COST-BENEFIT ANALYSIS OF ADAPTATION STRATEGY IN BANGLADESH

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Benefits and Costs of Adapting to Climate Change in Bangladesh

COPENHAGEN CONSENSUS CENTER

SMARTER SOLUTIONS FOR BANGLADESH

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Cost-Benefit Analysis of Adaptation Strategy in Bangladesh

Bangladesh Priorities

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Abbreviations

ADB	Asian Development Bank
AR5	The Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BAU	Business as usual
BBS	Bangladesh Bureau of Statistics
BCA	Benefit Cost Analysis
C	Carbon
CED	Cost of environmental degradation
CEGIS	Center of Excellence for Geospatial Information Science
CI	Confidence Interval
CIDA	Canadian International Development Agency
CO2	Carbon Dioxide
CO2-eq	Carbon Dioxide Equivalent
DFID	The Department for International Development, UK
DICE	The Dynamic Integrated Climate-Economy model
EC	Electrical conductivity
EP	Exceedance probability
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
G	Gram
GDP	Gross domestic Product
GHG	Greenhouse gases
GoB	Government of Bangladesh
GTZ	German Technical Cooperation Agency
Ha	Hectare
HH	Household
IUCN	The International Union for Conservation of Nature
IWG	International Working Group
JICA	Japan International Cooperation Agency
Kg	Kilogram
m	Meter
NPV	Net present value
PL	Post larvae
PV	Present Value
RDM	Robust Decision-Making
RICE	Regional integrated model of climate and the economy
ROA	Real Option Analysis
SCC	Social Cost of Carbon
SIDA	Swedish International Development Cooperation Agency
SIZ	The Sundarbans Impact Zone
SRF	The Sundarbans Reserve Forest
SD	Standard Deviation
SRES	Special Report on Emission Scenarios, IPCC, AR4
SST	Sea surface temperature
Tk	Bangladeshi taka

T	Tone
UNDP	United Nations Development Programme
UNEP	The United Nations Environment Programme
USAID	United States Agency for International Development
US$	US dollars
WCMC	The UNEP World Conservation Monitoring Centre
WDI	World Development Indicators, the World Bank
WG	Working Group

1. Brief description of the situation in Bangladesh

Due to its location and geological specifics, Bangladesh is among the most exposed countries to climate change. Low per capita income is an important resource constraint on the path to reducing exposure and coping with damage from climate change. This makes Bangladesh one of the most vulnerable countries with respect to the changing global environment. Bangladesh is already exposed to severe natural hazards and extreme weather events. Continuous sea level rise exacerbated by the sinking delta of the Ganges River creates an imminent threat to the multimillion-strong population of The Sundarbans and other coastal areas. Tropical cyclones, tidal surge, regular floods, droughts, and heat waves have already cost several million dollars per year.

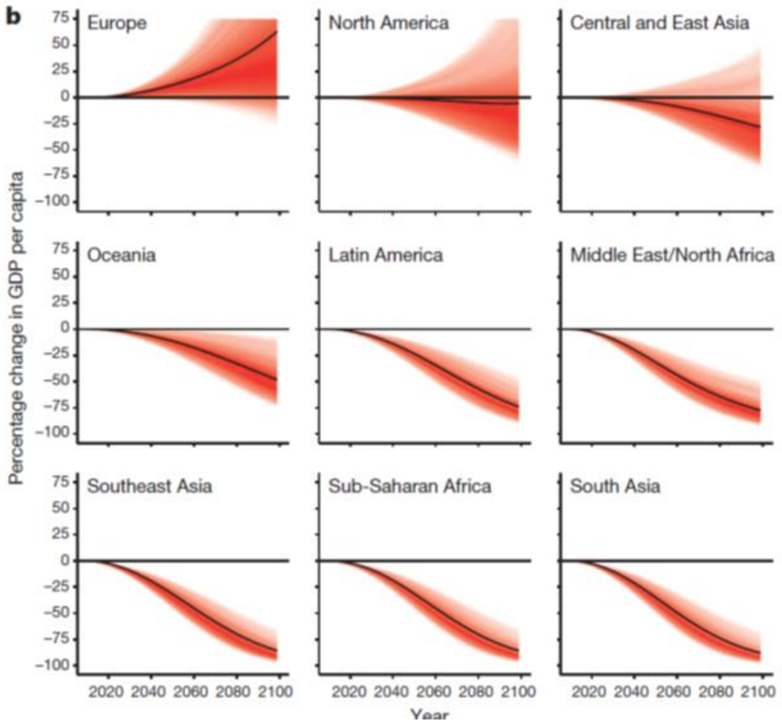
1.1. Climate change and economic growth

Future climate change will have profound consequences threatening the economic growth of the country and may compromise development goals dragging Bangladesh into a development trap. Burke et. al. (2015) predicts double-digit losses of GDP per capita due to climate change (see Figure 1). Such losses may be an unbearable burden for the socioeconomic system of Bangladesh. The damage functions presented in Figure 1 were calibrated based on historic data and, in our view, they reflect continuation of a business as usual (BAU) development scenario. Development according to a BAU scenario will lead Bangladesh into the "adaptation trap". Adaptation should be deeply embedded into the development strategy, combining reduction of exposure with building resilience on a foundation of structural transformations of the Bangladesh economy in favor of the manufacturing sector, with a simultaneous increase of productivity of labor forces employed in manufacturing and agriculture.

Table 1 summarizes major socioeconomic indicators critical for understanding the vulnerability of Bangladesh to climate change.

Combining implied projections of GDP for 2050, i.e. GDP per capita at $6,395 with the (Burke et. al., 2015) damage functions, we conclude that in the BAU scenario with climate change, an actual GDP per capita net of climate damage will be in a range of $3,200-4,800. Therefore an implied average net growth rate of GDP per capita will be in an interval of 2.8-4%.

Figure 1. Damage functions for the major regions, based on econometric analysis of historic data



Source: Burke et. al., 2015.

Table 1. Selected economic indicators in Bangladesh (current and 2050)

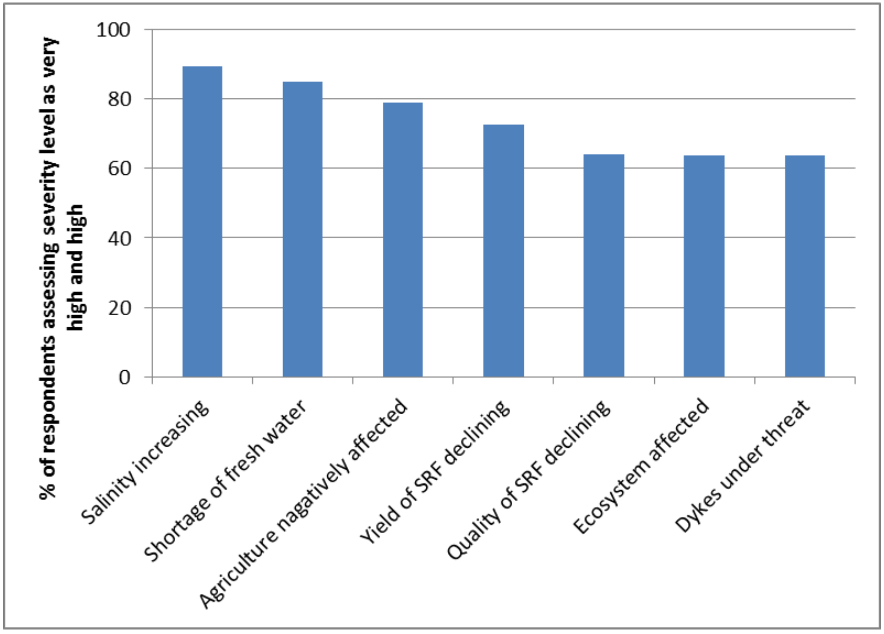
	Value	Year	Source/comments	Value	Source/comments
Population (millions)	159	2014	WDI, 2016	228	BBS
Population annual average growth rate	1.13%	2014	WDI, 2016	1.15%	BBS &State of the Coast, 2006
Coastal population (millions)	35	2003	State of The Coast, 2006	58	State of the Coast, 2006
Coastal population annual average growth rate	1.36%	1991-2001	State of the Coast, 2006	1.05%	State of the Coast, 2006
GDP (billions of constant 2005 US$)	119	2014	WDI, 2016	1,607	Projected with the growth rate in the following row
GDP average annual growth rate 2001-2014	5.8%	2001-2014	WDI, 2016	7.5%	Various Government announcements
Per capita GDP (constant 2005 US$)	478	2014	WDI, 2016	7,045	Estimated
Road length (km)	272,487	2007	BBS	340,609	Assumed 25% expansion
Share of paved roads	30%	2007	BBS	100%	Assumed
Primary school net enrollment rate	91%	2007	Ministry of Education	100%	WDI, 2016, average rate in comparator countries
Per capita electricity consumption (kWh)	278	2012	WDI, 2016	3210	WDI, 2016, average level in comparator countries

