Future Climate Scenarios for Kenya's Tea Growing Areas

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CIAT

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

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Index of Acronyms

BIOCLIM   Bioclimatic Analysis and Prediction System

CIAT   International Center for Tropical Agriculture

CV   Coefficient of Variation

DAPA   Decision and Policy Analysis

ECOCROP   The Crop Environmental Requirements Database

ESG   Earth System Grid

ETP   Ethical Tea Partnership

FAO   Food and Agriculture Organization

GARP   Genetic Algorithm for Rule-set Production

GBIF   Global Biodiversity Information Facility

GCM   Global Circulation Model

GHCN   Global Historical Climatology Network

GIZ   German International Cooperation

GPS   Global Position System

IPCC   Inter-governmental Panel on Climate Change

Masl   Meters above Sea Level

Maxent   Maximum entropy

NWP   Numerical Weather Prediction

R-HYdroNET   A Regional, Electronic Hydrmeteorological Data Network (for Latin America and the
                Caribbean)

SPAM   Spatial Production Allocation Model

SRES   Special Report on Emissions Scenarios

SRTM   Shuttle Radar Topographic Mission

WMO   World Meteorological Organization

1   Authors and contact details

The analyses presented here were conducted by the Decision and Policy Analyses group (DAPA) at CIAT under the leadership of Anton Eitzinger, with the collaboration of Peter Läderach, Audberto Quiroga, Antonio Pantoja and Jason Gordon.

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2   Executive summary

This document reports on the methods and results of a consultancy with the title "Future Climate Scenarios for Kenya's Tea Growing Areas" conducted for the Ethical Tea Partnership (ETP) and German International Cooperation GIZ.

The methodology applied was based on the combination of current climate data with future climate change predictions from 20 models for 2020 and 2050. The data of the current climate and the climate change was used as input to Maxent, a crop prediction model. The evidence data used for Maxent were collected by GPS through field work in Kenya.

The analysis focused on the specific municipalities that were of interest to the client and provided predictions of the future climate and predictions of the suitability of current tea-growing areas to continue growing tea by 2020 and 2050. The results show that the change in suitability as climate change occurs is site-specific. There will be areas that become unsuitable for tea (Nandi, Kericho, Gucha), where farmers will need to identify alternative crops. There will be areas that remain suitable for tea (Bomet, Kisii, Nyamira), but only when the farmers adapt their agronomic management to the new conditions the area will experience. There will be areas where suitability of tea increases (Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu). Finally, there will be areas where today no tea is grown but which in the future will become suitable (especially higher altitudes around Mount Kenya). However many of these latter areas are usually protected areas and it is not recommended to clear forest or invade protected areas in order to produce tea. Climate change brings not only bad news but also a lot of potential. The winners will be those who are prepared for change and know how to adapt.

In Kenya the yearly and monthly rainfall will increase and the yearly and monthly minimum and maximum temperatures will increase moderately by 2020 and will continue to increase by progressively 2050. The overall climate will become less seasonal in terms of variation throughout the year with temperature in specific districts increasing by about 1 ºC by 2020 and 2.3 ºC by 2050 and more seasonal in precipitation with the maximum number of cumulative dry month staying constant at 3 months. The implications are that the distribution of suitability's within the current tea-growing areas in Kenya for

tea production in general will decrease quite seriously by 2050. The suitable areas will migrate up the altitudinal gradient. Areas that retain some suitability will see decreases to between 35 and 55%, compared with today's suitability of 60 - 80%.

The optimum tea-producing zone is currently at an altitude between 1500 - 2100 meters above sea level (masl) and, by 2050, will increase to an altitude between 2000 - 2300 masl. Increasing altitude compensates for the increase in temperature. Compared with today, by 2050 areas at altitudes between 1400 - 2000 masl will suffer the highest decrease in suitability and the areas around 2300 masl the highest increase in suitability.

A comparison of potential diversification crops recommended by the project show that coffee performs similar to tea and would not be a good alternative crop. For more than 90% of these sites maize and cabbage will remain constant and pea will be much more suitable on 97% of this sites. Passion fruit will be much more suitable on 51% of these sites and banana on 14% of these sites more suitable for 2050.

3   Project Background and Objectives

The Ethical Tea Partnership (ETP) and the German International Cooperation (GIZ) aim to increase Kenyan tea producers' resilience to climate change, to secure their future livelihoods and make these livelihoods more environmentally and economically sustainable. In order to achieve this, the two partners have formed a 3-year Public-Private Partnership, which will train approximately 10,000 vulnerable Kenyan farmers on the most appropriate adaptation techniques.

The objectives of this study is to develop future climate scenarios indicating the adaptability/suitability of tea under changing climatic conditions for Kenya's tea growing zones, and indicating potentials for alternative crops suitable under predicted climate change.

Currently the tea growing areas in Kenya are in the following districts: Bomet, Embu, Kakamega, Kericho, Kiambu, Kirinyaga, Kisii, Meru, Murang'a, Nakuru, Nandi, Nithi, Nyamira, Nyeri, Trans-Nzoia and Vihiga

Figure 1: Study zone and Kenya's tea growing areas

4   Key objectives

To predict the change in climate for tea growing areas in Kenya

To predict the impact of progressive climate change on tea suitability in Kenya

To predict the impact of progressive climatic change on the most important diversification crops.

5   Methodology

5.a   Current climate

As current climate (baseline) we used historical climate data from www.worldclim.org database (Hijmans *et al.*, 2005). The WorldClim data are generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 bioclimatic variables (Hijmans *et al.*, 2005a).

In the WorldClim database, climate layers were interpolated using:

- • Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, amongst others.
- • The SRTM elevation database (aggregated to 30 arc-seconds, "1 km")
- • The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

For stations for which there were records for multiple years, the averages were calculated for the 1960-90 period. Only records for which there were at least 10 years of data were used. In some cases the time period was extended to the 1950-2000 period to include records from areas for which there were few recent records available (e.g., Democratic Republic of the Congo) or predominantly recent records (e.g., Amazonia).

After removing stations with errors, the database consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

The data on which WorldClim is based in Kenya are from 736 stations with precipitation data, 708 stations with mean temperature, and 61 stations with minimum and maximum temperatures.

<u>Bioclimatic variables</u>
Within the WorldClim database, there are bioclimatic variables that were derived from the monthly temperature and rainfall values to generate more biologically meaningful variables, which are often used in ecological niche modeling (e.g., BIOCLIM, GARP). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wettest and driest quarters). A quarter is a period of three months (1/4 of the year).

The derived bioclimatic variables are:

Bio1 = Annual Mean Temperature
Bio2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
Bio3 = Isothermality (Bio2/Bio7) (* 100)
Bio4 = Temperature Seasonality (standard deviation *100)
Bio5 = Maximum Temperature of Warmest Month
Bio6 = Minimum Temperature of Coldest Month
Bio7 = Temperature Annual Range (Bio5 – Bi06)
Bio8 = Mean Temperature of Wettest Quarter
Bio9 = Mean Temperature of Driest Quarter
Bio10 = Mean Temperature of Warmest Quarter

Bio11 = Mean Temperature of Coldest Quarter
Bio12 = Annual Precipitation
Bio13 = Precipitation of Wettest Month
Bio14 = Precipitation of Driest Month
Bio15 = Precipitation Seasonality (Coefficient of Variation)
Bio16 = Precipitation of Wettest Quarter
Bio17 = Precipitation of Driest Quarter
Bio18 = Precipitation of Warmest Quarter
Bio19 = Precipitation of Coldest Quarter

5.b   Future climate

Global circulation models

A global circulation model (GCM) is a computer-based model that calculates and predicts what climate patterns will be in a number of years in the future. GCMs use equations of motion as a numerical weather prediction (NWP) model, with the purpose of numerically simulating changes in the climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the concentration of greenhouse gases). The model focuses on each grid cell and the transfer of energy between grid cells. Once the simulation is calculated a number of climate patterns can be determined; from ocean and wind currents to patterns in precipitation and rates of evaporation that affect, for example, lake-levels and growth of agricultural plants. The GCMs are run in a number of specialized computer laboratories around the world. We used data in our analyses from these laboratories.

Generation of predictions for future climate

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was based on the results of 21 global climate models (GCMs), data for which are available through an IPCC interface, or directly from the institutions that developed each individual model. The spatial resolution of the GCM results is inappropriate for analyzing the impacts on agriculture as in almost all cases the grid cells measure more than 100 km a side. This is especially a problem in heterogeneous landscapes such as highly mountainous areas, where, in some places, one cell can cover the entire width of the range.

Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the likely impacts of climate change on agriculture are to be more accurately forecast.

We used a simple downscaling method (named delta method), based on the sum of interpolated anomalies to high resolution monthly climate surfaces from WorldClim (Hijmans *et al.*, 2005a). The method, basically, produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate (from WorldClim), taking into account the possible bias due to the difference in baselines. The method assumes that changes in climates are only relevant at coarse scales, and that relationships between variables are maintained towards the future (Ramirez and Jarvis, 2010).

CIAT downloaded the data from the Earth System Grid (ESG) data portal and applied the downscaling method on over 19 GCMs from the IPCC Fourth Assessment Report (2007) for the emission scenario

SRES-A2 and for 2 different 30 year running mean periods (i.e. 2010-2039 [2020s], 2040-2069 [2050s]). Each dataset (SRES scenario – GCM – time slice) comprises 4 variables at a monthly time-step (mean, maximum, minimum temperature, and total precipitation), on a spatial resolution of 30 arc-seconds (Ramirez and Jarvis, 2010).

5.c Crop prediction

Maximum Entropy

Maximum entropy (MAXENT) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent (one's) incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average -"average value for a set of sample points taken from the target distribution"(Phillips *et al*., 2006 pg234). Similar to logistic regression, MAXENT weights each environmental variable by a constant. The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution.

MAXENT is generally considered to be the most accurate model (Elith *et al*., 2006).

