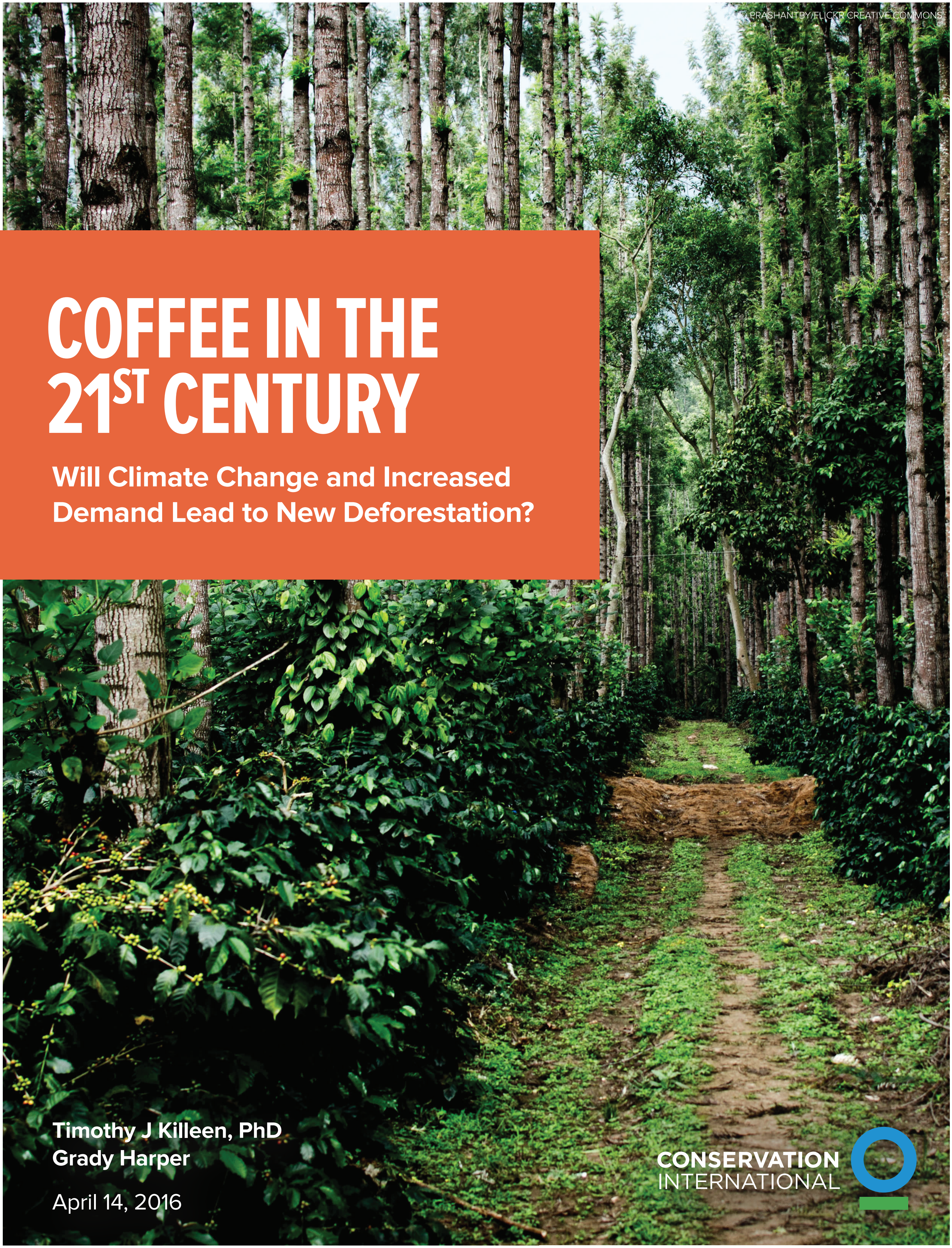

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# COFFEE IN THE 21ST CENTURY

## Will Climate Change and Increased Demand Lead to New Deforestation?

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CONSERVATION INTERNATIONAL

***Acknowledgments***

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***From the authors***

The authors would like to express our appreciation to Christian Bunn, Peter Laderach and Olivia Ovalle for the kind assistance with the spatial mapping data used in our studies, which is described in detail in their article: *A bitter cup: climate change profile of global production of Arabica and Robusta coffee (Climatic Change 129, 1-2 (2015): 89-101).* Similarly, we are indebted to Matt Hansen and his for the high-quality data made available by the global forest cover described in detail by their article: *High-resolution global maps of 21st-century forest cover change (Science 342, no. 6160 (2013): 850-853).* We thank Lee Hannah for putting us in contact with the right people and for convincing us that it is acceptable to cheat in golf. Finally, we salute the people of Finland for consuming more coffee than any other nation on the planet.

# Contents

## Executive Summary

***Component A* - The dimensions of future supply and demand:** The potential dimensions of future coffee supply chains were evaluated using supply and demand models based on differences in consumption (Low vs. High) and productivity as measured by yield (Low vs High). Projections to 2050 are based on historical trends between 1990 and 2010 documented by the International Coffee Organization (ICO). High consumption (HC) scenarios differ from low consumption (LC) scenarios by assuming that coffee consumption increases in traditional tea-drinking nations of East and South Asia, as well as in Sub-Saharan Africa, which experiences significant demographic growth post 2030. Low yield (LY) scenarios differ from high yield (HY) scenarios by assuming that elevated temperatures and modified precipitation regimes depress yields post 2030. The four basic model combinations (LCLY, LCHY, HCLY, HCHY) are evaluated as business-as-usual (BAU) scenarios, because they are based on the assumption that supply chains will favor coffee from producers from Brazil and Southeast Asia. Spatial footprints range from 99,000 $km^2$ (LCHY-BAU) to 202,000 $km^2$ (HCLY-BAU) by 2050. The most likely scenario (HCHY-BAU) was contrasted with an alternative scenario where coffee traders implement a diversified sourcing strategy (HCHY-DSS), which favors coffee growing regions in East Africa and Latin America. Due to lower yields in these regions, the projected global spatial footprint would increase from 160,000 $km^2$ (HCHY-BAU) to 210,000 $km^2$ (HCHY-DSS).

***Component B* - The impact of climate change on the geography of coffee production and risk from forest conversion:** The spatial footprints of current and future coffee production were compared to the total geographic area with the bioclimatic attributes required for coffee production. Coffee cultivation "suitability maps" were developed in a geographic information system(GIS) using current conditions for 19 bioclimatic attributes from the *WorldClim* database and a similar set of information derived from five global circulation models run for a 'representative concentration pathway' considered to be the most likely climate scenario in 2050 (*RCP6*). Currently, the spatial footprint of coffee cultivation (~100,000 $km^2$) is less than 2% of the total suitable area (5.9 million $km^2$) with bioclimatic attributes typical of current coffee plantation landscapes. By 2050, the potential demand for land under the HCHY-DSS scenario approximately doubles, while the total geographic area suitable for coffee cultivation decreases by ~50%. Nonetheless, the surplus of available land is still ten times greater than the projected cultivation area and, consequently, there should be no geographic constraint on future coffee production. However, a comparison of the suitability maps with a forest cover map derived from satellite images in 2010 show that approximately 60% of the area suitable for coffee production is covered by natural forest, a proportion which remains approximately the same in 2050. Globally, about 80% of suitable Robusta landscapes are covered by natural forest, while about 56% of Arabica landscapes are forested. Regionally, the risk from deforestation linked to both Arabica and Robusta cultivation is highest in the Andes and Southeast Asia, while Brazil and East Africa represent potential expansion areas with the lowest risk of deforestation.

## Background

Coffee is produced in more than seventy countries on five continents. There are two major cultivated species: Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*), each with a multitude of varieties adapted to a broad range of ecological and cultural conditions. Arabica represents 70% of global production, while Robusta represents about 30%. Traditionally, Arabica has been cultivated as "shade coffee" grown at higher elevations, while Robusta is "sun coffee" cultivated at lower elevations. There are exceptions, however, including Arabica varieties grown without shade at higher elevations and with shade at lower elevations, as well as Robusta varieties grown without shade at higher elevations. Overall, the trend is for eliminating shade from production strategies in order to maximize yields. In summary, the principal bioclimatic conditions can be summarized as follows:

- Arabica varieties have an optimum temperature range between 15° and 24° C; rainfall between 1500 mm and 2000 mm per annum and is typically cultivated at altitudes between 1000 and 2000 m (a.s.l.).
- Robusta varieties grow best in areas with a mean annual temperature between 22° to 26° C, requires abundant rainfall (~2,000 mm per annum), and grows best at altitudes between sea level to about 800 m (a.s.l.).

This environmental plasticity is a testament to the biological diversity within the genus *Coffea* and represents an insurance policy for future coffee production with respect to climate change. In spite of this inherent resiliency, the global coffee supply chain will suffer disruption, because existing varieties of both species are narrowly adapted to a specific set of environmental conditions. Adaptation will follow three general pathways:

1. Change cultural practices to alleviate the environmental stress of higher temperature (shade) and modified precipitation regimes (irrigation)
2. Manipulate the coffee genome to make varieties more resilient to high temperatures and drier (or wetter) climates
3. Implement integrated pest management strategies to limit the environmental stress caused by insects and plant pathogens.
4. Migrate production to areas with environmental conditions similar to current production zones.

The global trade in coffee is a two-stage process. Although some producing countries have a tradition of roasting coffee beans, approximately 90% of unroasted (green) beans are exported from tropical countries to Europe and the United States where they are blended, roasted and traded again as roasted beans or ground coffee. About 10% of this total is sold as soluble (instant) coffee.

The market for roasted coffee at the consumer level is segregated into two categories based on aroma and taste: Specialty Coffees (SC) and Mass Market (MM). The difference in quality is a function of the ecological condition of its cultivation origin, including soils, climate & altitude; the best coffees are Arabicas that are grown under shade at optimum altitudes, which vary according to latitude. Harvesting and post-harvest processing practices are also important: washed Arabica are very high quality, but dry processing technologies can produce good quality beans. Finally, management of the roasting and blending processes are essential for ensure quality control and are typically done at the end of the supply chain. Arabica dominates the market for SC blends, while both Arabica and Robusta beans are used to create MM blends and instant coffee.

## Potential Changes in Coffee Supply Chains

Robusta varieties may become more important as a source of both HQ and MM coffee, because that species is genetically adapted to the conditions of warmer lowland landscapes. Likewise, cultural treatments, like the use of shade and irrigation, may assist growers to cultivate Robusta in a warmer and drier environment. Because it is a lowland crop, its potential cultivation is not particularly constrained by any geographic area, at least within the tropics.

Vietnam is the currently the largest producer of Robusta coffee beans, followed by Brazil and Indonesia. Vietnam's dominance is relatively recent, having grown approximately 4-fold over the last twenty years. Yields are high and are linked to the use of technology; nonetheless, the sector is dominated by smallholders, who continue to rely on manual harvest of beans. Producers in Indonesia, particularly in lowland Sumatra, are also an important and growing source of Robusta beans. In Brazil, Robusta is grown in the North and on smallholder plantations in Rondônia.

Supplies of Arabica may be constrained in the future, because that species is more narrowly adapted to the cooler temperatures of mountain landscapes. Migration to higher altitudes is a limited option, because the spatial area available for cultivation is inversely correlated with altitude. Moreover, this spatial constraint will be augmented by resistance on the part of society to allow deforestation in remnant montane forests that provide ecosystem services via watershed protection.

Pressure to curtail the migration of Arabica plantations will be offset by increased market demand for espresso and other high-end coffee products, which is forecast to grow as more consumers become familiar with the superior taste of SC brands and denominations, particularly in emerging markets such as China and India that are traditionally tea-consuming countries. As such, the potential increase in demand for Arabica represents an extra deforestation threat in addition to altitudinal shifts caused by a warmer climate.

In spite of the challenges that face traditional producers of Arabica in many parts of Central America and the Andes, the world's largest producer of Arabica coffee, Brazil, has transformed its production paradigm over the last two decades. Large-scale producers have developed varieties adapted to full sun with significant increases in productivity on a per hectare basis (yield), while developing mechanical harvesting technologies that have greatly reduced the cost of harvesting and processing beans. Many Colombia producers have likewise adopted full sun Arabica production.

In this analysis, models are used to envision different potential configurations of coffee supply chains in the 21$^{st}$ Century. In Section A, we evaluate how changes in demographics and behavior impact the demand for coffee and compare scenarios that vary with respect to the geographic distribution of supply chains. In the second section, we evaluate the impact of global warming on the geography of coffee production and evaluate whether there will be enough coffee-suitable land available to meet demand. Finally, we compare current and future coffee production geographies with natural forest cover to evaluate the potential risk of forest conversion caused by the expansion or displacement of coffee production.

## Component A: The Dimensions of Future Supply and Demand

A methodological approach was devised to evaluate the potential growth of coffee supply chains in the context of supply and demand, which will be determined by future consumption (High vs. Low) and future productivity as measured by yield (High vs. Low). The four scenarios can be logically organized according to a 2 X 2 contingency table.

| Models | Low Consumption (LC) | High Consumption (HC) |
|---|---|---|
| Low Yield (LY) | LCLY | HCLY |
| High Yield (HY) | LCHY | HCHY |

All four can be considered BAU scenarios because it is difficult to predict consumption, which is dependent upon human behavior and economic growth and yield, which is dependent on biology, technology and the impact of climate change. Moreover, the four future scenarios y qualify as BAU scenarios because the model incorporates no changes in the geographic source of the commodities being evaluated. In essence, the four BAU models provide an objective visualization of the range of potential supply chain that may prevail in the future.

The model essentially flows through the following stages:

1. Document historical trends for consumption and production at the global scale, stratified for major economic and cultural regions.
2. Apply factors that project consumption per capita under low consumption (LC) and high consumption (HC) regimes for each region.
3. Incorporate the impact of future demographic growth on global and regional consumption.
4. Project future production based on historical patterns and projected demand forecast by the consumption models.
5. Develop model components with factors that forecast future supply under low yield (LY) and high yield (HY) production systems.
6. Project potential land use under geographic scenarios that vary according to where coffee is sourced.

***<u>Sources of Data:</u>***

Data on production and trade for individual countries was obtained from the International Coffee Organization[1] and converted from 60 pound (lb) bags to metric tons for: (1) production, (2) exports, (3) re-exports, and (4) imports, as well as (5) non-member exports and (6) non-member imports.

Data on consumption was based on the formula:

*consumption = (production + imports) – (exports + re-exports)*

[1] International Coffee Organization: http://www.ico.org/trade_statistics.asp

Data on historical yield is based on the parameter "area harvested" reported to (or estimated by) FAOSTAT,[2] which provides similar but slightly different values on production; consequently, national yield values were calculate based on the following formula:

*yield = [(mean yield FAOSTAT) + (ICO production /FAOSTAT area)]/2*

Regional values for mean yield are based on the sum of production values divided by the total regional area under cultivation. The FAOSTAT values were used because that database includes estimates of area under cultivation, information which is lacking in the ICO database. Differences between the two data sources are reconciled by calculating mean yield using different production values divided by the same area under cultivation.

***Time Scale:***

Mean values were calculated for five year intervals and reported as: 1995 (1990-1994), 2000 (1995-1999), 2005 (2000-2004), 2010 (2005-2009), and 2015 (2010-2014). Projections were made for each country at 10 year intervals until 2050.

