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African Countries with Highly Impacted Road Infrastructure due to Climate Change Impacts

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The final copy of this thesis has been examined by the signatories, and we
Find that both the content and the form meet acceptable presentation standards
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Abstract

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Thesis Title: African Countries with Highly Impacted Road Infrastructure due to Climate Change Impacts

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The Economics of Adaptation to Climate Change (EACC) was initiated by The World Bank to develop a more precise global estimate of the costs to adapt to climate change. The EACC study was designed to help developing countries, which are the most vulnerable to climate change, better understand and assess strategies to deal with the affects of climate change. In order to quantitatively estimate the costs of adapting to climate change, engineer-based models were developed that estimate the impact of climate stressors. This paper focuses on the stressor-response function dealing with roads in Africa. African countries are especially vulnerable to long-term disasters, such as droughts, sea coast change and flooding frequency. These climate change impacts have a significant emotional, economic and social toll on communities. The limited infrastructure of African countries makes each road a valuable asset. This paper attempts to identify the African countries that have the highest value roads. Also, building on previous research done by Paul Chinowsky, costs associated with climate change for African countries are compiled and the cost savings adaptation can create for each country are evaluated. From this data, African countries that are highly burdened by climate change costs are identified. Finally, countries that benefit the most from adaptation are identified. Sudan, Ethiopia, Eritrea, Niger and Mali are countries with low road densities. Chad, Malawi, Niger and Mozambique are highly impacted by the costs of climate change. Malawi, Lesotho and Mozambique have the most to gain from adaptation. Policy makers can use the data compiled in this report to better prepare roads for climate change. The positive changes these mitigation efforts can create will alleviate the social and economic impacts climate change has the potential to cause.

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Executive Summary

The Economics of Adaptation to Climate Change (EACC) study, sponsored by The World Bank, attempts to quantify costs associated with climate change. These "adaptation" costs reflect the additional costs associated with long-term climate alterations, such as droughts, sea coast change and flooding frequency. Identifying adaptation costs for developing countries can help inform decision makers so that they can better understand and assess risks created by climate change. Furthermore, better design and development strategies can be adopted to help minimize adaptation costs.

This study builds on previous research done by Paul Chinowsky at the University of Colorado. Climate change data for the entire continent of Africa was used to estimate costs associated with the impacts of climate change on African roads. The focus of this project was to compile this data into a central location and compare climate change costs for each African country. These comparisons will identify the African countries with the potential for extremely high costs due to climate change. By indentifying countries with the highest exposure to the impacts of climate change, more country specific research can be performed. The countries identified as part of this study will be able to utilize the available climate change studies and begin to act in order to mitigate significant climate change risks.

Regardless of global green house gas emissions, the annual global mean average temperature is expected to rise 2 degrees Celsius by 2050 (World Bank 2009a). This temperature increase will create potential for more intense and more frequent rainfall, drought, floods, heat waves, and other extreme weather events depending on the region. Communities need to take measures that "reduce the vulnerability of natural and human systems against actual and expected climate change effect" (IPCC 2007). Development and adaptation progress may come to a standstill or reversed as extreme weather events and rising sea levels take their tolls on communities. Infectious and diarrheal diseases will even have an impact on health standards. Agricultural productivity will also be negatively impacted as temperature and precipitation levels change.

Methodology

The issue of monetarily quantifying climate change adaptation has been brought to the forefront by the United Nations Climate Change Conference. The current study attempts to narrow quantitative efforts to paved and unpaved roads in Africa and expand current quantitative natural disaster data to climate change adaptation. The result will provide a quantitative comparison of climate change impacts across Africa on the road transport sector.

The World Bank defines adaptation costs are those “incurred by societies to adapt to changes in climate.” Operationalizing this definition is difficult. Adaptation costs are considered the costs of planned, public policy adaptation measure and exclude the costs of private adaptation. Adaption costs are estimated based on a reasonable population and GDP growth used to establish a development baseline.

Each African county’s road inventory was recorded using a percentage allocation methodology. The total road inventory for each country was obtained by available direct data or the commercial database of international road data (IRF 2009). The road inventory was then divided into the respective country’s climate zones breakdowns. GIS population distribution maps and climate zone maps where overlaid with one another in order to determine where population distribution and climate zone imbalances existed (ESRI 2010). For the countries where population distributions differed from climate zone allocations, the road inventory allocation was modified to reflect the population imbalance.

Climate models were selected from the list of twenty-sex IPCC approved models. Two global models were utilized as a baseline climate model for each country: global wet and global dry. These global models, which have a foundation in soils moisture effects are based on earlier work by the authors for the World Bank and represent NCAR_ccsm3-A2, wet, and CSIRO_mk2-AS, dry (WB report 2009a). In order to best represent an individual country's climate change impact two models were selected for each country, a median model and a maximum model. The data from these climate models was condensed into four sections for purposes of analysis:

1. Global effect – the average effect of the global wet and the global dry climate models on the infrastructure
2. Country Maximum – the average effect of the models that had the greatest effect on the specific country in terms of temperature and precipitation
3. Country Median – the average effect of the models that displayed the median effect on the specific country in terms of temperature and precipitation
4. Maximum effect – the maximum effect from the previous three categories annually in terms of overall cost impact on the infrastructure.

Precipitation and temperature are the primary stressors of road surfaces. Engineering-based models have been created that estimated the impact of climate stressors on individual infrastructure categories. These models were used to determine the cost impacts associated with paved and unpaved roads for each of the climate model scenarios. Annual maintenance and rehabilitation costs were calculated through 2100.

A common evaluation metric was created in order to compare each of the countries. Creating this metric is a challenge because of the vast differences in African Countries. The comparative metric must reflect the relative impact climate change has on a country while not overly weighting the cost of climate change. Impact Factor was created to provide the necessary relative comparison metric. The impact factor represents the degree of enhancement a country could have achieved given no climate change occurred.

The data used in this analysis is based on the maximum effect climate model without adaptation. The data from the max effect climate model is most frequently asked for by policy makers. From a policy stand point, understanding the worst case scenario and preparing contingency is important.

Furthermore, utilizing the worst case scenario demonstrates the need for urgency in expanding a country's infrastructure. Funds from the UN, World Bank, and other international banks will be more easily awarded when using a worst case data.

The methodology of analyzing data in this section involves displaying the data visually. In order to do this, two related climate change metrics are organized into XY scatter plots.

Salient Finds and Recommendations

The most vulnerable countries will be identified in the following three categories: 1) African countries which have the "highest value" roads, 2) African countries affected the most by climate change, and 3) African countries able to gain the greatest advantage through adaptation. These important categories will help policy makers identify the most in need countries within Africa.

The data indicates Sudan, Ethiopia, Eritrea, Niger and Mali are countries with low road densities. These countries have a significant interest in protecting their roads from climate change impacts and expanding their existing infrastructure. These countries share similar sizes and climate zones; Eritrea is smaller but still shares similar climate zones. The climate zones consist of desert, semi-desert and steppe. Each country is part of the Sahel, the transitional ecoclimatic zone that separates the Sahara desert in North Africa from the savannas to the South. These countries' population centers are typically located in the cooler areas in the country, leaving large geographic areas sparsely populated. Connecting these communities and maintaining road connections will be a difficult task.

Malawi, Mozambique, Chad and Zambia have the highest total cost as % of GDP. Chad and Malawi are also impacted with high total average costs. It is in the interest of policy makers within these countries to take measures to adapt for climate change. Malawi, Mozambique and Zambia are neighbors in Southern Africa. Each has a low income level, is ecologically diverse and highly populated. Mozambique and Zambia are large countries, while Malawi is a small country. The ecological diversity and large population, more so than country size, are what create potential for large climate change impacts. Chad is a very large country in West Africa with a low income level and a population of approximately 10 million (medium sized population for Africa). Chad is also ecologically diverse, being part of the Sahal desert region. Chad's ecological diversity and large road system, due to its size, create the potential for large climate change impacts.

Malawi, Chad, Togo, Burundi, Niger and Djibouti have the highest impact factors. These countries are prime candidates for decreasing the impact of climate change through adaptation. Each of these countries has impact factors around or greater than 600%. Malawi and Chad were previously identified as highly impacted with regards to climate change costs. Each of these countries has a low income level; Djibouti has the highest with a lower middle income level. These countries vary in size and population, which does not seem to have a large effect on impact factor. Each is ecologically diverse: Chad, Niger and Djibouti being drier desert climates; Malawi, Burundi and Togo are wetter climates in the deciduous and montane zones. All climate zones have high potential for being susceptible to climate change. The largest contributing factors in impact factor are climate change cost and kilometers of paved roads. High costs and fewer kilometers of paved roads are contributors to high impact factor. The high costs Malawi and Chad experience from climate change create the high impact factor even though their existing paved road infrastructure system is large. Chad is ranked 13th among African countries with the most paved roads, Malawi 16th. Niger, Togo, Djibouti and Burundi have lower costs but a small paved road infrastructure. Niger is ranked 28th among African countries with the most paved roads; Togo 34th, Djibouti 37th and Burundi 38th. The combination of relatively high costs and few kilometers of paved roads in addition to delicate ecosystems create these high impact factors.

It is promising that adaptation is so beneficial to the highest impacted countries. Malawi and Mozambique face extreme climate change impacts, yet they have the ability to greatly mitigate these impacts. Botswana, Democratic Republic of Congo and Kenya do not see the large benefits adaptation creates; regardless, benefits are created.

Chad, Malawi and Niger are notable for appearing extra vulnerable to climate change. This is not entirely surprising. Countries with low GDP and few roads are highly susceptible to climate change. The majority of African countries fit this description. Simply identifying the countries in the greatest need should not preclude any of the other countries from aid. Nearly every community in Africa is highly vulnerable to climate change impacts. This analysis simply attempts to identify starting points for researchers and policy makers. Adaptation proves beneficial to the majority of African countries.

Implications

Development is key to decreasing adaptation costs (World Bank 2009a). The greater the baseline level of development, the smaller is the impact of climate change; and, therefore the smaller level of adaptation. While development increase climate change vulnerabilities due to the increased value of infrastructure, these vulnerabilities are more easily handled with the larger GDP development brings about.

Climate change conscious development will be needed to prepare communities for the future. Climate proofing infrastructure to make it resilient to climate risk is a superior development strategy than simply building infrastructure without acknowledging the risks of climate impacts.

Since there is inherent uncertainty surrounding climate change, strategies are needed that is flexible to new climate knowledge. Climate change is a gradual process so designing for limited or no change in climate conditions while waiting for better information may be a sound strategy today; but as climate change occurs high maintenance costs and earlier than expected asset replacement may create extremely high costs. Policy makers will need to weigh current costs of investments against benefits for a large range of climate outcomes (World Bank 2009a).

Introduction

The Economics of Adaptation to Climate Change (EACC) study, sponsored by The World Bank, attempts to quantify costs associated with climate change. These "adaptation" costs reflect the additional costs associated with long-term climate alterations, such as droughts, sea coast change and flooding frequency. Identifying adaptation costs for developing countries can help inform decision makers so they can better understand and assess risks created by climate change. Furthermore, better design and development strategies can be adopted to help minimize adaptation costs.

This study builds on previous research done by Paul Chinowsky at the University of Colorado. Climate change data for the entire continent of Africa was used to estimate costs associated with the impacts of climate change on African roads. The focus of this project was to compile this data into a central location and compare climate change costs for each African country. These comparisons will identify the African countries with the potential for extremely high costs due to climate change. By indentifying countries with the highest exposure to the impacts of climate change, more country specific research can be performed. The countries identified as part of this study will be able to utilize the available climate change studies and begin to act in order to mitigate significant climate change risks.

Motivation

Regardless of global green house gas emissions, the annual global mean average temperature is expected to rise 2 degrees Celsius by 2050 (World Bank 2009a). This temperature increase will create potential for more intense and more frequent rainfall, drought, floods, heat waves and other extreme weather events, depending on the region. Communities need to take measures that "reduce the vulnerability of natural and human systems against actual and expected climate change effect" (IPCC 2007). Development and adaptation progress may come to a standstill, or reversed, as extreme weather events and rising sea levels take their tolls on communities. Infectious and diarrheal diseases will even have an impact on health standards. Agricultural productivity will also be negatively impacted as temperature and precipitation levels change.

Assuming greenhouse gas emissions are not drastically reduced, the average global temperature will increase more than 2 degrees Celsius by the end of the century. This change will likely cause irreversible and catastrophic impacts such as mass species extinction, extreme sea level changes and exponential growth in diarrheal and cardio-respiratory diseases (World Bank, 2009a). Reducing and preventing greenhouse gas emission is the only way to mitigate exacerbating the current climate change situation.

Disasters come in many varieties. The general public typically sees disasters as hurricanes, earthquakes, floods, etc. These types of disasters typically occur at an event time and are followed by a response and recovery phase (Chinowsky 2010). Disasters that are composed of long-term alterations, such as droughts, sea coast change and flooding frequency receive less attention from the general public, since their effects are slow evolving. Without the obvious and immediate impacts of "standard" disasters, long-term disasters receive far less media attention. However, the effects of long-term disasters are no less severe. The current attention climate change is receiving has given these events more exposure. Juxtaposed with the tangible impacts, which can be anticipated and planned for, the intangible impacts of climate change are more difficult to anticipate, plan for and even accept (Chinowsky 2010). Actions toward preparing for climate change have been slow in development. Many communities are still in the decision stage of climate change, focusing on discussions surrounding the existence of climate change. This paper attempts to provide African communities with insight into potential climate change impacts and show how creating climate change specific adaptations today can provide significant cost savings in the future.

Climate change has global impact. The impacts that climate change will have on the developed versus the developing world will be very different. The developing world faces impacts that are more severe.

Not only do developing countries not have the economic resources to successfully respond to long-term change, they have not yet developed robust infrastructure which will sustain future growth. These communities continued economic growth will be hindered by the potential impacts of climate change. Slow economic growth is already preventing needed development from occurring throughout Africa. Climate change impacts will cost African countries significant amounts of money; money that is needed elsewhere. These costs will continue to slow economic growth across Africa.

Fragile infrastructures are more susceptible to climate change. Communities with fragile or limited infrastructures are also more dependent on these infrastructures. These two factors combine to create large potential for significant changes to the social fabric of communities as climate change negatively impacts community infrastructures. Community relocation or long-term isolation are two possible outcomes of climate change (Chinowsky 2010).

The impacts of climate change often become a human rights issue. The United Nations Human Rights Council passed a resolution in 2009 focusing on the need to address climate change in terms of effects on human rights stating climate change, “will be felt most acutely by those segments of the population who are already in a vulnerable situation …” (United Nations 2009).

Objectives

Existing climate change literature typically examines climate change policy and related policy costs (e.g., carbon taxes and cap-and-trade system) but few studies address climate change adaption (Stern 2007; Claussen et al 2001; Nordhaus 2008). Current impacts associated with responding to extreme weather events and natural disasters have been studied, the changes in intensity or frequency brought about by climate change have not been investigated. Also, impacts from long-term changes in climatic norms have not been examined (World Bank 2009a). Therefore, anticipating climate change related infrastructure costs is a challenging task (TRB 2008). While direct cost models exist for natural disasters in various contexts, significant climate change costs do not exist since no significant event has occurred. Additionally, a wide range of long-term scenarios have been depicted for climate change demonstrating the large amount of uncertainties involved in predicting climate change costs.

The EACC study objectives are: "Develop a global estimate of adaptation costs for informing the international community's efforts to help the developing countries most vulnerable to climate change meet adaptation costs and to help decision makers in developing countries assess the risks posed by climate change and design strategies for adapting to it." Integrating robust adaptation strategies will need to be integrated into development plans and budgets to accomplish these objectives. Strategies must deal with uncertainty and competing social and economic needs.

Based on research being conducted for the World Bank (World Bank 2009a), the United Nations and the State of Alaska (Larsen et al 2008), this paper quantifies the relative impacts of climate change on the continent of Africa. To simplify the process and increase the accuracy of the finding, the analysis is placed in the context of a single infrastructure type, paved and unpaved roads, representing geographic and economic diversity (Chinowsky 2010). This data will provide public officials, attempting to prepare for climate change, with much needed data on the cost impacts created by climate change.