Ecocrop

For most of the crops that are not staples or commodity crops there is a lack of detailed information. Hijmans *et al.,* (2005b) have developed a mechanistic model based on the Ecocrop database (FAO, 1998 available at http://ecocrop.fao.org/ecocrop/srv/en/home) to spatially predict crop suitability without having prior knowledge or data available. The model essentially uses minimum, maximum, and mean monthly temperatures, and total monthly rainfall to determine a suitability index based on each parameter separately (i.e. temperature, rainfall), to finally determine an overall suitability rating (from 0 to 100) by multiplying both temperature and rainfall indices. Ecocorp does not require any coordinates or ground data and is therefore rather generic. To improve the results we use existing knowledge of geographic crop distribution such as the Spatial Production Allocation Model (SPAM), the Global Biodiversity Information Facility (GBIF), CIAT own databases and expert knowledge gathered on the ground. With a minimum of 60-100 geo-referenced sample sites gathered across the different sources we re-calculated the environmental factor ranges to improve the model. GPS-coordinates of the Kenyan tea growing sample sites are supplied by the project partners.

5.d Measure of confidence

Future crop suitability is predicted using each of the GCM models via Ecocrop algorithms described above. Two measurements of uncertainty are computed: (1) the agreement among models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location and (2) the coefficient of variation (CV) among models. After initial runs, models that are significantly different from those of the other models according to Tukey's (1977) outlier test will be removed from further analysis.

5.e Environmental factors driving change in suitability

In order to understand the relative importance of different climatic drivers, we then carried out a forward, step-wise regression analysis with the suitability shift per data point as the dependent variable and the model-average changes in the bioclimatic variables between the present and future as the independent variables, and calculating the relative contribution of each variable to the total predicted suitability shift in terms of the proportion of R-square explained when adding each variable to the linear regression model. This analysis was carried out separately for the data points showing positive and negative shifts in suitability.

6 Result I: Climate change summary of tea production sites

6.a The summary climate characteristics for all tea factory sites in Kenya
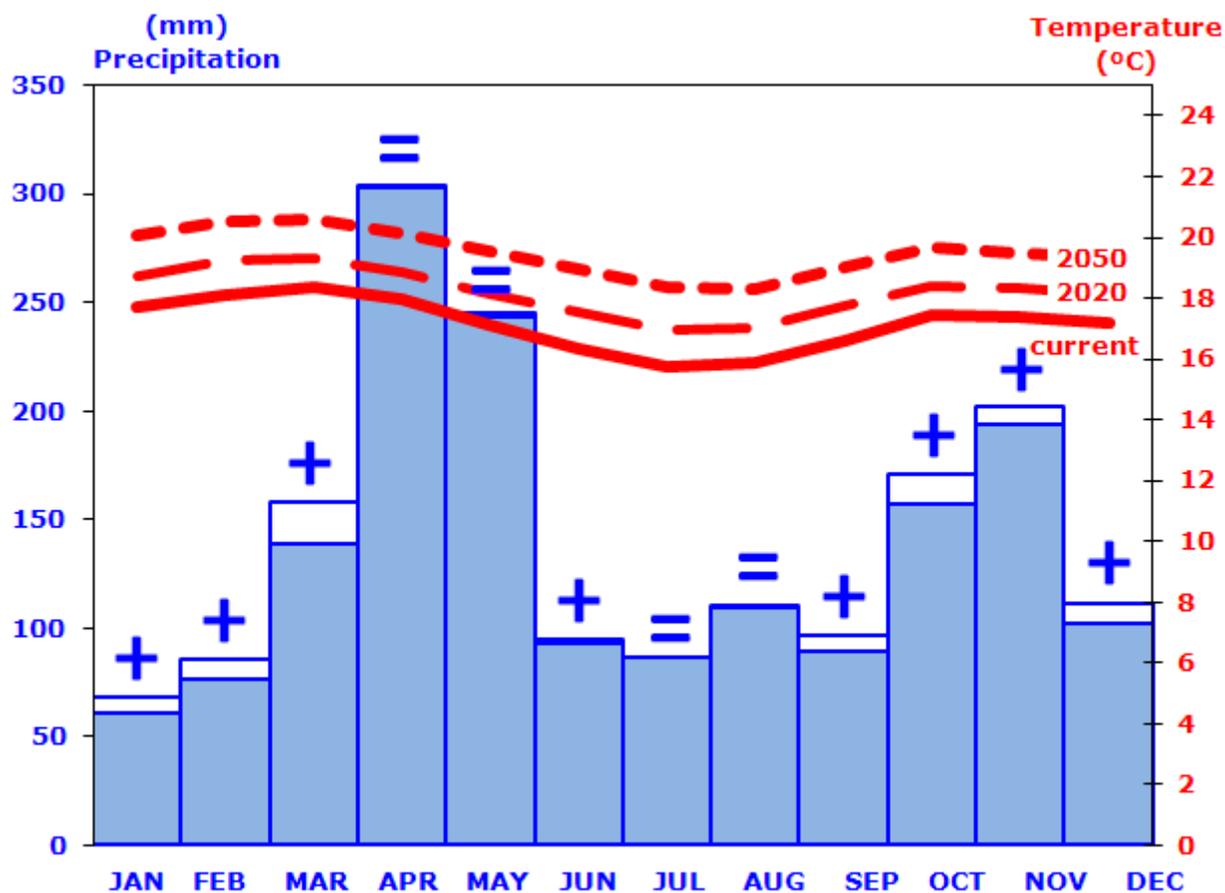
Figure 2: Climate trend summary 2020 and 2050 for sample sites

General climatic characteristics
- Rainfall increases from 1658 millimeters to 1732 millimeters in 2050 passing through 1694 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1.0 ºC in 2020
- The mean daily temperature range keeps constant on 14.8 ºC in 2050
- The maximum number of cumulative dry months keep constant in 3 months

- The maximum temperature of the year increases from 26.6 ºC to 29 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 8.9 ºC to 11.1 ºC while the coldest quarter gets hotter by 2.5 ºC in 2050
- The wettest month gets wetter with 308 millimeters instead of 304 millimeters, while the wettest quarter gets wetter by 20 mm in 2050
- The driest month stays constant with around 58 millimeters while the driest quarter gets wetter by 13 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal as it relates to temperature and precipitation variability through-out the year

Variability between models

- The coefficient of variation of temperature predictions between models is 5%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 4.6%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.b   Regional changes in the mean annual precipitation (2020)

Figure 3: Mean annual precipitation change by 2020 for 16 tea-growing districts of Kenya.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

The mean annual precipitation increases in 2020 on average by 36 mm and in 2050 by 74 mm. In 2020 the districts Meru and Nithi will have larger increase in precipitation than others (Figure 3) and in 2050

Kisii and Nyamira will have the largest increase (Figure 4). We observed the smallest increase in precipitation for 2020 in Kakamega and in 2050 in Embu, Meru, Kirinyaga and Nithi.

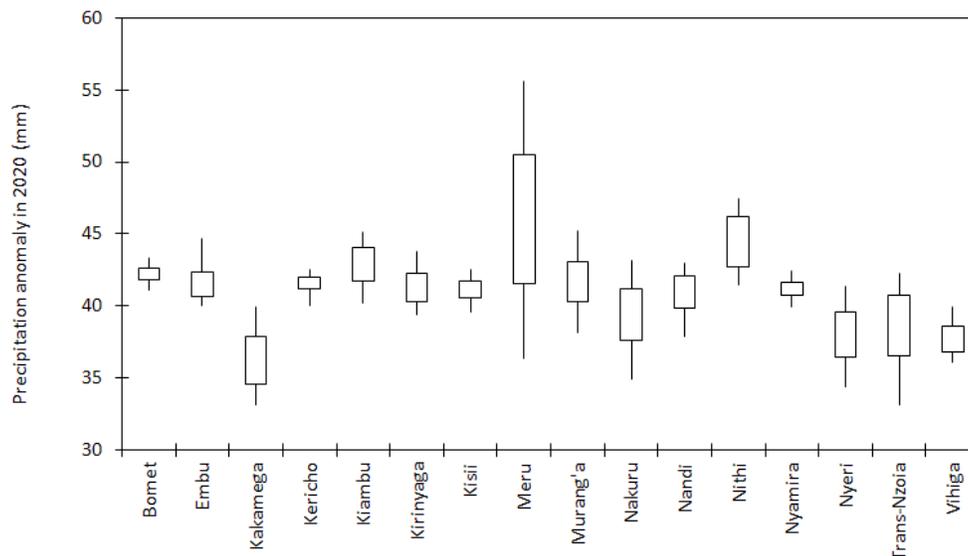## 6.c   Regional changes in the mean annual precipitation (2050)

Figure 4: Mean annual precipitation change by 2050 for 16 tea-growing districts of Kenya.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

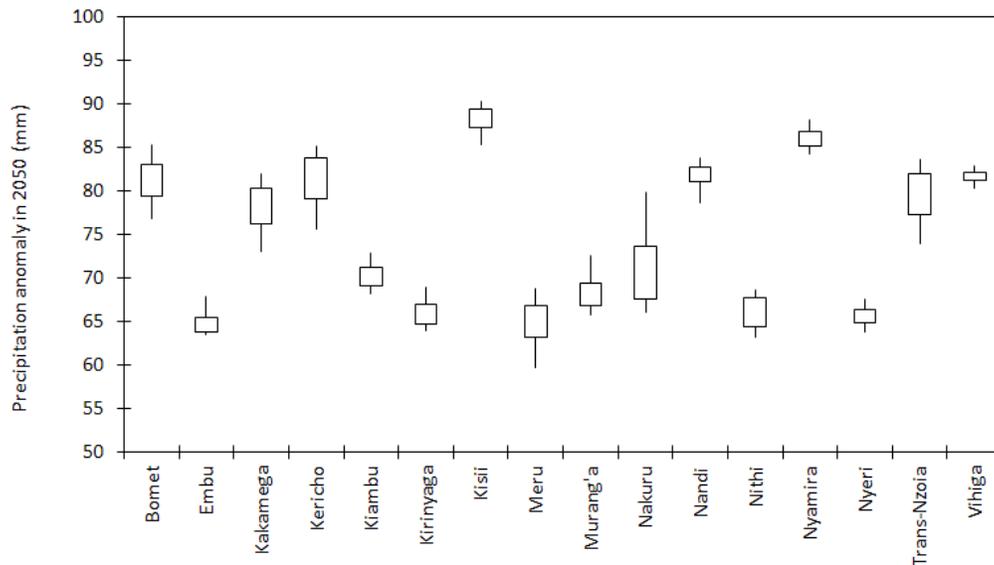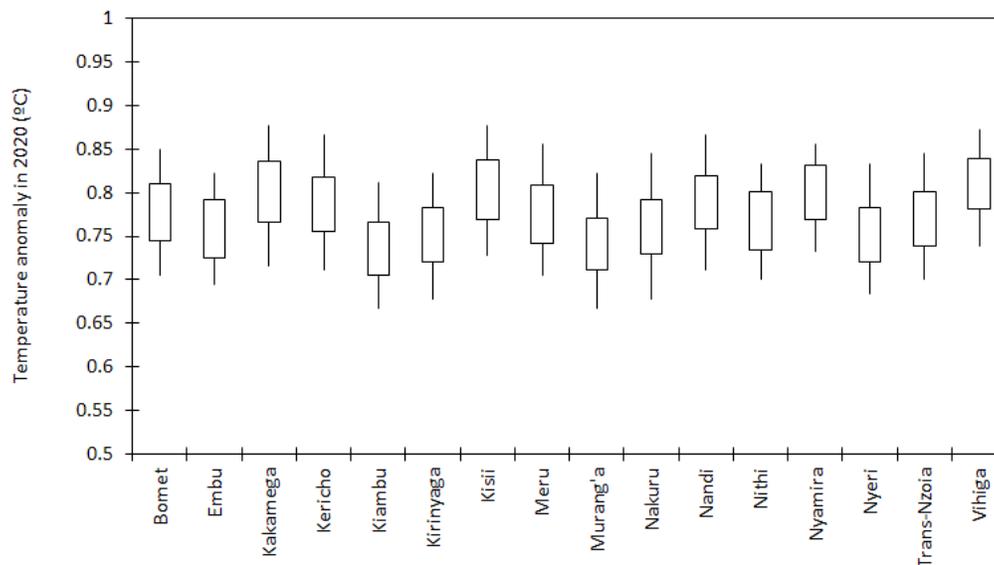## 6.d   Regional changes in the mean annual temperature (2020)

