The Hague Centre for Strategic Studies

THE NETHERLANDS IN THE GLOBAL FOOD SYSTEM

A METAFORESIGHT STUDY

The Hague Centre for Strategic Studies

GLOBAL TRENDS

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The Hague Centre for Strategic Studies (HCSS)

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FOREWORD

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The Netherlands is one of the world's leading countries in terms of food production and trade. The Dutch agro-food industry complex is well developed. World class technology is maintained by continuous innovation and close cooperation with clients. The agricultural sector, the food processing sector and the suppliers of food equipment and systems in The Netherlands have traditionally cooperated intensively and exchanged much information. This is the basis of its position as the world's second leading exporter of agricultural products, including processed food.

The world of food is changing rapidly. Significant challenges regarding ecological sustainability and those that have emerged as a result of our world's more volatile and uncertain state can be expected. This study was produced in this context and as part of the close cooperation and support HCSS provides to the Dutch Ministry of Economic Affairs on these topics. We hope that this study contributes to the understanding of future developments and to the development of a Dutch national food strategy.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This study addressed the question of future food challenges and how these may play out. Part of the analysis focused on the question as to how we may enhance our understanding of the effects of climate change, increased population growth and rising incomes worldwide on future food systems. The worldwide food system is vulnerable to many influences. The approach used in this study focused on the most significant possible influencers of drivers, or the elements having the most effect on how drivers will develop. This approach was employed due to our understanding that the system's complexity cannot be reduced to the drivers alone. The applied research method however allows us to look at the different aspects while recognizing their interlinkages.

In combining the most relevant aspects, it was clear from the outset that we are dealing with a complex and uncertain system of which we cannot oversee all possible interlinkages and for sure cannot predict all of their effects, and that these effects will influence parts of the food systems that might react in unexpected ways. These may also impact aspects of the system or countries in ways we would not have foreseen and anticipated. Financial modelling was one of the aspects that was, with the approval of our sponsor, explicitly left out of the analysis due to its complexity. The aim of this study was, therefore, not to try to predict future developments, but rather to be better aware of the role that major uncertainties play in the complex food world. The results show that there are large differences in the way that future food systems may look and behave, the effects of which can not always be influenced easily. This is an important basis for the global efforts required in developing food strategies and policies to mitigate the negative effects of climate change, population growth, etc. – or at the minimum to implement robust policies that can be implemented in an agile and flexible manner and that have the intended effect irrespective of the kind of future world we will live in. This report seeks to find out the consequences of changing dynamics in the global food system on the position of the Netherlands as a major player in the field of agriculture. In doing so the study analyzes a wide range of food products.[1] Following on this it examines what these changing dynamics mean for other countries' security of food supply and what role the Netherlands could play in addressing the resultant challenges.

For this reason, we identified the drivers, trends, and developments affecting food systems in the global economy, in terms of trade, demand, and supply. We raised several questions, such as 'What are the implications of relevant policy perspectives in the West and in emerging economies for the Dutch food system?', and 'How resilient is it to these implications and given the current priorities?' These last elements are described in the chapters on food trade and synthesis as well as in our conclusions and recommendations.

The study contains two elements. On the one hand, we set up qualitative research activities, focused mostly on the identification of relevant countries' policy approaches and on sketching the geopolitical context in which the food system and its impacts have to be placed. This qualitative assessment provided input for the quantitative research phase, which focused on the identification of statistical relations between key indicators of supply and demand. This research shows that the middle-class effect (i.e., people with higher income tend to change their food patterns), climate change effects on food systems and yield gaps (i.e., the difference between the theoretical and actual food production capacity on country level) are the most important drivers for the future global food system. In other words, they are the most important topics our policies should focus on to enhance the robustness of global food systems. For this reason, these drivers were used as the basis for the research approach.

We performed an extensive uncertainty analysis by applying the innovative research methodology Scenario Discovery on a System Dynamics model for 167 countries. Following this approach, we were able to simulate how food supply and demand may develop under different circumstances (i.e., as a consequence of different combinations of major uncertainties) for these countries through 2031. Although novel in nature, Scenario Discovery allows for a simultaneous, and dynamic analysis of big data, meaning that the models are capable of letting a high volume of variables interact, resulting in combinations that go beyond the analytical capacity of other modeling techniques.

Current trends and developments

On the basis of HCSS foresight studies on this topic,[2] the views of different foresight communities, including those of the 'West' (the US, the UK, and the Netherlands) and beyond (China, India, and Brazil), were analyzed. The stable supply of food worldwide is expected to come under increased pressure in the future. Two trends in particular are worth highlighting: on the one hand climate change and on the other pollution, diseases and inefficiencies.

Global supply issues

With respect to **climate change**, especially the Near East, Central Asia and Eastern and Northern Africa are especially prone to factors that affect epidemics and threaten the production of wheat. In many parts of the world, both water scarcity and seasonal flooding will present a major challenge to climate adaptation. Harvest failure in particular will occur in countries that will see the highest increases in their demand for food and whose populations' livelihoods depend on food production.

Next to climate change, the supply of food will be affected by energy scarcity, marine and terrestrial pollution, animal and plant diseases, food losses, and inefficient agricultural practices. These trends will not subside in the coming years, thus aggravating the overall consequences for our food systems. The loss of biodiversity in an ecosystem reduces the resistance of both crops and species towards climate change and increases the occurrence of diseases. According to the FAO, about one third of global food production, an amount equal to 1.3 billion tons a year, is lost or wasted before it is consumed by people.

Many challenges lay ahead. Human behavior, economic development and efficiency enhancing measures in combination with new technological developments might positively affect future outcomes. Technological change is a particularly important aspect here, as it can boost effective and efficient production of the agribusiness and its related processes such as logistics, trading, etc. Thus many effects play a role in the complex food system and there are no one trick technical solutions that can counter all future challenges. So, technology alone is not the solution. At the same time, in the entire agribusiness life-cycle, the sector relies on pivotal **technological changes** – and vice-versa. The capacity to integrate several technologies from different scientific fields will set the pace for the development of agribusiness. New technologies, ranging from 3D printing to genetic improvements and many others, are crucial to prevent and fight plagues and sicknesses, deal with climate change, improve productivity, establish a better link between consumers and producers, renew the industry, maximize resources, improve land productivity, and obtain environmental gains. These elements are described in the para 2.1 trends affecting supply.

Global demand issues

The trends in demand that will heavily influence the food system worldwide can sometimes hardly be influenced in the short run, and at the same time might have interrelated effects on each other. Most importantly, **demographic developments** are likely to have huge effects in combination with changing lifestyles and consumption patterns. Foresight studies indicate that rising urbanization rates will put pressure on urban infrastructure and even greater pressure on urban centers. This demographic trend may further increase the complexity of food systems, including demand and trade, modifying the economic structure first at the local, national level – but also impacting other layers given the interdependence of global supply and demand food chains.

A large number of middle-income countries will experience shifting consumption patterns in the coming years, in particular with respect to animal proteins. Demand for higher-quality food, dairy and meat is expected to increase in the developing world. Urban diets are on average more diversified and contain more micronutrients and animal proteins, as well as a considerably higher intake of refined carbohydrates and fats and lower intakes of fiber.

We found that this **'middle-class effect'** already occurs at GDP per capita levels above 1000$ and continues up until levels reaching between 20000$ and 30000$ per capita. This effect is reflected in an increase in protein and meat consumption in particular, which starts at around 20kg per capita annually, and reaches levels around 90kg per capita per year. After attaining its higher level, meat consumption gradually declines as income levels continue to rise beyond the 20-30000$ per capita threshold.

As a result of this growth in global demand, further increases in international trade can be expected. This will offer new opportunities for the Dutch (alternative) protein producing industry, amongst the traditional animal husbandry sector, to export both meat and milk and other products such as algae, in addition to knowledge and expertise. Some Dutch studies foresee a greater competition between 'food, feed, fiber or (bio)fuel', which may push up the prices of foodstuffs.

The quantitative modeling used in this study has generated interesting, and at times counterintuitive results. The model developed uses sub models for land use, food demand, food supply, agricultural productivity, and water availability, and focuses on trade potential as a main indicator for a country being able to produce the food it demands. When production is high and there is enough food for trade that is a positive indication, when the opposite is the case, this can be seen as a negative indicator for not being able to provide enough food for domestic demand.

Future trends and developments

Part of the analysis includes results that are descriptive by nature. It shows world maps and tables of countries that either have a trade surplus or do not. Timescales used are from 2011 up to 2031. The reason for doing so is that 2011 was the most recent base year for which all data was available.

The model was also used to explore the causes that impact a surplus or deficit that may arise in food production capacities of countries via the novel methodology Scenario Discovery. The main three drivers we specifically looked at were the middle-class effect (i.e., the combined effects of both economic developments and population growth), climate change (i.e., changing precipitation patterns), and the yield gap defined as the difference between the actual agricultural production and the potential of agricultural lands (i.e., maximum yield). Cultural aspects that may affect diet patterns were left out of the analysis as these are not easily quantifiable. On the basis of this scenario discovery, we identified some of the most important exploring future effects on the food system.

Future cereals and vegetal food types supply

Climate change affects the production of vegetal food types – that is, the supply side of the food system. Countries can be affected both by increasing and decreasing precipitation patterns. Those countries presently experiencing issues with droughts may be the most vulnerable to increasing precipitations – as these indeed cause soil degradation (erosion). The most important countries and regions affected in this respect include China, the Sahel region, Australia, South Africa and Argentina, as shown in Figure 1.

Decreasing precipitations affect countries in Europe, including the UK, France, Italy, and Spain, but also far beyond, including Brazil, the Democratic Republic of Congo (DRC), Nigeria, India, and Indonesia. Smaller countries in the Middle East and Southern Europe are equally affected.

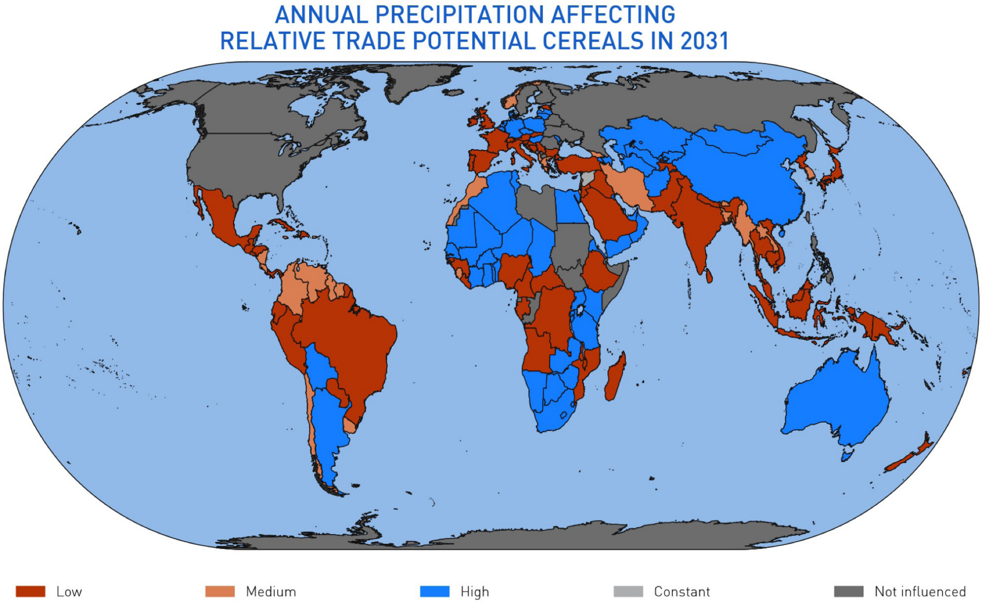

FIGURE 1. THE LOW TRADE POTENTIAL DUE TO FUTURE PRECIPITATION SCENARIOS CAUSES AFFECTED COUNTRIES TO BE MORE IMPORT DEPENDENT FOR CEREALS.

We found that on a global scale, several climate change issues may lead to a deficit of vegetal food types. However, on a national scale, and given that cereals are used as feed for cattle, the countries most strongly affected by this deficit will be those located in Sub-Saharan Africa, South-East Asia – in particular Indonesia and Bangladesh – as well as South America. European countries such as Spain and the UK will also face issues with their own cereal supply.

Soy imports are important commodity, yet cereal is and will remain the most important global feed. For this reason, it is important to note that due to the enduring cereal import dependency of the aforementioned developing economies (including most Sub-Saharan African countries), the production of cash crops in these countries will not feed into the global food market.

Bridging the yield gap may be one way to overcome this supply issue. While the yield gap for different vegetal sources may be caused by local climatological issues in countries such as Australia or Morocco, many countries still have a large, technological gap to bridge. These countries include all former Soviet states like Russia and Kazakhstan, most countries in Africa (excluding Egypt), and Central American countries (e.g., Honduras, Nicaragua, and Guatemala).

Many countries with a very high cereal import dependency are not among the most significant trading nations in the global food system (See para 4.2). Yet, taken together they make up a large share of the global population, especially through 2021. This makes identifying approaches to deal with their large import dependency even more crucial.

Future meat demand

We found that current estimates for GDP heavily affect the extent of the middle-class effect. If low current GDP estimates are accurate, the middle-class effect is most strongly felt in most Eastern European and Asian countries, including China and India. Some African countries – such as Ethiopia and Tanzania, but also the DRC and Mali – appear to be on the edge of the middle-class effect somewhere in the coming 15 years. Their global impact on food demand may be limited at the moment, yet taken together these African countries represent a significant share of the global population. As such, their impact on the future of meat trade can be expected to be considerable.

On a global scale, if no policy changes occur, none of the model runs showed that meat supply would match meat demand in 2031. The same applies also to other animal foods such as milk.

On a local scale, we found that China, India, Vietnam, Mexico, the Philippines, Myanmar, Pakistan, Indonesia, Colombia, and Egypt have the highest absolute meat import dependency in 2031. The Netherlands currently does not maintain trade relations with the Philippines, Myanmar, Pakistan, and Egypt. All these countries are developing economies, meaning their meat demand may substantially increase through 2031. At present, India is a net exporter of meat – but is set to potentially become one of the most significant meat importers. Additionally and as previously mentioned, the middle-class effect is already felt at low income levels. Therefore, we can expect that all African countries, because of economic growth, will also become important meat importers – this goes in particular for Egypt, South Africa, Ethiopia, and Nigeria. Further, Iraq and Saudi Arabia are two Middle-Eastern countries which, if political stability allows it, are set to see their meat import dependency increase.

Conclusions and policy recommendations

The challenges for the global food system are immense. The conclusions and recommendations in this report focused on the policy consequences for Dutch trade, development aid and knowledge and innovation. The scope for that reason was limited due to the complexity for applying the methodologies, and limitations to the project.

For that reason financial aspects and speculative issues were not taking into account. Cultural influences were not modelled either. And elements such as the intrastate flow of goods, urbanization and the challenge of how to feed megacities were not explicitly addressed.

On the basis of the Scenario Discovery, and given the limitations of the methods used, it is however possible to better understand the future consequences of the development of the most important drivers for the food system worldwide. It enables analysis of the plausible effects for individual countries over time. For policy makers, it is important to have clear aims, on the basis of which they can pinpoint their policies. The sustainable development goals (SDG2) targets are, or should, as a reference act as the basis for policy. Hunger and undernourishment is an overarching worry of the global community. The question therefore is whether the foreseen protein deficit can be dealt with adequately in time.

The analysis in chapter 3 shows that some countries that the Netherlands has focused on, either because of development aid goals, trade opportunities or other reasons, might need to perform a re-evaluation in the light of the insights from this analysis.

The analysis shows that relevant policy goals include the targeting of other or additional countries and to place greater emphasis on those countries affected by the **trends** and drivers identified. Also, more attention should be paid to the various **trade** partners that will gain in importance (e.g. Brazil, Canada, US and New Zealand for meat and Russia, Canada and Australia for cereals), and the evolution of Dutch export **knowledge.**

- Climate change effects are of particular importance for policy formation given the way in which they will affect the global food system. Whereas existing policies are mostly concerned with dry climatologic patterns, policies ought to focus on dealing with higher precipitations instead. Countries experiencing semi-arid conditions may also benefit from knowledge focusing on how to deal with flooding and other water-related soil degradation. Therefore it is important that both the effects of precipitation and drought are taken into account simultaneously given that both will have significant effects on countries' yield gaps.
- As the **middle-class effect** can be felt already at low GDP levels, the following countries were identified as areas of concern: China, India, Vietnam, Mexico, the Philippines, Myanmar, Pakistan, Indonesia, Colombia and Egypt. On a global scale, if no policy changes occur, none of the model runs showed that meat supply would

match meat demand in 2031. The same applies also to other animal foods such as milk. Meat and protein production, as the analysis shows, will not be on par by 2031, and countries have to deal with these deficits.

- There are **tremendous challenges** faced by a wide range of countries that will both be in need for support both from a humanitarian point of view, as well as lacking yield for their own people. This will create possibilities for the Netherlands agro-food eco-system including knowledge institutions, NGOs, governmental organizations and businesses.
- Existing **Dutch knowledge export**[3] is primarily directed to China, Indonesia, and India, and mostly concerns the growth of total factor productivity, next to water and energy shortages. In terms of productivity gains however, yield gap countries such as those from the CIS region (Russia, Kazakhstan, Turkmenistan), Central and South America (Guatemala, Honduras, Nicaragua, Panama, Bolivia), the Middle East (Iran, Jordan, and Iraq, Syria, both difficult at the moment because of the conflict) and Africa (Ethiopia, Kenia, Tanzania) should receive attention as well.
- As far as **Dutch trade relations** are concerned, future export partners will still include Germany, Belgium, and the UK in Europe. Relevant import partners currently include Germany, Belgium, and France; this circle needs to extend to Poland and other Eastern European nations. Outside Europe, export partners of importance to the Netherlands for meat will be China and India, and several regions: Central Asia, a number of ASEAN countries such as Indonesia, Malaysia and Brunei, the Middle East and Africa (see **Dutch knowledge export** above), Central and South America. Import partners beyond Europe should include Brazil, Canada, the US, and New Zealand for meat, while for cereals, partners should include Russia, Canada, and Australia.

INTRODUCTION

INTRODUCTION

The Netherlands holds a significant position in the global food system.[4] In 2013, it was the 8th largest export and import economy in the world,[5] and the second largest net exporter of agricultural products after the US in monetary terms.[6] Within the EU, the Netherlands occupies the 6th place in terms of the size of its agricultural market and it acts as an important provider of dairy, meat, fruits and vegetables to other European member states.[7]

Although the Dutch agricultural sector could feed its entire population in autarky at present,[8] the global food system is constantly changing, and with it, the position that the Netherlands occupies within this system. Since the 1950s agricultural production in the Netherlands has increased fivefold due to technological progress, the specialization and intensification of agriculture and farming, and many other factors.[9] Towards the future, changes in agricultural consumption and production patterns in countries around the world, population growth, the availability of arable land, water, climate change, geopolitics and other trends all have an impact on the global food system and which position our country takes up within that system. The agro-food sector is of vital importance to the Dutch economy, particularly on the supply side: cocoa, soy and palm oil are among its largest import streams. It should be noted that in terms of the main commodities imported, there are limited alternative sourcing options in Europe and few possibilities for substitution. Domestically, countries will formulate policies geared towards ensuring a stable supply of critical agricultural commodities for their own food security, as well as seek to expand their share of global export markets.

This report seeks to find out the consequences of changing dynamics in the global food system on the position of the Netherlands as a major player in the field of agriculture. In doing so the study analyzes a wide range of food products.[10] Following on this it examines what these changing dynamics mean for other countries' security of food supply and which role the Netherlands could play in addressing the resultant challenges.

Research questions
What are the drivers, trends and developments affecting food systems in the global economy, in terms of trade, demand and supply?

How resilient and relevant are current Dutch priorities, approaches and policies to these implications and future trends?

1.1 Project approach
The project entails both a qualitative as well as a quantitative analysis, whereby the former provides input for the latter. We assessed this combination to be useful in this domain, in order to go beyond traditional research whose insights and options cannot always be derived for the existing datasets and research body. With today's new and innovative modelling techniques and the considerable computer science knowledge that can be seized, more comprehensive, data-driven analyses have become possible. For this reason, a large part of the effort put into the study was devoted towards the quantitative work. Another reason was that the sponsor already has a considerable amount of data and reports of a more qualitative nature than it has on the quantitative approach that this report focusses on. In terms of the qualitative methodology, the text mining approach was deemed relevant as it makes it possible to analyse vast amounts of documents in different formats in an unbiased way. Given the project's time and scale, those quantities could not be approached in others ways.

Trends and drivers were extracted from the combination of both qualitative and quantitative methodologies, next to the separate analyses of both approaches' inputs, and next to cross checking consistency.

This research shows that the middle-class effect (i.e., people with higher income tend to change their food patterns), climate change effects on food systems and yield gaps (i.e., the difference between the theoretical and actual food production capacity on country level) are the most important drivers for the future global food system. In other words, they are the most important topics our policies should focus on to enhance the robustness of global food systems. For this reason, these drivers were used as the basis for the research approach.

The figure below shows the aspects that were taken into account while designing the project research and methodologies. A varied set of inputs was used during the course of the project, both structured and unstructured data and analysis with both a qualitative as well as a quantitative nature. By combining the different approaches it was possible to have a robust validation of results.

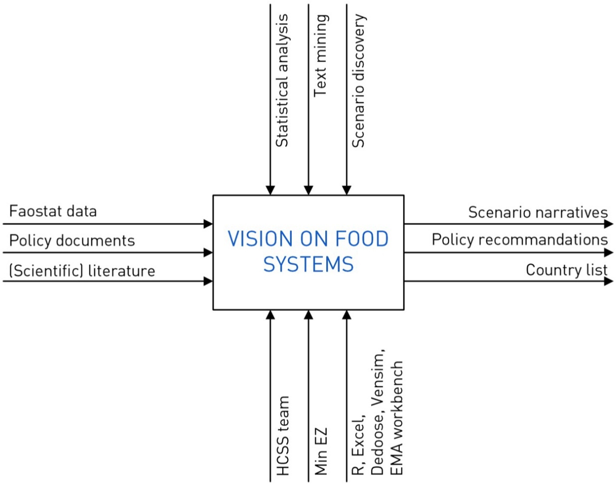

FIGURE 2. SETUP OF THE PROJECT

Qualitative work

The qualitative work focused mostly on the identification of policy approaches in relevant countries and in sketching the geopolitical context in which the food system and its impacts have to be placed. With their huge populations, countries such as China, India, or Brazil, will substantially contribute to the increase of global demand for food – particularly meat. It appears important to deduce from current trends and policy priorities the evolution of the food system through these countries' perspectives, and to better anticipate the risks, opportunities and shocks they can expect. Appendix B provides a more detailed explanation of the methodology itself, and Chapter 2 provides more background information on and the results of this research strand.

Quantitative work

The quantitative work focused on the identification of statistical relations between key indicators of supply and demand. For this work, HCSS performed an extensive uncertainty analysis by applying the novel research methodology Scenario Discovery[11] on a System Dynamics[12] (SD) model for a large number of countries (see Appendix A). SD is a modelling approach especially suitable for analyzing complex problems. The complexity in these issues is defined by the presence of feedback mechanisms across different parts of the system. An example of such a feedback regarding food production is that the increased land use for agriculture increases local water use, which leads to local water stress, which declines local productivity, which leads to an increased land use. SD allows explicitly modeling and simulating feedback structures like the one described in combination with delays and accumulation surrounding the problem of interest.

