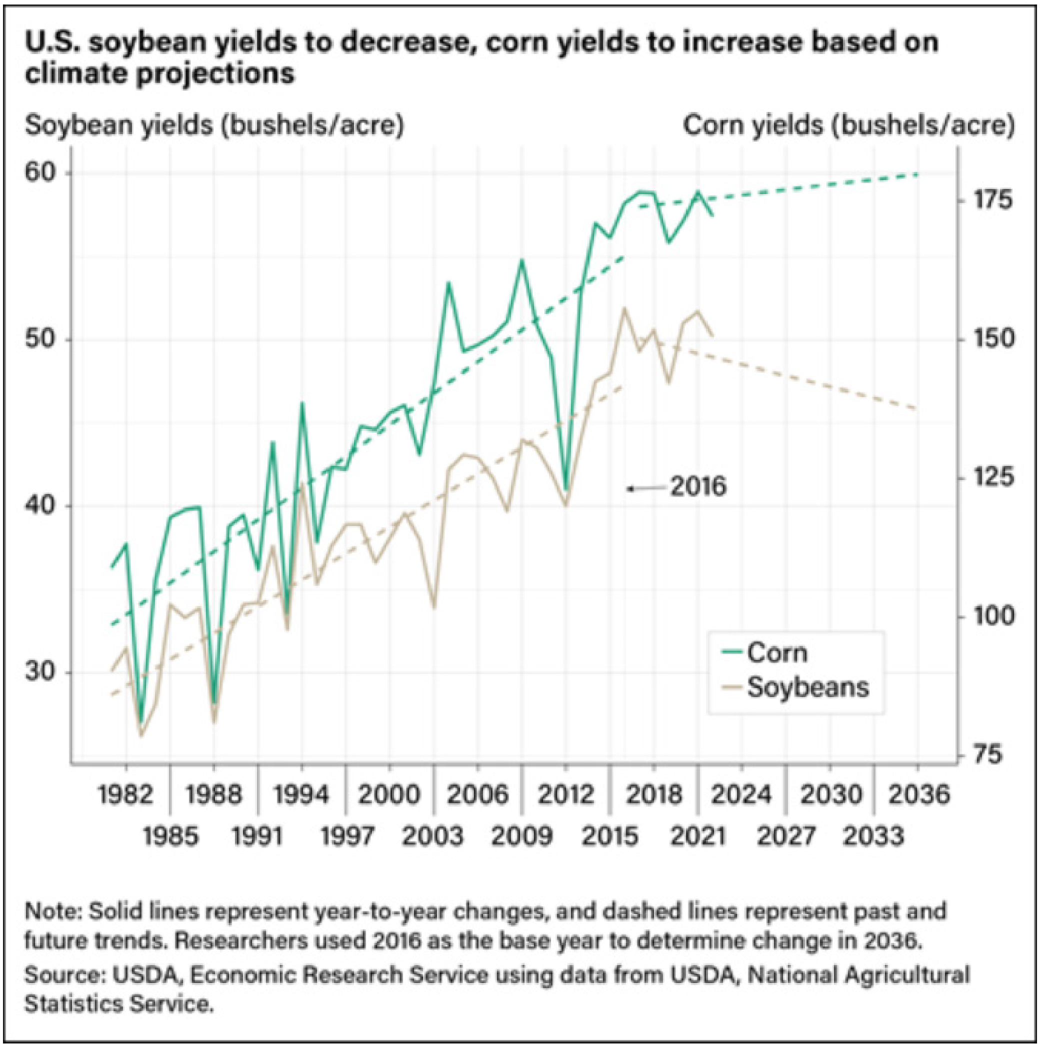

__Figure 3.4__ Future projections for corn and soya bean yields in the U.S.
Source: Beckman et al. (2023).

For a high-latitude country like Canada, future warming is expected to be more pronounced than the global average. Climate models for Canada, show that Canada's cold season will shorten, leaving a longer growing season. Warming accompanied by increased CO_2 may benefit crop production of small grains in southern Canada up to a 3°C global warming level, although benefits decline after 2.5°C of global warming.[9]

Kang et al. (2022) evaluate the effects of climate change on crop yields in Atlantic Canada, focusing on a region known for rain-fed potato production, often rotated with cereals like barley and oats. The study finds that climate change will negatively impact potato and barley yields. Despite increased precipitation, the negative effects of rising temperatures and the resulting water stress are likely to reduce crop yields.

3.7 Asia

East Asia is likely to experience significantly more warming and wetting, with extended extremes in intensity and frequency under 2°C of warming (You et al., 2022). This will manifest in increased weather extremes of cyclones, droughts, floods, heatwaves and thunderstorms (Singh et al., 2021). Under the average warming by 2040, sixteen million more people in Asia will be exposed to sea level rises, and 1-in-100 year extreme sea level events are likely to become annual events for many South-East Asian countries (IPCC, 2023). The monsoon region under all climate scenarios is likely to see a shift in its climate, with tropic and arid regions expanding, while temperate, cold and polar climates will shrink (Kim and Bae, 2021). In East Asia, monsoon patterns are projected to lead to increased precipitation in summer and a decrease in winter precipitation (Ham et al., 2018; see Figure 3.5 below on monsoon patterns). The monsoon season is likely to be extended in the Northern Hemisphere especially in East Asia, but will decrease in the Southern Hemisphere (Wang et al., 2021; Son and Bae, 2015). Some parts of East as well as North Asia have already observed an increase in plant growth season; meanwhile, other parts of Asia have not yet experienced changes or reversed changes (Shaw, 2022). For key crops like tea a northward shift of the distribution of climatically suitable areas is foreseen. Myanmar, Thailand and Vietnam could lose 57.8% of their climatically suitable areas, whereas China and Japan are projected to increase by 2.7% under a medium climate change scenario (Xiaoling et al., 2019). In China, maize, rice and wheat crops are likely to shift northwards by 2050, with this shift being minimal in a medium warming scenario (Zhang et al., 2017). The crop yields will remain stable or increase due to increases in temperature and the CO_2 fertilisation effect (Zhang et al., 2021). Currently, China has already matched shifting climate patterns with rice cultivation areas and this is true for the northwest region of China in particular (IPCC, 2019; Shi et al., 2014). A northwards shift of production of wheat and maize is also likely to benefit from increased precipitation under a medium warming scenario, which would lessen the threat of water resource issues (Xiao et al., 2020).

According to some studies, the research on climate change impacts in Central Asia is scarce compared to other regions (Vakulchuk et al., 2023). What we can tell is that climate change is causing fluctuation of river discharge and stream catchments (Didovets et al., 2024) which can have mixed results for water security in the region. Furthermore, the Aral sea which used to be the 4th largest inland sea has been reduced by 90% in size, due the economic activities during Soviet times, and now this undeveloped, arid, agricultural dependant region will be further stressed with droughts and temperature extremes while having low ability for adaptation (Sultonov and Pant, 2023). However, climate models suggest a 12% increase in wheat yields if temperatures moderately rise (Sommer et al., 2013) and all 15 models involved indicate that the region will experience increased precipitation under all climate scenarios (Jiang et al., 2020). These findings suggest that climate change will lead to more pronounced seasonal differences in precipitation patterns across the region. These could lend to more frequency of extreme droughts and floods as a result of periods of excessive rainfall and prolonged dry spells. For other key crops in the region such as cotton this could shift production zones north and east, which would move the production zone into currently forested, grassland or natural reserve territory (Mai and Liu, 2023).