Figure 5: Mean annual temperature change by 2020 for 16 tea-growing districts of Kenya.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

The mean annual temperature will increase progressively. The increase by 2050 is between 2.1 and 2.2 ºC (Figures 6) and for 2020 between 0.7 and 0.9 ºC (Figures 5).

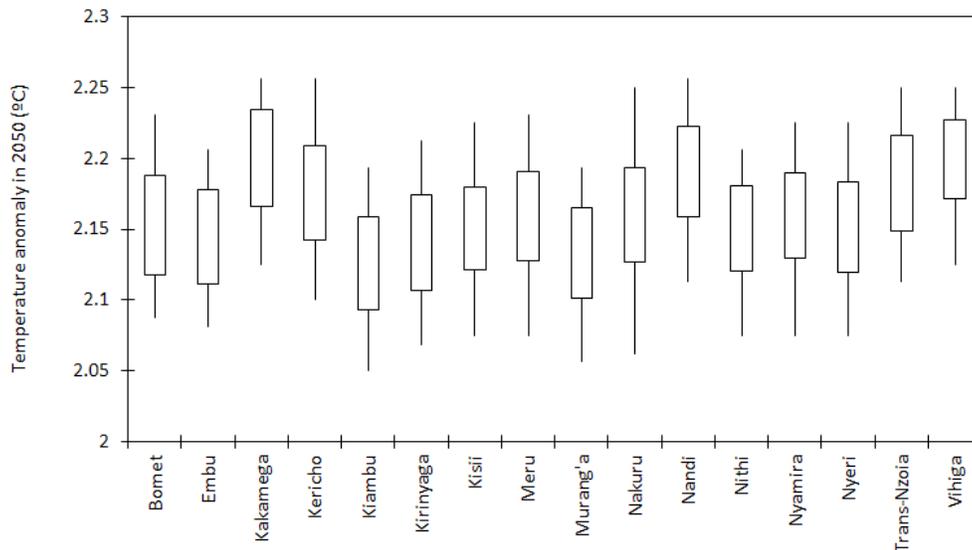**6.e   Regional changes in the mean annual temperature (2050)**

Figure 6: Mean annual temperature change by 2050 for 16 tea-growing districts of Kenya.

The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

7 Result II: Suitability maps of tea production areas

7.a Current suitability of tea production areas
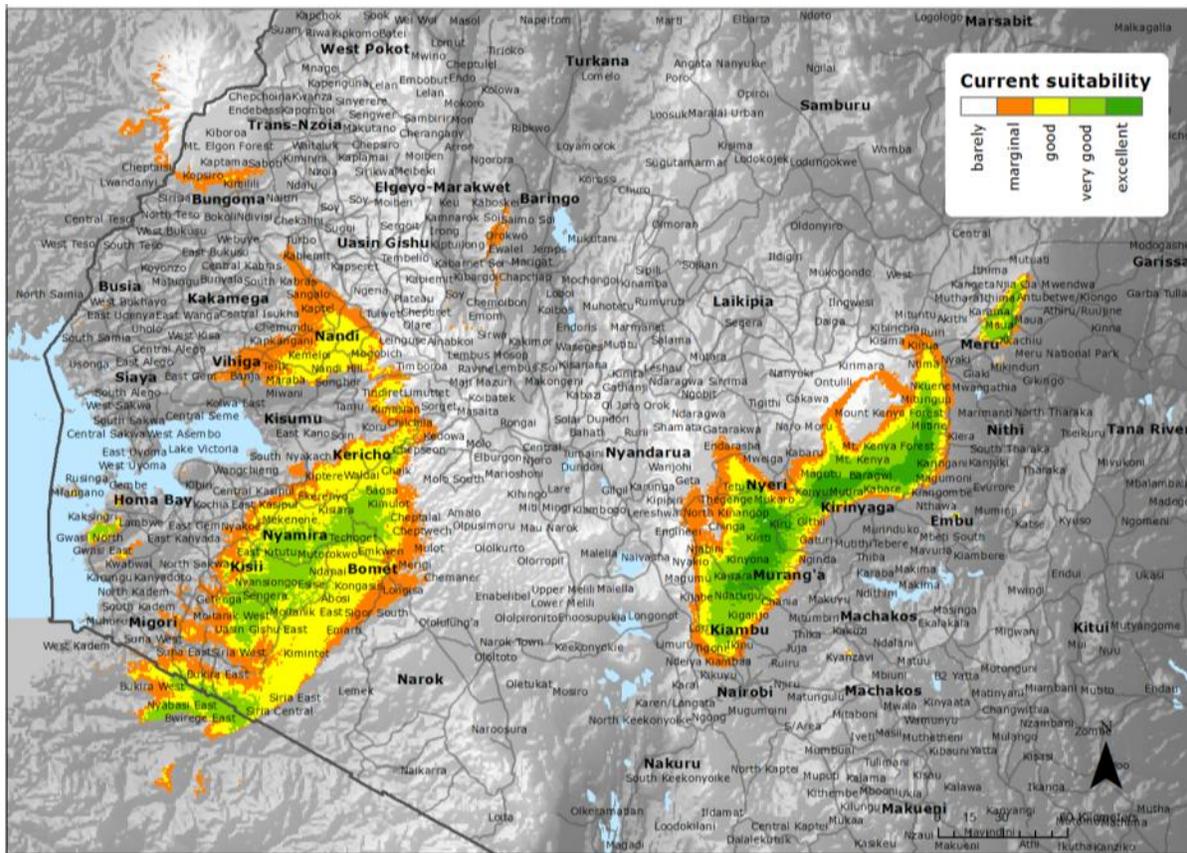
Figure 7: Current suitability for tea production within tea-growing districts of Kenya.

Currently, the main tea-producing areas in Kenya are located in the central region around Mount Kenya and between the Rift Valley and Nyanza in the west (Figure 7). According to the MAXENT model, the most suitable of them are concentrated in the higher areas of districts: Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu, Kisii, Nyamira, Kericho, Bomet, Narok, Migori. The remaining districts are in general rather less suitable.

Find more detailed maps of current and future tea suitability in focal regions in Annex I to V.

7.b   Future suitability of tea production areas

Figure 8: Suitability for tea production in 2020.
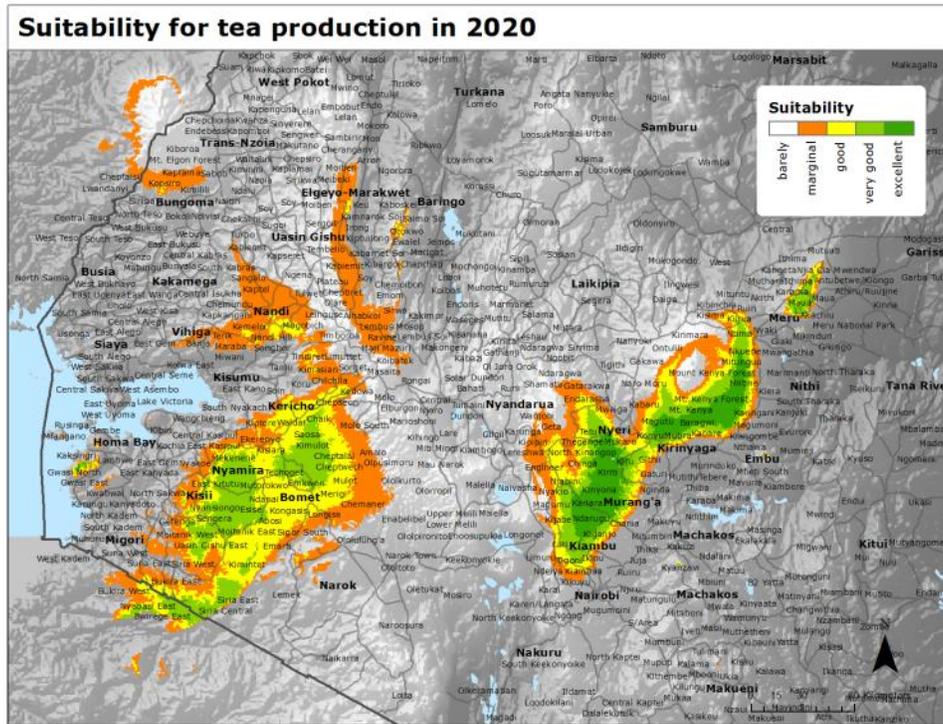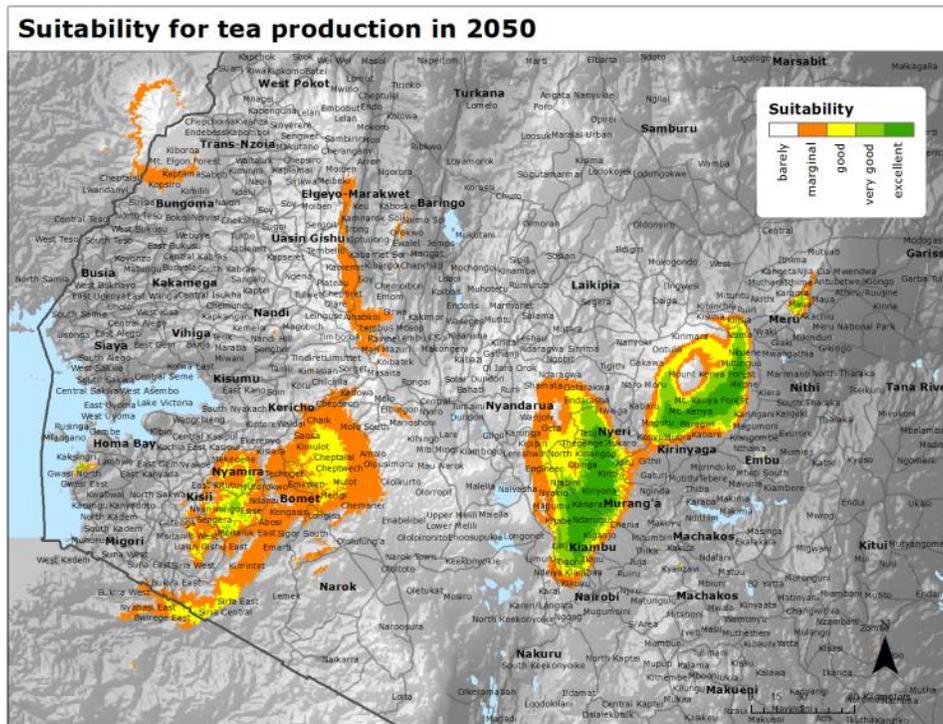