Source: WDI, 2016; World Bank, 2010

This is two times lower than the desirable growth rate announced by the Government at 7.5% (seen in Table 1). In sum, climate change should be treated as an important barrier to meeting development goals and it should be discussed in the context of a long-term development strategy.

Islam (2010) reported that when the population of SIZ was asked to assess the severity of different problems associated with climate change, they ranked salinity increase, lack of fresh water, losses in agriculture and declining yield of SRF the highest. Figure 2 below presents the results of this survey.

Figure 2. Ranking of climate change related problems by population of SIZ



Source: Islam (2010)

The population of Bangladesh is very poor to cope with climate risks with no external assistance. Rural income in the five selected zilas is very low (Asian Development Bank (ADB), 2006) with rural poverty level at about 50% and above in Khulna and Barisal divisions of the SIZ. The Table below compares the head count poverty ration in SIZ versus non-SIZ upazilas as reported in (Islam, 2010). The traditional production process does not support adequate living standards and provides preconditions for high malnourishment that results in further degradation of quality of labor and environmental health losses.

There are 3 essential categories to be considered for understanding risks of climate change and crafting an adaptation strategy:

- Hazards,
- Exposure, and
- Vulnerability.

Hazards constitute exogenous parameters. They are defined by patterns of climate change driven by anthropogenic GHG emissions and a response of the global climatic system to accumulation of GHG in the atmosphere. These exogenous factors are out of control of any individual country and should be treated as given for the integrated analysis of development policy in changing climatic conditions and for benefit-cost analysis (BCA) of adaptation. Global and regional climatic models are the best available source for hazard projections, while historic data helps to understand the current state of climate change and to track some important trends.

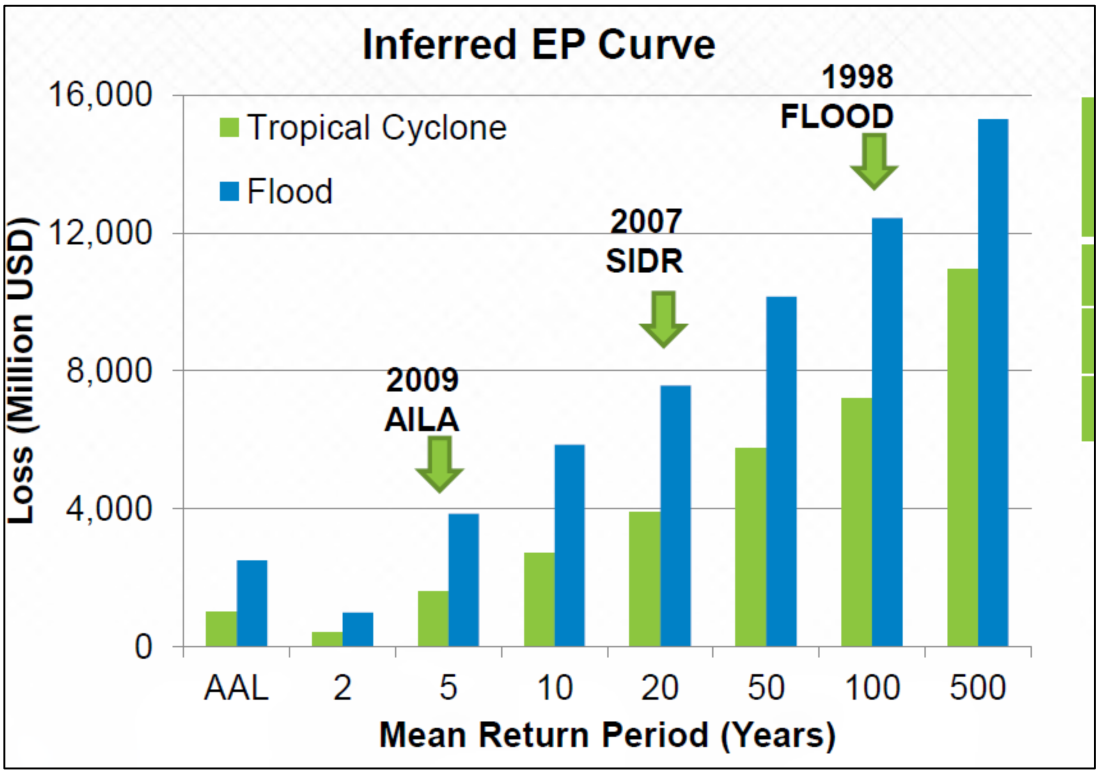
Uncertainty is a serious challenge for projection of future exposure to climate change; the issue of attribution complicates the interpretation of current extreme weather events. For example, should an increase in the severity of cyclones be attributed to climate change or just treated as result of a "normal" variability? Another example is how to separate an increase in inundation between ongoing geomorphological processers and the global sea level rise. Applying a holistic approach, we should avoid attribution issues and treat all benefits and all costs of interventions equally in BCA.

Exposure is more in the control of a country suffering from climate change. In the case of Bangladesh, reallocation of population from areas with a high rate of hazard would reduce exposure. Updating of early warning systems and building and reconstruction of shelters reduces exposure of population in areas with high rate of hazard to deadly consequences of tropical cyclones, storm surge and floods. However, these interventions will not reduce exposure of agriculture. Therefore there will be residual damage from extreme weather events, as well as from other negative impacts of climate change.

An ability of the country to deploy comprehensive adaptation interventions and to cope with residual damage determines the resilience of the country to climate change. Lack of ability or insufficient ability to implement adaptation interventions and withstand residual damage defines vulnerability to climate change. Vulnerability could be expressed in economic indicators, e.g. cost of adaptation as a share of GDP, gross capital formation and residual damage as a share of GDP, or final consumption as a share of the state budget. Understanding of uncertainty and probabilistic character of climate change is critical to understand vulnerability of a country to climate change. It is not enough to refer to long-term average damage from extreme weather events attributed to climate change. It is also important to consider a magnitude of an individual shock from, for example, a mega cyclone or flood.

Figure 3 illustrates average damage from cyclones and floods and annual variability. On average, the total damage from cyclones and floods is at about 2.5% of GDP (see Gomez, 2014), but the total damage could double or quadruple. A so-called "100 years event" may cause double-digit damage. This indicates an extreme vulnerability of Bangladesh to "climate shocks". Over the next decades the negative impact of climate change on Bangladesh will intensify. Both average annual damage from climate change, and the magnitude and frequency of a random shock may increase, triggered by mega cyclones and mega floods or unusually severe droughts and heat waves.

