Impacts of climate change on cocoa and the German chocolate industry

A case study within the CLIC project

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1 Scope and relevance

1.1 Overview

This case study presents an assessment of transnational climate impacts through German trade of cocoa and cocoa products. We will analyse the supply chain of cocoa beans and cocoa preparations (including chocolate) and its vulnerability towards climate change. We further examine the complexity of the supply chain along both climate impacts and adaptive measures. This case holds relevance for various reasons: Germany is the top world exporter of chocolate and one of the largest importers of cocoa-based products. Chocolate consumption within the country also stands among the highest in world rankings, as well as overall economic revenues, surpassed only by the United States.

Most of the world's cocoa production takes place in regions that are particularly affected by climate change. The rising temperatures combined with reoccurring and longer droughts will threaten the production volume under all climate scenarios. At the same time, current climate modelling studies show that climate impacts are rather region specific; hence, the impacts of climate change are not uniformly spread throughout countries. To assume a general vulnerability based on nation-states divisions could be hindering more precise evaluations focused on particularly vulnerable locations or ecosystems. In that sense, breaking down the supply chain and products such as chocolate into its different stages and components and studying relevant region-specific vulnerability to climate impacts leads to a wider yet more accurate scope for assessing cross-border impacts.

The objective of this case study is twofold: first, we seek to engage with methodological reflections, critiques and research gaps present in current literature. In doing so, we aim at making a contribution to the methodological debate on assessing transnational climate impacts on trade pathways and illustrate the possibilities of a holistic approach with a concrete case study. Second, we seek to explore the cocoa and cocoa preparations supply chain with a focus on Germany.

1.2 Structure

The case study first provides an overview on the sector and the supply chain of cocoa and cocoa preparations. It starts with the economic aspects, namely export and import relevance for Germany as well as an identification of main trading partners. Next, we present a description of the supply chain starting with the production of raw materials, essentially the cultivation of cacao trees. The treatment of cacao beans and further stages of processing and transport are explained subsequently. The study also presents the changing structure of cocoa demand, amid growing environmental and fair-trade awareness.

In a second part, the study analyses past and current climate impacts on cocoa production. Various climate and weather events are described at different spatial and temporal scales, followed by an assessment of the exposition and vulnerability of the cocoa supply chain towards them. This part also considers current adaptation strategies developed by local farmers, certification organizations and chocolate manufacturers to cope with extreme weather events.

The last part of the study evaluates possible future consequences of climate change on the economy of cocoa. The study proposes a series of adaptation recommendations for the whole supply chain, from local farmers to German stakeholders.

2 Overview of cocoa and its supply chain

2.1 Economics of cocoa in Germany

Cocoa products refer to a large variety of goods, from raw cocoa beans, shells or butter to chocolate – and Germany is a leading country for exports and imports of several of these products.

Germany imports 10% of the world's total cocoa beans, following the Netherlands and the United States (The Observatory of Economic Complexity 2020). According to the BDSI, the Federal Association of the German Confectionery Industry (Bundesverband der Deutschen Süßwarenindustrie), Germany imports raw cocoa mainly from Côte d'Ivoire, followed by other West African countries and with less importance from Latin American or even South Asian countries. The following graph provides an overview of Germany's cocoa imports:

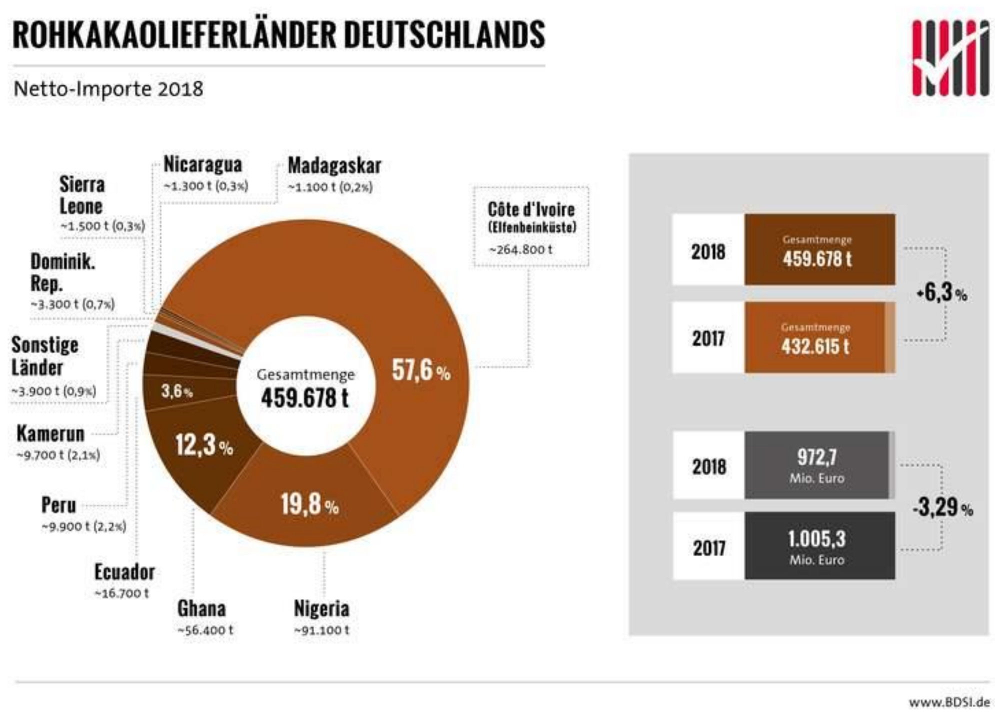

Figure 1: German cocoa imports by country (BDSI 2019)

Around 31% of the world's cocoa production of approximately 4.7 million tonnes is processed in Europe and around 10% of the world's cocoa harvest is processed in Germany alone (Bundesministerium für Ernährung und Landwirtschaft 2017).

Germany is the world's largest chocolate exporter in the world: Germany is responsible for 17% of the world's total exports, with all the main export destinations remaining within Europe (cf. **Fehler! Verweisquelle konnte nicht gefunden werden.**). Germany also imported chocolate with a value of 2.41 billion USD in 2018, mainly from European countries such as Belgium, Luxemburg, Switzerland and the Netherlands (International Trade Center 2019; The Observatory of Economic Complexity 2019).

Table 1: Overview of German chocolate exports and imports in 2018 (International Trade Center 2019; The Observatory of Economic Complexity 2019)

Chocolate	Countries	Value (USD) 2018	World Total	World Position
Export	To: France, United Kingdom, Poland	4.95 billion	17.3%	1°
Import	From: Belgium-Luxemburg, Switzerland, Netherlands	2.41 billion	8.6%	2°

The cocoa processing sector in Germany is composed of both large and small companies. 82 companies from the chocolate industry are members of the BDSI, whose members represent around 90% of the value of confectionery production in Germany (statista 2019a). The cultural importance of the chocolate industry also stands out: the average per capita consumption in Germany was 8.7 kg of chocolate in 2019, one of the largest worldwide (statista 2019b).

For the production of chocolate, several products derived from the processing of cocoa beans are used, including cocoa butter, cocoa paste or cocoa powder. While Germany is already importing and processing a large amount of cocoa beans itself, additional imports of cocoa products are necessary. For cocoa butter, fat and oil, Germany is yet the world's largest importer (International Trade Center 2019). Germany also imports unsweetened cocoa powder, mostly from the Netherlands, with a share of 74.5% of German imports of this product. Cocoa shells, husks, skins and other by-products are mainly imported from the Netherlands (62.2%) and Ghana (11.5%). Altogether, Germany's top countries for cocoa product imports are the Netherlands, Ghana and Côte d'Ivoire.

This implies a strong economic dependence of the sector on these countries, what could turn out to be a source of fragility for the reliability of imports: Cocoa-based products are characterized by a low complexity (The Observatory of Economic Complexity 2019). Thus, the structure of the world supply of cocoa is unlikely to be vulnerable to a multiplicity of small shocks, but rather to strong localized shocks in a few key countries.

2.2 The supply of cocoa

The supply chain of cocoa can roughly be separated into three main steps: 1) cultivation, 2) transportation and 3) processing and distribution. These logistic steps each correspond to a different geographical region in the world: a large majority of cocoa beans is cultivated in West Africa (minor parts in Asia or South America). The beans are then transported to – in this case – Germany via maritime transport. Most of the processing occurs in Germany, and the final products are distributed or exported to surrounding European countries. **Fehler! Verweisquelle konnte nicht gefunden werden.Fehler! Verweisquelle konnte nicht gefunden werden.** shows an overview of these steps:

Figure 2: Summary of the global supply chain of cocoa (Statistics Netherlands 2018)

2.2.1 Sourcing abroad

Cocoa beans come from the fruits of the *Theobroma cacao* tree. Since the introduction of the cocoa tree from Brazil and its spreading in West Africa in the 19th and early 20th century, mostly smallholder farmers have grown cocoa. Today, it is considered an archetypical smallholder crop in Africa, differently from Latin America where large cocoa estates are also common (Schroth et al. 2016, p. 232).

A distinction can be made between fine or flavour cocoa (about 8%) and bulk cocoa (ICCO 2019). Fine cocoa has additional aromas and a higher refinement of attributes, which is why farmers can achieve higher prices with this type. Both types can be grown in cocoa-suitable areas and do not differ geographically. While fine cocoa is important for farmers due to higher prices, industrial producers often decide for bulk cocoa since fine cocoa is more difficult to handle, has a lower yield and is less resistant to pest infestation.