Figure 9: Suitability for tea production in 2050.

In 2020 suitable areas start shifting but the average suitability in all districts remains nearly constant (Figure 8). We assume that most areas will still be suitable enough to grow tea under similar climate conditions. In 2050 tea production according to its climate-suitability is predicted to be more concentrated in Central Kenya (Figure 9). In this region, areas with high suitable will expand. The western region in general is anticipated to have a lower suitability level. The coefficient of variance (CV) for 2020 and 2050 bioclimatic variables ranges between 0 and 15%, even lower for tea-growing areas and may therefore be accepted as reliable (Figure 10).
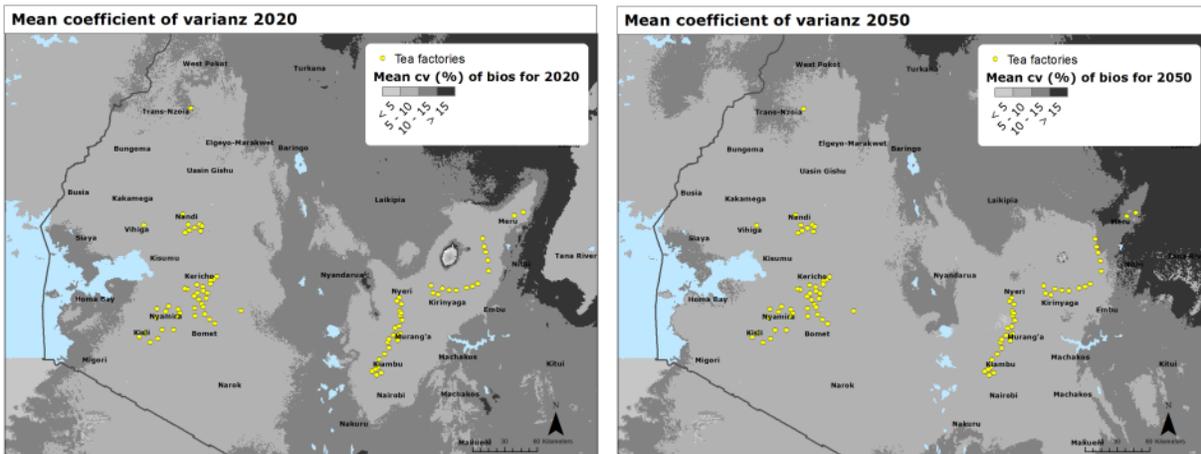

Figure 10: Mean coefficient of variance of bioclimatic variables in 2020 and 2050.

7.c   Suitability change of tea production areas
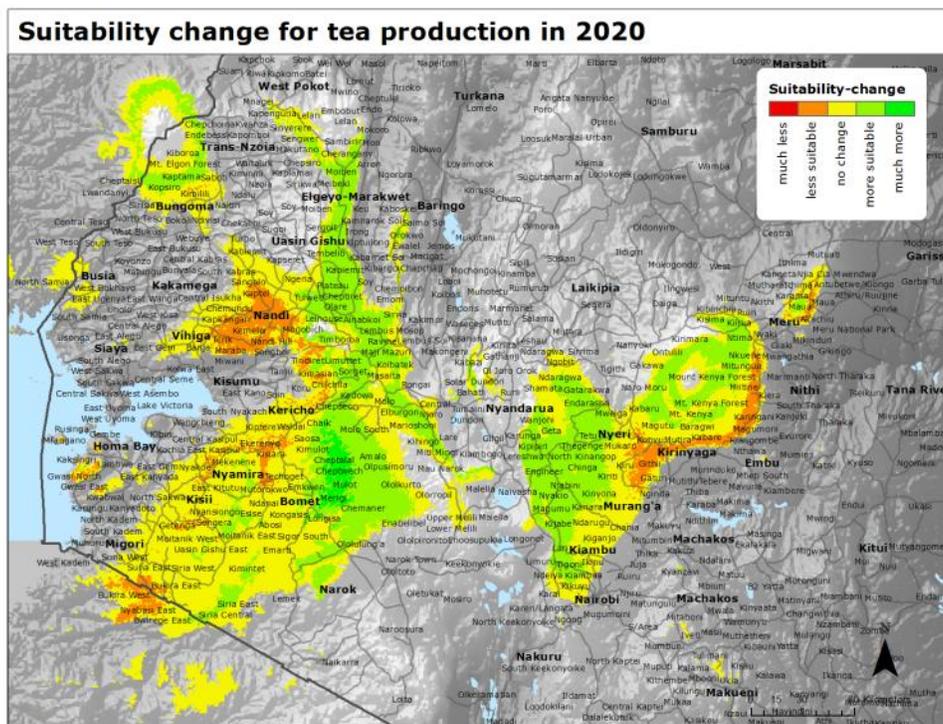
Figure 11: Suitability change for tea production in 2020.

While in the western area near Nandi the suitability of tea shows a slight decrease by 2020, some areas, especially in Central region and some parts of Rift valley are gaining suitability (Figure 11). In 2050, suitability of tea growing decreases quite seriously in the western parts (Figure 12). The average suitability of these areas decreases between 25 and 40%, whereas today they have suitability of 60 - 70%. Areas around Mount Kenya still remain on high suitability to climate in 2050. While there is a general shift to higher altitudes, those gaining areas increase suitability by around 15 to 20%. The most significant loss of suitability (up to -40%) can be observed in Nandi district. The measure of agreement of models predicting changes in the same direction as the average of all models at a given location is between 70% - 100% in tea growing areas (Figure 13).

Figure 12: Suitability change for tea production in 2050.

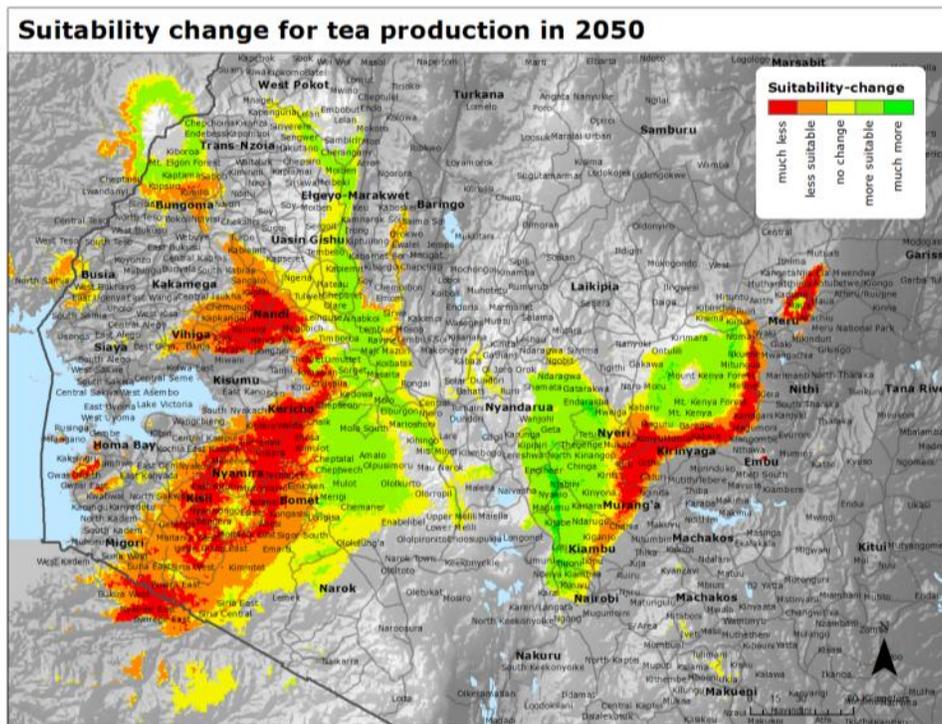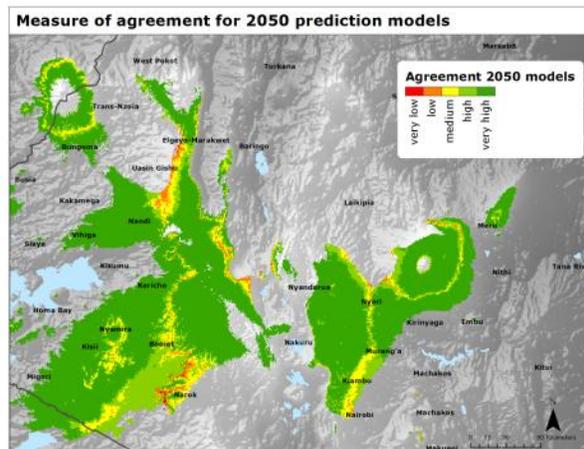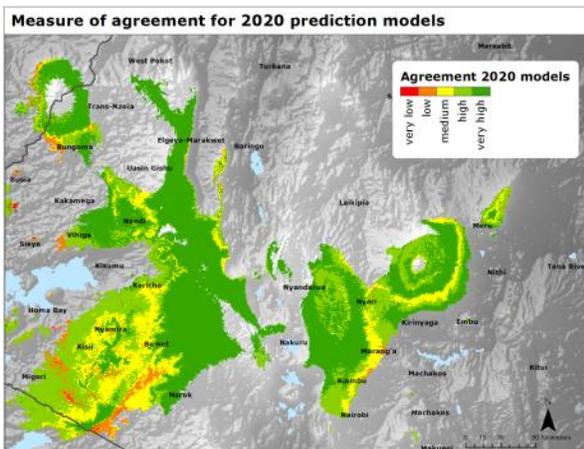Figure 13: Measure of agreement of models predicting changes in the same direction as the average of all models at a given location for 2020 and 2050.
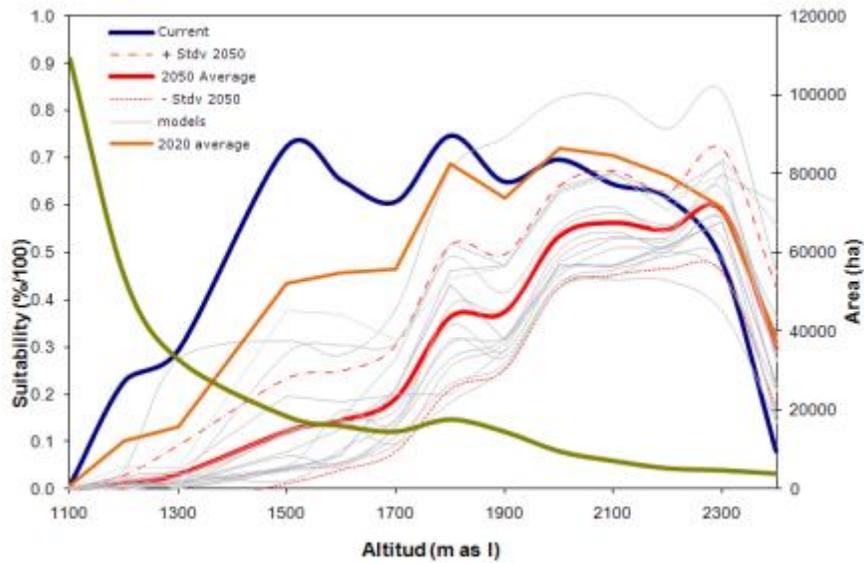
Figure 14: The relation between the suitability of areas for tea production and altitude for current climates, and predicted for 2020 and 2050 in Kenya.