Scenario Discovery is an approach that allows dealing with another important characteristic of complex problems: uncertainty. In Scenario Discovery, the goal is to find out under which circumstances (i.e., which combination of uncertain factors and structures characterizing the problem) what kind of problem behavior will occur. This is done by generating a multitude of plausible future scenarios, and linking scenarios of interest back to the specific uncertainties causing their behavior. An example demonstrated in this report is for which countries either the high or low precipitation scenario from the fourth assessment report of the IPCC[13] will cause problems for producing future food supply. Using Scenario Discovery, therefore, leads to a what-if analysis of under which circumstances problems may arise.

Goal of modeling exercise

The goals of the analysis in the end are to determine under which circumstances food deficits will occur by:

- Calculating development of trade potential for each country through time;
- The trade potential that originates in difference between supply and demand.

Drivers as a start

Important for the analysis was the decision made, together with the sponsor, to determine what important circumstances (uncertainties) would be taken into account and which would not.

Economic development vs. population development was seen as an important aspect. In the combination these factors provide insight into the middle class effect. These effects occur when people are able to spend more money and change their diet, having multiple effects on demand and supply and – as a consequence – on trade.

Climate change – precipitation scenarios and periodic droughts or wet periods was also seen as an important aspect. The effects of yield and availability of food for consumption and trade are important for the analysis of the types of policies should be undertaken.

An important factor that, on request, was explicitly left was **food prices**. The reason for doing so is that food price scenarios are very difficult to model (in a world model per country, which would be necessary when taken as part of the model). The available time and budget did not allow for this type of modeling. Similarly, cultural aspects that may affect diet patterns were left out of the analysis as these are not easily quantifiable.

Project elements

The project work was decomposed into their different elements. The figure below shows these elements and the logical flows between them, using outputs form one element as input for the next.

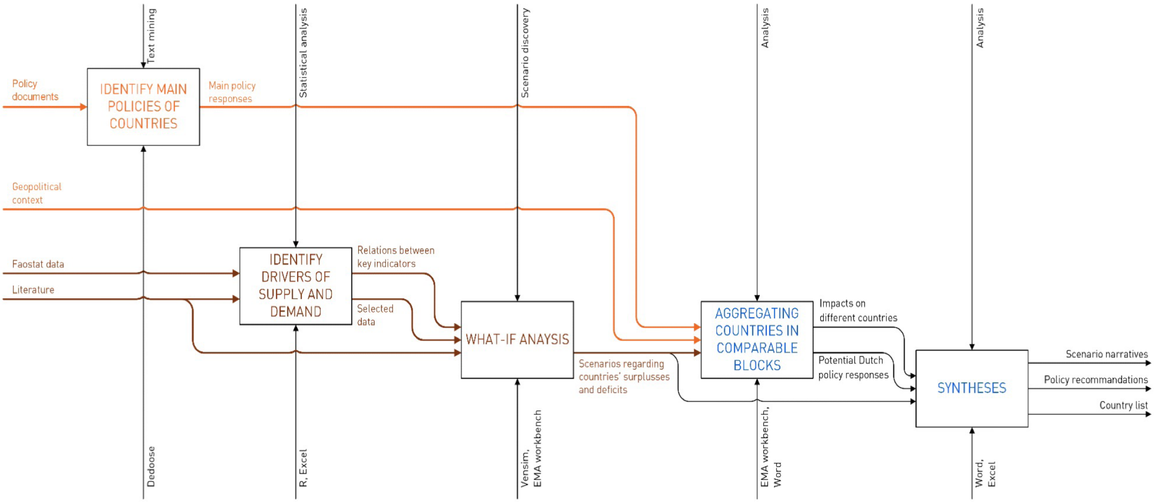

FIGURE 3. PROJECT ELEMENTS WITH TWO FLOWS

Because of the both qualitative and quantitative nature of the approach, two flows were identified. The results of both flows are represented in the report.

Specifically the quantitative modeling was a new way of analyzing for which literature analysis and data collection had to be undertaken as a basis for conceptualization and specification of the model. While developing the model test runs and actual runs were prepared and conducted. Especially what-if analyses were now possible, looking for extremes but also for no regret options.

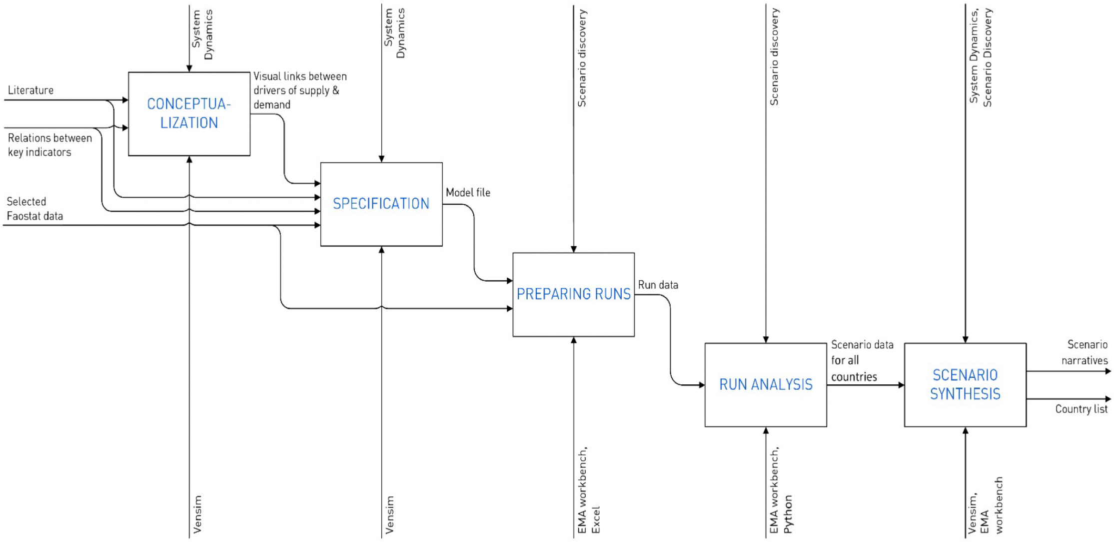

FIGURE 4. WHAT IF ANALYSIS

1.2 Readers guide

The report is structured in the following manner. Chapter 1 presents an overview of the main trends that are expected to affect the future of our global food system. Chapter 2 takes a closer look at the trade relationships of the Netherlands in the field of agriculture and highlights a number of EU and non-EU countries of particular interest given their importance to the Netherlands and their dominant position in the global food system. Subsequently, we examine some of the policy measures these countries take with the aim of either ensuring future food security, expand their footprint in the global agricultural export market, protect their domestic markets, or increase the overall efficiency of agricultural imports.

Chapter 3 presents the results of the modelling exercise, highlighting countries worldwide that are exposed to major food challenges. The chapter identifies the key challenges, where these are likely to strike the hardest and whether or how the effects, either directly or indirectly, will be felt in the Netherlands. Chapter 4 lists the report's main conclusions and identifies a number of options on how to adequately deal with the (in)direct effects of the identified challenges, as well as the policy measures formulated by important partner countries with the aim of securing the Netherlands' position as a major agricultural player well into the future.

2 TRENDS AFFECTING THE GLOBAL FOOD SYSTEM

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This chapter provides a brief overview of the main trends and developments that will affect the global food system. It will help, in a qualitative manner, in addressing the research question, as these trends will also affect the Dutch food system and policies undertaken globally. This background of developments help in understanding and anticipating the evolution of supply and demand, and should be kept in mind when exploring the future of food systems and policies. We provide some findings gleaned from the results of an extensive previous HCSS foresight study on the topic.[14] These present the views of different foresight communities, including those of the 'West' (US, UK, the Netherlands, whose overall level of competitiveness in the agricultural sector keeps playing a key role), and also beyond (China, India, Brazil). We cannot ignore that the development of large economies will continue to bring up serious challenges for the future of agriculture. And with their huge populations, countries such as China, India, or Brazil will substantially contribute to the increase of global demand for food – particularly meat.

The foresight methodology we used for the trend identification and analysis was one that HCSS developed over time and enables meta-analyses of insights described by the foresight community world-wide with an emphasis on the countries selected, in coordination with the sponsor. The foresight community is most of the time of high influence because of its capability to develop insights in possible future scenario's helping policy makers and decision makers to obtain a clearer vision as to what the future might bring and how to develop pathways to optimize course. More information on this methodology can be found in Appendix B.

The chapter describes both trends in supply as in demand but will start with some general observations of the foresights studies derived from the different country specific studies with a specific emphasis on the role of private corporation in food security. It also pays attention to possible shocks that can effect the food system.

Role of private corporations in food security

A few multinationals play a dominant role in the world market for food, as a consequence of an increasingly complex food chain. The center of gravity of this chain no longer lies at the producing end of the line, but rather with retailers and seed distributors. Although none of these multinational companies possess absolute monopolies in their part of the landscape, their relative power does give them the ability to strongly influence the Dutch food outlook – for instance through trade deals or a changed stance on intellectual property. Different views exist across the globe on the role of private corporations and food security.

The Brazilian foresight community places emphasis on a shift towards private, rather than public, control of Brazilian agriculture. This shift has spurred the growth of large agribusinesses to dominate production. Commensurately, however, there has been an increase in regulations which demonstrate Brazil's equal focus on environmental protection.

Conversely, China is more concerned with increasing levels of agricultural support through subsidies, demonstrating China's keenness for state-intervention. Financial and economic approaches seem contradictory in the case of China, whose government has shown a willingness to intervene in agricultural production in order to ensure food security. At the same time, this suggests that a shift towards a market–oriented structure can be expected.

Subsidies are also an important topic across US foresights, but instead of a clear direction, opinions regarding increasing or decreasing subsidies are conflicting. Results for UK studies reflect the concern to achieve the right balance between state intervention and letting the market allocate resources by itself.

African foresight reports give mixed messages on what should be done in terms of government policies towards agriculture. Some reports indicate that the government acts against the interest of farmers and, instead, should be far more supportive of farmers – particularly small-holders.

Private, large companies have created strong market concentrations that prevent smaller farms from entering the market. For India, market concentration is important because of the necessity to increase private sector investment. The financing of agriculture is deemed important for Indian agricultural longevity and is presented as necessary for the government to support public sector companies with business-focused strategies.

2.1 Trends affecting supply

The stable supply of food worldwide is expected to come under increased pressure in the future. Two trends in particular are worth highlighting: climate change and pollution, diseases and inefficiencies and some additional insight form the meta-foresight analysis.

Climate change

Climate change is a major threat to global food security, sustainable development and poverty eradication. The impacts of climate-related events, such as droughts, floods and wildfires demonstrate the vulnerability and exposure of food systems to a changing climate. The effects of climate change are however not distributed equally. Poor and low latitude countries such as Malawi and Bangladesh are most likely to be affected by climate change through drought and flood instances, respectively.[15] Some high latitude countries (Canada, Russia) may on the other hand benefit from the warmer temperatures and increase their agricultural production due to longer growing seasons. In other words, the impact of climate change will be unequally distributed around the world and exacerbate existing imbalances between 'developed' and 'developing' countries.[16] At the same time, major agricultural producers such as the EU (for wheat) or the US (for maize) will not be immune to climate change effects either, and have already experienced negative crop production due to reduced water availability and more frequent heat events.[17]

In the upcoming 20 years, the average temperature will likely increase from 0.3 °C to 0.7 °C relative to the period 1986-2005.[18] The IPCC in 2014 stated it is very likely that heat waves will occur with a higher frequency and longer duration. Already it found evidence that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.[19] Climate change can also result in more frequent epidemics – allowing them to appear earlier and at other regions due to higher temperatures. Especially in the Near East, Central Asia and Eastern and Northern Africa this can result in significant losses in wheat production.[20] Climate change further affects livestock, in terms of health, mortality and milk production. Rising temperatures can cause animal stress and affect their productivity; attempts to regulate the temperature will however lead to rising energy costs.

In addition, crops and livestock will require more water. In many parts of the world, water scarcity will present a major challenge to climate adaptation. About 70 percent of global water resources are used for agricultural purposes.[21] The UN predicts that in the upcoming 15 years, a shortage of 40% fresh drinking water for human consumption and farming will exist.[22] Since the 1970s already, the size of worldwide dry lands has doubled.[23] Decreases in water availability and more frequent droughts will severely damage agricultural production: with less rainfall, more evaporation and aridity, crops yield less. This will have a major impact on (heavily irrigated) agricultural regions, damaging their production. Droughts can also fuel out-of-control wildfires. Harvest failure will particularly occur in countries that will see the highest increases in their demand for food and whose populations' livelihoods depend on food production. In addition, due to climate change, renewable surface water and groundwater reservoirs will shrink, and intensify the competition for water among different sectors including the industrial, domestic and agricultural sectors.[24]

Pollution, diseases and inefficiencies

Next to climate change, the supply of food will be affected by energy scarcity, marine and terrestrial pollution, animal and plant diseases, food losses, and inefficient agricultural practices.[25] The vanishing of biodiversity and fight for arable land with producers of bio-fuel will negatively impact the global food supply. Due to changing diets and a growing demand for crops such as sugar-cane for the production of bio-fuel, the prices of the crops continue to rise. The loss of biodiversity in an ecosystem reduces the resistance of crops and species towards climate change and increases the occurrence of diseases. According to the FAO, about one third of global food production, an amount equal to 1.3 billion tons a year, is lost or wasted before it is consumed by people.[26] Food losses occur during the whole production chain; during harvest, storage, packaging, transport and market pricing.[27] The adoption of more intensive growing practices, including the extensive use of fertilizers and pesticides to increase crop yields, has caused soil and groundwater pollution.

Technological advances

In the entire agribusiness life-cycle, agribusiness is created by technological change – and vice-versa.[28] The capacity of integrating several technologies from different scientific fields will set the pace for the development of agribusiness. Advanced biotechnology, new hardware, software, the integration of IT, metalanguage, mathematical advancements and use of algorithmic information, computer modeling, advanced fertilizers, efficient use of machinery and equipment, genetic improvement or selection of plants and animals, new materials, nanotechnology, 3D-printers and robotics, will all play an important role in developing the agribusiness. They are crucial to prevent and fight plagues and sicknesses, deal with climate change, improve productivity, establish a better link between consumers and producers, renew the industry, maximize resources, improve land productivity, and obtain environmental gains.[29]

Research and innovation will be crucial for coping with the above described risks. Farmers will be required to invest in more sustainable and resource efficient production practices and the agricultural sector will be challenged to produce more with less resources. Poor farmers in developing countries will be most vulnerable, and least capable to adopt the necessary tools and techniques for a sustainable agricultural production.[30] As a result, foresights call for public investment support and 'farmer-friendly' policies as a key driver of positive change that could prevent more inequality.[31]

Additional foresight perspectives on supply

As informed by our analysis, Dutch foresight studies tend to downplay the potential role to develop or exploit new spatial areas of production. Instead, authors anticipate a key role for the ever-increasing implementation of – or transition to – new methods and management practices (e.g., application of IT; control of pests and diseases; innovation and new technologies). These will enable increases in agricultural productivity, as witnessed in the Netherlands itself.[32]

For some of the other countries examined by the foresight analysis (China, Brazil, EU), the implementation of new methods and management practices is primarily linked to the perceived need for greater agricultural mechanization. Shifts in production methods and management practices are seen as beneficial; they support an adaptation to changing supply needs and require moving away from traditional, small–scale production methods in order to increase efficiency.[33]

African foresights also insist on the need to move away from traditional methods, but this shift requires a stronger integration of new technology – facilitated by a precipitous increase in investment – and more knowledge on best practices in production.[34]

The UK requires greater efficiency in its food supply chain, but this is attributed to its strong dependency on agricultural imports rather than a dependence on small–scale farming methods.[35] The desire of the US for change in methods and management practices is related to a growing consumer desire to ensure environmentally friendly and sustainable agricultural production, rather than just boosting production.[36]

2.2 Trends in demand

There are important trends in demand that will heavily influence the food system worldwide although its effects will vary depending on the continent or even country level. The factors can sometime hardly be influenced in the short run and at the same time might have interrelated effects on each other too. Most importantly it is seen that demographic developments will have huge effects in combination with the trend towards changing lifestyles and consumption patterns.

Demographic trends

By 2050, the world population is projected to grow to between 9 and 10 billion people.[37] A continued aggregate global population growth (albeit offset and contrasted by aging populations in the West) is seen as an important driver by Dutch foresight studies, along with increasing urbanization. The Netherlands is expected to face a low level of stress in this respect. Population growth and urbanization rate are slow-paced, and productivity is on the rise. Nevertheless, supply trends matter. First, countries that will endure the most major changes are likely partners for development cooperation – for long-term assistance and or for emergency aid. Second, if the Netherlands has a trade relationship with these countries, it will likely be affected by this stress increase.[38]

At the global level, demographic and socio-economic change is accelerating the demand for food and diversification of agricultural products (larger amounts and different types of food). Rapid population growth will drive up the global demand for food: for every added healthy individual on earth, another 2,300 calories worth of food is needed.[39] This is expected to mostly occur in poor developing countries, where income elasticity of demand for food continues to be high. Combined with moderately high income growth, population increase could result in more than 60% increase in demand for food and other agricultural products by 2050.[40] This means that in order to keep up with growing food demands, the developing world needs to increase its agricultural production with 77%, and the developed world with 24%.[41]

In addition, populations are not only growing, they are also moving rapidly. Estimates indicate that by 2030, more than 60% of the world population will be living in urban areas and nearly 70% by 2050.[42] This shift is problematic considering that cities are population-rich but resource-poor. As a result of urbanization, more and more people will move away from self-sufficiency, which increases the need for commercial production.

Large urban markets create opportunities for establishing large supermarket chains. In turn, this will attract foreign investments and advertising from global corporations. Combined with trade liberalization and declining transportation costs, non-traditional food is becoming more accessible to urban populations. Hence, urbanization does not only drive up the need for production, but also puts pressure on the whole food chain, including transport and sales.

Foresight studies indicate that rising urbanization rates will put pressure on urban infrastructure and even greater pressure on urban centers to provide job opportunities, typically for the rural youth who are deciding not to 'return' to agriculture. This is especially problematic if there is persistently high unemployment and service delivery deficits in urban areas. This is particularly severe in cities of developing countries, such as Lagos, in Nigeria. At the same time, this situation could provide for important opportunities if adequately addressed and harnessed. Urbanization could allow African nations to take advantage of the excess of labor concentrated in cities to diversify African economies away from agriculture. This shows how demographics are to be accounted for as a powerful force of change behind food systems. Indeed, demographic trends may further increase the complexity of food systems, including demand and trade, modifying the economic structure first at the local, national level – but certainly impacting other layers given the interdependence of the global supply and demand food chains.

Changes in lifestyle and consumption patterns

The second pattern on the demand side is another increase – specifically in the demand for higher-quality products. A large number of middle-income countries will experience shifting consumption patterns over the coming years, in particular for animal proteins. Demand for higher-quality food, dairy and meat is expected to increase in the developing world. Egg and meat production has grown rapidly, and will probably continue to grow due to the diversification of diets driven by rising incomes. If growth in the milk sector is expected to accelerate, this is mainly because of increased demand in developing countries. For example, in India, these changes in consumption patterns have already resulted in the increased desire for foreign cuisine and the consumption of meat and dairy products. Bread, noodles and pasta are gaining popularity together with rice that is quick and simple to prepare compared to other cereals. The consumption of meat, fruits and vegetables is also increasing popular among urban populations. Urban diets are on an average more diversified and contain more micronutrients and animal proteins, as well as a considerably higher intake of refined carbohydrates and fats and lower intakes of fiber.[43]

We analyzed at how economic development is related to the consumption of various food types, especially meat. For this analysis, we collected food production data from Food and Agriculture Organization database and economic data from World Bank World Development Indicators database. We use food production as a proxy for food consumption. We also separated the data between the following regions – developed countries, Asia-Oceania, Latin American countries, Middle Eastern and North African countries, and Sub-Saharan African countries.

Regarding meat consumption, we observe that meat consumption is relatively stable for very low GDP per capita levels. Consumption will only start to increase when countries reach a certain threshold of economic development, which in most regions was at roughly the 1000 USD mark. After that, meat consumption does rise significantly until a country reaches upper middle income levels – that is, until GDP per capita reaches roughly 30,000 USD. After this level of affluence is reached, the demand for meat stagnates first, and decreases slowly at even higher GDP per capita levels.

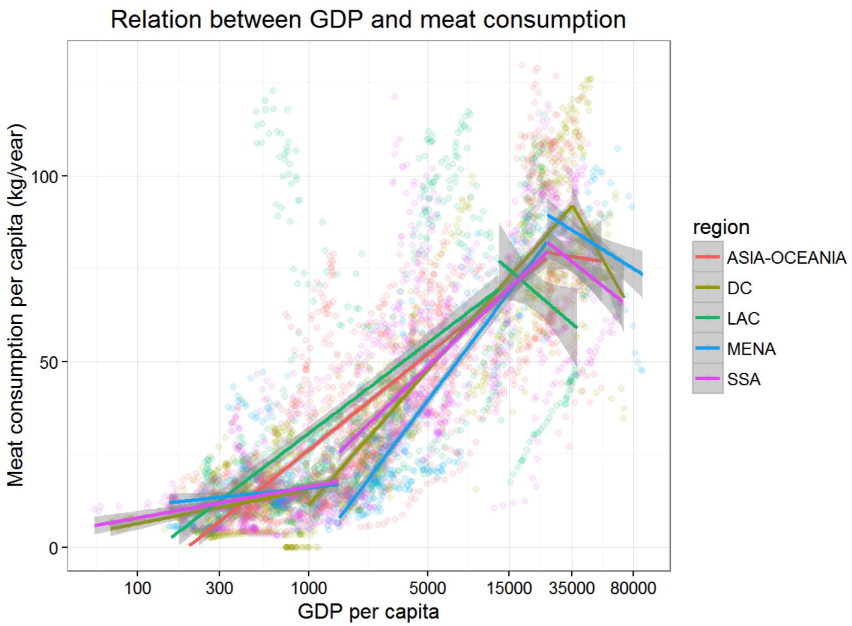

FIGURE 5. RELATION BETWEEN GDP PER CAPITA AND MEAT CONSUMPTION (BASED ON DATA FROM FAOSTAT)[44]

The demand for other types of food types such as seafood and pulses continues to rise after this threshold, which indicates that in the most developed countries, consumers appear to substitute meat for other, arguably healthier, sources of protein which have a smaller ecological footprint with regards to their production as well. The consumption patterns of pulses for example have a roughly inverse trend when compared to meat – the demand for this foodstuff appears to decrease significantly when a country reaches middle income, only to rise again when affluence has reached.

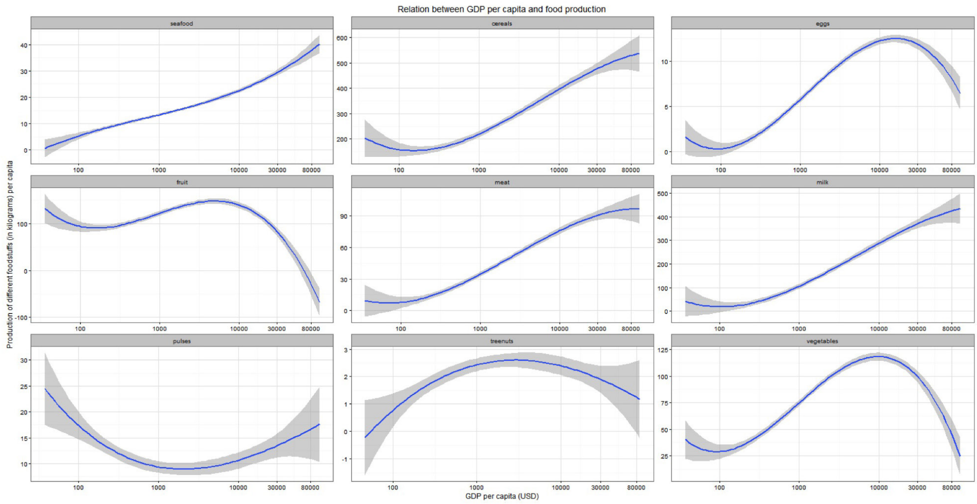

FIGURE 6. RELATION BETWEEN GDP PER CAPITA AND CONSUMPTION OF VARIOUS FOOD TYPES (BASED ON DATA FROM FAOSTAT)[45]

This trend reflects that as a country's GDP per capita rises and a larger share of its population reaches 'middle class' status the intake of animal protein increases as well.[46] As a result, countries that experience this effect will likely enter the global market for these goods or will have to divert exports to their domestic market. This, in turn, may lead to fewer producers and more competition between consuming countries.