With 76% of the world cocoa bean production, West Africa, mainly Côte d'Ivoireand Ghana, is the largest producer (Quarterly Bulletin of Cocoa Statistics, ICCO). Côte d'Ivoire is the largest cocoa producing country by volume, comprising 33% of global supply and Ghana is the second largest (Beg et al. 2017) . Côte d'Ivoire, Ghana, Nigeria and Cameroon share 68% of the global annual production, followed by Asian countries such as Papua New Guinea, Malaysia and Indonesia with 17% of the production. Latin American countries (Colombia, Brazil, Ecuador) produce 15% of the global annual production (Beg et al. 2017). A trend, according to in't Veld, is that private individuals in Latin America are starting to buy land to realize "high end" cocoa (in't Veld 9/25/2019). Latin American countries are shifting focus on the production of fine or flavor cocoa and less on bulk cocoa, which besides the sheer quantity, further increases the importance of bulk cocoa production in West Africa for the supply chain (Kadow 11/8/2019). In addition, cocoa is the key source of income for Ghana and Côte d'Ivoire, also being the primary source of livelihood for many smallholder farmers (Kadow 11/8/2019).

In Asian countries such as Thailand and Vietnam, cocoa cultivation is climatically possible, but still very low. These countries are likely to focus on a fine cocoa variety and can be assumed to remain a small market (in't Veld 9/25/2019). Overall, cocoa production in Asia is decreasing due to the more profitable cultivation of other crops (Kadow 11/8/2019). **Fehler! Verweisquelle konnte nicht gefunden werden.Fehler! Verweisquelle konnte nicht gefunden werden.** shows an overview of the current cocoa production throughout the world and its historic development:

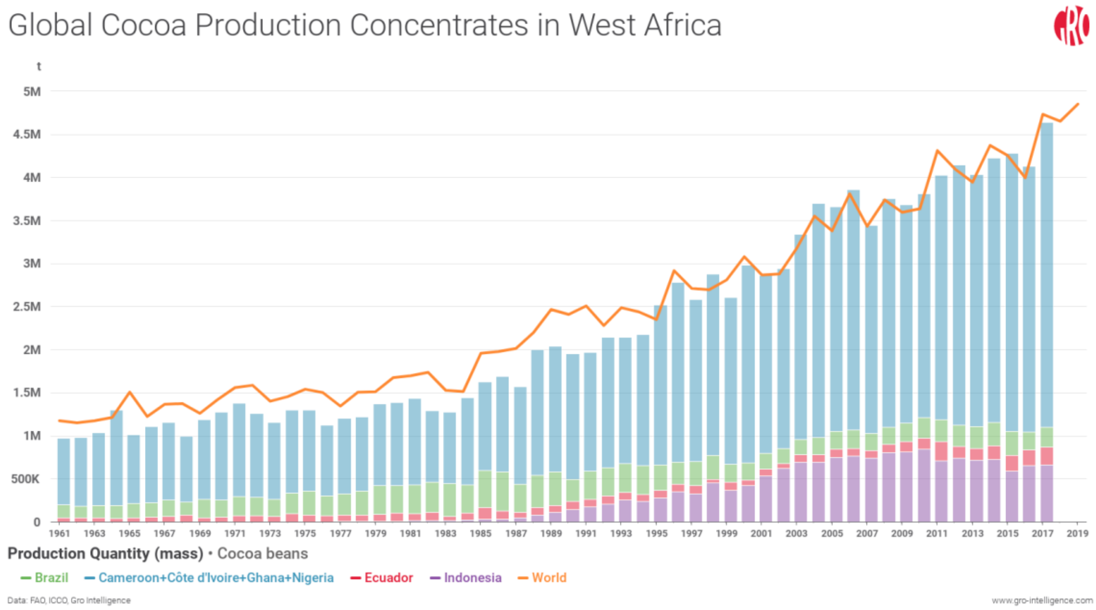

Figure 3: Production quantity of cocoa beans in various countries from 1961 until now (Gro Intelligence 2020)

Approximately 90-95% of the world's cocoa harvest comes from small, family-run farms of five to six million cocoa farmers. The total area of the typical farm in Africa and Asia is approximately two to four hectares and many farmers own only one plantation (Will 9/30/2019). Around 300-400 kg of cocoa beans in Africa and about 500 kg in Asia can be produced from each hectare (Beg et al. 2017). Apart from this dominating smallholder farm structure, some vertical integration can be observed: Ritter Sport for example, a German chocolate producer, owns a plantation in Nicaragua, where they grow, ferment and dry cocoa themselves (Ignatzi 2018; Will 9/30/2019). Furthermore, small producers such as XOGUE own their supply chain entirely by "bean to bar production" (in't Veld 9/25/2019).

Traditionally, cocoa was planted randomly, using the fertility of forest soils and profiting from the shade of trees (Wessel et al. 2015). When farmers seek to increase their production it is usually by occupying more land in the forest, since farm trees are old and cultivation methods are extensive, meaning yields remain low in productivity (Wessel et al. 2015).

Half a year after the flowering of the cocoa plant, it can be harvested (Will 9/30/2019). Harvesting of cocoa pods can be done throughout the year and is done manually. After harvesting, the beans have to be fermented, which determines the quality of cocoa powder (Beg et al. 2017, p. 110). Subsequently, the beans are dried to ensure transportability and storage suitability. Due to the high water content of the seeds and the attached fruit pulp, cocoa is not suitable for transport before fermenting and drying (Kadow 11/8/2019). Fermentation and drying is, at least in South America, often done by cooperatives or processing centres (Kadow 11/8/2019; Will 9/30/2019). Drying can be a problematic step since it is very difficult, and if not done properly, off-tastes and mould can develop (Will 9/30/2019). The dried and fermented cocoa beans are usually not processed in their respective countries of origin, but rather in Europe and North America.

Cocoa farming faces many issues: extreme weather, pests and diseases, political instability, lack of information, high transport costs, outdated methods, illiteracy among farmers and lack of access to big markets. Moreover, the cocoa value chain is very disorganized because farmers have to sell through a series of agents and traders. However, the industry is dependent on cocoa production and some players have acted towards increased production through a multi-stakeholder approach. In doing so, the opportunities for business include access to a secure, guaranteed supply of quality cocoa with transparent pricing (Beg et al. 2017, p. 113).

2.2.2 Transportation

The transport of cocoa products takes place by sea. In Germany, by far the most relevant port for imports is Hamburg, where about 200,000 tonnes of cocoa arrive every year, which equals two thirds of German raw cocoa imports (Hütz-Adams 2012). The general structure of the transports for each cocoa product can be analysed with the help of figure 4, which describes the raw cocoa and cocoa products imported by Germany in relation to the distance of each product's country of origin, represented in size by the import value in US Dollars (International Trade Center 2019).

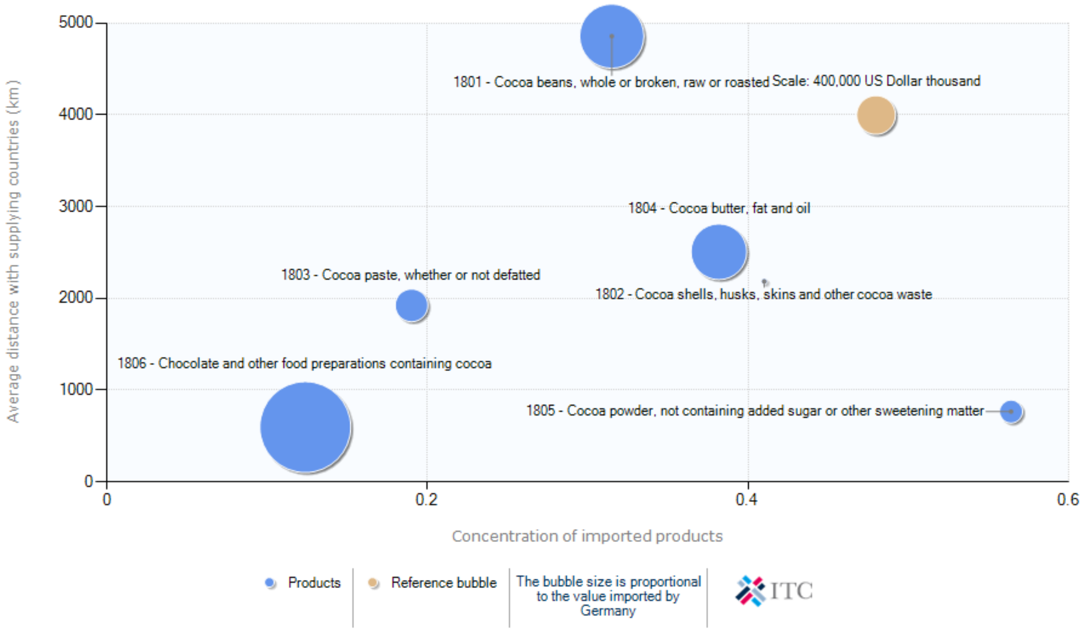

Figure 4: Concentration and average distance from supplying countries for cocoa products imported by Germany in 2018 (International Trade Centre 2019)

The average distance from supplying countries correlates with the degree of processing of the product. For cocoa beans the average distance is about 5,000 km, roughly the distance between Germany and the centre of West Africa. Cocoa butter, fat, oil, and paste, which are semi-manufactured, originate from around 2,000 km. Finished products such as chocolate or unsweetened cocoa powder are imported mainly from European countries (International Trade Center 2019). Through their processing, cocoa and its products thus gradually move closer to Germany.

2.2.3 Processing and distribution in Germany

Cocoa beans are the basis for the production of cocoa powder, cocoa butter and chocolate liquor, which are the main constituents of chocolate and other cocoa products (Beg et al. 2017, p. 108). The fermented and dried cocoa beans go through a series of processing steps, called "secondary post-harvest processing", such as roasting and grinding, to transform into a product. Secondary post-harvest processing of cocoa beans has traditionally been done in the countries importing the beans. However, recently, the grindings in the countries of origin have increased (Will 9/30/2019). For 2019, the estimates for Europe were 1.72 million tonnes, corresponding to only 36% of the total grindings (Quartely Bulletin of Statistics, ICCO).

There is a difference between the smallholder production with a minimal technological production level and the complex chain of processing of the product: Secondary post-harvest processing involves many steps from cleaning, deshelling and sterilization to roasting, grinding, pressing, refinement, conching and tempering (Kadow 11/8/2019). Beg et al. (2017) also emphasize the high degree of automation within the cocoa processing industry.

