THE ECONOMIC CASE FOR CLIMATE ACTION ***IN WEST-AFRICAN COCOA PRODUCTION***

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1 This report

The motivation of this report was to highlight the economic rationale to invest in climate change adaptation. To this end we describe an assessment of the potential cost of climate change impacts on cocoa production in West Africa. Stakeholders along the value chain - from West African cocoa producers to Northern chocolate makers - on the one hand acknowledge the reality of climatic change and the need for action, but on the other hand avoid investments into adaptation. This contradicts the scientific consensus that climate change is progressing, and that cocoa plantations with a lifespan of several decades will be exposed to different conditions than today.

We argue that the lack of action is caused by a "Parmenides fallacy". Such a fallacy occurs when stakeholders assess the value of an investment in innovation against the present state of the system, as opposed to valuing it against alternative future states. That is, stakeholders avoid investments that anticipate future climate change because the action would not have had positive returns with current (or past) climate conditions. Instead, adaptive action should be measured against a hypothetical future in which no action is taken to contain negative impacts. We hope that by providing a benchmark for the cost of inaction it becomes easier for stakeholders to argue for the benefits from investments in climate change adaptation.

We asked how cocoa producers in West Africa would be affected if the projected conditions of the 2050s hit today. Our analysis is a "ceteris paribus" argument with all other things being equal, except for climate conditions. In our analysis we left total production, number of producers and prices unchanged, and considered only a change of the climate. We have deliberately chosen to use a simplified approach to our analysis to not confound the reader through overelaborated modeling in which practitioners have no way to grasp the consequences of hidden assumptions. Thus, we are well aware of the limitations of our study but decided that clear assumptions about climate impacts would be more conducive to supporting our main result: a failure to act upon climate change will be very costly.

This way, we fall victim to the Parmenides fallacy ourselves: we did not account for a potential expansion of cocoa area, productivity increases or higher prices. Given the steady expansion of the cocoa market over the past decades it seems likely that production in West Africa may keep expanding over the coming thirty years. In such a case, the true cost of not adapting to climate change may be even higher. Some stakeholders may argue that the prevalence of cocoa production in the region also makes the opposite scenario feasible. Cocoa production in the region is bound to decline for reasons other than climate-maladaptation, e.g. because of soil depletion, deforestation or uncontainable diseases. However, soil and forest protection are generally considered to be no-regret climate smart activities, emerging pests and diseases are often attributed to climate change. This latter scenario can therefore be considered largely identical to the one considered here.

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2 Summary

Ghana:

- Cocoa production can be sustained in most of current cocoa-growing regions by the 2050s with a well-directed adaptation effort. Only the forest-savannah transition zone in the Northwest of the cocoa belt (Brong Ahafo, Northern Ashanti) will likely become unsuitable for cocoa such that income substitutes should be promoted. Projected gains in cocoa-suitable area are insignificant.
- More than half of current cocoa production (470,000 tons per year) is located in zones with high future climate risk for cocoa that would require systemic adaptation.
- Ghana's main cocoa-producing region (Western region) will likely face minor impacts from climate change up to the 2050s.
- The expected cost of inaction on adaptation by the 2050s was estimated at 410m USD per year which is about 1% of current real GDP. However, there is considerable uncertainty about future climate conditions and climate damages to unadjusted cocoa. We estimated a 90%-range of 270m-660m USD per year.

Ivory Coast:

- Cocoa will likely become unsuitable in the Northwestern transition zone of the Ivorian cocoa belt (Dix-Huit Montagnes, Haut-Sassandra, Moyen-Cavally). Some parts close to the Liberian border (in Bas-Sassandra and Moyen-Cavally) will probably become suitable for cocoa under 2050s climate.
- The cocoa sector in Ivory Coast will likely be hit more severely by climate change than the Ghanaian cocoa sector. About a quarter of current annual production (390,000 tons) is located in areas that are projected to be unsuitable by the 2050s.
- The West of the cocoa-growing region will probably require a high degree of adaptation, while the East faces a relatively low risk from climate change.
- The expected cost of inaction on adaptation by the 2050s was estimated at 1.1bn USD per year which is about 3.9% of current real GDP. Similar to the Ghana assessment, there are significant uncertainties. We estimated a 90%-range of 0.8bn-1.5bn USD per year.

Our approach used a Random Forest classification model to spatially differentiate the potential degree of climate change impacts in Ivory Coast and Ghana by comparing future (2040-69) to present (1950-2000) bioclimatic suitability for cocoa. We distinguished between four impact zones: Cocoa production can either be sustained under low or high adaptation effort (incremental or systemic adaptation) or will become unprofitable such that it needs to be substituted (transformation). Moreover, it may become a new option for farmers by the 2050s in previously unsuitable regions (opportunity). We considered several climate scenarios as well as different economic loss scenarios per impact zone. To estimate the economic cost of inaction we developed datasets of the current subnational distribution of cocoa production and overlaid the climate change damage functions. The use of several scenarios resulted in a most likely estimate, and a range of uncertainty.

3 Introduction

Ivory Coast and Ghana make up the world's most important region for the supply of cocoa beans. The two leading producers contributed about half of global cocoa production by 2014 (FAO 2017a). The sector is of vital importance for the rural economy in both countries, adding an estimated 7% and 3% of total GDP in Ivory Coast and Ghana respectively (GSS 2015, FAO 2017). About 1.5 million households are involved in growing cocoa in the two countries (COCOBOD 2017, World Bank 2014). The rise of the cocoa sector has been a key driver for alleviating rural poverty. The poverty rate among cocoa farmers in Ghana has declined from 60% in 1991/92 to 24% in 2005/06 (Coulombe and Wodon 2007). However, especially in Ivory Coast poverty among cocoa farmers is still a major issue as an estimated 60% lives below the poverty line (World Bank 2014). Both countries seek to enlarge future production and count on cocoa as a main driver of future growth and development (The Economist 2015, Ghana Business News 2017).

Recent studies suggest that cocoa farming in Ivory Coast and Ghana will face serious risks from climate change in the next decades (Läderach et al. 2013, Schroth et al. 2016). They found a decrease in climatic suitability for cocoa especially in the Northern areas of the cocoa belt, i.e. the transition zone to the savannah regions. Their results were driven by substantial increases in local temperatures of up to 2C in the 2050s relative to the 1950-2000 period.

Temperature increase has both a direct and indirect effect on the cocoa tree. Photosynthetic rates depend not only on temperature itself but, above all, on constant water supply. Due to increased evapotranspiration temperature rise has an indirect effect on humidity. It is well known that cocoa is a highly drought-sensitive crop (Carr and Lockwood 2011). Läderach et al. (2013) suggest the indirect temperature effect to be the main driver of the suitability changes, causing water stress for the cocoa plant especially during the short dry season in August and September. This is consistent with the experimental findings by Acheampong et al. (2013) who show that under dry season conditions in Ghana the plant growth of cocoa is water-limited. However, Schroth et al. (2016) found at least in the main dry season increased evaporation to be balanced by precipitation increases for much of Western Africa. They argue that the projected suitability reductions are induced by extreme temperatures that temporarily exceed the tolerable range of the cocoa plant. In fact, Diamond and Hadley (2008) showed in glasshouse experiments that for some cocoa genotypes temperature increases under current Ghanaian climate lead to significant reductions in plant growth. Hence, there is considerable evidence that climate change will not only shift zones suitable for cocoa but also pose serious adaptation challenges in regions where cocoa cultivation can generally be maintained.

Adaptation to climatic changes is often perceived as a costly intervention, while inaction is assumed to be cost free. Climate projections show a considerable degree of uncertainty about precipitation changes which is the factor that is most influential for yields. As a result stakeholders shirk investing in adaptive action. However, rating non-investment as preferential over adaptive action implicitly assumes that climate change will not have economic consequences. This report provides an assessment of the economic impact of climate change on cocoa production in Ghana and Ivory Coast. We calculate an estimate of the annual cost of climate inaction that represents the income lost by cocoa producers if they were confronted with projected climate conditions without preparation. Our estimate aims to help decision makers in evaluating the severity of climate change impacts and to provide a benchmark to assess possible investment into adaptation. We are aware that economic estimates of climate change impacts - although impressive in their apparent quantitative precision - must be interpreted with care and should be complemented by other lines of argument in the decision-making process (IPCC 2014a, pp. 224-225). Still, we believe that our approach is sufficient and useful for scaling the severity of the expected climate impact and estimating the cost of climate inaction for the cocoa sectors in Ghana and Ivory Coast.

We understand adaptation as a planned anticipatory intervention and not as an autonomous reaction by farmers (Füssel, 2007). Thus, we considered a scenario where, although farmers may individually make efforts to adjust based on their historic experience, there are no well-directed policy efforts to inform, prepare and support farmers in dealing with climate change. The need for anticipatory adaptation depends on the degree of climate impact. Vermeulen et al. (2013) distinguished between three different stages with different implications for adaptation: As long as the climate response stays within a range of the variability observed in the past, they recommended *incremental adaptation.* This implies that adaptation should focus on predicting and managing risk known from the past rather than anticipating new farming practices. The latter is *systemic adaptation* and becomes necessary as soon as the climate signal leaves the familiar variability range and a clear trend towards novel risks emerges. Finally, at even higher degrees of climate impact, *transformation* is required and farmers need to switch to alternative crops or consider off-farm work. It is the most challenging form of adaptation as it needs to smoothly implement structural changes to the local economy, diets and livelihoods.