Most foresights emphasize that change in lifestyle and consumption patterns is associated with increases in income – change in socioeconomic status is indicated as a driver of agricultural demand. Nevertheless, rising affluence – and a growing middle–class – is likely to put pressure on providing for resource-demanding and protein rich diets.

This will be coupled with greater emphasis on healthy and ethical and sustainable food in developed countries. In the West, changes in consumer consumption patterns imply a demand for healthier, more nutritious and more ecologically sustainable foods. Food safety and security are emphasized by the UK and China, but this is mostly due to both countries' dependence on agricultural imports. Brazilian and UK studies point to a greater demand of their populations for more product sophistication and variety.

As a result of this growing global demand, further increases in international trade can be expected. This will offer new opportunities for the Dutch dairy sector to export products as well as knowledge and expertise. Some Dutch studies foresee a greater competition between 'food, feed, fiber or (bio)fuel', which may push up the prices of foodstuffs.

Globally, vegetable oil is one of the most rapidly expanding sectors, fueled by the growth of food and feed consumption and imports of the developing countries. Increasing demand for oil crops for non-food-uses is also a major factor for the optimism in the sector, as is the availability of ample expansion potential of land suitable for the major oil crops.[47]

2.3 Shocks to the food system

Technical events

Technological events stand out as the main type of shock anticipated by the foresight literature. As proof of human adaptability, this suggests that technology will lead the way in dealing with current and future food security problems, in African countries as well as in China and Brazil. Technological advancements will be used to address issues such as agricultural pests, climate change, ease of access to market information, energy production, or the cost reduction of agricultural inputs. A better integration of technology into production processes is emphasized. In contrast, results for India show that biotechnology and nanotechnology are affecting the quality and consumer consumption levels of food. Arguably, these technological processes could be reducing the quality of the food, thus contributing to spreading poor- or malnutrition. Biotechnology is the most important factor of technological shocks according to a number of Western foresights. Although it was mentioned by some among the future 'wildcards', suggesting its impact is hardly predictable, authors seem to agree on its positive impact, as a source of new tools and choices for the farmers.[48]

Dutch studies also consider technology as a major driver of shocks and sudden events, though the overall externalities of such shocks or revolutionary breakthroughs are more often (though not exclusively) considered to be positive rather than negative. Indeed, De Wilde et al. trace the medium- and long-term impacts of a range of technologies – from genetic technology to synthetic biology, from robotics to 'smart materials' that change shape depending on environmental factors; big data IT infrastructures,[49] bio-informatics, vertical agriculture, and even (in a timeframe until 2050) nanotechnology and weather influence methods[50] – that are set to transform not only our agriculture, but every aspect of our food value chain.[51] For instance, one field in which Dutch scientific expertise – supported by targeted government policy – could prove to be a global game-changer, is the transformation of the food-(bio)energy nexus; several foresights, notably those by Veltenaar and De Wilde et al., argue that the severity of the impact of the biofuel transition on food availability depends to a very large extent on government investments into developing and scaling 'third-generation biofuels'. This follows from a typology of three 'generations' in biofuels: first-generation biofuels are produced from biomass (e.g., maize, sugarcane, palm oil, and animal fats) that is drawn directly from the food chain; second-generation biofuel is produced from the inedible rest products of food crops; it therefore does not remove food from the food chain, but indirectly it still competes with food because it utilizes the same production mechanisms, affecting food supplies. Third-generation biofuels involve the cultivation of algae on wastewater, which does not affect either the demand for- or supply of foodstuffs.[52]

Scientific innovation and technology, nurtured by smart government interventions and fueled by free produce trade, can achieve a transition to 'smart agriculture' that will enable the Netherlands and beyond, to optimize crop productivity within a sustainable environment. The hope is that this will help meet both the growth in aggregate demand, but also the changes in lifestyle and consumption patterns.

Other landmark innovations can also affect patterns of demand and trade: one such counter-intuitive technological wildcard is the possibility that developments in communication and workplace technologies may reduce the need for physical presence at work, thereby potentially slowing or even reversing urbanization rates (at least in the developed world), thereby considerably affecting both modes of production and consumption.[53]

Many of these technological breakthroughs will be beneficial, but some of them – such as the capability to influence the weather – are not only very politically controversial, but also carry risks of sparking irreversible, runaway processes if the consequences of an intervention are not understood well in advance.[54]

Natural shocks and events

We identify a focus on *natural shocks and events* as well. These relate to changes that have been disrupting normal weather patterns as a result of climate change. Extreme weather patterns exacerbate food insecurity issues – this was particularly a focus of EU, Dutch, and Indian studies.

Climate change effects emerge often as a natural shock rather than a driver of supply. Green or ecological approaches demonstrate the recurrent theme of concern for environmental responsibility in general, and not just across Western foresights. UK foresights associate concerns over the environment with consumer concerns, which is strongly related to waste management agendas. Most Dutch studies concur that natural shocks, specifically extreme weather patterns, are set to become more likely, frequent, and devastating as a result of climate change.[55] The consensus appears to be that we are in a better position to forestall or manage these through smart management, redundant (and diversified) sourcing, and scientific innovation. Less easy to forestall, however, is the risk of plagues: the gradual reduction in the biodiversity of global agricultural industries leaves food production and -stocks increasingly more susceptible to wildfire epidemics.[56] To counter this, the Netherlands should invest in produce diversification (possibly enabled by 'smart farming', for example).

Economic and financial effects

Dutch foresights point to *economic and financial shocks* and their negative impact, in the form of continuing (or renewed) economic crises.[57] Such crises are massively economically destructive in the extent to which they can curb the growth potential for the Netherlands – and beyond. Moreover, they can also leave research subsidies underfunded, and thereby detrimentally affect or slow efforts to mitigate the identified growing tensions between global food supply and demand. Finally, in the immediate term, economic crises, coupled with hikes in global food prices, can lead to dangerous political instability in fragile states, in turn disrupting trade flows and production, and sparking or exacerbating food crises.

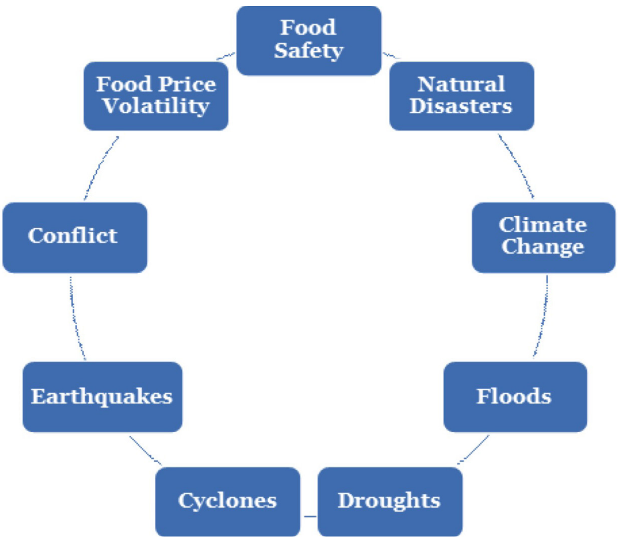

FIGURE 7. SHOCKS AFFECTING THE GLOBAL FOOD SYSTEM

In comparison to these threats, the impact of *illegal and criminal practices* on the global food supply is held to be relatively minor and manageable. Some studies briefly mention the possibilities of terrorism[58] or attacks against state infrastructure.[59] EU documents place an emphasis on the sudden changes in the economy, which have led and will continue to lead to significant decreases in EU farmers' incomes.

Political instability

Political instability can here be taken into account as a driver of shocks and a major source of uncertainty. Although instability as such does not appear to be on the rise worldwide (contrary to popular perception),[60] the increasingly interwoven nature of the food market means that distortions in one troubled country's production will stretch much further in their consequences than before. The world needs to increase its food production with 60% before 2050 or otherwise it will risk serious food shortages that could result into food riots, political turmoil, social unrest, civil war and terrorism.[61]

The pressure on supply, as well as on demand, does not only manifest itself through its direct effects, but also in an indirect manner through policy responses. Over the past few years, and as shown in the table below, countries have been preparing to face food shortages with stockpiling, panic buying, land deals and other distortive measures. The trend has been to set up small, often bilateral, partnerships that are rarely public in their announcement and short on detail. With more countries taking such steps, the risk of exclusion in a time of shocks and shortage arises. There has been a growing trend among developing countries to use income transfers to individual famers in order to achieve 'self-sufficiency' in agricultural products.

Rising food prices can trigger social unrest. As seen during the Arab Spring in countries such as Egypt and Tunisia, increased international food prices and unstable food security have contributed to the large levels of discontent amongst the civilian population against their governments' policies. In Egypt for example, local food prices rose by 37% during the period 2008-2010.[62] Given concerns with respect to ensuring stable food prices, governments may feel pressured to impose restrictions on the export of domestic agricultural products.

STRATEGIC ACTION	CONSEQUENCE	INSTANCES/EXAMPLES
Strategic stockpiling	– Less food available on the global market – Price-inflation abroad	China's wheat supply, estimated at 55-85 million tonnes[63]
Buying foreign land	– Poor use of domestic resources and capacity to deal with future growth of demand – Increasing vulnerability of purchasers to shocks elsewhere on the globe	China in 33 countries, the UK in 30, the US in 28; "0.75-1.75 percent of the world's agricultural land has been exchanged through international deals"[64]
Export restrictions	– Lower incomes for domestic producers – Higher prices abroad[65] – Panic-buying and hoarding by governments facing shortages	Restrictions were frequent during the 2007-2008 food crisis: "export restrictions by several countries during the 2007-8 food price crisis contributed to more than 60 percent of the rise in the global price of rice"[66]

TABLE 1. OVERVIEW OF GEOPOLITICAL INTERVENTIONS IN THE WORLDWIDE FOOD SYSTEM

These geopolitical interventions have important consequences, and are illustrated with instances.

3 FOOD TRADE OF THE NETHERLANDS

3 FOOD TRADE OF THE NETHERLANDS

3.1 Agricultural trade relations

The Netherlands is not only a major producer of dairy, meat and vegetables; it also plays an important role in global agricultural trade.[67] The Netherlands is a net exporter of food, and access to foreign markets is essential for maintaining its leading position. But, not all of the exported products originate from the Netherlands. Re-exports make a significant contribution to the total Dutch export: 24% of all exports are imported products which are processed in the Netherlands and then sold for export.[68] The majority of the gross added value (two third) in the agro sector is generated by raw agricultural materials produced in the Netherlands and about one third by imported and processed agricultural materials.[66]

This chapter analyzes the extent to which our top trade partners inside and outside the EU may put policies and strategies in place that could adversely impact the position of the Netherlands as a large agricultural player.

3.2 Inside Europe

Top Export Partners

Around 80% of Dutch agricultural exports go to European countries.[70] Germany, Belgium and the United Kingdom (UK) are currently the most important destinations for agricultural exports from the Netherlands (see Table 2). Germany is by far the biggest trading partner. The trade value is well over twice that of Belgium. In 2014, almost 26% of total agricultural exports were destined for Germany.[71]

RANK	COUNTRY	VALUE
1.	Germany	$ 20.119.958.607
2.	Belgium	$ 8.284.140.269
3.	United Kingdom	$ 7.724.624.915

TABLE 2. TOP 3 EU FOOD EXPORT PARTNERS. SOURCE: UN COMTRADE[72]

In the case of Germany, horticultural products (potatoes, vegetables and fruit) account for 30% of total agricultural trade, and animal products (dairy, meat, eggs) comprise 21%.[73] In recent years, the trade balance between the Netherlands and Germany has remained largely unchanged.[74] However, whereas the export of vegetables is on the rise, the export of meat has notably declined.[75] A possible related development is the German government's active policy of trying to lower the consumption of meat and dairy products among its citizens for environmental reasons.[76]

Exports to Belgium show a similar pattern as for Germany. A development that could be of relevance to the Dutch agro-food industry is the Belgian government's desire to reduce its dependency on soy as input for its feed sector. On the one hand, Belgium wishes to become less dependent on South America for security of supply reasons. Also, using European protein production gives farmers more options for crop rotation, thus reducing the likelihood of plant diseases and increasing economic stability.[77] In its Action Plan for alternative protein sources, the Belgian government makes explicit references to Dutch studies of alternative protein sources.[78] Whereas, the Netherlands is equally interested in developing alternatives to soy for its feed sector, the export of soy is an important component of the Dutch agro-food economy. A reduced dependency on imports from outside Europe could create opportunities for the Netherlands to export more soy or alternative sources of protein to Belgium.

The Netherlands is an important trade partner for the UK. Britain relies on a relatively small number of countries to satisfy its food imports and the Netherlands is the primary source of food from outside of the UK.[79] Meat and vegetables represent the biggest product groups exported to the UK, with dairy featuring less prominently. A factor that may affect Dutch agro-food exports is the referendum on the position of the UK in Europe. As British voters have decided to leave the EU, new arrangements will have to be made concerning trade between the EU and the UK, possibly impacting the cost of trade in agricultural products.

Top Import Partners

Next to being a large exporter, the Netherlands imports a considerable amount of agricultural commodities itself. In 2014, our country was Europe´s fourth largest food importer after Germany, the UK and France.[80] Looking at from where the Netherlands imports its agricultural commodities, the top three countries are virtually identical to the list of major export partners (see Table 3).

RANK	COUNTRY	VALUE
1.	Germany	$ 10.173.492.692
2.	Belgium	$ 7.145.461.064
3.	France	$ 3.632.813.272

TABLE 3. TOP 3 EU FOOD IMPORT PARTNERS[81]

Again, neighboring countries top the list, with the only difference being that France occupies third place instead of the UK. Intra-European trade as such remains one of the cornerstones of the Dutch food system. The Netherlands mainly imports products of animal origin from Germany and Belgium, such as meat and dairy. The greatest imports from France are cereals, such as wheat and maize.

3.3 Outside Europe

In general, the Netherlands has an agricultural trade surplus. However, when looking only at countries from outside of the EU, the Netherlands imports more than it exports to these markets.

Top Export Partners

Close neighbors set aside, in 2014 the Netherlands exported its agricultural commodities also far and away to countries such as China, the US, and Russia (see Table 4). About 20 % of agricultural exports in 2014 went to non-European countries.

RANK	COUNTRY	VALUE
1.	China	$ 2.869.294.351
2.	United States	$ 1.927.206.633
3.	Russia	$ 909.463.274

TABLE 4. TOP 3 FOOD EXPORT PARTNERS (NON EU)[82]

Dairy products and eggs are among the most exported products to all three countries. Dutch vegetables also form a significant part of the trade.

A number of trends and developments are worth highlighting. As countries become more affluent and populations more urbanized, consumption patterns change. In emerging economies such as China, higher household incomes and urbanization lead to dietary changes away from a traditionally carbohydrates-rich to a more protein based diet. As demand for protein is thus expected to rise, conversely, demand for grains and vegetables may decrease.[83] China's per capita consumption of beef and pork almost quadrupled in the last twenty years and show no signs of slowing down.[84] The consumption of milk and other dairy products in China equally grew spectacularly and is expected to grow even more in the future.[85] These changing trends are important developments for the Dutch agro-food sector in light of China's potential as an export market. Of interest also is the fact that the Chinese government and industry are looking for more sustainable and efficient production in order to satisfy changing consumer behavior. This provides opportunities for agricultural food mechanization.[86]

A key-development to watch with respect to the US is the implementation of the Transatlantic Trade and Investment Partnership (TTIP) Agreement; a regional trade agreement currently being negotiated between the US and the EU. TTIP aims to tackle costly "behind the border" non-tariff barriers that impede the flow of goods, including agricultural goods. Proponents of TTIP argue that further trade liberalization between the two blocs will lead to economic growth and cheaper products on both sides of the Atlantic.[87] For example, they argue that European producers will gain unprecedented access to the American market, a market where high-quality products from European origin will be in high demand.[88] However, critics of the agreement voice concerns about looser Genetically Modified Organism (GMO) regulations in the US and the risk of small European businesses being crowded out of the European market by large US farms.[89] At this moment, there is much uncertainty about the implications of TTIP, especially because specific contents of the treaty are still being kept from the public. However, it is beyond doubt that in the event that the negotiations on TTIP are concluded successfully that this will affect agro-food trade between the Netherlands and the US.

Due to the conflict in Ukraine and Russia's role therein, Russia takes up a special position at the moment. In response to western sanctions Russia banned the import of various agricultural products and imports from the EU, the US, Canada, Australia and Norway.[90] Some of the banned products include dairy (milk / cheese), meat from poultry, bovine and porcine, fish and crustaceans. A total of 56% of all imported agricultural and food products ($23.5 billion) is affected by the ban which includes $8.3 billion (35.8%) worth of completely banned products.[91] The Dutch export to Russia was adversely affected by the Russian boycott. In the first four months of 2015, agricultural exports to Russia diminished by almost 40% in comparison to the same period a year earlier.[92] Dairy (-8.4%) as well as cattle and meat products (-4.6%) suffered the most.[93]

The Russian boycott makes it harder for Russia to meet its food demand, yet it also forces Russia to improve its own food system. Russia is interested in Dutch agro-technology, including exports of greenhouses and milking robots.[94] In the long term, given that the EU's sanctions policy is tied to the formal implementation of the Minsk II cease-fire agreement concerning the war in Ukraine (something which looks increasingly unlikely to happen), it remains unclear when the EU – and as a result Russia – will lift their sanctions.

Top Import Partners

In 2014 the Netherlands' major import partners from outside of the EU were Brazil, the US and Indonesia (see Table 5).

RANK	COUNTRY	VALUE
1.	Brazil	$ 2.711.968.388
2.	United States	$ 2.002.641.198
3.	Indonesia	$ 1.146.503.807

TABLE 5. TOP 3 IMPORT PARTNERS (NON EU)[95]

The main products imported from these three countries are soybeans and palm oil.[96] Soy primarily comes from Brazil and the US and is used extensively as a 'feed' in the Dutch cattle sector, and as a major ingredient for processed food. From Indonesia, the Netherlands chiefly imports palm oil – a product also heavily used in processed foods.

The Netherlands is a major player in international soy trade and the second largest importer in the EU, accounting for 24% of total EU imports in 2014.[97] Globally, the Netherlands' share is much smaller however, at a mere 3% of the world's total.[98] Even though the Dutch feed industry is looking for alternative protein sources to reduce its dependency on soy, the import of soy is likely to remain important in the future.

The Netherlands faces competing demand for soybeans from a number of different countries. Chief among these is China, which imports 59% of the total volume of soybeans exported worldwide.[99] Mexico and Germany import roughly the same amount of soy beans as the Netherlands.[100] Particularly in China, demand for soybeans has grown spectacularly. Per capita consumption of soybeans in China has increased by approximately 400% over the past three decades and it is expected to increase more in the future.[101] The US Department of Agriculture (USDA) for example expects

China to increase soybean imports to "support rising domestic meat production."[102] They forecast China to import around 112 million metric tons of soybeans by 2023.[103]

The number of agricultural products that could act as a substitute for soy is limited at the moment and alternative sourcing options inside of Europe are scarce. The 400.000 hectares of soya grown in Europe today is only around 3% of what Europe needs for its animal feed.[104] Increased competition for soy on the global market might therefore be problematic for the Netherlands. Next to China, India is a major importer of soybeans. In its projections, USDA expects India's soybean oil imports to grow by 28% to 1.2 million tons by 2020.[105] Factors that will continue to contribute to an import growth for India are a projected increase of domestic demand for vegetable oil and limited capacity to expand the production of oilseeds.[106] Competition for the Brazilian and US soy market is thus expected to increase. In 2015, more than 55% of US' soy exports are destined for China.[107] Since US production growth is limited due to land constraints, the global increase in demand will have to be covered by producers in South America, mainly Brazil.[108] Brazil has more spare farmland than any other country in the world. While determining the precise amount of available land is complicated, Brazil has been said to contain around 13% of the world's equivalent potential arable land.[109] Moreover, the FAO expects Brazil's total arable land usage to increase to over 120 million hectares by 2050.[110] However, whether it will be able to do so in a way that is both ecologically and socially responsible is another matter.

The Netherlands is the largest EU importer of palm oil, acting as a trading hub for other European countries.[111] Palm oil acts as a crucial input for a number of industries in the Netherlands as it is used in processed foods, animal feed, as well as for energy purposes in the form of biofuel. Due to its relatively low price, demand for palm oil worldwide has greatly increased in the past two decades. Throughout Indonesia, the number and size of palm oil plantations have expanded rapidly in order to meet the increase in demand. Indonesia plans to almost double its production of palm oil to 40 million tons by 2020 and expects to expand the area for palm oil cultivation to 13 million hectares.[112]

Although the growth in palm oil plantations has the potential to provide employment for many Indonesians, it is also acts as a major contributor to deforestation, a loss of biodiversity, increased greenhouse gas emissions and social-political unrest between the local population and palm oil companies. Through the draining, burning and conversion of peatland into palm oil plantation large amounts of carbon dioxide are released into the atmosphere, causing Indonesia to be a significant emitter of greenhouse gases.[113] The negative environmental and societal impacts of palm oil production have prompted the Netherlands to develop a framework for sustainable palm oil production in Indonesia.[114] In January 2015, Minister Ploumen of Foreign Trade and Development Cooperation also announced a desire to enter into partnerships with major palm oil producers China and India with the aim of working together to improve environment and social conditions in the palm oil sector.[115]

The Netherlands is a frontrunner on certified palm oil and has expressed its commitment to ensuring it imports only sustainably produced palm oil by the end of 2015.[116] On a collaborative effort Denmark, Germany, France, the Netherlands and the UK announced in December 2015 that they would seek an end to illegal deforestation by private companies and make palm oil production 100% sustainable by 2020.[117]

3.4 Export of Dutch knowledge and expertise

The Netherlands is a global leader when it comes to the export of agricultural know-how and technology. The Dutch agro-food sector has a strong reputation, and is internationally recognized for its innovations that enable the cultivation, process and transport of high quality agricultural products.[118] The Dutch climate, coupled with high prices for land and labor, has forced the sector to continuously improve the efficiency of production. Through technological advancements and innovations, the Netherlands is able to maintain a competitive position within the EU and the rest of the world.

The success of Dutch agricultural innovation is also reflected in the growth of Total Factor Productivity (TFP), which measures total output growth relative to the input of labor and capital. The Netherlands has managed to maintain, and even increase agricultural production while reducing the required input.[119] The improvements in the agricultural production systems and processes have resulted in a level of productivity that is five times higher than the European average.[120] Next to higher production efficiency, investments in knowledge and technology have contributed to improved product quality and lower prices. As the number of farms in western European countries declines, technology will soon play an even larger role in sustaining current production levels.[121] Due to the limited availability of arable land, it is expected that the Dutch agricultural sector will increase its efforts to export agricultural technology, expertise and intellectual property.

