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Section 3.0 Differential Adaptation and the 50 Poorest Countries

Climate change will have a highly differential impact on various countries and regions on the planet. In general, this impact requires two forms of country or regional response:

- Resiliency to recover from large scale climate changed induced weather events. In the USA, Hurricanes Sandy (2012) and Harvey (2017) represent the kind of large scale events for which there has been little resiliency or recovery plan.

- Adaptation to loss of natural resources as a result of mostly changing precipitation patterns and/or wholesale loss of land due to sea level rise and associated inland flooding.

Effective response to these issues requires substantial country investments in new forms of infrastructure and governmental emergency responses in order to effectively cope with the problem. This requires available capital and, to first order, GDP per capita can serve as a proxy for available capital that can be redirected towards adaptation. A related index, known as the Gini coefficient, often used in economics, can also serve as a proxy, or at the very least provides a uniform measure of economic inequality between countries [79]. GDP per capita data for the year 2016 is available from the World Bank database [80] which we have used to construct Table 4.

In table 4 we select the 50 poorest countries under this criterion. Note that we omit very small island countries from this list. Investments required for climate change adaptation within a given country, despite being heavily researched [81 - 85] remain rather unknown and are highly dependent on the details of any given county. Many estimates suggest that the annual cost for a country like the US is a few tens of billions of dollars per year (BN) perhaps up to as much as 100 BN. While it is difficult to estimate adaptation costs for any county, we do not here that most adaptation would consist of new kinds of infrastructure (better flood control, improved irrigation for agriculture, new kinds of crops, etc) and infrastructure. In addition, these costs are likely to be significantly higher for countries vulnerable to sea level. As the goal of this exercise is to reveal the strong disparity in individual country resources with respect to their ability to invest in climate change resiliency we adopt the following scheme): for land locked countries we use a cost of 5 BN per annum and for countries vulnerable to sea level rise we use 10 BN. Obviously, these costs are a strong function of the area of the country that requires protection but those details are very difficult to obtain and not necessary for our primary purpose of illuminating disparity in terms of the fractional GDP cost needed for environmental adaptation.

Table 4: The 50 poorest countries in terms of GDP per capita comparison to the United States

Country	Index	Principle contributions to GDP	% of GDP	Land/Sea
1. Burundi	0.005	Agriculture	>100	Land

2. Malawi	0.005	Agriculture/Biodiversity	95	Land
3. Niger	0.006	Agriculture/Uranium	75	Land
4. Mozambique	0.007	Agriculture	90	Sea
5. Central African Republic	0.007	Agriculture	>100	Land
6. Madagascar	0.007	Agriculture/Textiles/Vanilla	100	Sea
7. Somalia	0.008	Agriculture	>100	Sea
8. Dem. Rep of Congo	0.008	Agriculture/Mineral Extraction	15	Land
9. Liberia	0.008	Agriculture/Forestry/Shipping	>100	Sea
10. Sierra Leone	0.009	Agriculture/Mining/Tourism	>100	Sea
11. Guinea	0.009	Bauxite Mining/Fisheries	>100	Sea
12. Afghanistan	0.01	Livestock/Forestry/Mineral Extraction	25	Land
13. Togo	0.01	Agriculture/Phosphates	>100	Sea
14. Uganda	0.011	Coffee/Mineral Extraction	20	Land
15. Guinea-Bissau	0.011	Trade via Port Traffic	>100	Sea
16. Burkina Faso	0.011	Cotton and Gold Exports	40	Land
17. Chad	0.012	Oil Exports	50	Land
18. Rwanda	0.012	Agriculture/Coffee	65	Land
19. Ethiopia	0.012	Agriculture/Livestock	7	Land
20. Nepal	0.013	Tourism/Agriculture	20	Land