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[9] Climate Change in Canada | Climate Atlas of Canada.

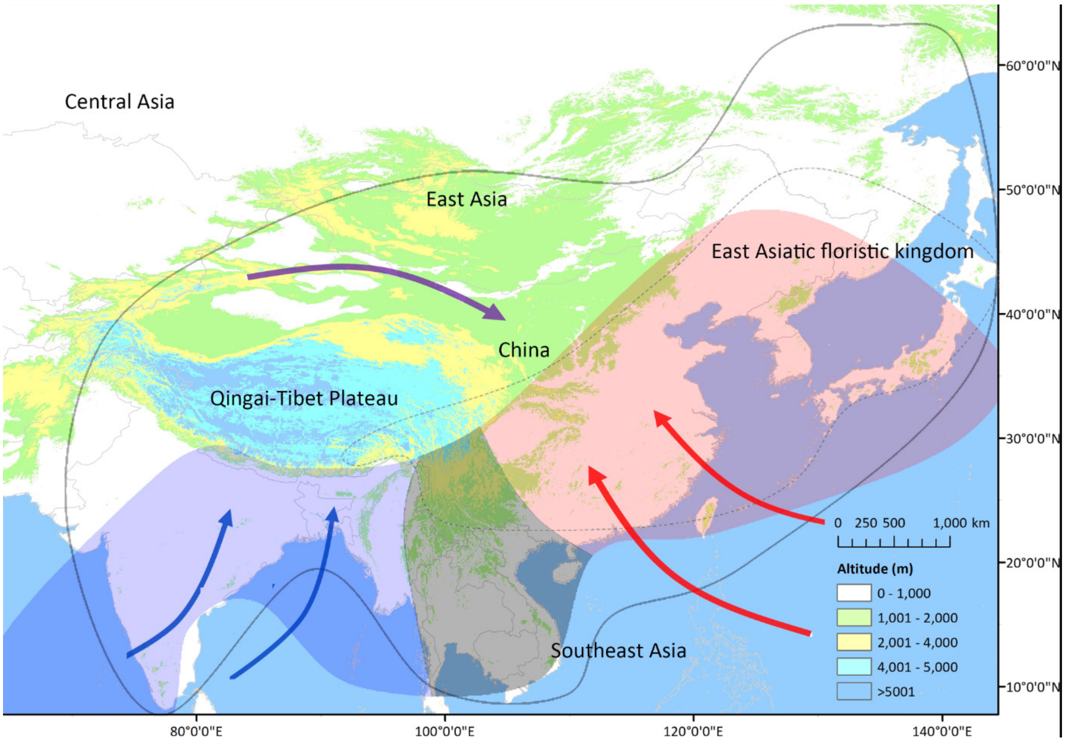

Figure 3.5 *The East Asian monsoon system which encompasses the East Asian summer monsoon (EASM, red arrows), the Indian summer monsoon (ISM, blue arrows), and the Asian winter monsoon (AWM, purple arrows). Ranges of East Asia (Manchester et al., 2009) and East Asiatic floristic kingdom (Wu and Wu, 1996) are illustrated through a black line and a dotted line. The modern summer monsoon areas are those recognized by Wang and Ho (2002); red, blue, and grey areas indicate the EASM, ISM, and transitional region of the EASM and ISM, respectively*
Source: Cited from Ye et al. (2022).

North Asia is classified as boreal land and forests, encompassing mostly Siberia in Russia's far east, the Northern Islands Hokkaido in Japan, Korea and North East China (Grishin, 1995). A study on growing degree days of small cereals has concluded that by the year 2100 roughly 76% of the boreal region might reach feasible growing degree days compared to the current 32% (King et al., 2018). This means the growing region for small cereals will vastly shift vertically on a global scale but this will have to be managed with the highly seasonal water variations of the region (King et al., 2018). Another study suggests that region will also be met with increased precipitation under all future climate projections, especially during the winter months, which may impact the seasonal water variations (Wu et al., 2024).

Temperature rise will negatively impact crop yields in tropical parts of South Asia where these crops are already growing at their temperature ceilings (Sivakumar and Stefanski, 2010). Overall, the region will find multiple challenges to adapt as climate change will increase flash floods, drought, salinity, cyclones, storms, landslides and irregular precipitation (Saidur Rhaman et al., 2022). This irregular precipitation could lead to changes in the productivity of current coconut, oil palm and rubber tree plantations in the insular part of South East Asia, while an increase in temperature will allow for the potential expansion of rubber and coconut cultivation in the northern mainland (Appelt et al., 2023).

On a global scale, India is a major producer of rice, wheat, pulses and also produces barley, peas, maize, millet and soya beans in significant amounts.[10] Increasing global temperatures will have significant impacts on the country's agricultural output (Mendelsohn, 2014; Mall et al., 2017; Pathak, 2023). Climate change will result in increased frequencies of extreme weather events, increased precipitation, droughts, floods and cyclones, with adverse effects for fresh water supply from Himalayan glaciers and rivers (Krishnan, 2020; Verma, 2021). Himalayan glaciers are melting at rapid rates and in the future melt waters will initially increase runoff through the major river systems, maybe even leading to floods, but this will be followed by

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[10] India at a glance | FAO in India | Food and Agriculture Organization of the United Nations.

dry spells and droughts as the glaciers dry up (Verma, 2021). For irrigated rice, a rise of up to 3°C is likely to result in higher water requirement but the use of water-saving techniques can greatly reduce the water needs in key rice growing regions of India and mitigate the risk to current growing regions (Surendran et al., 2021).

3.8 Australasia/Oceania

With increased global temperatures and rising sea levels, locations such as atolls, coasts, deltas and river flood plains may become uninhabitable in certain regions of Oceania (Campbell et al., 2014). The small pacific island nations also face issues of crop failure due to drought, while the islands rely almost exclusively on precipitation for their fresh water and have very shallow ground water reserves in the best case (Liu, 2007). The small size of the islands means climate patterns offer little opportunity for adapting food-growing conditions. In the case of Vanuatu, for example, the 2015 drought caused the loss of all yam and taro crops (Savage et al., 2021). Future impacts of climate change on water quantity and quality in Pacific Island states are subject to large uncertainties in global climate models and results should be interpreted with caution (Grose et al., 2014; Iese et al., 2021). For key staple crops in the Pacific Islands - sweet potato, banana, coconut and different varieties of cassava, taro and yams - increases in extreme weather events are likely to be greater challenges than changes in mean temperature (Bell and Taylor, 2015). Conclusions from the IPCC report (IPCC, 2023), Asian Development Bank (ADB, 2011) and literature (Barnett, 2020) agree that there is a negative impact from climate change in the Pacific Islands but there is no consensus on long-term impacts of higher temperatures or precipitation changes on the region. There is agreement that climate change will negatively impact food security but it is debated whether extreme weather events like cyclones are more of a threat than the gradual long-term changes. A review by Trudinger et al. (2023) found that most academic studies use qualitative data and only 20% of studies used quantitative biophysical data. The impact on the Pacific Islands is therefore unlikely to be positive but further research is needed to better understand the effects on individual islands in the region.