Figure 3. Damage from floods and tropical cyclones



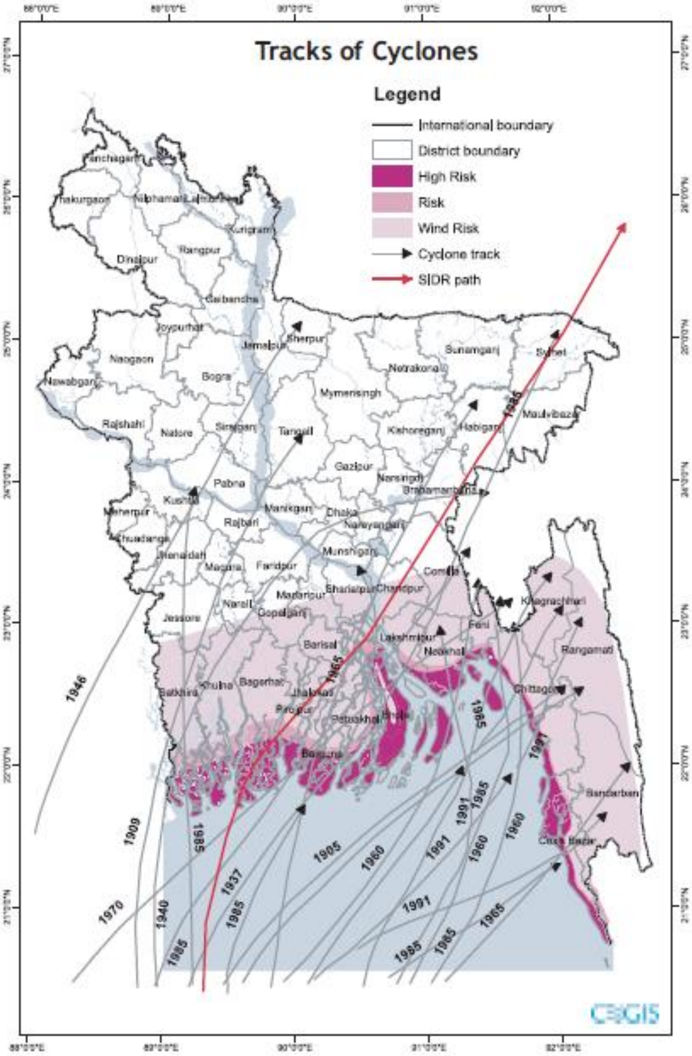
Source: adapted from Gomez, 2014.

1.2. Major hazards from climate change and need for adaptation

Tropical cyclones, floods, droughts and other extreme weather events create an immediate threat for Bangladesh's economy. Sea level rise attributed to climate change exacerbated by sinking Ganges Delta creates a longer-term impact in The Sundarbans and coastal zone on the southeast. Cyclones of various intensity hit coastal Bangladesh almost every year in April-May or October-November.

In the literature, tropical cyclones are indicated as a significant source of natural hazard and damage for human health, agriculture, real estate, infrastructure and personal property. Cyclone occurrence is highly uncertain. Although published data is incomplete and very often not comparable, based on available sources it is possible to conclude that the major cyclones' return period is 10 years (Dasgupta et al, 2010). Figure 4 presents the tracks of cyclones in Bangladesh in the last 50 years. This figure is adopted from Ministry of Environment and Forests (2009).

Figure 4. Tracks of cyclones in Bangladesh in the last 50 years



Source: CEGIS

Casualties from cyclones and floods in Bangladesh are devastating and according to Table 2, the annual number of deaths from tropical cyclones per affected population is about 5.6 times higher than in India.

Table 2. Casualty from extreme weather events

	Tropical cyclones	Mesoscale convective clusters	Tropical cyclones	Mesoscale convective clusters
	India		Bangladesh	
Number of events	97	37	34	100
Number of deaths	41,406	3,289	162,879	11,152
Events/year	2.5	0.9	0.9	2.5
Deaths/year	1,062	82	4,176	279
Deaths/event/year	427	89	4,790	112
Affected/year	1,759,367	163,124	1,219,676	174,926
Affected/year/event	707,374	174,350	1,399,040	69,970

Source: World Bank, 2014, p.107

Life losses and injuries attributed to extreme weather events is an immediate concern that should be addressed. Multipurpose shelters and an early warning system should be considered as the most urgent intervention since it could potentially prevent up to 5000 lives loses a year. However, it would not prevent other losses due to floods and cyclones.

Table 3 summarizes losses from a "super cyclonic storm" (excluding life losses and injuries). Agriculture is accountable for 26% of the total damage. However, for less intensive cyclones and floods, agricultural losses may dominate.

Table 3. Damages and losses during a single super cyclonic storm

	Damages and Losses (Cyclone Sidr)			Damages and Losses (Average Severe Cyclone)
	Current Million US$	Constant Million 2009 US$	Share of total (%)	Constant 2009 Million US$
Housing	839	978	50	900
Agriculture	438	510	26	469
Transport	141	164	8	151
Water resource control	71	83	4	83
Education infrastructure	69	80	4	73
Industry/Commerce/Tourism	52	61	3	56
Urban and municipal	25	29	2	27
Power	14	16	1	15
Other	26	30	2	28
Total damages and losses	1675	1952	100	1802
Share of GDP		2.6%		2.4%

Source: World Bank 2014, p.32

About 70 % of the population live in rural areas and depend on agriculture as an important source of income and as subsistence. The population of The Sundarbans already suffering from insufficient production is disturbed by extreme weather events, increased salinity and other factors of natural resource degradation.

Figure 5 presents potential rice requirement and actual production for the two different population growth scenarios in the SIZ. If aquaculture continues to develop, then rice shortage will increase dramatically. It is necessary to increase productivity to sustain even the existing level of consumption, which is already insufficient, with about 40-50 % of children under 5 malnourished in the SIZ[1].

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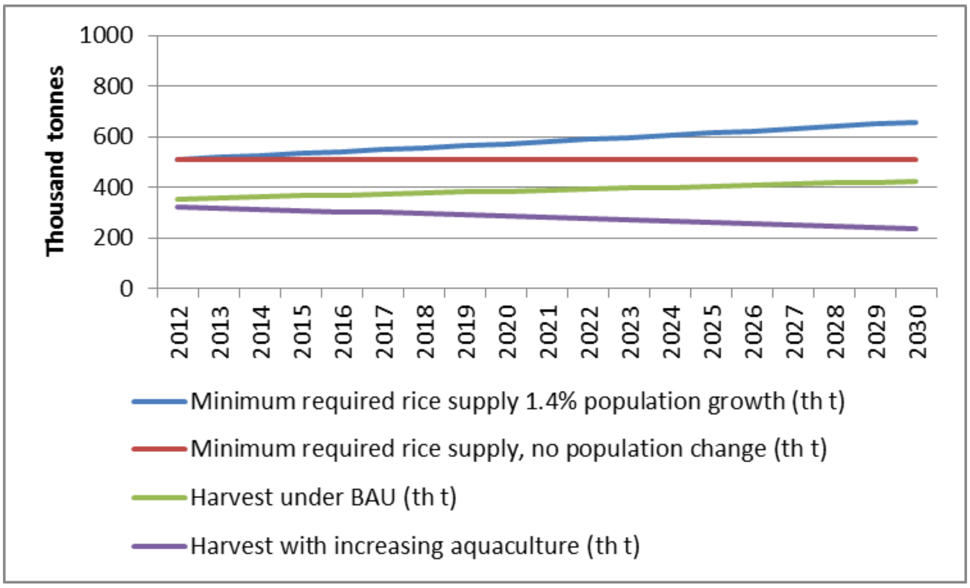
[1] DHS 2007 data