21. Haiti	0.013	Agriculture/Mineral Extraction	>100	Sea
22. Mali	0.013	Agriculture/Livestock/Cotton	35	Land
23. Benin	0.013	Trade	95	Sea
24. Tajikistan	0.013	Agriculture/Mineral Extraction	70	Land
25. Tanzania	0.015	Agriculture/Natural Gas	25	Sea
26. Senegal	0.017	Trade/Fisheries	70	Sea
27. Yemen	0.017	Agriculture/Fisheries/Oil and Gas	40	Sea
28. Zimbabwe	0.017	Tobacco/Precious Metals	30	Land
29. Cameroon	0.018	Agriculture/Oil Exports	40	Sea
30. Kyrgyzstan	0.018	Agriculture/Gold Exports	85	Land
31. Mauritania	0.019	Agriculture/Livestock/Iron Ore	>100	Sea
32. Zambia	0.02	Cooper exports	20	Land
33. Cambodia	0.022	Rice and Garment Exports	50	Sea
34. Myanmar	0.022	Rice and Garment Exports	15	Sea
35. Bangladesh	0.023	Rice and Garment Exports	5*	Sea
36. Kenya	0.025	Tourism/Agriculture	15	Sea
37. Pakistan	0.025	Wheat, Coal and Mineral exports	4	Sea
38. Ghana	0.026	Tourism; Gold and Cocoa exports	25	Sea
39. Ivory Coast	0.026	Coffee and Cocoa exports	35	Sea

40. Rep. of Congo	0.027	Petroleum Exports	>100	Sea
41. India	0.029	Multi-Faceted	<1	Sea
42. Moldova	0.033	Wheat and Wine exports	80	Land
43. Uzbekistan	0.035	Wheat, Cotton and Gold exports	7	Land
44. Nicaragua	0.037	Coffee, Cotton and Tourism	75	Sea
45. Nigeria	0.037	Agriculture; Oil Exports	3	Sea
46. Vietnam	0.037	Rice, coffee and oil exports	5	Sea
47. Ukraine	0.038	Wheat, corn and mineral exports	12	Land
48. Laos	0.041	Rice exports; tourism	35	Land
49. Honduras	0.041	Coffee exports	50	Sea
50. Sudan	0.042	Gold, cotton and Oil exports	5	Land

*Bangladesh, thanks to large exports in the clothing industry has shown one of the world's highest GDP growth rates over the last 2-3 years [86,87]

A recent study [88] has found that the current global spending on climate change adaptation is only ~ 0.4% of global GDP. This paltry amount is similar to what the US chooses to invest in its well documented crumbling infrastructure [89,90] (e.g. sewers, roads, bridges, airports, etc). This is a direct indication that, like the US, countries of the world, collectively, are steadfastly ignoring the kinds of infrastructure investments needed for climate change adaptation even though many of them to have the resources to make the requisite investment. From Table 4, we can group the selected 50 countries into four categories

- Category A: The 19 countries with GDP percentages > 75%. These countries that have no ability to invest in their own climate adaptation and hence are dependent upon foreign investment. In general, these countries are fairly small and/or dependent upon a single sector to support their export economy. In most cases, infrastructure investment will be required to better manage water resources for agricultural and/or mining operations. Of these 19 countries, only 3 (Kyrgyzstan, Moldova, Nicaragua) or not located in Africa:

- Category B: The 16 countries with GDP percentages from 25-75%. In general, these countries have larger total economies than those in previous category but investments at this level, while financially possible, are very unlikely to occur. Of these 16 countries, 10 are located in Africa.

- Category C: The 7 countries with GDP percentages from 10-25%. In most cases, particularly for the countries of Africa in this category, their total economy is strongly buoyed by the kinds of mineral resources that are being overconsumed in the rest of the world. This indicates an interesting kind of climate change adaptation dynamic. While the rest of the world may de-facto claim it is up to individual countries to marshal their own resources, when climate change threatens a valuable worldwide commodity harvest (e.g. Cooper in Zambia) the tenor of this attitude may well change.

- Category D: The 8 countries with GDP percentages < 10%. These countries, in general, have large global economies. India is a numerical artifact here as its GDP per capita is relatively low since its capita is very large. Bangladesh in this category as arguably the most in danger country in the world due to sea level rise. Currently Bangladesh is a rising economy and its GPD has rapidly increased thus giving that country perhaps some much needed capital to help with mitigate rising sea level and storm surge. Vietnam is another country where rising sea level poses a serious threat to its extensive rice fields [91,92] but has also emerged as a growing economy.