The Netherlands already exports a wide variety of agricultural technology, ranging from greenhouse lighting, robotics, and irrigation systems to drought-resistant seeds. The demand for Dutch technologies is particularly high among countries that suffer from water or energy shortages, as well as countries that seek to improve their food security. The Netherlands has the second largest private investment rate in agro-food R&D measured as a share of its GDP.[122] Also, it is the third largest exporter of food machines and fourth largest exporter of agricultural machines.[123] In 2014, the export of agricultural machinery accounted for 1.8 billion euros and went primarily to countries such as Iran, Brazil and Russia.[124] The Netherlands produces 80% of the world's poultry processing machines, and is a market leader in machinery for red meat, bakery and cheese products.[125]

Outside the EU, market opportunities for Dutch knowledge and expertise are linked to countries with a similar small scale farm structure, such as China and Indonesia.[126] A deeper interest in innovation, competitiveness, knowledge and research in China, has opened doors for technological and scientific cooperation with Dutch knowledge institutions. In 2014, Royal Friesland-Campina, in cooperation with Wageningen University and China Agricultural University, opened the *Sino-Dutch Dairy Development Center* (SDDDC) in Beijing to strengthen the exchange of knowledge between Dutch and Chinese companies in the dairy chain. With the help of Dutch dairy experts, the center seeks to improve the production, quality and safety of Chinese dairy products. In addition, the Netherlands shares knowledge and expertise on genetics, animal health and welfare, milking robots, smart logistics and cold chain technologies.[127]

In 2012, the Netherlands and India established an *Indo-Dutch Action Plan* to stimulate greater efficiency in the Indian agro-food sector. [128] The Indian government aims to double its food production in five years and has made funds available to utilize Dutch knowledge and expertise.[129] However, a thorough improvement of the whole food chain is required given that between 30 to 40 percent of total agricultural production in India is lost in the post-harvest process.[130] The products that do get exported ultimately cannot be sold on the European market due to inferior quality that falls below European standards. For the realization of the Action Plan, 10 Dutch-Indo Centers of Excellence (CoE) have been established to share knowledge on horticulture, dairy cattle, and potato, meat and pork chains.[131] The centers provide training and business opportunities to Indian farmers to improve their current production methods and techniques.

In Indonesia, the growing demand for protein-rich products has offered Dutch companies opportunities to export agricultural products such as seeds, fertilizers, post-harvest handling and greenhouses.[132] The Netherlands can, as frontrunner in terms of Climate SMART agriculture, offer Indonesia the required knowledge and expertise to improve food quality and sustainability in order to gain access to the

European market.[133] In the Indonesian poultry sector, Dutch knowledge and expertise is used to increase the poultry production while assuring the highest standards for food safety and hygiene. *FoodTechIndonesia* brings a wide variety of Dutch and Indonesian companies together to promote efficient cooperation in the poultry value chain, and stimulate knowledge transfers, access to human resources and capacity building.[134] Other projects between the Indonesian and Dutch agro-food sector focus on the diversification of nutrition intake, building resilient and sustainable crop protection systems and efficient water management (e.g., *Jakarta Coastal Development Project*).

Since the implementation of the Russian boycott, the focus of exports has remained on knowledge and expertise, rather than products. In addition, the export of Dutch machinery and transport equipment to Russia declined in first four months of 2015 to 473 million euros, down from 890 million euros during the same period in 2014.[135] Interestingly, while boycotting Dutch agricultural products, the Russian government has offered Dutch farmers subsidies and a free plot of land for setting up an agricultural company in Russia.[136] Also, given that Russia is keen on growing its own high-quality produce, Dutch greenhouse builders such as Dalsem, Certhon, KUBO, and VB Group are being engaged to build high-tech greenhouses spanning tens of hectares in the country.[137]

4 CAUSES OF FOOD DEFICITS

4 CAUSES OF FOOD DEFICITS

The main part of the analysis of the project is quantitative by nature. This analysis is done by developing models that make it possible to integrate many uncertainties that in itself are useful as input but may also influence other factors or drivers. Given this combination, there is a need for complexity modelling. The model used for the analyses in this research is based on a small number of assumptions and restraints.

4.1 Methodology and scope

In this modeling exercise, we look at the development of food supply and demand for every country in world for which enough data was available. As such, we were able to run our model for 167 countries. Countries that were excluded were mostly island states, and countries that do not have sufficient data available due to low size, low development level, or severe civil war. The latest year for which sufficient data was available was 2011, hence it was chosen as the start year of the simulations. The simulations cover 20 years, making 2031 the end year. For a more elaborate view of the model and description of the methodology than presented in this section, see Appendix A.

Methodology

The simulation model used is a System Dynamics (SD) model.[138] SD is a mathematics based modeling language which mainly focuses on the causal links between different variables in combination with stocks and flows. As such, it is able to simulate the effects of feedbacks, accumulation, and delays in a system. As complexity is defined by these effects, SD models allow us to deal with complex problems. Future global food supply and demand is a good example of such a problem.

Another characteristic of the future global food system is the high degree of uncertainty. This is already found in the data collected by the FAO,[139] including AQUASTAT,[140] which was used as model run input and to differentiate between the circumstances found in each country. The uncertainty becomes more profound if we look, for example, at the different scenarios that exist or can be created for population growth (e.g., low, medium, high, and constant growth scenarios provided by the UN)[141] and economic growth for each country.[142] We can however assume that the combination of these two in the often used indicator GDP per capita is linked to the mixture of food types consumed in any country. On the supply side, similar uncertainties exist. The yield gap and the effects of climate change are particularly important to mention. In the case of the yield gap, it is important to know what the highest possible yield is in a specific country. As this data is not easily found, we derived the maximum yield figures from the best practices in all countries. We do admit, however, that this is a strong simplification of reality. The effects of climate change, on the other hand, are more similar to the different population size scenarios. Consequentially, we used 4 different precipitation scenarios (low, medium, high, and constant) provided by the World Bank,[143] and based on the IPCC Fourth Assessment report.[144]

Modeling countries' food systems

As a consequence of all this uncertainty, the goal of this quantitative approach is not to provide one future world scenario, or a base case, but to provide a bandwidth for the potential of food trade for every country. We use a novel research methodology called Scenario Discovery[145] to find the causes of especially undesirable future scenarios. We specifically investigate under which circumstances a decline of food production self-sufficiency will take place, in other words, when the important dependency of countries will increase. The overall model developed for this research makes use of sub models for food demand, land use, food supply, agricultural productivity and water availability and focuses on trade potential. The structure of the model on a high aggregation level can be seen in Figure 8.

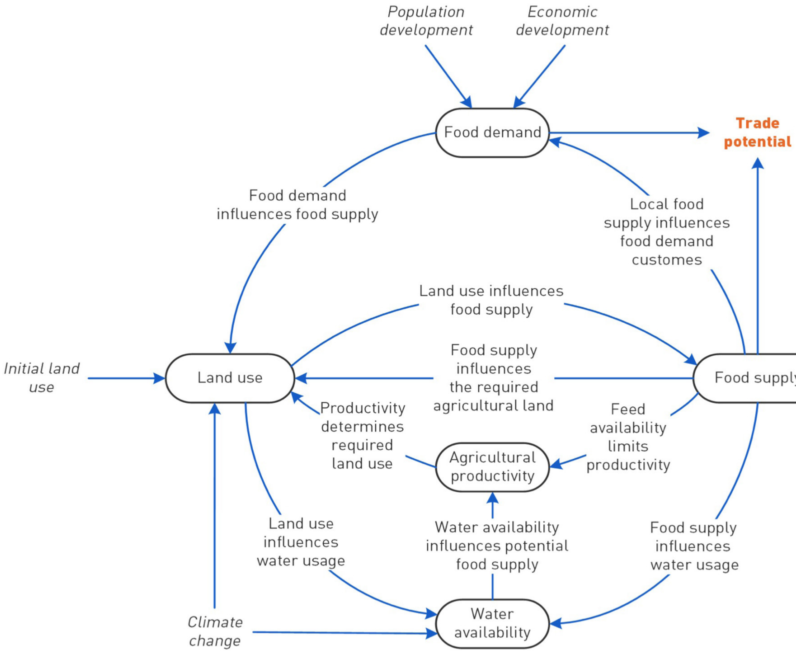

FIGURE 8. THE MODEL AT THE HIGHEST AGGREGATION LEVEL

The model simulates demand, supply, and productivity for 11 different types of food. Table 6 gives an overview of these food types and the kind of land use that is associated with growing this particular type of food, fish and meat from game animals are not modeled, as they are not produced by land base agriculture. For a more explicit elaboration of the model and description of the methodology, see Appendix A.

NR	AGGREGATE	LAND TYPE
1	Cereals	Arable land
2	Roots and Tubers	Arable land
3	Pulses	Arable land
4	Tree nuts	Permanent crops
5	Vegetables and Melons	Arable land
6	Sugar crops	Arable land
7	Oil crops	Arable land/Permanent crops
8	Fruit excl. Melons	Permanent crops
9	Meat	Pastures and meadows
10	Milk	Pastures and meadows
11	Eggs	Pastures and meadows

TABLE 6. FOOD AND FEED CATEGORIES BY LAND TYPE

The **demand food sub-system** contains a top-down way of calculating food demand.[146] We simulate the size of the economy by departing from the countries' present GDP size and assuming a constant growth over time. Both the initial GDP size and the GDP growth factor are uncertain. The GDP growth factor is country specific, where the uncertainty bandwidth was determined by taking the average GDP growth as projected by the USDA[147] minus and plus two standard deviations. The population size is determined by choosing one of four UN population scenarios.[148] By combining the GDP and population size on any moment, the GDP per capita can be calculated. We did statistical analysis for each of the 11 food types to find the relation between the development level measured in GDP per capita and the per capita food consumption. By using these relations, we simulate how food demand may grow. To account for local differences in food consumption, we assume that the food consumption will start from the countries' initial consumption, which can be derived from FAOSTAT data in 2011. The total food demand per category includes the humane consumption and the feed use for cattle. Finally, the absolute trade potential is the supply per food category minus the total demand, whereas the relative trade potential is calculated by taking the countries' food supply minus the food demand as part of the food demand.

The **land use sub-system** simulates how a countries' land use develops over time. The land use distinguishes between forest area, permanent meadows and pastures, arable land, permanent crops, and other land. These land types correspond to the categories found in the FAOSTAT land use data.[149] The other land category includes urban land use. If the population size increases, the other land area also increases, only discounted for the availability of agricultural and forest areas. The total agricultural land area can grow only by reducing the forest area. As the forest area decreases, the possibility to do so decreases accordingly. If food demand patterns change such that a different ratio between the agricultural land use types is needed, they may change over time. However, we assume that it will be difficult to convert permanent pastures and meadows to other agricultural land types. This can be understood by the example of cattle grazing in high mountain meadows, which cannot be used for growing annual or permanent crops.

The **food supply sub-system** simulates how local food supply may evolve. This is done by taking the initial land use per crop type divided over the different land use types (Table 6), and try to follow the necessary land use by combining the food demand with the dynamic agricultural productivity per area. Finally, we also calculate the feed use by looking at the size of the amount of livestock needed for meat, milk, and eggs production. We assume that the feed use per food type will develop in a similar manner as it did between 1991 and 2011 (Table 7). We use this development to calculate the new feed use relative to the original local feed use to account for local traditions in feeding livestock.

	Cereals	Pulses	Roots and Tubers	Treenuts	Vegetables and lemons	Sugar crops	Oil crops	Fruits excl melons	Meat	Milk	Eggs	Fish and seafood	Total
Use in 1991 [1000 tons]	643398	13164	144767	0	9757	38567	14361	4242	47	101262	3	27229	997555
Use in 2011 [1000 tons]	816104	12930	176134	0	52604	50930	34661	5497	74	78637	73	23463	1252309
Share 1991	64,50%	1,32%	14,52%	0,00%	0,98%	3,87%	1,44%	0,43%	0,00%	10,16%	0,00%	2,73%	100,00%
Share 2011	65,17%	1,03%	14,08%	0,00%	4,20%	4,07%	2,77%	0,44%	0,01%	6,29%	0,01%	1,88%	100,00%
Share 2031	*65,85%*	*0,81%*	*13,63%*	*0,00%*	*18,04%*	*4,28%*	*5,32%*	*0,45%*	*0,01%*	*3,88%*	*0,11%*	*1,29%*	*100,00%*
Total increase 1991-2011	126,84%	98,22%	121,67%	0,00%	539,14%	132,06%	241,36%	129,59%	157,45%	77,66%	2433,33%	86,17%	125,54%
Growth per year (linear)	1,34%	-0,09%	1,08%	0,00%	21,96%	1,60%	7,07%	1,48%	2,87%	-1,12%	116,67%	-0,69%	1,28%

TABLE 7. GLOBAL FEED USE DEVELOPMENT FROM 1991 TILL 2011, AND THEN FORECASTED FOR 2031

The agricultural productivity sub-system simulates the development for the yields for the 8 crop types defined in our model. We assume that the country's yield will grow with the same factor as the country's economy. The total yield may not be larger than the maximum possible yield, which grows with a factor for average technological progress. The difference between the maximum possible yield and the local yield, relative to the maximum possible yield, is called the relative yield gap. If the relative yield gap becomes smaller, the growth of the local yield will be hindered, leading to asymptotic behavior towards the maximum possible yield. Finally, the yield is corrected for the relative soil fertility. We assume that decreasing water availability in the root zone or top soil – which may be caused by temporary droughts or changing precipitation patterns – will lead to decreased soil fertility. The soil can regain its fertility by the natural land degradation time factor. If this time factor, which is considered to be a global uncertainty, is relatively small, the soil quality will recover faster than when this factor is relatively high. The soil degradation effect can be envisioned as an effect similar to the Dust Bowl in the Northern American prairies in the 1930s. We account for increased availability of water via a similar effect. If the water availability is higher than normal plus a threshold – as we assume the soil may contain a bit more water than normal without causing problems – the soil fertility is decreased as well. This is similar to erosion effects seen in many regions throughout the world.

Finally, the **water availability sub-system** simulates the availability of water in the top soil and in the ground water volume. The top soil water is replenished by the rain supply, which in turn is defined by the average precipitation scenario and potential periodic relative increases or decreases in precipitation. The total root zone water use mainly contains agricultural water use. Irrigations water minus the country specific evaporation rate also dissipates into the root zone. Unused water percolates from the root zone to the ground water stock. The ground water flow also contains recharge from surface and ground water entering the country, and internally produced surface and ground water. Ground water is extracted for human consumption and for irrigation purposes if the soil water availability is insufficient. Finally, the ground water stock is drained as it has an average lifetime in the stock.

NR	VARIABLE NAME	MIN	MAX	UNIT
1	Average lifetime of groundwater	50	500	yr
2	Delay on changes in annual plant production	3	10	yr
3	Delay on changes in permanent crops production	10	20	yr
4	Duration of extreme weather event	1	6	yr
5	Maximum increase in agricultural land per year	0.01	0.1	1/yr
6	Natural land degradation restoration time	0.5	5	yr
7	Normalization factor GDP per capita	9000	11000	$
8	Reallocation delay on agricultural land	20	100	yr
9	Share permanent meadows and pastures allocatable	0	0.2	-
10	Start time extreme weather event	2015	2025	yr
11	Technological progress	0	0.06	1/yr
12	Threshold for flooding	1.1	2	-
13	Water use cereals	0.45	0.8	m/yr
14	Water use fruits excl melons	0.9	2.2	m/yr
15	Water use oil crops	0.45	0.7	m/yr
16	Water use per GDP	9.405E-12	1.411E-11	km3/$
17	Water use permanent meadows and pastures	0.5	0.9	m/yr
18	Water use pulses	0.35	0.5	m/yr
19	Water use roots and tubers	0.5	0.7	m/yr
20	Water use sugar crops	0.55	2.5	m/yr
21	Water use treenuts	0.5	0.7	m/yr
22	Water use vegetables and melons	0.4	0.8	m/yr
23	Initial maximum possible yield cereals	760	1140	t/(yr km2)
24	Initial maximum possible yield fruits excl melons	2320	3480	t/(yr km2)
25	Initial maximum possible yield oil crops	400	600	t/(yr km2)
26	Initial maximum possible yield pulses	440	660	t/(yr km2)
27	Initial maximum possible yield roots and tubers	4040	6060	t/(yr km2)
28	Initial maximum possible yield sugar crops	10000	15000	t/(yr km2)
29	Initial maximum possible yield treenuts	760	1140	t/(yr km2)
30	Initial maximum possible yield vegetables and melons	3520	5280	t/(yr km2)
31	Severity of extreme weather event	-0.5, -0.2, 0.0, 0.2, 0.5		-
32	Switch annual precipitation scenarios	1, 2, 3, 4		-
33	Switch population scenarios	1, 2, 3, 4		-

TABLE 8. ALL GENERIC UNCERTAINTIES USED IN THE ANALYSIS WITH BANDWIDTH (MIN, MAX) AND UNITS.

For the Scenario Discovery approach, we have run the model 10000 times per country. For these 10000 runs, we selected each time a different sample of values for all uncertainties using the EMA workbench developed at the TU Delft.[150] The uncertainties can be generic (i.e., the same for all countries in the world), or country specific (i.e., the initial GDP and expected GDP growth). Table 8 shows all generic uncertainties that are used in the analysis with bandwidth (min, max) and their units. The four precipitation patterns and four population scenarios were of course country specific, but they were selected using the global uncertainties switch annual precipitation scenarios and switch population scenarios.

Limitations

Our approach has several important limitations. The most important limitation considers the fact that we did not take the monetary value of the different food types into account. There are a number of practical reasons for having done so. While there is much data available about the value of food, long-term food price scenarios are not as widely available and are generally less reliable. Further, if these price scenarios can be found, they are not necessarily consistent with the simulated food production in the different countries. While there are methods to overcome these issues, for example by either modeling the food system on a global and regional scale to develop food price scenarios, similar to earlier HCSS work,[151] or by using more methodologically advanced techniques in which the different country models 'communicate' about their surpluses and deficits caught in price levels which feedback to these countries. While the latter approach is theoretically possible, to the best of our knowledge, it has thus far never been done in such an extensive study.

Financial modelling was one of the aspects, approved by the sponsor, that was explicitly left out of the analysis due to its complexity. An important consequence of not taking food prices into consideration is that incentives to create national surpluses of food are not considered in our simulations. Surpluses thus only arise in our simulations if land is sufficiently available, yields are sufficiently high, and demand is sufficiently low. Developments like the fast rise of palm oil production in Malaysia or soy production in Argentina can, therefore, not be simulated due to this limitation.

4.2 Countries' performance

As part of the analysis based on the model, there are results that are descriptive by nature. For each of the analytical angles that are used, we included a world map, a description of the results and a table listing the top countries that are affected.

Relative trade potential

The first indicator that is examined is the relative trade potential. This indicator is defined as the supply minus the demand, as part of the demand. In other words, if a country is completely import dependent, the value for this indicator will be -1. If a country is able to export, this may of course be more than the size of the demand, making the relative trade potential for export not limited. In the maps shown in this section, shades of red are used for the relative import dependency (darker is worse) and shades of green for the relative export potential, where darker green is better.

TOTAL RELATIVE TRADE POTENTIAL 2011

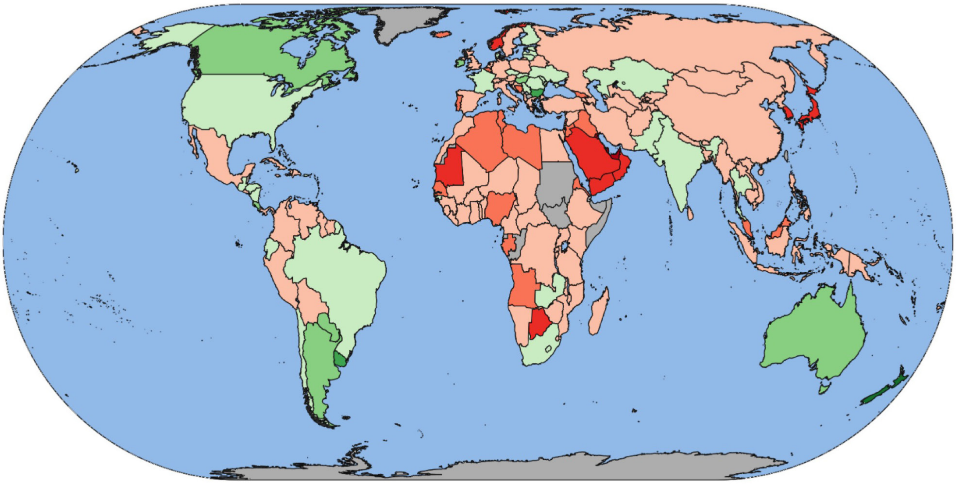

FIGURE 9. COUNTRIES WITH PRESENT TOTAL RELATIVE TRADE POTENTIAL IN 2011. RED COLORS CORRESPOND TO RELATIVE FOOD DEFICITS, WHERE DARKER RED CORRESPONDS TO HIGHER RELATIVE DEFICITS. GREEN COLORS CORRESPOND TO RELATIVE FOOD SURPLUSES, WHERE DARKER GREEN CORRESPONDS TO HIGHER RELATIVE SURPLUSES.

In this map (Figure 9) we look to the average relative trade potential for each country in 2011. What this figure and the FAO data clearly show is that especially small island nations, Middle-Eastern nations, most African nations, and former communist nations generally are import dependent for all food types. This does not mean, however, that the financial food trade balance is negative. Indeed, for example, the Netherlands imports more food than it exports, in tonnage, and is thus import dependent, but has a positive financial food trade balance.

In the next figure (Figure 10), we see how this import dependency may shift towards 2031. We see that especially African, Latin American, Middle-Eastern, and Central Asian countries may stay or become food import dependent.

TOTAL RELATIVE TRADE POTENTIAL 2031

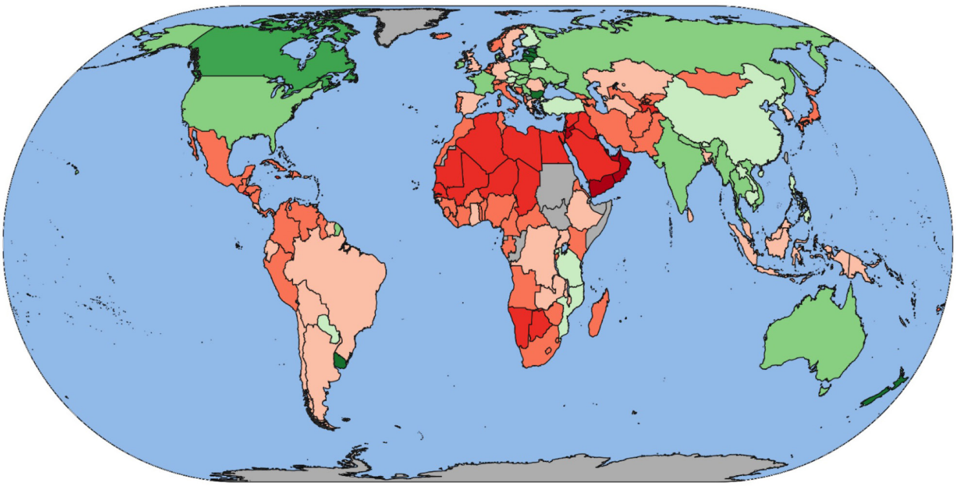

FIGURE 10. COUNTRIES WITH AVERAGE TOTAL RELATIVE TRADE POTENTIAL IN 2031

Table 9 shows the top 10 countries with highest relative import dependency for all food in 2011 and 2031. For the countries in 2031 it is stated whether they are currently considered a developing nation and whether they have an aid or trade relation with the Netherlands. It is clear that none of these countries plays an important role in the global food trade. This is understandable, as either the size of these countries (e.g., as Seychelles, Trinidad and Tobago, and Antigua and Barbuda are relatively small island nations) or their climate (e.g., the United Arab Emirates, Qatar, and Bahrain are mainly composed of arid land in the Middle East) does not allow them to produce much food in traditional ways. That is also why it is logical that they will have the largest relative food import dependencies, both in 2011 and in 2031. All these countries together, however, do have a large population and do need to be fed, both now and in the future. Especially about the Middle-Eastern countries it should be noted that they have young and fast growing populations.