Background

Climate change in the infrastructure sector has been discussed in a qualitative manner and typically focuses on broad recommendations and warnings (World Bank 2009a). This paper will attempt to apply quantitative adaptation approaches to climate change by utilizing data collected from responding to natural disasters. The knowledge accumulated from society's past experience in dealing with single event disasters can be used to shift the focus of climate change from qualitative to quantitative. While single event disasters (floods, earthquakes, droughts, etc.) are not directly analogous to climate change, the response and recovery of these types of disasters can provide foundational models which can be used to anticipate the impact and adaptation response that could occur as a consequence of climate change (Chinowsky 2010). Data from local, regional and nation government disaster responses have been documented over several decades. This data can provide a sound basis for climate change response models.

As climate change events begin to occur, individuals will naturally begin to learn and adapt to the changing severity and frequency of natural events. Adaptive learning will help offset the negative effects brought about by these changes (Chinowsky 2010). Improvements in capital stock will provide better responses designed to maximize resources and infrastructure designed to minimize damage. Adaptation is most beneficial for opportunities with extended useful life scenarios. The transportation and energy infrastructure of most nations typically have the greatest capacity for adaptive improvement design in response to climate change events (World Bank 2009a).

Although it is not explicitly stated, the adaptive learning concept is at the core of natural disaster studies undertaken by agencies such as the Federal Emergency Management Agency (FEMA). Clemson University (Clemson, 1999) and the State of Florida (Florida, 1996; Florida, 2002) have generated major studies about the costs of adaptation and the adoption of proposed solutions. Unfortunately, little adaptation opportunities have been found in the road sector due to the established engineering standards for paved roads (Chinowsky 2010). Continued efforts are required to create new concepts that are viable alternatives, which can be adopted by standardized and make economic sense. Unpaved roads in developing countries create a bigger challenge due to the limited available economic stimulus.

Research completed by the Transportation Research Board in the United States, the Scottish Executives and Austroads in Australia are notable efforts in general weather studies and qualitative predictions (TRB 2008; Galbraith et al 2005; AUSTROADS 2004). These reports compare weather-related disasters and their perceived severity with predicted climate change impacts. Further studies have advocated determining specific impacts of temperature, rain, snow and ice, wind, fog and coastal flooding on roads (CCSP 2006). These studies show that the impact on roads is severe in all studies involving rainfall, with slightly less severe impacts by other weather conditions.

The global threat posed by climate change has received more attention in recent years. Much of that focus falls on developing countries, countries that are least able to adapt to the threats of climate change (World Bank 2009a). The United Nations Framework Convention on Climate Change (UNFCCC) has focused on the adaptation and mitigation by countries to climate change (UNFCCCC 2010). Developing countries were the focus of that effort. Identifying potential threats, adapting to change, incorporating adaptation into development plans and securing climate change adaptation funding are all pieces of the study (UNFCCC 2009, UNFCCC 2010).

Developing countries, planning for climate change are faced by two complicated factors: 1) current lack of infrastructure and 2) widespread changes predicted due to climate change. According to World Bank, Africa (excluding South Africa) had only 171,000 kilometers of paved roads. For comparison purposes, that is around 18% fewer roads than Poland, which is roughly the size of Zimbabwe. African communities have been focusing on the completion of the trans-African highways, which has removed some focus on existing roads causing them to deteriorate. This is especially unfortunate for those communities who depend on these roads. As evidence of this trend, World Bank has shown that 17% of sub-Saharan African primary roads were paved but in 1998 only 12% of primary roads were paved. 80% of unpaved roads were considered in fair condition 85% of rural feeder roads in poor condition and could not be used during the wet season. In an extreme case, only 30% of the Ethiopian population has access to all-weather roads (Mutume 2002).

Climate change is estimated to impact water resources, agriculture and food security, sea levels and coastal ecosystems, rural access, healthcare, energy supply, education and infrastructure. The African

Development Bank Group has estimated African nations require around $40 billion USD per year to help handle climate change related challenges (Kaberuka 2009).

Methodology

The issue of monetarily quantifying climate change adaptation has been brought to the forefront by the United Nations Climate Change Conference. The current study attempts to narrow quantitative efforts to paved and unpaved roads in Africa and expand current quantitative natural disaster data to climate change adaptation. Multiple climate scenarios, over an extended period of time, are utilized in order to limit the uncertainties associated with potential climate change outcomes. The result will provide a quantitative comparison of climate change impacts across Africa on the road transport sector.

The timeframe chosen for this study is from present to 2100. This timeline was chosen because of the growing uncertainties of climate change impacts beyond this period. The complexity of the analysis favors precise estimates in the near term.

Africa is an extremely diverse continent. The cultures, climate zones, politics, economies and development levels are just a few areas that differ drastically. The data from climate change models are also diverse. These variations create challenges in establishing a methodology for producing meaningful results. This study is divided into several distinct pieces. The results from these pieces were then combined into an overall finding. This section provides background on these pieces and discusses the overarching analytical measurement used to compare African countries. The majority of this methodology was created from a collaborative effort between multiple parties (Chinowsky 2010, World Bank 2009a).

Defining Adaptation Costs

The World Bank defines adaptation costs are those “incurred by societies to adapt to changes in climate.” Operationalizing this definition is difficult. Many studies point to economic development as the best way to handle adaptation (Project Catalyst 2009, Stern 2007). Development diversifies economies, which increases climate change resiliency, as dependence on vulnerable sectors decreases. Development creates more resources that can be used to handle climate change risks.

The World Bank suggests that adaptation measures range from discrete adaptation to climate-smart development to development not as usual. Adaptation costs are defined as costs in addition to the costs of development. Development costs that need to be undertaken or would have been undertaken regardless of climate change are not included in adaptation costs. The costs of doing more or different development are included.

Adaptation deficit is utilized to establish a development baseline. This baseline projects economic growth of a country in the absence of climate change. The additional effect of climate change, in most cases, will reduce this growth due to additional costs associated with climate change. The difference in these projections will provide a quantitative amount for climate change. Adaptation deficit has two meanings. One meaning addresses the current shortfalls countries have for current climate conditions. These shortfalls exist due to the uncertainties surrounding climate change. Resources are not being allocated, or are being under allocated, because of under informed communities. The cost of fixing these shortfalls to bring countries up to “acceptable” development levels for dealing with current climate conditions is one definition of adaptation deficit. The second definition deals with the inability of poor countries to create the capacity to adapt to climate change because of lower stages of development. Development decreases this type of adaptive deficit.

The World Banks asks, “Should the costs of climate proofing infrastructure be measured relative to current provision or to the levels of infrastructure countries would have had if they had no adaptation deficit?” Due to the difficulties surrounding establishing the costs of closing adaptation deficits, the study does not address these costs or measure adaptation from a baseline which the adaptation deficit has been closed. Studies do address these costs are likely to have higher adaptation costs.

The adaptation measures focus on publicly planned adaptation with focus on 'hard' options involving engineering solutions. The objective of this focus is to help government plan for climate risks.

Establishing a Development Baseline

While establishing an adaptation deficit is not required, creating a development baseline is. Reasonable development paths were assumed per country sectors. In the infrastructure sector, the baseline is established by considering historical levels of infrastructure performance.

Determining how much to adapt is a problem in economics (World Bank 2009a). Resources must be allocated to adaptation as well as other needs. Desirable and feasible levels of adaptation depend on available income and resources. Alternatives exist for determining costs. The extremes involve adapting completely so that communities are as well off as before climate change, or performing no adaptation, and simply deal with the full impacts of climate change. A reasonable alternative to these two extremes is to define adaptation as the cost of restoring pre-climate change welfare standards to the point where benefits exceed costs. This study defines adaptation costs as the costs of development initiative needed to restore welfare to levels prevailing before climate change without taking into account residual damage. For the infrastructure sector, the level of service is the welfare proxy.

Road Inventory

Each African country's road inventory was recorded using a percentage allocation methodology. The total road inventory for each country was obtained by available direct data or the commercial database of international road data (IRF 2009). This data had three existing categories: primary, secondary and tertiary. No validation was done on the classification system. This data, also, identified roads as paved or unpaved. Thus, each country had six road classifications.

The road inventory was then divided into the respective country's climate zones breakdowns. The method used to divide is illustrated in the following example. Niger has two climate zones: desert, which covers 85% of the country and steepe, which covers 15% of the country. Given that Niger has 1,000 kilometers of primary paved roads, then 850 kilometers of primary roads would be assigned to the desert climate zone and 150 kilometers would be assigned to the steppe climate zone. Each of the road inventory types would be divided between climate zones in this manner.

This method is simple and typically effective but it does leave room for larger error in select cases. Sometimes a country's road inventory will not break down based on climate zones. Significantly more roads may exist in one climate zone than another even though this former climate zone is smaller. Libya is an excellent example of this scenario. The populated areas in Libya are along the Mediterranean coast, where small pockets of warm Mediterranean climate exist. The larger portion of Libya's roads will exist in these pockets. By far, the largest climate zone in Libya is warm desert. Therefore, dividing Libya's road inventory by the previously illustrated method will erroneously divide roads into the warm desert climate zone. The following section will illustrate how this scenario is handled.

Population Centers

Countries typically have a comparable population distribution to their respective climate zones. This is not true for certain geographic areas where population density differs significantly from the portions of the climate zones. In North Africa, arid desert climates are the vast majority of the geographic area. However, the population densities are in the narrow band of temperate climate along the Mediterranean Sea coast. Therefore, dividing road inventory by country portions of climate zones produces skewed results.

GIS population distribution maps and climate zone maps were overlaid with one another in order to determine where population distribution and climate zone imbalances existed (ESRI 2010). For the countries where population distributions differed from climate zone allocations, the road inventory allocation was modified to reflect the population imbalance. The following example explains the modified distribution. For a climate zone that encompasses 20% of a country, but contains 40% of the country's population, the road inventory allocation is adjusted to reflect the 40% distribution rather than the 20% climate zone distribution. This method only works with the assumption that greater population densities contain greater road densities, due to the increased need for infrastructure development in highly populated areas. This adjustment was not necessary for every country, but every country compared with a GIS population distribution map, to ensure that the proper road inventory allocation was made.

Climate Zones

To apply the proper climate models to a geographic region climate zones must be identified (Chinowsky 2010). Furthermore, infrastructure elements are affected differently depending on which climate zone they exist in. Specific infrastructure impacts can be paired with their specific climate zone and corresponding climate change model. All the African countries are subdivided into their respective climate zones. This was done using the Koppen-Geiger classification system. Established by Vladimir Koppen between 1884 and 1936, the Koppen method of climate zone classification focused on the annual temperature and precipitation cycles throughout the world (Lohmann et al 1993). Five primary climate classifications exist under this system: tropical, arid, temperate, cold and polar. Each classification has specific temperature and precipitation ranges. These primary categories were further divided using smaller ranges of humidity and precipitation, creating 31 climate zone classifications. Rudolf Geiger refined and mapped all the climate zones in 1961. Koppen and Geiger's work provide a strong basis for determining climate zones and their classification system is used throughout the world. Today, researchers continually refine, track and map these climate zones.

Utilizing the Koppen-Geiger map provided the framework for the current study to divide the counties into zones. The Koppen-Geiger map was combined with a GIS map allowing climate zone percentage of each country to be determined. Depending of the country, this division ranged from 2 (such as Niger) to 10 (such as Tanzania) distinct climate zones.

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General Circulation Models

Climate models were selected from the list of twenty-six IPCC approved models. The inherent uncertainties involved in climate projections must be handled with a range of adaptation cost and a range of climate scenarios. The selected models represent variances in both projected precipitation increases and development scenarios within given countries (IPCC 2007). The models contain annual predicted precipitation and maximum temperatures. Multiple models are utilized in an effort to provide a broad picture of potential climate change impacts without focusing on extreme possibilities. These models capture a diversity of predictions and capture the inherent uncertainty of climate projections. They also report specific climate variables, such as temperature and precipitation minimum and maximum changes, which are needed for sector analyses.

Two global models were utilized as a baseline climate model for each country: global wet and global dry. These global models, which have a foundation in soils moisture effects are based on earlier work by the authors for the World Bank and represent NCAR_ccsm3-A2, wet and CSIRO_mk2-AS, dry (WB report 2009a).

In order to best represent an individual country's climate change impact two models were selected for each country, a median model and a maximum model. Since the focus of this study is on road infrastructure, temperature and precipitation have the largest effect on cost. Therefore, the temperature and precipitation properties of climate models where used to determine which model to use. Twenty-two models were investigated with a focus on their respective precipitation and temperature averages for each decade from 2010 through 2100. The annual wet and hot properties were totaled through 2100 for each country. Using the totals, the corresponding maximum model and median model were selected for each country. This process produced four country models: country maximum hot, country maximum wet, country median hot and country median wet. Including the two global models, six total models are analyzed for each country.

The data from the six climate models was condensed into four sections for purposes of analysis:

1. Global effect – the average effect of the global wet and the global dry climate models on the infrastructure
2. Country Maximum – the average effect of the models that had the greatest effect on the specific country in terms of temperature and precipitation
3. Country Median – the average effect of the models that displayed the median effect on the specific country in terms of temperature and precipitation
4. Maximum effect – the maximum effect from the previous three categories annually in terms of overall cost impact on the infrastructure.

Road Impacts

This section provides a summary of the methodology used by The World Bank (2009a) to determine the impacts of climate change on paved and unpaved roads. This process is based on the effects of precipitation and temperature on paved and unpaved roads. Precipitation and temperature are the primary stressors of road surfaces. Engineering-based models have been created that estimate the impact of climate stressors on individual infrastructure categories. These models quantify the cost impact of a specific stressor based on the intensity of the stressor and the type of infrastructure it affects (Chinowsky 2010). The impacts of stressors are translated into stressor-response values that represent quantitative impacts a specific stressor has on a specific infrastructure element. For example, an increase in precipitation will have a specific quantitative impact, which decreases road lifespan (Chinowsky 2010). Another example would be an increase in precipitation will have increased maintenance cost for existing roads. There are two general categories these stressor-response factors are divided into: new construction costs and maintenance costs. New construction costs are considered the additional costs associated with the design and construction of an infrastructure asset, which are directly due to expected climate change impacts over the lifespan of the asset. Maintenance costs (or savings) are considered the additional costs associated with achieving an infrastructure asset's design lifespan, which are directly due to expected climate change impacts over the lifespan of the asset. More simply put, construction costs are those costs involved with road design and construction that will be additionally incurred due to climate change; maintenance costs are those costs involved with road maintenance that will be additionally incurred due to climate change. For both categories, the goal is the establish costs required to preserve the design life span for the infrastructure asset. The underlying concept of this goal is the preference for retaining infrastructure rather than frequently replacing infrastructure.

Two general approaches are utilized when determining stressor-response values for new paved road construction costs. One approach deals with the costs associated with changing building codes for paved roads; the other approach deals with incremental costs associated with design changes for unpaved roads. The building code methodology is based on the concept that new paved road codes will be updated in order to prepare for significant climate change stressors that are predicted to occur during road life spans. Historic evidence provides a basis that a major update of design standards results in a 0.8 percent increase in construction costs (FEMA 1998). The readily available data suggest that such code updates would occur with every 10 centimeter (cm) increase in precipitation or 3 degree Celsius maximum temperature increase (Blacklidge Emulsions 2009; NOAA 2009).

A more direct method is used to determine unpaved road construction costs. The stressor-response relationship for unpaved roads ties the change in construction costs with the change in maximum monthly precipitation. Research findings have shown that 80% of unpaved road degradation can be attributed to precipitation (Ramos-Scharron and MacDonald 2007). Tonnage of traffic and traffic rates attribute to the remaining 20%. Temperature has not been found to have a cost correlation with the cost of building unpaved roads. Therefore the base construction costs for unpaved roads experiences an 80% of the percentage increase of the maximum monthly precipitation. For example, if precipitation increases 10% in a location, then the base construction cost of unpaved roads in the locations increases by 80% of this amount (i.e. 8%).