In the following we describe the steps necessary to develop our results. Finally, we concluded on the adaptation needs for cocoa production in the two countries and discussed limitations of our study.

4 Data and methods

We first developed a spatial estimate of the degree of climate impact by the 2050s in Ghana and Ivory Coast, comparing present and future modeling assessments of bioclimatic suitability for cocoa. Based on this evaluation, we determined which above type of adaptation is adequate. Next, we investigated how much cocoa production is located in each of the impact zones and developed scenarios to estimate of the cost of inaction on farmer's income without adaptation.

4.1 Suitability analysis

To determine zones of different climate impact in Ghana and Ivory Coast we modeled changes in bioclimatic suitability for cocoa under present and 2050s climate conditions using a Random Forest classification model (Breiman, 2001). A complete description of the data, variables and methods used in the suitability assessment can be found in Bunn et al. (under revision). First, a database of locations where cocoa is currently cultivated was assembled. Second, monthly climatological means of the 1950-2000 period, interpolated onto a 0.5 arcminute grid, were downloaded from the *WordClim* database (Hijmans et al., 2005), representing our current baseline climate. They were used to calculate 19 bioclimatic variables commonly used in modeling of crop suitability (Nix, 1986). Third, applying Random Forests in unsupervised variation to six biologically meaningful bioclimatic variables, different clusters of cocoa suitability were detected within the occurrence data. These clusters can be interpreted as different climate zones all of which allow for cocoa cultivation, yet under different climate conditions. Fourth, using all bioclimatic variables and an additional soil variable as independents, Random Forest classifiers were trained to distinguish between suitable areas (falling into one of the suitable climatic zones) and unsuitable areas for cocoa. The classifiers were applied to climate data from for 19 climate scenarios of the 2050s obtained from downscaled projections from different climate models forced by the RCP6.0 emission scenario. This resulted in 19 distinct suitability maps for the 2050s. To explicitly account for the uncertainty from diverging climate projections, we conducted the entire analysis with each of the 19 suitability maps.

We determined adaptation needs following the framework of Vermeulen et al. (2013) by comparing present and future cocoa suitability: First, *transformation* will be required in suitable areas which are projected to become unsuitable. Second, in areas that will change from one suitable climate zone to another, cocoa can still be cultivated, provided that farming practices are adequately adapted to the new conditions (e.g. higher average temperatures, weaker dry season). Here we recommended *systemic adaptation*. Third, as long as the climate zone remains the same, only *incremental adaptation* will be necessary. Finally, we added a fourth category of *opportunity,* referring to zones which are currently unsuitable for cocoa but which are projected to become suitable in the future. In the following, we will refer to the four categories as *impact zones*.

4.2 Subnational distributions of cocoa production

To determine how much production is currently located in each of the impact zones, we analyzed subnational distributions of cocoa production from Ghana and Ivory Coast. For Ghana the spatial units were the 65 districts where the Ghana Cocoa Board (COCOBOD) aggregates cocoa sales. Although similar, these districts do not coincide with the political administrative districts of Ghana. To remove effects from short-term fluctuations in production we calculated the average of the 5-year period between the 2010/11 and 2014/15 harvesting seasons. The resulting distribution of average production is shown in Figure 1.

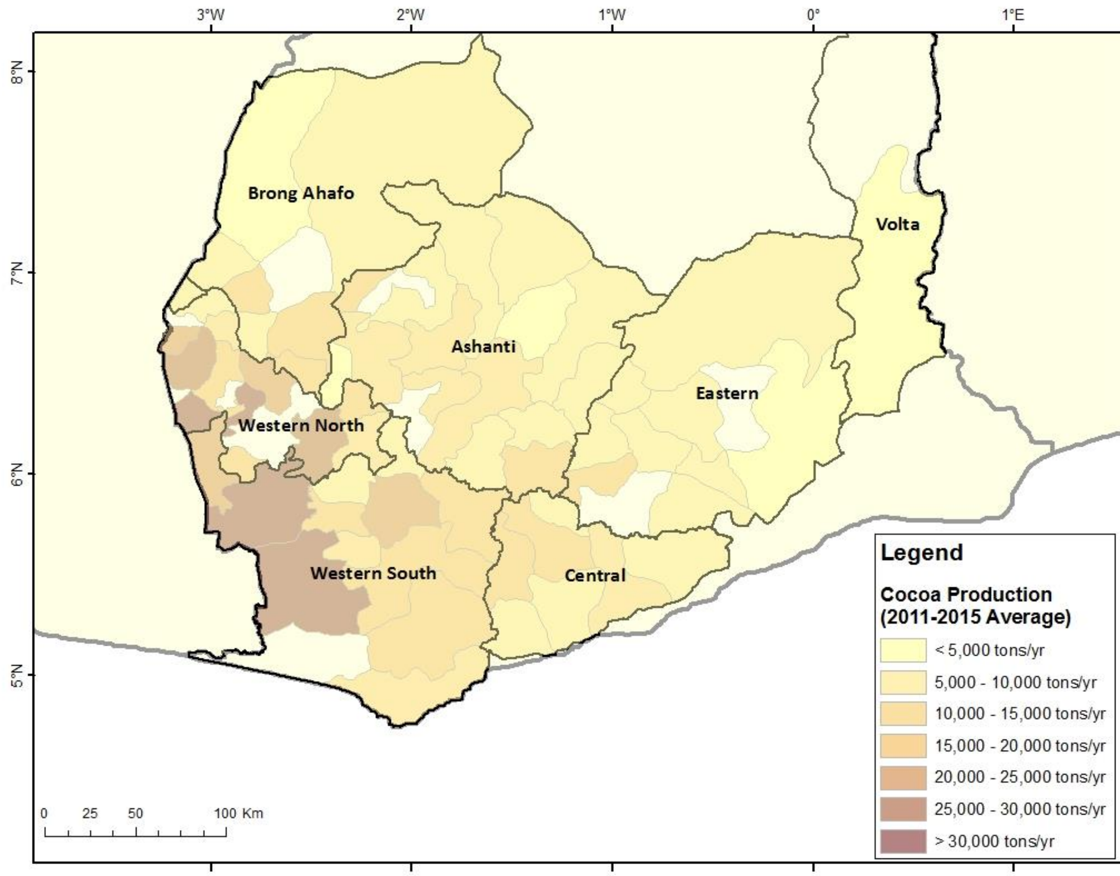

Figure 1: Average cocoa production in Ghana between 2010/11 and 2014/15 from the COCOBOD dataset. The data are on 65 administrative districts defined by COCOBOD.

For Ivory Coast, no recent production data was available publicly at district scale. We therefore distributed the average total annual production of 2011-2014 obtained from FAO (2017a) following the subnational distribution of the 1998-2002 period. To obtain this subnational distribution, we averaged production data from the *Agro-Maps* database (FAO 2017b) between 1998 and 2002 and disaggregated it onto a 1km grid. We then removed areas like water bodies, urban areas or forest where cocoa cultivation is impossible based on land use data from ECJRC (2014). Finally, using suitability estimates, we assigned higher cocoa area shares to locations with higher suitability. Figure 2 presents the resulting distribution for 2011-2014 aggregated onto department level in Ivory Coast. Due to the distinct datasets used for the two both countries, we conducted the following analysis for Ghana and Ivory Coast separately.