COUNTRY RANKING 2011	COUNTRY CLASSIFICATION[152]	RELATION WITH THE NETHERLANDS[153]	COUNTRY RANKING 2031	COUNTRY CLASSIFICATION	RELATION WITH THE NETHERLANDS
United Arab Emirates	Developing economy	Trade relationship	Qatar	Developing economy	Trade relationship
Qatar	Developing economy	Trade relationship	Kuwait	Developing economy	Trade relationship
Bahrain	Developing economy	Trade relationship	Bahrain	Developing economy	Trade relationship
Kuwait	Developing economy	Trade relationship	United Arab Emirates	Developing economy	Trade relationship
Seychelles	Developing economy	None	Oman	Developing economy	Trade relationship
Trinidad and Tobago	Developing economy	None	Jordan	Developing economy	None
Antigua and Barbuda	Developing economy	None	Antigua and Barbuda	Developing economy	None
Brunei Darussalam	Developing economy	None	Yemen	Developing economy	Aid relationship
Saudi Arabia	Developing economy	Trade relationship	Cabo Verde	Developing economy	None
Oman	Developing economy	Trade relationship	Algeria	Developing economy	None

TABLE 9. COUNTRIES WITH HIGHEST RELATIVE IMPORT DEPENDENCY FOR ALL FOOD IN 2011 AND 2031

RELATIVE TRADE POTENTIAL MEAT 2011

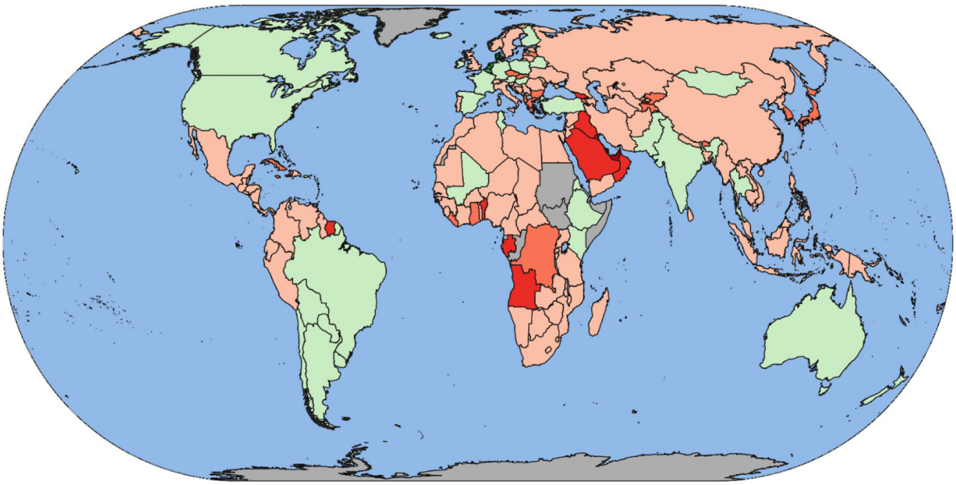

FIGURE 11. COUNTRIES WITH RELATIVE TRADE POTENTIAL MEAT IN 2011

When we compare Figure 11 and Figure 12, we see how the relative import dependency of meat may shift over time. The biggest changes are visible in India and China, as well as all African and South-East countries. The reason for this shift lies mostly in the economic development of these countries, while their production will have more issues with coping with the consequential demand growth.

RELATIVE TRADE POTENTIAL MEAT 2031

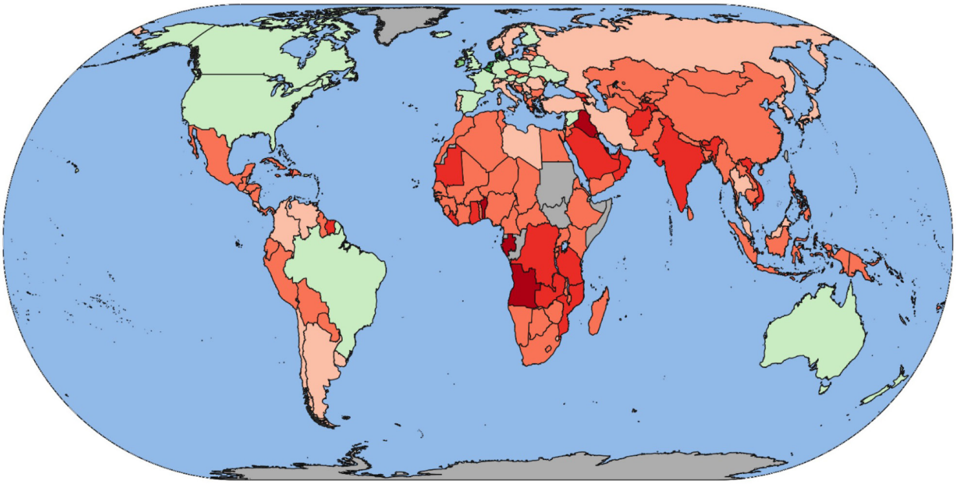

FIGURE 12. COUNTRIES WITH RELATIVE TRADE POTENTIAL MEAT IN 2031

When we look at the countries with highest relative import dependency for meat in 2011 and 2031, we can observe that this list again contains many small island nations. By looking a bit further, we found that Qatar, Iraq, Benin, Gabon, Angola, and Kuwait are among the countries with highest relative import dependencies for meat in 2031. Especially the African countries are in that sense interesting, as they do have large populations and fast population growth.

COUNTRY RANKING 2011	COUNTRY CLASSIFICATION[154]	RELATION WITH THE NETHERLANDS[155]	COUNTRY RANKING 2031	COUNTRY CLASSIFICATION	RELATION WITH THE NETHERLANDS
Antigua and Barbuda	Developing economy	None	Antigua and Barbuda	Developing economy	None
Saint Vincent and the Grenadines	Developing economy	None	Saint Vincent and the Grenadines	Developing economy	None
Qatar	Developing economy	Trade relationship	Qatar	Developing economy	Trade relationship
Grenada	Developing economy	None	Comoros	Developing economy	None
Comoros	Developing economy	None	Grenada	Developing economy	None
Bahamas	Developing economy	None	Bahamas	Developing economy	None
Saint Lucia	Developing economy	None	Saint Lucia	Developing economy	None
United Arab Emirates	Developing economy	Trade relationship	Iraq	Developing economy	Trade relationship
Seychelles	Developing economy	None	Benin	Developing economy	Transitional relationship
Dominica	Developing economy	None	Antigua and Barbuda	Developing economy	None

TABLE 10. COUNTRIES WITH HIGHEST RELATIVE IMPORT DEPENDENCY IN 2011 AND 2031 FOR MEAT

Absolute trade potential

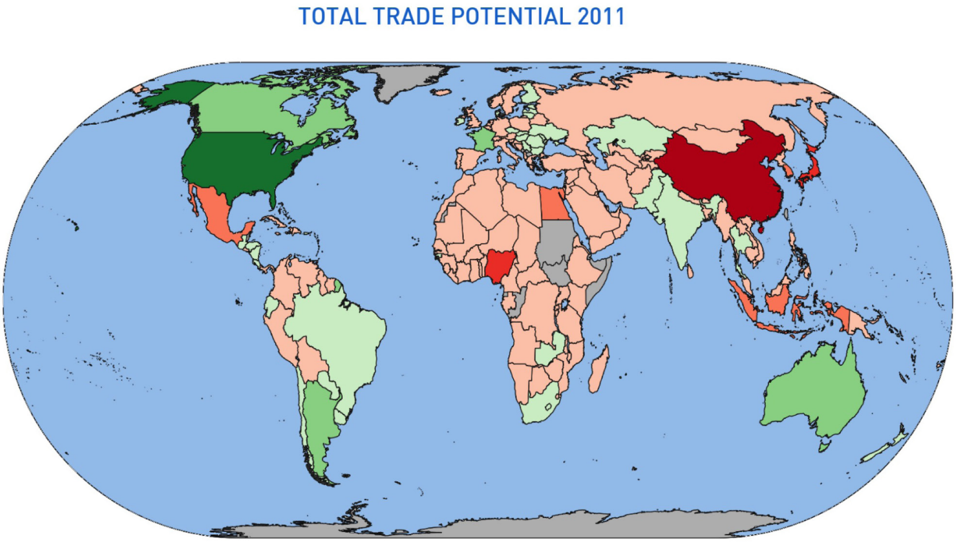

FIGURE 13. COUNTRIES' TOTAL TRADE POTENTIAL IN 2011

The total trade potential is most dependent on the size of a country, and not so much on the local relation between supply and demand. Therefore, the US is clearly visible as the largest agricultural exporter in 2011 (Figure 13). On the other end of the spectrum, we see China and Nigeria as countries with the highest demand for food imports. It is understandable that this dependency is caused by the large populations in these countries, combined with relatively bad yields in agricultural production.

When we look at the trade potential of meat in 2011 (Figure 14), this view shifts slightly. Especially Russia and China are currently heavily import dependent for meat, together with Mexico, Viet Nam, Saudi Arabia, Italy, and Japan. The US and Brazil, on the other hand, are currently the largest exporters of meat.

TRADE POTENTIAL MEAT 2011

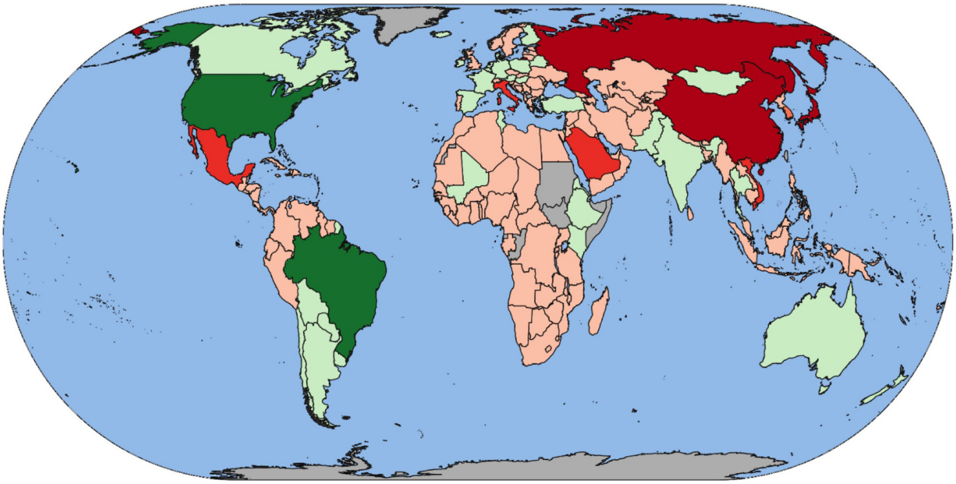

FIGURE 14. COUNTRIES' TRADE POTENTIAL FOR MEAT IN 2011

Table 11 shows the top 10 countries with highest demand for meat imports in 2011 and 2031. For the country names in 2031 it is stated whether they are currently considered a developing nation and whether they have an aid or trade relationship with the Netherlands.

COUNTRY RANKING 2011	COUNTRY CLASSIFICATION[156]	RELATION WITH THE NETHERLANDS[157]	COUNTRY RANKING 2031	COUNTRY CLASSIFICATION	RELATION WITH THE NETHERLANDS
China	Developing economy	Trade relationship	China	Developing economy	Trade relationship
Japan	Developed economy	Trade relationship	India	Developing economy	Trade relationship
Russian Federation	Economy in transition	Trade relationship	Viet Nam	Developing economy	Trade relationship
Italy	Developed economy	None	Mexico	Developing economy	Trade relationship
Mexico	Developing economy	Trade relationship	Philippines	Developing economy	None
Saudi Arabia	Developing economy	Trade relationship	Myanmar	Developing economy	None
Viet Nam	Developing economy	Trade relationship	Pakistan	Developing economy	None
Republic of Korea	Developing economy	Trade relationship	Indonesia	Developing economy	Transitional relationship
Iraq	Developing economy	Trade relationship	Colombia	Developing economy	Trade relationship
South Africa	Developing economy	Trade relationship	Egypt	Developing economy	None

TABLE 11. COUNTRIES WITH HIGHEST DEMAND FOR MEAT IMPORTS IN 2011 AND 2031

TOTAL TRADE POTENTIAL 2031

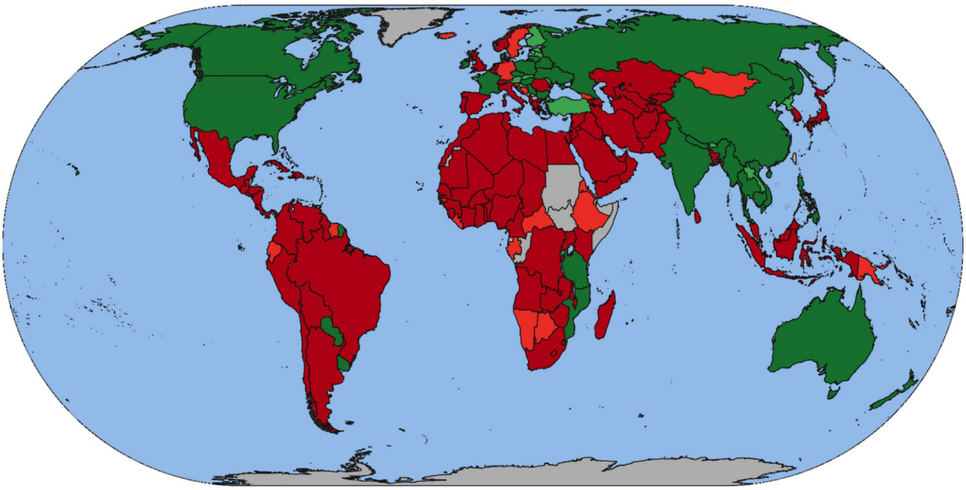

FIGURE 15. COUNTRIES' TOTAL TRADE POTENTIAL IN 2031

When we look at how the trade potential for all food (Figure 15) and meat (Figure 16) develop, we see a strong shift. Practically all nations in Latin America and Africa may become large importers of food. However, improvements in yields may bring significant improvements for Russia, China, India, and most South-East Asian countries. However, the strong population growths in Africa may increase issues for all countries apart from Tanzania and Mozambique.

Population rich countries, especially of course India and China, are amongst those countries with the highest potential future demand for meat. The modelling however did not include cultural behavior what in the case of India might have a damping effect on meat consumption. In these countries, the middle-class effect poses changes for the local diet, which becomes less carbo-hydrate dependent, and more protein dependent. In this case, also the South-East Asian countries, like Vietnam, Myanmar, and Indonesia may become top 10 importers of meat in 2031.

TRADE POTENTIAL MEAT 2031

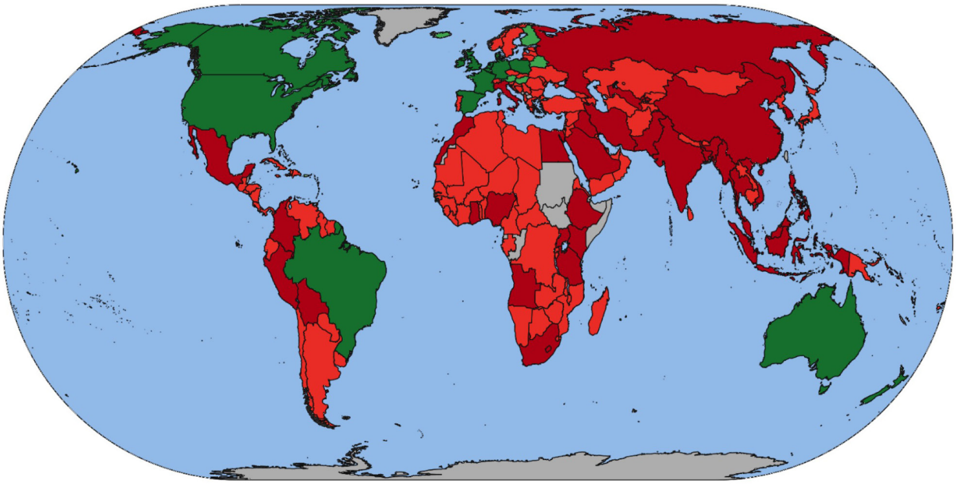

FIGURE 16. COUNTRIES TRADE POTENTIAL FOR MEAT IN 2031

Relative yield gap

Now we will look at the development of the yield gap. Agricultural yield is defined as production per area. It depends on technical capabilities of farmers, local customs, and local climate. We used FAO production and area harvested data[158] to calculate the yield in 2011. We compared all yield figures for all countries to determine the maximum possible yield, or international best practice. Climate constraints were thus not taken into account by trying to find this number. Further, it turned out that some countries (e.g., Oman and the United Arab Emirates) with very low production figures had a very high yield. These figures were considered outliers.

For cereals it turned out that presently (Figure 17) mostly developed nations in temperate zones have both a low yield gap (lightest blue) and a significant production. Egypt is in that sense an exception, but its long tradition of cereal production in the Nile delta gives it a position where water is sufficiently available, together with high energy input from the sun due to its latitude. All other African countries have more issues with the production of cereals at higher yield levels. Another interesting country is Russia, which is clearly lacking behind in agricultural yields for cereals.

RELATIVE YIELD GAP CEREALS 2011

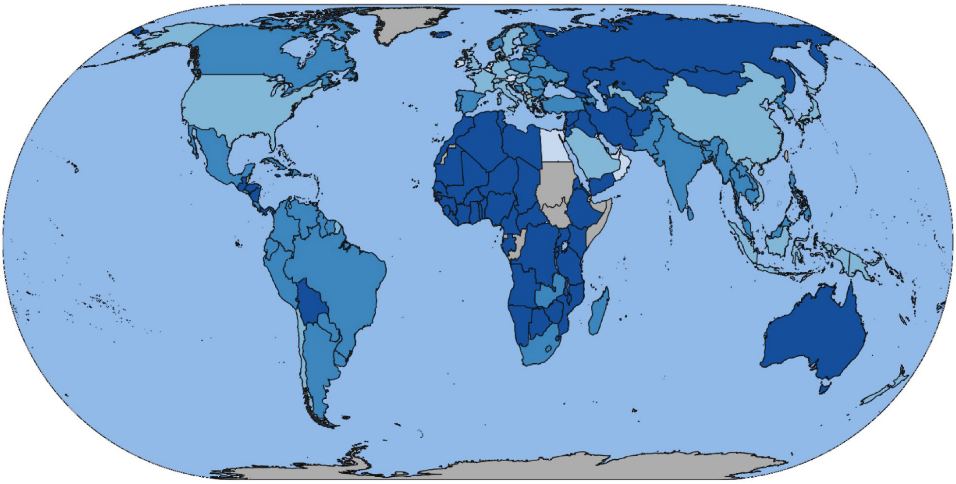

FIGURE 17. COUNTRIES RELATIVE YIELD GAP FOR CEREALS IN 2011. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

Table 12 shows the top 10 countries with highest yield gap for cereals, and roots and tubers in 2011. For the country names in 2031 it is stated whether they are currently considered a developing nation and whether they have an aid or trade relation with the Netherlands. It is clear from this list that the countries with the highest yield gaps often are parts of climate regions making agriculture more difficult, or have economic circumstances linked to a low level of industrialization in agriculture.

YIELD GAP CEREALS 2011	COUNTRY CLASSIFICATION[159]	RELATION WITH THE NETHERLANDS[160]	YIELD GAP ROOT AND TUBERS 2011	COUNTRY CLASSIFICATION	RELATION WITH THE NETHERLANDS
Bahrain	Developing economy	Trade relationship	Mauritania	Developing economy	None
Iceland	Developed economy	None	Sao Tome and Principe	Developing economy	None
Seychelles	Developing economy	None	Saint Lucia	Developing economy	None
Saint Lucia	Developing economy	None	Eritrea	Developing economy	None
Cabo Verde	Developing economy	None	Gambia	Developing economy	None
Niger	Developing economy	None	Central African Republic	Developing economy	None
Namibia	Developing economy	None	Grenada	Developing economy	None
Botswana	Developing economy	None	Saint Vincent and the Grenadines	Developing economy	None
Eritrea	Developing economy	None	Haiti	Developing economy	None
Lesotho	Developing economy	None	Gabon	Developing economy	None

TABLE 12. COUNTRIES WITH HIGHEST YIELD GAP FOR CEREALS, AND ROOTS AND TUBERS IN 2011

For roots and tubers (Figure 18), we see a slightly less pronounced yield gap picture compared to cereals. However, it is still clear that the level of industrialization of a country has a strong effect on productivity and yield of agriculture. This also means that technological development may increase agricultural productivity in those countries in which the effect cannot be explained by climatologic conditions. It is interesting in that sense that many countries in arid regions (e.g., the MENA countries) do not score as poorly as with cereals.

RELATIVE YIELD GAP ROOTS AND TUBERS 2011

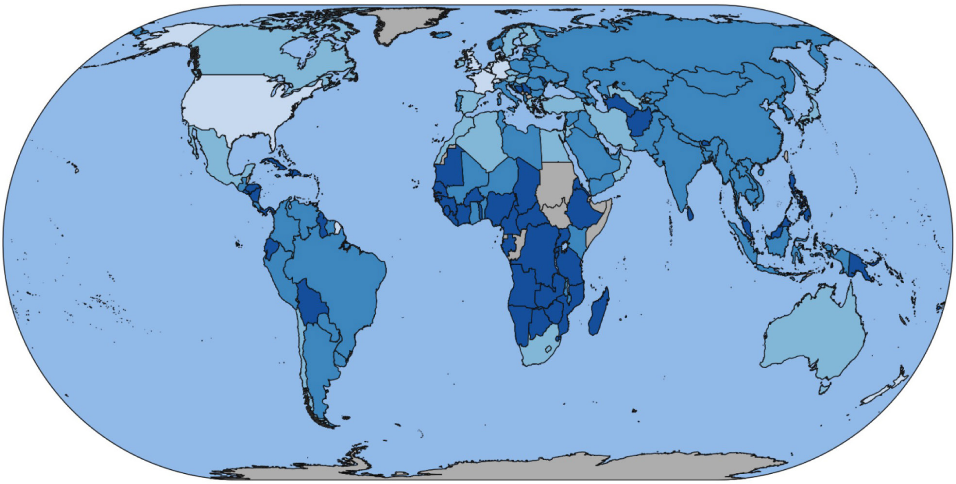

FIGURE 18. COUNTRIES RELATIVE YIELD GAP FOR ROOTS AND TUBERS IN 2011. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

In the model, we distinguished between the 'technical' relative yield gap, and the relative effective yield gap, which is the yield adjusted for the development of soil fertility. Soil fertility is, as assumed by us, affected strongly by the amount of water available. Both too much water (flooding) and too little water (droughts) can affect soil fertility and cause deviations from the normal situation.

Therefore, these figures show the differences in yield caused by changed precipitation patterns as a consequence of climate change. As seen in Figure 19, the countries most affected by these developments in terms of relative yield gap are, for cereals, the countries in Sub-Sahara Africa (most notably in the east of this region), the Central-Asian countries, New Zealand, and the US.