With progressive climate change, areas at higher altitudes benefit on tea-suitability (Figure 14). Altitude was not used in the suitability modeling and is therefore independent of the other variables. Altitude is however very much correlated with temperature-related variables. The optimum tea-producing zone is currently at an altitude between 1500 and 2100 masl and will by 2050 increase to an altitude between 2000 and 2300 masl. Compared with today, by 2050 areas at altitudes between 1400 and 2000 masl will suffer the highest decrease in suitability and the areas around 2300 masl the highest increase in suitability (Figure 14).

8   Result III: Environmental factors which drive the suitability of tea

The regression analysis identifies primarily the bioclimatic variables related to precipitation increase and general increasing temperature as drivers of the predicted suitability shifts.

The increases of precipitation and min temperature during the cold season together with Isothermality (quantification of how large the day-to-night temperature oscillation is in comparison to the summer-to-winter oscillation) explain 97.5% of decreasing suitability for 2020.

The 45% of observed locations with increasing suitability for 2020 are influenced by increasing precipitation during the wet season and a general annual and precipitation increase (Table 1).

Table 1: Contribution of different bioclimatic variables to the predicted shift in suitability for tea in Kenya, between the present and the 2020s, separating locations with decreasing and increasing suitability[a]

Variable	Adjusted R2	R2 due to variable	% of total variability	Present mean	Change by 2020s
Locations with decreasing suitability (n=61, 55 % of all observations)					
BIO 19 – Precipitation of coldest quarter	0.6176	0.6176	76.4	295 mm	+ 31 mm
BIO 03 – Isothermality	0.7314	0.1138	14.1	85	- 2
BIO 06 – Min temperature of coldest month	0.7876	0.0562	7.0	10.0 °C	+ 1.0 °C
others	-	-	2.5		
Locations with constant or increasing suitability (n=50, 45 % of all observations)					
BIO 16 – Precipitation of wettest quarter	0.2897	0.1298	31.1	706 mm	+ 12 mm
BIO 12 – Annual precipitation	0.1042	0.1042	25.0	1620 mm	+ 41 mm
BIO 01 – Annual mean temperature	0.1577	0.0535	12.8	16.9 °C	+ 0.8 °C
BIO 17 – Precipitation of driest quarter	0.3759	0.0519	12.4	192 mm	+ 5 mm
BIO 19 – Precipitation of coldest quarter	0.4170	0.0411	9.9	263 mm	+ 1 mm
BIO 08 – Mean temperature of wettest quarter	0.3240	0.0343	8.2	17.4 °C	+ 0.7 °C
others	-	-	0.6		

[a]Variables explaining less than 4% of total variability are not listed.

The regression analysis for changes in suitability on observed sample points for 2050 describes temperature seasonality as main driving factor for negative suitability change (Table 2). Increasing precipitations explain 89.9% of positive suitability change for 22.5% of observed points.

Table 2: Contribution of different bioclimatic variables to the predicted shift in suitability for tea in Kenya, between the present and the 2050s, separating locations with decreasing and increasing suitability[a].

Variable	Adjusted R2	R2 due to variable	% of total variability	Present mean	Change by 2050s
Locations with decreasing suitability (n=86, 77.5% of all observations)					
BIO 04 – Temperature seasonality	0.3308	0.3308	55.1	680	- 20
BIO 16 – Precipitation of wettest quarter	0.3804	0.0496	8.3	605 mm	+ 24 mm
BIO 18 – Precipitation of warmest quarter	0.5497	0.0360	6.0	374 mm	+ 35 mm
BIO 03 – Isothermality	0.4153	0.0349	5.8	84.6	- 1.5
BIO 19 – Precipitation of coldest quarter	0.4726	0.0292	4.9	307 mm	+ 47 mm
BIO 09 – Mean temperature od friest quarter	0.4434	0.0281	4.7	18.7 °C	+ 2.1 °C
BIO 13 – Precipitation of wettest month	0.5003	0.0277	4.6	253 mm	+ 7 mm
others	-	-	10.6		
Locations with constant or increasing suitability (n=25, 22.5% of all observations)					
BIO 18 – Precipitation of warmest quarter	0.5459	0.5459	66.6	542 mm	+ 7 mm
BIO 12 – Annual precipitation	0.8194	0.1909	23.3	1635 mm	+ 69 mm
BIO 01 – Annual mean temperature	0.6285	0.0485	5.9	15.9 °C	+ 2.1°C
BIO 03 – Isothermality	0.5800	0.0341	4.2	79	- 1.2
others	-	-	0		

[a]Variables explaining less than 4% of total variability are not listed.

9 Result IV: Indications of adaptation strategies

9.a Identification of potential diversification strategies

To address potential diversification strategies for tea farms affected by progressive climate change on their tea production we identified six crops[1]:

- Maize
- Pea (pigeon variety)
- Cabbage

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[1] In this work just crops were analyzed. Beyond that, dairy cow and dairy goats are potential diversification enterprises for tea farmers in Kenya.

- Banana
- Passion fruit
- Coffee (Arabica and Robusta)

Because of a lack of detailed information from GPS ground data suitability of alternative crops, except coffee, were calculated using a mechanistic model based on the Ecocrop database. We improved the model by using existing knowledge of geographic crop distribution and calibrated the input-values on a regional scale. Suitability for coffee comes from previous CIAT work in Kenya, "Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector" (Laderach *et al.*, 2010), and was calculated same as tea by using the MaxEnt approach.

9.b Suitability of potential diversification crops
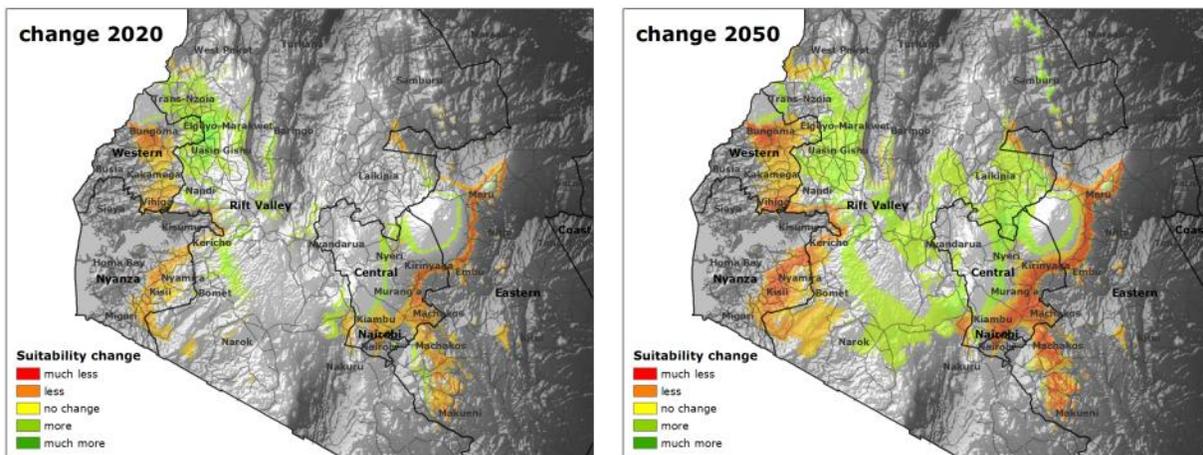
Suitability of Coffee (Arabica and Robusta)

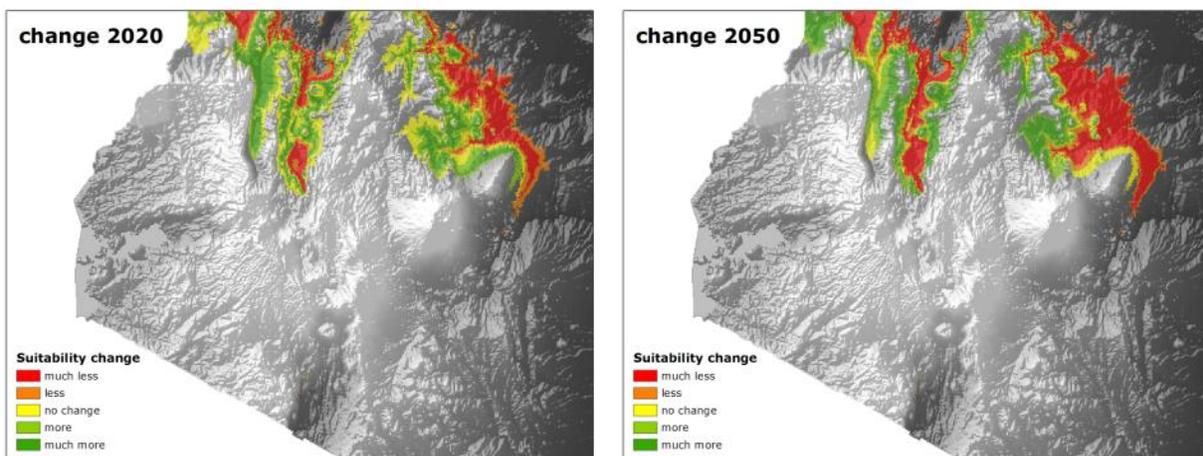Figure 15: Suitability change of Arabica coffee.