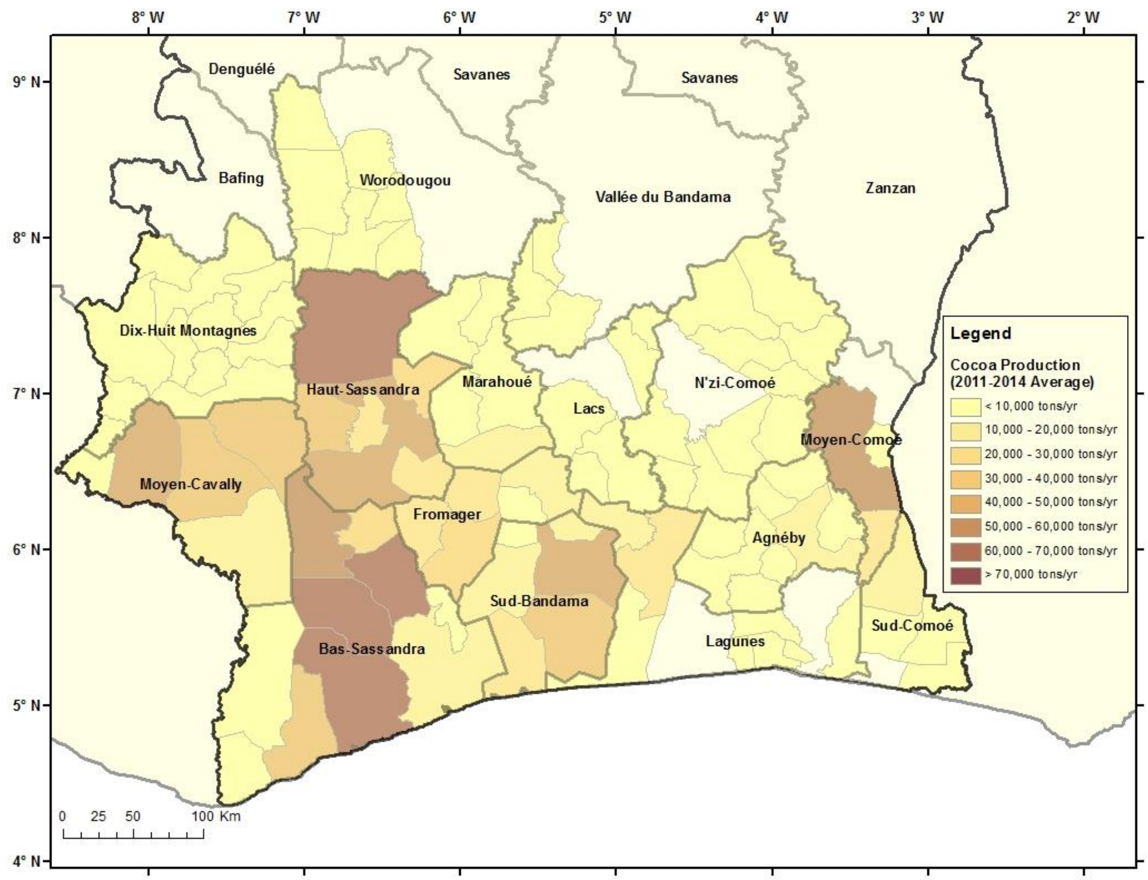

Figure 2: Estimated average cocoa production in Ivory Coast between 2011 and 2014. The subnational distribution was constructed based on production data from Agro-Maps for the 1998-2002 period as well as land use and suitability information. The average 2011-2014 total production from FAO (2017a) was distributed over this subnational distribution. The map shows the aggregation of the 1km grid used in the analysis onto Ivorian department level.

To determine the distribution of production by impact zone, we assumed that within the spatial units of our datasets cocoa production is distributed evenly over the area. Hence, we assigned production to the impact zones according to the area share of the impact zones in the spatial unit of production. For example, if 10,000 tons were produced in a spatial unit where 50% of the area had been assigned to the transformation zone, we estimated 5,000 tons of it to be located in this transformation zone. This was done for each of the two countries and the 19 climate scenarios.

4.3 Cost of inaction scenarios

Using empirical scenarios of potential production losses (Table 1), we calculated the cost of inaction on formerly cocoa-generated income per impact zone and country. It should be noted that the potential losses corresponded to the cost of no adaptation only because we assumed successful adaptation to fully restore current cocoa-generated income for farmers. We deduced the potential losses from cocoa-generated income per impact zone and summed the cost of inaction over the impact zones for Ghana and Ivory Coast respectively. For methodological consistency, we did not make an aggregate estimate of the two countries. This facilitates the discussion of our results as the impact zones and production distribution were derived differently for Ghana and Ivory Coast. We furthermore computed the cost as percentage of current (2011-2015 average) real GDP with respect to 2010 base year prices (World Bank 2017). Considering a total of 171 scenarios, i.e. the combinations of 19 climate projections, three impact scenarios and three adaptive capacity scenarios, we finally derived a probability distribution of the annual cost of climate change inaction for each of the two countries.

The first step was to calculate the current cocoa-generated income per impact zone. This was done by multiplying the production per impact zone with the average cocoa producer price in USD paid between the 2010/11 and the 2014/15 harvesting seasons. The averaging served to remove short-term price fluctuations. In both countries, cocoa prices are set by governmental agencies: The Ghana Cocoa Board (COCOBOD) in Ghana and the Conseil du Café-Cocoa in Ivory Coast. For Ghana, we obtained the nominal prices from the Ghana Ministry of Finance (2017). The nominal prices in Ivory Coast were collected from various sources including news media articles (Ivory Coast Cocoa Prices, 2017). The real price was obtained by dividing the nominal producer price by the Consumer Price Index with respect to the base year 2010 (World Bank, 2017). This was necessary to remove distortions due to inflation.

We developed scenarios of potential climate change losses from reported productivity losses in the literature and empirical evidence. Quantitative assessments of yield losses due to climate change under unadjusted farming practices typically use process based crop simulation models. There are various models to estimate climate change impacts on the major crops such as wheat, soy or rice (Rosenzweig et al. 2014). Yet, such crop modeling does not exist for cocoa. The only model we are aware of was developed by Zuidema et al. (2005). It largely overestimates cocoa yields observed in Ghana (simulating 6000 kg/ha, while observed yields are around 250-500 kg/ha, Kongor et al. 2017) because it estimated yield potential without accounting for the low adoption of good management practices by West-African smallholders. Using regression analysis on precipitation data to estimate cocoa productivity, Anim-Kwapong and Frimpong (2008) concluded that available future projections make negative impacts on yield likely, although without providing quantitative estimates.

To develop cost scenarios, we conducted a literature research to categorize the risks faced in each of the impact zones. Taking uncertainty of losses into account, we assumed nine different equally likely scenarios. First, we considered three scenarios characterized either by *low*, *moderate* or *high* damages in zones of *incremental* and *systemic adaptation*. We refer to them as *impact scenarios* as we think that the major uncertainty is the sensitivity of the cocoa tree to changes in climate conditions under current management practices. Second, we considered three scenarios of either *low*, *moderate* or *high* losses in zones of transformation and opportunity. We refer to them as *adaptive capacity scenarios* since in this case the uncertainty is mainly about the ability of smallholder farmers to autonomously diversify or transform their portfolio in the face of climate change. The question is to what extent cocoa farmers in transformation zones can find alternative sources of income and how easily farmers in opportunity zones can start earning with cocoa in the absence of institutional guidance and support through adaptation policies. The combination of either low, moderate or high climate impact with low, moderate or high adaptive capacity provided us with a total of nine loss scenarios.

Impact Zone	Assumed Economic Damage	Uncertainty Factor
Incremental Adaptation	**10%/15%/20%** of current cocoa-generated income	low/moderate/high **climate impact**
Systemic Adaptation	**30%/40%/50%** of current cocoa-generated income	low/moderate/high **climate impact**
Transformation	**100%/80%/60%** of current cocoa-generated income	low/moderate/high **autonomous adaptive capacity**
Opportunity	Opportunity cost: adaptation leads to additional production on **10%/15%/20% of opportunity area** at yields of 230 kg/ha	low/moderate/high **autonomous adaptive capacity**

Table 1: Assumed climate change damages by impact zone used in the cost of inaction analysis. Impact scenarios determine the benefit of incremental and systemic adaptation, adaptive capacity scenarios determine benefit of transformation and opportunity action.

In the following, we explain our climate impact scenarios for each zone:

Incremental adaptation zone (10%/15%/20% income losses):

Depending on the impact scenario, we assumed annual cocoa production losses without incremental adaptation at 10%, 15% or 20% compared to today. Incremental adaptation zones were projected to be relatively less affected by climate change than other regions. Although our suitability analysis classified the future climate to be similar to a climate under which cocoa is currently produced, this does not imply that local climate will not have changed. Depending on the region, annual mean temperatures in Ghana and Ivory Coast are expected to have increased on average 1.7-2.1C by the 2050s relative to the 1950-2000 mean (Bunn et al., under revision). As indicated before, there is multiple evidence to believe that rising temperatures will negatively affect cocoa suitability. Moreover, in areas where cocoa would theoretically benefit from climate change, it is questionable whether farmers can harness these improvements as long as their management practices are not adjusted. For instance, adequate shading, the usage of heat-resistant varieties or training to react to new pest threats will be necessary. Yet, smallholder cocoa farmers often rely on knowledge from acquired from past experiences on how to cope with weather conditions. Those traditional practices have been observed to fail more and more in recent years (Asante et al. 2017). Thus, without adaptation any change in climate can be considered disadvantageous to them as historic knowledge becomes less useful. However, as there is no major shift in climate zones, the production losses will be relatively small.