Australian staple crops are sorghum, cotton, rice, wheat, barley and canola. Seventy-two per cent of Australian agriculture is exported, among which grains, oilseeds and pulses have been the fastest growing export segment.[11] Climate change has already been attributed to extreme weather events in Australia, including an increase in wildfires (Canadell et al., 2021). Between 1990 and 2015, water-limited yield potential in Australia decreased by 27% due to reduced rainfall and rising daily maximum temperatures (Hochman et al., 2017). Additionally, in New South Wales high temperatures and low rainfall were found to have a detrimental effect on crop growth, especially during the reproduction stage of growth (Innes et al., 2015). Historical analyses have indicated that the spatial distribution of wheat grown in Western Australia’s wheat belt has shifted 70 km southwest of the wheat belt, but this has been limited in real yields due to improvement in water management and crop genetics (Fletcher et al., 2020). Canola production in the same wheat belt has been successfully expanded to all but the driest regions thanks to improved varieties and reliable rainfall prediction (Kirkegaard et al., 2021; Meier et al., 2020). But this expansion may face challenges due to the increasingly uncertain precipitation patterns mentioned earlier.

New Zealand’s staple food production is largely livestock based: beef and sheep make up 45% of farm types and dairy 21%.[12] Less than 1% of land use is dedicated to crop land, the vast majority (51%) is dedicated to grassland for pasture grazing (AGFIRST, 2017). The primary climate change-related concern for New Zealand is the resilience of pastures for livestock feed and studies. Keller et al. (2021) suggest that the pasture yields in New Zealand are robust to climate change, as more favourable growing conditions are seen for the winter and spring, as well as improved CO_2 fertilisation from increased GHG in the atmosphere. The primary concern lies in water-stressed regions, although New Zealand has a great wealth and abundance of fresh water from glaciers, mountains, fresh water lakes and rivers, ground water aquifers and water storage. The areas that already experience droughts (Eastern Canterbury and Gisborne) are likely to experience more frequent and severe droughts in the coming decades (Collins et al., 2012).

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[11] Snapshot of Australian Agriculture 2024 - DAFF.

[12] Statistics New Zealand, Agricultural Census 2017.

4 Effects of climate change on markets and EU food security

4.1 Impacts of climate change on global food trade

4.1.1 How climate change affects agriculture and food markets?

Climate change affects the global food markets through impacting yields, which leads to changes in production and subsequently the price of a product and consumption responses. Moreover, climate change affects agricultural trade through non-uniform effects on agricultural production between countries. Because countries will be affected unevenly through climate change (yields may increase or decline), their trade patterns will change to compensate for production losses and surpluses. These autonomous adjustments determine the effect of climate change on trade, whereby the extent to which markets can adapt to climate effects on local food production depends on the openness of borders or obstacles to trade flows.

To map and analyse climate effects on food markets, integrated models are used that include both biophysical and economic indicators (see Nelson et al., 2014; Zimmermann et al., 2018; Van Meijl et al., 2018; Janssens et al., 2020; Gouell and Laborde, 2018; and Rosegrant et al., 2023, for examples of global integrated climate change impacts assessments on agricultural trade that combine biophysical [mainly crop models] and economic models. See also Figure 4.1 to illustrate the climate, biophysical and economic a modelling chain). Studies with such integrated models show that market-mediated adjustments mitigate the effects of climate change. New climate change-induced patterns of comparative advantage within and between countries are emerging. The yield changes caused by climate change trigger large price movements that lead to adjustments in production, demand and trade, reducing welfare losses worldwide (as international prices go up), although there are winners and losers (compared to a situation when no trade feedbacks and market re-adjustments are taken into account). Typically, these model simulations are long-term foresight analyses which do not consider extreme weather events or price volatility.

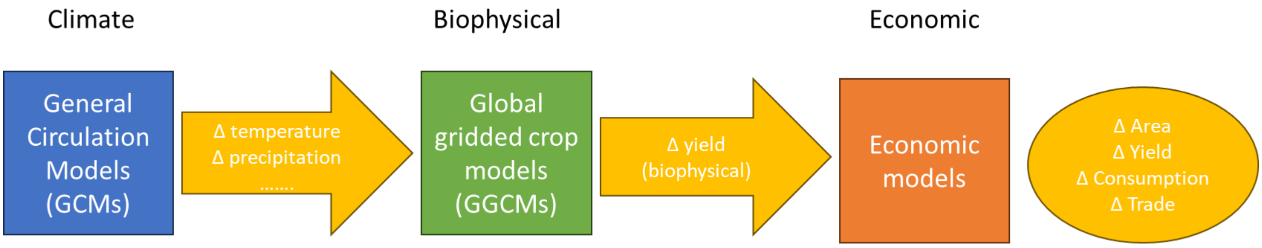

Figure 4.1 *The impact modelling chain from climate through to crop and economic effects*
Source: Adapted from Nelson et al. (2014).

There are a large number of climate, biophysical (crop) and (global) economic models, each with its own structure, parameters (and uncertainties around them) and spatial coverage. There is also a great variation in outcomes of projections of climate changes and their effects on agricultural markets. In the so-called AgMIP project (Agricultural Model Intercomparison and Improvement Project),[13] a global community of experts is working on aligning and making model outcomes comparable. Overall, model intercomparison analyses reveal consistency in terms of direction of change to climate change, but relatively strong heterogeneity in the magnitude of the effects between models. Hence, when interpreting results, it should always be taken into account that these are strongly related to the technical, agronomic and socio-economic assumptions and relationships of the models used.

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[13] From the Netherlands, Wageningen UR and PBL are partners of AgMIP – for more information, see Home - agmiporg.

4.1.2 Trade as an adaptation mechanism to climate change impacts on agricultural production

As we have seen in the previous chapter, climate change may enhance suitability of growing certain crops in an agroecological zone, potentially benefiting countries able to increase their production levels and strengthen their trade positions. In their analysis of how local and international market adjustments mediate the effects of climate change on yields, production and consumption of food globally, Gouell and Laborde (2018) illustrate that few countries will achieve welfare gains by achieving higher yields and profiting from higher prices for their export products (countries improve their terms of trade: agricultural products become more expensive compared to non-agricultural products). Agricultural prices are increasing (as a result of climate change) because food demand is generally inelastic (meaning demand will only decrease when prices go up significantly), at least for most food crops. One implication is that the countries that initially export a large share of their agricultural production (e.g., Argentina, Brazil, Canada, France, Ukraine) will benefit from climate change even if they suffer productivity losses, as the burden of climate change adaptation is shifted to consuming countries through higher international prices. The opposite is also true: countries that are net food importers suffer from terms of trade losses.