A large element of uncertainty exists with both these methodology because perfect climate change foresight is assumed. Stressor-response values represent the relationship between road construction costs at the time of initial design and construction and climate change costs projected during the road's lifespan.

The methodology for determining maintenance costs is similar to the construction cost methodology. For paved road, maintenance costs are those costs required to prevent a reduction in paved road lifespan caused by potential climate change stresses. To calculate this cost, the percent change in climate stress is associated with a reduction in paved road lifespan. These incremental climate change stresses are scaled for their respective effects on maintenance cost. Research has shown that precipitation-related maintenance represents 4 percent of maintenance costs and temperature-related maintenance represents 36 percent of costs for paved roads (Miradi 2004). Once lifespan reduction has been determined, the avoidance cost is calculated by multiplying the potential percent reduction in lifespan by the initial construction cost of an asset. For example, a 10% potential lifespan reduction for an asset will increase maintenance costs by 10% of the assets construction cost.

The same methodology is used to determine unpaved road maintenance costs as unpaved road construction costs. Unpaved maintenance costs are associated with changes in the predicted maximum monthly precipitation. As previously stated precipitation causes 80% of unpaved road degradation.

Accordingly, unpaved maintenance costs increases by 80% of the monthly precipitation change. For example, if the predicted maximum monthly precipitation increases by 1%, unpaved road maintenance costs will increase by 0.8% for the month.

These approaches were used to determine the cost impacts associated with paved and unpaved roads for each of the six climate model scenarios. Annual maintenance and rehabilitation costs were calculated through 2100.

Impact Factor

A common evaluation metric is needed in order to compare each of the countries. Creating this metric is a challenge because of the vast differences in African Countries. Variations include amount of current road inventory, annual expenditure on roads, country GDP and the projected climate change cost for each country. The comparative metric must reflect the relative impact climate change has on a country while not overly weighting the cost of climate change. Impact Factor was created to provide the necessary relative comparison metric. The following formula represents the quantitative term:

$$IFx = (CCx / SRCx) / PRx$$

Where:

- X: A specific country
- IF: Impact Factor for a country
- CC: Total estimated climate change cost for a country including both maintenance and new costs through 2100
- SRC: Cost of constructing a kilometer of new, secondary paved road
- PR: Current paved road inventory within a country in kilometers

The impact factor represents the degree of enhancement a country could have achieved given no climate change occurred. The percentage indicates the increase in paved roads that could have been achieved if money was not being diverted to climate change adaption. Adaptation costs should reduce impact factor because these costs work to reduce the negative effects associated with climate change.

The cost of constructing a kilometer of new, secondary paved road is based on World Bank projects in Mozambique, Ethiopia and Ghana. These costs are comparable to international cost indexes. Costs differ by less than 5% across Africa; therefore an average cost of $250,000 is used throughout Africa.

Roads have an impact on communities through many different ways. Indicators such as maternal health, level of education, poverty, gender equity, economic development and transport are higher in areas where the rural areas have greater accessibility to developed urban centers and there is greater connectivity between communities. (Roberts et al 2006). This metric was designed to capture an underlying economic component, which reflects a country's need to continually enhance its infrastructure. Countries with small existing road infrastructure will be affected be a larger degree than countries with large existing road infrastructure.

The impact factor metric is designed to illustrate the relative impact of climate change on road infrastructures. A country with limited infrastructure is impacted to a greater degree by higher maintenance and development costs than a country with a robust infrastructure. Even though both countries are faced with various development and maintenance costs, the limited country is greatly affected while the other is more easily able to maintain an infrastructure capable of creating economic stimulus.

Result Display Methodology

The data used in this analysis is based on the maximum effect climate model without adaptation. The data from the max effect climate model is most frequently asked for by policy makers. From a policy stand point, understanding the worst case scenario and preparing contingency is important. Furthermore, utilizing the worst case scenario demonstrates the need for urgency in expanding a country's infrastructure. Funds from the UN, World Bank and other international banks will be more easily awarded when using a worst case data.

The methodology of analyzing data in this section involves displaying the data visually. In order to do this, climate change data is organized into XY scatter plots. Two related metrics are compared using XY scatter plots. The methodology behind the metric comparison and the resulting conclusion is discussed in detail in the following sections. The axes of the graphs have been modified to best organize the data. In some cases axes are reversed to capture the desired pattern. Also, axis scales have been truncated to best organize the data. Only the countries with least desirable data are shown. In several cases outliers exists. Outliers are removed from the graph in order to produce useful figures. The sections below discuss outliers, in order to capture the rationale behind removing them.

The axes of the plots are ordered in a way to form four areas: Areas A, B, C and D. Area A in the graph is the least desirable area. Country data that plots in this area indicates worst case scenarios for both of the metrics being compared. Areas B and C represent country data that is worst case for one of the two compared metrics. Area D in the graph is the most desirable area. Country data that plots in this area indicates more desirable metric levels. While Area D is the most desirable area, the graph axes have been trimmed to capture the countries with the worst data. The countries that are not shown on the graphs have more desirable metric data. Therefore, all countries that appear on the figures have undesirable metric levels.

Results

The radically different economic levels, climate regions, geographic sizes, populations and politics that exist within Africa make direct comparisons difficult. This report does not attempt to analyze each country in detail; rather, it attempts to identify the countries that stand out as especially vulnerable to climate change. The most vulnerable countries will be identified in the following three categories: 1) African countries which have the “highest value” roads, 2) African countries affected the most by climate change and 3) African countries able to gain the greatest advantage through adaptation. These important categories will help policy makers identify the most in need countries within Africa.

The attempt to identify the African countries in the most need is done in an attempt to highlight the highest risk areas within Africa regarding climate change impacts. It is not intended to be used as an indication to provide less assistance for African countries not identified. The developing, unstable nature of African countries makes each a relevant candidate for climate change aid. This data must be used in coordination with each country's culture. The individual cultures within Africa will have a large impact on how the impacts of climate change are handled. Often times these cultural impacts are difficult to understand and quantify. Regardless the results provided will help illuminate climate change impacts.

The best and worst countries will be identified in each category. More emphasis is put on the worst countries. General information is given for the identified countries, such as GDP, ecological diversity, population, location, etc.. This information is provided so that potential insight may be gained; although, this information does not provide direct correlation to climate change impacts. Simply because a country with bigger climate impacts is also a geographically large country does not mean that all large African countries have big climate impacts. A specific example: Malawi is highly affected by climate change and has very similar climate zones to Republic of Congo but Republic of Congo is not nearly as affected by climate change as Malawi. It is a combination of a myriad of variables that create high climate change impacts in one country but not another.

Highest Value Roads

The impacts of climate change on roads will hit communities with limited road structures the hardest. A country whose road system is weak will find its communities more quickly isolated due to road degradation. Robust road infrastructures provide resiliency to climate change impacts. As infrastructure degrades due to climate change impacts, alternate routes will be necessary. Countries that do not have the capacity to provide alternative routes must place higher values on existing roads. Proper maintenance of high value roads becomes mandatory in order to ensure road degradation is prevented. The costs associated with maintenance are mandatory to ensure communities are not left isolated from surrounding communities and external life lines. The countries identified in this section have a higher than average need for infrastructure expansion and road degradation prevention.

Climate change impacts may be wide spread, such as drought, or local, such as floods. Therefore, road degradation may be uneven within a country. This analysis does not drill down below the country level. This type of analysis would be helpful for local authorities. This analysis does show those countries with weak road infrastructure and provides good starting points for community focused analysis and research.

The methodology for determining road importance for a country is done by comparing the country's population, area and total kilometers of roads. The unpaved road network in Africa is extensive and communities depend on them. Unpaved roads are less costly to build; therefore, African communities are more likely to build these types of roads. Unfortunately, the impacts of climate change are harsh on unpaved roads causing drastic increases in necessary unpaved road maintenance cost. Simply using kilometers of paved roads would not reflect African community's dependence on unpaved roads.

By dividing the total kilometers of roads in a country by the area and the population of the country, the road to area ratio and road to population ratio can be found. These ratios represent road densities and are used to determine road importance. Countries with high road densities, such as South Africa, will have more roads, making individual roads less important. Countries with low road densities will depend on the few roads they have to a higher degree than countries with higher road densities. The figure below shows the African Countries with the lowest road densities. The table 1 in the appendix contains the data utilized to determine each country's road densities.

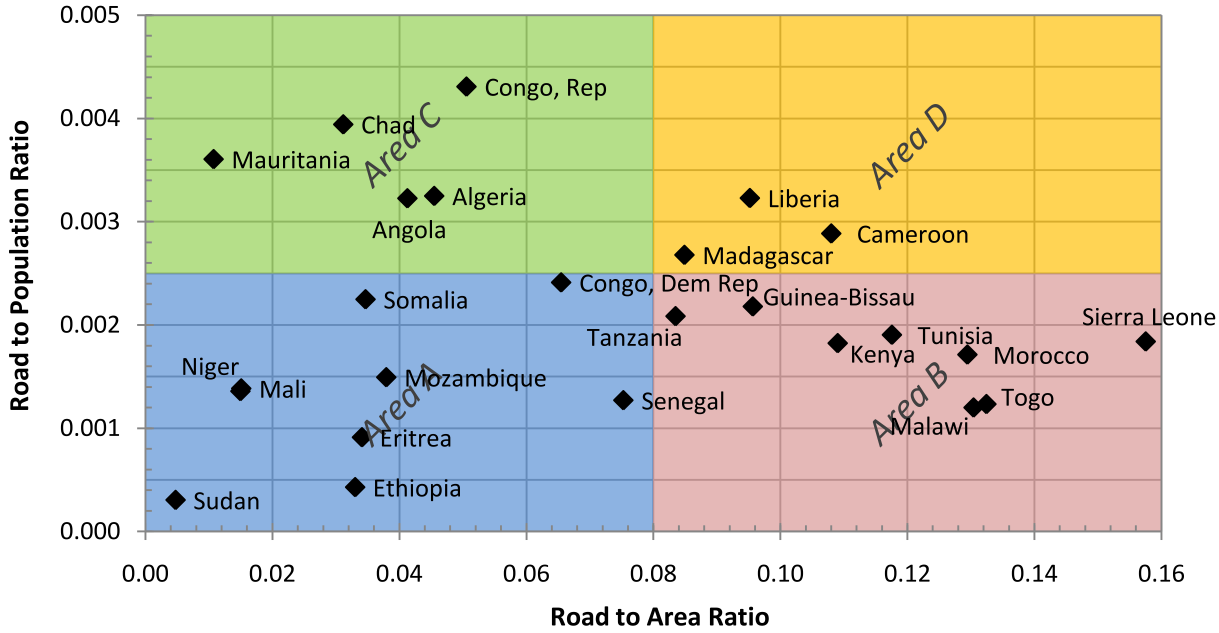

Figure 1: Road density scatter plot

The graph visually shows the road to population ratio and the road to area ratio for the African countries with the lowest road densities. The graph is divided in to four areas: Areas A, B, C and D. Area A highlights the lowest road densities in terms of population and area. Area B highlights the lowest road densities in terms of population but not area. Area C highlights the lowest road densities in terms of area but not population. Area D highlights relatively high road densities in terms of population and area. Area A is the least desirable graph location; Area D is, relatively, a more desirable graph location. Area B highlights relatively high road to area ratios but low road to population ratios. Area C highlights relatively high road to population ratios but low road to area ratios.

Countries in Area A have the highest probability for having insufficient road densities in terms of both population and area. These countries need to begin to take steps in protecting their current roads from climate change impacts and in expanding their current road infrastructure. Countries in Area B have a high probability of having insufficient road densities in terms of population. It is likely that large population centers in Area B counties have insufficient roads. Countries in Area C have a high probability of having insufficient road densities in terms of area. It is likely that intra-country infrastructure is lacking.

The data indicates Sudan, Ethiopia, Eritrea, Niger and Mali are countries with low road densities. These countries have a significant interest in protecting their roads from climate change impacts and expanding their existing infrastructure. These countries share similar sizes and climate zones; Eritrea is smaller but still shares similar climate zones. The climate zones consist of desert, semi-desert and steppe. Each country is part of the Sahel, the transitional ecoclimatic zone that separates the Sahara desert in North Africa from the savannas to the South. These countries' population centers are typically located in the cooler areas in the country, leaving large geographic areas sparsely populated. Connecting these communities and maintaining road connections will be a difficult task.

Zimbabwe, South Africa and Burkina Faso are countries with high road densities. These countries have a many kilometers of roads making both road and population to area ratios high. South Africa has the most number of roads in Africa, Zimbabwe is 5th and Burkina Faso is 6th.

Countries with large road to population ratios but small road to area ratios are Namibia, Botswana and Libya. Botswana and Libya have upper middle income levels and are large countries with small populations. Namibia has a lower middle income level and is a large country with a small population. The large areas of these countries require more kilometers of roads. The combination of larger road networks due to these countries sizes and their small populations creates the large road to population ratio.

Rwanda and Burundi are countries with large road to area ratios but small road to population ratios. Both have low income levels and are small countries with medium population levels. These poor, small countries have few roads. They rank 33rd and 34th in total kilometers of roads respectively. Rwanda and

Burundi's small size creates the large road to area ration. Their medium populations and few kilometers of roads create the small road to population ratio.

Even though these countries have high road densities, it is not an indicator that climate change will have no impact on these countries. Especially in the case of Rwanda, Burundi, Burkina Faso and Zimbabwe, since their low income levels prohibit proactively responding to climate change impacts and affording addition infrastructure costs due to climate change. Other metrics will need to be investigated to determine the potential threats climate change could pose for these countries.

Highly Impacted Countries

The cost of climate change is a direct indicator of the impact of climate change. Countries that incur large climate change costs are highly impacted by climate change. However, many of these countries have high costs due to the large amount of infrastructure that is being affected. Typically, these types of countries have a corresponding high GDP. For example, South Africa has a relatively high total average climate change cost of $4 million, but this cost is small compared to its $495 million GDP. It is those countries with high costs and smaller GDPs that are the most impacted.

Total average climate change cost is the total amount of climate change cost from 2020 to 2050. In other words, it is the estimated costs associated with climate change over 40 years. Average climate change is predicted on a decade basis using the methodology discussed in the Road Impacts section above. The cost data is estimated using the Max Effect climate change model.

In order to provide perspective on climate change cost, the total average climate change cost of a country was divided by the country's current GDP. This metric is call 'total cost as % of GDP'. The aim of this metric is to provide perspective on how large of a burden cost is on a country. The higher this percentage the larger the climate change cost burden is for a country. This metric does not reflect the true percentage of climate change cost to GDP, nor does it intend to do so. GDP is simply the current country's estimated GDP. To truly reflect the actually percentage of climate change cost to GDP, a growth rate (or decline) would need to be predicted so that future GDP would be predicted and total from 2020 to 2050. This entirely different metric would create much smaller percentages with extremely large factors of error. 'Total cost as % of GDP' is simply a metric used to reflect a county's climate change compared to their current GDP.

The figure below compares total average cost of climate change to the total average cost of climate change as a percentage of GDP for African countries with the lowest metric values. The table 2 in the appendix contains the data used in this graph for all countries studied. Both axes have been modified to properly organize the data. The Y axis has been reversed and truncates data above $12 billion. Two countries have costs above $12 billion; they are discussed below. The X axis has been reversed and truncates data below 10%. Countries with a total climate change costs as a percentage of GDP below 10% are not considered to be the highest impacted countries.