Section 3.1.1 Some Specific Country and Regional Examples

A noteworthy precursor of the devastating effects of storm surge induced flooding on an agricultural economy is provided by Honduras in the case of Hurricane Mitch 1988. That system devastated many productive agricultural areas in Honduras and it took years for that country to recover from that single event [93,94]. If the nature of climate change is to increase the frequency of these kinds of events [95, 96] then countries like Honduras, Vietnam and Bangladesh may be put on an irrecoverable trajectory. In cases like these, which may become numerous, what international organizations are going to come to the aid of these countries, when they are stressed beyond their own means? In the specific case of Bangladesh, if their country is completely inundated, how can they be recompensed?

Overall Table 4 shows that most all of Africa will have the most difficult time adapting to climate change. Those countries where overall industry contributes similar or more as agriculture to the overall GDP will likely be more resilient. For most of the country of Africa, climate change will likely have dramatic effects on agriculture and livestock breeding [97,98,99,100]. Irrigation practices will have to be changed (that will be an infrastructure investment); new forms of crops will need to be planted as traditional crop yields of wheat and maize will no longer be efficient in the new climate. These new forms will likely involve fruits and vegetables than can flourish in the expected coming very hot and dry climate. In addition, changes in climate invariably will produce changes in the kinds of insect populations that bring disease to livestock and Africa is particularly vulnerable to this outcome [102,103]. A specific example is provided by Ghana where climate change and rising sea level will impact fisheries, agriculture and biodiversity which will lead to a predicted loss in labor productivity that will be equivalent to 6% of GDP in 2030 [101].

A good example of climate change adaptation as an international problem lies in the form of deep water port vulnerability. Currently, some 80-90% of world freight moves by ship to fuel the global consumption craze. Is it therefore the correct expectation that the individual country that contains a specific port should be solely responsible for making the large-scale infrastructure needed to reduce its vulnerability to sea level rise and the associated occasional storm surge? The specific example of the deep-water port in Karachi serves to illuminate this problem. Recently, China has made a large-scale investment to establish and economic corridor (e.g. a superhighway) from western China through Pakistan to Karachi [102,103]. This will allow for the manufacturing base in western China to get its goods to the global market earlier. However, sea level rise models suggest that this port will be underwater by 2060 [104]. Clearly Pakistan does not have enough GDP resources to deal with eventuality and so who pays for preserving Karachi as a point of global distribution? China alone? The rest of the world? Who? And even if it is decided who, who is, how do they pay?

The existence of the port of Karachi means that the global consumer has access to resources/goods. Removal of this part would therefore decrease resource availability. As resource availability becomes an increasingly fundamental limit to economic growth, individual countries then need to attack the problem with increasing severity if they are to remain economically competitive. Climate change directly threatens resource availability which then directly affects any countries future ability to remain economically competitive. A specific example here would involve the Ukraine, which is listed in Table 4, and is the 6th leading exporting of wheat with a total export amount that is about 75% of the USA. If climatic conditions in Ukraine change to the point that their wheat crop is substantially compromised, then much of the economic livelihood of the Ukraine will also be compromised.

The concept used above for countries can be applied to individual cities to again show very strong difference in adaptation. A good example of direct adaptation is provided by the city of London and the construction of the Thames (river) Barrier to protect citizens and businesses against future storm surge events exacerbated by sea level rise. Indeed, elevated flood risk is one of the main predictions of most all climate models, and example of which is shown in Figure 25 and indicates that most of Europe well experience a 100% increase flood risk this century compared to the last century. Indeed, over the period of 2010-2016 there have been 13 once in a century floods induced by very heavy rain events. The 2012 floods in Russia and the 2014 floods in Romania, Croatia and Serbia were both accompanied by significant fatalities. The frequency of these recent far larger than the statistical average of these events would predict and there is growing recognition that changing and increasing flood patterns across Europe are a major component of their regional climate change [105,106,107]