Because of these different impacts, food-importing and relatively poor countries in tropical zones are particularly vulnerable to climate change. Their high share of agriculture in GDP makes them economically more sensitive to agricultural yield shocks due to climate change. Their dependence on food imports exposes them to detrimental terms of trade shocks. And their geographic location is most exposed to the negative effects of climate change on yields. The ultimate effects of climate change on local prices depend on the flexibility of local supply and demand (high or low price elasticity of demand and/or supply) and the costs of trade. Domestic supply adjustments are an important mechanism to limit price increases due to the effects of climate change on agricultural production. Because these adjustments redistribute crop production between countries, as well as within countries, international trade plays a strong role in balancing domestic supply and demand schedules in the new situation. It follows that the ability of countries to adapt to climate change is also strongly related to their ability to adapt their import sources.

4.2 Impacts of climate change on EU trade flows and security of supply: results from model projections

Some recently conducted studies on climate change effects on European food markets while accounting for global market feedback are Blanco et al. (2017) and Hristov et al. (2024). Both studies incorporate biophysical simulations into the agroeconomic model CAPRI, which provides results simultaneously at the global level (around 40 trade blocks all around the globe) and at a more disaggregated level within Europe (around 270 NUTS 2 regions). Time horizons of the projections are 2030 in Blanco et al. (2017) and 2050 in Hristov et al. (2024). Despite this and other differences between the two studies, findings of both studies are in line with each other.[14] Due to its more pronounced impacts estimated - which may be due to the longer time horizon considered - we summarise the results of Hristov et al. (2014) below.

In Hristov et al. (2024) yield shock scenarios are simulated for six crops: wheat, barley, grain, maize, rice and soya beans. The analysis shows that while agricultural productivity in relevant non-EU agricultural production and exporting regions decline significantly, the EU farming sector may be benefiting given their competitive advantage in terms of lower biophysical yield losses, especially in the Northern parts of Europe where in some regions biophysical yields increase. Trade responses and market re-adjustments are the main reasons for a potential increase of EU wheat and maize production by 2050. There are, however, great differences between regions: some regions in Northern Europe along with most of Southern European

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[14] Blanco et al. (2017) show results of scenarios in which carbon fertilisation effects are included and in which they are not. Results assuming no carbon fertilisation are in line with those of Hristov et al. 2024 which only presents scenarios not including carbon fertilisation effects. Plants use sunlight, carbon dioxide from the atmosphere, and water for photosynthesis to produce oxygen and carbohydrates that plants use for energy and growth. Rising levels of CO_2 in the atmosphere drive an increase in plant photosynthesis—an effect known as the carbon fertilization effect. Biophysical simulations show that crop productivity effects are largely determined by the degree of carbon fertilisation, leading to decreased productivity in the absence of carbon fertilization and increased productivity otherwise.

regions are expected to be negatively impacted by climate change, even after market adjustments have been made.

Cereal producers in Southern Europe are more negatively affected than those in Northern Europe (in terms of biophysical effects of climate change on yields). Soya bean yields though will be positively affected by climate change in both Northern (France and Germany) and Southern Europe (Spain and Portugal) but as the soya bean production area is rather small in both Northern and Southern Europe, absolute changes in production levels are relatively low although relative changes may seem significant. Changes in the production of wheat and maize (and barley) are much more important as they involve a much higher volume of at the aggregate level of production of the five crops included in the analysis.

The results of the study show that the interplay of climate change impacts in other major production areas outside Europe and respective trade adjustments lead to significantly different changes in endogenous (i.e., trade-adjusted) yields; market adjustment leads to a dampening effect on the climate change induced yields. In Northern Europe, despite biophysical yield increases due to climate change (i.e., longer growing season and changes in precipitation), yields are lower after market adjustments, because increased supply will depress market prices, reducing incentives to produce these crops more intensively. In Southern Europe, wheat yields, despite being heavily affected by climate change, respond positively to the adjustment of global market adjustments. As a result, negative yields in some regions become still positive, while in regions with strong negative yields due to climate change effects, trade-adjusted yields will be somewhat higher, but will ultimately remain negative.

The consequences for the EU’s trade position, however, differ per product and per region. For example, the EU will produce more rice (especially in Italy) but will remain a net importer. This also applies to maize and soya, but the net import position of the EU for these two products will decrease. The production and export of wheat will increase further (the EU is already a significant net exporter) as will that of barley. Because more barley and maize will become available in Northern Europe, the impact on livestock farming will be limited - the model even projects limited growth in livestock production in a number of regions. However, it is pointed out that productivity in livestock farming will mainly be affected by climate change-related temperature increases impacting animal health and this is not included in this study.

To illustrate how regional cereal production will change from the baseline, Figure 4.2 illustrates the results of the HADGEM2 (climate) model under a RCP2.6 (very stringent) scenario and a middle of the road scenario RCP4.5, and the effects on average yields of winter wheat for the time period 2040-2069. Figure 4.2 demonstrates the expected average yields for the period 2040-2069 under heat and drought stress conditions, based on higher CO_2 levels as identified as RCP2.6 and RCP4.6 scenarios. The aim of presenting this figure is to visualise that even under average to low climate change pathways, the benefits of elevated CO_2 are offset by the plant growth stress caused by increased drought and heat stress.

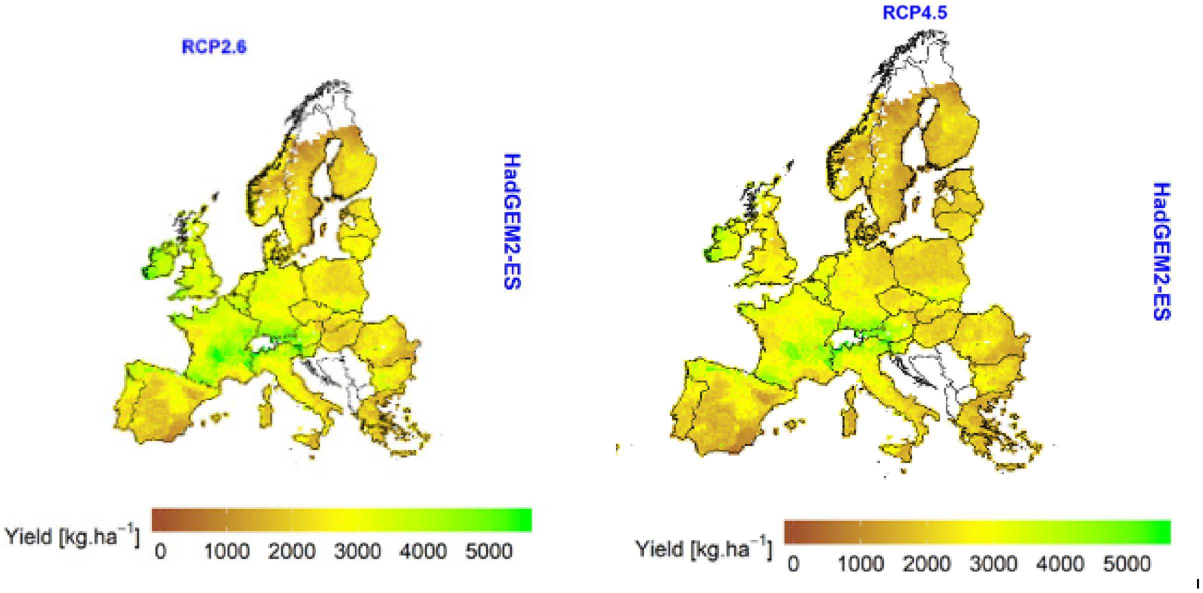

Figure 4.2 *Maps of average yield (kg/ha) for winter wheat for time period 2 (2040-2069), assuming elevated* CO_2 *levels (429,499 ppm, for RCP2.6, RCP4.5). This map is based on simulations carried out by the FA model under rainfed conditions, including heat and drought stress, corresponding to Treatment 6 (T6) (see Cooke, 2020)*