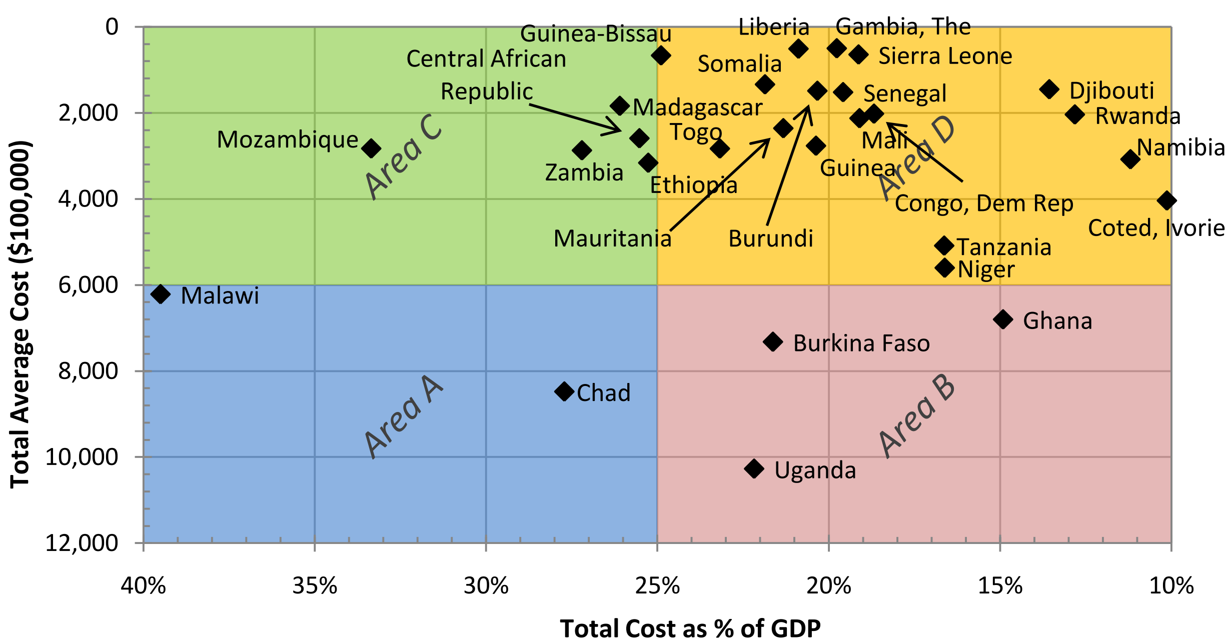

Figure 2: Cost analysis graph

Two outliers are not shown on this graph: Algeria and Nigeria. Both countries have estimated total costs over $16 billion. The high total average cost is due to the total kilometers of roads each country has. Nigeria has the second most kilometers of roads in Africa, second only to South Africa; Algeria is fourth. Algeria has the most kilometers of paved roads in Africa; Nigeria is fifth. Both of these countries have high GDPs; Nigeria ranks second to South Africa and Algeria ranks third. Therefore, Algeria and Nigeria have low total costs as percentage of GDP. The graph above attempts to capture the highest impacted countries so Algeria and Nigeria have been removed to better scale the graph. Nigeria would fit on the bottom right corner of the graph in Area B, while Algeria would not be shown because its total costs as percentage of GDP is below 10%.

The countries with the greatest cost impact from climate change are those in Area A and Area C to a lesser degree. The countries in Area A of the graph have high climate change costs, which represents a large fraction of their current GDP. Countries in Area C have lower climate change costs and this cost represents a significant portion of their current GDP. Countries in Area B have large costs as well as larger GDPs to absorb them. Countries in Area D have more manageable cost levels and larger GDPs to absorb these costs.

Malawi, Mozambique, Chad and Zambia have the highest total cost as % of GDP. Chad and Malawi are also impacted with high total average costs. It is in the interest of policy makers within these countries to take measures to adapt for climate change.

Malawi, Mozambique and Zambia are neighbors in Southern Africa. Each has a low income level, is ecologically diverse and highly populated. Mozambique and Zambia are large countries, while Malawi is a small country. The ecological diversity and large population, more so than country size, are what create potential for large climate change impacts. Chad is a very large country in West Africa with a low income level and a population of approximately 10 million (medium sized population for Africa). Chad is also ecologically diverse, being part of the Sahal desert region. Chad’s ecological diversity and large road system, due to its size, create the potential for large climate change impacts.

Countries with low climate change cost as a percentage of GDP are Botswana, Swaziland, Republic of Congo, Equatorial Guinea and Gabon. These countries may be able to allocate fewer resources to climate change adaption.

Botswana and Swaziland are in Southern Africa and are both mainly savanna climate zones. Botswana is a wealthier nation in the upper middle income level with a small population. Swaziland is a small country in the lower middle income level with a small population. Gabon and Republic of Congo are neighbors in Central Africa and are both mainly tropical climate zones. Gabon and Republic of Congo are both medium sized country with small populations. Gabon has an upper middle income level, while Republic of Congo is lower middle. The combination of smaller populations, higher income levels and more stable ecology make these countries less susceptible to climate change impacts.

Total cost is not the only metric that can indicate impact. Instead of comparing cost, the impact factor metric attempts to estimate the percentage of roads lost due to climate change costs. Impact factor is another way to measure the affects of climate change. The impact factor metric is used to reflect the greater impact countries with fewer roads will experience. A high impact factor reflects the negative impacts of limited infrastructure growth for countries with small existing road infrastructures. A low impact factor reflects a country with a more resilient road infrastructure system.

Infrastructure is an integral part of a community’s economy and social fabric, causing the benefits gained from building roads to be compound in nature. African countries have the opportunity to expand infrastructure by taking steps to reduce the impacts of climate change through adaptation. This expansion is more important to those countries without existing road infrastructure. Simply basing climate change impact on cost does not capture this important concept.

The XY scatter plot below graphs countries total impact factor and total climate change cost relative to GDP. Table 2 in the appendix contains the data for the graph. 'Total Cost as % GDP' is utilized to normalize impact factor verse a country's GDP, similar to how this metric was utilized in normalizing total cost. This graph will provide a different view on how climate change is affecting African countries.

Both graph axes have been reversed. The X axis has been reversed and truncates data below 10%. Countries with a total climate change costs as a percentage of GDP below 10% are not considered to be the highest impacted countries. Furthermore, countries with total cost as % GDP below 10% have impact factors below 200% and; therefore, are not highly impacted.

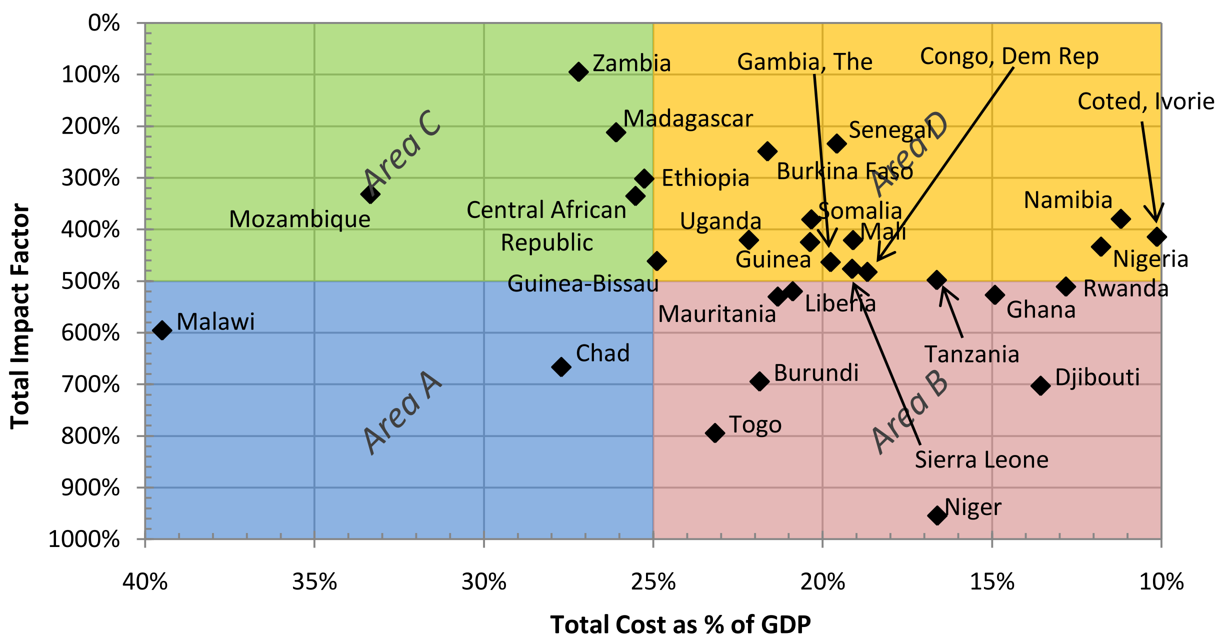

Figure 3: Impact factor analysis graph

The countries with the greatest impact from climate change are those in Area A. Countries in Area A have large impact factors and large costs relative to GDP. Countries in Area C are experiencing high costs relative to GPD but less significant impact factors. Countries in Area B are being impacted by climate change but costs are small relative to GDP. Countries in Area D have less significant impact factors and costs relative to GDP.

Countries in Areas A and B have road infrastructures that are more susceptible to the impacts of climate change. These countries have the greatest opportunity to create a positive impact on their road infrastructure. Adaptation opportunities can be investigated to allow future funds to build new roads rather than be used for maintenance. The expanding infrastructure will provide potential for social and economic advancement.

Malawi, Chad, Togo, Burundi, Niger and Djibouti have the highest impact factors. These countries are prime candidates for decreasing the impact of climate change through adaptation. Each of these countries has impact factors around or greater than 600%. Malawi and Chad were previously identified as highly impacted with regards to climate change costs. The other countries appear in Area D of the cost analysis graph.

Each identified country has a low income level; Djibouti has the highest with a lower middle income level. These countries vary in size and population, which does not seem to have a large effect on impact factor. Each is ecologically diverse: Chad, Niger and Djibouti being drier desert climates; Malawi, Burundi and Togo are wetter climates in the deciduous and montane zones. All climate zones have high potential for being susceptible to climate change. The largest contributing factors in impact factor are climate change cost and kilometers of paved roads. High costs and fewer kilometers of paved roads are contributors to high impact factor. The high costs Malawi and Chad experience from climate change create the high impact factor even though their existing paved road infrastructure system is large. Chad is ranked 13th among African countries with the most paved roads, Malawi 16th. Niger, Togo, Djibouti and Burundi have lower costs but a small paved road infrastructure. Niger is ranked 28th among African countries with the most paved roads; Togo 34th, Djibouti 37th and Burundi 38th. The combination of relatively high costs and few kilometers of paved roads in addition to delicate ecosystems create these high impact factors.

South Africa, Morocco and Batswana are countries with low impact factors and large GDPs. South Africa and Morocco have large GDPs and robust road infrastructures. Large GDPs can more easily absorb the cost impacts of climate change creating small cost as percentage of GDP while robust road infrastructures create small impact factors. Botswana is a more interesting case. It has a smaller GDP (ranked 16^{th}) and few kilometers of paved roads (ranked 14^{th}) yet still has low impact factor and cost relative to GDP. This is because Botswana's climate change cost is small. Savanna and steppe, its main climate zones, must be relatively resilient to the effects of climate change.

Total cost and impact factor are related due to the way impact factor is calculated. As climate change cost rise impact factor is also likely to increase. Countries with large existing road infrastructures are likely to have larger costs but smaller impact factors. Countries with small existing road infrastructures are likely to have smaller costs but larger impact factors. A direct comparison of these two metrics will highlight those countries that will face both high costs and potential for difficulty building new roads due to climate change costs.

The figure below shows the relationship between cost and impact factor. Table 2 in the appendix contains the graphed data. The Y axis has been reversed and truncates data above $12 billion. Two countries have costs above $12 billion and are discussed below. The X axis has been reversed and truncates impact factors below 200%. Countries with impact factors below 200% are not considered highly impacted. The countries with impact factors below 200% typically have costs of less than $6 billion.

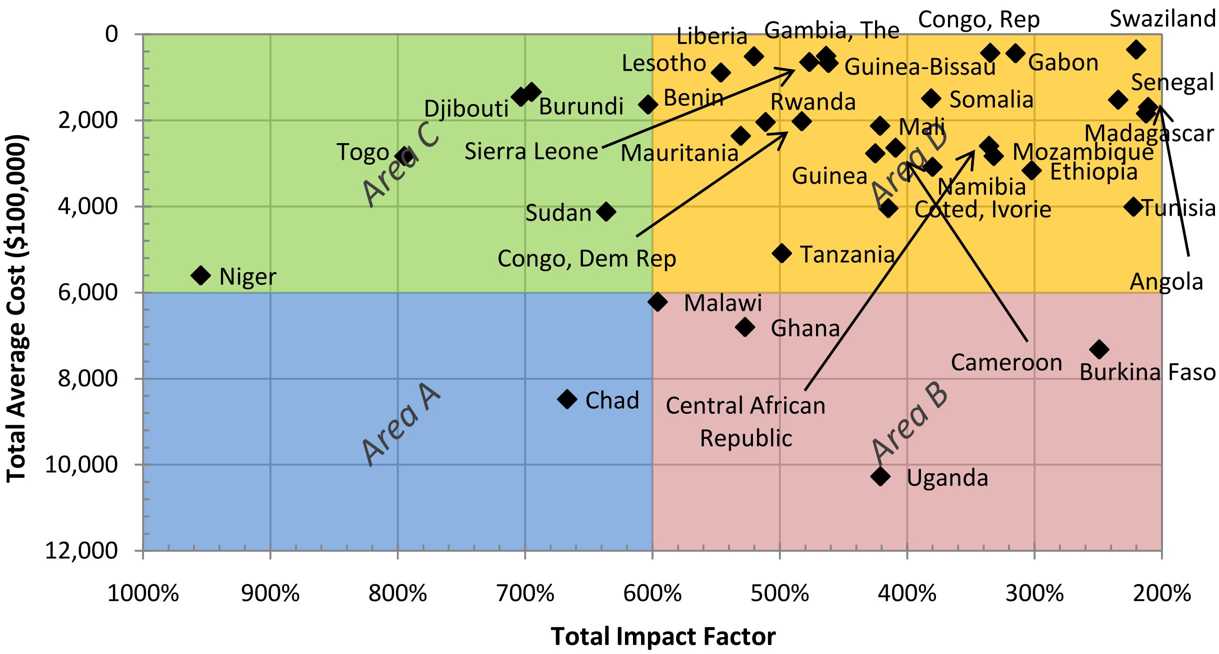

Figure 4: Highly impacted countries

Once again, Algeria and Nigeria have total average costs over $16 billion. They are not shown on this graph. Nigeria has an impact factor of approximately 400% so it would appear in Area B. Algeria has an impact factor of approximately 180% so it would not appear on this figure. Algeria is the one country with an impact factor below 200% with costs about $6 billion.

Countries with high impact and high cost are in or near Area A. Niger, Chad, Malawi, Sudan and Ghana are all highly impacted by climate change. Niger, Chad and Sudan are all large neighboring countries in the Sahal region of the Sahara desert. These three poor, ecologically diverse countries are highly susceptible to climate change due to the large road networks required to connect the countries. Malawi and Ghana have low income levels, are ecologically diverse and highly populated. They have large road infrastructures to support their population. This combination creates the potential for large climate change impacts.

Botswana, Swaziland and Equatorial Guinea are on the opposite side of this analysis; having both low cost and impact factor. Botswana and Equatorial Guinea have large GDPs and small populations. Swaziland has a smaller GDP and a small population. The countries are also composed of climate zones that are more resilient to climate change. This combination creates less potential for climate change impacts.

Highly Impacted Countries Summary

A handful of countries rank poorly in all three of these comparisons: Chad, Malawi, Niger and Mozambique. These countries have high climate change costs, high impact factors, small GDPs and few roads. This is a troubling combination for these countries because it makes them especially vulnerable to the impacts of climate change.

Adaptation Potential

Adaptation can drastically decrease the costs climate change can create. Enormous returns on investment can be made over the long term by proactively preparing roads for climate change. The adaptation steps modeled into the data provide quantitative cost benefits, which can be compared to data without adaptation. By calculating the percent change between the data without adaptation and the data with adaptation for each country in Africa, the potential of adaptation can be seen. Table 2 in the appendix contains the quantitative data and the percent change for each country. The five countries with the highest adaptation advantage and five countries with the lowest adaptation advantage are shown in the table below.