***Stratification:***

Both historical data and future projections were summarized for the major geographic regions and reorganized into the regions used in the analysis:

| Consumption | Production |
|---|---|
| • European Union | • Brazil+ |
| • North America | • Southeast Asia |
| • Latin America | • Central America |
| • East Asia | • Andes |
| • Middle East & North Africa | • East Africa |
| • Eastern Europe | • South Asia |
| • Southeast Asia | • Central Africa |
| • Sub Saharan Africa | • West Africa |
| • South Asia | • Caribbean |
| • Oceania | • Oceania |
| • Central Asia | |

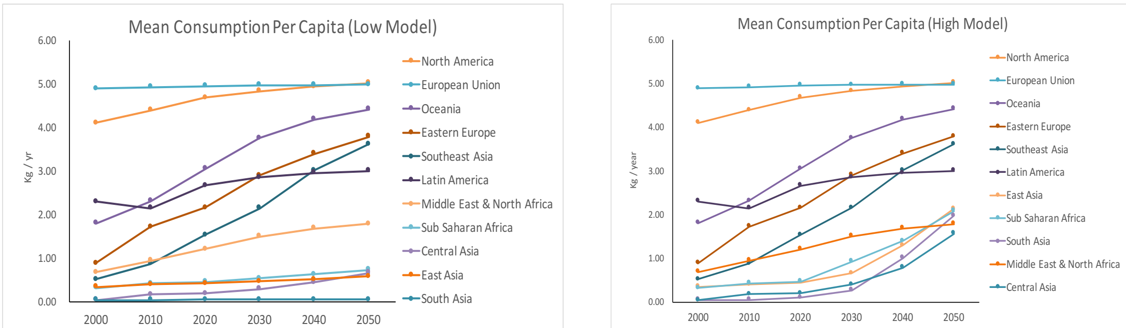
*Note: Brazil includes Paraguay and the Guianas, Southeast Asia includes Indonesia, and Central America includes Mexico.*

## Model Components and Outputs

***Consumption per capita*** per year is based on historical trends for each country and future growth in consumption is contingent on a factor based on whether a region is a coffee producer or not, and the historical preference for tea versus coffee. The factors are weighted so that emerging and developing economies enjoy greater growth in coffee consumption, while advanced economies are assumed to be near the maximum per capita consumption (see below).

2 FAOSTAT: http://faostat3.fao.org/home/E

*Consumption per capita*




The Low Model (LC) component projects recent historical consumption into the future, according to the following rules:

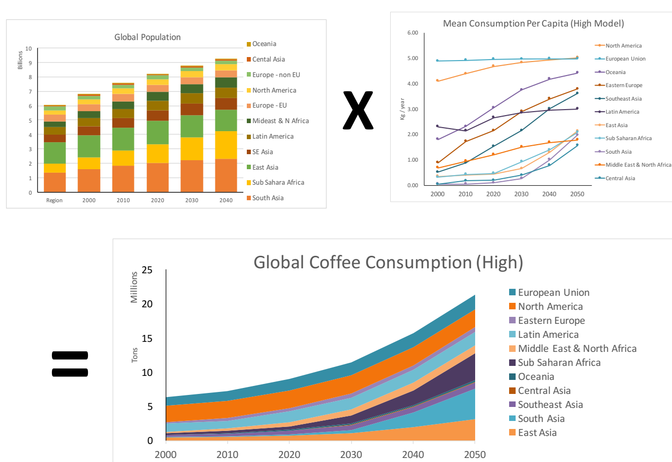
- if per capita consumption > than 4 kg/yr then growth rates fall 50% each decade
- if per capita consumption < 4 but > 2 kg/yr then growth rates fall by 50% in last two decades
- if per capita consumption < 2 but > 1 kg/yr then growth rates are reduced by 50% in last decade
- if per capita consumption < 1 kg/yr then growth rates are constant over all decades

The High Model (HC) component projects recent historical consumption into the future, according to the same rules – except:

- if per capita consumption < 1 kg/yr then growth rates are doubled.

Essentially, the LC scenario assumes that tea drinking nations and Sub Saharan Africa do not change habits, while HC scenario assumes that coffee consumption grows at significantly higher rates in tea drinking nations and Sub Saharan Africa

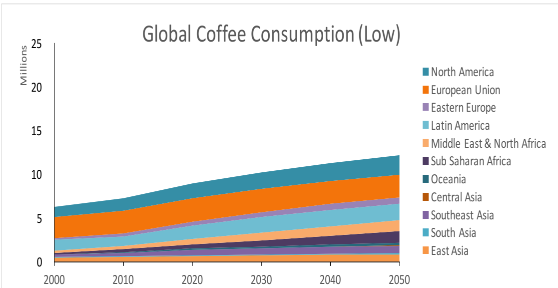
***Global Coffee Consumption*** is calculated by multiplying per capita consumption by the projected population, stratified by region from 2010 to 2050, as portrayed for the High Consumption(HC) example below:

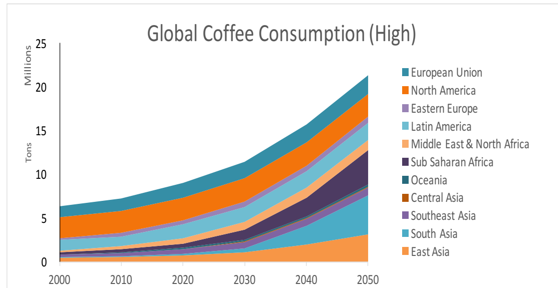


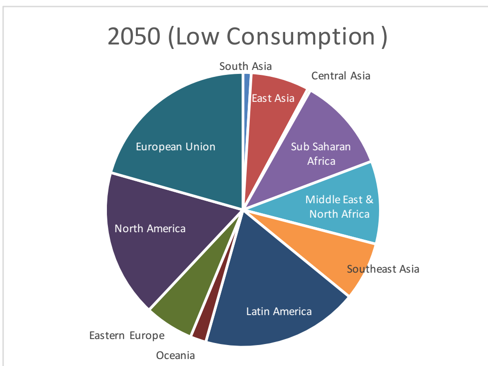

Consumption in the EU and North America are assumed to be stable, but their proportional share of global consumption is radically reduced in the HC scenario due to expansion in demand from East Asia, South Asia and Sub Saharan Africa, particularly after 2030. Demand for coffee increases by 50% under the LC scenario and by 163% under the HC scenario. The difference between the LC and HC models is almost 10 million tons per year by 2050 (12 Mt versus 21 Mt); for comparison, consumption in 2015 is projected to be 8.1 Mt.

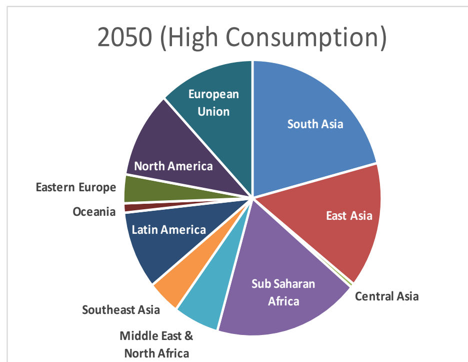
Projected demand is particularly large after 2030 when the demographic growth in Sub Saharan Africa and increased consumption in South Asia becomes more pronounced. Coffee consumption has been growing at double digit rates in China and India over the last decade, so the HC scenario is a realistic scenario.

*Global Coffee Consumption under LC and HC Scenarios*



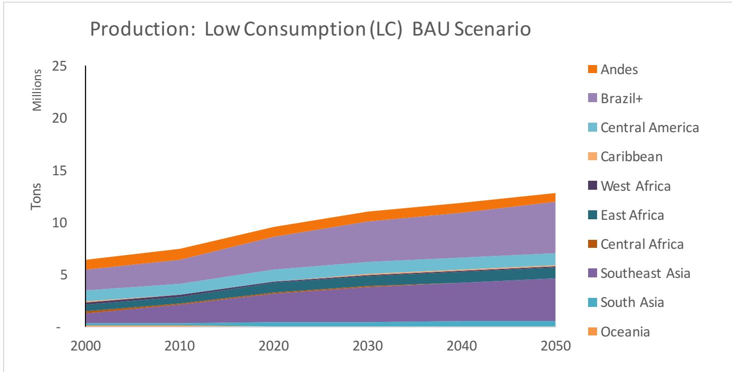



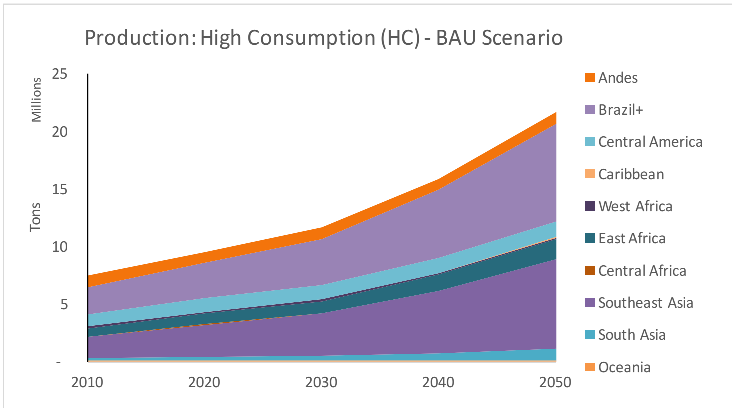

***<u>Estimated Global Coffee Production</u>*** was derived from the consumption curves to generate modeled estimates of annual demand that would be matched by production, which was allocated among geographic regions based on trends established over the last 20 years (see next page). As such, both the LC and HC production scenarios are considered BAU scenarios, because both project current market share into the future. These model scenarios assume the majority of coffee supply will originate in Brazil (32% of global market share) and Southeast Asia (27% of global market share).

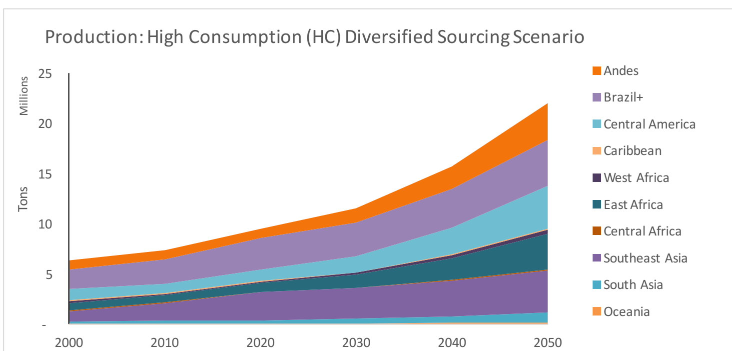
Growth in production in Vietnam has radically changed global supply chains since 1990, increasing from less than 3% to more than 17% of global production. Some analysts question country's capacity to increase production and Vietnam may not maintain market share under the HC scenario. However, other countries in Southeast Asia could copy the Vietnamese Robusta production model, particularly Indonesia which has a well developed coffee sector that includes both Robusta and Arabica growers.

In contrast, the Diversified Sourcing Scenarios (see bottom tier) show how supply chains would evolve if traders organized their supply chains to ensure that traditional coffee producers in other regions also increase market share. The top two graphics envision different levels of coffee consumption, but similar sourcing scenarios, while the bottom two graphics show the same level of global production but allocate that production to different geographies.

*A Comparison of Three Different Production Scenarios*



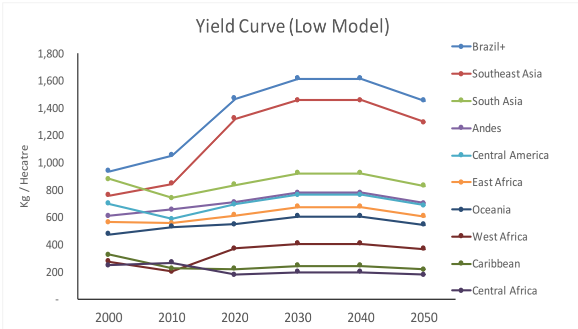



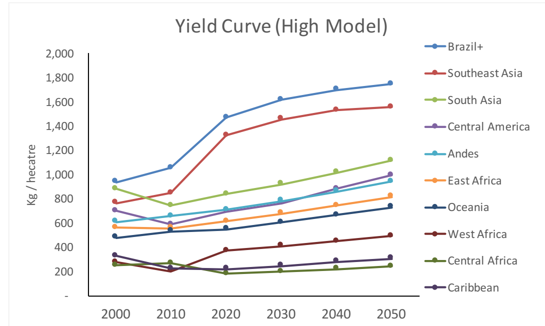

***Yield Curves*** are based on historical trends of mean annual increases in yield documented over the last two decades. These are summarized for each of the major producing regions and are based on the total regional volume of coffee produced and total regional area under cultivation.

The High Yield (HY) model assumes that agronomists and geneticists will be able maintain historical rates of yield growth in spite of any potential impacts from climate change. Brazil+ and Southeast Asia were assigned annual rates of 2% between 2010 and 2020 (versus historical rates of 4 - 6% between 1990 and 2015). However, rates of growth in yield are reduced by 50% per decade afterwards for both regions, based on the assumption that producers are approaching the maximum potential yield of both Robusta (Vietnam) and Arabica (Brazil). All other regions were assigned annual rates of growth for yield growth of 1% between 2020 and 2050; however, no region or country is assumed to attain the yields currently enjoyed by Brazilian and Vietnamese coffee farmers.

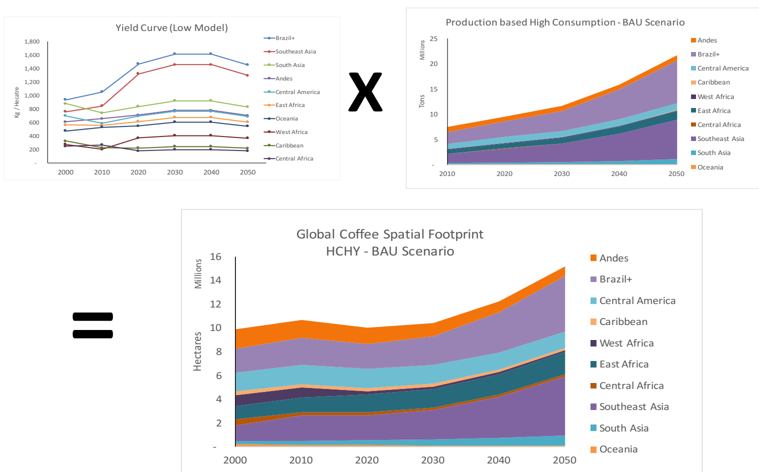
The Low Yield (LY) model is based on the same historical data and similar rates of yield improvement until 2030, but assumes that climate change negatively impacts yields after 2030, causing yield growth to stagnate by 2040 and decrease by 1% annually between 2040 and 2050 (see below)

*Yield Curves for Coffee*



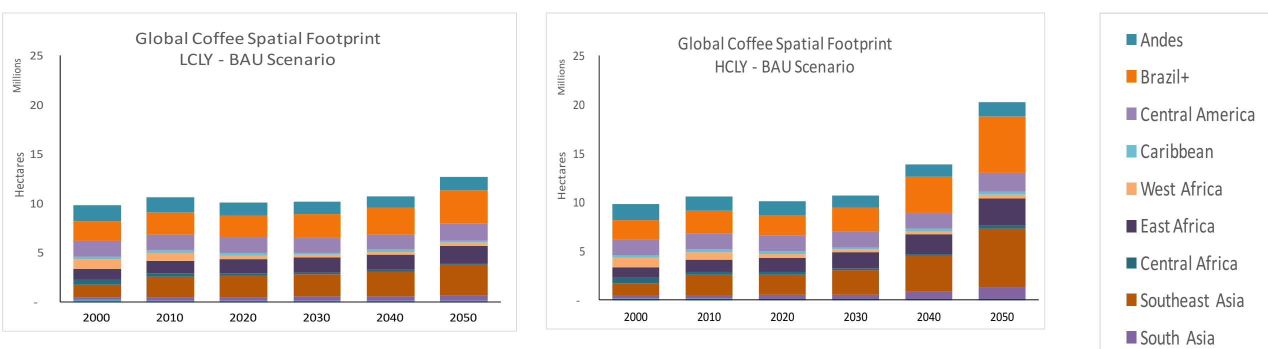



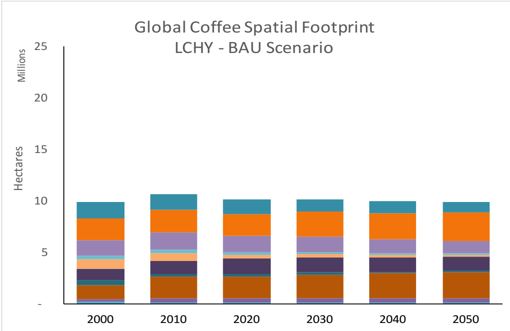

***Spatial Footprints*** *are* calculated by multiplying the yield curve by the production curve, both of which are stratified by region from 2010 to 2050, as portrayed graphically for the Low Yield (LY) and the High Consumption(HC) models below:

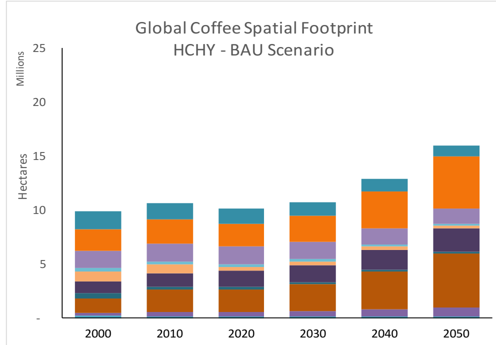



The two consumption models (LC and HC) are thus combined with the two yield models (LY and HY) to generate four BAU scenarios, which assume that supply chains of the future will follow sourcing patterns of the recent past.