The figure above is from a third complementary paper - Cooke (2020) - using multi-crop models to simulate wheat and maize production yield under climate change scenarios. This serves as a visual aid to assist with understanding the change in harvest explained in the two papers by Blanco et al. (2017) and Hristov et al. (2024).

Both EU studies referred to above do not discuss the consequences for food security explicitly. The studies' expected production and price effects of the yield shocks caused by climate change do, however, allow a link to be made with food availability and accessibility - two important dimensions of food security - in the EU. According to Hristov et al. (2024), the EU production of wheat, rice and maize will increase and the net-trade position of the EU for these important food crops will improve, while the production of barley, soya and other (protein) pulses will remain more or less stable. For animal products, a small increase in production is expected despite higher feed costs (but this projection is surrounded by a lot of uncertainty). All in all, based on this research it can be concluded that climate change does not threaten the availability of important staple crops in the EU. The prices of food crops and animal products will increase, and these differ considerably between Member States, but at the same time at the overall EU level they will not have negative consequences for the demand and use of the products included in the analysis. This also seems to indicate that climate change has little to no consequences for the access and affordability of food in the EU. However, for certain Member States and certain (less affluent) population groups, price effects may have consequences for access to food. Further research is needed to clarify this and the potential impacts climate change may have for food utilisation (i.e., food consumption patterns) in the longer run.

4.3 Climate change impacts on products for which the EU heavily depends on imports from non-EU countries

4.3.1 Introduction

The research discussed in Section 4.2 covers important agricultural commodities produced in the EU. As presented in Chapter 2, the EU food consumers highly depend on imports from countries outside the EU for fish, tropical fruits and seasonal vegetables, coffee/tea/cocoa, soya beans and vegetable oils such as sunflower and palm oil. Except for soya beans, these products are generally not considered (in detail) in global climate and agroeconomic models. Thus, product-specific analyses are required to provide more in-depth insights into the potential effects of climate change on production and trade of these products. Therefore, for a few products, in this subsection we explore the expected climate change impacts in regions from which the EU mainly imports these products, with a brief appreciation of what this could mean for EU security of supply of these imported products in the future. In addition, product and market backgrounds are provided in text boxes (at the end of the chapter) to underpin the statements in the main text.

4.3.2 Soya beans

The EU imports soya bean/meal mainly from the USA, Brazil and Argentina. Climate change impacts in these countries point at an overall decline in yields due to changing weather patterns and more difficult growing conditions due to climate change-induced precipitation loss and temperature increase (see Section 3.5 and Section 3.6). Soya bean zones may expand in southern Canada and in Argentina, though Ali et al. (2022) estimate that Brazil’s future soya bean production would be 1.5% lower by 2030 under the scenario of lowest emissions (RCP2.6) and 2.5% lower by 2030 under the scenario of highest emissions (RCP8.5); both estimations assume that there is no effect of CO_2 fertilisation on yield. A (GTAP) model simulation of the responses of global soya bean supply and price to yield shocks caused by climate change indicates that exported volumes by the ten top soya bean producers in the world will decline and international (import) prices may significantly rise (Qioa et al., 2023).

4.3.3 Vegetable oils: sunflower and palm oil

Ukraine is EU’s main source of sunflower and rapeseed oil, while Malaysia and Indonesia are the leading suppliers of palm oil. Climate change effects in these countries may significantly affect the agronomy of these crops. Ukraine, though, is a large country with three large agroecological zones. The magnitude and direction of the climate effects vary by region and scenario but overall temperatures increase and precipitation patterns change: more precipitation in winter and spring but less summer rainfall in the southeast (USAID, 2016). Sunflower seeds are mainly produced in the southeast of the country, also the area where agriculture is currently severely restricted by the war Ukraine is involved in. It is also known that, although the soil fertility in the country is often praised, soil fertility is declining due to wind and water erosion. The consequences of climate change are added to the destruction of the present war with Russia and the associated obstacles to investing in good agricultural practices to combat soil erosion. This perspective leads Moldavan et al. (2023) to state that, in 2030, Ukrainian agriculture will have a different crop structure, with a significantly smaller area devoted to sunflowers and rapeseed. This could severely limit EU imports of sunflower seed and oil. An alternative major sunflower seed producer is Russia, but given the current political tensions, expanding trade with Russia is not opportune. There are, however, opportunities to import more rapeseed from countries such as Canada and Australia as a replacement for sunflower seed. Incidentally, the EU is the world’s largest rapeseed producer, with France and Germany being its top producers.

The largest producers of palm oil in the world are Indonesia (60% of supply) and Malaysia (25%) and obviously the EU mainly sources palm oil from these two countries, but also from Columbia, Costa Rica and Guatemala. As climate change raises temperatures, oil palm plantations encounter adverse agronomic consequences, reducing their suitability in countries around the equator. Projections for Malaysia and Indonesia suggest that yields could decrease by 30% if temperatures rise 2˚C above the optimal level and rainfall drops by 10% in Malaysia (Paterson and Lima, 2017). The areas in Indonesia and Malaysia that are now well suited for oil palm production will decrease strongly (almost by half), while there are also opportunities to shift production to new areas. However, this will mainly entail a loss of biodiversity and ecological functions of mainly forest areas. The way climate change affects the EU's security of supply of palm oil lies mainly in how the dominant suppliers deal with the consequences of climate change; after all, there are hardly any alternative suppliers. Olive, sunflower or rapeseed oil from within the EU could serve as an alternative. Other alternatives such as shea or coconut and soya oil must be obtained from elsewhere in the world.

4.3.4 Cocoa

Cocoa is cultivated in hot and humid regions, mostly in West Africa where it is mostly grown by smallholder farmers on farms averaging 2 to 4 hectares in size. Côte d'Ivoire and Ghana are by far the two largest cocoa growing countries, accounting for nearly 60% of global cocoa production, followed by Ecuador with 9%. The EU imports a large portion of global cocoa from West Africa. The Netherlands is the largest importer of cocoa beans in the world, responsible for 26% of global cocoa imports in 2016, the most recent year reported by FAOSTAT (FAOSTAT, 2019). In the Netherlands, cocoa beans are processed by several large companies into semi-finished products such as cocoa mass, cocoa butter and cocoa powder. These semi-finished products are then further processed by companies in the Netherlands into chocolate or other cocoa products, or exported (CBS, 2020).