COUNTRY	ADAPTIVE ADVANTAGE
Malawi	94%
Lesotho	93%
Mozambique	93%
Swaziland	90%
Central African Republic	90%
Gabon	45%
Congo, Rep	31%
Botswana	23%
Congo, Dem Rep	22%
Kenya	18%

Figure 5: Percent change improvement due to adaptation

It is promising that adaptation is so beneficial to the highest impacted countries. Malawi and Mozambique face extreme climate change impacts, yet they have the ability to greatly mitigate these impacts. Botswana, Democratic Republic of Congo and Kenya do not see the large benefits adaptation creates; regardless, benefits are created.

Adaptation benefits depend on the severity and duration of climate change impacts, specifically temperature and precipitation levels. Countries where climate models predict continually rising temperatures and/or precipitation levels will benefit from adaptation to a greater degree than countries with predicted intermittent climate changes. If predicted climate changes are not significant, adaptation will not have a large beneficial impact.

Temperature changes typically affect paved roads to a larger degree than precipitation. Precipitation changes typically affect unpaved roads to a larger degree than temperature. Therefore, African countries' specific road systems are a contributing factor to adaptation benefits. Countries with high paved road percentages will be affected differently than those countries with high unpaved road percentages.

Adaptation benefits - depends on the severity and the continuance of climate change. In countries where climate change is happening at both temperature and precipitation levels, then adaptation will help significantly since you are reducing significant amounts of maintenance. In countries were only precipitation is an issue, you do not get quite the return since precipitation does not cause as much damage as temperature, so the overall benefit is lowered.

Visually comparing how adaptation affect cost and the impact factor can be seen in the following graphs. The methodology for displaying this data is slightly different from the figures above. On each graph Area A is the most desirable area. The desired result of adaptation is changing the high cost without adaptation to a low cost with adaptation. Area A captures those countries with this potential. Area D represents high cost with adaptation and relatively low cost without adaptation. This creates a scenario where adaptation is less effective. Area C and B contain countries with varying degrees of adaptation success.

The figure below visually captures the affects of adaptation on African countries with high costs. Table 2 in the appendix contains the graphed data. The Y axis has been truncated above $9 billion and below $1 billion. The X axis has been truncated above $2.6 billion. The outliers are discussed below.

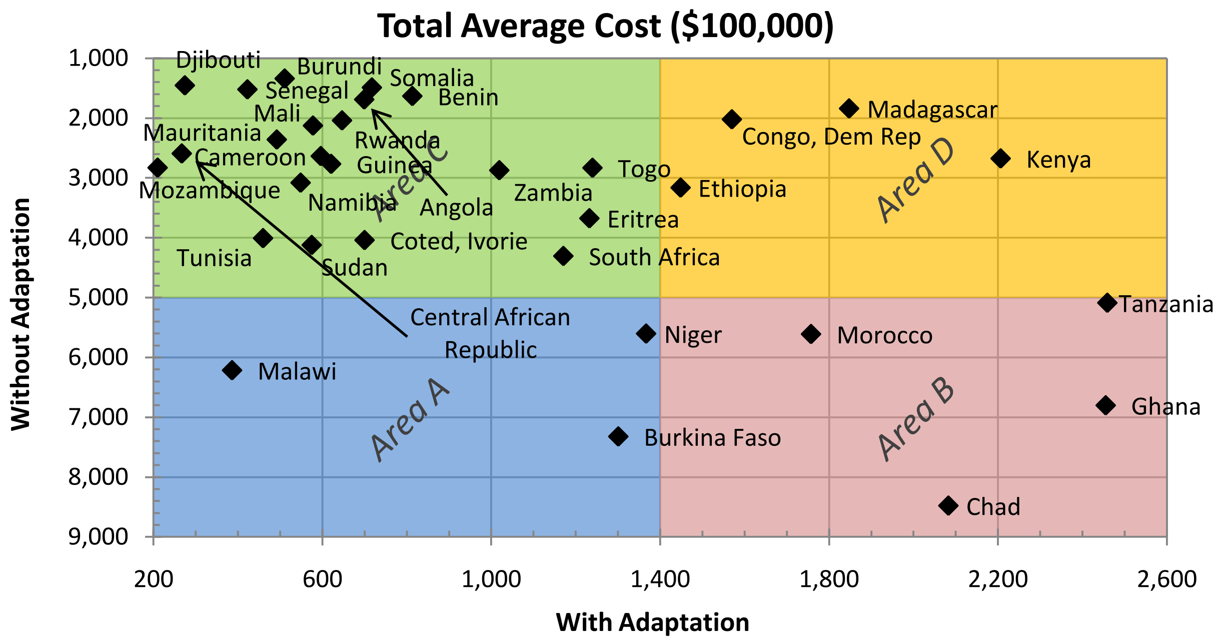

Figure 6: Total average cost adaptation comparison (High Costs)

Algeria, Uganda and Nigeria are not shown on this figure. All three countries have without adaptation coast of over $10 billion due to their large road networks. Uganda and Nigeria have with adaptation costs of over $5 billion. Algeria a large advantage due to adaptation and would fit into Area A. Uganda and Nigeria do not have as large of an adaptive advantage and would fit in Area B.

The majority of African countries with high costs show improvement with adaptation. The largest decreases in cost can be best seen with Malawi, whose cost dropped from approximately $618,000,000 to less than $50,000,000. The other countries in Area A experience large benefits as well. Madagascar and Kenya experience relatively little benefit. The countries in Area D experience little benefit.

The figure below visually captures the affects of adaptation on African countries with low costs. Table 2 in the appendix contains the graphed data. The Y axis has been truncated above $1 billion and below $200 million. The X axis has been truncated above $400 million.

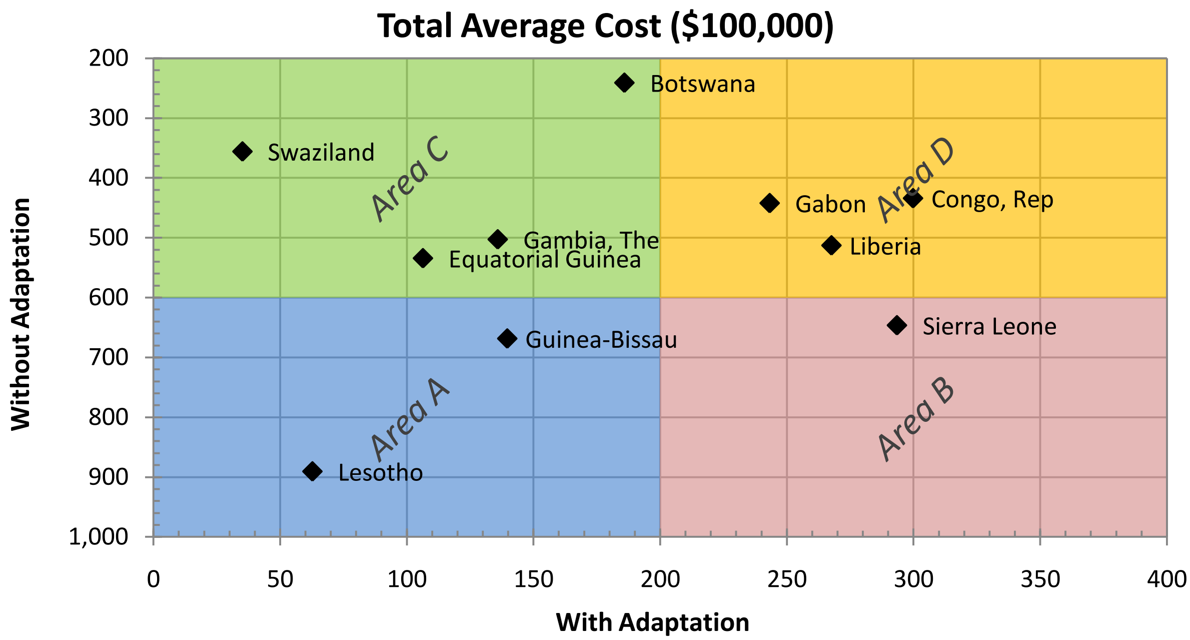

Figure 7: Total average cost adaptation comparison (Low Costs)

African countries with lower costs have mixed results with adaptation. Countries like Lesotho and Swaziland experience large benefits. Gabon and Liberia experience limited benefits.

A similar analysis can be done with total impact factor to visualize the drastic improvement adaptation can create. The adaptive percent improvement for countries is the same for cost and impact factor so the positions of the countries are similar to the cost analysis. Impact factor normalizes the countries on a more relative scale. The figure below displays this improvement. Table 2 in the appendix contains the graphed data.

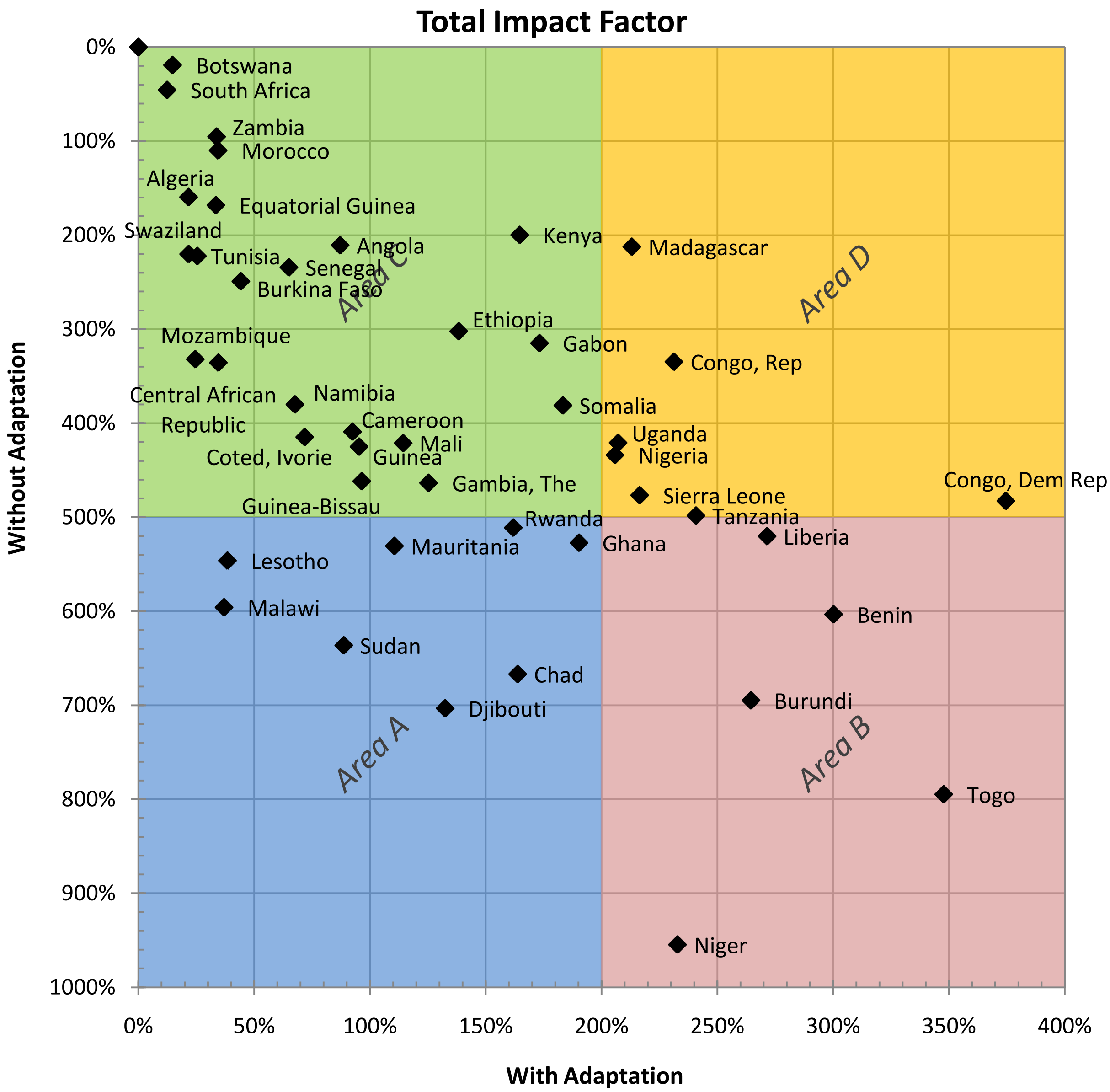

Figure 8: Impact factor adaptation comparison

Adaptation Potential Summary

These three separate analyses indentify countries which have the high potential to be impacted by climate change. Chad, Malawi and Niger are notable for appearing extra vulnerable to climate change. This is not entirely surprising. Countries with low GDP and few roads are highly susceptible to climate change. The majority of African countries fit this description. Simply identifying the countries in the greatest need should not preclude any of the other countries from aid. Nearly every community in Africa is highly vulnerable to climate change impacts. This analysis simply attempts to identify starting points for researchers and policy makers. Adaptation proves beneficial to the majority of African countries. These results provide quantitative data which shows how much adaptation can decrease the impacts of climate change.

Results Conclusion

Sudan, Ethiopia, Eritrea, Niger and Mali are countries with low road densities. Chad, Malawi, Niger and Mozambique are highly impacted by the costs of climate change. Malawi, Lesotho and Mozambique have the most to gain from adaptation.

The data presented in the sections above illustrates the impacts of climate change in several different ways: road densities, costs, impact factors, and adaptive advantages. The most important factor for policy makes is adaptive advantage. This metric demonstrates the importance of adaptation for a country. Investment in roads can be more easily made because of the quantifiable return on investment the adaptive advantage demonstrates. The most important factor for aid organization is impact factor. This metric provides valuable insight into which countries will be impacted the most by climate change. Aid organization can use this metric to identify where their efforts are needed the most.

Individual Country Analysis

This section takes a closer look at Malawi. Granular data will be used to show how climate change affects Malawi per decade. Malawi's GDP of $12.8 million (USD) ranks 30th amongst the African countries studied. Malawi is 118,500 square kilometers and is a smaller African country. Malawi is located in West Africa and borders Mozambique, Zambia and Tanzania. Malawi has an estimated population of approximately 15 million people, which is a higher population than most African countries. Malawi has 15,451 kilometer of roads, 45% of which are paved. Malawi is in an ecologically diverse area of Africa and contains several different climate zones, including tropical, subtropical, montane, flooded grasslands, savannas and shrublands. Malawi's ecological diversity, high population and small size make for an interesting case study.

The data for Malawi can be seen in the table 3 in the appendix. This data has been graphed in various ways to provide insight on the effects of climate change on Malawi's roads and how adaptation can mitigate these effects.

The figure below shows non-cumulative, Max Effect data for Malawi. The data has not been modified for adaptation. Average cost per decade is measured using bars and the Y axis on the left. Impact factor per decade is measured using the line and the Y axis on the right. A steady rise in cost and impact can be seen throughout the decades. This indicates that the max effect climate change model predicts climate change impacts to worsening as time passes.

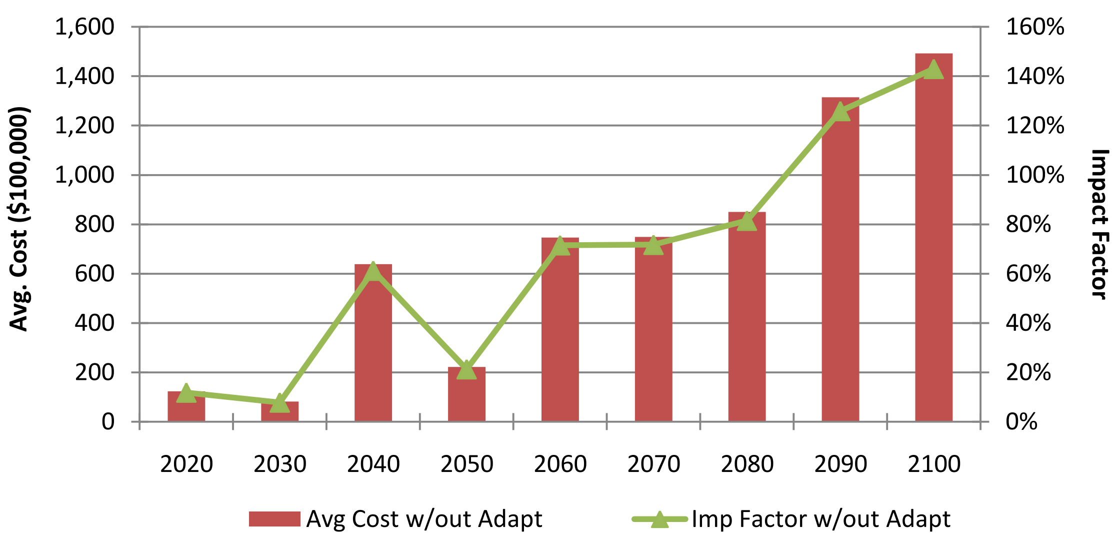

Figure 9: Max Effect, non-cumulative cost and impact factor per decade

Adaptation has a large beneficial impact on Malawi. The figure below shows cumulative average costs per decade from the max effect climate change model for Malawi. The average costs with adaptation and without adaptation are plotted on the same scale. Average costs of climate change without adaptation rise rapidly over the decades, combining to over $6 billion in 2100. Average costs of climate change with adaptation rises slowly over the decades, combining to under $400 million in 2100.