RELATIVE YIELD GAP CEREALS 2031

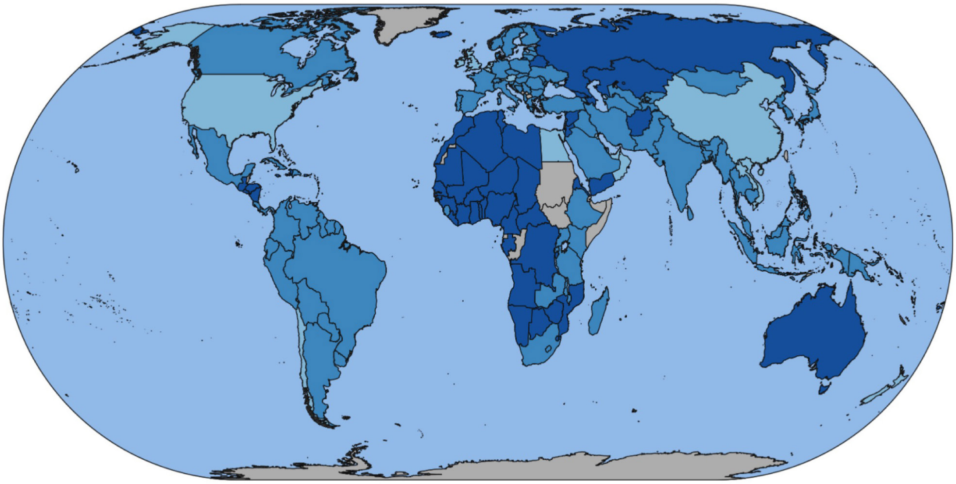

FIGURE 19. COUNTRIES RELATIVE YIELD GAP FOR CEREALS 2031. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

RELATIVE EFFECTIVE YIELD GAP CEREALS 2031

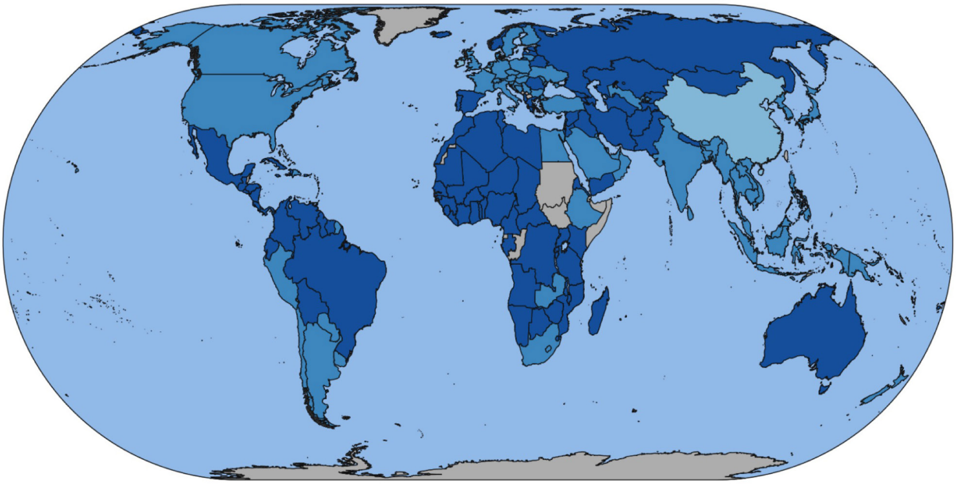

FIGURE 20. COUNTRIES AVERAGE VALUES FOR THE RELATIVE EFFECTIVE YIELD GAP FOR CEREALS IN 2031. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

As seen in Figure 20, the countries most affected by these developments in terms of relative effective yield gap are, for cereals, the countries in Sub-Sahara Africa (e.g., Mali, Niger, Ethiopia, Angola, and Mozambique).

Table 13 shows the top 10 countries with the highest yield gap for cereals, and roots and tubers in 2031. For the country names in 2031 it is stated whether they are currently considered a developing nation and whether they have an aid or trade relationship with the Netherlands.

With the exception of Bahrain, none of these countries have a significant relationship with the Netherlands. All countries are developing economies, some are islands, and most are relatively small nations in terms of their populations.

YIELD GAP CEREALS 2031	COUNTRY CLASSIFICATION[161]	RELATION WITH THE NETHERLANDS[162]	YIELD GAP ROOT AND TUBERS 2031	COUNTRY CLASSIFICATION	RELATION WITH THE NETHERLANDS
Seychelles	Developing economy	None	Saint Lucia	Developing economy	None
Bahrain	Developing economy	Trade relationship	Grenada	Developing economy	None
Iceland	Developed economy	None	Mauritania	Developing economy	None
Saint Lucia	Developing economy	None	Eritrea	Developing economy	None
Cabo Verde	Developing economy	None	Trinidad and Tobago	Developing economy	None
Namibia	Developing economy	None	Saint Vincent and the Grenadines	Developing economy	None
Niger	Developing economy	None	Sao Tome and Principe	Developing economy	None
Eritrea	Developing economy	None	Swaziland	Developing economy	None
Botswana	Developing economy	None	Gambia	Developing economy	None
Grenada	Developing economy	None	Antigua and Barbuda	Developing economy	None

TABLE 13. COUNTRIES WITH HIGHEST YIELD GAP FOR CEREALS, AND ROOTS AND TUBER IN 2031

RELATIVE YIELD GAP ROOTS AND TUBERS 2031

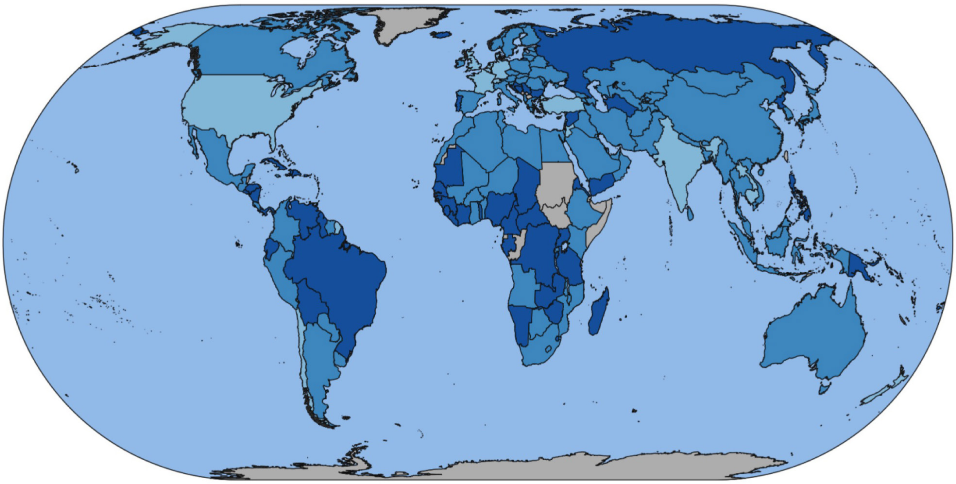

FIGURE 21. COUNTRIES RELATIVE YIELD GAP FOR ROOTS AND TUBER IN 2031. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

RELATIVE EFFECTIVE YIELD GAP ROOTS AND TUBERS 2031

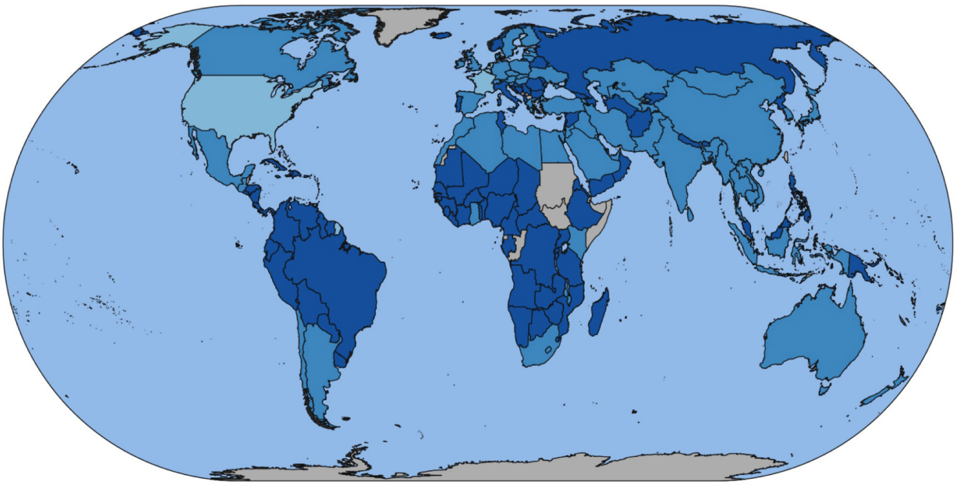

FIGURE 22. COUNTRIES AVERAGE VALUES FOR RELATIVE YIELD GAP AND EFFECTIVE YIELD GAP FOR ROOT AND TUBERS IN 2031. DARKER COLORS CORRESPOND WITH A HIGHER RELATIVE YIELD GAP

4.3 Causes high food import dependency

It is interesting to see the causes of an increased import dependency for cereals, meat, and roots and tubers. On the basis of this scenario discovery approach it was analyzed what the effects were with specific regard to the main drivers that were envisioned and used in the modeling, and were considered to be the most important in exploring future effects on the food system. The three drivers are the middle class effect – the combined effects of both economic developments and population growth – climate change and yield gap – the difference between the actual agricultural production and the potential of agricultural lands (i.e., maximum yield).

Middle class effect

One of the key drivers of the relative demand for meat imports in 2031 is the middle-class effect.

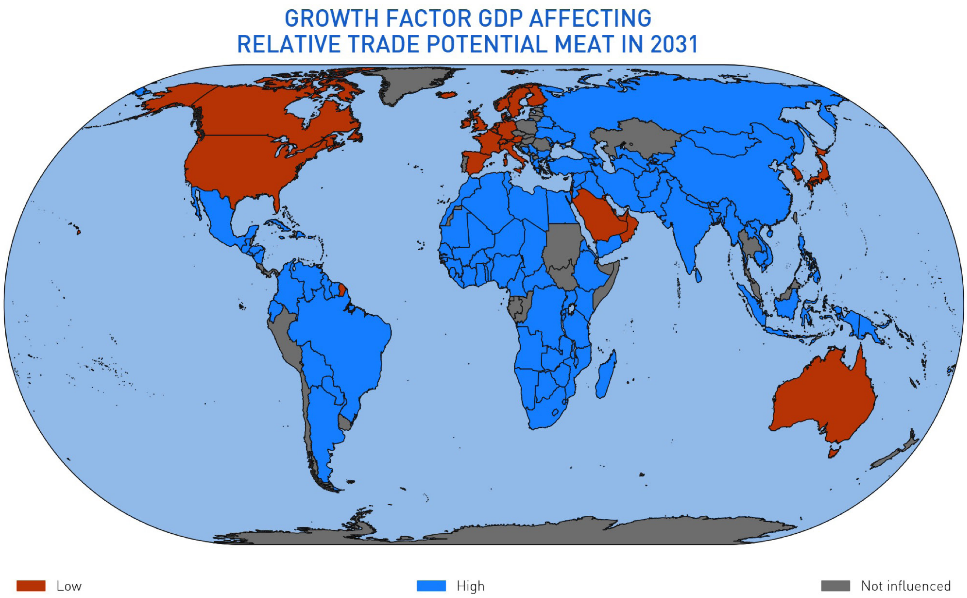

FIGURE 23. GDP GROWTH CAUSING A LOW RELATIVE TRADE POTENTIAL FOR MEAT IN 2031

This effect is caused by low population growth with relatively high economic growth. Many countries are affected. Mostly, at present, this concerns the higher echelons of lower income countries, or the lower echelons of middle-income countries. The uncertainties impacting these developments most are economic and population uncertainties (Table 14). The table makes clear that economic and middle-class effects are most pronounced for the demand for meat imports.

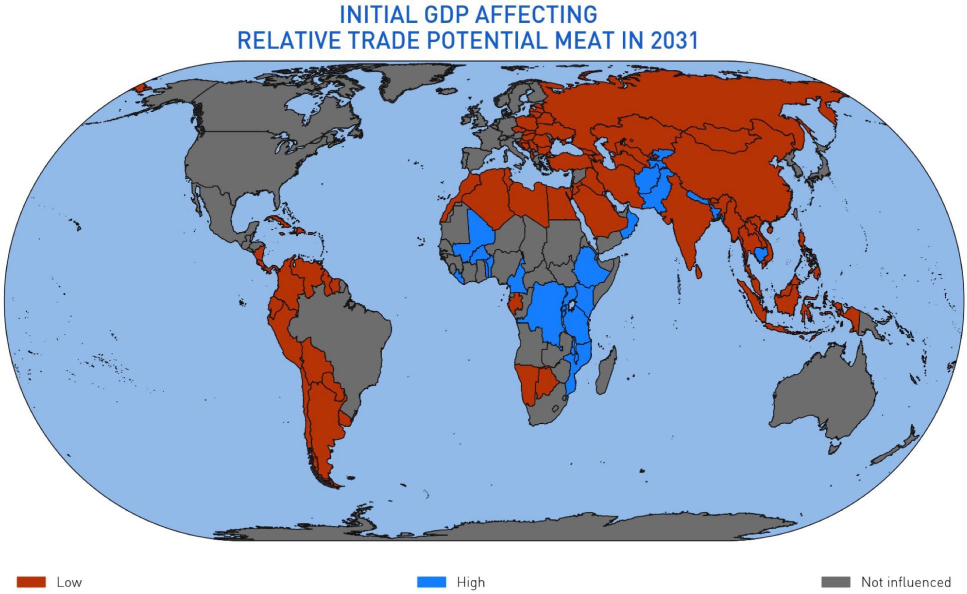

FIGURE 24. INITIAL GDP UNCERTAINTY CAUSING A LOW RELATIVE TRADE POTENTIAL FOR MEAT IN 2031

In Figure 24 we see that the initial GDP uncertainty affects the relative trade potential for meat in many countries. The issue here is that the actual value of a country's GDP is deeply uncertain, and that multiple methods exist for calculating the size of the GDP. This is both the case for different GDP estimates published by single institutions (c.f., nominal GDP values and purchasing power parity, PPP, GDP values), as for estimates published by different institutions (c.f., GDP values published by the World Bank, the UN, and the CIA World Factbook). As population estimates can be considered to be less uncertain – as the population can be counted, while the GDP has to be modeled – the actual status of a country's GDP per capita is arguably most dependent on the estimate for the GDP. The GDP per capita is the prime proxy for the development level used in this study, and therefore, for the middle-class effect.

When we observe Figure 24 once more, we see that those countries that are already observing a middle-class effect get higher relative trade deficits for meat when the GDP estimate used was on the lower portion of the total bandwidth. This can be understood as when they have relatively much to improve in the local purchasing power for food; the meat demand will increase more than when this middle-class effect was already underway for a longer period of time. On the other hand, we see that countries with a potential, however small it may be, for reaching the middle-class effect will have the highest deficits when the GDP estimate used is on the high side of the spectrum.

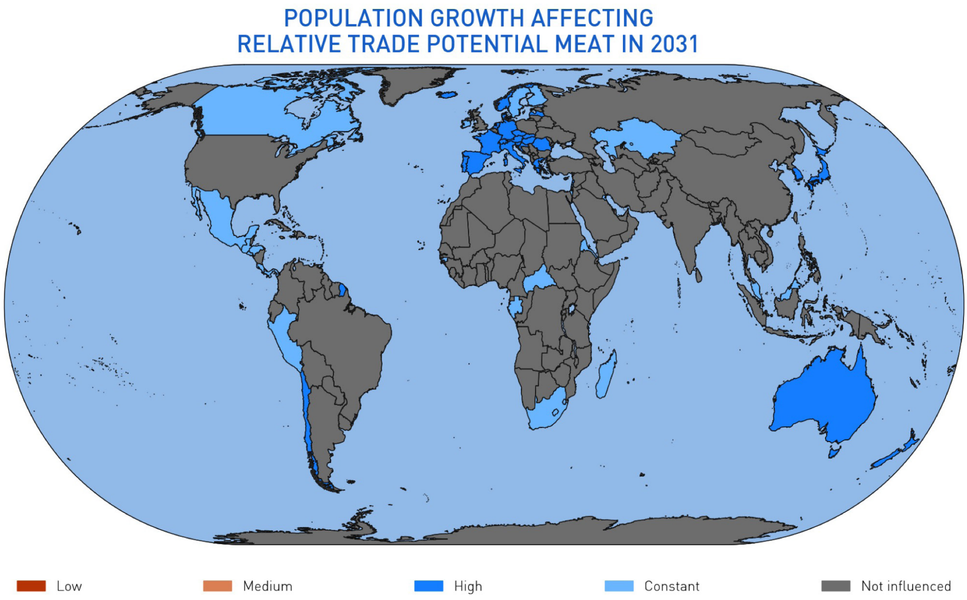

FIGURE 25. POPULATION GROWTH SCENARIOS CAUSING A LOW RELATIVE TRADE POTENTIAL FOR MEAT IN 2031

High and constant population growth affect mostly countries where the GDP level is already relatively high, as it has a detrimental effect on the average GDP per capita, making middle-income countries' meat demand level out with low or medium scenarios. For countries in Western Europe and Australia, however, it is clear that when the population growth is relatively high until 2031, the meat demand will increase most.

Table 14 shows which types of impact we have observed for how many countries per food type. We clearly see in this table that climatic change, expressed here by the change in annual precipitation, mostly increases the import dependency for cereals and roots and tubers, while the meat production is not affected. For vegetal food types it can thus be stated that increased import dependency is purely an issue of supply, than of demand. For meat, however, increased import dependency is purely an issue of increased demand.

UNCERTAINTY	TYPE OF IMPACT	CEREALS (# COUNTRIES)	MEAT (# COUNTRIES)	ROOTS AND TUBERS (# COUNTRIES)
Low annual precipitation	Climate	62	0	61
Medium annual precipitation	Climate	30	0	33
High annual precipitation	Climate	57	0	58
Constant annual precipitation	Climate	1	0	1
50% increase in precipitation	Climate (shock)	0	0	1
Low initial gdp	Economic/middle class	0	75	0
High initial gdp	Economic/middle class	0	27	0
Low growth factor gdp	Economic/middle class	16	29	18
High growth factor gdp	Economic/middle class	0	110	0
High population growth	Economic/middle class	0	29	0
Constant population growth	Economic/middle class	0	27	0
High normalization factor gdp per capita	Economic/middle class	0	10	0
Low delay on changes in annual plant production	Yield	0	0	4
Low reallocation delay on agricultural land	Yield	2	0	3
Low technological progress	Yield	0	0	1
Low maximum increase in agricultural land per year	Yield	25	0	24
High natural land degradation restoration time	Yield	120	0	117
Nothing found		7	1	2

TABLE 14. UNCERTAINTIES LEADING TO IMPORT DEPENDENCY IN NUMBER OF COUNTRIES

Climate change

When we observe which countries are most affected by the different scenarios for changing precipitation patterns, we see in Figure 26 that it is not easy to classify which regions are more affected by increasing or decreasing precipitation.

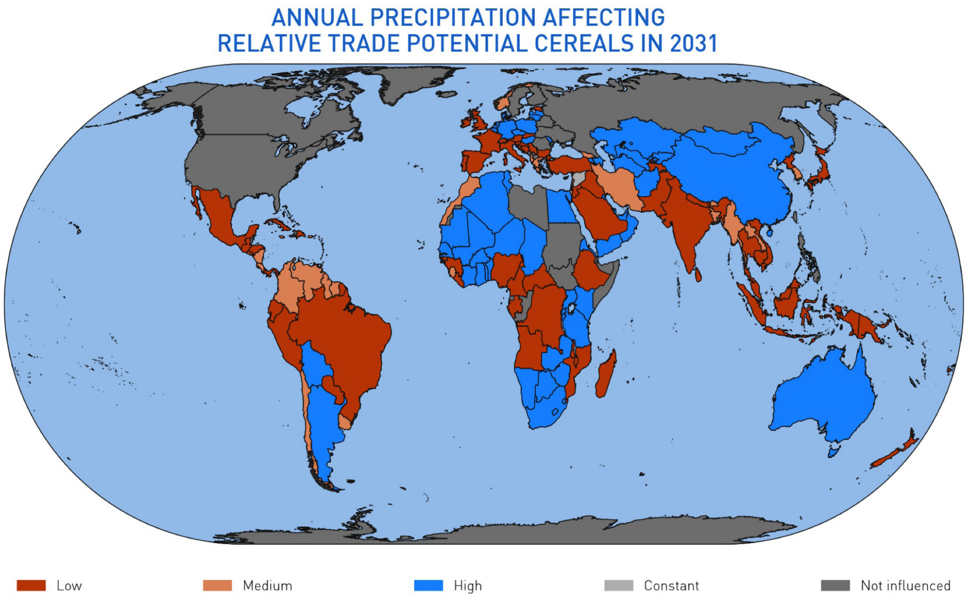

FIGURE 26. ANNUAL PRECIPITATION SCENARIOS CAUSING A LOW RELATIVE TRADE POTENTIAL OF CEREALS IN 2031. THE MAP OF ROOTS AND TUBERS IS SIMILAR

This is as country A or B being more sensitive for increasing precipitation does not mean that the decreasing precipitation has no effect on agricultural production. It solely means that that particular scenario's changes are most detrimental. It should be noted that the uncertainty in these precipitation scenarios is so large, that for many countries in the world it is not known whether climatic change will leave them with decreasing or increasing rainfall. It can, therefore, be such that the high precipitation scenario is simply more extreme than the low precipitation scenario, compared to the present precipitation levels. Further, a country's agricultural system can be expected to be optimized for current precipitation levels. Countries like Australia and Namibia, which are used to arid conditions, are therefore more affected by wetter conditions, as they may cause soil erosion. On the other hand, countries which on average experience high rainfall, like Brazil, the DRC, and Great Britain, will have greater issues with dealing with decreasing precipitation. In any case, for climate adaptation policies aimed at agricultural production, measures need to be taken both for increasing and decreasing precipitation level if this precipitation uncertainty exists.

Related to this issue is the effect of the natural land degradation restoration time visible in Figure 27. In practically all countries vulnerable to changing precipitation patterns, the effects will be smaller if soil degradation restores as fast as possible, in effect increasing the countries' resilience as the maximum effect of soil degradation and time to recover will then be smaller.

Yield gap

Yield gap reflects a large difference between agricultural production (i.e., yield) and potential of agricultural lands (i.e., maximum yield). It is caused by local traditions, lower availability of modern technology, and local climatic circumstances.

NATURAL LAND DEGRADATION RESTORATION TIME AFFECTING RELATIVE TRADE POTENTIAL CEREALS IN 2031

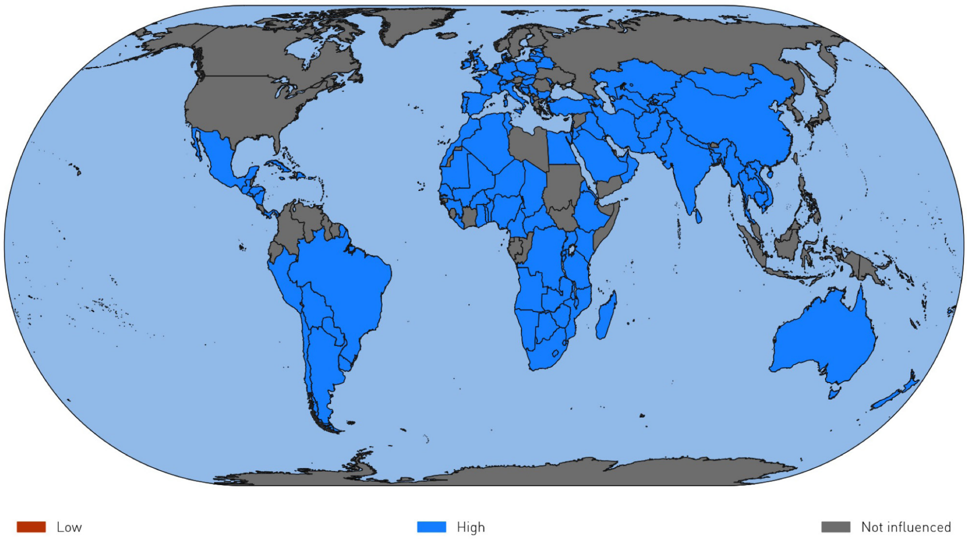

FIGURE 27. NATURAL LAND RESTORATION TIME UNCERTAINTY CAUSING A LOW TRADE POTENTIAL FOR CEREALS

Many countries are affected, at present mostly both lower and middle income countries. This is due to delays in improving yield relative to GDP per capita development: a country becomes richer first, then increases yield of agriculture.