Today, about 10-20 large companies worldwide dominate the market for the grinding of cocoa beans into cocoa mass and the first processing steps to cocoa butter and cocoa powder. The three market leaders alone account for more than 40% of the global cocoa crop and the five largest companies more than 55%. There are also a number of medium-sized companies in the market. In Germany, 15 companies are still grinding cocoa (Hütz-Adams 2012).

In German retail trade, a large market concentration can be observed, with EDEKA, REWE, Aldi Group and the Schwarz Group (Kaufland, Lidl) having a market share of around 85% (Hütz-Adams 2012, p. 21). At the same time, the chocolate industry has a large variety of imported branded products. Chocolate manufacturers have a strong brand power due to their products' specificities, considering that chocolate products differ in shape, size, processing quality and flavour. Hence, individual chocolate manufacturers have managed to build up a steady bargaining position with retailers. This is true even for discounters, as evidenced by Aldi-Nord having concluded a contract for the listing of products of the chocolate company Ferrero (Fassnacht and Königsfeld 2012; Hütz-Adams 2012).

2.3 The changing structure of the demand for cocoa

The demand side of the cocoa market is changing due to several institutional and social transformations. Whilst the annual chocolate consumption per capita in Germany is stable and one of the highest in the world, consumption habits are slowly changing. European regulations are also playing a decisive role in the German market, as the composition of chocolate is subject to European Parliament and Council Directive 2000/36/EC.

2.3.1 Sustainable and organic cocoa

The situation of workers in today's cocoa production continues to be highly problematic. About 2 million children are working in the cocoa sector in West Africa (Bertrand et al. 2017). According to the list of goods produced by child labour or forced labour 2018 by the U.S. Department of Labor, cocoa is considered to be produced and harvested under child labour in Brazil, Cameroon, Ghana, Guinea, and Sierra Leone, and under child and forced labour in Côte d'Ivoire and Nigeria. The total cocoa exports of these 7 countries sum up to more than 70% of the world production (International Trade Center 2019).

It is clear that these issues, together with environmental awareness, affect the structure of chocolate demand in Germany. This changing demand is accompanied by an emergence of several fair-trade labels, with the aim to guarantee good conditions of work and of salary for farmers: e.g. Fair Trade, Rainforest Alliance and UTZ Certified. According to Tagbata and Sirieix (2008), fair trade certification labels could have a positive impact on chocolate product demand, materialized by an increase of the product price of 20% to 30% (especially when combined with an organic label). These results are corroborated by Vecchio and Annunziata (2015), who show that the willingness to pay is higher for fair trade chocolate.

The following figure from the BDSI shows a stable and rising tendency of the share of sustainably produced cocoa, even though they do not list which labels are taken into account:

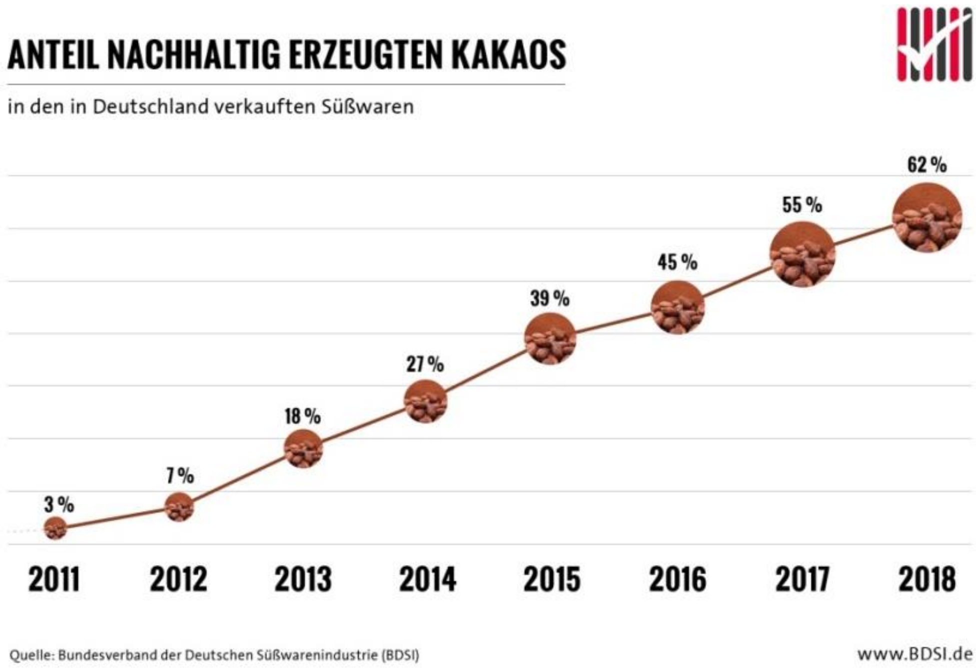

Figure 5: Proportion of sustainably produced cocoa (BDSI 2020)

2.3.2 Environmental impact and chocolate demand

The increasing environmental and climate change awareness could also challenge a cultivation that is quite demanding in terms of CO_2 emissions through deforestation and land use. A study on the environmental impact of cocoa production and processing in Ghana, based on a life cycle assessment approach, shows to what extent each step of the production impacts the environment:

- The production of cocoa beans uses CFCs and halogens, fertilizers with heavy metals as well as pesticides, and thus contributes to ozone layer depletion, eco-toxicity and human toxicity among the whole lifecycle.
- Processing has a global warming and atmospheric acidification impact due to the use of fossil fuels in boilers and roasters.
- Transportation under these aspects is seen as less significant compared to the other stages (Ntiamoah 2008).

Another considerable impact of cocoa cultivation is land use. A study on the Guinea Rain Forest of West Africa estimated its reduction to 18% of the original area at the start of the new millennium, because of the expansion of extensive smallholder agriculture, and among them cocoa (Gockowski 2010). The author evaluates that if they had used intensified cocoa technology, available since the 1960s, they could have saved over 21,000 km^2 of deforestation, corresponding to an emission of nearly 1.4 billion tonnes of CO_2 for the same production. The consequences of deforestation in this area are also dramatic for biodiversity, as global rainforests contain at least one third of global plant and animal biodiversity for only a 7% surface (Dirzo 2003). The situation in Ghana and Côte d'Ivoireis particularly worrying, as their increases of annual deforestation rates are the highest in the world, with 60% and 26%, respectively from 2017 to 2018 (Global Forest Watch 2019).

Thus, cocoa crop production is not only affected by but also contributes to climate change. Additionally, extensive land use and the degradation of natural resources may further increase local climate risks. Having this in mind, the need for action in the cocoa sector is twofold: limiting the climate change potential of the production (mitigation) and limiting the effects of climate change on the production (adaptation). Accordingly, mitigation strategies should be devised together with adaptation strategies.

3 Relevance of extreme weather and impacts of climate change for cocoa

3.1 Climatic conditions relevant for the production of cocoa

According to literature, ideal climatic conditions for cocoa production are a well-distributed rainfall of at least 1200 mm per year and a mean shade temperature of 27°C with a daily variation of less than 8°C (Kishore 2010 as cited in Ofori-Boateng and Insah 2014). According to the interviews, growing cocoa furthermore requires a minimum average temperature of 20°C in the coldest month of the year. There is no upper limit, since cocoa grows well in very hot environments. Regarding precipitation, about 1500-2000 mm is ideal for cocoa, which should be evenly distributed over the year. High relative humidity is necessary as well. If rain falls short, the water holding capacity of the soil determines the survival of the plant. However, in long dry periods, irrigation is indispensable. Too much water can also be problematic, but manageable through drainage solutions (Kadow 11/8/2019; Will 9/30/2019). Cocoa should be grown in shady forests, as shady trees are important for larger fluctuations in temperature. When the plants grow older (from the 3rd year), less shade is required. Low exposure to wind is also advantageous for the cocoa plant, but of less relevance (Will 9/30/2019). Furthermore, cocoa has a good adaptability regarding the pH value and nutrients of the soil (Kadow 11/8/2019). These climatic conditions are typical for the tropics, which is why cocoa is grown in a belt about 10-15° South and North of the equator (Will 9/30/2019).

3.2 Extreme weather and climate threats

This part analyses various climatic or weather events that affect cocoa production. From the literature review, three general categories of such events can be constructed: climate change in general, a climate event in particular and an individual weather event occurring within a short time. As for the climate event, the most significant is the El Niño–Southern Oscillation (ENSO), and especially its El Niño phase. Few other extreme weather events are analysed in detail in the literature review: this study will focus on the 1982/1983 drought, i.e. an individual event occurring in a rather short time.

3.2.1 Global climate change

Among the various effects of climate change on several physical indicators, two of them are recurrent in cocoa crops studies: the increase of temperature (mean or extreme) and the change in precipitation patterns. While global land and ocean temperatures show an increase during the 20th century (NOAA 2020), the trend is not that clear when it comes to precipitation patterns (Pachauri and Mayer 2015). For cocoa production, both extremes are relevant: The most relevant climatic changes for cocoa production have been increased dry periods and increased heavy rain events (Will 2019). The following analysis of El Niño–Southern Oscillation and the 1982/1983 droughts provides evidence that especially a reduction in precipitation has a significantly negative effect on cocoa crops.

3.2.2 El Niño–Southern Oscillation (ENSO)

The El Niño–Southern Oscillation (ENSO or El Niño) is an irregular periodic climatic phenomenon that creates variations in winds and surface temperature, especially over the tropical eastern Pacific Ocean, but affects the climate in most tropical or subtropical areas.

The oceanic circulation in the Pacific causes seawater at the South American coast to be much cooler than in Indonesia in a normal year. Coupled with precipitation, this leads to desertification in South America and Monsoon in Indonesia. The forces of this phenomenon, the trade winds, are weakened in an El Niño year, which means that the sea surface temperature in South America is much higher than usual. Its counterpart is La Niña, which refers to a cold extreme (Executive Committee ICCO 2010).