Systemic adaptation zone (30%/40%/50% income loss):

We assumed systemic adaptation would save 30%, 40% or 50% of cocoa production annually in the respective regions depending on the impact scenario compared to today. In zones of systemic adaptation, the projected risks from temperature increase will be aggravated by a shift in climate zones. Although the climate will still be suitable for cocoa, farmers will face a climate which either may have been experienced before but in a different cocoa-producing region of the country, or are novel conditions without precedent. This will require more fundamental changes to farming practices. For example, suitability analysis suggested that much of the Eastern region in Ghana will by the 2050s likely experience the type of climate found today in the Western region (results not shown here, see Bunn et al.). Thus, a farmer of the Eastern region who is used to a relatively long dry season, might be confronted with the hot and wet climate of the Western region characterized by a much shorter and weaker dry season. Even though these conditions are generally more favorable for cocoa (e.g. Kongor et al. 2017), different farming practices will be required in the face of altered climatic and biological stresses. For instance, a wetter and shorter dry season may demand shifting the cropping calendars and adjusting the amount of shading optimal for the cocoa tree (Acheampong et al., 2013).

Furthermore, a shift of climatic zones alters patterns of pests and diseases, a challenge which smallholder cocoa farmers already struggle to cope with today (Anim-Kwapong and Frimpong 2008, West and Quist-Wessel 2015, Kongor et al. 2017). Kongor et al found in a survey among cocoa farmers that the black pod disease and the swollen shoot virus occur more often in the warm and wet Western region and that, moreover, regular pest and disease control increased yields significantly. Pests and diseases can lead to considerable damages. The black pod disease, for instance, was estimated to cause yield losses of at least 40% in Ghana and Ivory Coast every year (Wessel and Quist-Wessel, 2015). Pest and disease management is a complex issue especially without the frequent use of fungicides which are not common in Ghana and Ivory Coast. The effect of shading of cocoa trees, for instance, is ambiguous. While certain diseases can be fought with it, others may strive even more (Wessel and Quist-Wessel, 2015). As the spread of these species are highly sensitive to climate conditions, the shift in climate zones poses major threads to unprepared cocoa farmers.

Transformation (100%/80%/60% income loss):

Depending on their capacity to autonomously transform away from cocoa under unfavorable climate, we estimate the income losses without adaptation at 60%, 80% or 100% compared to today. Transformation zones are projected to become unsuitable for cocoa by the 2050s. Following previous research, we expect transformation zones mainly in the forest-savannah transition zones at the Northern margin of the cocoa belt in both countries (Läderach et al. 2013, Schroth et al. 2016). Negative climate impacts on cocoa cultivation have already been observed in the forest-savannah transition zone in Ghana (Asante et al. 2017): Farmers reported, for instance, a shift to prolonged dry periods associated with higher incidences of pests and diseases. Although yields are not significantly lower than in other parts of Ghana except for the Western region (Kongor et al. 2017), cocoa production is already low given the area size (Figure 1). This is because after an intense period of drought and bushfires in the 1980s, most of the cocoa farms in the region were destroyed and cocoa farmers were forced to shift mostly to maize as a drought-resistant food crop to sustain themselves (Asante et al. 2017). It indicates that the forest-savannah transition zones are already vulnerable and at risk to severe losses by climatic shocks.

The example furthermore demonstrates that cocoa farmers autonomously diversify and substitute their formerly cocoa-generated income by other means as cocoa becomes unsuitable. However, the cocoa farmers from the survey by Asante et al. emphasized major economic difficulties during and after the bushfire period. Maize farming is not considered as profitable as cocoa which is why despite unfavorable climate conditions farmers have meanwhile returned to cocoa. This shows that, although farmers may find alternative income sources, transforming away from cocoa without institutional support will likely cause considerable economic hardship. As poverty among cocoa farmers in Ghana and Ivory Coast continues to be a major challenge, livelihoods in future transformation zones will be particularly vulnerable.

Opportunity (10%/15%/20% of opportunity area used for cocoa cultivation):

Finally, depending on whether autonomous adaptive capacity is low, moderate or high, we therefore assume that planned adaptation would generate gains equivalent to the amount of cocoa cultivated at yields of 230 kg/ha on 10%, 15% or 20% of the area in opportunity zones. Some regions awere projected to become suitable for cocoa in the future due to climate change. Here, the local farmers will incur an opportunity cost if they do not consider cocoa as a new possible source of income. To seize the opportunity, farmers need not only to know about this new option but also acquire means and knowledge to run a profitable cocoa farm. Again, it depends on the autonomous adaptive capacity of farmers of how well they manage to transform into cocoa. We assume that as soon as the regions become suitable for cocoa, local farmers will consider planting cocoa. The role of planned adaptation will be more crucial in helping to increase yields and building sustainable structures for cocoa cultivation in an area where the crop has traditionally not been grown. As we are not aware of such transformation processes in the past, it is hard to estimate the opportunity cost. We assume that planned adaptation could give rise to a cocoa sector similar to the one in the forest-savannah transition zone today. Cocoa would be one important source of income at about the yields of 200-250 kg/ha, while other crops could be profitable, too (Kongor et al. 2017). Based on the 2011-2015 mean production, we estimated the area share used for cocoa cultivation to be about 15% in Brong Ahafo.

5 Results

5.1 Suitability change

The suitability analysis provided us with 19 impact maps of suitability change by the 2050s for Ghana and Ivory Coast respectively. To obtain a most likely scenario of the degree of impact, we chose the suitability change that was most frequently observed among the 19 scenarios. Figure 3 shows the resulting impact map for Ghana: In most parts of Brong Ahafo and a few parts of Northern Ashanti and the Volta region, previously suitable climate will become unsuitable for cocoa such that transformation will be required. Most of the other regions will experience a change in the climate zone suitable for cocoa which implies systemic adaptation in our framework. The Western regions as well as parts of the Central and Volta region face the weakest climate impact on cocoa where incremental adaptation will be sufficient. Finally, opportunity zones were hardly discernable on the map, although this most likely scenario included a few pixels in the South of the Western region as well as in the Eastern region where previously unsuitable land was projected to become suitable.

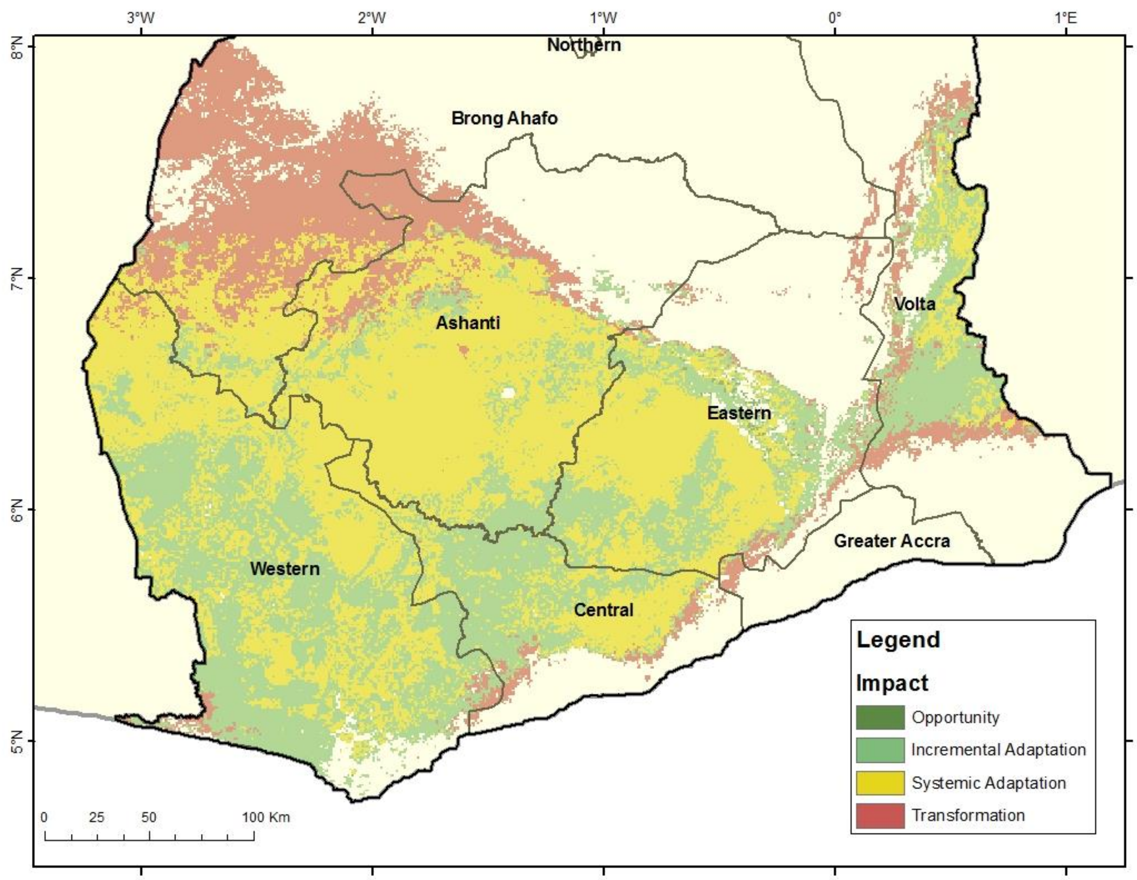

Figure 3: Zones of most likely climate impact on cocoa suitability by the 2050s relative to 1950-2000 in Ghana. The scenario was obtained by choosing the most frequent change observed among the 19 climate projections.