The yield gap issue may be especially problematic for China if on a global scale it will not be possible to let the maximum possible yield for roots and tubers increase sufficiently, making the potential yield increase in China itself also lower.

5 SYNTHESIS

5 SYNTHESIS

After the analyses of the preceding chapter, it is interesting to see how robust current Dutch agricultural policies are with regard to trends witnessed already by different countries both within and outside Europe, and the food trade system in the Netherlands. We will obtain these results by comparing the insights from Chapter 2 on trends affecting the global food system and Chapter 3 regarding current food trade in the Netherlands with our simulation results from Chapter 4.

5.1 Trends and shocks affecting supply and demand

As we compare the contextual analysis of Chapter 2 and the research carried out in Chapter 4, we find that climate change is the most important issue (particularly with regard to changing precipitation patterns), for the future supply of vegetal food sources when it comes to demand. We also found that the middle-class effect (that is change in lifestyle and consumption patterns) is key for both current low-income countries and current middle-income countries, while demographic trends are only significant in current high-income countries.

The overall climate change phenomenon seem to have more effects than temporary, even multi-year, shocks in precipitation levels. However, it should be noted that changing precipitation patterns may not imply a change in average precipitations overall (i.e., is it going to be more wet or more dry), which is how it was interpreted in our research, but may rather mean a change in the bandwidth of yearly precipitation for every country.

5.2 Trade relations

A number of key findings can be harvested based on combining inputs of Chapter 3 and Chapter 4.

Inside Europe

Relevant export partners to the Netherlands and within Europe currently include Germany, Belgium, and the UK. In the future, this group of countries is not expected to change. This is understandable, as their geographic proximity cannot be changed, while the already high-income level of these countries does not make significant changes in both food demand and supply patterns. Only population growth can have an impact, but, as we know, even the high population estimates for these countries forecast a very modest growth in population size.

The most important import partners in Europe currently include Germany, Belgium, and France. The strength of their relations with the Netherlands is likely to remain similar in the future. Poland and other Eastern European nations can be expected to gradually gain in importance in the future.

Outside Europe

Export partners of importance to the Netherlands currently include China, the US, and Russia. In the future, export countries for meat would include Russia, China, and India, although Russia can be expected to become a net food exporter, and will therefore have a decreasing importance as key export partner to the Netherlands. The group picture may become more regional in the future, and is set to include Central Asia, several ASEAN countries such as Indonesia, Malaysia, and Brunei, the Middle East and Africa, Central and South America. In other words, the Netherlands should be prepared to deal with partners from the whole of Asia, the whole of Africa, the whole Central and Southern part of the American continent excluding Brazil.

Regarding import partners, Brazil, the US, and Indonesia are currently key to the Netherlands. We anticipate that Indonesia will be of lesser importance in the future as an import partner, while Brazil, Canada, the US, and New Zealand will gain in importance, particularly in terms of their meat trade status. For cereals, partners will include Russia, Canada, and Australia – and perhaps Tanzania, Mozambique, and Ethiopia.

5.3 Dutch knowledge export

Present Dutch knowledge export is primarily directed to China, Indonesia, and India, and mostly concerns the growth of total factor productivity (TFP, i.e., the total output growth relative to input of labor and capital). Further, knowledge is shared about water and energy shortages.

Efforts on TFP may need to focus more on yield gap countries such as CIS countries, Central and South American countries, the Middle East and Africa. China, Indonesia, and India may not be where most productivity gains can be found.

While most efforts regarding water and climatological issues currently focus on droughts, our findings suggest that in many countries, especially those experiencing semi-arid conditions, may also benefit from knowledge focusing on how to deal with flooding and other water-related soil degradation.

6 CONCLUSIONS AND RECOMMENDATIONS

6 CONCLUSIONS AND RECOMMENDATIONS

With the use of input coming from the qualitative analyses of the HCSS foresight studies in combination with the modelling results from both the descriptive analytics as well as the scenario discovery, it was possible to better understand the future consequences of the most important drivers for the food system worldwide, as well as the possible effects over time for the various countries. On this basis, some policy consequences as well as consequences for Dutch trade were identified.

6.1 Consequences for Dutch policy

As a consequence of the possible changing effects of the drivers on the food system, policies might need to change and adjust. In this paragraph, possible future focus shifts and adaptations are listed. With the modeling results it was generally possible to identify no-regret options for policy, having a robust approach towards anticipating future uncertain developments at the same time. It is acknowledged that these policy options will have to be scaled and probably be region- and/or country-specific. When developing the new policies, detailed analyses and country-specific analyses will be required.

For policy makers, it is important to have clear aims based on which they can pinpoint their policies. The analysis shows that relevant policy goals include targeting other or additional countries, placing more emphasis on those affected by trends and drivers identified and various trade partners that will gain in importance, and the evolution of Dutch knowledge export.

Consequences for Dutch knowledge export

- In terms of Dutch knowledge exports, efforts made for total factor productivity (TFP) may need to focus more on yield gap countries such as CIS countries, Central and South American countries, the Middle East and Africa. China, India, and Indonesia may not be where most productivity gains can be found. Countries

experiencing semi-arid conditions may also benefit from knowledge focusing on how to deal with flooding and other water-related soil degradation.
- To increase yields, it is important to have food prices that incentivize higher food production. This can be made possible by increasing technology availability in those areas with the highest yield gaps. This is an effect that may especially have effects for larger scale farmers.

The need for an increase of the value of food

Without a well-functioning market where food commodity prices allow supply and demand to adjust to each other (i.e., taking the monetary value of food into account), it will be hard to produce enough food, on a global scale, to satisfy changing food demand patterns. The availability of meat and oil crops is particularly critical in this sense.

The causes of this food scarcity are caused by developments on both the demand side and the supply side. On the demand side, the middle-class effect causes increased food demand per capita. Therefore, the food scarcity is often not a matter of life or death, but of lifestyle. In itself this is, of course, not a negative effect, as larger parts of the world population will have increased income.

On the supply side, food producers and farmers will have to deal with the consequences of water scarcity caused by temporary droughts and climate change, and a yield gap caused by limited technology availability.

- Hence a well-functioning global food market can potentially mitigate these effects. Such a market should be **transparent and be optimized with technology capabilities** for increasing yields.
- **Additional measures could include decreasing meat demand and increasing meat supply.**

The need to increase transparency

Enhanced transparency helps all actors in the food value chain to give access to information about present and historic food prices per food commodity. Making technology available is important because it may increase the availability of market information and technology information to allow farmers to bigger yield growth, especially when a large proportion of small-scale farmers can have access to the Internet to increase information availability for them.

In particular, important and key countries to do so are, for example, countries in Sub-Sahara Africa, the Indian peninsula, and South-East Asia. In these countries, limited access to information, combined with limited financial resilience of local farmers, and often the position of middle men with incentives to keep prices low for local farmers reduce the income of food production, and reduce options for increasing it. For example, when a local farmer in rural Sub-Sahara Africa is growing maize in the wet season, he or she will generally have very limited financial reserves left from selling the previous harvest – the wet season is in many of these countries known to be the 'hunger period'. He will thus be more easily convinced to accept low prices offered by local middle men.

Increasing farmers' information position on global food prices will empower them in taking action to reduce these harmful effects.

The need to increase the capability to deal with water scarcity

In many regions of the world, water is already a limited resource. The analysis shows that climate change induced reduced water availability will especially have detrimental effects on food production in countries around the equator, India, most countries in the Middle-East, and also Southern-European countries.

There are multiple ways of dealing with these negative effects, mostly aimed at reducing the water intensity levels of farming.

One way is to change the crop types grown in specific regions. The water demand for for maize, for example, is very high. In regions characterized by either permanent low water availability or temporal multi-week droughts in the growing season, millet and sorghum may significantly increase local food production and, consequentially, local farmer income.

Another way is to reduce the evaporation of water in inefficient irrigation systems. This can be done, for example, by covering irrigation channels or make less use of flooding the fields with water as means of irrigation.[163]

Finally, yet another way is to stop promoting the production of cash crops by small-scale farmers and instead encourage them to focus on more sustainable and less intensive forms of subsistence agriculture, or permanent crops. While this may decrease their income from agriculture, at the same time it may significantly increase the reliability of their food production throughout the year of, for example, permaculture-like types of agriculture.The reduced agricultural income may further be compensated by increased options for other economic activities if the type of farming is not only less resource input dependent, but also less time input dependent. The used modelling technique in itself though could not substantially support this analysis further because the necessary analysis for this kind of question was not carried out.

The need to increase the capability to deal with an excess of water caused by climate change

Our results showed that many countries that are sometimes already quite stressed in terms of water availability may have issues if precipitations increase over time. The same may happen when, regardless of present water scarcity, precipitations may increase considerably. Examples of these countries are China, countries in the Sahel region, but also Germany and Poland. In these countries, it is of great importance to be able to deal with increased annual precipitation. This means in practice:

- Being able to buffer a temporal excess of water
- Being able to let high water levels decrease relatively fast
- Making sure that soil erosion is halted as much as possible.

Current policy approaches focus on circumstances involving dry climatic conditions. It is our assessment that they should also and more significantly **focus on higher precipitations.**

6.2 Consequences for Dutch trade potential

The ways in which the Dutch trade relations will involve and with which countries were investigated, giving an estimate of the future Dutch trade potential and which countries trade policies should target.

As the middle-class effect can be felt in low GDP per capital levels already, the following countries were identified as areas of concern to take into account: China, India, Vietnam, Mexico, the Philippines, Myanmar, Pakistan, Indonesia, Colombia, and Egypt. On a global scale, if no policy changes occur, none of the model runs showed that meat supply would match meat demand in 2031. The same applies also to other animal foods such as milk.

Regarding approaches aiming at increasing the effect of Dutch trade relations in Europe, Poland and other Eastern European nations can be expected to gradually gain in importance in the future next to Germany, Belgium, and France as current export partners to the Netherlands. Outside Europe, the Netherlands should be prepared to deal with partners from the whole of Asia, the whole of Africa, and the whole Central and Southern part of the American continent excluding Brazil. With regard to import partners, Indonesia will be of lesser importance in the future, while Brazil, Canada, the US, and New Zealand should be included in the radar, particularly in terms of their increased significance in meat trade. For cereals, partners will include Russia, Canada, and Australia.

APPENDIX A – MODEL DESCRIPTION

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In this Appendix, we discuss the models used for analyzing the impact of food on the trade potential of the Netherlands and its relations to others. The specifics of the modeling method and Exploratory Modeling & Analysis (EMA) are discussed, while the general modeling assumptions, as well as a discussion on general model validity are also given.

A.1 System Dynamics and Scenario Discovery in general

System Dynamics

In this study, two different simulation models are used. These simulation models were made using the System Dynamics (SD) method.[164] SD is a quantitative modeling method which allows us to make causal relations between different factors explicit as mathematical equations and, as such, replicate feedback structures similar to the feedback mechanisms seen in real complex issues.

SD models allow us to simulate the simultaneous interactions of different feedback mechanisms, generating non-linear dynamic scenarios for the system elements represented in the model. One run with an SD model is thus an internally consistent set of dynamic scenarios for each system element modeled.

Scenario Discovery

Many complex systems are characterized by deep uncertainty about their functioning. Deep uncertainty can be defined as: "where analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, (2) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or (3) how to value the desirability of alternative outcomes."[165]

A method which allows for the development of scenarios for these systems is Scenario Discovery.[166] Scenario Discovery builds on the intuitive logic scenario techniques and allows for the exploration of the consequences of deep uncertainty with quantitative (simulation) models. As such, Scenario Discovery fits within the broader Exploratory Modeling & Analysis (EMA) methodology.[167] The application of Scenario Discovery with SD models, which methodologically can be referred to as Exploratory System Dynamics Modeling & Analysis (ESDMA),[168] allows the exploration of dynamic scenarios of systems that are both complex and uncertain.[169] As each scenario generated in the set corresponds to an individual SD model run, each scenario is internally consistent.

A.2 General modeling assumptions

In essence, all assumptions made in the modeling process are uncertain. The extent to which the assumption is uncertain depends on the amount of consensus (e.g., in the literature) about the assumption. However, for many of these assumptions no direct literature is available and where literature is available, this does not always indicate an absence of uncertainty. In this case, and also when no alternative assumptions are available, we assume that all assumptions are uncertain.

Method assumption

The first level of uncertainty, and consequentially, in the assumptions lies in choosing the simulation modeling method. As each method has both limitations and strengths, choosing a specific method influences the outcomes the model can generate. As such, it is important to choose a method that fits the characteristics of the problem.

The SD modeling method used in this study has several implicit and explicit method assumptions. SD can be used for forecasting scenarios based on input. The transformation of input to output in SD happens by focusing on the internal causal relations within a system. Another, contrasting method in this respect is econometrics. In extremis, econometrics focuses on estimating the correlation between input and output variables. SD is thus more a white box method, while econometrics is a black box method. As was indicated above, SD is a modeling method specifically suitable for complex problems. It functions by top-down unraveling the causal structure of the system of the research problem. It can thus be contrasted with Agent Based Modeling (ABM)[170], which is characterized by a strict bottom-up approach: the agents in the system are modeled and the top-down behavior is considered emergent. A final characteristic of SD modeling is the assumption of gradual or continuous change in the model variables. Discrete events or shocks can thus be modeled exogenously, but this is, in SD literature, generally considered to be undesirable.

The limitations of a particular modeling method can, from an uncertainty perspective, be overcome most elegantly by using multiple types of modeling, which complement each other in this perspective. However, it should be noted that choosing multiple methods makes the modeling phase in a research program longer, and generally requires multiple analysts from different modeling backgrounds to overcome biases attached to having a dominant field of work per analyst.

Model assumptions and uncertainties

After the choice has been made to use a specific modeling method, the first issue is the perspective from which the model is built. This can be seen as perspective uncertainty. A simple example may be the difference between a top-down and a bottom-up approach to calculating demand. Top-down, demand is calculated by looking at the economic development level of the population (GDP per capita) and the size of the population. Via a correlation between resource use and GDP per capita, the demand for a specific resource can be calculated. Bottom-up, one could look at the demand for specific uses of a resource and how far this demand has been met. Depending on an autonomous demand growth for each use, the aggregated demand can be calculated. When specific resource uses are considered, this may have a profound impact on other elements in the model as well. The perspective choice may thus influence the complete structure of a model, in essence leading to two different models.

On a slightly lower aggregation level, assumptions have been made about structural (formula) and parametric value uncertainties. Structural uncertainties are in essence modeling choices about formulas. Every model formula is thus an assumption. The majority of formulas can be derived using common sense, but specific formulas and model structures are not trivial.

The parametric uncertainty (with, as special variant, trend uncertainty) is the most concrete version of uncertainty encountered in the modeling process. All parameters in the model, except the definitions of specific parameter boundaries, are assumed to be uncertain. For a complete overview of all relevant assumptions, see the model

Model validity and limitations

A model is generally considered valid when it is suitable for the purpose intended.[171] Often this state of the model is referred to as model validity. Validating models used for scenario discovery, as in this study, is somewhat different compared to models that can rely on one reference run, as is done in traditional modeling. The absence of a reference run and the focus on different plausible dynamics in the system renders historic comparison largely obsolete. However, the issue of validation can, although only partly, be overcome by specific techniques, aiming at *ex ante* correct construction of the model, and *ex post*, face validation of the behavior shown by the model. All techniques described below were performed for both models in this research.

The *ex ante* validation contains basically three different checks and best practices. First, all variables in an SD model have units as well as values or formulas. A unit check can be performed in order to check whether the model is constructed consistently with regard to the units. A second check is to see whether literature exists with regard to specific relations between variables. Given the fact that correlations are only seldom useful in an SD model and statistic causal relations are not always translatable into a simulation model, this is however seldom possible. The third check is a sanity check, to see whether model relations make sense. We performed this in model construction workshops with energy experts.

Ex post, after model construction, it is possible to check whether the behavior of the model satisfies plausibility or extreme condition checks, for example, negative values for stockpiled resources should not be possible. Even if only one run in the whole set of scenarios generated with the model shows impossible behavior, this indicates model errors that need to be corrected. Further, the uncertainty analysis helps to detect these errors. A final check is whether the behavior shown by the model at least contains the expected behavior in the set of generated scenarios. If this is not the case, it should become clear why this does not happen and whether this is a plausible explanation for the impossibility of the initially expected behavior. In this study we used peer review sessions with energy experts for this purpose.

A.3 Model description

The overall model is composed of 5 different sub-models for food demand, land use, food supply, agricultural productivity, and water availability (Figure 28).