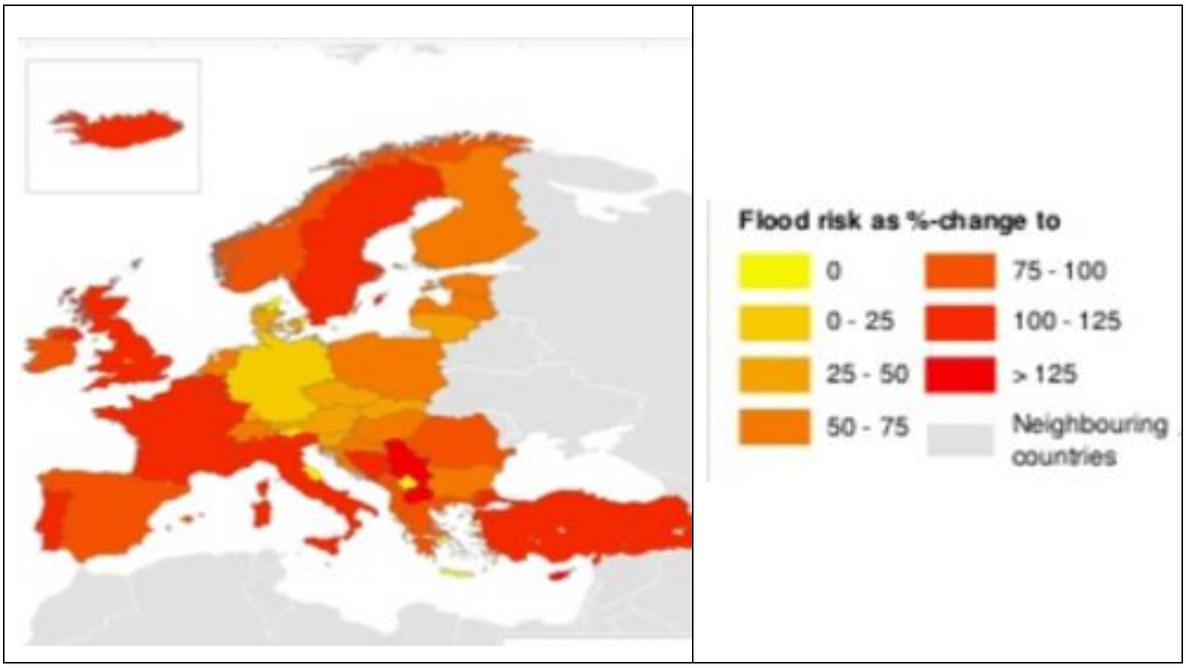

Figure 25. Expected change in European Flood risk by 2050.

In table 5 we compare the spending rates [88] in a few selected cities in both the developed and developing world to indicate the overall disparity. Here we tabulate spending amounts over a two period, 2014-216 for 5 selected cities, compared to their populations, to again show strong disparity between the developed and developing world. The data in this table show a range of about 60 in this kind of spending. Huge urban populations may be particular vulnerable to single climate induced events which serve to stress emergency response, facilities for care, and probable short-term relocation needs. Obviously, cities like Lagos and Mumbai have not made anywhere near the required investments to help prevent a large-scale catastrophe.

Table 5: Per citizen climate change adaptation spending for 5 selected cities

City	Total Spending (millions)	2016 Population (millions)	Spending Per Citizen
New York City	1624	8.58	190
London	991	8.78	113
Beijing	853	21.5	40
Mumbai	329	21.3	15
Lagos	52	17.5 – 21*	2.5 -- 3

*The official population of Lagos, Nigeria is in dispute.

We close this section with particular reference to two recent climate scenarios and their associated costs. The wettest scenario comes from the National Center for Atmospheric Research (NCAR - USA) and the driest scenario comes from the Commonwealth Scientific and Industrial Research Organization (CSIRO – Australia). In general, adaptation costs can be broken up into six sectors; infrastructure improvements, coastal zone remediation, water supply management, agricultural stocks, human health (i.e. the well documented rise of vector borne diseases such as malaria and dengue fever [108, 109, 110]), and recovery from extreme weather events. The likely two largest near-term expenditures will involve coastal zone protection and recovery from extreme weather events (which are most likely to happen in coastal zones). Over time, infrastructure costs are likely to be the highest. Some highlights of these studies are:

- For a world which will be +2C warmer in 2050, the estimated annual costs over the period 2010-2050 are 75 – 100 BN. This is very likely an underestimate as our accelerating rates are putting us on a trajectory of +3C by the year 2050. In addition, the costs are unlikely to be thought of as annual costs (similar for instance to foreign aid) but these costs are negatively impacted by the sticker shock that 100 BN per year for 4 years is 4 trillion dollars.
- For both scenarios, the region of highest impact is East Asia which is predicted to bear 25% of the total coast and the lowest impact region is that of the Middle East and North Africa (not surprisingly since it already is mostly a desert) at a level of 3%. This once again shows there to be significant disparity from region to region.
- In general adaptation costs will increase over time, particularly the longer one waits to strategically implement them. Mathematically, these costs do become a lower percentage of predicted GDP growth which means that may some countries (like Bangladesh above) will become less vulnerable to climate change as their economies grow. But there is an important interplay him: if economic growth (like coffee exports in Honduras) require

resources particularly vulnerable to climate change, then GDB growth won't matter if no initial protection mechanisms arise.