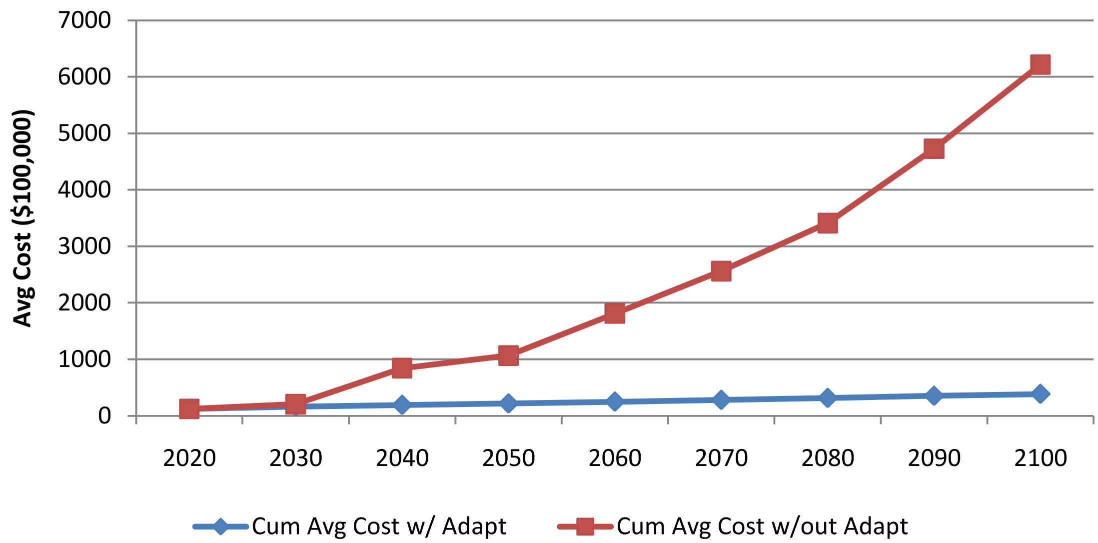

Figure 10: Max Effect, cumulative average costs with and without adaptation per decade

Bubble graphs better illustrate the benefits adaptation provides Malawi. The two figures below plot impact factor and average cost relative to Malawi's current road expenditure per decade. Average cost relative to current road expenditure or 'cost as % of Exp' metric is a similar metric to the 'cost as % of GDP' metric discussed above. Instead of using current GDP to create a more insightful relation to a country's economy, current road expenditure is used to create a more insightful relation to a country's current infrastructure costs. This is helpful when comparing before and after adaptation costs. On the figures below, impact factor is graphed on the Y axis and cost relative to road expenditure is captured by bubble size. The data is non-cumulative.

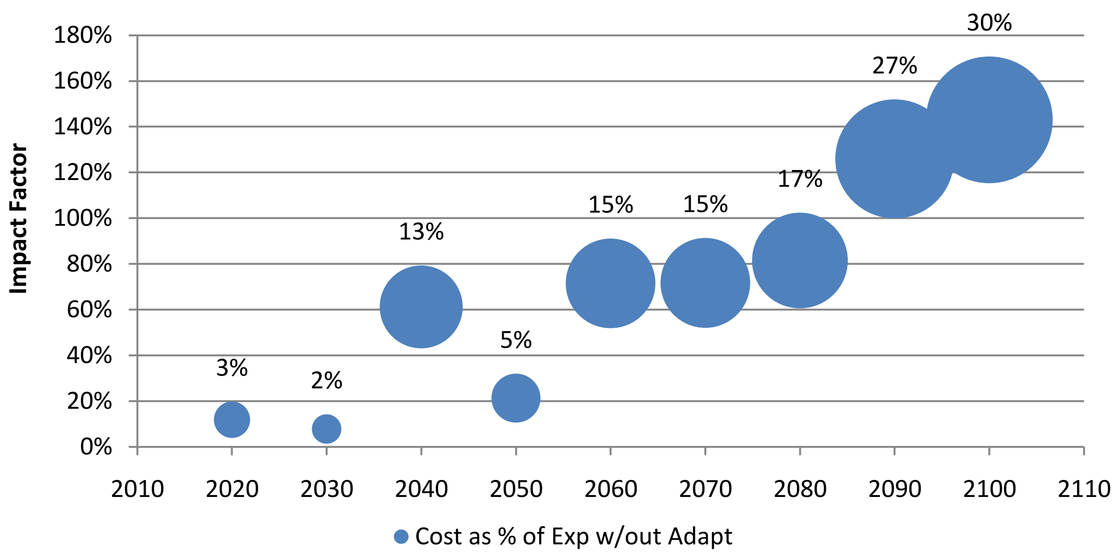

Figure 11: Impact factor and cost relative to road expenditure bubble graph without adaptation

Malawi's impact factor and cost relative to road expenditure without adaptation rises throughout the decades. In 2100, Malawi has its largest impact factor of over 140% and cost relative to road expenditure of approximately 30%.

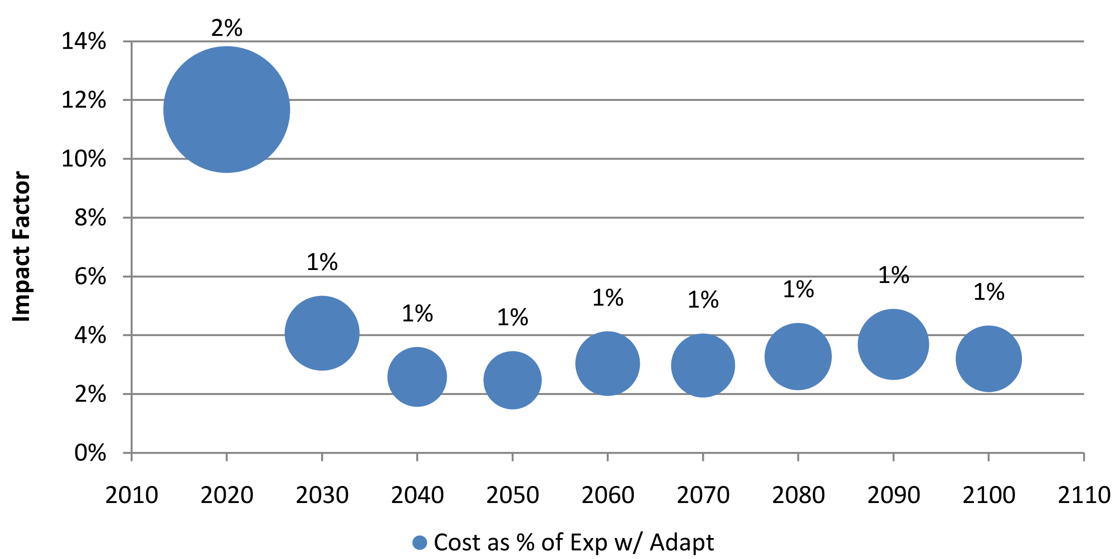

Figure 12: Impact factor and cost relative to road expenditure bubble graph with adaptation

With adaptation the figure looks radically different. Impact factor never exceeds 12% and costs relative to road expenditure never exceeds 3%. The largest cost relative to road expenditure is seen in 2020 when Malawi is paying for adaptation costs. These costs prevent future maintenance costs from escalating causing costs relative to road expenditure to remain under 1% for the remaining decades.

The max effect climate change model data is used most frequently but data from other climate change models can be utilized. The figure below graphs average costs per decade for the four climate change models. Comparing climate change model data for Malawi shows that Malawi is susceptible to the affects of climate change regardless of which model is utilized. The graphed data is cumulative. The max effect model predicts the largest costs of over $6 billion, country median average and country average models predict cost between $3 and $4 billion and global average modal predicts costs of approximately $2 billion. For all climate models, costs steadily rise throughout the decades.

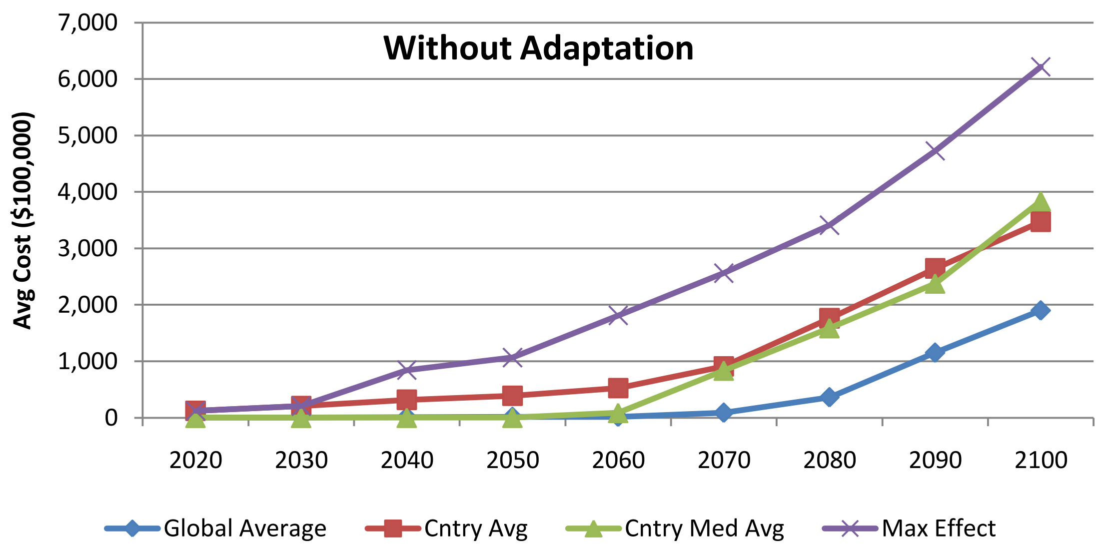

Figure 13: Costs per decade for alternative climate change models

The figure below show how adaptation improves both costs and impact factors for the four climate models. Cost is measured using bars and the Y axis on the left. Impact factor is measured using data points and the Y axis on the right. Four totals are given for each climate model: costs with and without adaptation and impact factor with and without adaptation. This figure visually show that regardless of which climate change model data is used for Malawi, adaptation creates large advantages in terms of cost and impact.

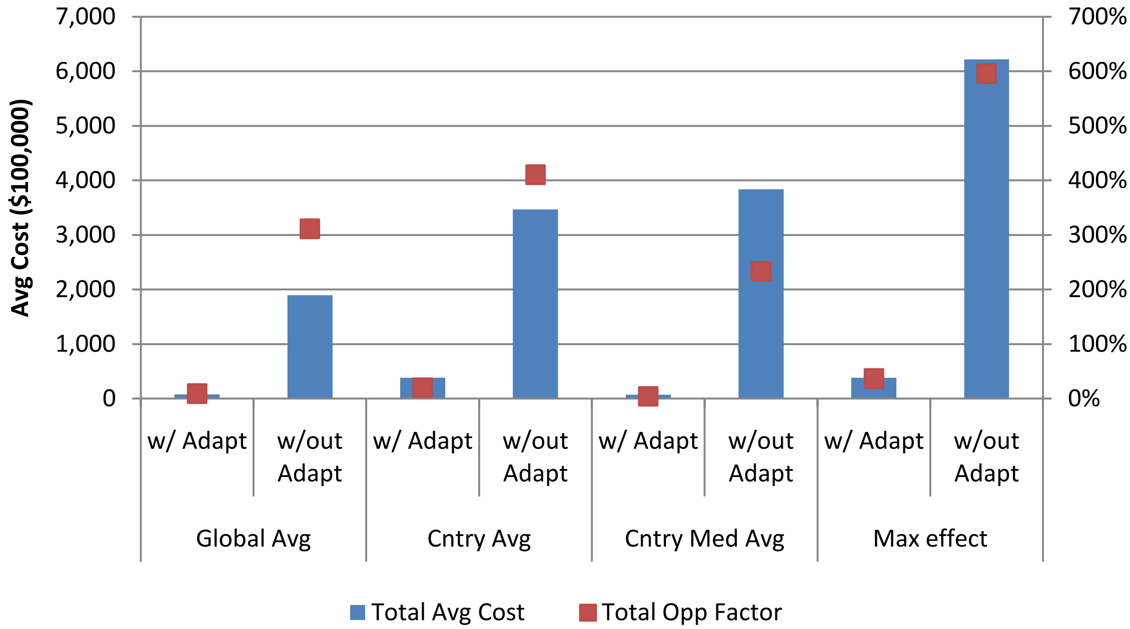

Figure 14: Total costs and impact factors for alternative climate models

Individual Country Analysis Summary

Malawi benefits greatly from adaptation. An investment in upgrading Malawi's road investment today will create a large return on investment. Regardless of which climate model is used, adaptation is justified. Without adaptation Malawi will face continually increasing costs due to climate change preventing expansion of their road infrastructure and; therefore, limiting their economic growth. Malawi policy makers should begin to take step in preparing for climate change today.

Implications

Infrastructure is an integral part of a community's social fabric (Chinowsky 2010). The importance of infrastructure to a community depends on a myriad of factors. Infrastructure provides crucial connections to surrounding communities and resources. The potential degradation of roads with increased environmental exposure may contribute to communities becoming displaced. Christian Aid described internal displacement as a 'hidden crisis' in the world and expects displacement to rise exponentially with increasing conflicts and disasters linked to climate change.

The poorest people in developing countries will have the largest and worst experiences due to the impact of climate change. Physical, economic and social vulnerabilities exacerbate climate change risks. Providing access to information and civic representation for these high impact communities is a priority. Understanding what adaptation means for these types of social groups and what external support is required, can provide pivotal information that can be use to set priorities in climate policy and action.

Several of the factors that contribute to a community's reliance on infrastructure include; geographic location, economic position, social stability and cultural characteristics. With the wide range of concerns facing communities, the prioritization of concerns of the individuals, families, social groups and overall community play a role in how infrastructure damage will be handled.

With fewer roads per geographic area and per capita, rural roads are vital. They enable remote communities to access basic services, generate income and gain employment. Rural roads are a major contributor for alleviating poverty. Investments in rural infrastructure improve the living condition of rural communities, which are typically the poorer communities in a country. Furthermore,

Urban communities are more dependent on incoming food supplies than rural communities. Rural communities have a larger capacity to be self sufficient; urban communities do not have this luxury. Therefore, urban roads that connect vital trade routes must be maintained.

People displaced due to the impacts of climate change are afflicted with some of the most traumatic human experiences. Loss of community, property, employment, business, education and family are possible. Displaced people may be faced with squalid, dangerous settlements, urban slums or family member's crowded houses. Displaced people maybe unable to make a living for themselves, instead they are forced to depend on other for basic essentials. Their local language or dialect and customs may mark them as outsiders causing discrimination. These types of conditions create an environment where exploitative, perilous work conditions become possible. Many displaced people may be entirely internally displaced, meaning international law and organization dedicated to protecting 'official' refugees and unable to provide assistance. Frequently governments are unable to help internally displace people and are often actively hostile towards them. Therefore, little media and political attention will be provided, causing limited potential to relieve refugee suffering (Christian Aid, 2007).