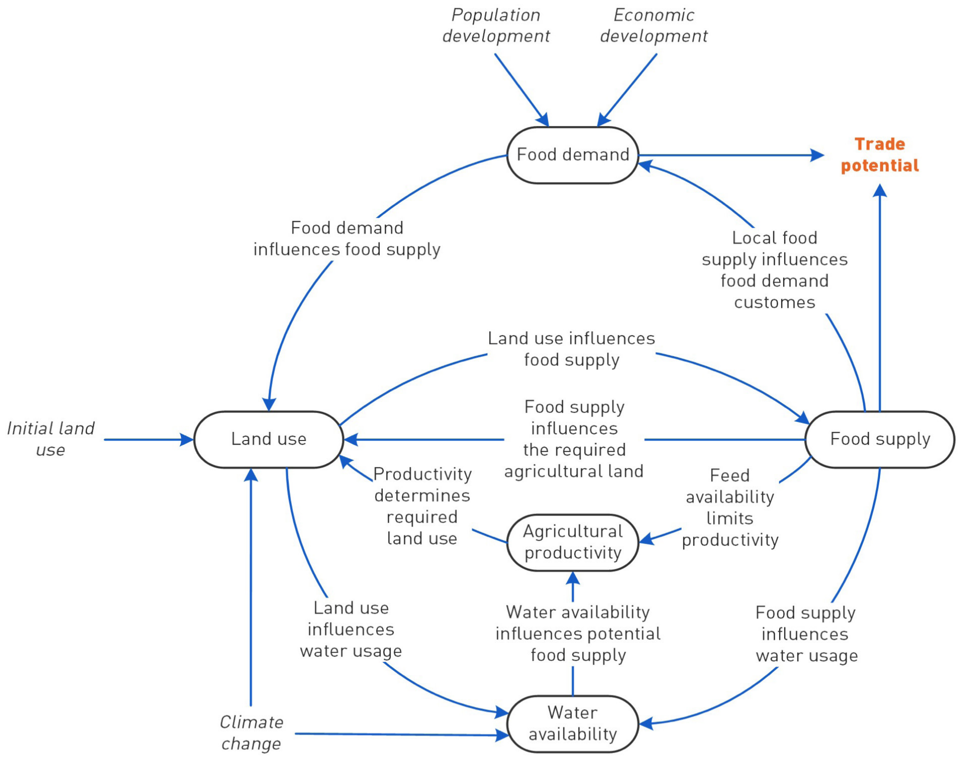

FIGURE 28. MODEL OVERVIEW

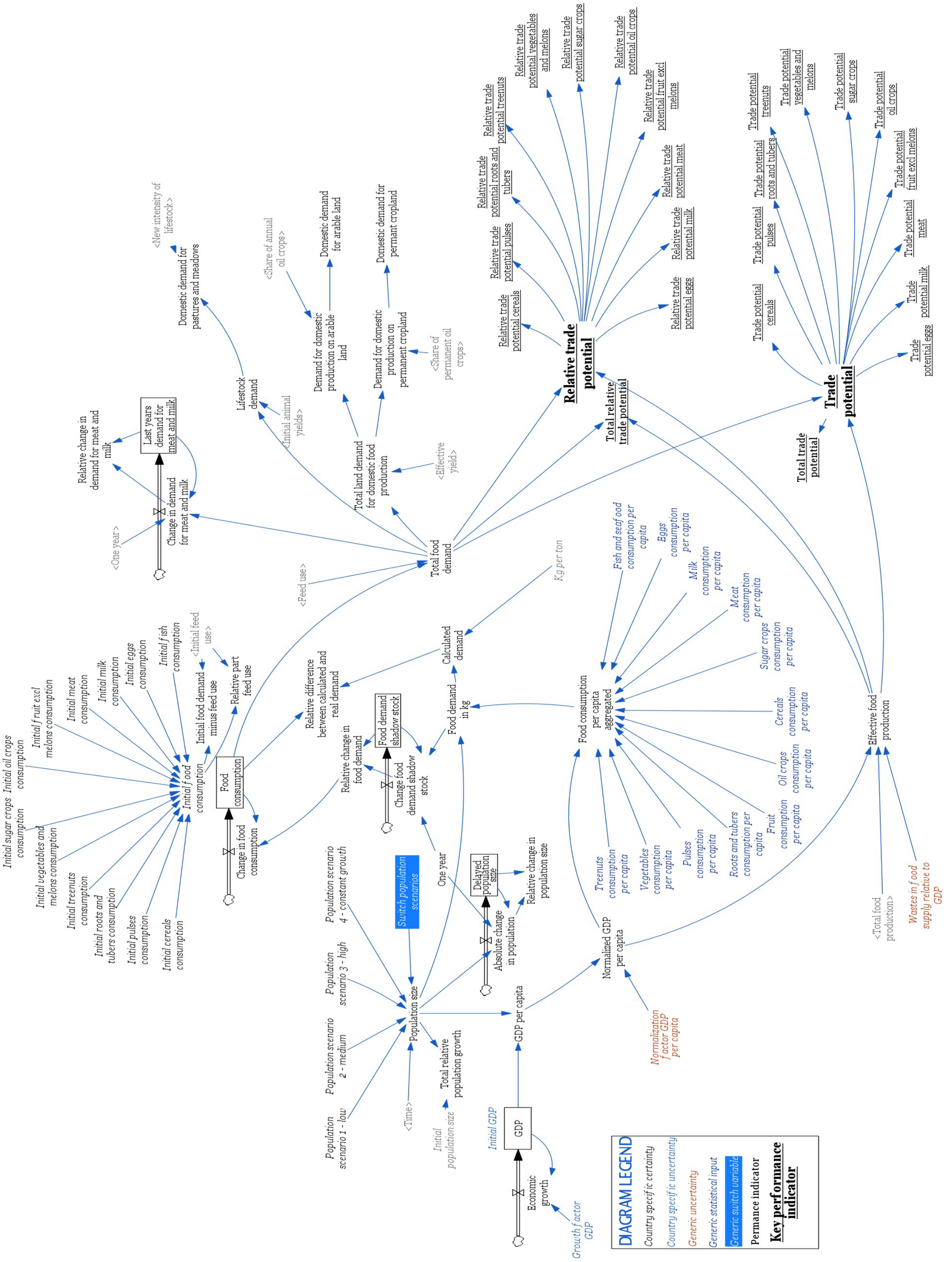

FIGURE 29. FOOD DEMAND SUB-MODEL

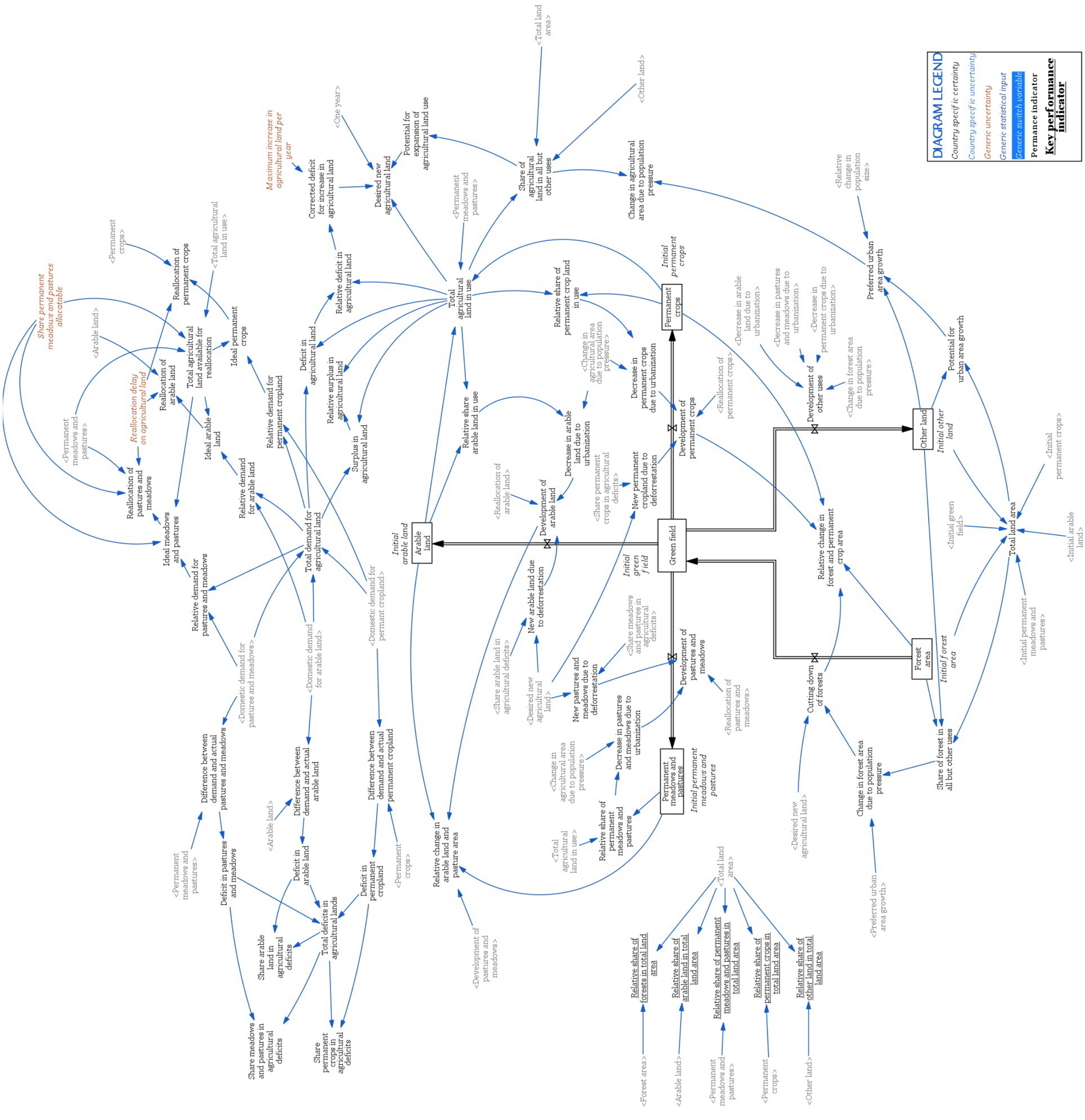

FIGURE 30. LAND USE SUB-MODEL

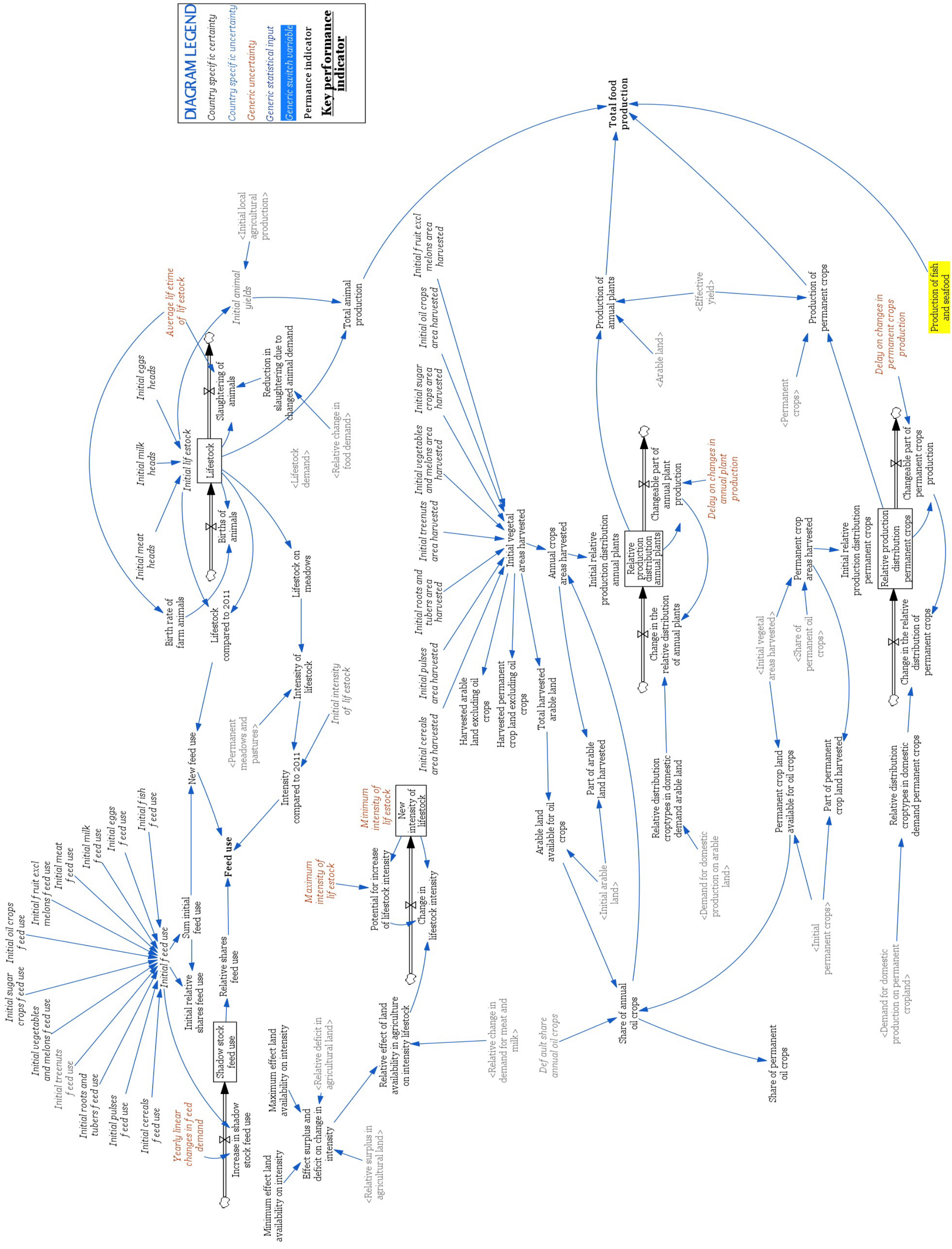

FIGURE 31. FOOD SUPPLY SUB-MODEL

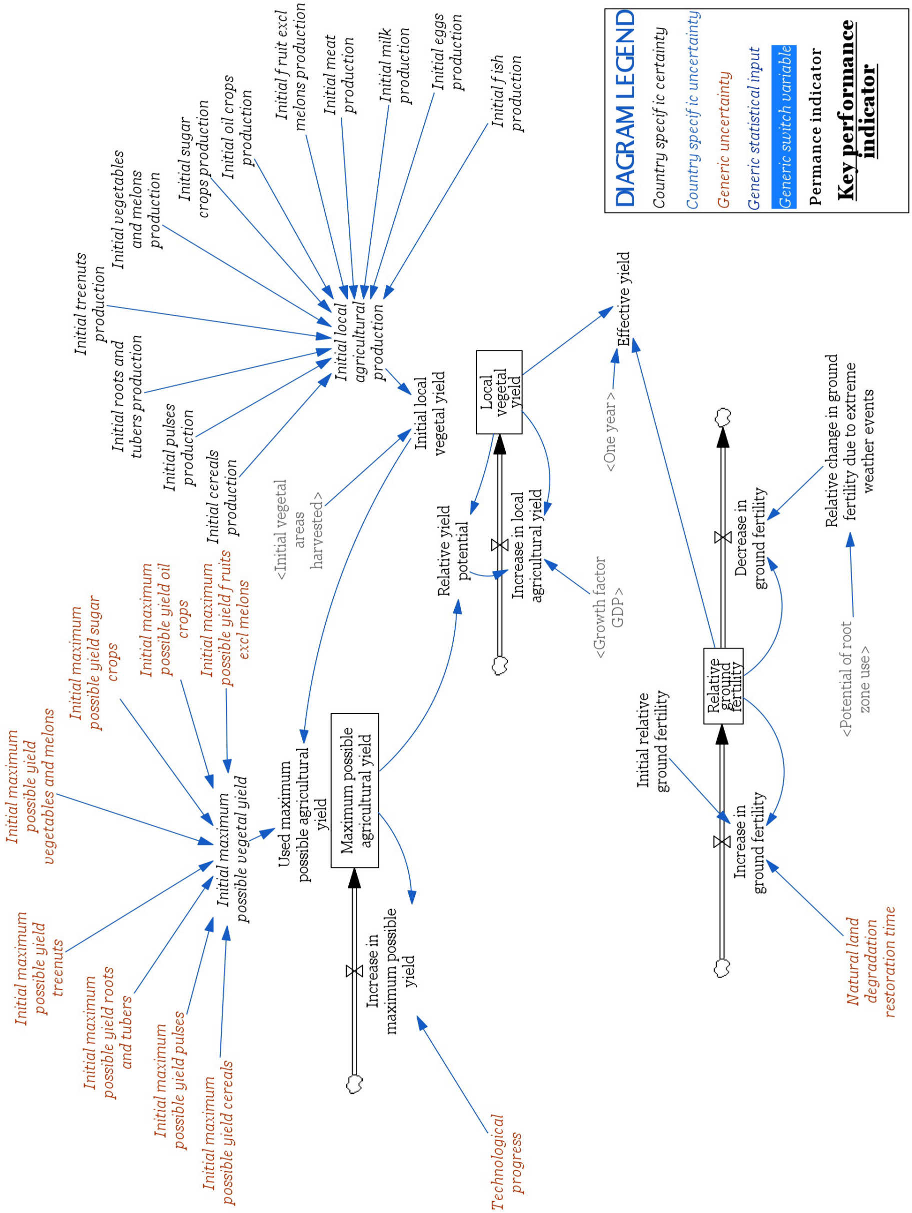

FIGURE 32. AGRICULTURAL PRODUCTIVITY SUB-MODEL

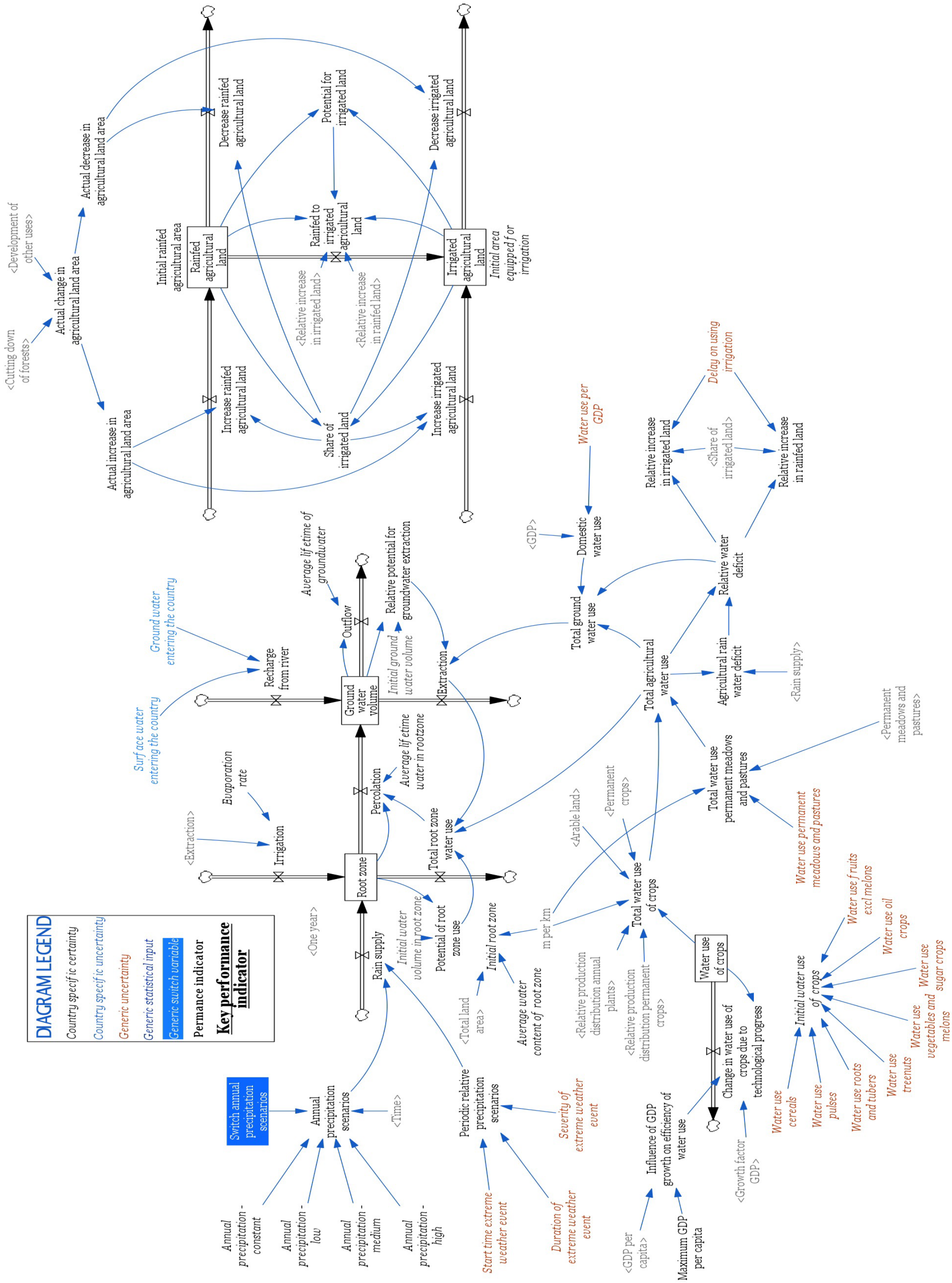

FIGURE 33. WATER AVAILABILITY SUB-MODEL

APPENDIX B –'METAFORESIGHT' METHODOLOGY

APPENDIX B – 'METAFORESIGHT' METHODOLOGY

In this study, we make use of the innovative 'Metaforesight' methodology for agriculture and food. The goal of this approach is to enhance awareness of emerging issues and drivers of change from other parts of the world. It intends to reveal visions of the future from emerging economies and languages that are generally not addressed in Western foresight studies.

Metaforesight adds value to decision making and planning processes, as it is a systematic way of gaining a better understanding of the bandwidth of views about the future security environment – views that do not only include those from Western countries. The idea is to support the production of more robust, adaptive and flexible strategies for the long term.

This study first builds on the latest state of the art in research on trends, drivers of change, criticalities within the global food system to generate visions in terms of scenarios and building blocks for the future. The research particularly uses resources such as the 2014 HCSS study *Future Contours of Agriculture and Food*, which provided a broad vision on the future of food systems displayed by foresight studies from emerging agricultural economies. Using manual coding, it had yielded fresh insights to feed into the discussion by policy and research management groups. From the perspective of a global 'agricultural and food' economy, it is indeed important to be aware of visions/policy perspectives of the future from emerging economies, such as China, India, Brazil, which are likely to be decisive factors in the future of agriculture. For example, the *Future Contours* study includes Chinese visions on how to sustain Chinese food consumption through 2030. Some of these insights were used for this project, and summarized in this report. Understanding their views about drivers of change and building blocks for the future may shed light on important developments and global developments that may affect the future of the global food system.

This research strand has a more qualitative nature. It draws on the insights of the foresight community of several 'language domains' reflecting the perspectives of Brazil, China, India, Africa, and those of the West (some - US, EU, UK, The Netherlands) for the world of food and agriculture through 2050. The workload consisted in updating the manual coding results of foresight studies used in the 2014 *Future Contours* study, restructuring it along the lines of a new coding scheme relevant to this project, and executing the same task with new foresights feeding the selection (the 'Western' cluster). In total, our collection includes 151 foresight studies.

Manual coding serves to identify relevant pieces of information on the topic in every study (e.g., ...), to outline the parameters pre–defined and refined, informing our analysis on the different elements that emerge, and ultimately, to address the research questions. Once redefined, the coding scheme ensured that all relevant issues could be identified in the foresight database i.e., as described below, drivers, of supply, of demand, of mitigation, and shocks, but also policy perspectives.

- *Drivers of demand* are actions or trends or developments that have an effect on what buyers (companies, industries, consumers, people in general) want to buy as well as the volume/quality of the buy
- *Drivers of supply* are actions or trends or developments or situations or structures that have an effect on how the supply chain works, on what is produced, on how the systems delivers (quantified with efficiency, qualified in terms of situations, etc.), and on how companies, industries (buyers, but which can also be suppliers) supply
- *Drivers of mitigation* are actions or policies that intent to mitigate negative or sub-optimal externalities or developments emerging from the food system. Mitigating here is the action to solve existing problems and which is taken by the government, companies, or workers. For example, it can include making changes in existing subsidy policies to make these more efficient
- *Policy perspectives and options* for food systems are ways of approaching the food system. They include ideologies, attitudes, models or tendencies that affect the food system. They reflect the views of governments (e.g., transitioning from a State-centered food system to a more private investment system or views on competition); societal views (e.g., agricultural jobs connoted with low social status); or managerial approaches (e.g., investment in human capital or new technologies as a way forward), among others. One illustration of a policy perspective can be a subsidy policy being established, or that ceases to exist.

- *Sudden events or shocks* are unexpected or unpredictable occurrences, innovative breakthroughs or game changers (these can be difficult to grasp from a non-expert perspective) that affect the food system either positively (e.g., good weather conditions) or negatively (e.g., droughts).

This report includes a summary cross-comparing and synthesizing the main takeaways. Much deeper analyses were produced at first in order to achieve this cross-comparison and overview. These and the list of foresight studies collected for this exercise are available on request.

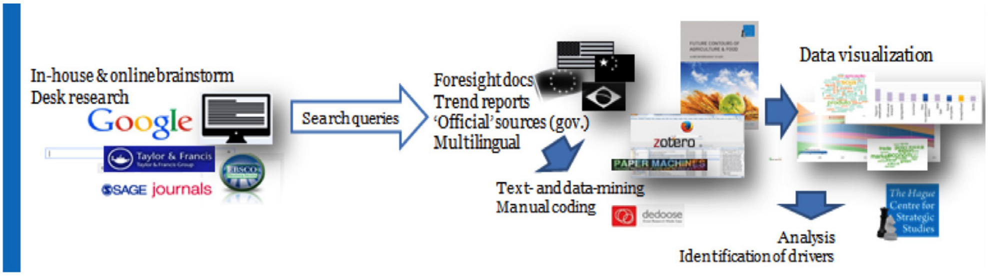

FIGURE 34. METAFORE FOR FORESIGHTS: RESEARCH PROTOCOL, FROM BRAINSTORM TO DATA COLLECTION, ANALYSIS AND VISUALIZATION

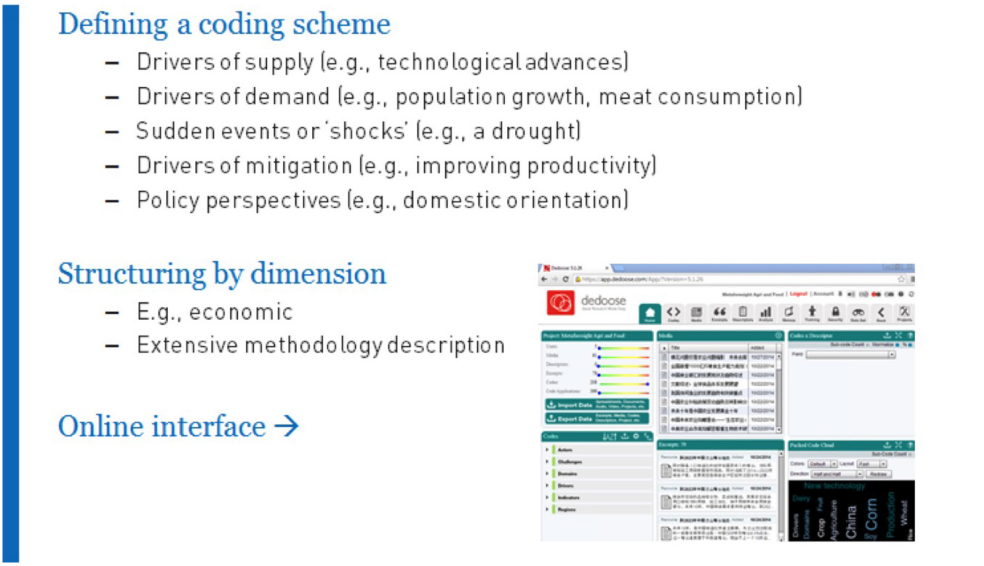

FIGURE 35. WHAT IS MANUAL CODING?

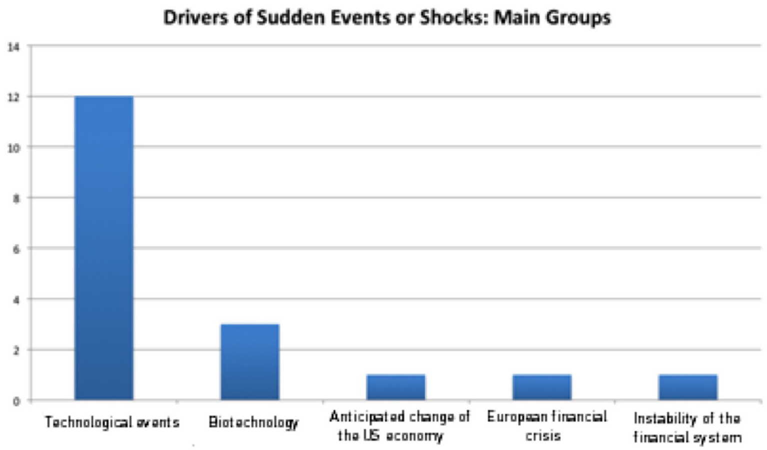

FIGURE 36. EXAMPLE OF MANUAL CODING RESULTS VISUALIZED FOR THE PARAMETER 'SHOCKS' BASED ON THE CHINESE FORESIGHTS. THE NUMBER ON THE AXIS INDICATES THE NUMBER OF TEXT FRAGMENTS CODED AS SHOCKS.

ENDNOTES

ENDNOTES

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45 GDP on axis x is visualized on a logarithmic scale. The relationship between indicators is visualized using a third degree polynomial curve. Output is faceted based on food types. 95% confidence intervals are shown around the regression lines. Data is from 1961 to 2013.

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