In Ivory Coast, our suitability analysis of 2050s climate shows a larger area share estimated to become unsuitable for cocoa under the most likely scenario (Figure 4). Transformation zones are mainly in the Northwest of the Ivorian cocoa belt (Dix-Huit Montagnes, Haut-Sassandra, Moyen-Cavally) as well as at the Southern margin (parts of Bas-Sassandra, Sud-Bandama, Lagunes and Sud-Comoé). Facing a shift in climate zones by the 2050s, systemic adaptation will become relevant in the West of the country (Bas-Sanssandra, Southern Haut-Sanssandra, Fromager) and a few

Eastern parts close to the Ghanaian border (Agnéby and Moyen-Comoé). Finally, the center of the Ivorian cocoa belt (Sud-Bandama and the Norht of Lagunes) will probably only face a minor climate impact on cocoa such that incremental adaptation would be sufficient. Close to the Liberian border (in Bas-Sassandra and Moyen-Cavally), there are hitherto unsuitable areas for cocoa which will likely become suitable by the 2050s.

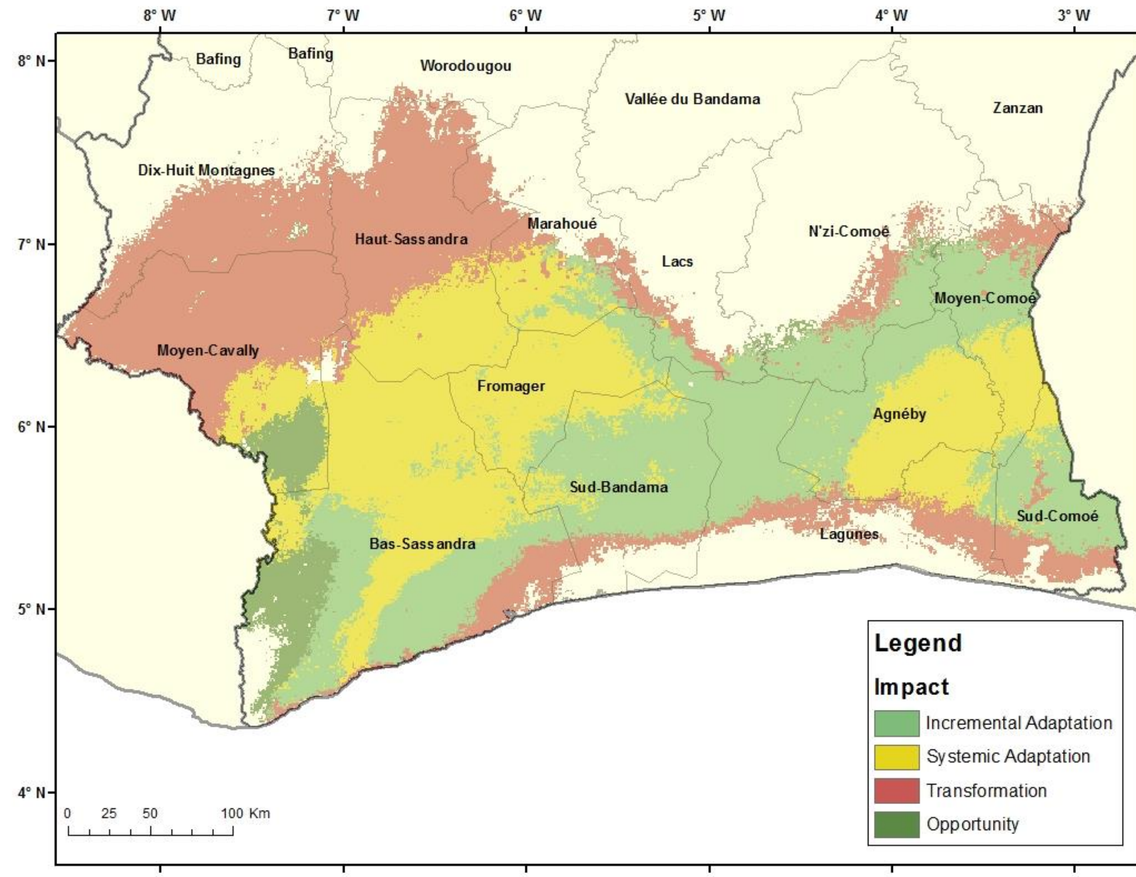

Figure 4: Zones of most likely climate impact on cocoa suitability by the 2050s relative to 1950-2000 in Ivory Coast. The scenario was obtained by choosing the most frequent change observed among the 19 climate projections.

5.2 Affected production

Climate impacts differ greatly across the cocoa zone. For both countries we evaluated the share of production that can be assigned to the different impact zones in each climate change scenario. We focused on the results of the most likely impact scenario and the uncertainty range. The major share of Ghanaian cocoa is produced in areas that are likely to remain suitable for cocoa (Figure 5). Analyzing the median of the climate projections, i.e. neither particularly optimistic nor pessimistic scenario, we found that more than half of current production was located in zones of systematic adaptation (470,000 tons). About another third of the production came from regions with minor adaptation needs (290,000). A small share (6%) was produced in zones projected to become unsuitable for cocoa by the 2050s (50,000). Opportunity zones should currently not contribute any production because in our model they only become suitable in the future. We nevertheless found a small share of production distributed in these zones which can be attributed to the uncertainty in the suitability analysis, the distribution assumptions and the data.

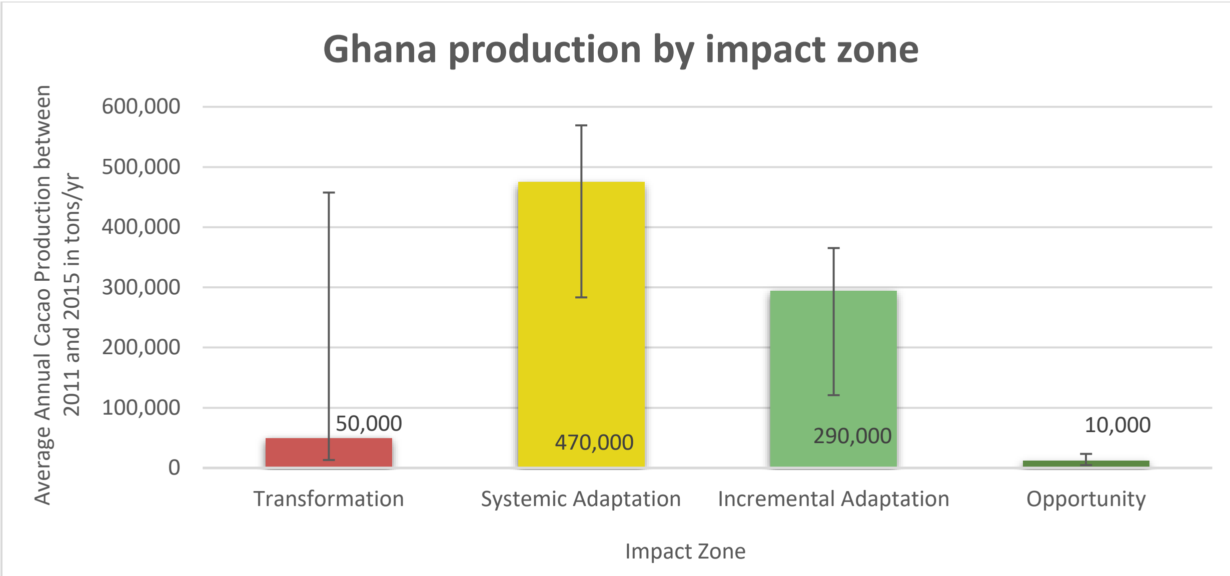

Figure 5: Distribution of current (2010/11-2014/15) annual cocoa production of Ghana over the four impact zones. The colored bars are the median over the 19 climate projections. The error bars denote the 90%-range.

The distribution of current production by impact zones was subject to considerable uncertainty caused by diverging climate projections. The errors range refers to each impact zone separately as in every climate scenario the distribution added up to the total production. Still, the range was quite large especially for the upper bound of production located in transformation zones. This is because two out of the 19 climate projections predicted much more transformation area in Ghana than the median scenario suggested. This downside risk of large transformation zones due to climate uncertainty can be found in all of the following results for Ghana.