Figure 5. Rice production and consumption scenarios in the SIZ

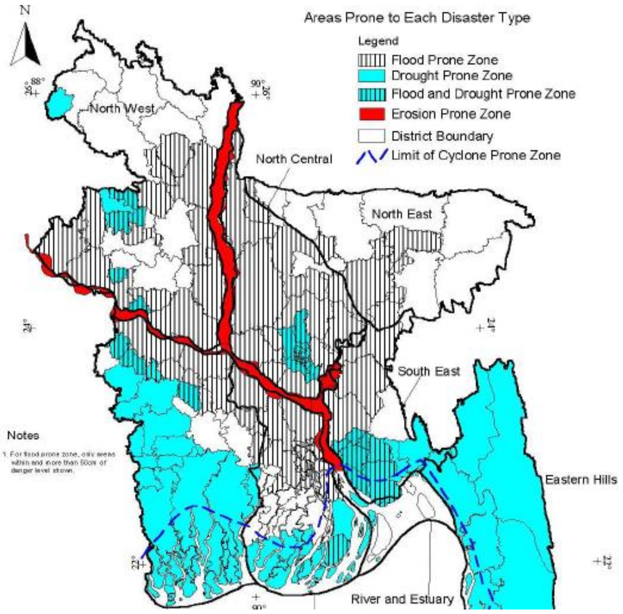


Source: World Bank, 2012

According to figure 6, almost the entire territory of Bangladesh is prone to various natural disasters that interfere with agriculture. Increase in intensity and frequency of these events is attributed to climate change. The cyclone-prone zone is the most vulnerable to climate change. Polders protect population in this zone and agricultural land. However, over time the reliability of polders is diminishing (see figure 7).

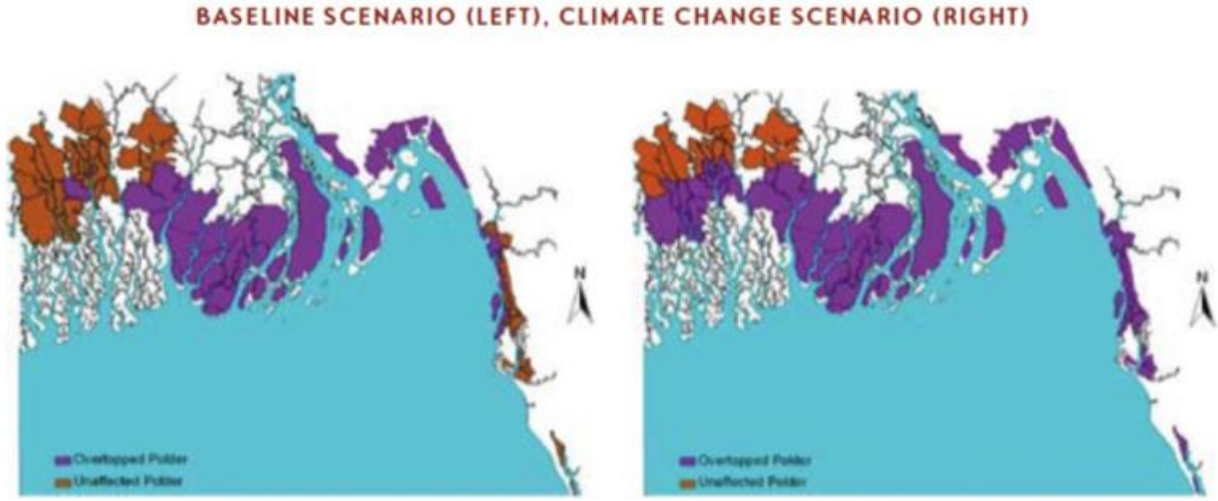
Note that climate change, on one hand, contributes to a permanent decline of productivity in agriculture (salinity, erosion, permanent losses of agricultural land due to sea level rise). On the other hand, agriculture is subjected to random shocks attributed to extreme weather events with devastating consequences for affected areas.

Figure 6. Areas prone to various natural disasters



Source https://germanwatch.org/en/download/8347.pdf

Figure 7. Polders exposed to climate change



Source: World Bank, 2014 p. 38

According to the World Bank synthesis study (World Bank, 2010a) where crop yields are separately modeled for 16 different regions using climate predictions from 16 global circulation models for 3 emission scenarios, "…cumulative rice production is expected to decline by 80 million tons (about 3.9% each year) over 2005-50. Agricultural GDP is projected to be 3.1% lower each year (US$36 billion in lost value-added) and total GDP US$129 billion lower due to climate change over the 45-year period 2005-2050" (p.43). It contradicts the goals of GDP growth summarized in table 1.

Radical increase of productivity in agriculture is an important priority in adaptation to climate change.

Some agricultural lands would be lost due to sea level rise (see table 5) and salinity increase on inundated lands due to continuous and intensifying storm surge and regular failure of dykes.

Table 5. Global mean surface temperature change and sea level rise

		2046-2065		2081-2100	
	Scenario	Mean	Likely range	Mean	Likely range
Global mean Surface Temperature Change (°C)	RCP2.6	1.0	0.4-1.6	1.0	0.3-1.7
	RCP4.5	1.4	0.9-2.0	1.8	1.1-2.6
	RCP6.0	1.3	0.8-1.8	2.2	1.4-3.1
	RCP8.5	2.0	1.4-2.6	3.7	2.6-4.8
	Scenario	Mean	Likely range	Mean	Likely range
Global mean Sea Level Rise (°C)	RCP2.6	0.24	0.17-0.32	0.40	0.26-0.55
	RCP4.5	0.26	0.19-0.33	0.47	0.32-0.63
	RCP6.0	0.25	0.18-0.32	0.48	0.33-0.63
	RCP8.5	0.30	0.22-0.38	0.63	0.45-0.82

Source: AR5, WG1, Stocker, 2014.

Major hazards attributed to climate change like sea level rise, cyclones, floods etc., act as compounding factors mutually amplifying the negative effect of each other on economy and society. Agriculture suffers from all natural hazards directly (harvest losses as a result of extreme weather events) and indirectly (decreasing productivity of agricultural land due to salinity, waterlogging etc.).

While existing literature provides a comprehensive assessment of current economic losses and damages attributed to climate change, the forward looking analysis is fragmented and presents various elements of future hazards and damages. A comprehensive analysis of the future damages should be conducted based on integrated modeling of economic growth and climate change in combination with application of a computable general equilibrium (CGE) model. But even summarizing funding of existing literature, one can conclude that climate change already interferes with economic growth, and in the future climate change may become a major barrier for Bangladesh to become a mid-income country.

Major vulnerability in the midterm in Bangladesh is linked to a low degree of protection of population from floods and tropical cyclones, especially for population in sea-facing polders. In the long-run, the major issue is loss of productivity in agriculture and industry that may become an impassable barrier for the Bangladesh economy to reach a higher steady state and “join the club” of middle income countries.

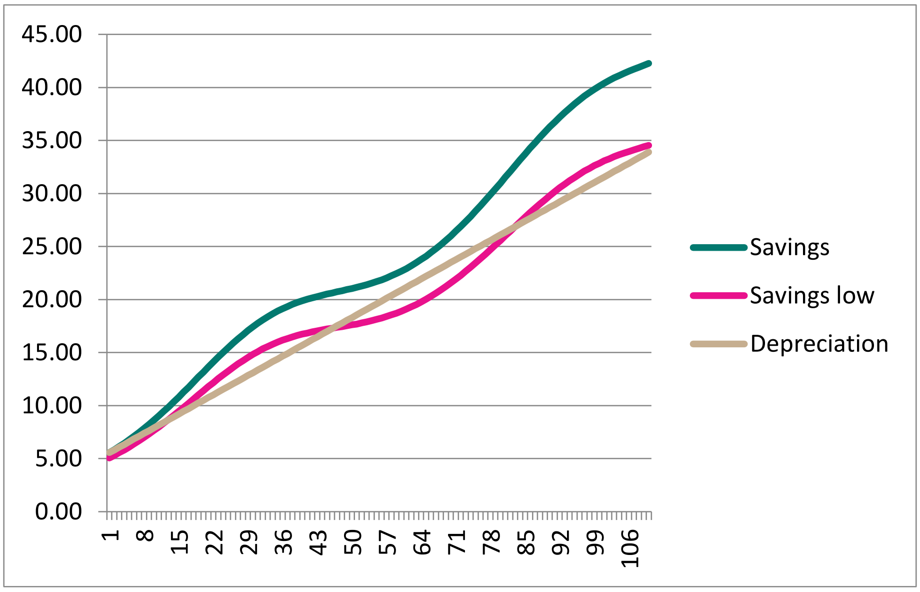
1.3. Limited resources to cope with climate change

1.3.1. Long-run macro analysis

In the long-run, resilience to climate change depends on economic potential of a country. The same damage of US$2 billion is accountable for 2.6 % of GDP (see table 3) in Bangladesh, while for a country like South Korea it would be just 0.14% of GDP (WDI, 2016). The Netherlands regularly experiences damages from storm surge, but despite a higher absolute value of damages from severe events, in relative terms it constitutes a fraction of a percent of GDP.