Climate change will reduce the suitability of current cocoa production areas and shift them to regions with high forest cover. If cocoa production increases there, this will have consequences for biodiversity. Implementing adaptive agricultural practices (e.g., new varieties, irrigation or shade) is a way to make cocoa production more resistant to climate change effects. In order to maintain security of supply, the EU (the Netherlands) could support growers in current production areas.

Projections from the GAEZ v. 4 methodology show that the size of suitable areas to grow cocoa in Ghana in the future is likely to increase under an RCP 2.6 climate change scenario. However, attainable production yields are projected to decrease in the future. Results show an overall 4.8% increase in land suitability for 2050 compared to the 1981-2010 period (Figure 4.5 in text box 4.3 below). However, the overall change in yield compared to the historical situation is expected to decline by 15.6%, based on an RCP 2.6 climate change scenario. No similar assessment is available for Côte d'Ivoire.

4.3.5 Conclusion

In conclusion, climate change is reducing production in the regions from which the EU mainly imports soya, sunflower, palm oil, and cocoa. There is a risk that these products will become less readily available to the EU in the future and that their prices will increase. There are alternatives to soya and oil-bearing products, but not to cocoa. However, the latter is not a staple food but rather a luxury product that could very likely become more expensive in the future.

Text box 4.1 On soya beans

The EU heavily depends on imports of soya beans and soya meal, with over 90% of the soya used in the EU being imported from outside the EU, mainly the USA, Brazil and Argentina. Almost all soya beans are crushed into soya meal and soya oil, and almost all soya meal is used as a feedstuff in the animal feed industry to feed livestock in the EU, making the livestock potentially very vulnerable to climate change. The main driver for the EU’s import of soya beans (annual average 14.4 million tonnes in 2018-2023) and soya meal (annual average 16.5 million tonnes in the same period) is its use of soya meal in animal feed.

Annual soya bean cultivation in the EU28 increased from around 1.2 million tonnes in 2005 to over 3.1 million tonnes in 2024 (Eurostat). The main soya bean producing Member States have been quite stable in these years, with Italy producing around 50% of total production, Romania around 20%, France around 15%, Croatia and Austria around 10% and the rest of the EU28 together around 5%. All the soya beans cultivated in the EU are non-GM, because cultivation of GM soya is prohibited in the EU.

The decision of an arable farmer in the EU to grow soya beans depends not solely on yield and revenue price of soya beans, but also on the competition with other crops, such as grains (e.g., wheat) and corn. A farmer will include soya beans in the crop rotation instead of other crops if soya beans are economically more viable than other crops. Whether soya beans are more economically viable depends, amongst others, on the productivity and revenue prices compared to those of other crops. In many regions of the EU, growing conditions are more favourable for grains and corn than for soya due to climate and soil. For many EU farmers, growing other crops such as grains and corn is more economically viable than growing soya beans without a sufficiently high price premium.

The animal feed industry mainly uses soya meal, because it is a high-protein feedstuff. To replace soya proteins in animal feed, alternative plant proteins are available, such as rapeseed, sunflower seed, palm kernels, groundnut, linseed, wheat, cottonseed, DDGS, peas, beans, lupine, alfalfa, clover, quinoa, duckweed, amaranth, and potato (see Nowicki et al., 2010). It should be noted that it is not a simple replacement of soya protein for another plant protein. To ensure the same feed quality, new feed compositions need to be developed, using multiple of such alternative plant-based feedstuffs. Nonetheless, substituting soya proteins in animal feed for alternative plant proteins could have a negative impact on animal productivity, the extent depending on animal species. Replacing soya protein in EU animal feed by other plants proteins would result in a serious increase in animal feed prices, if such amounts were even available in the EU or on the world market.

In the EU, soya oil is primarily used in food, followed by biodiesel production, technical applications, and other uses. The EU uses only a fraction of the total world production of vegetable oils, and potential alternatives are available. The most used alternatives for soya oil include rapeseed oil, sunflower seed oil, and palm oil, but the extent to which these alternatives can replace all functionalities of soya oil needs to be further analysed, as well as the economic consequences of shifting towards alternatives for soya bean oil.

Text box 4.2 On palm oil

Indonesia and Malaysia are the main producing countries and provide 84% of global palm oil production. In addition to palm oil, palm kernel oil is also produced. In 2020, production amounted to 7.8 million tonnes (Oil World and DASPO, 2021). The Netherlands is the largest palm oil importer in Europe, with Spain and Italy close behind (FAOSTAT, 2021). In 2020, 2.1 million tonnes of palm oil and 0.2 million tonnes of palm kernel oil were imported into the Netherlands, intended for the manufacture of products for human consumption (CBS, StatLine, palm oil).

Indonesia and Malaysia each dedicated respectively 15 million and 5 million hectares of land to the production of oil palm fruits in 2022 (FAOSTAT). The distribution of areas suitable for growing oil palm at the current climate are shown in Figure 4.3.

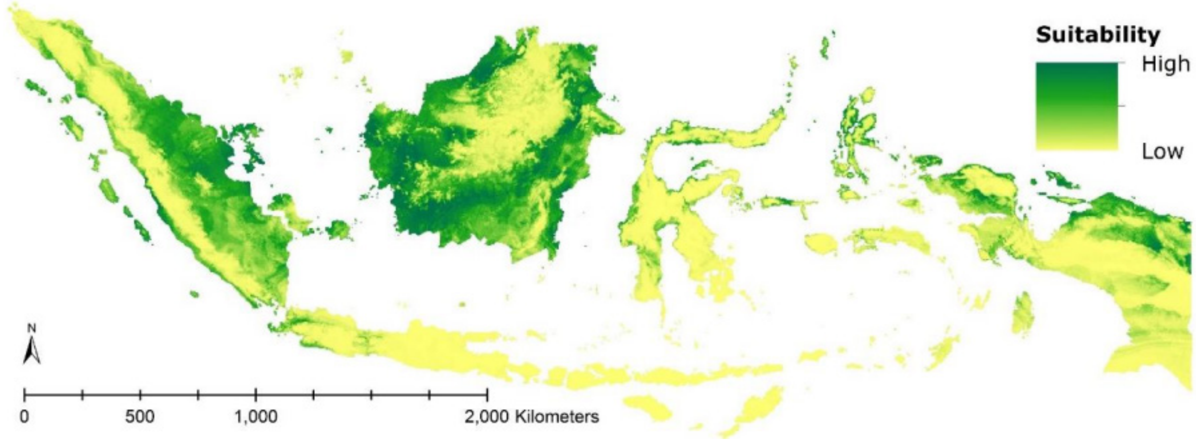

Figure 4.3 *Modelled distribution of areas suitable for growing oil palm in Indonesia and Sarawak at the current climate*
Source: Fleiss et al. (2017).