*The Spatial Footprint of four BAU scenarios for Coffee*





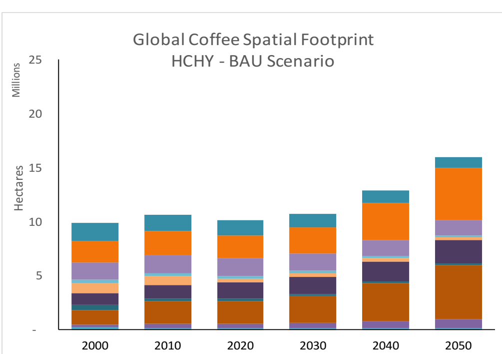



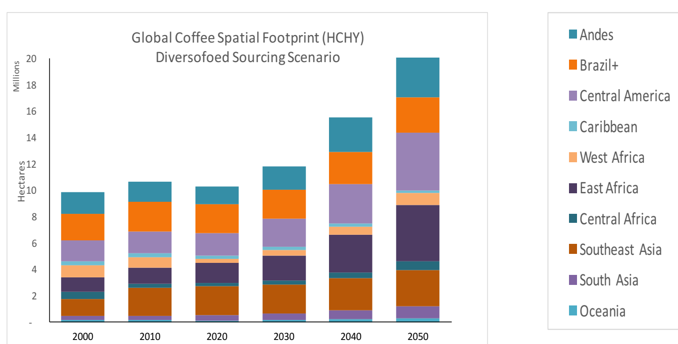

The LCHY-BAU scenario would allow the coffee sector to maintain an approximately equivalent spatial footprint, while a LCLY-BAU scenario would require a moderately larger footprint. Both the HCLY-BAU and HCHY-BAU scenarios require significant expansion of coffee plantations; in both cases, this would require about 65,000 hectares of increased production each year between 2020 and 2030. By way of comparison, Costa Rica has about 150,000 hectares of plantations currently in production. Post 2030 when projected consumption increases dramatically, the differences in the two yield models lead to very different spatial footprints:

- The HCLY-BAU model would require about 310,00 hectares per year by 2035 and almost 600,000 hectares per year by 2050
- The HCHY-BAU model would require about 210,00 hectares per year by 2035 and almost 310,000 hectares per year by 2050

To meet future demands under a HCHY-BAU scenario, Brazil would need to double the area under coffee cultivation from about two million hectares to almost five million hectares by 2050. Similarly, both Vietnam and Indonesia would need to approximately double their coffee plantations by 2050 under a HCHY-BAU scenario, or quadruple plantations under a HCLY-BAU scenario. The spatial footprint of coffee production is dramatically different when based on a Diversified Sourcing Scenario (DSS), because it assumes that coffee companies choose to source coffee stocks from all of the major coffee production regions – rather than concentrating their supply in the two regions that have enjoyed the greatest productivity growth over the last two decades (see next page).

*Comparison of HCHY-BAU scenarios HCHY-DSS*



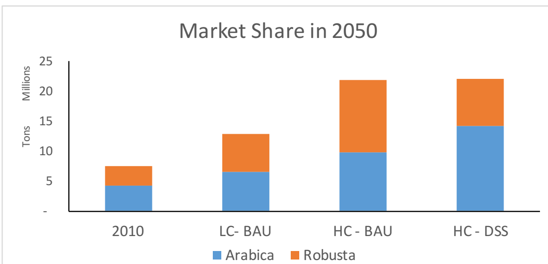



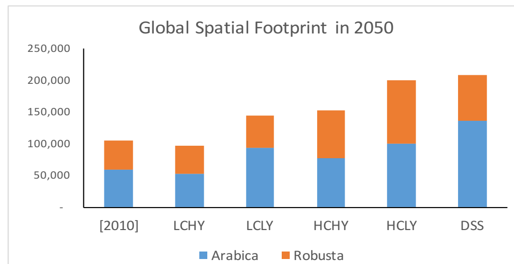

In the HCHY-DSS scenario the total spatial footprint for global coffee production is about 36% greater than the HCHY-BAU Scenario, while it would about 5% greater than the HCLY-BAU scenario. A geographically diversified supply chain would provide resilience to global supply chains and protect consumers from climatic disruptions in Brazil and Southeast Asia. More importantly, geographical diversification would ensure that coffee provides social and economic benefits to hundreds of thousands of small farmers in other producing regions.

## Arabica versus Robusta

The relative proportion of Arabica versus Robusta coffee has changed gradually over the last two decades with an increase in Robusta production, largely due to expansion of Robusta production in Vietnam. Under the BAU scenarios, the relative proportion of the two coffee species remains approximately the same after 2020, with a slight increase in the market share of Robusta. In large part, future increases in Robusta production in Southeast Asia are matched by future increases in Arabica production in Brazil; however, since Brazil also produces Robusta, the total market share of Robusta species continues to expand. This is not the case, however, in the DSS scenario. In this scenario, the relative market share of Arabica is increased, because production is allocated to traditional coffee growing countries in the Andes, Central America and East Africa. Because projected yields are assumed to smaller in these regions, the global spatial footprint of Arabica likewise increases, reversing the trend of previous decades.

*Robusta versus Arabica*




## Component B. The Impact of Climate Change on the Geography of coffee Production and the Risk from Forest Conversion

It is well known that the cultivation of Arabica coffee is limited to cooler montane regions of the tropics. Robusta is more tolerant of heat, but retains an upper temperature limit that likewise restricts its growth from the warmest regions of the humid tropics; it is also not well adapted to prolonged dry seasons.[3] Consequently, both species will be impacted by climate change. Assuming that plant breeders cannot develop new varieties adapted to warmer and more unstable climates, the spatial distribution of coffee cultivation will be displaced to areas that maintain the optimum climatic conditions. As such, the modeling framework used in this analysis assumes that landscapes suitable for coffee cultivation under current bioclimatic conditions will be similar to landscapes suitable for coffee cultivation in future decades.

The climatic conditions characteristic of the current plantation landscapes species were identified by Bunn *et al* (2015)[4] and are based on 19 bioclimatic variables from the *WorldClim* dataset.[5] In that study, these parameters where used to map the relative suitability of tropical regions for the cultivation of both Arabica and Robusta under current conditions. Subsequently, the same suite of bioclimatic attributes were used to identify the potentially suitable cultivation landscapes based on the same bioclimatic parameters derived from five global circulation models (GCMs) run for the

[3] DaMatta, Fábio M., and José D. Cochicho Ramalho. "Impacts of drought and temperature stress on coffee physiology and production: a review." Brazilian Journal of Plant Physiology 18.1 (2006): 55-81.

[4] Bunn, C., P. Läderach, O. Ovalle, and D. Kirschke. 2014. "A bitter cup: Climate Change profile of global Arabica and Robusta production." In *Proceedings of the 25th International Conference on Coffee Science*. 25th International Conference on Coffee Science. Armenia, Colombia. http://link.springer.com/article/10.1007/s10584-014-1306-x

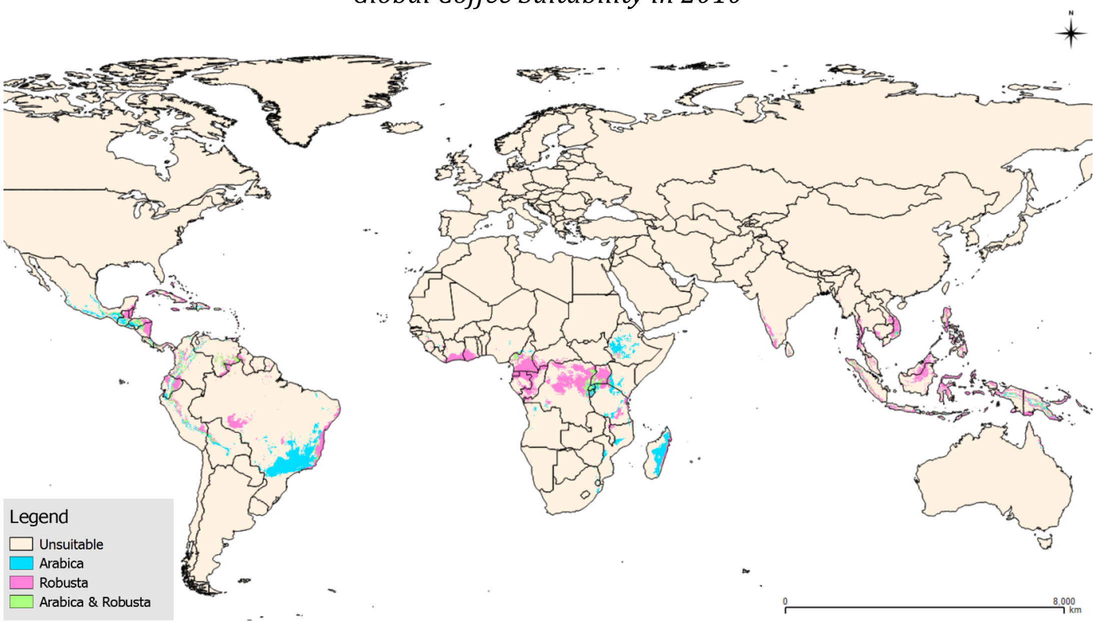
[5] Hijmans, R. J., S. Cameron, J. Parra, P. Jones, A. Jarvis, and K. Richardson. "WorldClim." University of California, Berkeley (2008). (http://www.worldclim.org/

representative concentration pathway 6 (RCP6)[6] in 2050 (see next page).

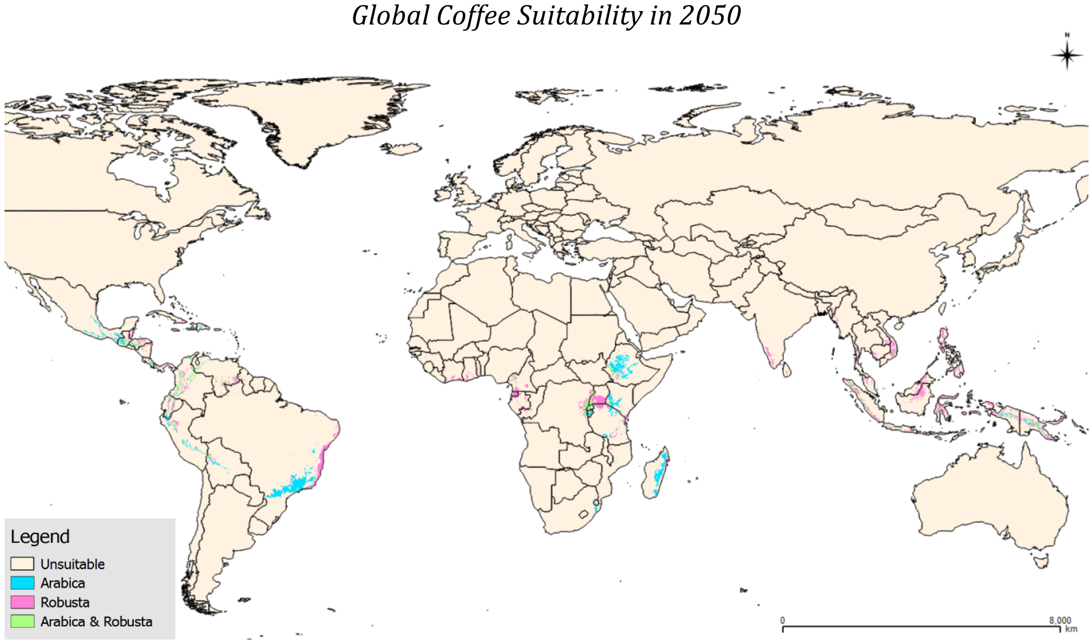
The analysis forecasts an approximately 50% reduction in the area suitable for coffee cultivation (see next page), which will reduce the areas suitable for Robusta cultivation to a much greater extent, when compared to potential Arabica cultivation areas. This was not an expected outcome and may be an artifact of the modeling framework that has overly constrained the tolerance of Robusta to increase temperature or drought stress that might be managed via management practices or the ability of plant breeders to increase the heat tolerance of new coffee cultivars.

[6] *GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROCESM-CHEM, and NorESM1-M,* from Stocker, Thomas, Qin Dahe, Gian-Kasper Plattner, Melinda Tignor, and Pauline Midgley. "IPCC expert meeting on assessing and combining multi model climate projections." *Boulder, Colorado, USA* (2010): 25-27.

*Global Coffee Suitability in 2010*



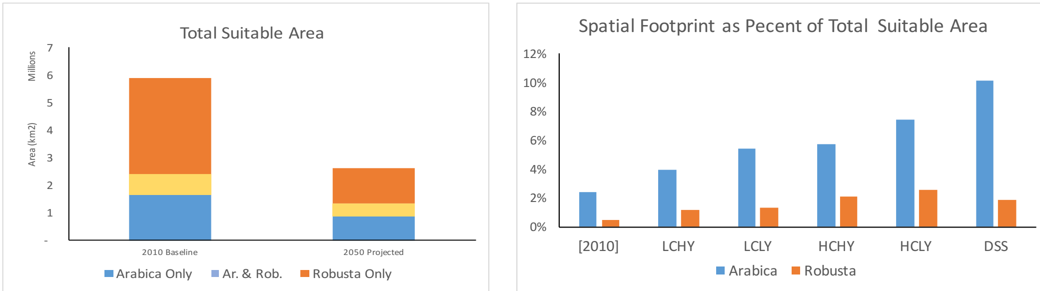

*Global Coffee Suitability in 2050*




The geographic area suitable for cultivating coffee were stratified according to three criteria: (1) Suitable for Arabica (2) Suitable for Robusta and (3) Suitable for both Arabica and Robusta (green). A selection of regional and country level maps is provided in the Appendix

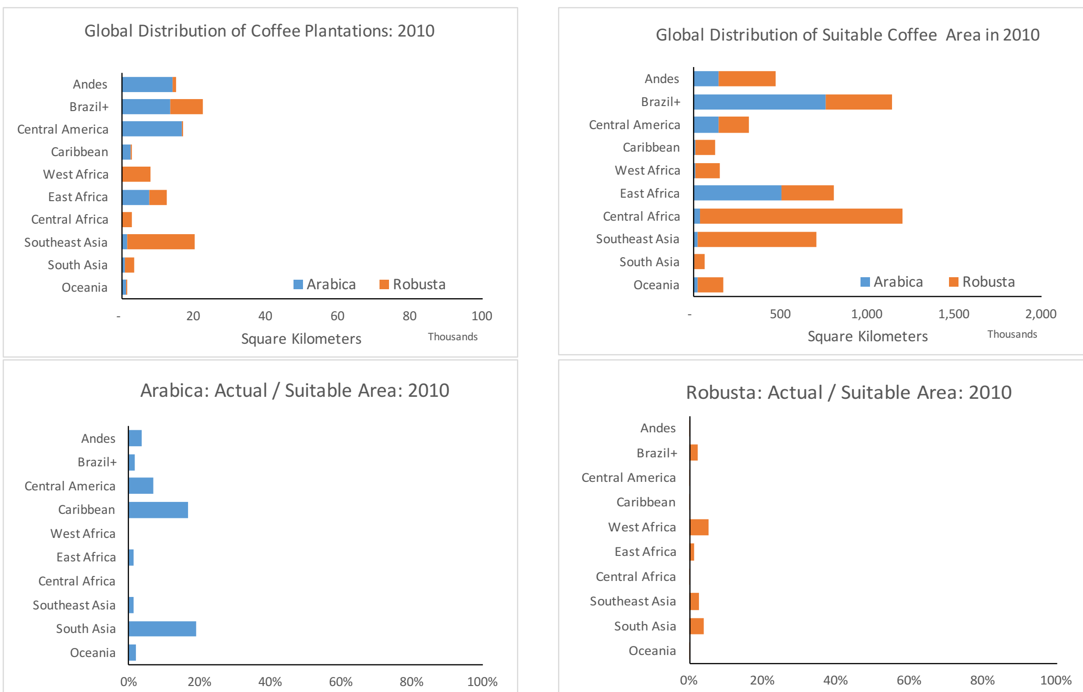
Regardless of the massive loss of climatically suitable habitat, the demand for land to establish or maintain coffee plantations will only be only a fraction of the total area proportion of suitable area with the necessary conditions to support the cultivation of coffee (see next page, right panel).