Climate hazards will likely increase over time. Due to its geographical location, Bangladesh will always be exposed to climate change. Building resilience to climate change, in our view, should be a top priority of a development strategy. Structural changes of economy with a corresponding significant increase in productivity of agriculture, manufacturing, services, etc., is the only way to converge to a higher steady state, and to become a middle-income country.

Figure 8. Low and high steady states



Source: Estimates by the authors.

Figure 8 illustrates transition to a higher steady state. If a savings rate corresponds to the blue line, an economy will be on a convergence path to a higher steady state. If however, savings are insufficient (orange line), an economy may be trapped in a lower steady state. Climate change has three ways of interfering with continuous economic growth and convergence to the highest steady state:

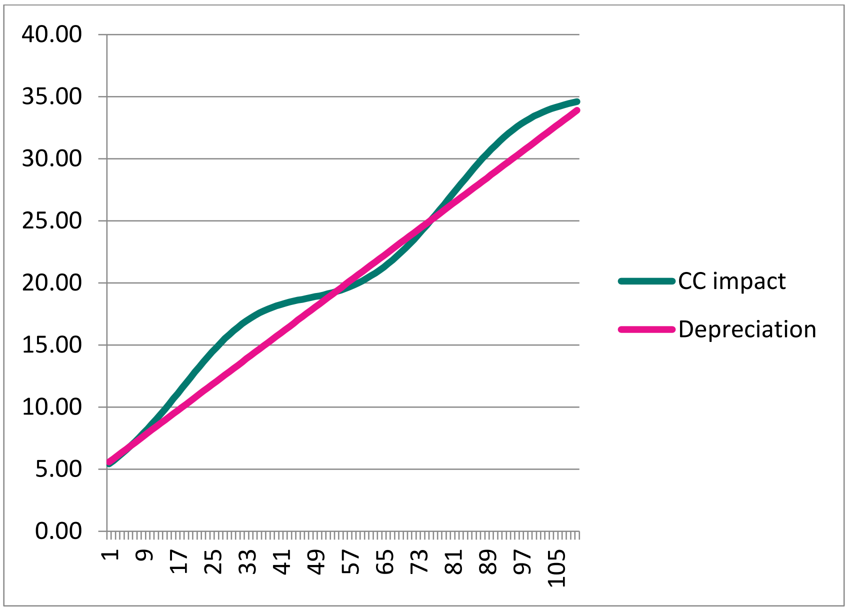
- Permanent damage reduces total productivity of economy. For a given savings rate (calculated as a percentage of output), an economy exposed to severe climate change would mobilize less resources to continue capital accumulation. The blue curve shifts downward;

- Uncertainty and risks attributed to climate change reduces risk adjusted return on capital. Therefore savings rate decline and the blue curve also shifts downward.
- Extreme weather events destroy wealth and contribute to degradation of agricultural lands. In terms of an economic growth model, these damages are reflected in a higher depreciation rate of accumulated capital. The grey curve shifts upward.

As soon as a blue curve crosses the depreciation line, an economy is at risk of sliding to a lower steady state.

The critical question: how "far down" may climate damage shift the blue curve directly reducing productivity of economy and indirectly suppressing incentives for savings and investment into risky assets?

Figure 8. A. Economy converges to a lower steady state

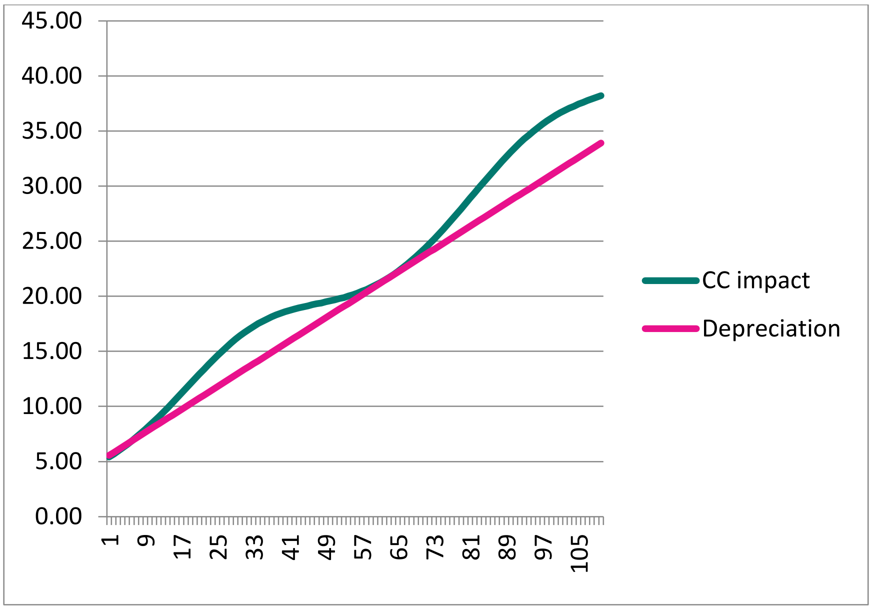


Source: Estimates by the authors.

Figure 8.A illustrates the situation when climate change makes a real difference to long-term economic growth. Figure 8.B. illustrates the situation when the country is on the edge to be locked in a lower steady state.

Figure 8.B. highlights a situation when adaptation focuses on prevention of negative productivity shocks on economy or, more broadly, increases productivity of an economy.

Figure 8.B. Country on the edge to be locked in a lower steady state



Source: Estimates by the authors.

1.3.2. Midterm perspective

In the midterm, there are several pressing needs for adaptation to climate change that require mobilization of resources immediately. The cost of climate change constitutes a burden on households, municipal and state budgets.

Relatively low GDP (in absolute terms and per capita) creates an obvious constraint to mobilize resources for adaptation. Various development priorities are in competition for public money and multilateral development assistance.

Nevertheless, in 2008 the government of Bangladesh adopted the Climate Change Strategies and Action Plan, which was revised in 2009. The strategy focuses on the following priorities (see Mallick et al 2012):

- Food security, social protection and health,
- Comprehensive disaster management,
- Infrastructure development and protection
- Research and knowledge management,
- Mitigation and low carbon development, and
- Capacity building and institutional strengthening.

The total cost of adaptation programs for the five years is estimated at around US$5 billion (Climate Change Unit, 2012) i.e. about US$1 billion per year. It is about 0.6% of Bangladesh 2014 GDP, 3.6% of gross capital formation, about 7% of tax revenues and 37% of net development assistance. The government of Bangladesh established the Climate Change Trust Fund and was able to allocate about US$ 100 million annually in its budget. Multinational development assistance plays an important role in mobilization of relevant funds. Table 6 summarizes ongoing projects on climate change. Committed funds are sizable, but are unlikely to be sufficient to meet all adaptation needs of Bangladesh.