The Oceanic Niño Index (ONI) tracks the running 3-month average sea surface temperatures in the east-central tropical Pacific. It shows two types of temperature anomalies: Since 1950, the ONI for El Niño, i.e. temperatures warmer than usual, has increased. On the other side, the ONI for La Niña, i.e. colder temperatures than usual, has decreased.

Consequences of ENSO mainly concern the temperature in the Pacific region. However, its impacts are broader. ENSO also changes precipitation patterns, and has effects even for regions far from the original El Niño regions, such as West Africa (Executive Committee ICCO 2010). Several regions in the Côte d'Ivoireand Ghana, severely affected by dryness, are also intensive cocoa producing areas. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows a significant correlation between the occurrence of an El Niño event and the probability of drier-than-normal conditions (Executive Committee ICCO 2010).

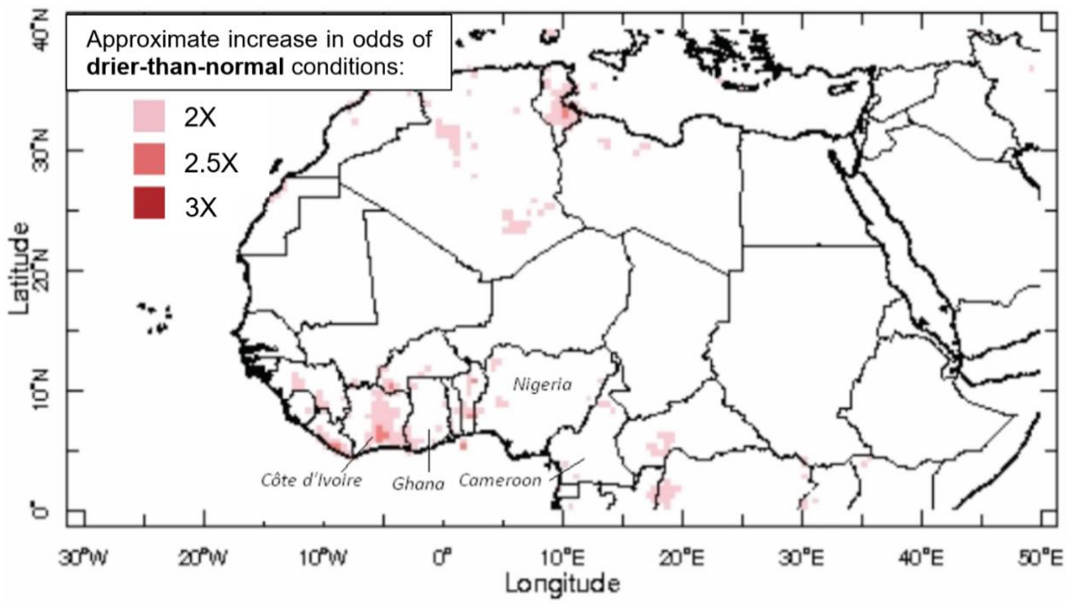

Figure 6: Increase in odds of drier-than-normal conditions in West Africa during El Niño events, in January-March (Executive Committee ICCO 2010)

According to the ICCO, cocoa production is highly sensitive to changes in weather conditions. While several factors influence the annual production of cocoa, weather conditions are likely to be the most important one. As the weather can vary significantly from one season to another, cocoa production has shown a sharp year-on-year change. Changes in global production from previous seasons ranged from -19% (in the 1965/1966 season) to almost +30% (in 1984/1985). Statistical and econometric analyses reveal that in particular El Niño events have a significant negative impact on cocoa production: It is estimated that El Niño reduces cocoa production, on average, by 2.4% at world level (Executive Committee ICCO 2010). **Fehler! Verweisquelle konnte nicht gefunden werden.** shows how the succession of El Niño/El Niña events correlates with a change in the annual cocoa production. Almost all El Niño seasons correspond to a drop in the production, while most El Niña seasons correspond to an increase. However, several other parameters may also have influenced the production.

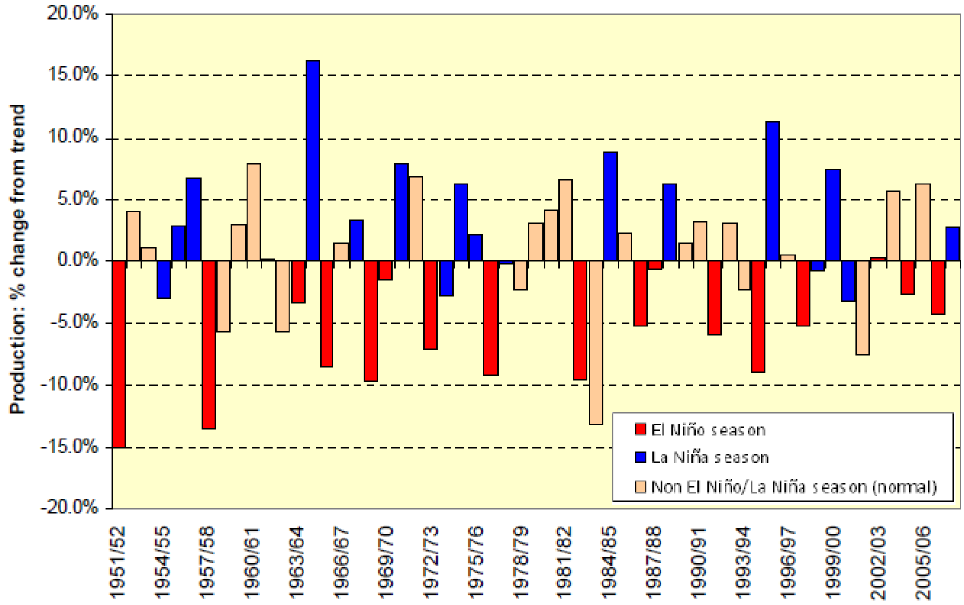

Figure 7: El Niño/La Niña and departure from trend of annual cocoa production (Executive Committee ICCO 2010)

Due to its location, Ecuador is the country suffering the most, with cocoa production declining by over 6% on average. As a comparison, the estimated impact of El Niño on cocoa production in Africa is only 1.44%. Cocoa output falls on average by 2.4% in Indonesia, by 2.0% in Côte d'Ivoire, by 1.7% in Ghana and by 1.2% in Nigeria (Executive Committee ICCO 2010, p. 1).

ENSO's negative effects are confirmed by Gateau-Rey et al. (2018) for cocoa agroforests in Bahia, Brazil. They consider impacts of the 2015/2016 ENSO-related droughts in randomly chosen farms and show that droughts caused high cocoa tree mortality (15%) and severely decreased cocoa yield (89%). It also increased the infection rate of the chronic fungal disease witches' broom (Moniliophthora perniciosa) (Gateau-Rey et al. 2018).

3.2.3 The 1982/1983 droughts

The droughts in 1982 and 1983 in the cocoa belt of Côte d'Ivoire give an idea of how dependent cocoa crops are on good precipitation conditions.

The year of 1982 began with a more-than-average rainfall (January-August), but was followed by a severe drought that lasted until December that year. During this period, the relative precipitation was at an exceptionally low level. A similar pattern could be observed in 1983, with a more-than-average rainfall in spring and summer, and a severe drought from July to November. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the precipitation profile of that season compared to the average. 1982/1983 was also an El Niño season, which probably also contributed to this extreme weather event. A drought similar to the one these years has not been recorded ever since (Kassin et al. 2008).

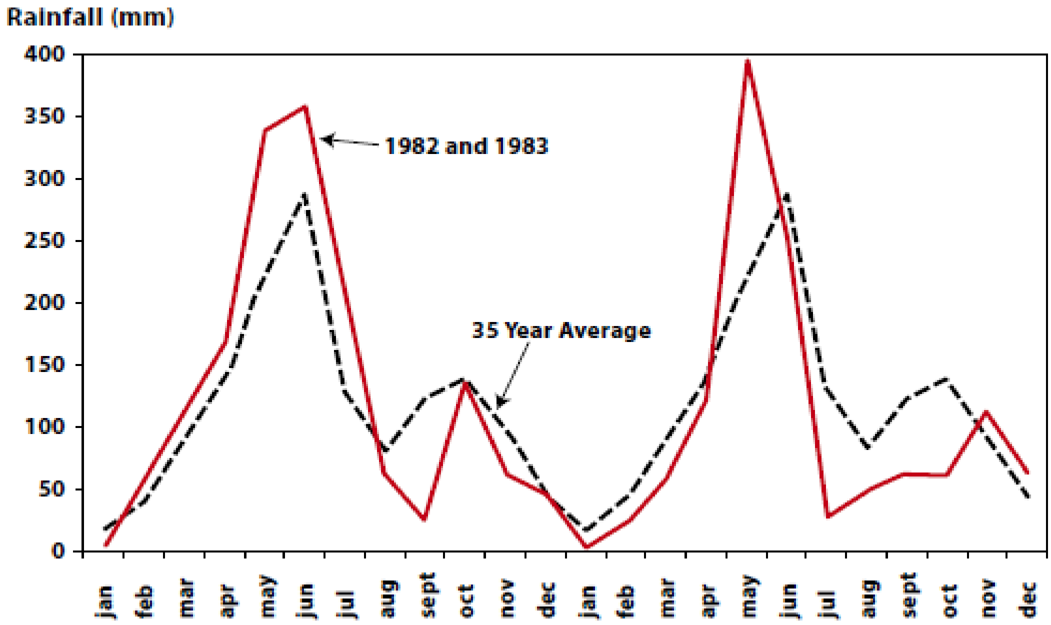

Figure 8: Rainfall pattern of 1982/1983 in the cocoa belt of Côte d'Ivoire compared to 35-year average (Ruf et al. 2015)

These droughts directly affected the ability of cocoa trees to produce cocoa beans, and it increased the number of fires that destroyed a vast amount of farms. According to Ruf et al. (2015), the dry-season fires caused an unprecedented number of farm failures and even occasional hunger. The authors also show that several decades later, these fires were still present in the memories of cocoa farmers interviewed. **Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates that both the production and yield of cocoa in Côte d'Ivoire dropped by about ¼ in the 1982/1983 harvest season:

Harvest season	Production (1,000 t)	Yield (kg ha^{-1})
1980/81	417	499
1981/82	465	516
1982/83	360 (−23 %)	378 (−27 %)
1983/84	411	432
1984/85	565	549
1985/86	555	505

Source: Ministère de l'Agriculture (1986)

Figure 9: Production and per-hectare yields of cocoa in Côte d'Ivoire between 1980/1981 and 1985/1986 (Ruf et al. 2015)

3.3 Impacts on cocoa's supply chain and vulnerability

3.3.1 Assessing involved countries' vulnerability

As the German cocoa regulation states in §2, cocoa is the only main ingredient which is allowed for the production of cocoa products (Bundesministerium der Justiz und für Verbraucherschutz, Bundesamt für Justiz 2003). This leads to a lack of substitutability of cocoa for the chocolate industry, since chocolate can only be made from cocoa.