Figure 16: Suitability change of Robusta coffee.

Robusta coffee has its suitable areas in lower altitudes than tea and therefore would not be a diversification crop. Therefore we analyzed Arabica coffee.
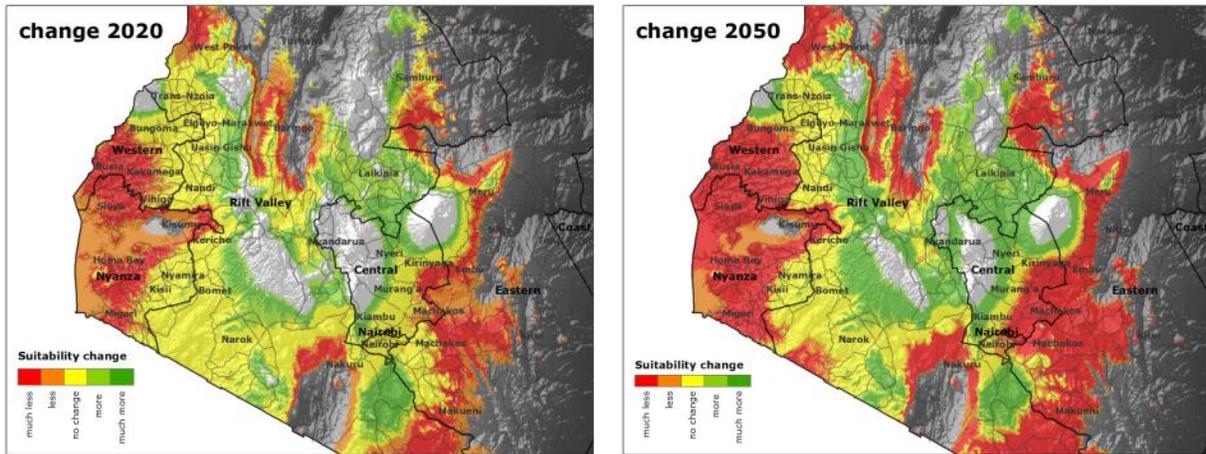
Suitability of Maize

Figure 17: Suitability change of maize.

While suitability of maize (Figure 16) and cabbage (Figure 18) remains constant, Arabica coffee is losing most of its suitability in the same areas as tea by 2050 (Figure 15). Pea performs quite well on predicted changes (Figure 17) in general but especially in tea-growing regions, whereas banana has its suitable areas in lower altitudes than tea (Figure 19) and results of increasing passion-fruit suitability-change match with areas where tea is losing its suitability (Figure 20).
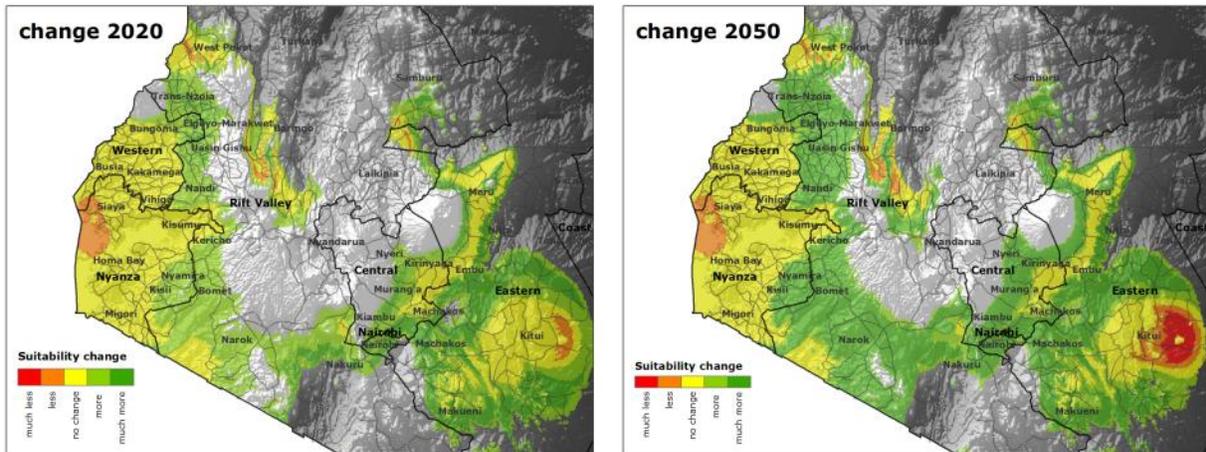
Suitability of Pea

Figure 18: Suitability change of pea.

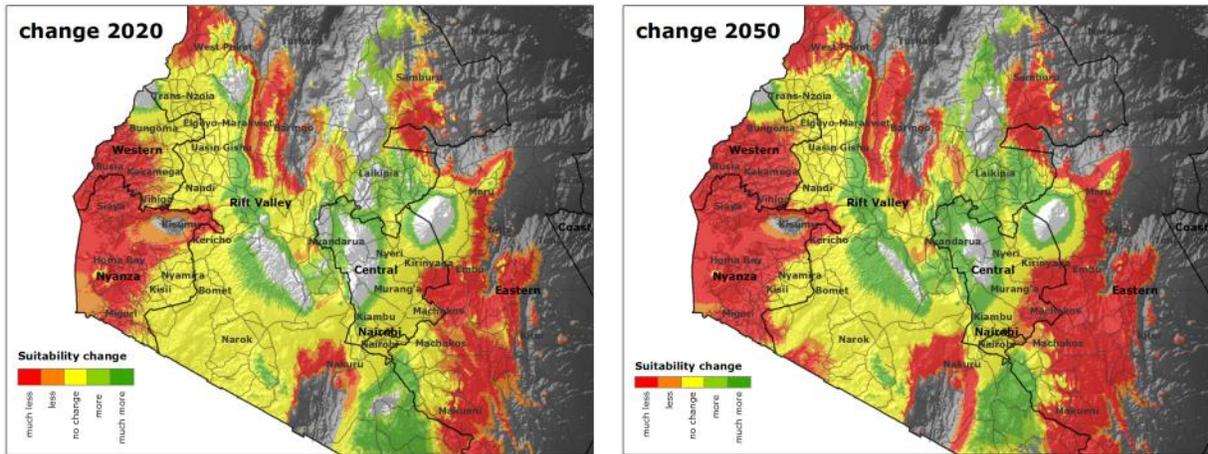## Suitability of Cabbage

Figure 19: Suitability change of cabbage.
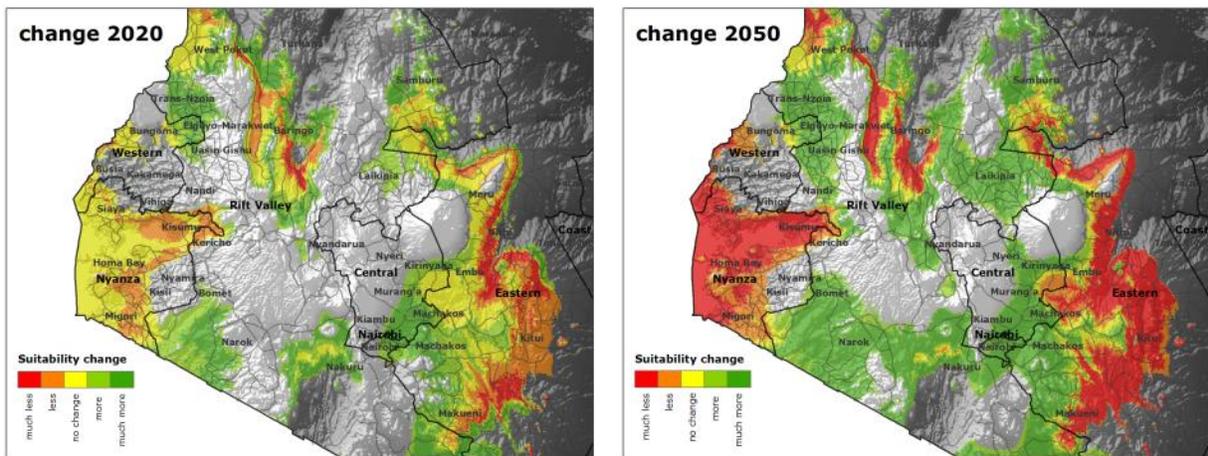
Suitability of Banana

Figure 20: Suitability change of banana.
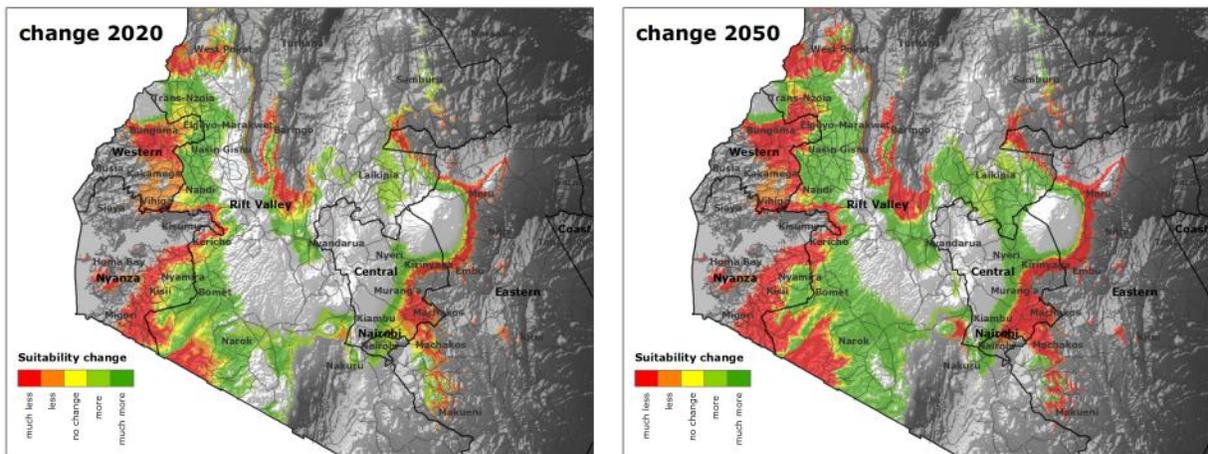
Suitability of Passion fruit

Figure 21: Suitability change of passion fruit.