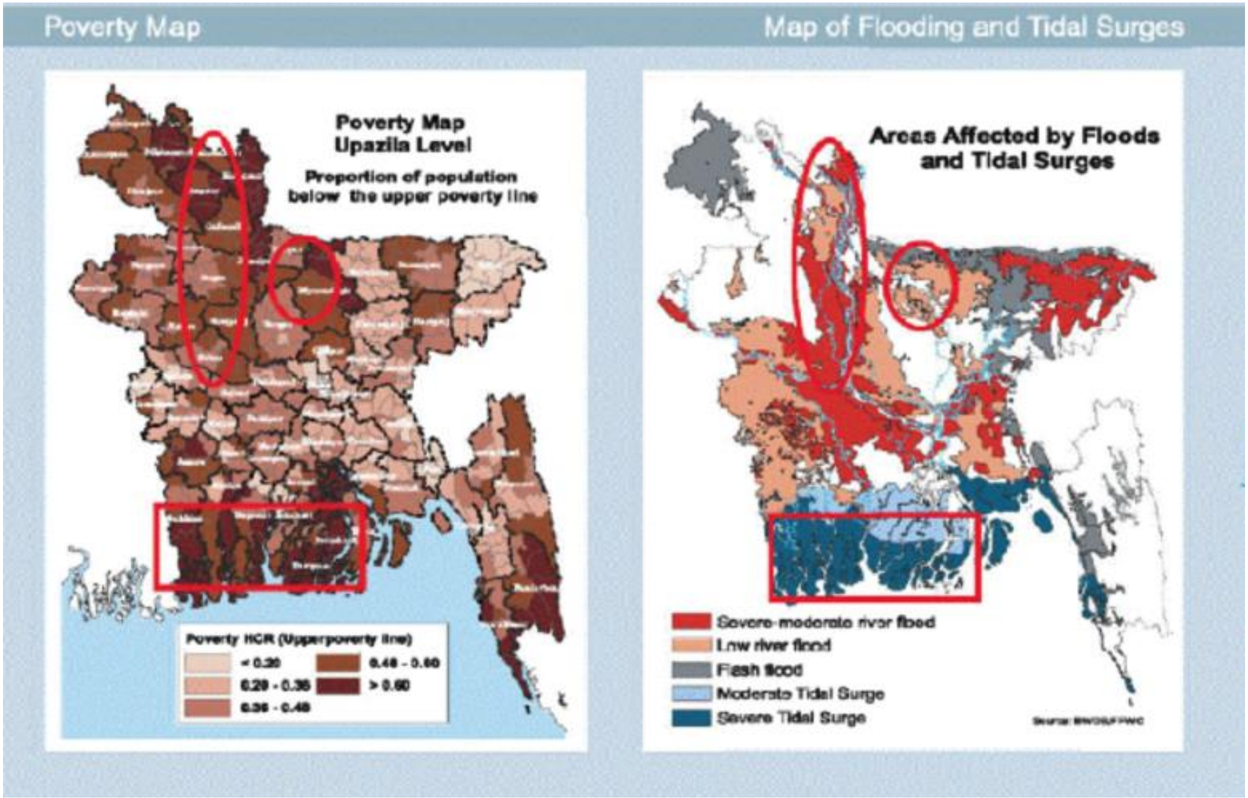
Presented in Table 6 overview of international assistance to Bangladesh to support adaptation is an illustration of insufficient funds currently available for adaptation in Bangladesh.

Poverty exacerbates gaps between available resources and need to implement near-term interventions and compensate for residual damage from climate change.

Figure 9 demonstrates overlapping of poverty, flooding and tidal surge including current situation and forecast up to 2050.

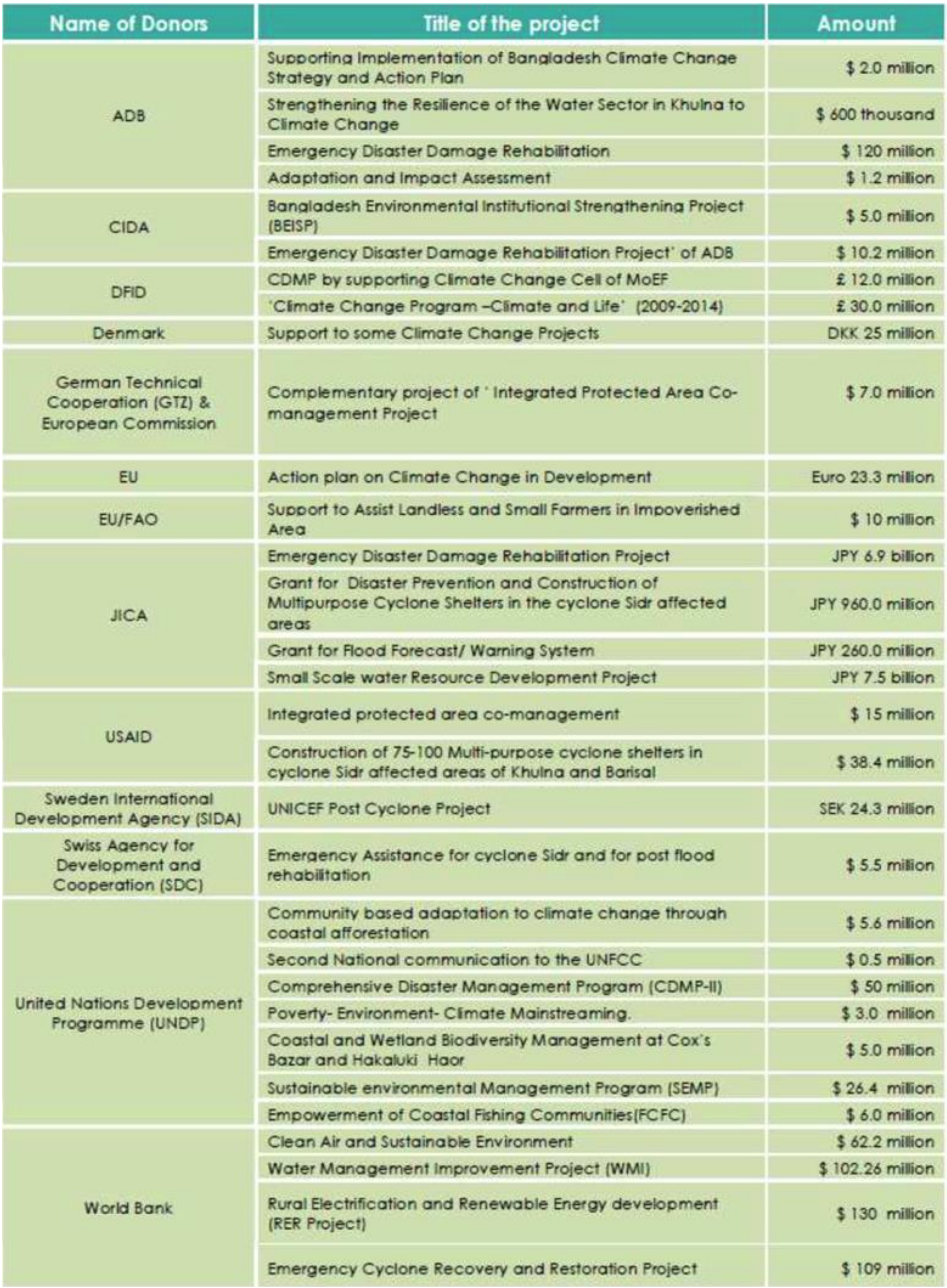
The impacts of climatic hazards are geographically concentrated in the regions with a higher concentration of the poor. These regions are most vulnerable and have the lowest capacity to implement adaptation interventions and cope with residual damage from climate change.