The areas suitable for palm oil cultivation are expected to shift throughout the 21st century (Corley and Tinker, 2015). Increased droughts and risk of flooding are likely to reduce oil palm yields in the future, but these losses may be partially mitigated by higher temperatures and carbon dioxide levels, which can increase plant productivity. Warmer temperatures during the 21st century will allow oil palm to grow in new locations, although the total area suitable for growing oil palm will decrease. However, adaptive management of oil palm should help reduce loss of yield, such as by preparing for irrigation, developing and planting oil palm varieties which tolerate different climates, preparing for changes to pests and diseases, and supporting pollinators (Fleiss et al., 2017).

Text box 4.3 On cocoa

Cocoa is mainly produced in West-Africa (Côte d'Ivoire and Ghana), in addition to several countries in Latin America (Ecuador) and Indonesia (see Figure 4.4.) Over the past 60 years, the area of land used for cocoa production increased by 180% (corresponding to almost 8 million hectares) and currently covers more than 12 million hectares (ITC, 2020)

The exposure of cocoa-producing regions to extreme climatic events is expected to increase as climate change progresses. Prolonged dry periods and flooding are expected to be the leading determinants of crop productivity and farmer food security (Okoffo et al., 2016). To maintain cocoa production, rainfall should be plentiful and well distributed through the year, with levels between 1,500 mm and 2,000 mm. At the same time, dry spells where rainfall is less than 100 mm a month, should not exceed three months.

Bunn et al. (2018) have modelled the effects of climate change on global cocoa production based on a RCP6.0 climate scenario. Their study projects the overall climatic suitability to decrease across the most important cocoa growing regions in the world. Available areas of high suitability will be diminished while areas with low suitability scores may be increasingly available. Most of the positive suitability changes for cocoa growing were found in regions that hold high forest cover (Hansen et al., 2013). Bunn et al. (2018) furthermore argue that the adoption of adaptive agricultural practices (e.g., novel varieties, irrigation, or shading) that expand the climatic range under which cocoa may be produced profitably may result in alternative developments of the distribution of cocoa in the future.

Figure 4.4 *Occurrence of cocoa plantations across the globe*
Source: Bunn et al. (2018).

An assessment of the change in the extent of suitable areas and yield for cocoa by agro-ecological zones has been made for Ghana through the application of the GAEZ v4 methodology. The projection shows that the size of suitable areas to grow cocoa in Ghana in the future is likely to increase under an RCP 2.6 climate change scenario, although attainable production yields are projected to decrease in the future. Results show an overall 4.8% increase in land suitability for 2050 compared to the 1981-2010 period (Figure 4.5). However, the overall change in yield compared to the historical situation is expected to change by -15.6% based on an RCP 2.6 climate change scenario. Contrary to most regions in the country which will see a decline in suitable areas for cocoa production, the Northern region and Savannah region will experience an increase in suitable areas for cocoa production and therefore production yields, although this will not be sufficient to offset the projected decline in attainable production yields from other regions. A similar analysis based on the GAEZ methodology is not available for the other main cocoa producing country, Côte d'Ivoire.

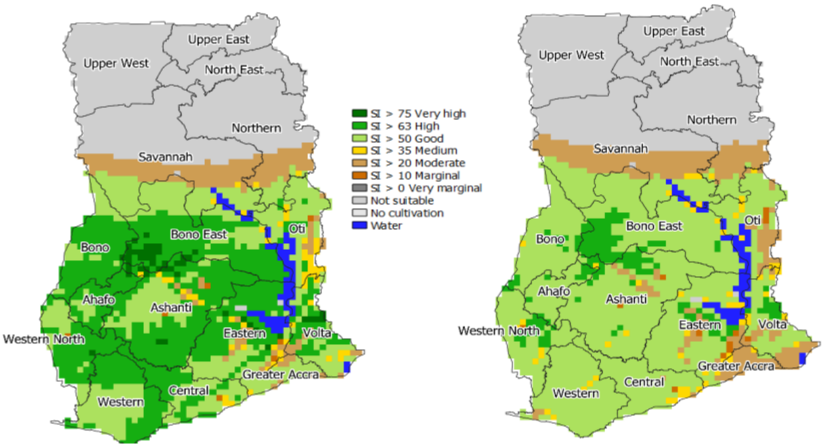

Figure 4.5 *Suitability of cocoa in the periods 1981-2010 (left) and 2050s (right)*
Source: Ghana country profile (GAEZ methodology).

5 Major findings and some policy adaptation recommendations

This report analyses how climate change will impact global food production and international trade in food and agricultural commodities, and what consequences these shifts can have for the availability of and access to food in Europe and the Netherlands. To answer the question, the latest literature has been used. This includes a disclaimer: calculating climate effects on agricultural production is very complex due to the multitude of climate and biophysical factors that play a role and the assumptions that have to be made about them. In that light, the results of studies are an indication of a possible future, and not a prediction of what it will be.

Major findings

- The EU is the world's major exporter of agricultural and food products but also an importer of a wide range of products, such as tropical fruits and nuts, coffee/tea, oilseeds and fats and oils. More detailed trade data show that EU imports from 30 countries amount to EUR 1 billion or more, which demonstrates the great diversification of the origins of the EU's agricultural and food imports, but for some products the concentration of suppliers outside the EU is high.
- Climate impacts in Europe are leading to shifts in crops from south to north, as the south experiences higher temperatures and less/more irregular precipitation and the growing season in the north is extended. Biophysical yields increase in northern EU and decline in southern regions although significant differences in yield developments occur due to climate change.
- Outside the EU, climate impacts on agricultural production and productivity are already clearly visible. This is particularly the case in MENA and SSA, where climate change has already led to lower yields per hectare. Further warming and increasing water scarcity are leading to declining expected yields of key food products in these regions, where rapid population growth is also expected.
- In Latin America, changing weather cycles and further warming also often negatively impact agricultural yields of soya, corn, quinoa and potatoes, but also of coffee and bananas. Within North America, the production of soya and grains will shift northwards, with an expected decrease in yields per hectare for soya.
- In Asia, shifts in crops from south to north are also occurring as a result of climate change, but in China this does not seem to have negative consequences for the yields of wheat, rice and corn. This is in contrast with countries in South Asia (e.g., India) and Southeast Asia where further temperature increases lead to reduced grain and plantation crop (palm oil) production. Climate change leads to shifts in crops in Australia and requires better water management to limit the effects of drought and temperature increases on basic food products.
- Climate impacts on agricultural production vary widely across regions of the world and market linkages (domestic and through international trade) help to dampen the effects: supply and demand are brought back into balance, but at a generally higher price. The consequence is that countries that currently export a large part of their agricultural production will benefit from climate change, even if they suffer productivity losses, because the burden of climate change adaptation shifts to consuming countries through higher international prices. The converse is also true: countries that are net food importers suffer losses in terms of trade. Because of these different effects, food-importing and relatively poor countries in tropical zones are particularly vulnerable to climate change.
- Domestic supply adjustments are an important mechanism to limit price increases resulting from the effects of climate change on agricultural production. Because these adjustments redistribute crop production across countries, but also within countries, international trade plays a strong role in balancing domestic supply and demand schedules in the new situation. It follows that the ability of countries to adapt to climate change is also strongly related to their ability to adjust their import sources.