*Robusta versus Arabica*



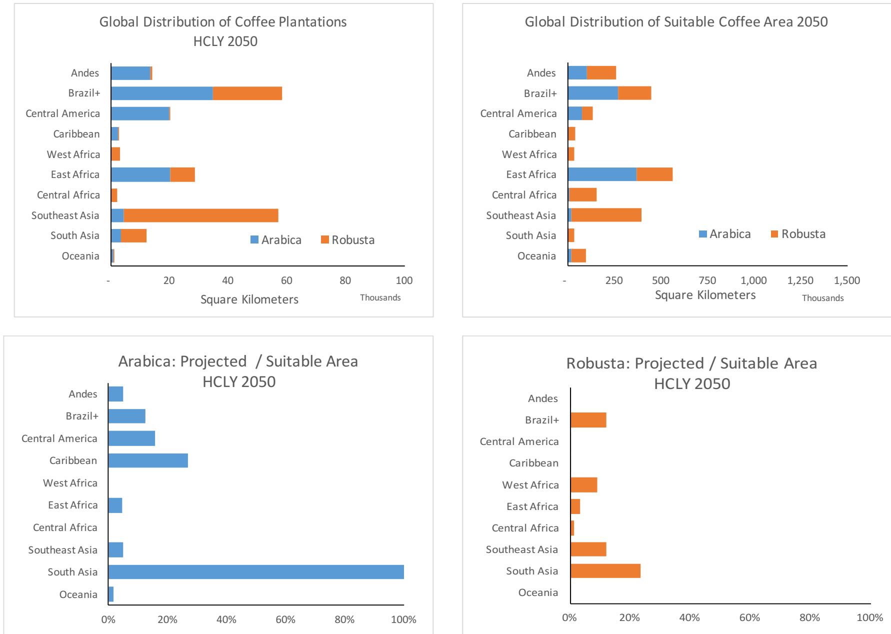

The dimension of the surplus of potential cultivation area when compared to the actual demand varies among regions, but in no case is there any constraint that should impact the expansion of current production (see below)

*Coffee Production and Geographic Areas Suitable for Coffee Cultivation in 2010*



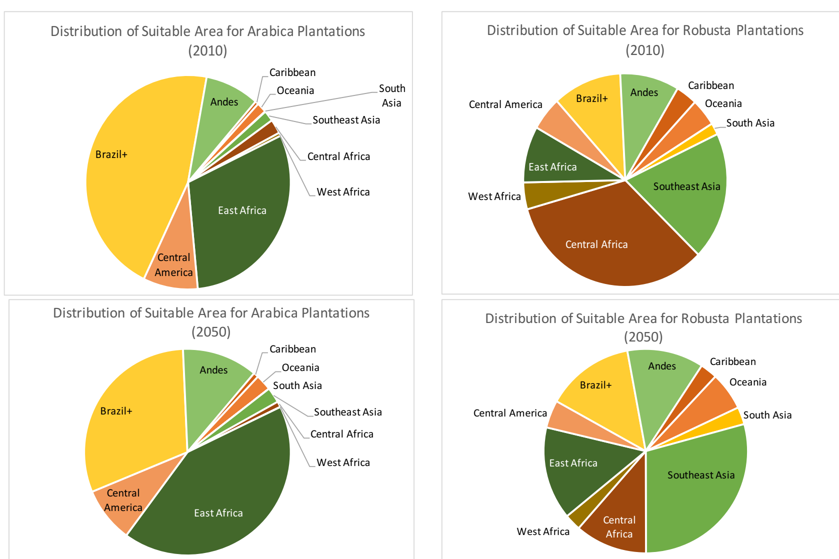

The expansion of coffee cultivation and the demand for land will depend upon which of the scenarios prevails in the future, but even under a demand-intensive scenario (HCLY-BAU), the surplus in suitable land compared to the potential demand remains overwhelming (see next page), with the sole exception of South Asia where the climatic model predicts a shortfall in area suitable for Arabica cultivation.

*Coffee plantations and Geographic Areas Suitable for Coffee Cultivation in 2050*



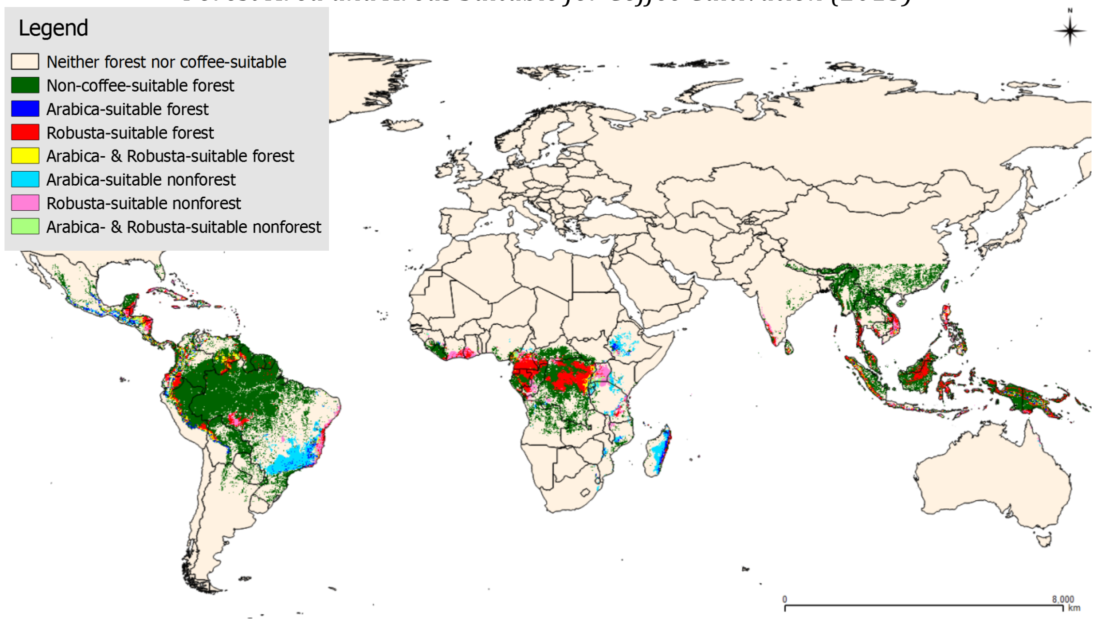

In spite of the surplus of areas suitable for coffee production, there may be a shift in investment due to the availability of land in 2050 when compared to 2010. The relative abundance of suitable land for Arabica cultivation remains essentially the same, although Brazilian landscapes are less abundant compared to East Africa. In contrast, the distribution of suitable Robusta area is radically altered due to the reduction of area from Central Africa as potential production area.

*Global Distribution of Geographic Areas Suitable for Coffee Cultivation*

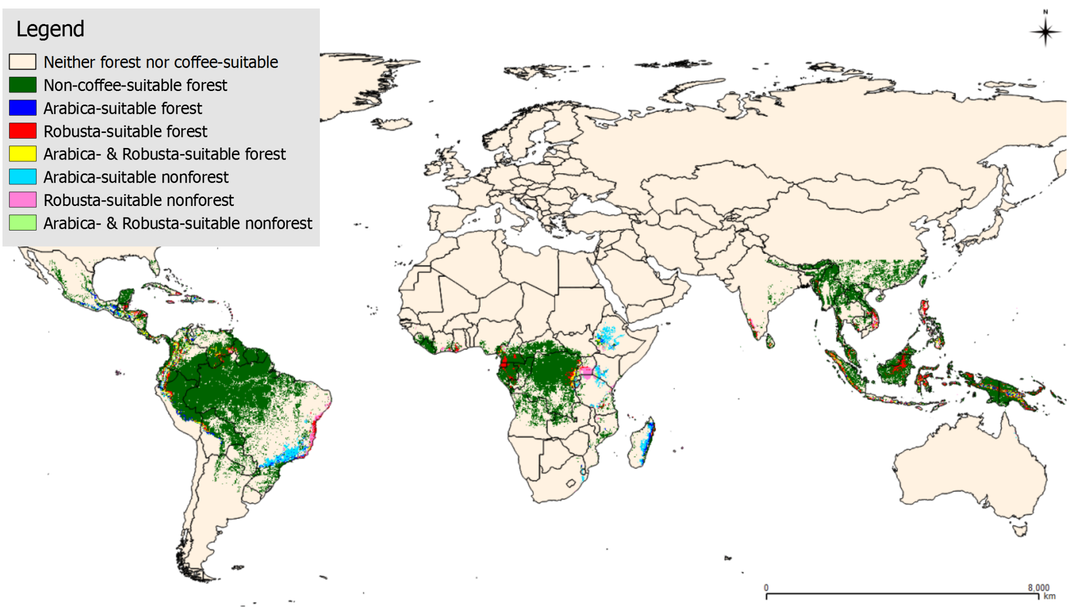



The above comparison, however, does not take into account the constraints that might be placed on the expansion or displacement of coffee plantations by restrictions on land use in forest areas. The potential overlap between extant natural forest and landscapes suitable for coffee cultivation was evaluated by overlaying the suitability maps derived from the *WorldClim* and *RCP6* data layers with a global forest cover map derived from Satellite imagery by the University of Maryland Global Forest Change 2000-2013 digital map.[7]

*Forest Area and Areas Suitable for Coffee Cultivation (2013)*




*Forest Area and Areas Suitable for Coffee Cultivation (2050)*




The threat of forest conversion from the expansion or displacement of coffee plantations increases when the available suitable area is covered by extant natural forest. A comparison of the suitable area with forest cover stratified by region shows that this risk is greater in some regions than others.

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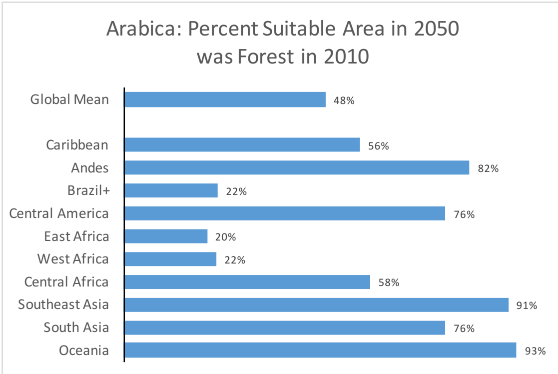
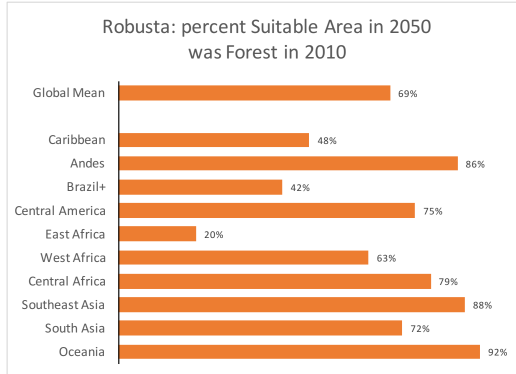
http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.1.html

*Overlap between Suitable Coffee Areas and Forest Cover*



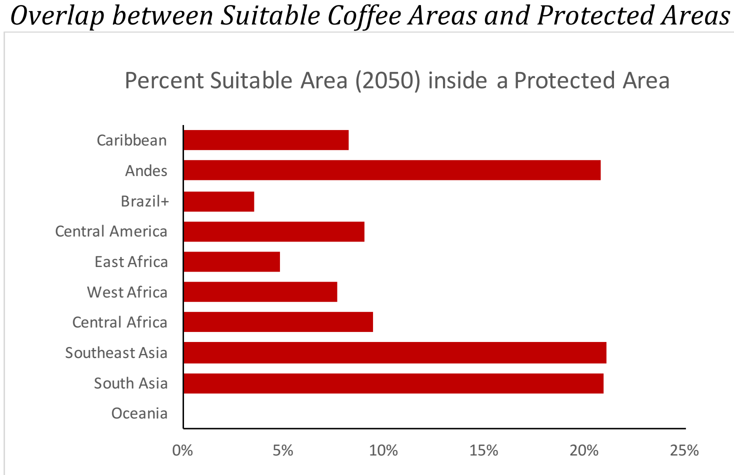




For example, Brazil and East Africa have the largest suitable areas for Arabica and the lowest forest cover within the potential expansion landscapes. Consequently, future expansion in these regions carries the lowest risk of future deforestation. Nonetheless, other non-forest landscapes might be at risk, particularly in East Africa where upland landscapes are covered by natural grasslands home to the continent's charismatic mega-fauna. The risk from deforestation linked to Arabica cultivation is relatively high in the Andes and Southeast Asia, at least when the data is summarized at the regional level.

Similarly, Brazil and East Africa both offer limited risk for deforestation for Robusta expansion, while the Andes and Southeast Asia have the most forest resources located within the areas identified as suitable for Robusta cultivation.

The potential conflict between the expansion of or displacement of coffee plantations and management of established protected areas is relatively small and should be manageable in most instances. (see below)

*Overlap between Suitable Coffee Areas and Protected Areas*



## Discussion

It is difficult to predict consumer behavior decades into the future, particularly regarding a non-essential commodity such as coffee. Coffee consumption has expanded over centuries and decades and its popularity as a beverage continues to grow both within traditional coffee consuming cultures, as well as in societies that have long preferred tea. If these trends continue the demand for coffee will double or even triple by mid Century. Most of this growth is due to demographics, as even moderate levels of coffee consumption in China and India have large impacts on global supply chains. Equally important is the projected demand from Sub-Saharan Africa, which is projected to experience a massive increase in population and where coffee production may foster increased coffee consumption.

The two consumption scenarios evaluated show the range of the potential demand over the next two decades, from about 7.5 million tons per year today to between 12 (LC) and 21 (HC) million tons by 2050. The HC scenario is probably the most likely and may even be a conservative estimate of future demand, as it assumes that coffee consumption in North America, Europe and Latin America remains stable. Recent trends in decreased soft drink consumption may foster greater growth in cold coffee drinks, however, while consumption in Latin America could conceivably grow to resemble European countries as that region becomes more affluent.