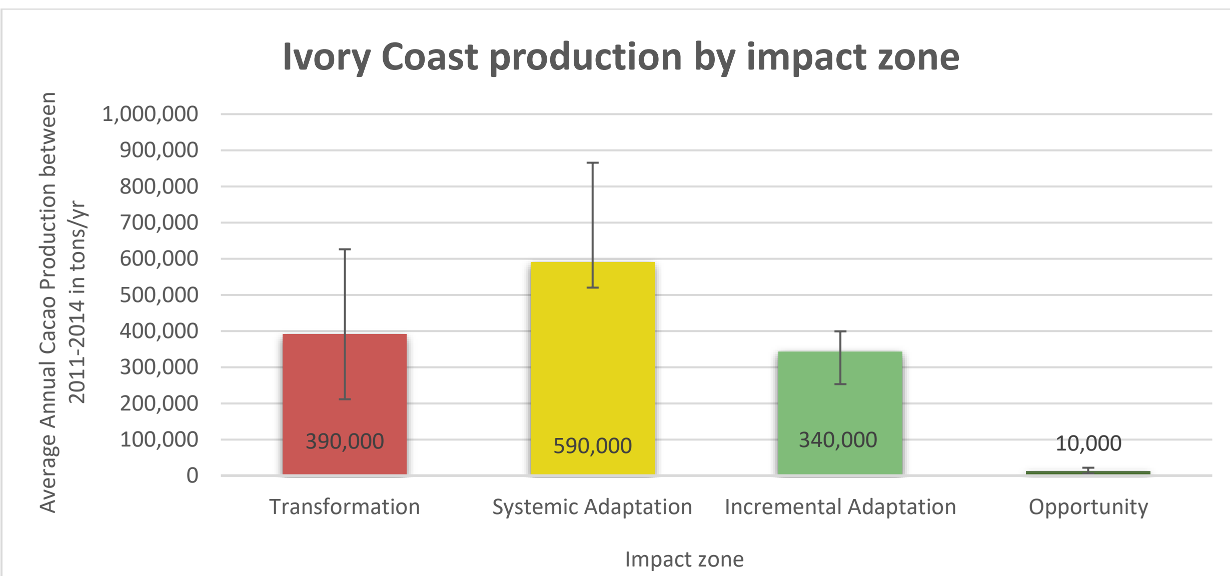

Figure 6: Distribution of current (2011-2014) annual cocoa production of Ivory Coast over the four impact zones. The colored bars are the median over the 19 climate projections. The error bars denote the 90%-range.

The situation in Ivory Coast was found to be more challenging (Figure 6). Considering median scenarios, about a quarter of current production was located in transformation zones (390,000 tons). Zones assigned to systemic adaptation contributed almost half of the cocoa output (590,000), while the remaining quarter faces minor adaptation needs (340,000). In this intermediate scenario, the production in areas of Ivory Coast estimated to require transformation or a high degree of adaptation was about as high as the total Ghanaian production. The climate-related uncertainty was similar to the one in Ghana only that there is high agreement on a considerably larger share of transformation areas. Thus, based on the suitability analysis and the estimated 2011-2014 distribution of cocoa production, near-term climate change will hit cocoa in Ivory Coast more severely.

5.3 Cost of inaction

Finally, we use cost of inaction to benchmark the value of adaptive action in terms of economic impact on the cocoa sector. Our analysis suggested that in Ghana about half of the benefits from adaptation can be expected from implementing systemic adaptation (240m USD/year). Moreover, about 110m USD per year would be gained on average by action on transformation, while incremental adaptation and opportunity action would give less than 100m USD annually. Figure 7 shows the cost estimate for Ghana split up into impact zones in the most likely scenario. The colored bars denote expected cost and error bars 90% ranges over the 171 combinations of climate and damage scenarios. In the two very unfavorable climate scenarios, the cost incurred in transformation zones would be about five times as high as in the most likely scenario.

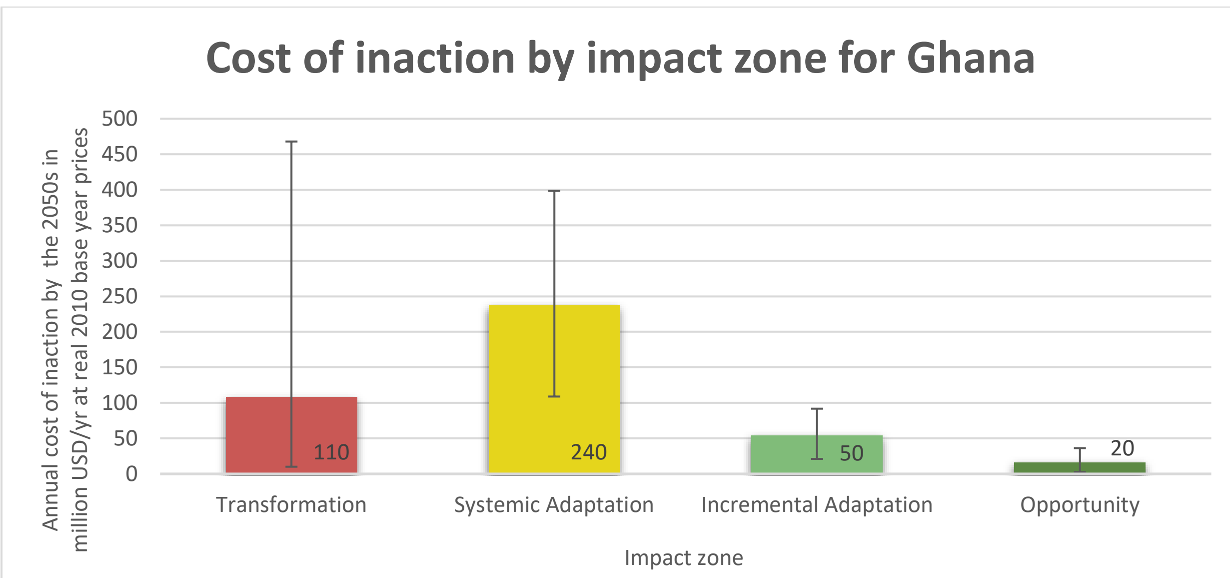

Figure 7: Cost of inaction for Ghana by the 2050s per impact zone in million USD per year. The colored bars show the expected (mean) scenario, while the error bars represent the 90%-range. The cost of inaction used real prices with respect to the 2010 base year.

The expected benefits of adaptation in cocoa for Ghanaian farmer incomes were estimated at 410m USD/year which corresponds to 1% of current (2011-2015 average) real GDP at 2010 base year prices (Figure 8). The 90% range over all 171 scenarios was 270m-660m USD (equivalent to 0.7-1.6% of GDP). The probability distribution was not symmetric and indicated a downside risk of extreme values, i.e. very low cost (e.g. less than 250m USD) are rather unlikely, while very high cost (higher than 570m USD correspondingly) are relatively more likely. Moreover, we analyzed the relative contribution of the sources of uncertainty in our assessment and compared the percentage standard deviations of cost over the climate and the damage scenarios with each other. We found cost on average to be similarly sensitive (20-30%) to our damage assumption as to the climate projections.

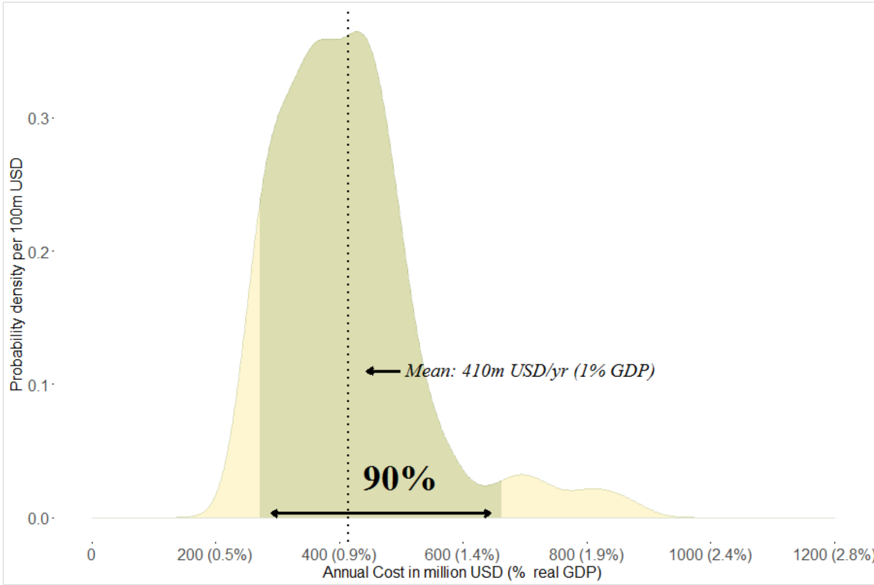

Figure 8: Probability density distribution of our cost of inaction estimate in million USD per year for Ghana over the 171 combinations of damage and climate scenarios. The GDP is average real GDP between 2011 and 2015 at 2010 base year prices.

The cost of inaction were considerably higher in Ivory Coast (Figure 9). This was caused by higher production levels as well as the larger share of transformation zones. In fact, main producing regions such as Haut-Sassandra and Bas-Sassandra were projected to become partly unsuitable. The cost of inaction in transformation zones were estimated at 600m USD per year in the median scenario, more than the expected total cost of inaction in Ghana. The corresponding cost of inaction on systemic adaptation are 400m USD per year, while for zones of incremental adaptation or opportunity they are both below 100m USD per year.