Several indicators provide information on the vulnerability of production to climate change and the capacity of adaptation. The **Transnational Climate Impact index** estimates a country's exposure to impacts of climate change occurring in other countries (Benzie et al. 2016). The index considers four climate risk pathways (people, biophysical, trade and finance) and nine indicators. It shows a high exposure for the Côte d'Ivoire (4.9) and Ghana (5.6). However, the exposition of industrialised countries such as Germany (5.8) and the Netherlands (7.1) is higher due to their position on the global market with a dependency on other countries' economies.

The **ND-GAIN index**, devised by the University of Notre Dame (USA), provides a more detailed quantification of readiness (9 indicators) and vulnerability (36 indicators). It illustrates the comparative resilience of countries by plotting the vulnerability of a country to disruptive climate events against its readiness to mobilize public and private sector investment for adaptive actions (Chen, Noble, I. et al. 2015).

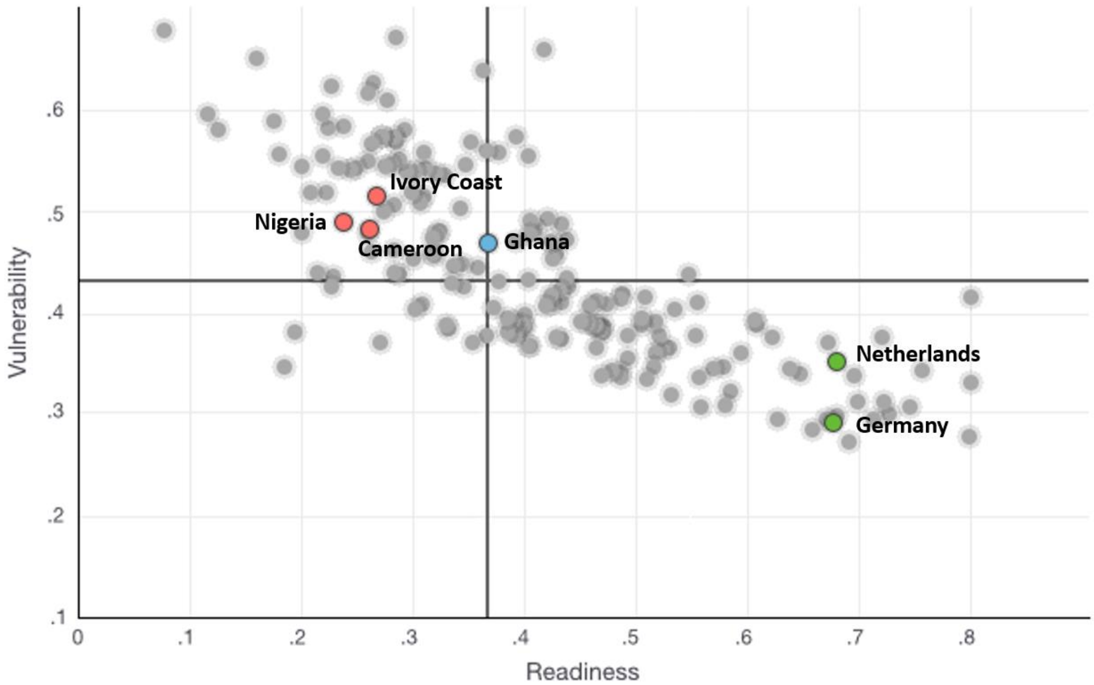

Figure 10: The ND-GAIN Matrix (Notre Dame Global Adaptation Initiative 2017)

Several indicators show devastating scores for cocoa producing countries: the agriculture capacity[1] of Côte d'Ivoire, Ghana and Nigeria is close to 0.99 (where 1 is the most vulnerable). The readiness indices of Côte d'Ivoire, Nigeria and Cameroon are also considered as low (0.271, 0.242, and 0.246 respectively). Figure 10, the so-called ND-GAIN Matrix, summarizes the two aggregated components of the index for all countries, with a highlight on the four main cocoa producing countries. For comparison purposes and due to their dependence in regard to cocoa trade, it also shows Germany and the Netherlands. The additional grey axes within the matrix show the median of all countries. Thus, Ghana, Côte d'Ivoire, Cameroon and Nigeria in the upper left quadrant are countries with high vulnerability and low readiness, which means that these countries have a great urgency for adaptation action and a great need for investment to improve readiness. Ghana shows a slightly higher readiness compared to its neighbours in West Africa. Germany and the Netherlands in the lower right quadrant show - in contrast to the Transnational Climate Index - low vulnerability and a high level of readiness. According to ND-GAIN, they are thus well positioned to adapt (Notre Dame Global Adaptation Initiative 2017). However, the Netherlands' vulnerability is significantly higher than Germany.

3.3.2 Impacts along the supply chain

Regarding the impacts of climate change, literature largely focuses on the **production** step of the supply chain.

The majority of studies on cocoa production and climate change are future-oriented, dealing with different emissions scenarios, their consequences on temperature and precipitation, and the possibilities of adaptation (cf. chapter 4). However, Ofori-Boateng and Insah (2014) focus on the present and devise an econometric model based on the crop yield response theory that estimates the impact of various parameters on the cocoa crop in West Africa. The model considers four parameters as inputs: labour, capital, temperature and precipitation. The study finds that currently, mainly extreme temperature events have a significant negative impact on cocoa production.

Interviews with different industrial producers reveal that until now, globally, there are few severe climate change impacts on cocoa production. Cocoa is subject to natural fluctuations in harvest yields, which is why the industry is well adapted to changes (Will 9/30/2019). Productivity is rising on the global scale and especially for West Africa, which leads to rising harvest yields (FAOStat 2019). About ¾ of the world cocoa harvest comes from West Africa, so it is very unlikely that the entire belt around the equator or all West African countries suffer from a bad harvest at the same time. Furthermore, even if all West African cocoa growing regions are largely affected by an extreme weather event, other countries such as Indonesia or South American countries could (temporarily) provide substitutes. It can also be observed that cocoa prices are less influenced by climate events, but rather by market mechanisms such as speculation (Kadow 11/8/2019; Will 9/30/2019).

However**, locally**, climate change is affecting the production of cocoa severely. Smallholder farmers across the tropics already face numerous risks to their agricultural production, such as pest and disease outbreaks, (local) extreme weather events and market shocks. Due to the smallholder structure, this often undermines the entire household income and food security. Farmers often directly depend on agriculture and have limited resources to cope with shocks; any reduction in the agricultural productivity can have tremendous impacts on their income, nutrition, food security and well-being. Climate change is expected to affect smallholder farmers largely by further aggravating the present risks (Harvey et al. 2014).

A study on Indonesian cocoa smallholder farmers shows that they often employ poor arming methods and lack knowledge on pest control. This has led to a reduction in productivity and

[1] Combination of data on fertilizers, irrigation, pesticide and tractor use, from the FAO and the World Bank (Chen, Noble, I. et al. 2015).

caused many farmers to change cocoa cultivation areas to oil palm or rubber (Witjaksono 2016). A study on Liberia, West Africa, gives detailed explanations on the vulnerability of smallholder farmers. They are especially vulnerable regarding their limited access to technical assistance for selection and propagation as well as to shading methods. The ability to invest in effective pest controls is also limited due to low farm profitability. Furthermore, due to small volumes, frequent harvest rounds are more expensive and low profitability makes investments in post-harvest infrastructure difficult. Rural populations are also highly susceptible to a reduced market access due to poor road conditions. Furthermore, local climate predictions are difficult since almost no meteorological information is available on Liberia (Schroth et al. 2015).

Interviews with German chocolate producers also revealed the following local effects:

- Ritter Sport's plantation in Nicaragua experienced a strong El Niño year in 2014/15 (only shortly after its setup in 2012). However, this did not lead to a bottleneck in Ritter Sport's production (Will 9/30/2019).
- A supplier of XOGUE in Cuba was severely affected by hurricanes in two subsequent years. The cocoa plants were completely destroyed, which led to a shortfall for 4-5 years (in't Veld 9/25/2019).

No particular impacts of climate change were found regarding **transport to Germany**, apart from the general consideration that temperature must be controlled through a specific positioning of the beans in the cargo. Global temperature increase has not jeopardized the possibility of a secure cargo transport of cocoa beans until now. Sea level rise could possibly put harbour infrastructures at risk; however, waterfronts are "climate-stable" so far (Will 2019). Furthermore, transport is not a time-critical stage of the supply chain since the cocoa industry is not a just-in-time industry (Will 9/30/2019).

Processing and distribution, as explained above, mainly take place in the importing country, except for the sun drying of the beans on the farm. There is no indication for a causal effect between the national impacts of climate change in Germany and these two stages. All interviewees stated that the effect on the processing industry is low, but it is high on smallholder farmers in the regions affected.