The technology and culture of coffee cultivation vary greatly among regions. Traditional shade coffee practices generally also tend to be low yielding, but may continue to capture market share due to the superior qualities associated with shade coffee varieties, as well as the tendency to rely on hand-harvesting, which ensures that beans are picked at the optimum moment. It is a common assumption that Arabica varieties have inherently lower yields when compared to Robusta varieties, but producers in Brazil have demonstrated that when Arabica is cultivated using technological practices similar to Robusta plantations, yields are approximately equivalent.

The intensification of coffee plantations in Brazil and Vietnam has transformed coffee supply chains over the last twenty years. If these trends continue and coffee traders continue to favor low cost producers, then Brazil and Southeast Asia will continue to dominate global supply chains. There is some concern that Vietnam may have limited capacity to expand production, but other regions in Southeast Asia are likely to adopt the Vietnamese production model. Unlike Brazil, Vietnamese producers are largely smallholders and their coffee production model may be attractive to smallholders on the Indonesian island of Sumatra, which has a long history of coffee production. Similarly, the Brazilian model could be adopted by Arabica producers in Colombia and Kenya.

The superabundance of suitable coffee growing areas is remarkable. This does not mean, however, that there will not be large-scale displacement of coffee plantations over the next 40 years. If geneticists are unable to breed new varieties adapted to warmer conditions or plantation managers fail to develop cultural practices that mitigate the impacts of climate change, then producers will be forced to migrate their plantations to cooler and more humid landscapes. Since a plantation produces for twenty to thirty years, the impact of climate change might cause producers to prematurely abandon existing plantations causing disruptions to existing supply chains or impacting the long-term economic return that underpins the current system.

In the case of Arabica, this would be largely an altitudinal shift, which could favor producers in the Andes, where potential habitat is available upslope, or perhaps on south facing slopes that experience less insolation. The total suitable area would be reduced by 44% from about 2.3 to 1.3 million $km^2$, but this is still far in excess of the projected demand between 53,000 (LCHY-BAU) and 136,000 $km^2$ (HCHY-DSS).

An unexpected outcome from the modeling exercise was the very large reduction in the potential area suitable for Robusta cultivation. The total suitable area would be reduced by 59% from about 4.2 to 1.6 million, which is likewise still far in excess of the projected demand. Proportionally, this represents a much greater impact from climate change on the species that is widely assumed to be more resilient to higher temperatures. Notably, the largest greatest reduction was observed in Central Africa, the geographical origin of Robusta and, presumably, the region with the greatest genetic diversity within its wild populations and traditional cultivars. Other areas that experienced a modeled reduction in the suitability of Robusta landscapes was Rondônia Brazil, which is currently a major producer of Robusta coffee, and the Coastal Caribbean, which is not (see Appendix).

These predictions might actually be an artifact of the modeling methodology, which is based on a suite of bioclimatic attributes derived from landscapes where Arabica and Robusta are actually grown – rather than on the known (or assumed) range of their heat and drought tolerance. In a preliminary modeling effort, based on temperature and precipitation regimes, the projected suitable area was almost five times greater than the ranges based on climate attributes.

Regardless of which modeled scenario is closest to an actual future outcome, all of them represent similar threats to forest cover, because the reduction in suitability impacts the non forest area at approximately the same level as natural forest area. The greatest threat from expanded or shifted Arabica production would most likely occur in the Andes and Central America, since most of the upslope areas in these regions are covered by montane [cloud] forest, a biome that is particularly rich in species diversity and endemism. In contrast, potential Arabica landscapes in Brazil and East Africa are largely non forest landscapes. In Brazil, most of this area is probably agricultural landscapes or degraded pasture. Potential production landscapes in East Africa face an even more serious management challenge due to a rapidly expanding human population and the need to convert both forest and non-forest habitat for food production. Most of the potential Robusta expansion areas in 2050 are located in Southeast Asia, which increases the risk to forested landscapes and biodiversity hotspots on the islands of Borneo, Sumatra, Sulawesi and Papua.

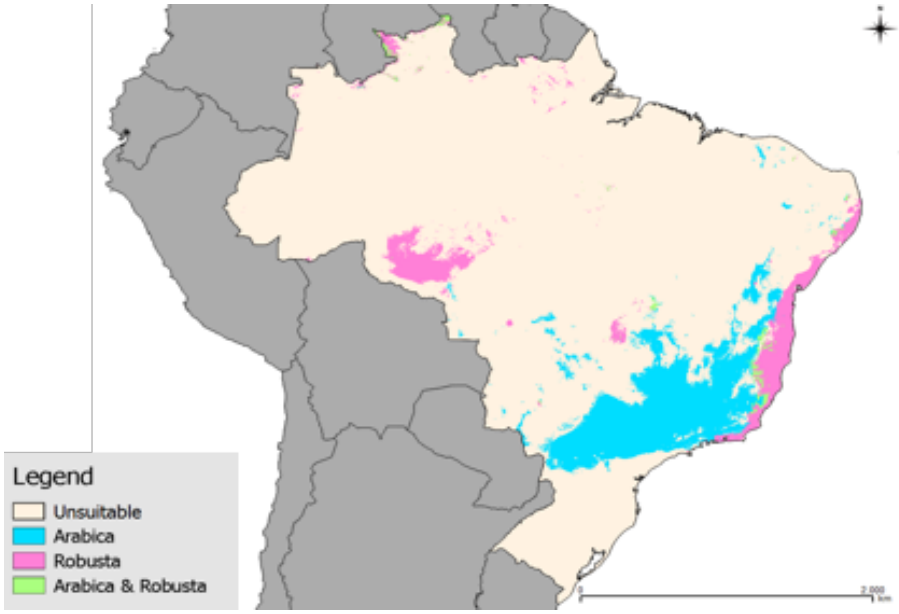
Many of the suitable Robusta landscapes are located in montane areas and occupy landscapes located below Arabica landscapes, with overlapping zones that are appropriate for both species. This highlights the possibility that existing Arabica coffee plantations may be replanted with Robusta varieties or, potentially, inter-specific hybrids that incorporate the flavor characteristics of Arabica with the environmental tolerance of Robusta.

## Conclusion

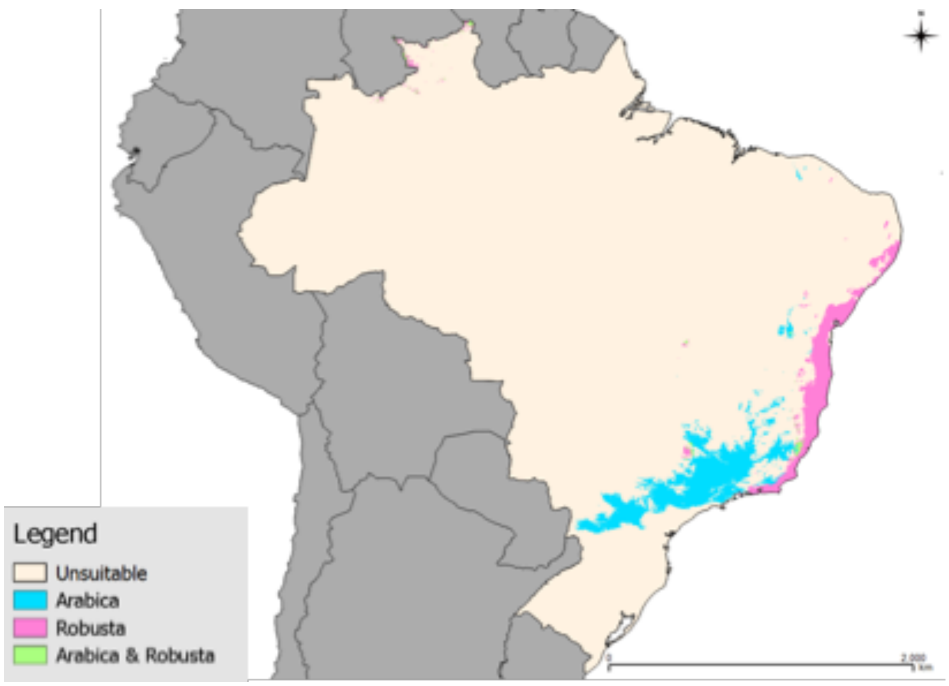
Coffee consumption will experience strong growth over the next 30 years leading to the expansion of plantations in regions that currently cultivate both Arabica and Robusta. The scale of this growth will largely depend on consumer beverage preferences in East Asia, South Asia and Sub Saharan Africa. The impact of that consumption on supply chains will likewise be influenced by their relative consumption of mass market coffees from intensive production system, largely Robusta, and specialty coffees composed of Arabica varieties cultivated under shade and harvested by hand.

Coffee supply chains are likely to experience significant disruption due to climate change over the next forty years. This should not lead to a shortage of available land to support the cultivation of either Robusta or Arabica coffees, however, but there may be a topographic or latitudinal shift as traditional coffee production areas become too warm or prone to periodic drought-like conditions. The shift of coffee production landscapes may lead to significant deforestation, since many of the suitable areas in 2050 are currently covered by natural forest ecosystems. The largest risk for future deforestation will be in Central America and the Andes due to expansion or shift in Arabica production and Indonesia due to expansion or shifts in Robusta cultivation.

**Brazil 2010 Coffee Suitability**



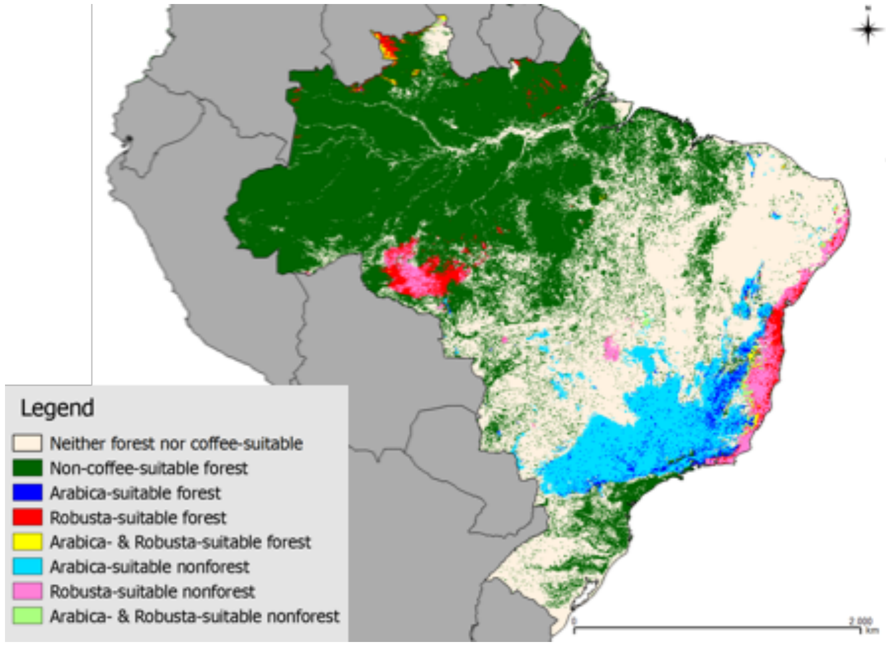

**Brazil 2050 Coffee Suitability**



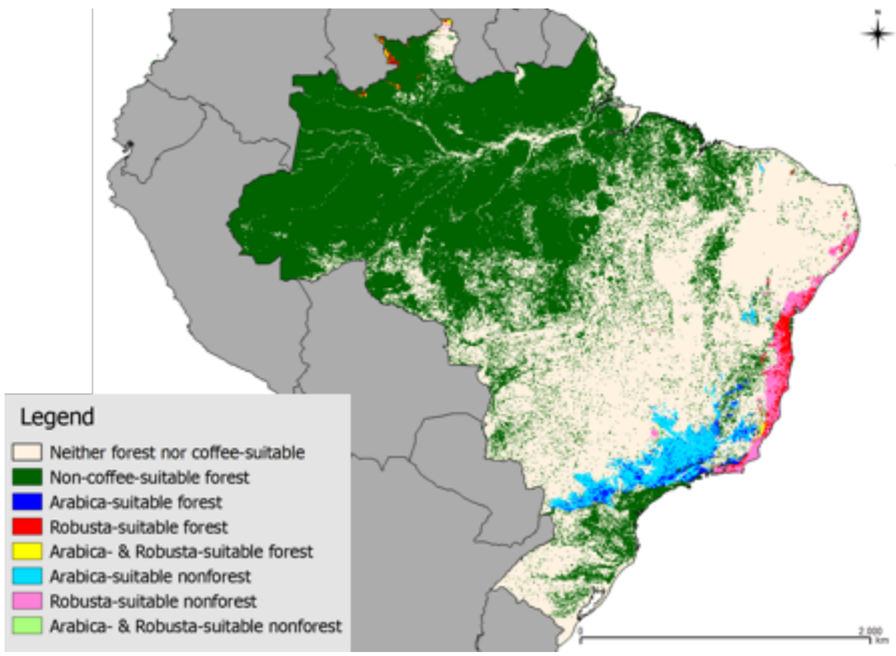

| Brazil | 2010 | 2050 |
|---|---|---|
| Suitable Area (km2) | 1,158,613 | 451,788 |
| Arabica | 797,575 | 279,769 |
| Robusta | 400,581 | 182,609 |
| Plantation Area (km2) | 28,426 | 44,810 |
| Arabica | 12,857 | 34,881 |
| Robusta | 8,572 | 23,254 |

The area suitable for cultivation decreases by more than 50%, but still vastly exceeds the projected demand for coffee cultivation under the HCLY-BAU scenario, but Rondônia becomes a non viable coffee cultivation region.

## Brazil 2010 Coffee Suitability and 2013 Forest Cover



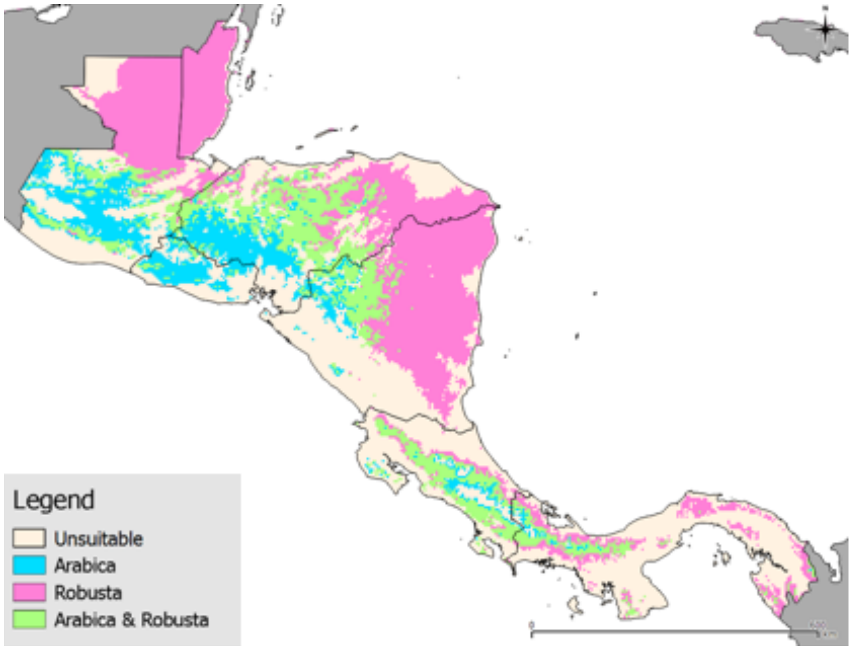

## Brazil 2050 Coffee Suitability and 2013 Forest Cover



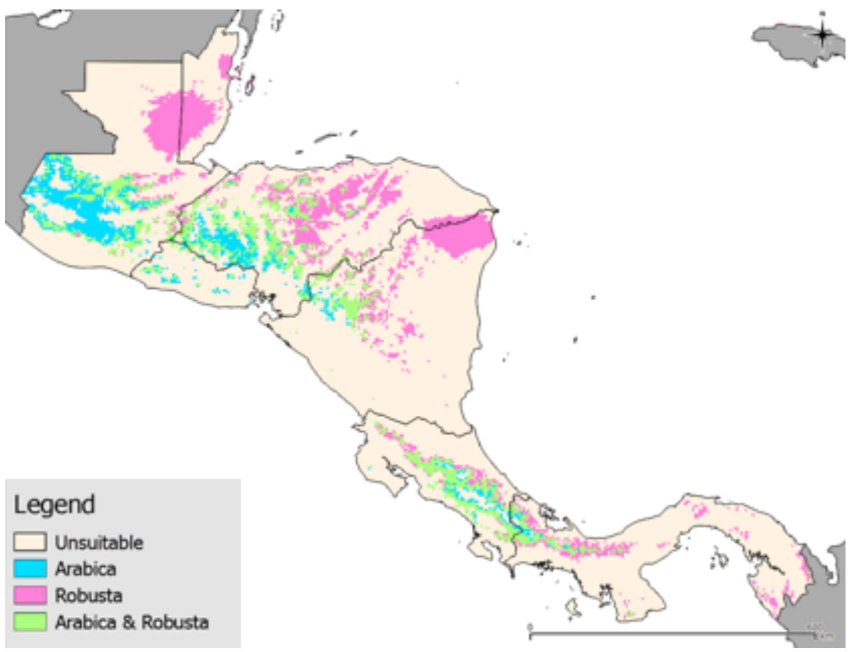

| Brazil | 2010 | 2050 |
|---|---|---|
| Suitable Area Forest (km2) | 301,538 | 125,450 |
| Arabica | 130,020 | 61,199 |
| Robusta | 192,385 | 71,010 |
| Suitable Area Non forest(km2) | 857,075 | 326,338 |
| Arabica | 667,555 | 218,570 |
| Robusta | 208,196 | 111,599 |