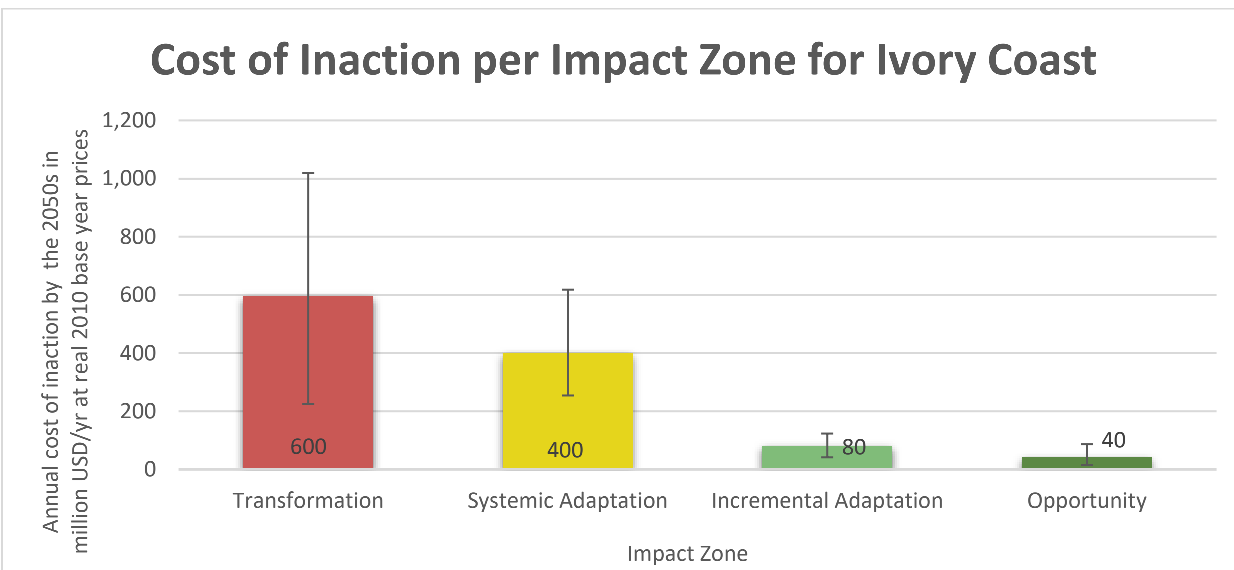

Figure 9: Cost of inaction for Ivory Coast by the 2050s per impact zone in million USD per year. The colored bars show the expected (mean) scenario, while the error bars represent the 90%-range. The cost of inaction used real prices with respect to the base year 2010.

We therefore estimated the total expected cost of inaction for Ivory Coast by the 2050s at 1.12bn USD per year which corresponds to 3.9% of current Ivorian real GDP (Figure 10). Among the 171 scenarios we considered, 90% were within the range of 0.8bn-1.45bn USD per year. As for Ghana, there was a low probability of very high cost due to one climate scenario that projected almost the entire region to become unsuitable for cocoa. This would lead to very high cost up to 2.3 billion USD annually. Similar to the Ghana analysis, costs were about as sensitive to climate projections as to our damage assumptions.

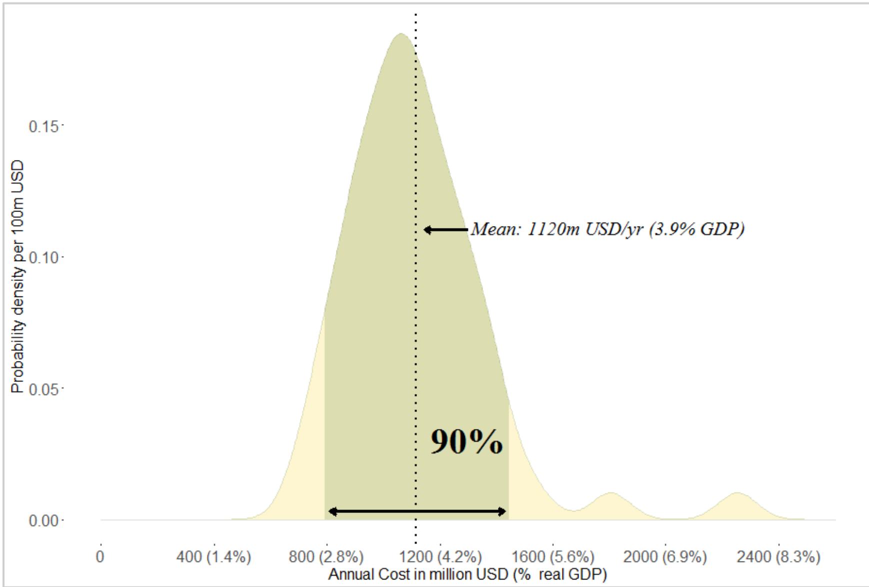

Figure 10: Probability density distribution of our cost of inaction estimate in million USD per year for Ivory Coast over the 171 combinations of damage and climate scenarios. The GDP is average real GDP between 2011 and 2015 at 2010 base year prices.

6 Discussion

Our cost of inaction analysis aimed at providing a benchmark to help stakeholders evaluating investment into adaptation by developing empirical potential production loss scenarios. The general framework of the economics of adaptation distinguishes between different degrees of adaptation effort associated with different adaptation cost (IPCC 2014b, pp. 950-963). We considered our cost of inaction to be the potential benefits of a certain adaptation effort. Specifically, we assumed a counterfactual in which cocoa production is restored to current levels where possible, income losses where cocoa becomes unprofitable are compensated and opportunities where cocoa will be a novel attractive option for farmers are seized. Hence, the adaptation effort we considered was not defined by its cost but by its adjustment impact. A full-fledged cost-benefit analysis of adaptation would have to take adaptation cost as well as different possible degrees of adaptation effort into account. However, our impact assessment is sufficient as long as stakeholders may easily estimate that adaptation cost are significantly higher or lower than our estimate.

We argue that a full quantitative integration of the cost-side might not be necessary to encourage action on adaptation in the West-African cocoa sector. Many potential adaptation measures for West-African smallholder cocoa farmers increase productivity also under current climate conditions and are therefore no-regret options. Better pest and disease control, the usage of drought-resistant varieties or training famers on the optimal amount of shading will not only reduce future climate risk but increase efficiency today. Especially the use of fungicides and fertilizer would augment yields considerably but is so far too costly for the majority of smallholder cocoa farmers (Wessel and Quist-Wessel 2015, Kongor et al. 2017). Only few interventions, as for instance encouraging a transformation of cocoa-based farming to other crops, might actually turn out ineffective or counterproductive in case the anticipated climate impact will not occur. Finally, increased productivity could have other co-benefits by reducing deforestation as forest clearing and extensification of cocoa area has so far often served as means to increasing production (Wessel and Quist-Wessel, 2015, Ruf and Varlet 2017). Climate change must therefore be understood as an additional risk in a region where low productivity and environmental problems already pose serious challenges to cocoa farming.

We calculated the cost of inaction for different combinations of climate and damage scenarios. This served to obtain a range of the cost of inaction and test their sensitivity in the face of climate and impact uncertainty. In our setting, we found both climate and impact uncertainty to significantly affect the cost of inaction each with about equal relative influence. The climate scenarios were based on large-scale climate modeling, while the damage scenarios were assumptions that we found to be plausible after reviewing the literature on reported climate risks for cocoa in the region. However, neither uncertainty is easy to reduce. The skill of climate models in projecting regional and seasonal precipitation, the key determinants of cocoa suitability, is still very limited and will probably remain so for a while (Ramirez-Villegas et al. 2013). Moreover, developing a robust crop model for cocoa would require considerable effort of data acquisition, calibration and validation as has been experienced for crop modeling for maize, wheat or rice (Rosenzweig et al. 2014). A promising preliminary step to improve climate impact estimates on cocoa yields could be to develop statistical models on the basis of observed climate variability similar to a Ricardian Analysis (e.g. Seo et al. 2005). However, such analysis would only be valid for the near-term of a few decades as long as the climate signal does not leave the range of observations from past climate variability.

The cost of inaction we calculated must be understood as an order-of-magnitude estimate which is still based on relatively conservative assumptions. The benefits of adaptation by the 2050s would actually require knowledge of future cocoa production and prices. Demand will likely grow in the future and both countries announced to expand future production. The development of prices, though, is extremely difficult to predict. We think that decision makers might find it easier to interpret hypothetical changes to the current known situation than relative to an uncertain economic projection. It demonstrates the scale of climate change impacts against a familiar background. Strictly speaking, our cost of inaction should be interpreted as the cost incurred if 2050s climate conditions hit the unprepared cocoa sectors in Ghana and Ivory Coast today.

Finally, our cost of inaction estimate referred to aggregate income loss for cocoa farmers. It did not include cost for the supply chain of cocoa such as transportation and other value adding activities. Our approach focused on the economy-wide aggregate impact, not on a perspective of vulnerability of livelihoods and development. This makes a difference especially when looking at specific, more vulnerable regions. For instance, Brong Ahafo may only contribute 6% to Ghana's total production, its production loss may not weigh in much on the national scale. However, inaction on transformation could have devastating consequences in a region with relatively poor cocoa farmers (Asante et al. 2017). For assessing the impact from a broader perspective of social development, more indicators such as poverty rate or education level would need to be considered in addition.