The potential relocation caused by disintegrating road networks due to climate change impacts has considerable costs in terms of macroeconomic and human suffering. As families find themselves competing over limited resources they are more likely to split. Younger generations will typically head to urban centers, leaving behind a vulnerable subset of society. A breakdown of family community will occur, in addition to an increase in the risk for conflicts.

As current weather extremes take their toll on developing countries' economies and social constructs, losses of human and economic capital are occurring. Regions with climates that are exacerbated by climate change and have limited capacity to deal with current issues will be further hampered in development (Chinowsky 2010). These regions will experience additional loss of life, assets, productivity and infrastructure. This is particularly true for small countries and countries with low economic diversity. In these types of countries, the impact of climatic extremes cannot be absorbed by a limited economy.

The data indicates Sudan, Ethiopia, Eritrea, Niger and Mali are countries with low road densities. These countries have a significant interest in protecting their roads from climate change impacts and expanding their existing infrastructure. Chad, Malawi, Niger and Mozambique are highly impacted by the costs of climate change. Malawi, Lesotho and Mozambique have the most to gain from adaptation.

Chad, Malawi and Niger are notable for appearing extra vulnerable to climate change. These countries have high climate change costs, high impact factors, small GDPs and few roads. This is a troubling combination for these countries because it makes them especially vulnerable to the impacts of climate change.

The data presented in the research illustrates the impacts of climate change in several different ways: road densities, costs, impact factors, and adaptive advantages. The most important factor for policy makes is adaptive advantage. This metric demonstrates the importance of adaptation for a country. Investment in roads can be more easily made because of the quantifiable return on investment the adaptive advantage demonstrates. The most important factor for aid organization is impact factor. This metric provides valuable insight into which countries will be impacted the most by climate change. Aid organization can use this metric to identify where their efforts are needed the most.

Countries with low GDP and few roads are highly susceptible to climate change. The majority of African countries fit this description. Simply identifying the countries in the greatest need should not preclude any of the other countries from aid. Nearly every community in Africa is highly vulnerable to climate change impacts. This analysis simply attempts to identify starting points for researchers and policy makers.

Limitations

Many assumptions and simplifications must be made when performing a study of this magnitude. Calculating a cost of adaptation is a complex problem that involves multiple institutions, decision makers and projected government investments many years into the future. A consistent approach is used to project the necessary economic growth, structural change, climate change and human behavior over an extended timeline. This consistency is required to establish adaptation costs.

This study's largest limitation involves assuming country level climate change is knowable and policy makers adapt accordingly. In reality decision makers do not have perfect foresight and have extremely difficult decisions based on an unknowable future.

Understandably, the climate models are not perfect. Different climate models produce varying levels of adaption more so the different economic models. Adaptation costs can vary by several degrees of magnitude depending on which climate model is used.

Climate change impacts are expected to increase over time. The limited timeline of this study may only capture the 'first wave' of climate change. Major climate impacts, such as melting ice sheets, are not expected to occur well past 2100 and are expected to cause extreme climate changes.

Operationalizing adaptation costs is difficult due to the uncertainty surrounding climate projections. In general, studies indicate the temperatures will increase, rainfall will become more intense but less frequent, sea levels will rise and extreme climate events will become more frequent and intense and regional climate systems will be altered (World Bank 2009a). Specific climate change affects per location are not available. Different models produce significantly different and in some cases conflicting, temperature and precipitation alterations. These large differences are due to the timing of systemic changes, such as melting of ice sheets, alteration of sea currents and the dieback of the Amazon rainforest. These systemic changes and the thresholds that trigger them are difficult to predict. These changes are capable of creating large, unknown and potentially irreversible processes.

'Soft' adaptation measure costs are not captured in this study. Measures such as early warning systems, community preparedness programs, watershed management, zoning and water pricing are considered 'soft' measures. Calculating the cost of these measures is extremely difficult. Even eliciting effective actions of 'soft' measures are extremely complex (Ostrom 1990).

Countries with poverty are likely to have population migration. The study uses population demographics for the United Nations Population Division. Population movements will likely impose heavy infrastructure costs. These movements are already unpredictable. Coupled with climate change impacts, these movement may increase in frequency while remaining unpredictable.

The efficiency of adaptation is modeled in an optimal way per sector. Cross sector cooperation and benefits are not accounted for. This adds an upward bias to adaptation cost. Economic models assume rational behavior. This is not true in reality. The bias this assumption creates is unknowable.

Innovation and technical changes are not taken into account in this study. Costs are based on what is known today rather than what will be understood in the future. This adds an upward bias to adaptation costs.

Cournty specific characteristics and sociocultural and economic conditions must be incorporated into adaptation designs. Incorporating these aspects of a country into an adaptation cost is extremely difficult.

Recommendations

Adaptation to a 2 degree Celsius warmer world will be costly. Development is key to decreasing adaptation costs (World Bank 2009a). The greater the baseline level of development, the smaller the impact of climate change; and, therefore the smaller the level of adaptation. While development increase climate change vulnerabilities due to the increased value of infrastructure, these vulnerabilities are more easily handled with the larger GDP development brings about.

Climate change conscious development will be needed to prepare communities for the future. Climate proofing infrastructure to make it resilient to climate risk is a superior development strategy than simply building infrastructure without acknowledging the risks of climate impacts.

Since there is inherent uncertainty surrounding climate change, strategies are needed that are flexible to new climate knowledge. Climate change is a gradual process so designing for limited or no change in climate conditions while waiting for better information may be a sound strategy today; but as climate change occurs high maintenance costs and earlier than expected asset replacement may create extremely high costs. Policy makers will need to weigh current costs of investments against benefits for a large range of climate outcomes (World Bank 2009a).

Further Research

Currently the study breaks down data per country. This division of data is a natural breakdown for the developed world. In some regions of Africa this division may not be the most beneficial. A breakdown per climate zone may create a clearer picture for researchers and policy makers. This division would allow the climate zones most affect to be identified. Better climate zone specific policies could be created to mitigate these affects.

Since designing policy for climate control is extremely difficult due to the uncertainties that surround climate control, hedge strategies and contingencies could be designed by researchers. These strategies could be designed using engineering based methodologies. A decision maker in a developing country would be more likely to utilize a pre-developed climate package that handles the uncertainty and economic risks associated with climate change. If adoption of these packages becomes more common place the social risks could be decreased, saving communities from extreme hardships.

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Appendix

Table 1: Summary Data

Country	Income Level	GDP (PPP)	Road Expenditures	Exp % of GDP	Total Km of Roads	Total Km of Paved Roads	Paved/ Unpaved Ratio	Area (Sq. Km)		Road/Area Ratio	Paved/Area Ratio	Population		Road/Pop Ratio	Paved/Pop Ratio	Pop/Area Ratio	GDP per Capita
Algeria	Lower Middle	$239,600,000,000	$499,399,409	0.21%	108,302	76,028	0.7020	2,381,740	Very Large	0.0455	0.0319	33,333,216	Very Large	0.0032	0.0023	14.00	$ 7,188.03
Angola	Lower Middle	$114,400,000,000	$163,923,558	0.14%	51,429	5,349	0.1040	1,246,700	Very Large	0.0413	0.0043	15,941,000	Large	0.0032	0.0003	12.79	$ 7,176.46
Benin	Low	$13,250,000,000	$99,375,000	0.75%	19,000	1,805	0.0950	112,622	Small	0.1687	0.0160	8,439,000	Medium	0.0023	0.0002	74.93	$ 1,570.09
Botswana	Upper Middle	$26,000,000,000	$138,989,798	0.53%	25,798	8,410	0.3260	581,726	Large	0.0443	0.0145	1,839,833	Very Small	0.0140	0.0046	3.16	$ 14,131.72
Burkina Faso	Low	$18,790,000,000	$370,163,000	1.97%	92,495	19,602	0.2119	274,000	Medium	0.3376	0.0715	13,228,000	Large	0.0070	0.0015	48.28	$ 1,420.47
Burundi	Low	$3,247,000,000	$63,965,900	1.97%	12,322	1,286	0.1044	27,830	Very Small	0.4428	0.0462	7,548,000	Medium	0.0016	0.0002	271.22	$ 430.18
Cameroon	Lower Middle	$42,760,000,000	$157,452,770	0.37%	51,346	4,298	0.0837	475,442	Medium	0.1080	0.0090	17,795,000	Large	0.0029	0.0002	37.43	$ 2,402.92
Central African Republic	Low	$3,327,000,000	$65,541,900	1.97%	24,307	5,151	0.2119	622,984	Large	0.0390	0.0083	4,216,666	Small	0.0058	0.0012	6.77	$ 789.01
Chad	Low	$16,260,000,000	$406,500,000	2.50%	40,000	8,477	0.2119	1,284,000	Very Large	0.0312	0.0066	10,146,000	Medium	0.0039	0.0008	7.90	$ 1,602.60
Congo, Dem Rep	Low	$21,330,000,000	$420,201,000	1.97%	153,497	2,794	0.0182	2,344,858	Very Large	0.0655	0.0012	63,655,000	Very Large	0.0024	0.0000	27.15	$ 335.09
Congo, Rep	Lower Middle	$16,410,000,000	$44,138,000	0.27%	17,289	864	0.0500	342,000	Medium	0.0506	0.0025	4,012,809	Small	0.0043	0.0002	11.73	$ 4,089.40
Coted, Ivorie	Low	$35,820,000,000	$358,200,000	1.00%	80,000	6,496	0.0812	322,460	Medium	0.2481	0.0201	17,654,843	Large	0.0045	0.0004	54.75	$ 2,028.91
Djibouti	Lower Middle	$2,011,000,000	$14,133,250	0.70%	3,065	1,379	0.4500	23,200	Very Small	0.1321	0.0595	496,374	Very Small	0.0062	0.0028	21.40	$ 4,051.38
Equatorial Guinea	High	$190,200,000,000	$173,893,000	0.09%	2,880	2,119	0.7358	28,051	Very Small	0.1027	0.0755	504,000	Very Small	0.0057	0.0042	17.97	$ 377,380.95
Eritrea	Low	$23,200,000,000	$15,516,343	0.07%	4,010	874	0.2180	117,600	Small	0.0341	0.0074	4,401,000	Small	0.0009	0.0002	37.42	$ 5,271.53
Ethiopia	Low	$4,198,000,000	$82,700,600	1.97%	36,469	6,980	0.1914	1,104,300	Very Large	0.0330	0.0063	85,237,338	Very Large	0.0004	0.0001	77.19	$ 49.25
Gabon	Upper Middle	$20,990,000,000	$49,404,467	0.24%	9,170	936	0.1021	267,668	Medium	0.0343	0.0035	1,384,000	Very Small	0.0066	0.0007	5.17	$ 15,166.18
Gambia, The	Low	$2,471,000,000	$48,678,700	1.97%	3,742	723	0.1932	10,380	Very Small	0.3605	0.0696	1,517,000	Very Small	0.0025	0.0005	146.15	$ 1,628.87
Ghana	Low	$36,570,000,000	$530,265,000	1.45%	57,614	8,602	0.1493	238,534	Medium	0.2415	0.0361	23,000,000	Large	0.0025	0.0004	96.42	$ 1,590.00
Guinea	Low	$10,480,000,000	$206,456,000	1.97%	44,348	4,342	0.0979	245,857	Medium	0.1804	0.0177	9,402,000	Medium	0.0047	0.0005	38.24	$ 1,114.66
Guinea-Bissau	Low	$933,400,000	$18,387,980	1.97%	3,455	965	0.2794	36,125	Very Small	0.0956	0.0267	1,586,000	Very Small	0.0022	0.0006	43.90	$ 588.52
Kenya	Low	$63,730,000,000	$669,165,000	1.05%	63,265	8,933	0.1412	580,367	Large	0.1090	0.0154	34,707,817	Very Large	0.0018	0.0003	59.80	$ 1,836.19
Lesotho	Lower Middle	$3,273,000,000	$22,601,683	0.69%	5,940	1,087	0.1830	30,355	Very Small	0.1957	0.0358	1,795,000	Very Small	0.0033	0.0006	59.13	$ 1,823.40
Liberia	Low	$1,627,000,000	$32,051,900	1.97%	10,600	657	0.0620	111,369	Small	0.0952	0.0059	3,283,000	Small	0.0032	0.0002	29.48	$ 495.58
Libya	Upper Middle	$95,880,000,000	$461,228,107	0.48%	83,200	47,590	0.5720	1,759,540	Very Large	0.0473	0.0270	6,036,914	Small	0.0138	0.0079	3.43	$ 15,882.29
Madagascar	Low	$20,500,000,000	$574,000,000	2.80%	49,827	5,780	0.1160	587,041	Large	0.0849	0.0098	18,606,000	Large	0.0027	0.0003	31.69	$ 1,101.80
Malawi	Low	$12,810,000,000	$493,185,000	3.85%	15,451	6,956	0.4502	118,484	Small	0.1304	0.0587	12,884,000	Large	0.0012	0.0005	108.74	$ 994.26
Mali	Low	$15,520,000,000	$305,744,000	1.97%	18,709	3,368	0.1800	1,240,192	Very Large	0.0151	0.0027	13,518,000	Large	0.0014	0.0002	10.90	$ 1,148.10
Mauritania	Low	$6,568,000,000	$129,389,600	1.97%	11,066	2,966	0.2680	1,030,700	Very Large	0.0107	0.0029	3,069,000	Small	0.0036	0.0010	2.98	$ 2,140.11
Morocco	Lower Middle	$146,700,000,000	$265,718,924	0.18%	57,799	35,841	0.6201	446,550	Medium	0.1294	0.0803	33,757,175	Very Large	0.0017	0.0011	75.60	$ 4,345.74
Mozambique	Low	$20,170,000,000	$716,035,000	3.55%	30,400	5,685	0.1870	801,590	Large	0.0379	0.0071	20,366,795	Large	0.0015	0.0003	25.41	$ 990.34
Namibia	Lower Middle	$13,580,000,000	$134,625,198	0.99%	42,237	5,406	0.1280	825,418	Large	0.0512	0.0065	2,031,000	Very Small	0.0208	0.0027	2.46	$ 6,686.36
Niger	Low	$10,450,000,000	$130,625,000	1.25%	18,951	3,913	0.2065	1,267,000	Very Large	0.0150	0.0031	13,957,000	Large	0.0014	0.0003	11.02	$ 748.73
Nigeria	Low	$357,200,000,000	$4,465,000,000	1.25%	193,200	28,980	0.1500	923,768	Large	0.2091	0.0314	154,729,000	Very Large	0.0012	0.0002	167.50	$ 2,308.55
Rwanda	Low	$10,130,000,000	$121,560,000	1.20%	14,008	2,662	0.1900	26,798	Very Small	0.5227	0.0993	7,600,000	Medium	0.0018	0.0004	283.60	$ 1,332.89
Senegal	Low	$22,380,000,000	$469,980,000	2.10%	14,805	4,332	0.2926	196,723	Small	0.0753	0.0220	11,658,000	Medium	0.0013	0.0004	59.26	$ 1,919.71
Sierra Leone	Low	$4,622,000,000	$91,053,400	1.97%	11,300	904	0.0800	71,740	Small	0.1575	0.0126	6,144,562	Small	0.0018	0.0001	85.65	$ 752.21
Somalia	Low	$5,731,000,000	$112,900,700	1.97%	22,100	2,608	0.1180	637,657	Large	0.0347	0.0041	9,832,017	Medium	0.0022	0.0003	15.42	$ 582.89
South Africa	Upper Middle	$495,100,000,000	$2,128,220,000	0.43%	364,131	62,995	0.1730	1,221,037	Very Large	0.2982	0.0516	47,432,000	Very Large	0.0077	0.0013	38.85	$ 10,438.10
Sudan	Lower Middle	$92,810,000,000	$37,929,774	0.04%	11,900	4,320	0.3630	2,505,813	Very Large	0.0047	0.0017	39,154,490	Very Large	0.0003	0.0001	15.63	$ 2,370.35
Swaziland	Lower Middle	$5,882,000,000	$24,340,000	0.41%	3,594	1,078	0.2999	17,364	Very Small	0.2070	0.0621	1,032,000	Very Small	0.0035	0.0010	59.43	$ 5,699.61
Tanzania	Low	$57,890,000,000	$1,013,075,000	1.75%	78,891	6,808	0.0863	945,087	Large	0.0835	0.0072	37,849,133	Very Large	0.0021	0.0002	40.05	$ 1,529.49
Togo	Low	$5,202,000,000	$102,479,400	1.97%	7,520	2,376	0.3160	56,785	Small	0.1324	0.0418	6,100,000	Small	0.0012	0.0004	107.42	$ 852.79
Tunisia	Lower Middle	$84,040,000,000	$214,746,000	0.26%	19,232	12,662	0.6584	163,610	Small	0.1175	0.0774	10,102,000	Medium	0.0019	0.0013	61.74	$ 8,319.14
Uganda	Low	$43,220,000,000	$950,840,000	2.20%	70,746	16,272	0.2300	236,040	Medium	0.2997	0.0689	27,616,000	Very Large	0.0026	0.0006	117.00	$ 1,565.03
Zambia	Low	$18,500,000,000	$527,250,000	2.85%	91,440	20,117	0.2200	752,614	Large	0.1215	0.0267	14,668,000	Large	0.0062	0.0014	19.49	$ 1,261.25
Zimbabwe	Low	$332,000,000	$63,896,000	19.25%	97,267	18,481	0.1900	390,757	Medium	0.2489	0.0473	13,010,000	Large	0.0075	0.0014	33.29	$ 25.52