Table 3: Comparison of suitability change of tea and diversification crops on 85 tea growing factories in Kenya

2020 suitability change	Tea	Coffee					Maize					Cabbage					Pea					Banana					Passion fruit				
much less	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
less suitable	12	-	-	90	10	-	-	-	100	-	-	-	-	100	-	-	-	-	90	10	-	-	-	-	-	-	-	-	20	40	40
no change	73	-	5	61	26	8	-	-	52	20	26	-	-	87	7	6	-	-	2	52	7	-	-	-	-	-	-	3	5	18	36
more suitable	15	-	38	39	15	8	-	-	15	38	38	-	-	62	23	15	-	-	-	23	-	-	-	-	-	-	-	-	-	15	8
much more	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

2050 suitability change	Tea	Coffee					Maize					Cabbage					Pea					Banana					Passion fruit				
much less	42	97	3	-	-	-	-	3	91	6	-	-	3	97	-	-	-	-	-	3	97	-	-	-	14	9	14	6	11	14	51
less suitable	21	94	6	-	-	-	6	-	50	33	11	6	-	94	-	-	-	-	6	-	94	-	-	-	28	-	-	6	-	11	78
no change	25	57	43	-	-	-	-	-	5	5	90	-	-	67	19	14	-	-	24	62	-	-	-	-	5	-	-	-	-	14	24
more suitable	12	10	70	20	-	-	-	-	-	20	80	-	-	40	-	60	-	-	-	40	-	-	-	-	-	-	-	-	-	-	10
much more	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 compares suitability change for tea growing factories and their potential for diversification into other crops. As mentioned above coffee (arabica) performs similar (even worse) to tea and would not be a good alternative crop to tea. While on 42% of all tea factory sites suitability of tea is predicted to be much less for 2050, on 97% of these sites suitability of coffee will be also much less, for more than 90% of these sites maize and cabbage will remain constant and pea will be much more suitable on 97% of this sites. Passion-fruit will be much more suitable on 51% of these sites and banana on 14% of these sites more suitable for 2050.
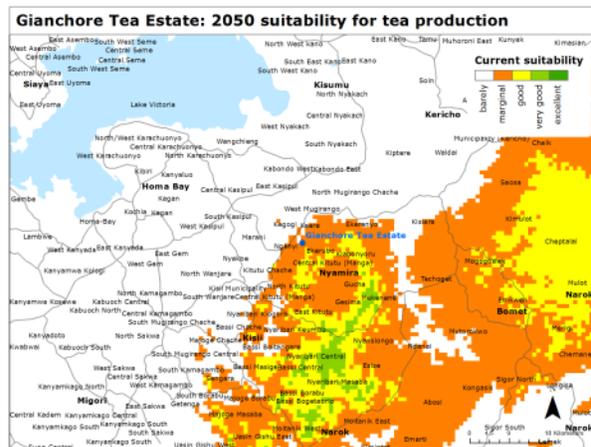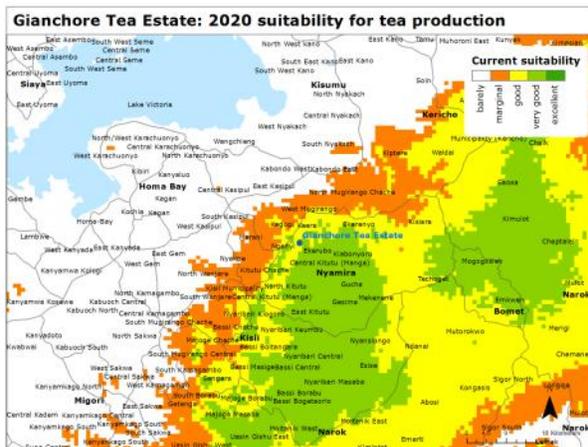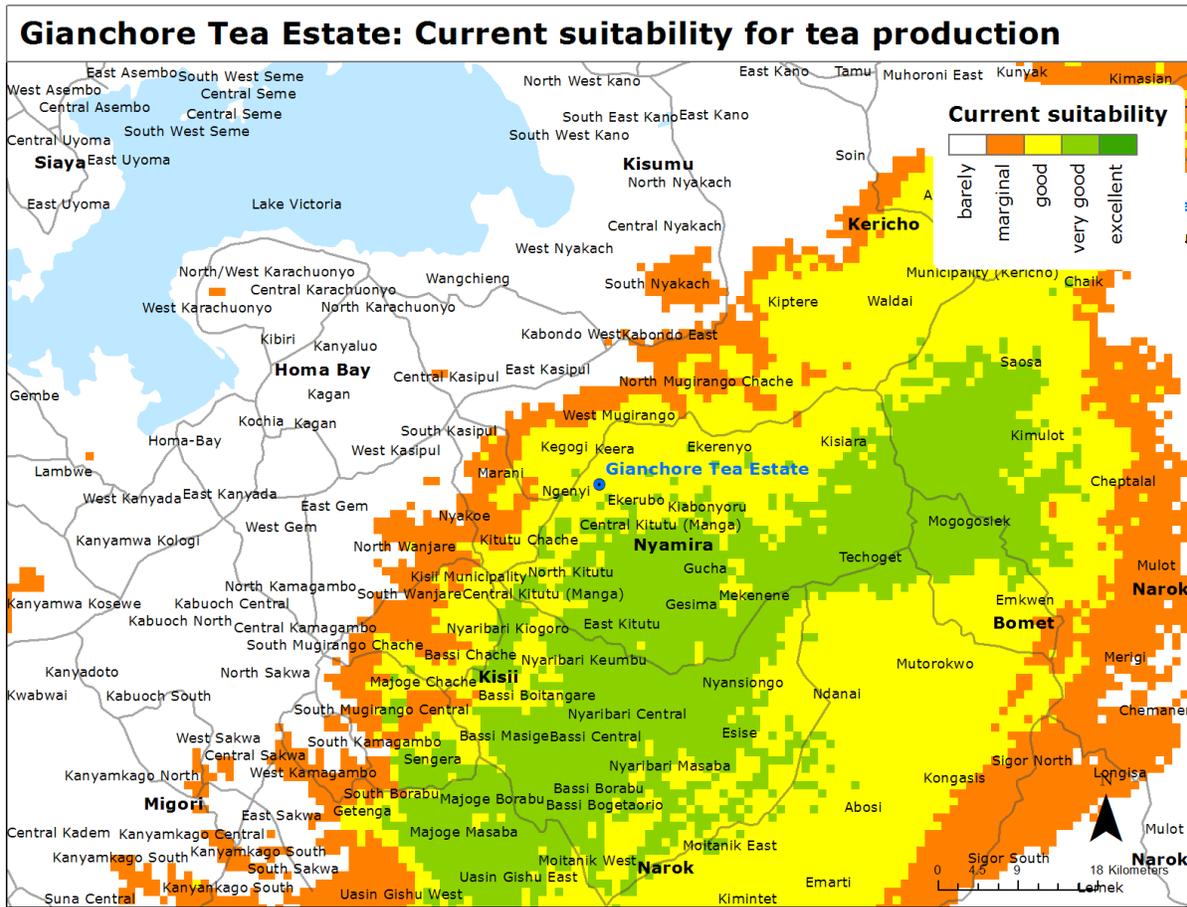
10 Conclusions