Section 3.1.2 The Adaptation Deficit

We can map our previous idea of differential adaptation on to the term *adaptation deficit*, which is widely used in the literature [111,112,113,114]. There are two manners in which this term is commonly employed: a) defining the notion that countries are generally underprepared for current climate change conditions, let alone future ones and b) poor countries have significantly less capacity to adapt, as discussed previously. Since adaptation costs and weather volatility are both likely to rise over the next few decades, a proper visualization of adaptation deficit is shown in Figure 26 from which it is qualitatively clear that we are currently under capacity (because a deficit exists) and further delay of planning and investment will only cause costs to rise to meet the inevitable required additional capacity.

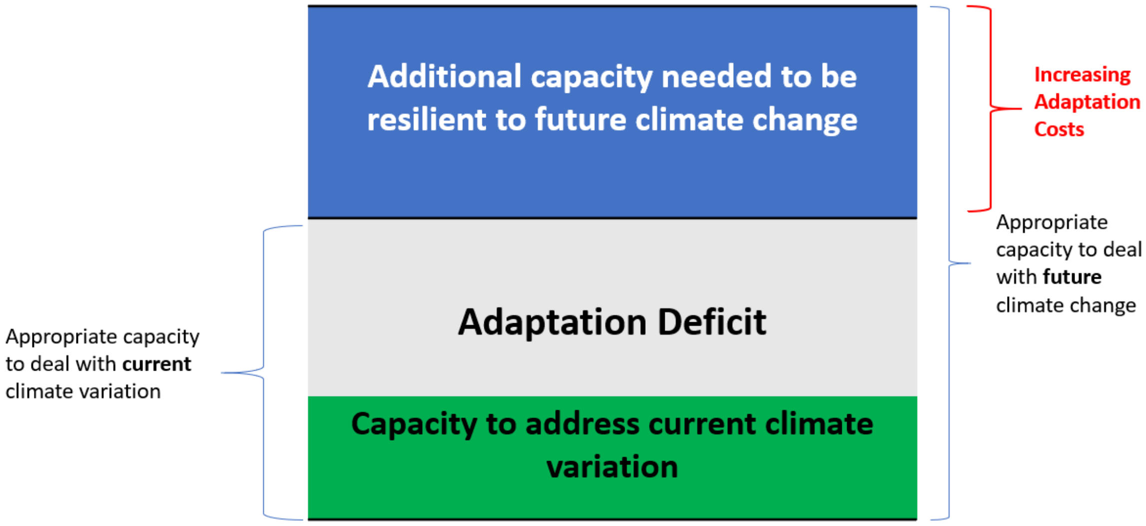

Figure 26: Visual representation of adaptation deficit as presented to include a vertical expansion to better represent increasing adaptation costs as time goes by.

Clearly, determining the correct level of adaptation to current climate variability is very challenging, and this challenge is exacerbated if, by their very nature, poor countries are unable to make adequate investments. A good example is provided by storm surges in low lying coastal areas, perhaps triggered by a Category 5 Hurricane or a super-typhoon. These large storms, of course, do not respect country boundaries and the amount of physical damage they inflict upon a landscape is certainly independent of GDP. So, a situation that occurs in the state of Texas will likely have a much different social impact and recover than if the same situation occurs in Haiti, Bangladesh, or Vietnam. Currently there is an insufficient global response to help mitigate this highly differential adaptation ability. Part of the problem likes in the tremendous uncertainty of the actual impact of potential climate events [115,116,117,118]. But we seem to let this uncertainty paralyze global planning for the future, instead of catalyzing the international community to be much more proactive under the assurance that significant events will happen in the future, we just don't know when and to whom.

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