3.4 Adaptation strategies in an unstable environment

Adaptation is an opportunity to manage the negative impact of climate change, by reducing the loss or by utilizing opportunities to increase production. As presented by Codjoe et al. (2013), adaptation can be anticipatory (i.e. systems adjust before the impact) or reactive (as a direct response to a current impact). An adaptation strategy is not only about applying a technical solution, but should be understood as the complex process of learning about risks, evaluating response options, and creating the conditions that enable adaptation (Codjoe et al. 2013). Furthermore, time should be taken into account: Due to the smallholder farm structures and uncertainty about the measures, local implementation of adaptation measures may be time consuming (Kadow 11/8/2019).

Codjoe et al. (2013) provide insights about the way farmers perceive and understand climate change in rural Ghana. About 1/3 of the respondents are of the general view that the change in climate is a result of God's plan signifying the end of times. About a fifth of the respondents see the usage of heavy machines on land, air and water and urbanization as a major cause. Other farmers attribute climate change to deforestation, to the sinful nature of man, and to the manipulation by the "whites". Arguably, the understanding of the situation is far from the scientific assessment, but it does not necessarily mean that the farmers' agricultural techniques or adaptation strategies are not suitable. Concerning the relative importance of weather variables, a majority of the respondents regard rainfall as the most important variable in their cocoa production, followed by relative humidity and sunshine – which is quite coherent with the econometric estimations.

3.4.1 Area-specific approach

Schroth et al. (2016) stress the strong differentiation of climate vulnerability within the cocoa belt. According to the authors, the most vulnerable areas are near the forest-savannah transition in Nigeria and eastern Côte d'Ivoire and the least vulnerable areas are in the southern parts of Cameroon, Ghana, Côte d'Ivoire and Liberia. Therefore, as climate change does not affect all cocoa producing areas uniformly, the vulnerability to the impacts of climate change is also largely area-specific, so that adaptation strategies should be adjusted locally. As Kadow (11/8/2019) states, depending on the local climate, a different management focus is necessary: For example, in areas becoming wetter, more attention should be given to disease tolerance, especially to fungi, which are of less relevance in drier areas.

3.4.2 Adaptation measures

As seen above, climate affects particularly the production stage. Therefore, adaptation strategies also focus on the organisation of the production. The interviews with industry experts revealed some short-term adaptation measures: A short-term adaptation measure and a straight-forward approach in dry seasons or during droughts is irrigation (Kadow 11/8/2019; Will 9/30/2019). However, this is often difficult, as surface water is not always readily available and the retrieval of groundwater is not only technically but also environmentally challenging (Will 9/30/2019). Furthermore, many smallholder farmers do not have the financial capabilities to purchase irrigation equipment.

In the opposite situation, when too much rain occurs, e.g. in a prolonged rainy season, cocoa cannot be dried. Usually, most smallholder farmers dry naturally, i.e. in the sun. An adaptation option is investing in a geothermal drying plant or into roofing, but this is very cost-intensive. Financing possibilities for these adaptation options are limited to bank loans and a few funding organisations such as Forest Finance (in't Veld 9/25/2019).

Furthermore, the literature review identifies several medium- to long-term adaptation strategies which are currently implemented or will be implemented in the near future. This study divides them into three categories: Agroforestry, high-input agronomy and crop diversification. They are described in the following sections.

3.4.2.1 Agroforestry

Agroforestry is a land-use management strategy that promotes the use of trees around or in crops, for the benefit of the crop and potentially the inherent benefit of the trees. The main advantage of planting trees in cocoa crops is to provide shade to the cocoa trees, reducing the leaf temperatures of cocoa by up to 4 °C (Almeida 2007). In the context of global warming, such an adaptation is going to be more and more relevant. Furthermore, the presence of shade trees can have a lot of other uses, from diversification with timber products, biological pest control, a possible increase in the pollination of cocoa trees, to ecosystem services such as soil, water and biodiversity conservation together with carbon storage (Schroth et al. 2016).

While agroforestry is popular in Central Cameroon, cocoa farmers generally favour a no-shade system without considering agroforestry as an option (Wessel et al. 2015). This is quite paradoxical as most researchers consider cocoa agroforestry more sustainable. Ruf provides some insights by interviews with farmers: to them, the availability of high-yielding, light-tolerant hybrids makes the planting of shade trees superfluous and those who consider tree diversification preferred the planting of trees in separate plots (Ruf 2011). Moreover, Schroth et al. (2016) reveal that cocoa farmers in drought-prone parts of Ghana do not use shade trees because they feel that these would compete for water with cocoa during the dry season. Interestingly, this opinion is corroborated by Abdulai et al. (2018), who state that cocoa in full sun is more resilient to sub-optimal and extreme climate than cocoa agroforestry. The authors explain that although agroforestry is perceived as potential adaptation strategy to sub-optimal or adverse environmental conditions such as drought, their empirical results do not support this. Under extreme climate with severe drought conditions, the role of these popular shade trees on cocoa plants becomes critical as competition for soil water is intensified with cocoa plants. According to the authors, water limitation overrides the seemingly favourable microclimatic moderations brought about by the association of cocoa with shade trees.

Despite this study, most researchers seem to recognize agroforestry as a sustainable alternative to high-input agronomy, which could prevent farms from negative effects of climate change. Therefore, it presents a suitable adaptation strategy for areas where the temperature extremes are a major threat, but still are not under a severe drought pressure. In highly drought prone areas, integrated concepts such as agroforestry and reforestation in the surrounding areas should be assessed as possible long-term solutions, depending on the major local risk factors.

Agroforestry is also the system that Ritter Sport uses on their own plantation in Nicaragua (Will 9/30/2019). On their plant in Nicaragua, the agronomic component of cocoa is complemented by the forestry component of shadow trees. This increases biodiversity, creates a healthy soil life and a microclimate structure within the plant (Will 9/30/2019, 2019). Furthermore, the surfaces drain less. According to Will (2019), with agroforestry, climate change is managed in a more stable way, which is why he considers it a key response to climate change.

3.4.2.2 High-input agronomy

High-input agronomy, or intensive farming, is characterized by higher levels of input use per area unit in order to increase yields. In cocoa production these inputs are mainly fertilizers. Wessel et al. (2015) reveal that in areas where environment and management are not the main yield-limiting factor, an optimal use of fertilizers could increase the yield by about 50%.

However, due to the singular structure of cocoa farms in West Africa, high-input agronomy is not widely spread. Most farms are small, family-owned, and little efficient. Most farmers do not earn enough income from their cocoa to pay for fertilizers. This situation leads to an economic vicious circle, where low efficiency leads to low income and low income does not allow for any input investment. The interviews led by Codjoe et al. (2013) corroborate this analysis: A third of the interviewed farmers do not use fertilizers because it is very expensive and another third because it is not available when needed.

From an environmental point of view, the use of fertilizers can be an interesting trade-off to reduce deforestation, as it allows to produce more on the same area. On the other hand, the soil is intensively exploited and cannot regenerate its nutrients. The spreading of nitrates in the environment contributes to eutrophication and deregulation of the nitrogen cycle. Environmentally friendly input alternatives could be the use of other crop residues as a natural fertilizer. 24% percent of farmers use such techniques according to Codjoe et al. (2013).

3.4.2.3 Crop diversification

Finally, crop diversification can be an interesting economic alternative, especially when the climatic conditions of the farm evolve too far from optimal conditions (Läderach et al. 2013). Cocoa production, like other agricultural commodities, depends to a large extent on the interaction between comparative advantage and resource endowments (Ofori-Boateng and Insah 2014). This economic notion becomes central when choosing the crop to be produced. There is no convincing evidence that producing only cocoa would be more efficient than a diversification. Crop diversification helps to diversify risks and takes into account the climate trends by choosing crops that are drought-tolerant and resistant to temperature stress. Schroth et al. (2016) also highlight the importance of diversification to reduce the vulnerability of farming systems, especially in environmentally sensitive areas.

Increasing genetic diversity is the basis of many adaptation strategies and often determines their success, e.g. to adapt to drier conditions. Since a few years, the World Cocoa Foundation and the Cocoa Research Association (CRA) have been involved in an initiative called CacaoNet, a global network for cacao genetic resources with the target to optimize the use and conservation of genetic resources. Their global strategy states that through international collaboration they want to improve the livelihoods of 5-6 million farmers in developing countries by improving the use of genetic resource collections (Alliance of Bioversity International and the International Center for Tropical Agriculture 2020). The method most commonly used is “on-farm-conservation”, because the seeds cannot be stored in seedbanks, but trees must be grown. It is challenging to achieve a comprehensive exchange of cocoa plants, since this means decreased yields for three years or more and financing is scarce. However, approaches such as microcredits may be a solution to this (Kadow 11/8/2019). The CacaoNet strategy seeks solutions by providing a framework to secure funding for the most pressing issues (Alliance of Bioversity International and the International Center for Tropical Agriculture 2020).

Genetic diversity, the cultivation system and local adaptation can be named key adaptation categories (Kadow 11/8/2019). However, adaptation strategies are as varied as the local climates are. Codjoe et al. (2013) clearly reveals that farmers perceive climatic changes differently and develop various kinds of strategies to cope with them. Most researchers confirm the intuition that there is no universal adaptation strategy. However, the poor level of scientific knowledge and relevant agronomic techniques could be harmful to farmers. While certain measures, such as crop diversification, seem widely applicable, there is no such consensus for agroforestry or high-input agronomy. Furthermore, if adaptation only focusses on how to optimize yields and profits, it can have dramatic environmental or climatic externalities.