- In Kenya the yearly and monthly rainfall will increase and the yearly and monthly minimum and maximum temperatures will increase by 2020 and will continue to increase progressively by 2050.
- The implications are that the distribution of suitability within the current tea-growing areas in Kenya for tea production in general will decrease quite seriously by 2050.
- The optimum tea-producing zone is currently at an altitude between 1500 and 2100 masl and will by 2050 increase to an altitude between 2000 and 2300 masl.
- Compared with today, by 2050 areas at altitudes between 1400 and 2000 masl will suffer the highest decrease in suitability and the areas around 2300 masl the highest increase in suitability.
- A comparison of potential diversification crops recommended by the project shows that coffee performs similar to tea and would not be a good alternative crop. For more than 90% of these sites maize and cabbage will remain constant and pea will be much more suitable on 97% of these sites. Passion fruit will be much more suitable on 51% of these sites and banana will be more suitable on 14% of these sites for 2050.
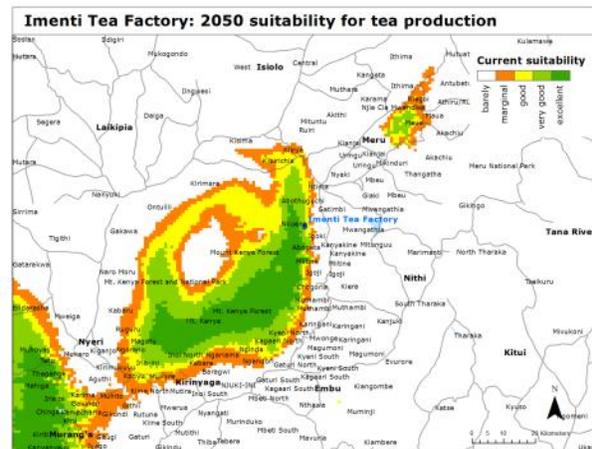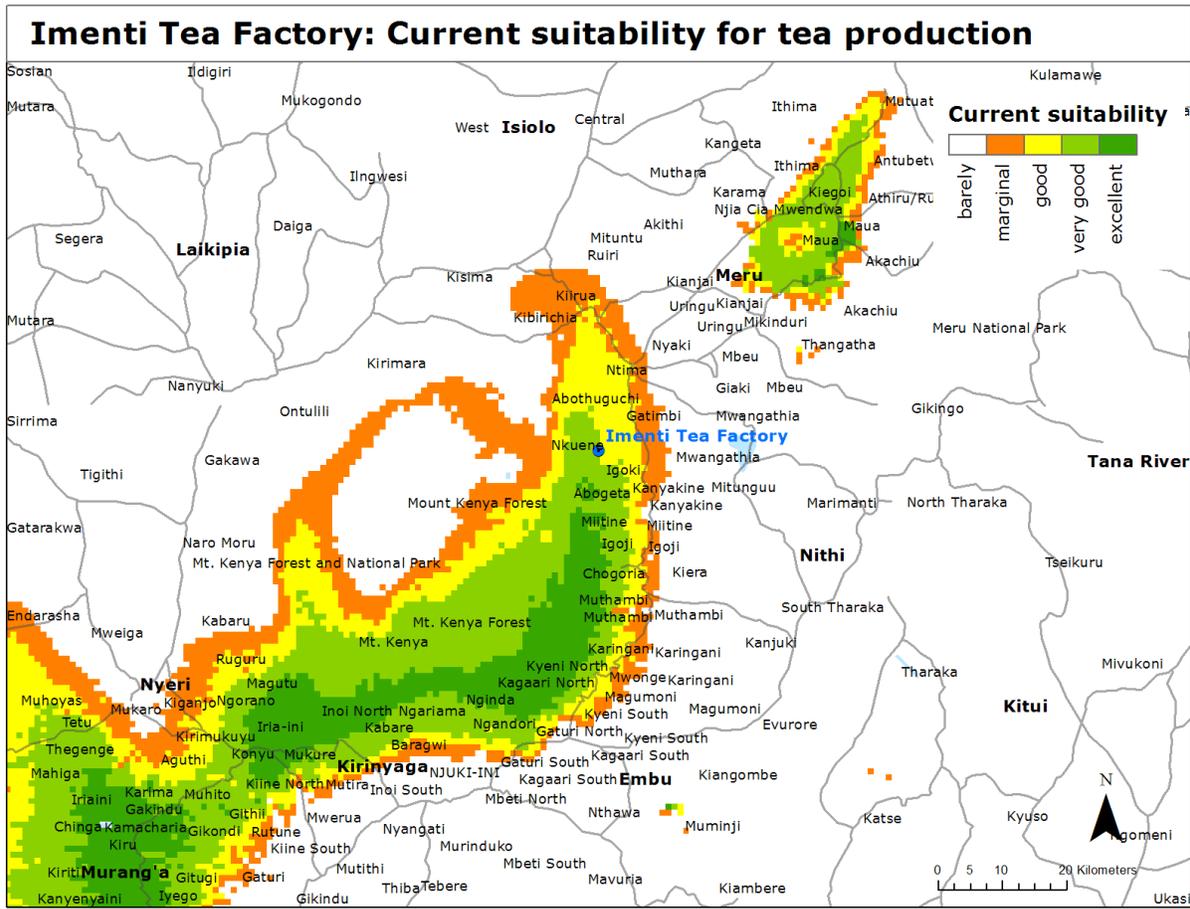
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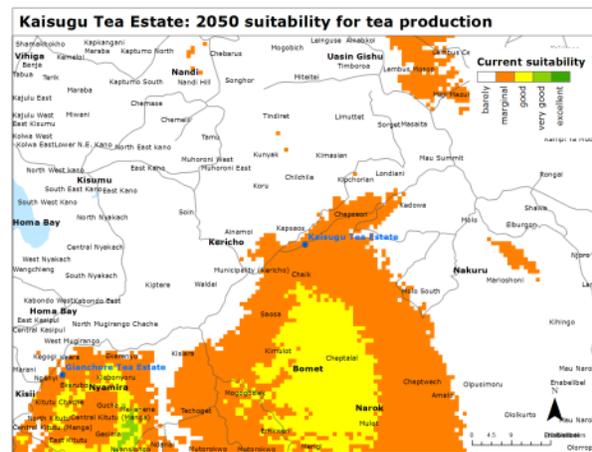Tukey J.W. (1977) Exploratory data analysis. Addison-Wesley Publishing Co., Reading, MA.

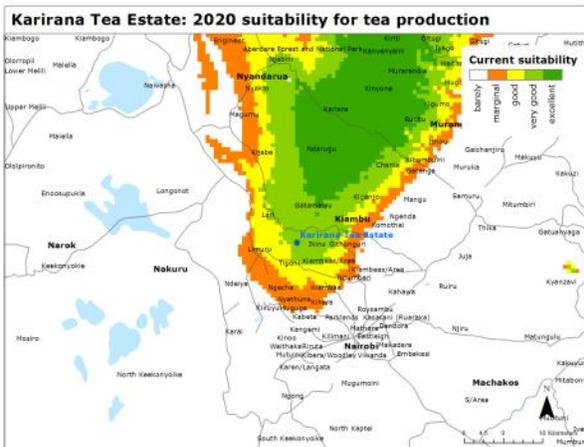## Annex I: Suitability maps of Gianchore Tea Estate

Gianchore Tea Estate: Current suitability for tea production

Gianchore Tea Estate: 2020 suitability for tea production

Gianchore Tea Estate: 2050 suitability for tea production

Annex II: Suitability maps of Imenti Tea Factory

Imenti Tea Factory: Current suitability for tea production

Imenti Tea Factory: 2020 suitability for tea production

Imenti Tea Factory: 2050 suitability for tea production
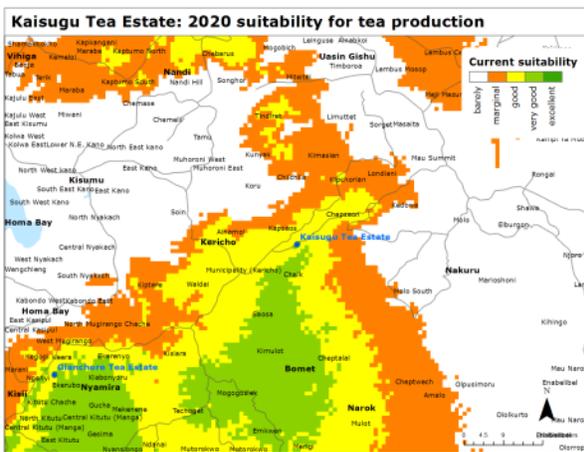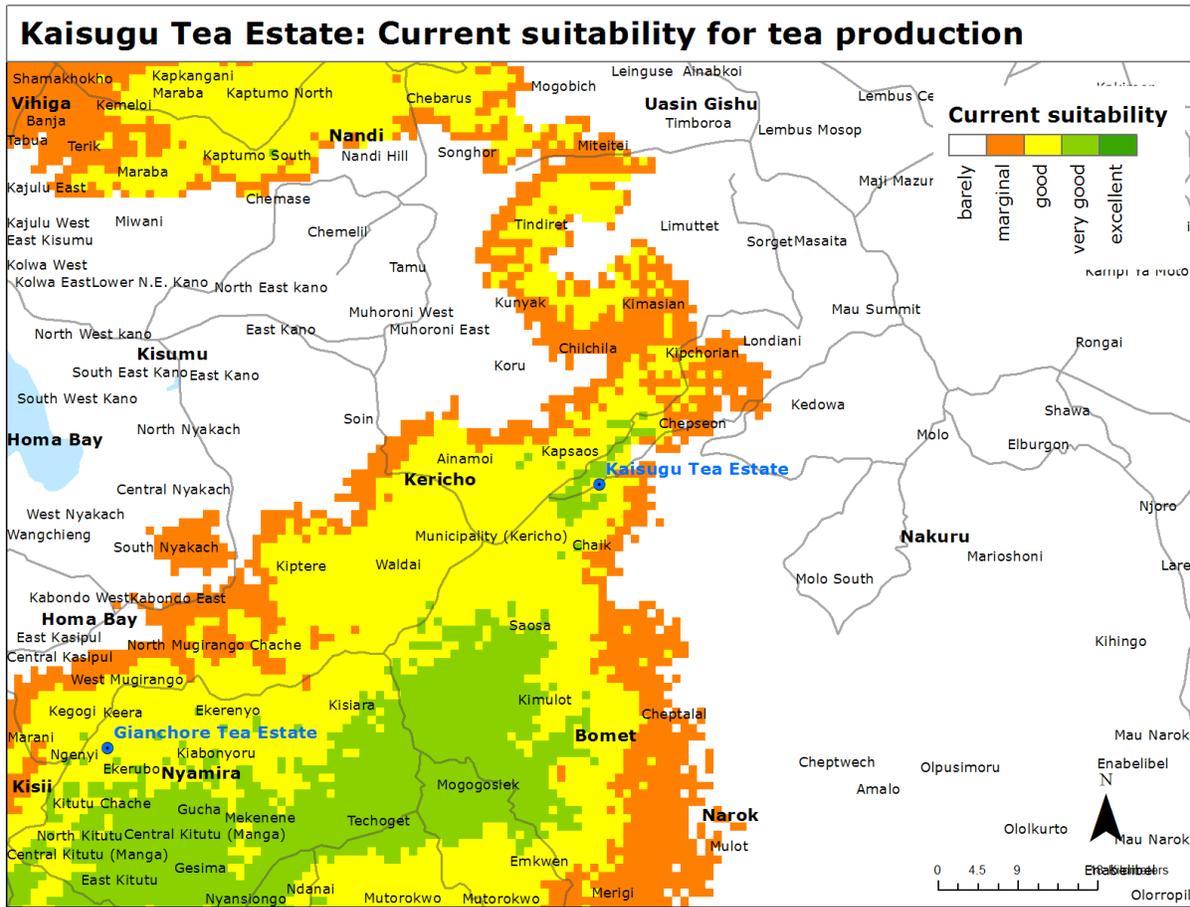
Annex IV: Suitability maps of Karirana Tea Estate

Karirana Tea Estate: Current suitability for tea production

Karirana Tea Estate: 2020 suitability for tea production

Karirana Tea Estate: 2050 suitability for tea production

Mudete Tea Factory: Current suitability for tea production

Mudete Tea Factory: 2020 suitability for tea production

Mudete Tea Factory: 2050 suitability for tea production