The impact of climate change on suitable area affects forest and non forest areas approximately equally, but most of the area available for expansion is in non forest landscapes

## Central America 2010 Coffee Suitability



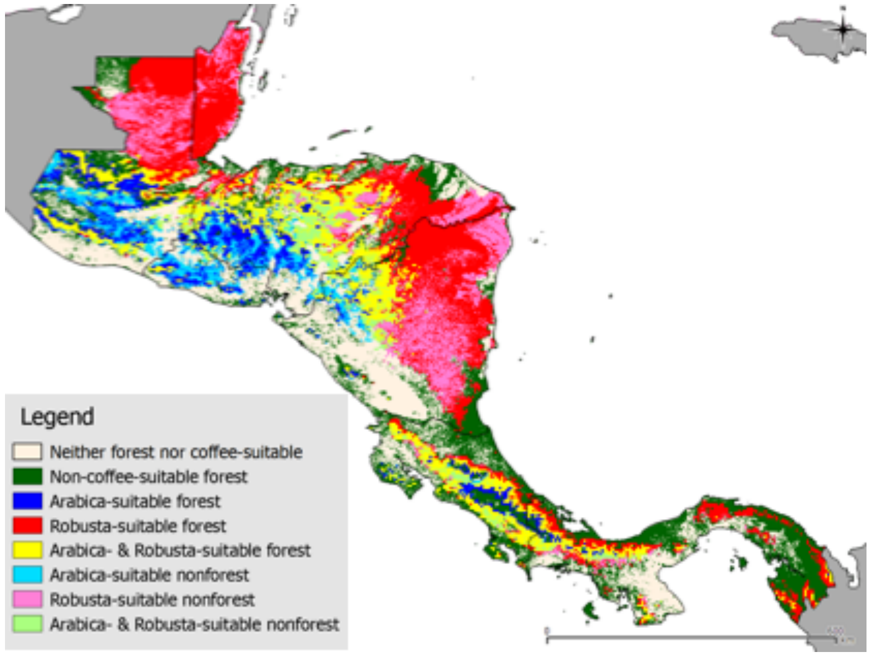

## Central America 2050 Coffee Suitability



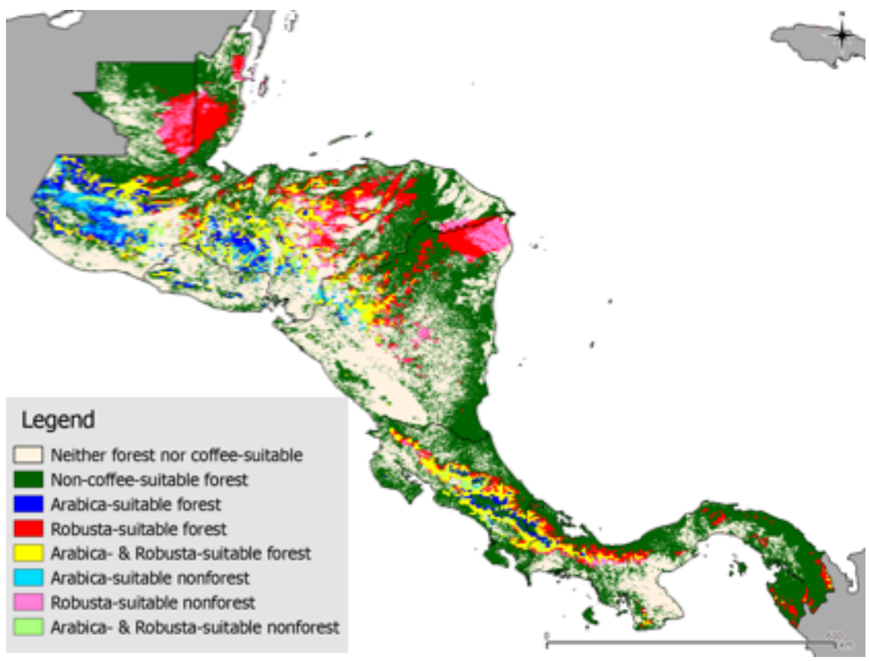

| Central America | 2010 | 2050 |
|---|---|---|
| Suitable Area (km2) | 285,216 | 126,448 |
| Arabica | 136,338 | 71,312 |
| Robusta | 228,741 | 99,592 |
| Plantation Area (km2) | 16,615 | 43,648 |
| Arabica | 16,449 | 43,212 |
| Robusta | 166 | 436 |

The area suitable for cultivation decreases by more than 50%, but still vastly exceeds the projected demand for coffee cultivation under the HCHY-DS scenario

## Central America 2010 Coffee Suitability and 2013 Forest Cover



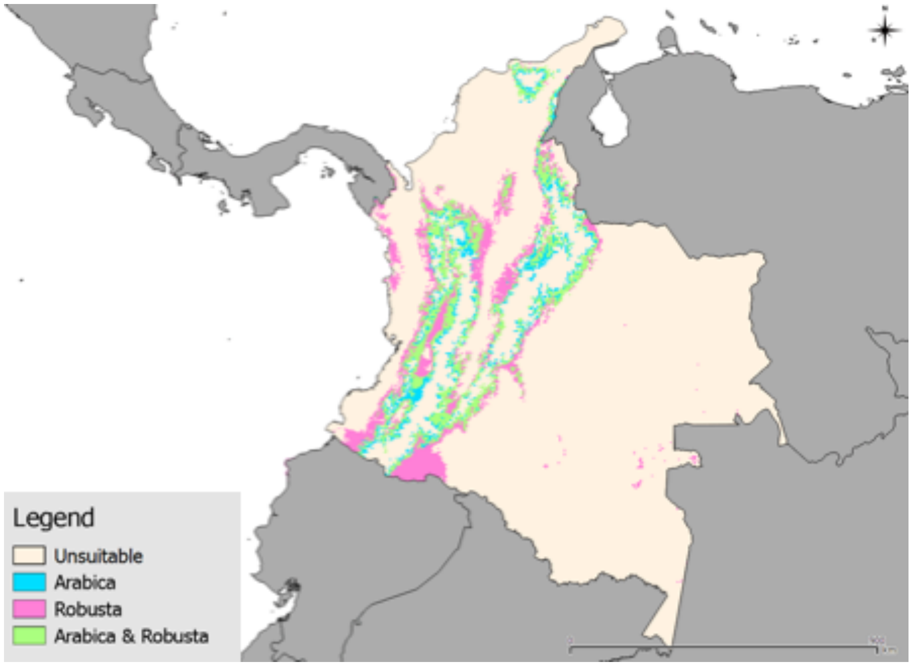

## Central America 2050 Coffee Suitability and 2013 Forest Cover



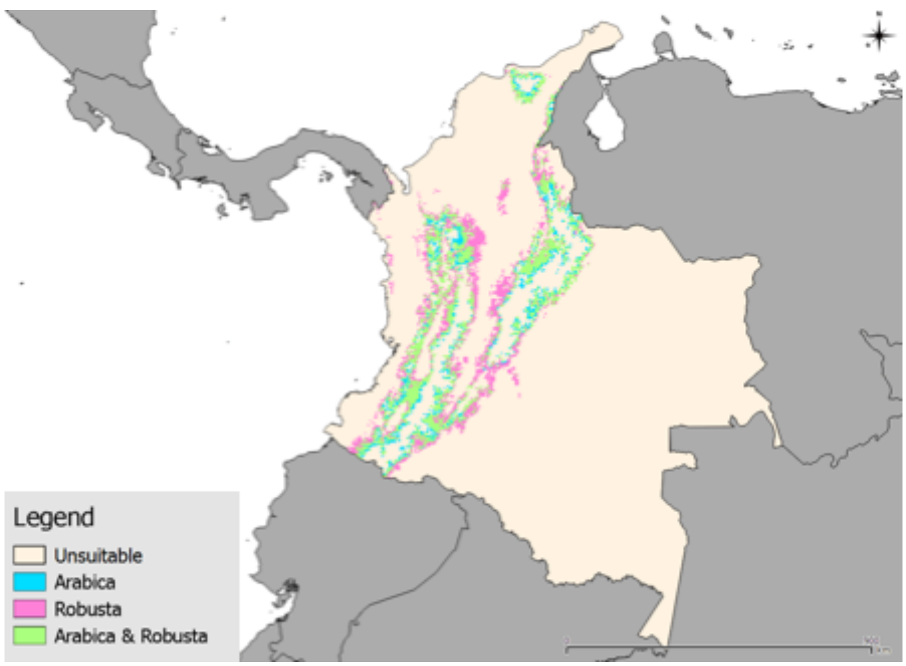

| Central America | 2010 | 2050 |
|---|---|---|
| Suitable Area Forest (km2) | 185,749 | 112,622 |
| Arabica | 88,348 | 52,667 |
| Robusta | 154,914 | 74,014 |
| Suitable Area Non forest(km2) | 99,467 | 13,826 |
| Arabica | 47,989 | 18,645 |
| Robusta | 73,827 | 25,578 |

The impact of climate change on suitable area affects forest and non forest areas approximately equally, but for Arabica to expand to meet demand under a HCHY-DS Scenario some deforestation would be almost inevitable

## Colombia 2010 Coffee Suitability



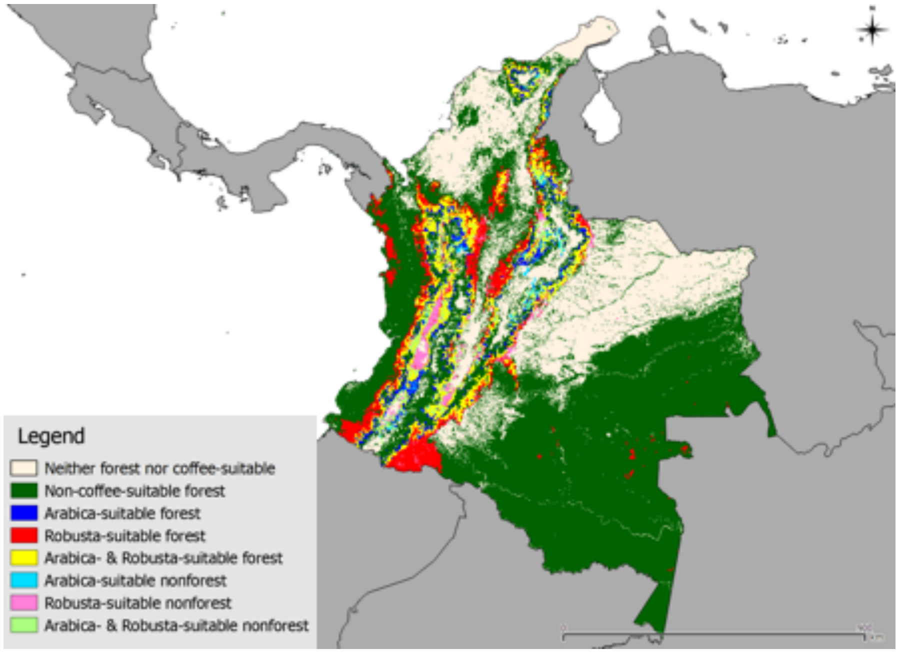

## Colombia 2050 Coffee Suitability



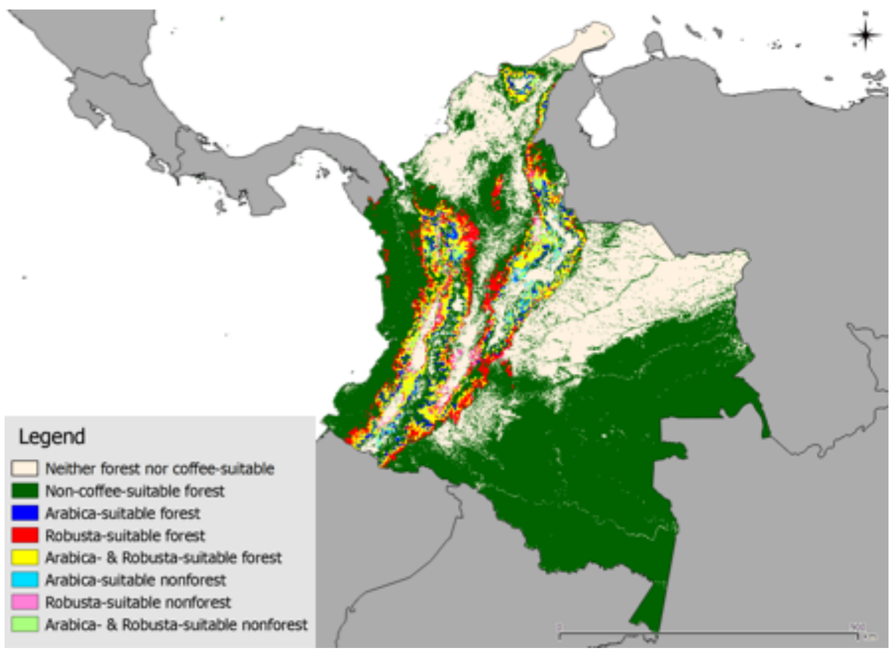

| Colombia | 2010 | 2050 |
|---|---|---|
| Suitable Area (km2) | 182,165 | 140,371 |
| Arabica | 106,779 | 88,509 |
| Robusta | 151,183 | 119,727 |
| Plantation Area (km2) | 7,652 | 21,818 |
| Arabica | 5,356 | 15,272 |
| Robusta | 2,296 | 6,545 |

The area suitable for cultivation decreases by about 30%, but still vastly exceeds the projected demand for coffee cultivation under the HCHY-DS scenario; the largest spatial area is a transition zone that is suitable for both coffee species.