3.4.3 Efforts of the German chocolate industry

Compared to its economic importance worldwide, cocoa is still a scientifically understudied crop. Future efforts are needed in regard to climate change resilience, disease tolerance, productivity, organoleptic quality and heavy metal accumulation (Kadow 11/8/2019). Chocolate producers also only lately started to deal with the entire supply chain. Until 20 years ago, there was little focus on how cocoa is cultivated. And still, the relationship between local cocoa farmers and international stakeholders continues to be minimal, according to Roldan et al. (2013). For example, most farmers are not aware of certifications and only 7% are actually certified. However, for those who are working under contract and who know the terms and conditions, there is a strong positive correlation with awareness on cocoa price fluctuations, sustainability and certifications.

The interview with Hauke Will reveals that efforts of the German chocolate industry are rather directed towards the avoidance of child labour than to climate change (Will 9/30/2019). It is a more complex issue to support farmers in the field of climate change. Furthermore, pressure is not high enough yet: It is estimated that within 20-25 years, there won’t be a bottleneck regarding global cocoa supply (Will 9/30/2019). Given the number of issues of cocoa production such as child labour, production, organisation structures and deforestation – climate change seems not to be perceived as the most pressing issue (yet).

The German Initiative for Sustainable Cocoa (GISCO), a multi-stakeholder initiative, involves many different players in the industry as well as federal members. GISCO is oriented towards social and productivity issues, and aims to improve the livelihood of smallholder farmers as well as to increase the percentage of certified cocoa in collaboration with governments in cocoa-producing countries (GISCO n. d.). Furthermore, the initiative CocoaAction is a consortium of mainly big chocolate producers, with the aim of enabling collaboration to ensure voluntary industry-wide standards for sustainability (World Cocoa Foundation 2020).

An international initiative is the website *climatesmartcocoa.guide*. CIAT and the Rainforest Alliance have developed a comprehensive website on climate-smart cocoa, which is designed for everyone working with smallholder cocoa production. It provides an overview on the entry points for working with climate-smart agriculture in the field of cocoa, provides a risk assessment tool and even a guideline for an action plan (CIAT and Rainforest Alliance 2019).

On top of that, several chocolate producers work bilaterally on projects (Kadow 11/8/2019). On its own plantation in Nicaragua, Ritter Sport introduces new varieties with nurseries to make cocoa cultivation more resilient. They also evaluate the sustainability of all cocoa sources and train smallholder farmers within cooperatives to build agroforestry systems and other diversification options. The employees are also trained towards quality control (Ignatzi 2018). Cooperatives own machines centrally but pay attention to the needs of smallholder farmers ("downsizing mechanization"), which increases efficiency in daily life and ensures their future (Will 2019). Farmers are also supported to get certifications and thereby access education (Rizo 2019). One could argue that the plantation by Ritter Sport, being one of the largest in the world, exploits smallholder farmers even more – however, Ritter Sport arguably ensured to many smallholder farmers that they want to increase the amount of supply from them (Ignatzi 2018). This makes cocoa production more stable for smallholder farmers and less volatile in value, which ensures their living (Hernández Pérez 2019).

4 How will climate change and extreme weather events affect the sector in the future?

4.1 Climate projections for cocoa-growing suitability

Climate projections are a key tool to estimate future cocoa production. As stated above, mainly two climate events are relevant: modification of water availability and rise of temperatures. Both parameters affect the suitability of cocoa production to local climates and most cocoa producing areas will be severely exposed to climate change impacts.

Water availability depends on precipitation patterns and on the degree of evapotranspiration, i.e. the combined effect of the plant transpiration and ground evaporation that contributes negatively to water availability. According to the IPCC, the area-average long-term positive or negative precipitation trends have low confidence for the Southern Hemisphere (Pachauri and Mayer 2015). However, for high-emissions scenarios, it is very likely that climate change will increase the number of extreme precipitation events in many regions.

As mentioned in the previous sections, the world's cocoa industry largely depends on the **West African cocoa belt**, not only because of the sheer volume of cocoa grown there, but also because it is the most important origin of high-quality bulk cocoa - as opposed to specialty cocoa - that cannot be readily replaced by other cocoa origins. Therefore, this chapter focuses the analysis on West Africa.

Cocoa output in West Africa is estimated to be reduced by increasing temperature and declining precipitation trends (Ofori-Boateng and Insah 2014). Since this is the most likely scenario, Ofori-Boateng and Insah (2014) conclude that cocoa production in West Africa could suffer serious threats in the near future if no adaptation takes place.

The seminal study by Schroth et al. (2016) analyses this in more detail: They show that the maximum dry temperature will substantially increase during the dry season in West Africa until the 2050s. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows this change between the current (upper map) and predicted (lower map) maximum temperature among the cocoa belt. The red lines show the cocoa producing areas. This temperature increase means that by the 2050s, temperatures are reached which are not experienced within the cocoa belt yet, especially in the countries Guinea/Sierra Leone/Liberia, and the Northeast of Côte d'Ivoire. Once the optimum temperature is exceeded, photosynthetic rates within cocoa decrease, leading to reduced growth and development. Cocoa can tolerate a maximum of 38°C according to FAO (2007) as cited in Schroth et al. (2016). This temperature will not be reached by 2050 according to the simulations. However, it is an average value and local temperature could exceed this limit in hot and dry (e.g. El Niño) years.

In contrast, for the indicator of water availability, changes in the cocoa belt are described as minor, as the increase in rainfall will be compensating the increasing dry season evapotranspiration (Schroth et al. 2016). Thus, while water availability seems to be one of the major threats to cocoa production today, it might become secondary in the future, compared to the increase of the maximum temperature.

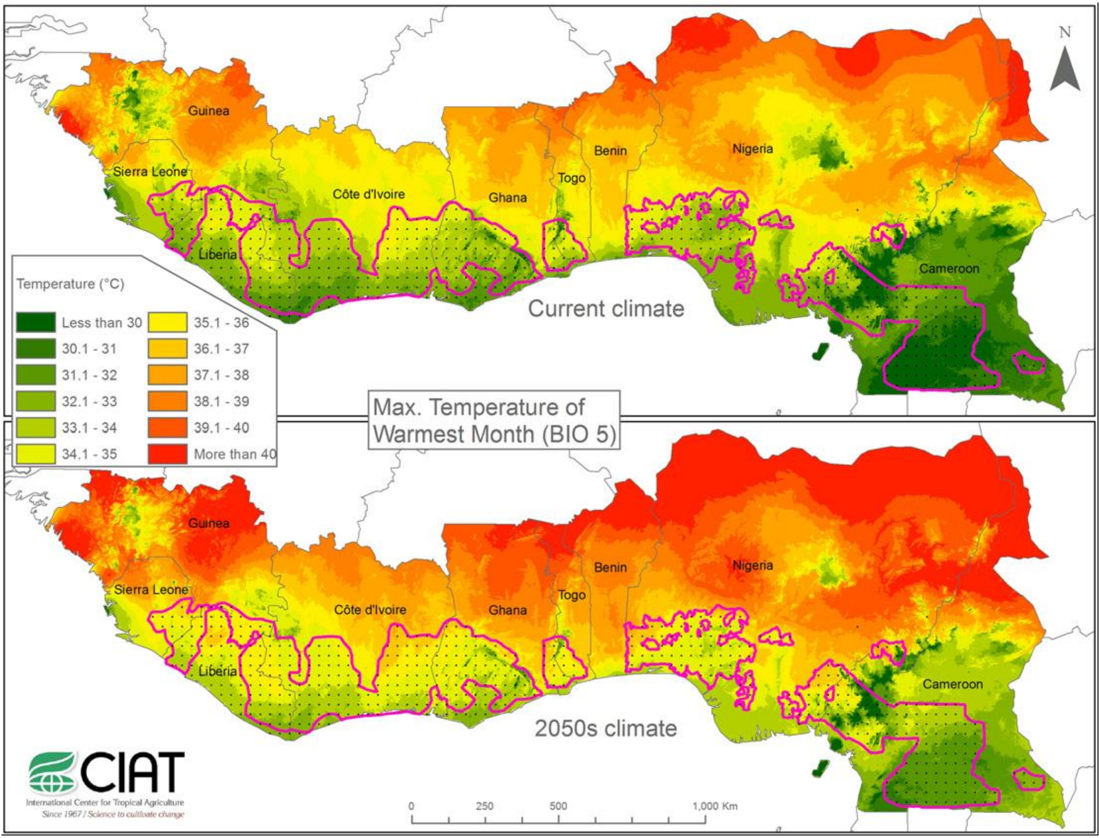

Figure 11: Maximum temperature of the warmest month under current and projected 2050s climate conditions in the West African cocoa belt. The dotted area shows the extent of current cocoa production as used for model calibration. (Schroth et al. 2016)

Schroth et al. (2016) further combine the climatic data of WorldClim with an indicator of climatic suitability for cocoa. The model incorporates crop-environment interactions through a machine learning approach based on the current climatic conditions in cocoa growing areas. One of the main conclusions is that the changes in suitability are area-specific.

Fehler! Verweisquelle konnte nicht gefunden werden. shows the evolution of each area's suitability. The third map ("suitability change") shows the change in suitability from the current state to the one predicted for the 2050s. Cocoa producing regions will see major change, mostly negative, but also positive in some areas. Most of the severely impacted areas are situated in the Northern regions of the cocoa producing areas. Some areas will become severely unsuitable for cocoa (Lagunes and Sud-Comoe in Côte d'Ivoire), where farmers will need to identify alternative crops. However, these regions offer good conditions for other crops in the future (Läderach et al. 2013). According to the study, there will be areas that remain suitable for cocoa, but only if farmers adapt their agronomic management to the new conditions. Some areas are also projected to increase in suitability of cocoa production (e.g. Kwahu Plateu, between Eastern and Ashanti regions in Ghana). Finally, new areas are predicted to emerge where currently no cocoa is grown but which might become suitable in the future, e.g. the district of Dix-Huit Montagnes in Côte d'Ivoire (Krain 2011).