Figure 9. Poverty and extreme weather events



Source: The World Bank, 2010a

Table 6. Summary of ongoing projects on climate change in Bangladesh



Name of Donors	Title of the project	Amount
ADB	Supporting Implementation of Bangladesh Climate Change Strategy and Action Plan	$ 2.0 million
	Strengthening the Resilience of the Water Sector in Khulna to Climate Change	$ 600 thousand
	Emergency Disaster Damage Rehabilitation	$ 120 million
	Adaptation and Impact Assessment	$ 1.2 million
CIDA	Bangladesh Environmental Institutional Strengthening Project (BEISP)	$ 5.0 million
	Emergency Disaster Damage Rehabilitation Project' of ADB	$ 10.2 million
DFID	CDMP by supporting Climate Change Cell of MoEF	£ 12.0 million
	'Climate Change Program –Climate and Life' (2009-2014)	£ 30.0 million
Denmark	Support to some Climate Change Projects	DKK 25 million
German Technical Cooperation (GTZ) & European Commission	Complementary project of ' Integrated Protected Area Co-management Project	$ 7.0 million
EU	Action plan on Climate Change in Development	Euro 23.3 million
EU/FAO	Support to Assist Landless and Small Farmers in Impoverished Area	$ 10 million
JICA	Emergency Disaster Damage Rehabilitation Project	JPY 6.9 billion
	Grant for Disaster Prevention and Construction of Multipurpose Cyclone Shelters in the cyclone Sidr affected areas	JPY 960.0 million
	Grant for Flood Forecast/ Warning System	JPY 260.0 million
	Small Scale water Resource Development Project	JPY 7.5 billion
USAID	Integrated protected area co-management	$ 15 million
	Construction of 75-100 Multi-purpose cyclone shelters in cyclone Sidr affected areas of Khulna and Barisal	$ 38.4 million
Sweden International Development Agency (SIDA)	UNICEF Post Cyclone Project	SEK 24.3 million
Swiss Agency for Development and Cooperation (SDC)	Emergency Assistance for cyclone Sidr and for post flood rehabilitation	$ 5.5 million
United Nations Development Programme (UNDP)	Community based adaptation to climate change through coastal afforestation	$ 5.6 million
	Second National communication to the UNFCC	$ 0.5 million
	Comprehensive Disaster Management Program (CDMP-II)	$ 50 million
	Poverty- Environment- Climate Mainstreaming.	$ 3.0 million
	Coastal and Wetland Biodiversity Management at Cox's Bazar and Hakaluki Haor	$ 5.0 million
	Sustainable environmental Management Program (SEMP)	$ 26.4 million
	Empowerment of Coastal Fishing Communities(FCFC)	$ 6.0 million
World Bank	Clean Air and Sustainable Environment	$ 62.2 million
	Water Management Improvement Project (WMI)	$ 102.26 million
	Rural Electrification and Renewable Energy development (RER Project)	$ 130 million
	Emergency Cyclone Recovery and Restoration Project	$ 109 million

Source: Mallick et al 2012

2. Methodology for benefits and cost estimation

2.1. Uncertainty and risk quantification for BCA

Cost-benefit analysis is a powerful tool to support the decision-making process. It helps a decision maker to choose among a wide range of well-specified alternatives (development goals, investment strategies, etc.) providing a common denominator to assess and rank them in a consistent way. In our case alternatives are specified as a potential decision of a country to navigate capital formation in order to build "the assets portfolio" less vulnerable to the climate change related events. According to AR5 WG 3, benefit-cost analysis (BCA) is extremely useful when dealing with well defined problems like the benefits and costs assessment of building dykes to reduce the likelihood and consequences of cyclones given a projected sea level rise attributed to climate change. Another example mentioned in AR-5: BCA can provide a framework for defining a range of global long-term abatement targets across countries to facilitate negotiations (see also Stern, 2007).

"The main advantage of BCA in the context of climate change is that it is internally coherent and based on the axioms of expected utility theory. As the prices used to aggregate costs and benefits are the outcomes of market activity, BCA is, at least in principle, a tool reflecting people's preferences…this line of reasoning can also be the basis for recommending that this approach not be employed for making choices if market prices are unavailable. Indeed, many impacts associated with climate change are not valued in any market and are therefore hard to measure in monetary terms. Omitting these impacts distorts the cost-benefit relationship" (AR 5, WG 3, Chapter 2 p.28).

Acknowledging an important role of BCA for decision-making, AR-5 also stresses major challenges when defining the optimal level of mitigation actions:

(1) The need to determine and aggregate individual welfare,
(2) The presence of distributional and intertemporal issues, and
(3) The difficulty in assigning probabilities to uncertain climate change impacts."[2]

"A strong and recurrent argument against BCA (Azar and Lindgren, 2003; Tol, 2003; Weitzman, 2009, 2011) relates to its failure in dealing with infinite (negative) expected utilities arising from low probability, catastrophic events often referred to as 'fat tails'." (AR 5, WG 3, Chapter 2 p.28).

AR-5 WG -2 summarizes different tools for decision making under uncertainty that can be applied in different contexts and with different degree of quantification of available information: from loose

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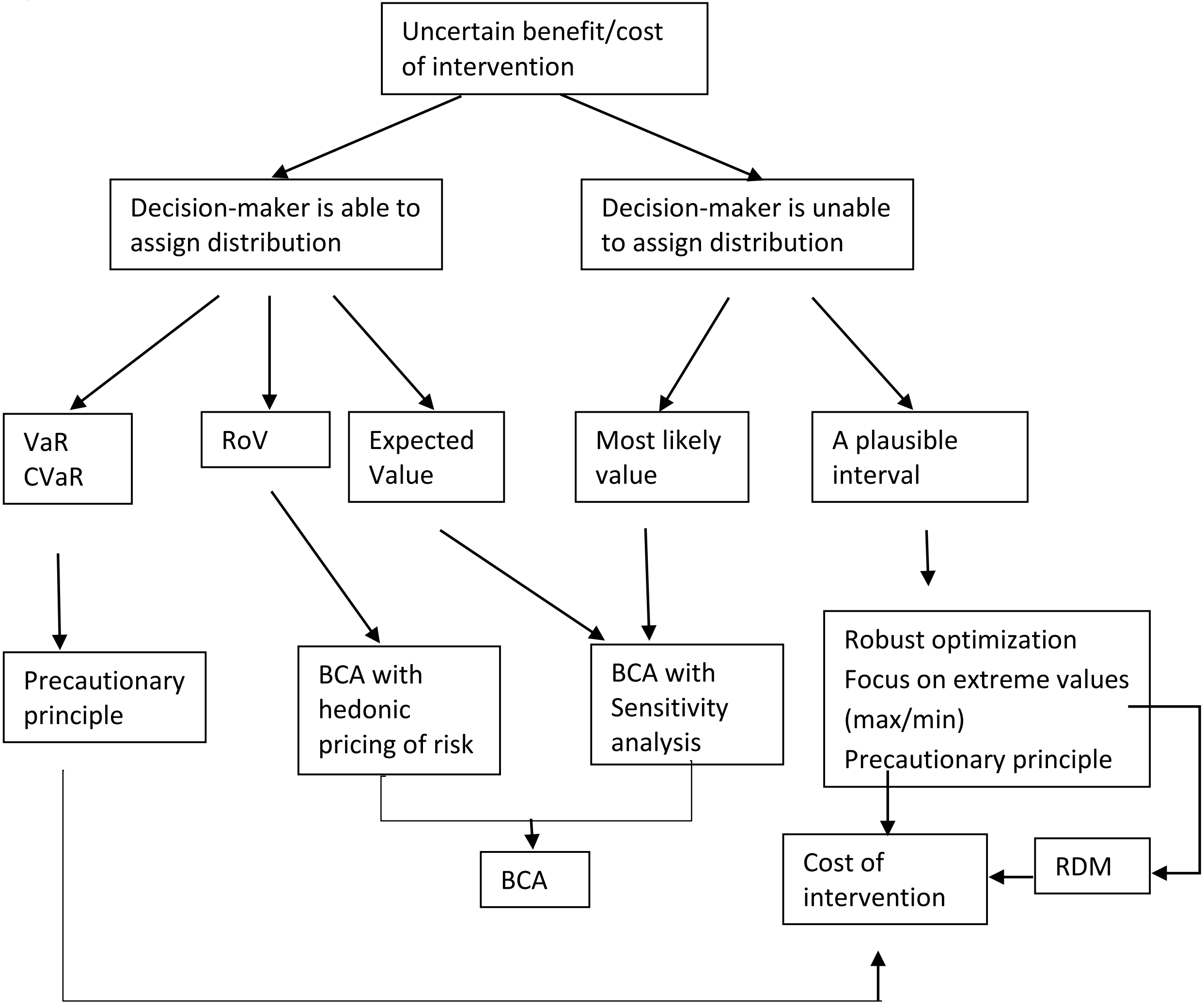
[2] http://opim.wharton.upenn.edu/risk/library/IPCC-AR5-WG3-Ch02_Mitigation-of-Climate-Change_Assessment-of-Response-Policies.pdf p.27.

specification of a plausible interval to fitting specific probability distributions. Watkiss et al, 2014) provides taxonomy and discusses strengths and weaknesses of each method (see diagram adopted from Watkiss et al, 2014).