7 Appendix

7.1 Household Analysis in Ghana

As was done for production, we analyzed the number of cocoa-growing households in Ghana currently located in the respective impact zones. As there was no such data for Ivory Coast and, moreover, the results are similar to the analysis of affected production, we excluded it from the main text.

We collected household data on subnational level from the *2010 Population and Housing Census* (PHC) conducted by the GSS (2014). We downloaded all district reports of the PHC that were available online and extracted the number of households engaged in cacao production (cacao households) as well as the number of households engaged in crop activity (crop households). The data aggregation was impeded by the fact that the census had been done on 216 new districts of Ghana established in 2012. Yet, the coordinates of the new districts were not available to us such that the analysis could only be done on the 137 districts of 2007. If new districts had been carved out of old districts, we assigned the PHC data to those districts. In ambiguous cases, we assigned it to the nearest surrounding district.

However, only about 40% of the PHC district reports contained data on the number of households engaged in cacao production (cacao households). Therefore, we conducted the following imputation for missing districts: The PHC provides data on crop households for all except one district. This district was excluded from the analysis. For the remaining, we calculated the percentage of cacao households relative to the crop households and interpolated this percentage for the missing districts using an inverse-distance method (see appendix 6.1). Finally, we multiplied the interpolated percentage with the crop households observed in the district to obtain an estimate of the cacao households. Essentially, we assume that the share of farmers growing cacao in the missing districts is about as high as observed in neighboring districts. In order to work with a maximum number of consistent observations, we only merged new districts to old districts which either all contained data on cacao households or no data on cacao households at all. There were 14 out of 216 districts without cacao data that would have needed to be merged with districts in which cacao household data were observed. Those districts were also excluded from the analysis.

The resulting map of cacao households in Ghana is shown in Figure 12. The distribution of households is similar to the distribution of production (Figure 1). The Western region and Southern Ashanti are the core regions of cocoa cultivation in Ghana. Assuming cocoa households to be distributed evenly within each district, we calculated the number of households per impact zone (Figure 12). The resulting distribution is again similar to the one for production (Figure 13) only that from the perspective of households transformation can be considered more important. The relative share of households in likely transformation zones is higher than the relative production share. A possible explanation is that farmers in the forest-savannah transition zone of Ghana have already diversified more such that cocoa farming is only one source of income (Asante et al. 2017).

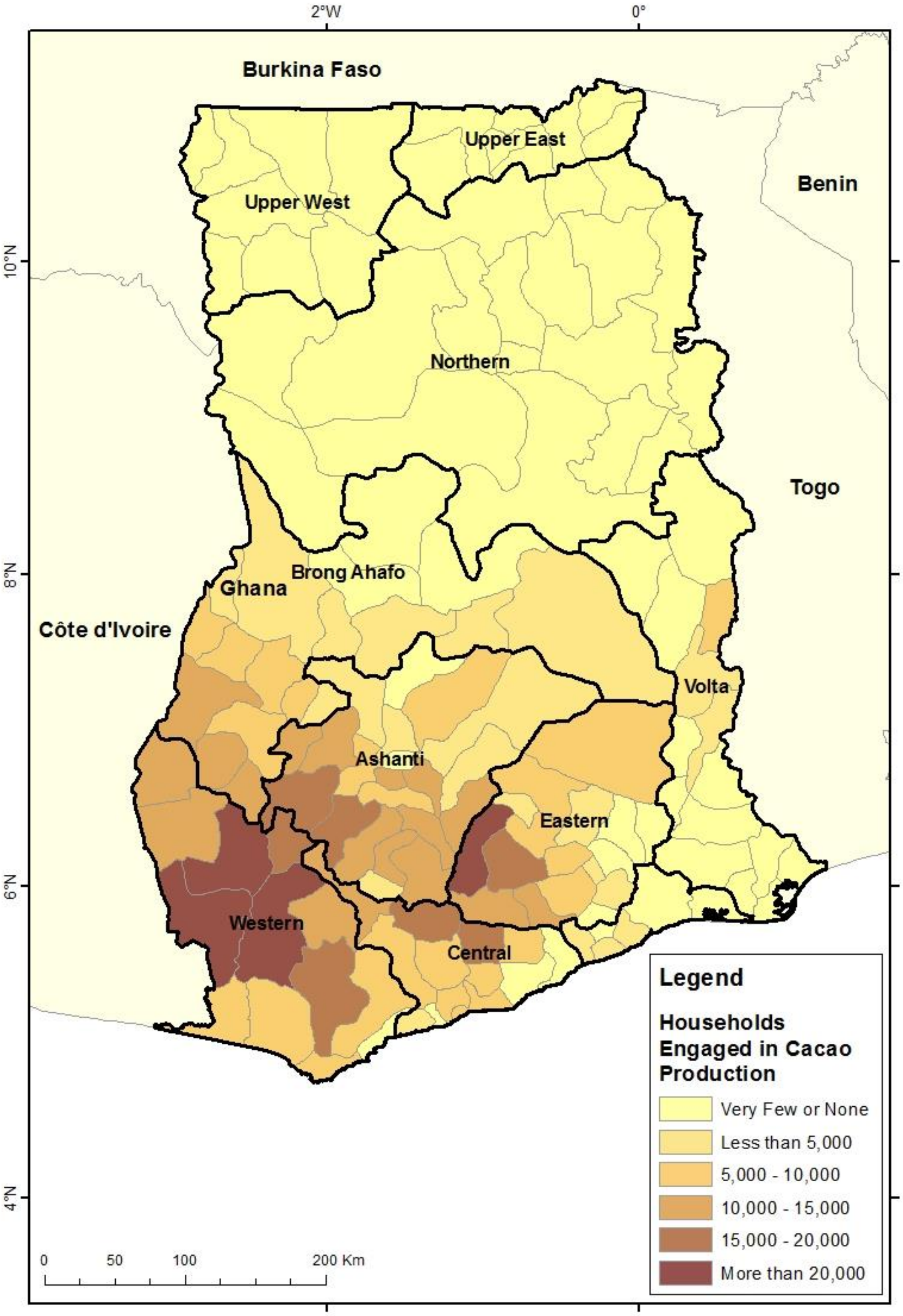

Figure 11: Estimated distribution of households engaged in cacao production on district level in Ghana based on data from the GSS (2014).

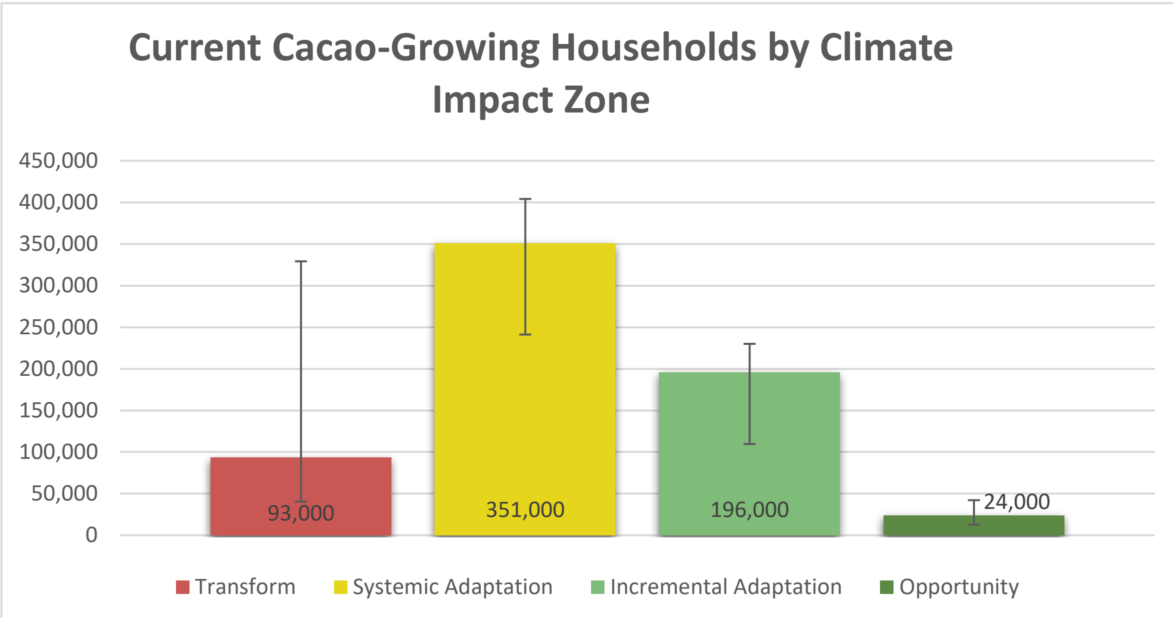

Figure 12: Number of current (2010) cacao-growing households in Ghana per climate impact zone. The colored bars show the median of the 19 climate scenarios. The error bars denote the 90% range.

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