## Colombia 2010 Coffee Suitability and 2013 Forest Cover




## Colombia 2050 Coffee Suitability and 2013 Forest Cover




| Colombia | 2010 | 2050 |
|---|---|---|
| Suitable Area Forest (km2) | 144,925 | 112,622 |
| Arabica | 83,856 | 69,677 |
| Robusta | 120,135 | 96,510 |
| Suitable Area Non forest(km2) | 37,240 | 27,749 |
| Arabica | 22,923 | 18,832 |
| Robusta | 31,048 | 23,217 |

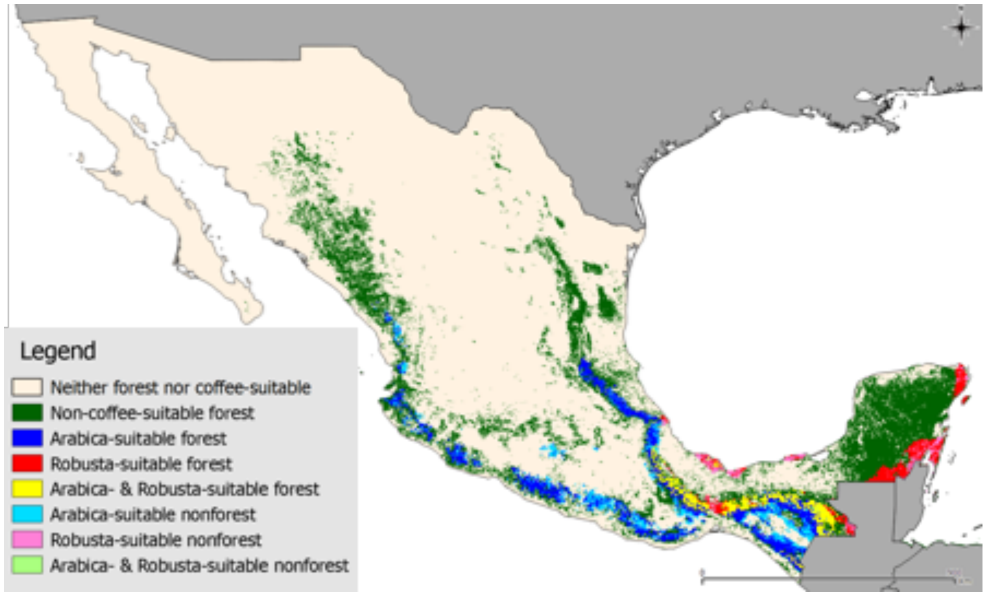
The impact of climate change on suitable area affects forest and non forest areas approximately equally, but most of the area for expansion is located in forest landscapes

## Mexico 2010 Coffee Suitability

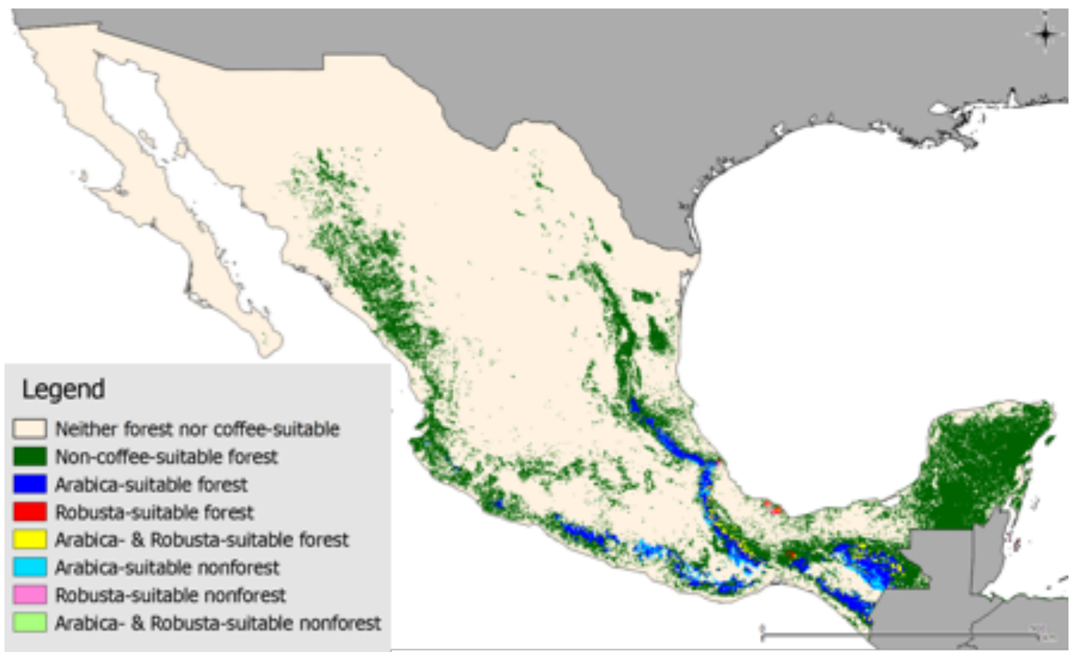

## Mexico 2050 Coffee Suitability


| Mexico | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area (km2) | 136,665 | 55,454 | The area suitable for Arabica cultivation decreases by about 40%, and by about 90% for Robusta, which approximates the potential demand under the HCHY-DS scenario |
| Arabica | 107,223 | 54,144 | |
| Robusta | 50,310 | 6,124 | |
| Plantation Area (km2) | 7,083 | 18,110 | |
| Arabica | 4,958 | 12,677 | |
| Robusta | 2,125 | 5,433 | |

## Mexico Current 2010 Suitability and 2013 Forest Cover

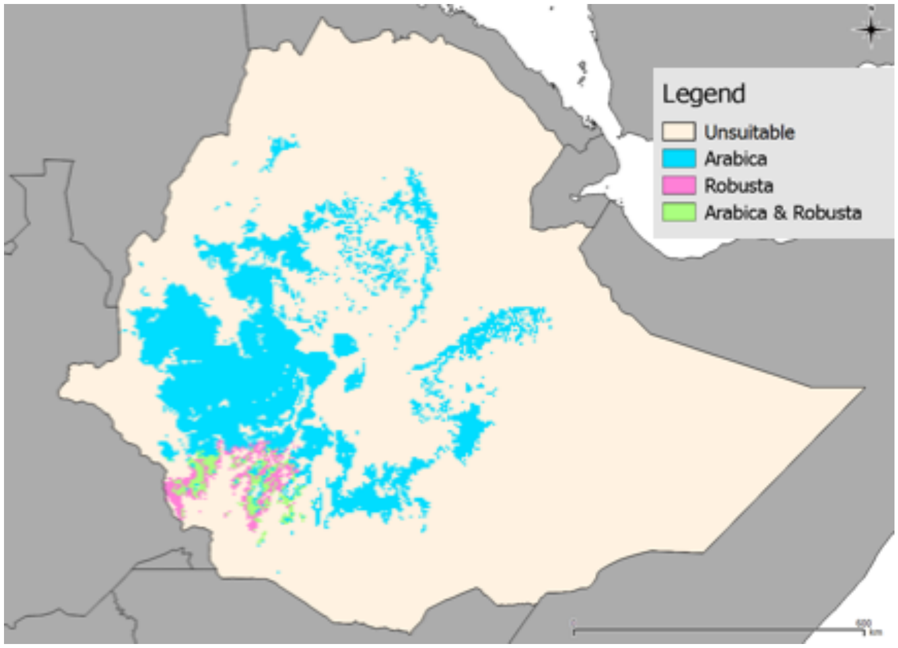



## Mexico 2050 Coffee Suitability and 2013 Forest Cover

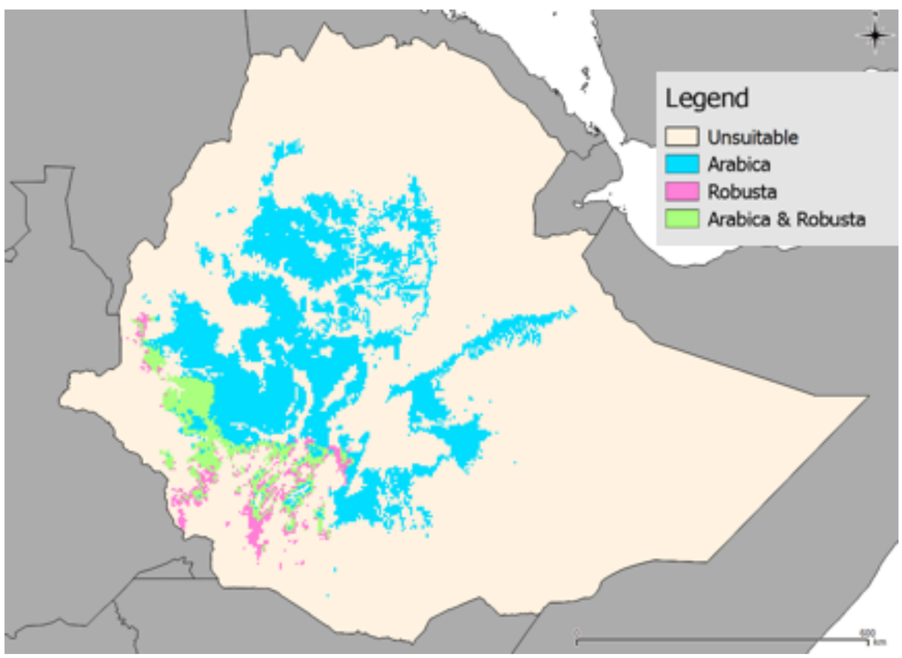



| Mexico | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area Forest (km2) | 96,275 | 43,485 | The impact of climate change on suitable area affects forest and non forest areas approximately equally, but most of the area for expansion is located in forest landscapes. |
| Arabica | 75,865 | 42,601 | |
| Robusta | 39,952 | 5,581 | |
| Suitable Area Non Forest(km2) | 40,390 | 11,969 | |
| Arabica | 31,358 | 11,543 | |
| Robusta | 10,358 | 543 | |

## Ethiopia 2010 Coffee Suitability

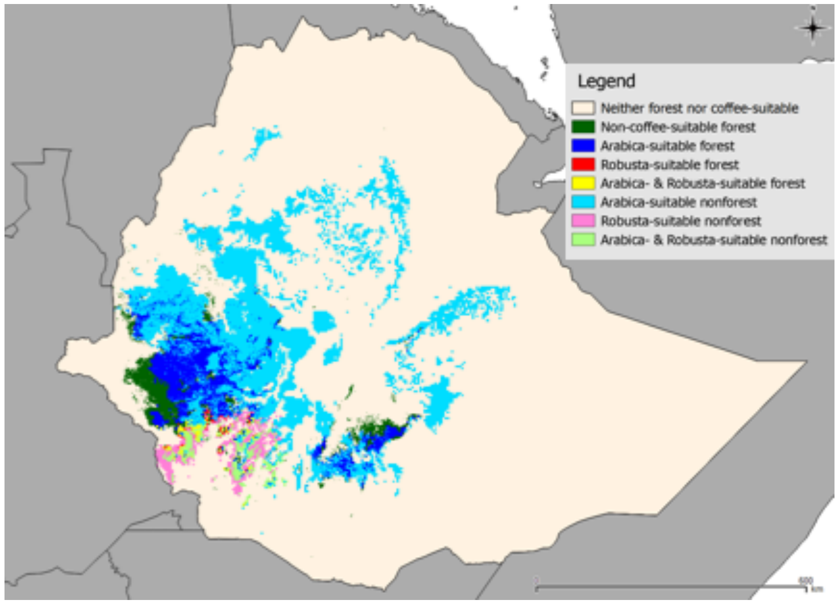



## Ethiopia 2050 Coffee Suitability

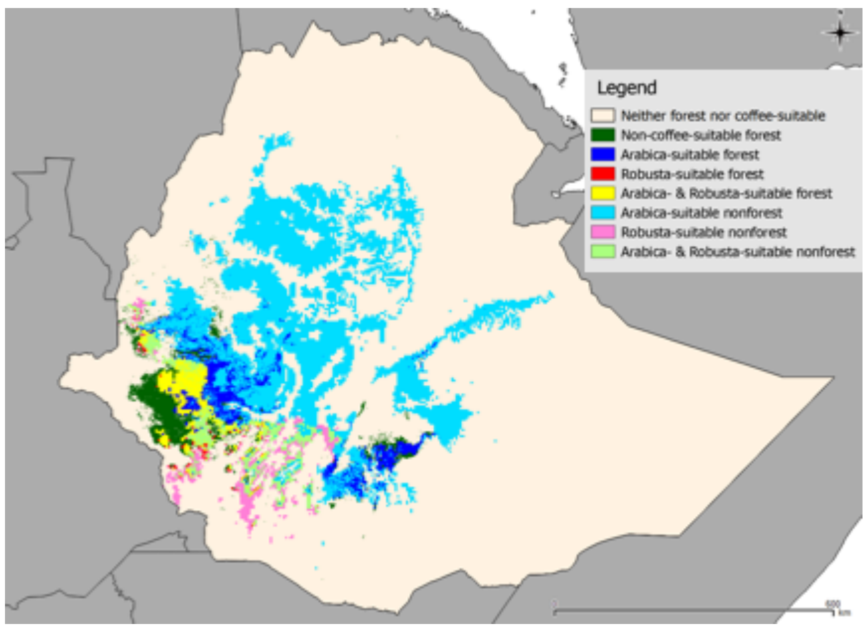



| Ethiopia | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area (km2) | 179,347 | 208,682 | The area suitable for Arabica cultivation actually increases due to climate change |
| Arabica | 168,787 | 195,265 | |
| Robusta | 19,609 | 38,709 | |
| Plantation Area (km2) | 5,144 | 18,218 | |
| Arabica | 5,144 | 18,218 | |
| Robusta | - | - | |