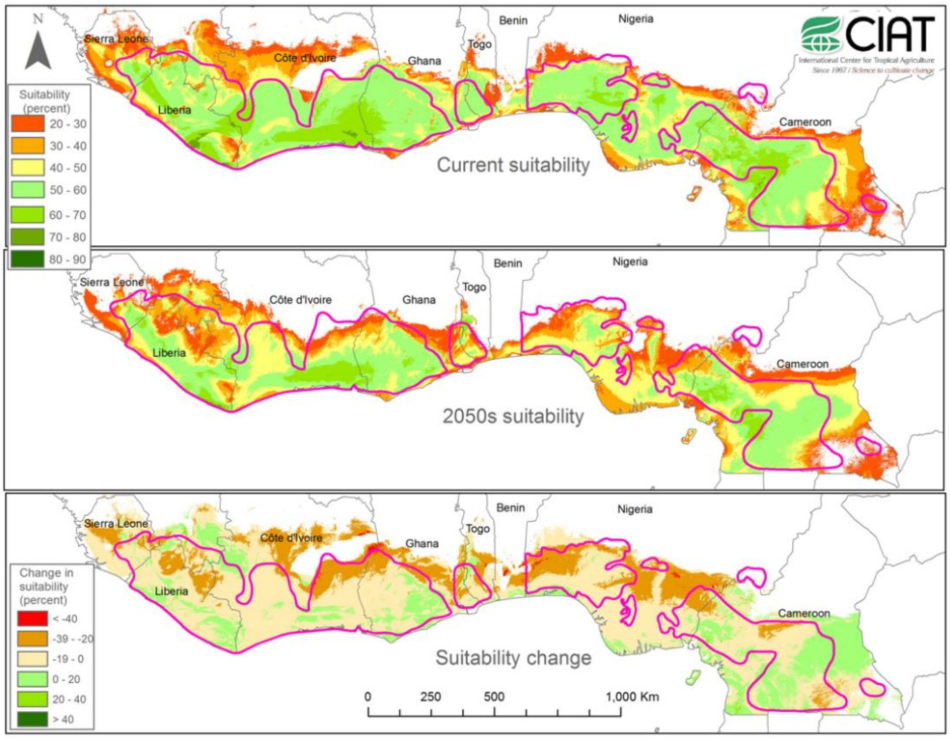

Figure 12: Relative climatic suitability (in percent) for cocoa of the West Africa cocoa belt under current and projected 2050s climate conditions, as well as suitability change (Schroth et al. 2016)

Will states that the cultivation of cocoa will move to higher elevations in the next 20-25 years. Until now, in higher elevations, coffee is cultivated. However, at some point, it is not possible to change to higher elevations anymore, so cocoa will replace coffee in these areas. Will assumes that this will not affect the overall global production quantity of cocoa but initially only move the cultivation to other regions. This will be facilitated by the current research and development of new varieties (Will 9/30/2019).

Although cocoa production has increased so far, according to Kadow, action should nevertheless be taken now since it is not yet clear which measures need to be taken. Implementation, until obtaining concrete results, will take time. So, while changes are only expected in the long term, the uncertainty of suitable local measures should be reduced now.

4.2 Future strategies of adaptation

Considering the need to update the existing and largely insufficient implementations, future adaptation strategies need to be devised.

Following the conceptual distinction of Codjoe et al. (2013), adaptation is not only a reaction to current disruption but also an anticipation to reduce the impact of future disruption. In this sense, developing a more sustainable agronomy fits the aim of adaptation, as a step to deal with predicted climate impacts. Adaptation particularly reveals the indirect and transnational dimension of the climate impact considered in this case study. German imports of cocoa in a suitable quantity and quality depend on the level of adaptation of local farmers, mainly in West Africa. If German companies do not commit themselves to anticipative adaptation in a near future, the cost of reactive adaptation in the future could be significantly higher.

4.2.1 From climate suitability predictions to adaptation

The IPCC Special Report on Climate Change and Land (IPCC 2019) shows that large shifts in land-use patterns and crop choice will likely be necessary in most regions of the world. This is particularly significant in the West African regions where the suitability conditions for the cocoa crop will change. At the same time, suitability conditions for other crops will also change, which may create opportunities for crop diversification and land conversion from one crop to another.

From the climate predictions on cocoa sustainability mentioned in 4.1, four groups of lands can be devised:

1. Lands that will turn to be unsuitable
2. Lands that will turn less suitable
3. Lands which will become more suitable
4. Lands that were not cultivated before but that will become suitable for cocoa

The adaptation solution for the first category is certainly to stop the cocoa production before the 2050s to implement a crop suitable to the new conditions, but the future remains unclear for the other categories. The different strategies summarized in section 3.4.2 (agroforestry, high-input agronomy, and crop diversification) can be applied depending on the local conditions:

In a future climate, where the main threat to cocoa production may be heat, agroforestry could be an important lever, as the trees surrounding the crops can reduce the cocoa trees leaf temperature by up to 4°C (Almeida 2007). In cases of severe drought pressure as well as in a drier climate where temperature is not a major threat, agroforestry has to be assessed carefully before implementation (cf. section **Fehler! Verweisquelle konnte nicht gefunden werden.**).

According to IPCC (2019), diversified cropping systems and practicing traditional agro-ecosystems of crop production with a high number of crop varieties are less vulnerable to possible future catastrophic losses. For cocoa, as mentioned above, some studies show that diversification can improve the cocoa yield and the overall revenue of farmers, as well as reduce their exposure to climate. Thus, crop diversification, as it reduces the sensitivity of the farm, seems to be a good strategy in most cases, unless the conditions for cocoa growing are particularly favourable.

High-input agronomy and deforestation to enlarge the size of the exploitation are the main coping measures currently in practice. It appears that for cocoa as for other crops, it is only a short-term solution, as it impoverishes the soil and is radically opposed to the mitigation or resilience perspective (cf. section 3.4.2.2).

4.2.2 Actors synergy along the supply chain

The level of knowledge transfer, technology transfer and deployment, financial mechanisms, and early warning systems is described as key for agricultural transformation by IPCC (2019). However, this is certainly not sufficient for cocoa production in West Africa and elsewhere.

To cope with the major climatic changes that will occur in the 21st century, the various actors of the global chocolate supply chain must further commit themselves to adaptation. As shown above, climate change awareness or understanding of agroforestry is lacking for many farmers. Therefore, the contact with local farmers, who are the most vulnerable, needs to be strengthened. As we have seen in the previous section, the ties between the other stages of the supply chain also need improvement – which is why a closer collaboration between the various stakeholders should be of high priority.

4.2.3 Co-benefits of adaptation, mitigation, resilience and poverty eradication

As promoted with high confidence by the Summary for Policy Makers of the IPCC Special Report on Land (IPCC 2019), adaptation should be devised in a comprehensive policy approach together with mitigation, resilience, and poverty eradication. Adaptation without mitigation will accelerate the disruption of the climate that jeopardizes cocoa production; adaptation without resilience will be inefficient in the long run if it does not allow the ecosystem to naturally regenerate; adaptation without poverty eradication will reinforce inequalities generated by climate impacts.

Implemented together, these policies can have co-benefits that go beyond the goals of each one. For instance, a more resilient farm is less vulnerable to weather variability created by climate change, which is part of the aim of adaptation strategies. As climate is a long-term issue but with early effects, these various strategies have to be seen in synergy in the long term. The coordination between actors is essential to design such an ambitious plan. If adaptation measures exist to make a cocoa plantation efficient in a warming climate, a broader perspective is necessary to make the whole economy of cocoa more resilient. As German stakeholders are largely committed to this market, it is both their responsibility and interest to go in this direction.

5 Reflection

Chocolate production in Germany will remain highly relevant in the future, since cocoa demand is growing and there is no substitution product to the cocoa bean. The current climate sensitivity of cocoa crops in Latin America, due to ENSO, could prefigure the future climate impacts of the much larger cocoa producing countries in West Africa. Suitability predictions for the cocoa belt in West Africa assume a loss of land suitable for cocoa production until the 2050s. However, current predictions on the development of cocoa production are not very reliable. They depend on many unknown variables such as readiness to adapt, substitution products, evolution of demand and other economic mechanisms.

Major climate **adaptation** strategies are agroforestry and crop diversification. Nevertheless, they are not implemented sufficiently yet. Farmers lack knowledge on adaptation and awareness and the involvement of the industries in Germany and other processing countries is low. Furthermore, there is no overarching adaptation strategy, which is always suitable, but its suitability always depends on the local conditions.

As Will states, "*climate change is not only a physical problem, but because of the smallholder farmer structure also a social one*" (Will 9/30/2019). He assumes that there will be a devastating social impact through climate change. It is the individual fates of the farmers which have to be taken into account, rather than the largescale plantations (Will 9/30/2019). This corresponds to the overall findings of this case study, which show that the vulnerability of the German cocoa industry is limited. In contrast, smallholder farmers will be severely affected by climate change, especially in the West African cocoa belt. To achieve a more resilient cocoa production, we **recommend** considering co-benefits of various strategies – adaptation, resilience, mitigation and poverty eradication. A sole focus on adaptation is unlikely to work in the long term.

Further research succeeding this case study could investigate the conceptual and the geographical lack of connection in the cocoa industry. Conceptually, the connection between the disruption of cocoa production and pricing needs investigation: prices are determined on a global scale, while production is disrupted locally. For instance, the correlation between ENSO and the development of prices could be analysed in detail in a future study. Geographically, there is need for research on the lack of connection within the supply chain between the source countries and the processing countries.

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7 Annex 1: Interview Partners

Interview partner	Affiliation	Date of the interview
Holger in't Veld	Founder and owner of XOGUE (bean to bar production)	25 September, 2019
Hauke Will	Head of agricultural production, Ritter Sport (Alfred Ritter GmbH & Co. KG)	30 September, 2019
Dr. Daniel Kadow	Chairman of the FCC ECA CAOBISCO Joint Research Fund and Quality and Productivity working groups and Director of the Round Table Cocoa Hamburg	8 November, 2019