- Studies analysing climate impacts on production and use of cereals and soya indicate that climate change does not threaten the availability of major food crops in the EU. Prices of food crops and animal products will increase and vary considerably between Member States, but at the same time they will not have a negative impact on the demand for and use of the products included in the analysis at EU level as a whole. This also suggests that climate change will have little to no impact on access to and affordability of food in the EU. However, for certain Member States and certain (less affluent) population groups, price effects may have consequences for access to food. Further research is needed to clarify this and the possible impacts of climate change on food use (i.e., food consumption patterns) in the longer term.
- Climate change is causing a decline in production in the regions from which the EU mainly imports its soya, sunflower and palm oil and cocoa. There is a risk that these products will become less readily available to the EU in the future and that their prices will increase. There are alternatives to soya and oil-bearing products, but not to cocoa. However, the latter is not a staple food but rather a luxury product that could very likely become quite expensive in the future.

Finally, the various shifts of agroecological zones due to climate change will require significant adaptation strategies, including breeding new crop varieties, changing farming practices, improving water management, and developing policies to support farmers in transitioning to new agroecological conditions. The shifts, however, will also have broader implications for food security, economic stability, and the livelihoods of farming communities worldwide.

Suggested policies to adapt to climate change effects.
Short-term trade-distorting effects caused by extreme events are primarily the responsibility of the private sector, which must safeguard against risks that could disrupt the continuous flow of supply. This can be due to extreme weather conditions that cause harvests to fail, but also due to logistical problems or wars that can cause the flow of supply to come to a standstill. In practise, companies conclude (long-term) contracts for this purpose and spread risks by obtaining raw materials from multiple suppliers in different regions. Companies can also diversify their business and thus reduce their dependence on one commodity.

There is a government role to play in limiting the potential climate impacts on food security of EU citizens. At the European level, the European Commission, Council and Parliament are jointly responsible for developing a strategy to combat the consequences of climate impacts on food security. Such a strategy could include the following components:

- Conclude trade agreements to gain and guarantee access to as many markets as possible outside the EU. This is a continuation of the EU strategy to conclude trade agreements with third countries in a cautious manner – namely through gradually reducing tariffs and expanding tariff-free import quotas. Free(er) tradability of food is a crucial adaptation measure to climate change but there are also concerns about the environmental impact of more intensive trade (Anderson, 2022). In order to address the environmental impacts of increased trade the EU should further promote the globalisation of regulations and standards, taking into consideration sustainability requirements in the development of trade agreements. Moreover, the EU should encourage an increase in the transparency of the production systems in exporting countries to promote the sourcing of sustainable import products.
- Support regions vulnerable to climate change to limit its impact on local production (and indirectly EU imports) or to help implement adaptation and mitigation strategies. Examples of such aid include investment support to improve climate-smart agricultural techniques, increase soil fertility and reduce crop losses. However, the EU itself also has a major role to play in mitigating climate change effects.
- Promote growing crops that can serve as an alternative to the product that now mainly has to be imported from outside the EU – examples are protein crops as an alternative to soyaa; algae as an alternative to palm oil.
- Make efforts to adopt a strategic sustainability perspective as a means to mitigate the risks of supply disruptions for the agri-food sector. Such a strategy is also in line with the Commission’s ambitions expressed in the Farm to Fork strategy, as part of the European Green Deal. Engaging in greater resource efficiency and sustainable supply chains will prevent rapid resource depletion and create long-term security of supply.

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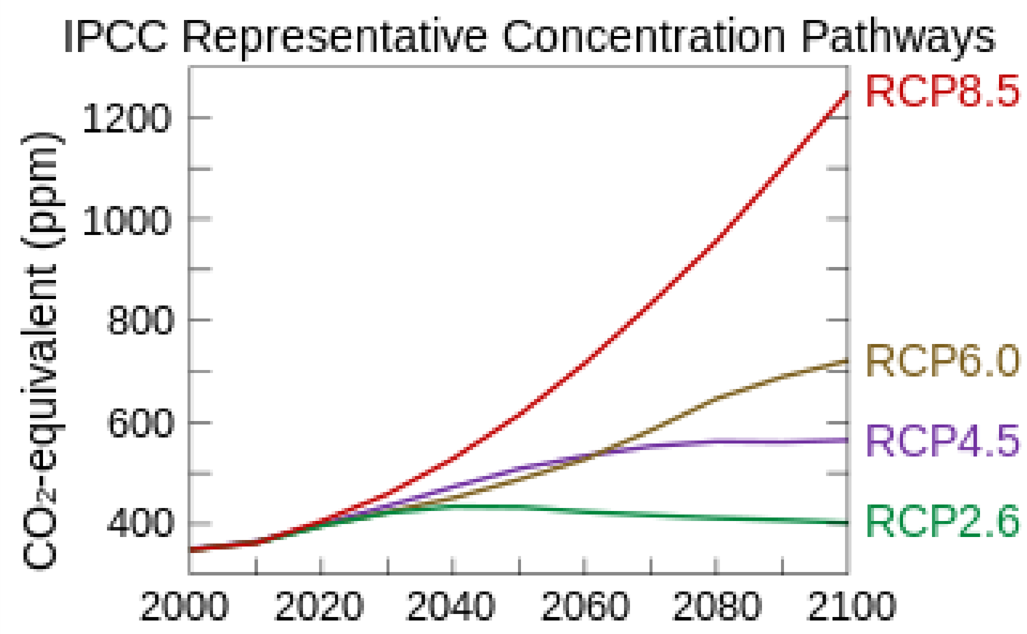
Appendix 1 Representative Concentration Pathways (RCPs)

Representative Concentration Pathways (RCPs) are climate change scenarios for projecting future greenhouse gas concentrations. These pathways (or trajectories) describe future greenhouse gas concentrations (not emissions) and have been formally adopted by the IPCC. The pathways describe different climate change scenarios, all of which were considered possible depending on the amount of greenhouse gases (GHG) that would be emitted in the coming years. The four RCPs - originally RCP2.6, RCP4.5, RCP6, and RCP8.5 - are labelled according to a possible range of radiative forcing values in the year 2100. The higher values mean higher greenhouse gas emissions and therefore higher global surface temperatures and more pronounced climate change effects. The lower RCP values, on the other hand, are more desirable for humans, but achieving them would require more stringent climate change measures.

RCP 1.9 is a pathway that limits global warming to below 1.5 °C, the aspirational goal of the Paris Agreement. RCP2.6 limits warming to 2°C, RCP4.5 limits warming to 3°C and the earth exceed 4 °C in the RCP8.5 pathway. The RCP 8.5 pathway has been thought to be very unlikely, but still possible as feedbacks are not well understood. RCP8.5 is generally taken as the basis for worst-case climate change scenarios. It is still used for predicting mid-century (and earlier) emissions based on current and stated policies (Source: Van Vuuren et al., 2011).



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To explore
the potential
of nature to
improve the
quality of life

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