## Ethiopia2010 Coffee Suitability and 2013 Forest Cover

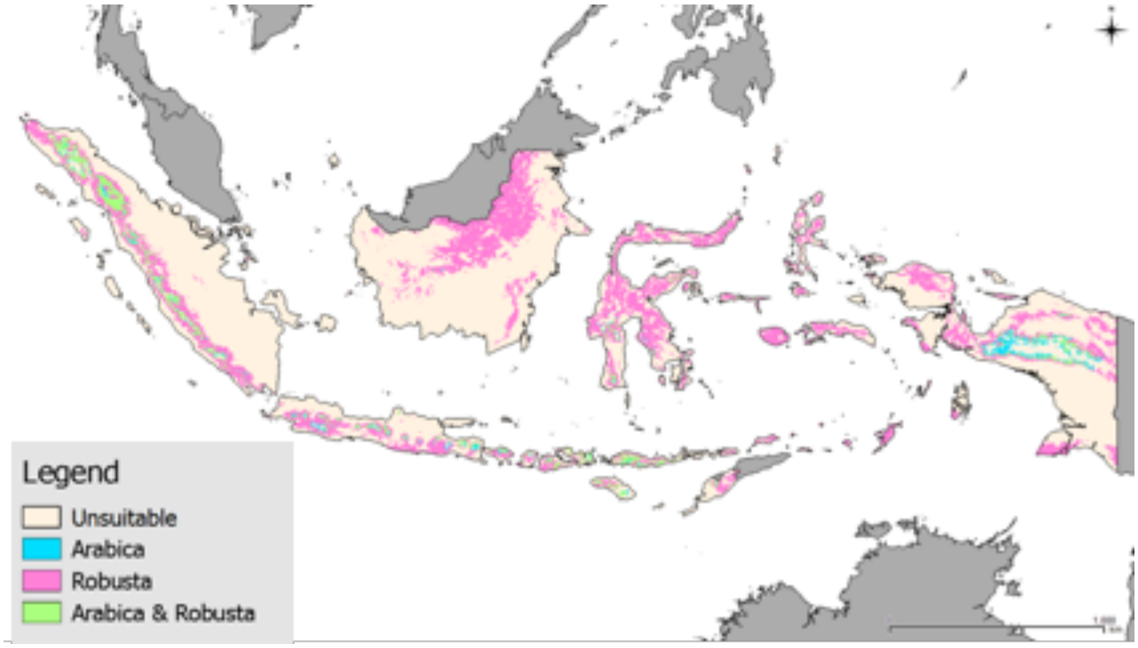



## Ethiopia 2050 Coffee Suitability and 2013 Forest Cover

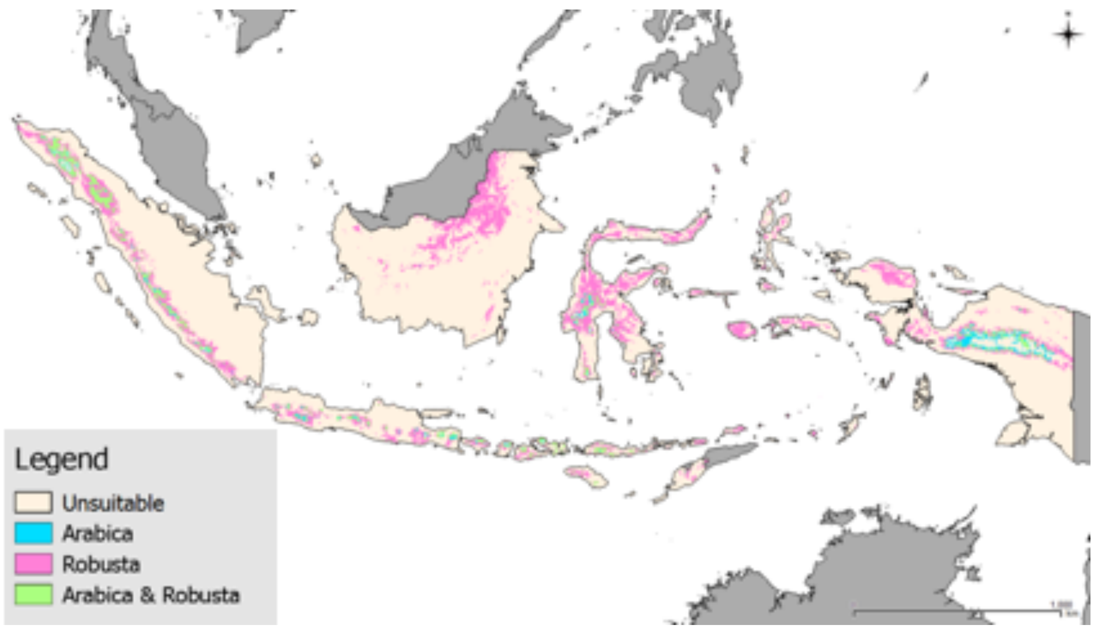



| Ethiopia | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area Forest (km2) | 31,248 | 29,652 | The impact of climate change on suitable area affects forest and non forest areas approximately equally, but most of the area for expansion is located in non forest landscapes. |
| Arabica | 30,298 | 28,314 | |
| Robusta | 2,611 | 12,298 | |
| Suitable Area Non Forest(km2) | 148,099 | 179,030 | |
| Arabica | 138,489 | 166,951 | |
| Robusta | 16,998 | 26,411 | |

## Indonesia 2010 Coffee Suitability

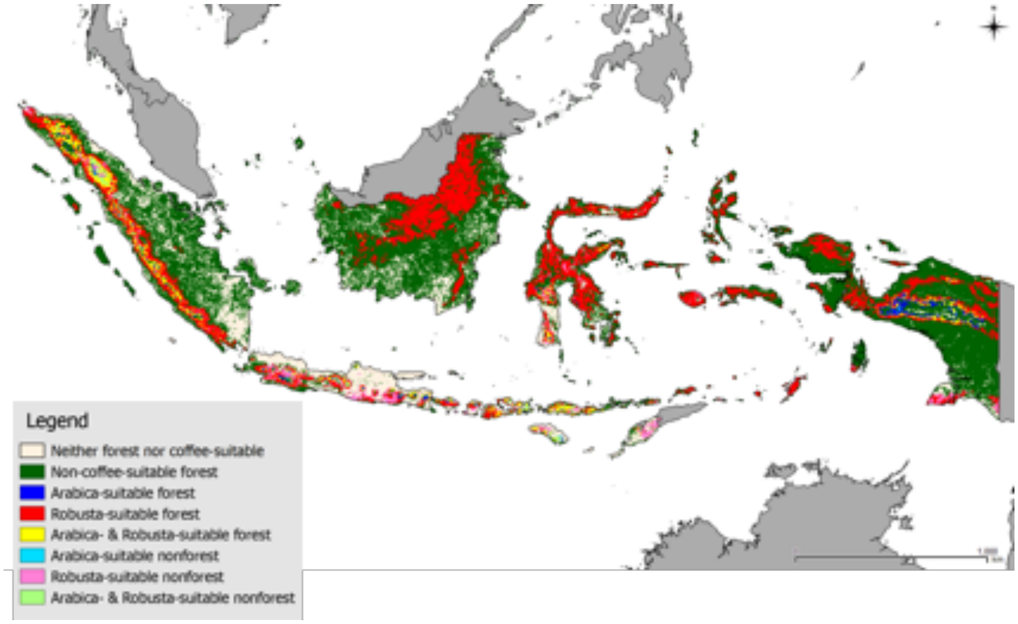



## Indonesia 2050 Coffee Suitability

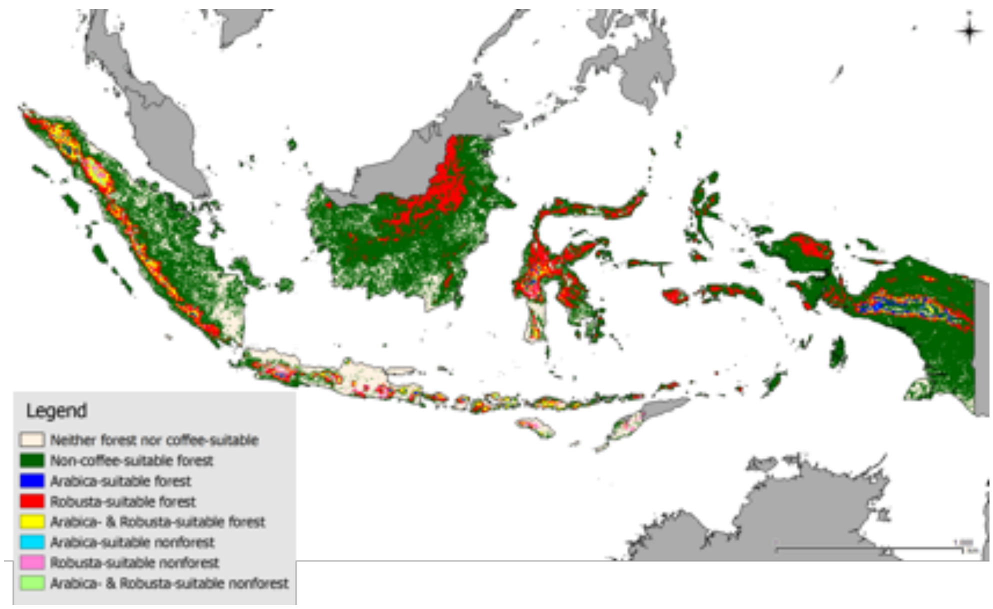



| Indonesia | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area (km2) | 535,757 | 337,198 | Although it is well known for its elite Arabica coffees, Robusta production predominates; climate change restricts the potential area suitable for Robusta more severely than Arabica |
| Arabica | 90,222 | 77,246 | |
| Robusta | 512,985 | 317,000 | |
| Plantation Area (km2) | 12,651 | 15,275 | |
| Arabica | 2,530 | 3,055 | |
| Robusta | 10,121 | 12,220 | |

## Indonesia2010 Coffee Suitability and 2013 Forest Cover



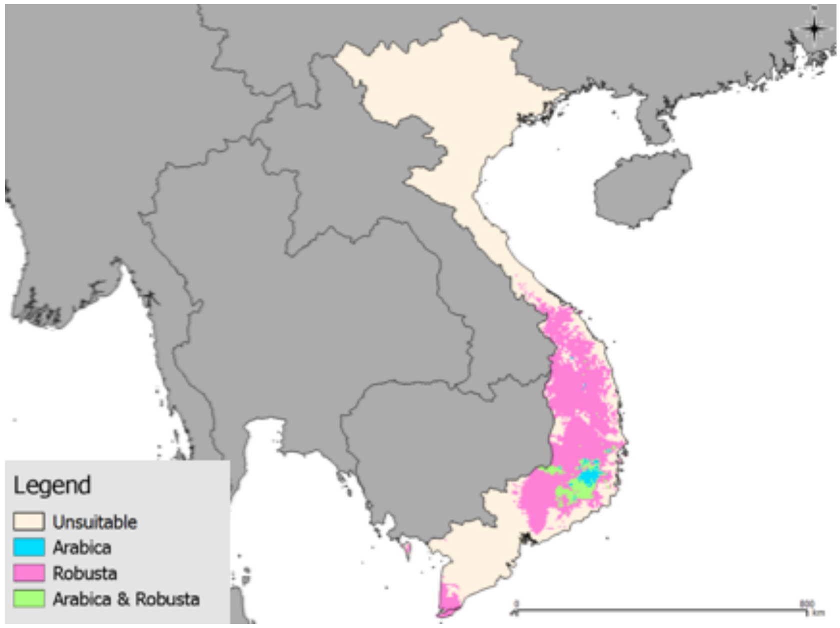

## Indonesia 2050 Coffee Suitability and 2013 Forest Cover



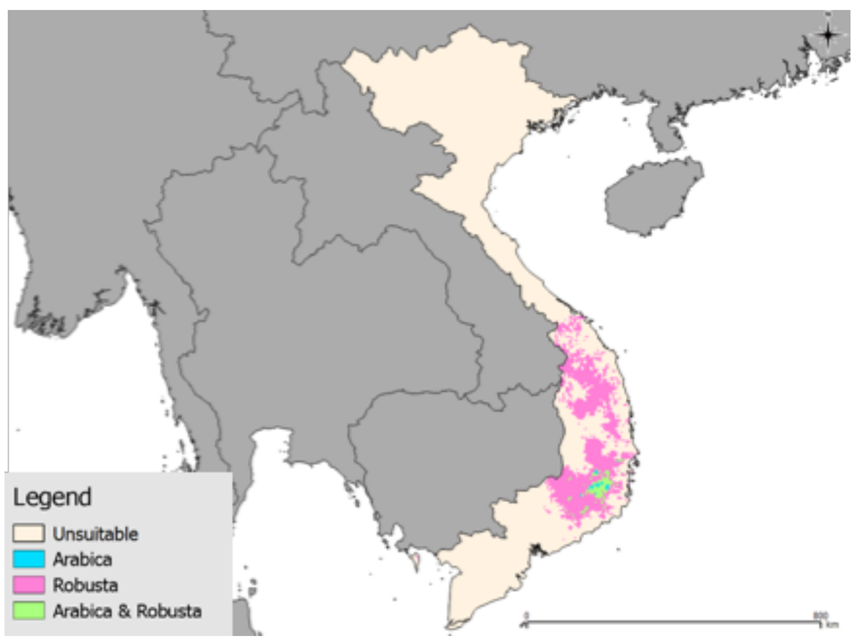

| Indonesia | 2010 | 2050 |
|---|---|---|
| Suitable Area Forest (km2) | 483,509 | 312,158 |
| Arabica | 79,053 | 70,249 |
| Robusta | 462,424 | 292,994 |
| Suitable Area Non Forest(km2) | 52,248 | 25,040 |
| Arabica | 11,169 | 6,997 |
| Robusta | 50,561 | 24,006 |

The vast majority of landscapes suitable for the expansion or displacement of coffee production are currently covered by forest vegetation, but non forest landscapes suitable for coffee production still cover approximately twice the area of future demand under a HCHY-DS scenario.

## Vietnam 2010 Coffee Suitability



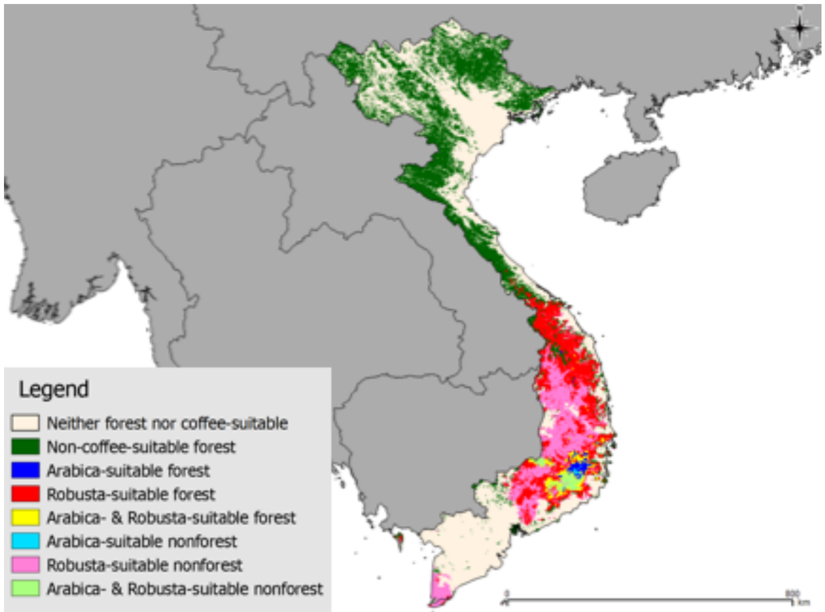

## Vietnam 2050 Coffee Suitability



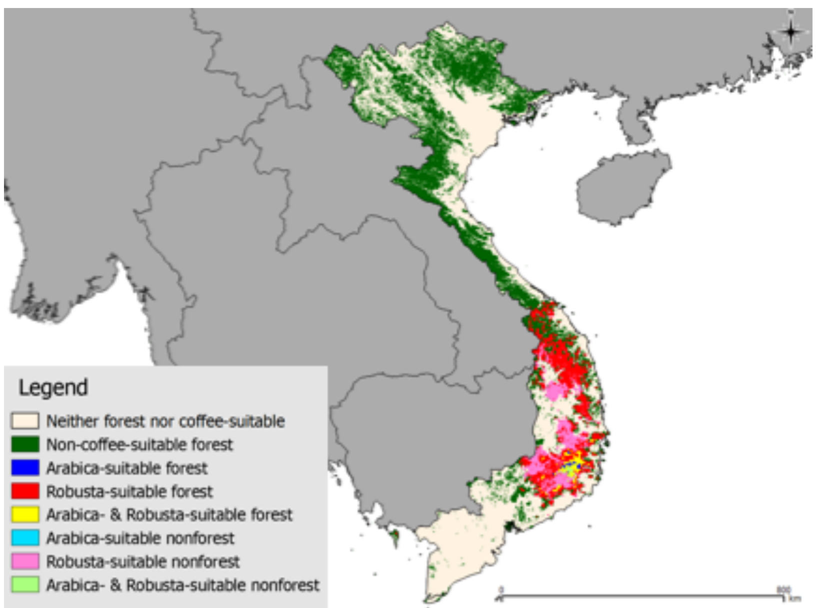

| **Vietnam** | **2010** | **2050** |
|---|---|---|
| Suitable Area (km2) | 86,681 | 46,963 |
| Arabica | 9,878 | 3,645 |
| Robusta | 84,326 | 46,473 |
| Plantation Area (km2) | 5,434 | 18,105 |
| Arabica | 163 | 543 |
| Robusta | 5,271 | 17,562 |

The area suitable for Robusta cultivation decreases by almost 50%, while Arabica is reduced by more than 60%; nonetheless, the area suitable for coffee cultivation is still more than twice as great as the potential demand under a HCLY-BAU scenario

## Vietnam 2010 Coffee Suitability and 2013 Forest Cover




## Vietnam 2050 Coffee Suitability and 2013 Forest Cover




| Ethiopia | 2010 | 2050 | |
|---|---|---|---|
| Suitable Area Forest (km2) | 46,769 | 31,351 | Climate change impacts the forest and non forest areas approximately equally, but most of the area for Robusta expansion is located in forest landscapes and the demand for area exceeds the potential supply of on forest landscapes |
| Arabica | 6,534 | 3,117 | |
| Robusta | 44,713 | 30,870 | |
| Suitable Area Non Forest(km2) | 39,912 | 15,612 | |
| Arabica | 3,344 | 528 | |
| Robusta | 39,613 | 15,603 | |

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