Table 2: Country totals using max effect climate change model

Country	With Adaptation				Without Adaptation				Adaptation % Change
	Total Avg Cost	Tot Impact Factor	Total Cost as % of Exp	Total Cost as % of GDP	Total Avg Cost	Tot Impact Factor	Total Cost as % of Exp	Total Cost as % of GDP	
Algeria	2,346	21.7%	47.0%	1.974%	17,281	159.5%	346.0%	2.597%	86%
Angola	699	87.1%	14.0%	1.351%	1,691	210.7%	33.9%	1.437%	59%
Benin	813	300.2%	81.8%	7.363%	1,634	603.4%	164.4%	7.983%	50%
Botswana	186	14.7%	13.4%	4.883%	241	19.1%	17.3%	4.904%	23%
Burkina Faso	1,301	44.2%	35.1%	18.422%	7,324	249.1%	197.9%	21.628%	82%
Burundi	510	264.5%	79.8%	19.302%	1,341	694.9%	209.6%	21.860%	62%
Cameroon	596	92.4%	37.8%	3.453%	2,637	409.1%	167.5%	3.931%	77%
Central African Republic	267	34.5%	40.7%	18.532%	2,594	335.7%	395.7%	25.526%	90%
Chad	2,082	163.8%	51.2%	23.781%	8,480	666.9%	208.6%	27.715%	75%
Congo, Dem Rep	1,570	374.6%	38.6%	18.466%	2,023	482.7%	49.8%	18.678%	22%
Congo, Rep	300	231.2%	7.1%	2.603%	434	334.7%	10.3%	2.685%	31%
Coted, Ivorie	700	71.8%	19.5%	9.195%	4,042	414.8%	112.8%	10.128%	83%
Djibouti	274	132.5%	193.9%	7.688%	1,455	703.4%	1029.6%	13.561%	81%
Equatorial Guinea	106	33.4%	68.5%	0.828%	534	168.1%	344.4%	0.851%	80%
Eritrea	1,232	939.6%	149.0%	1.133%	3,677	2804.0%	444.6%	2.187%	66%
Ethiopia	1,448	138.3%	175.1%	21.179%	3,164	302.2%	382.6%	25.267%	54%
Gabon	243	173.2%	49.2%	2.234%	442	314.9%	89.5%	2.329%	45%
Gambia, The	136	125.3%	27.9%	18.280%	503	463.6%	103.3%	19.765%	73%
Ghana	2,455	190.3%	46.3%	13.721%	6,803	527.3%	128.3%	14.910%	64%
Guinea	620	95.3%	30.1%	18.322%	2,768	425.0%	134.1%	20.371%	78%
Guinea-Bissau	140	96.4%	75.9%	19.226%	669	461.7%	363.6%	24.893%	79%
Kenya	2,206	164.6%	33.0%	9.796%	2,677	199.8%	40.0%	9.870%	18%
Lesotho	63	38.4%	27.7%	6.406%	891	546.3%	394.1%	8.936%	93%
Liberia	268	271.5%	83.5%	19.375%	513	520.3%	160.0%	20.882%	48%
Libya	0	0.0%	0.0%	4.329%	0	0.0%	0.0%	4.329%	0%
Madagascar	1,847	213.0%	32.2%	26.101%	1,841	212.3%	32.1%	26.098%	0%
Malawi	386	37.0%	7.8%	34.951%	6,217	595.9%	126.1%	39.504%	94%
Mali	577	114.3%	18.9%	18.102%	2,128	421.2%	69.6%	19.101%	73%
Mauritania	492	110.5%	38.0%	18.479%	2,361	530.7%	182.4%	21.324%	79%
Morocco	1,757	34.4%	66.1%	1.750%	5,612	109.9%	211.2%	2.013%	69%
Mozambique	210	24.6%	2.9%	32.054%	2,831	332.0%	39.5%	33.353%	93%
Namibia	548	67.6%	40.7%	9.326%	3,082	380.1%	228.9%	11.192%	82%
Niger	1,366	232.8%	104.6%	12.558%	5,604	954.7%	429.0%	16.613%	76%
Nigeria	8,945	205.8%	20.0%	11.500%	18,864	433.9%	42.2%	11.778%	53%
Rwanda	646	161.9%	53.2%	11.438%	2,041	511.2%	167.9%	12.815%	68%
Senegal	422	65.0%	9.0%	19.089%	1,522	234.3%	32.4%	19.580%	72%
Sierra Leone	293	216.4%	32.2%	18.365%	646	476.7%	71.0%	19.129%	55%
Somalia	717	183.3%	63.5%	18.981%	1,491	381.1%	132.0%	20.331%	52%
South Africa	1,170	12.4%	103.7%	3.892%	4,308	45.6%	381.5%	3.956%	73%
Sudan	574	88.7%	151.4%	0.430%	4,123	636.3%	1087.1%	0.812%	86%
Swaziland	35	21.7%	14.4%	3.784%	356	220.1%	146.2%	4.329%	90%
Tanzania	2,459	240.8%	24.3%	16.175%	5,089	498.3%	50.2%	16.629%	52%
Togo	1,239	347.7%	120.9%	20.113%	2,833	794.8%	276.5%	23.176%	56%
Tunisia	459	25.4%	21.4%	2.354%	4,009	222.2%	186.7%	2.777%	89%
Uganda	5,055	207.1%	53.2%	20.970%	10,274	420.9%	108.1%	22.177%	51%
Zambia	1,019	33.8%	19.3%	26.201%	2,874	95.2%	54.5%	27.204%	65%
Zimbabwe	0	0.0%	0.0%	173.212%	0	0.0%	0.0%	173.212%	0%

Table 3: Malawi data per decade

		Decade:	2020	2030	2040	2050	2060	2070	2080	2090	2100	Total
Global Avg	Avg Cost	w/ Adapt	3	3	3	4	5	12	15	18	15	79
	Avg Cost	w/out Adapt	3	3	3	3	3	72	273	790	748	1899
	Cum Avg Cost	w/ Adapt	3	6	10	14	19	31	46	64	79	
	Cum Avg Cost	w/out Adapt	3	6	10	13	16	88	361	1152	1899	
	Opp Factor	w/ Adapt	0.3%	0.4%	0.4%	0.4%	0.5%	1.2%	1.6%	2.3%	2.3%	9.4%
	Opp Factor	w/out Adapt	0.2%	0.2%	30.8%	10.8%	16.7%	39.2%	50.0%	76.9%	86.5%	311.4%
	Cum Opp Factor	w/ Adapt	0.3%	0.7%	1.0%	1.5%	2.0%	3.1%	4.8%	7.1%	9.4%	
	Cum Opp Factor	w/out Adapt	0.2%	0.4%	31.2%	42.0%	58.7%	97.9%	147.9%	224.8%	311.4%	
	Cost as % of Exp	w/ Adapt	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.5%	0.5%	2.0%
	Cost as % of Exp	w/out Adapt	0.0%	0.0%	6.5%	2.3%	3.5%	8.3%	10.6%	16.3%	18.3%	65.9%
	Cum Exp %	w/ Adapt	0.1%	0.1%	0.2%	0.3%	0.4%	0.7%	1.0%	1.5%	2.0%	
	Cum Exp %	w/out Adapt	0.0%	0.1%	6.6%	8.9%	12.4%	20.7%	31.3%	47.6%	65.9%	
	Cost as % of GDP	w/ Adapt	3.853%	3.852%	3.853%	3.853%	3.854%	3.860%	3.862%	3.864%	3.861%	34.711%
	Cost as % of GDP	w/out Adapt	3.853%	3.852%	3.853%	3.853%	3.852%	3.906%	4.063%	4.467%	4.434%	36.133%
	Cum GDP %	w/ Adapt	3.853%	7.705%	11.558%	15.411%	19.265%	23.124%	26.986%	30.850%	34.711%	
	Cum GDP %	w/out Adapt	3.853%	7.705%	11.558%	15.410%	19.263%	23.169%	27.232%	31.699%	36.133%	
Cntry Avg	Avg Cost	w/ Adapt	122	42	27	26	32	31	34	38	33	386
	Avg Cost	w/out Adapt	123	81	113	72	134	388	850	884	827	3472
	Cum Avg Cost	w/ Adapt	122	164	191	217	249	280	314	352	386	
	Cum Avg Cost	w/out Adapt	123	205	318	390	523	911	1761	2645	3472	
	Opp Factor	w/ Adapt	5.8%	2.0%	1.4%	1.4%	1.7%	1.7%	1.9%	2.1%	1.9%	20.0%
	Opp Factor	w/out Adapt	5.9%	3.9%	5.4%	5.8%	42.2%	54.3%	76.5%	105.3%	111.1%	410.5%
	Cum Opp Factor	w/ Adapt	5.8%	7.9%	9.3%	10.7%	12.4%	14.1%	16.0%	18.2%	20.0%	
	Cum Opp Factor	w/out Adapt	5.9%	9.8%	15.2%	21.0%	63.2%	117.5%	194.0%	299.3%	410.5%	
	Cost as % of Exp	w/ Adapt	1.2%	0.4%	0.3%	0.3%	0.4%	0.4%	0.4%	0.5%	0.4%	4.2%
	Cost as % of Exp	w/out Adapt	1.3%	0.8%	1.1%	1.2%	8.9%	11.5%	16.2%	22.3%	23.5%	86.8%
	Cum Exp %	w/ Adapt	1.2%	1.7%	2.0%	2.3%	2.6%	3.0%	3.4%	3.8%	4.2%	
	Cum Exp %	w/out Adapt	1.3%	2.1%	3.2%	4.4%	13.4%	24.9%	41.0%	63.3%	86.8%	
	Cost as % of GDP	w/ Adapt	3.945%	3.883%	3.871%	3.870%	3.875%	3.874%	3.877%	3.880%	3.876%	34.951%
	Cost as % of GDP	w/out Adapt	3.946%	3.914%	3.938%	3.906%	3.954%	4.153%	4.514%	4.540%	4.496%	37.360%
	Cum GDP %	w/ Adapt	3.945%	7.828%	11.699%	15.569%	19.444%	23.318%	27.195%	31.075%	34.951%	
	Cum GDP %	w/out Adapt	3.946%	7.860%	11.798%	15.704%	19.658%	23.811%	28.325%	32.865%	37.360%	
Cntry Med Avg	Avg Cost	w/ Adapt	1	0	0	3	4	13	17	19	15	74
	Avg Cost	w/out Adapt	1	0	0	0	86	748	752	790	1458	3837
	Cum Avg Cost	w/ Adapt	1	1	1	4	9	22	39	59	74	
	Cum Avg Cost	w/out Adapt	1	1	1	1	88	836	1589	2379	3837	
	Opp Factor	w/ Adapt	0.1%	0.1%	0.1%	0.2%	0.3%	0.8%	1.0%	1.1%	0.9%	4.5%
	Opp Factor	w/out Adapt	0.1%	0.1%	0.1%	0.0%	4.3%	36.0%	36.1%	59.6%	97.7%	233.9%
	Cum Opp Factor	w/ Adapt	0.1%	0.2%	0.3%	0.4%	0.8%	1.6%	2.6%	3.6%	4.5%	
	Cum Opp Factor	w/out Adapt	0.1%	0.2%	0.3%	0.3%	4.6%	40.5%	76.6%	136.1%	233.9%	
	Cost as % of Exp	w/ Adapt	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.2%	1.0%
	Cost as % of Exp	w/out Adapt	0.0%	0.0%	0.0%	0.0%	0.9%	7.6%	7.6%	12.6%	20.7%	49.5%
	Cum Exp %	w/ Adapt	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.5%	0.8%	1.0%	
	Cum Exp %	w/out Adapt	0.0%	0.0%	0.1%	0.1%	1.0%	8.6%	16.2%	28.8%	49.5%	
	Cost as % of GDP	w/ Adapt	3.851%	3.850%	3.850%	3.852%	3.853%	3.860%	3.864%	3.865%	3.862%	34.707%
	Cost as % of GDP	w/out Adapt	3.851%	3.850%	3.850%	3.850%	3.918%	4.434%	4.437%	4.467%	4.988%	37.645%
	Cum GDP %	w/ Adapt	3.851%	7.701%	11.551%	15.403%	19.257%	23.117%	26.981%	30.846%	34.707%	
	Cum GDP %	w/out Adapt	3.851%	7.701%	11.551%	15.401%	19.319%	23.753%	28.190%	32.657%	37.645%	
Max Effect	Avg Cost	w/ Adapt	122	42	27	26	32	31	34	38	33	386
	Avg Cost	w/out Adapt	123	81	639	222	746	748	850	1314	1492	6217
	Cum Avg Cost	w/ Adapt	122	164	191	217	249	280	314	352	386	
	Cum Avg Cost	w/out Adapt	123	205	844	1066	1812	2560	3411	4725	6217	
	Opp Factor	w/ Adapt	11.7%	4.1%	2.6%	2.5%	3.0%	3.0%	3.3%	3.7%	3.2%	37.0%
	Opp Factor	w/out Adapt	11.8%	7.8%	61.2%	21.3%	71.5%	71.7%	81.5%	126.0%	143.0%	595.9%
	Cum Opp Factor	w/ Adapt	11.7%	15.7%	18.3%	20.8%	23.8%	26.8%	30.1%	33.8%	37.0%	
	Cum Opp Factor	w/out Adapt	11.8%	19.6%	80.9%	102.1%	173.7%	245.4%	326.9%	452.8%	595.9%	
	Cost as % of Exp	w/ Adapt	2.5%	0.9%	0.5%	0.5%	0.6%	0.6%	0.7%	0.8%	0.7%	7.8%
	Cost as % of Exp	w/out Adapt	2.5%	1.6%	13.0%	4.5%	15.1%	15.2%	17.2%	26.6%	30.3%	126.1%
	Cum Exp %	w/ Adapt	2.5%	3.3%	3.9%	4.4%	5.0%	5.7%	6.4%	7.1%	7.8%	
	Cum Exp %	w/out Adapt	2.5%	4.2%	17.1%	21.6%	36.7%	51.9%	69.2%	95.8%	126.1%	
	Cost as % of GDP	w/ Adapt	3.945%	3.883%	3.871%	3.870%	3.875%	3.874%	3.877%	3.880%	3.876%	34.951%
	Cost as % of GDP	w/out Adapt	3.946%	3.914%	4.349%	4.023%	4.433%	4.434%	4.514%	4.876%	5.015%	39.504%
	Cum GDP %	w/ Adapt	3.945%	7.828%	11.699%	15.569%	19.444%	23.318%	27.195%	31.075%	34.951%	
	Cum GDP %	w/out Adapt	3.946%	7.860%	12.209%	16.232%	20.664%	25.099%	29.613%	34.488%	39.504%	