Not all methods are comparable with BCA framework. Ability to specify subjective probability is critical to select an appropriate analytical tool. Figure 10 summarizes this selection.

Figure 10. BCA under uncertainty



Source: adopted from Watkiss, 2014.

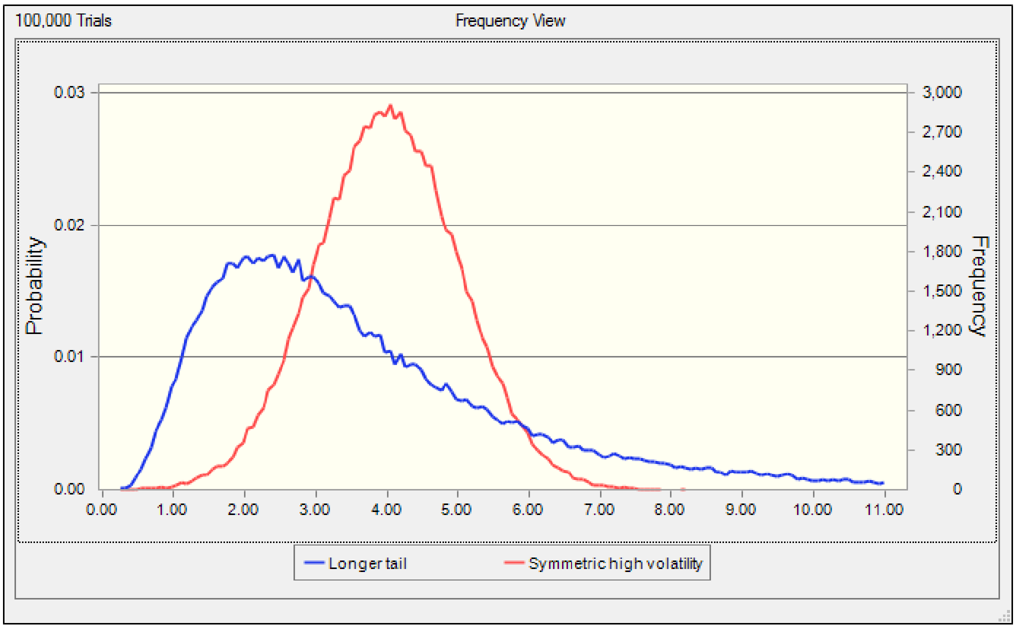
BCA provides a ranking of alternatives and BCA with Real Option Value (ROV) of risk provides balanced metrics for benefits and cost of adaptation policy (see Anda et al 2009). Investing in any assets can produce two possible outcomes: a positive return or a loss of capital. Investing in assets vulnerable to climate change is associated with an increased probability of a loss of capital in the future as a result of changing exogenous conditions.

Putting aside an issue of quantification of environmental goods and services, and assuming we are dealing with quantifiable monetary terms indicators, the major issue is ability to assign subjective probabilities to underlying uncertain parameters. This ability or inability may determine choice of an analytical tool illustrated in Figure 10. Inability to represent an uncertain parameter with a distribution is a reason to prefer robust optimization and robust decision-making (RDM). However, if a decision-maker inclines to choose a single value to represent an uncertain parameter (i.e. just ignore risk), BCA could be conducted in a “deterministic” form.

2.2. Expected value and risk

The conventional method of conducting BCA relies on the mean value of an uncertain parameter, i.e. just relies on the first moment of distribution. But, the three other moments of the distribution (variance, skewness and kurtosis) can also be important. Variance, skewness and kurtosis (the last two describe the tail of the probability distribution) constitute information lost in aggregation. For example, the two probability distributions shown in Figure 11 have different expected value and different shape.

Figure 11. Distributions with one having a lower expected value but a heavier tail



Source: Presented by the authors.

The blue line describes a distribution with a relatively lower mean but with a relatively heavy tail. The red distribution has relatively higher expected value but much lighter tail. Assume that each of depicted in figure 11 distributions represents the sum of adaptation cost and residual damage for two alternative interventions. Which intervention should be selected? Conventional approach suggests that a “blue” alternative should be selected. Expected value of adaptation cost plus residual damage is lower. However, since an actual cost will be revealed until after an adaptation intervention was selected, a decision maker may end up in a situation when an actual cost (mainly residual damage) is much higher than anticipated. In contrast to independent random shocks, when losses in one time period would be compensated by surplus in another time period, climate change is represented by correlated shocks attributed to irreversible changes of climatic system. In this case, the shape of distribution should not be ignored.

Anda et al. (2009) propose an application of a real options analysis to address uncertainties in environmental policy. They argued that advanced option pricing formulas could capture differences in distributions and provide consistent metrics to price risk and uncertainty for economic valuation and integrated assessment analysis (see also Golub et al, 2014). These examples illustrate how application of a single expected value as a substitute for the underlying distribution may result in misrepresentation of benefits and costs of abatement interventions.

2.3. Application of Real Option Analysis for valuation of risk and return

A decision-maker should use Real Options Analysis (ROA) to estimate an impact of climate change as a natural extension of benefit cost analysis framework under uncertainty.

Consider an adaptation intervention that costs Z (capital cost) and reduces damage from D_0 to D_1. The difference D_0 - D_1 = D_R is a residual damage. Residual damage is a deferred liability. Selecting an adaptation strategy (intervention) decision maker commits cost Z and simultaneously takes a liability D_R known up to probability distribution. In conventional BCA, the total cost of intervention assumed to be equal to $Z+E(D_R)$, where $E(D_R)$ denotes an expected value of a residual damage. An actual value of a residual damage reveals when an extreme weather event attributed to climate change takes place. Exposure to residual damage is similar to exposure of holding a short position on commodity or a share. A stock price may spike much above its expected value, then a short position would cost its holder the expected value (cost anticipated when a share was sold short) plus the difference between an actual price and expected price. If projected price is highly uncertain it may be risky to sale this share short. Economic value of this risk could be calculated as a cost of hedging position. A holder of the short position can buy a call option on the stock and cover the short position. A call option price reflects magnitude of uncertainties.

Residual damage is equivalent of a short position on a stock market. But in contrast to a stock market speculator, a decision maker deals with an exposure to the future damage from the very beginning. In absence of adaptation this exposure is D_0. The risk adjusted value of this future damage is $E(D_0)+P(D_0)$, where $P(D_0)$ is value of risk that could be calculated using option pricing methodology. Now benefits of adaptation could be calculated as $E(D_0)+P(D_0)$ - $E(D_R)$-

$P(D_R)$. Then benefit cost ratio $\frac{E(D_0)+P(D_0)- E(D_R)-P(D_R)}{Z} = \frac{E(D_0)-E(D_R)}{Z} + \frac{P(D_0)-P(D_R)}{Z}$

Conventional BCR calculation takes into account expected values only. Then

$$CR = \frac{E(D_0) - E(D_R)}{Z}.$$

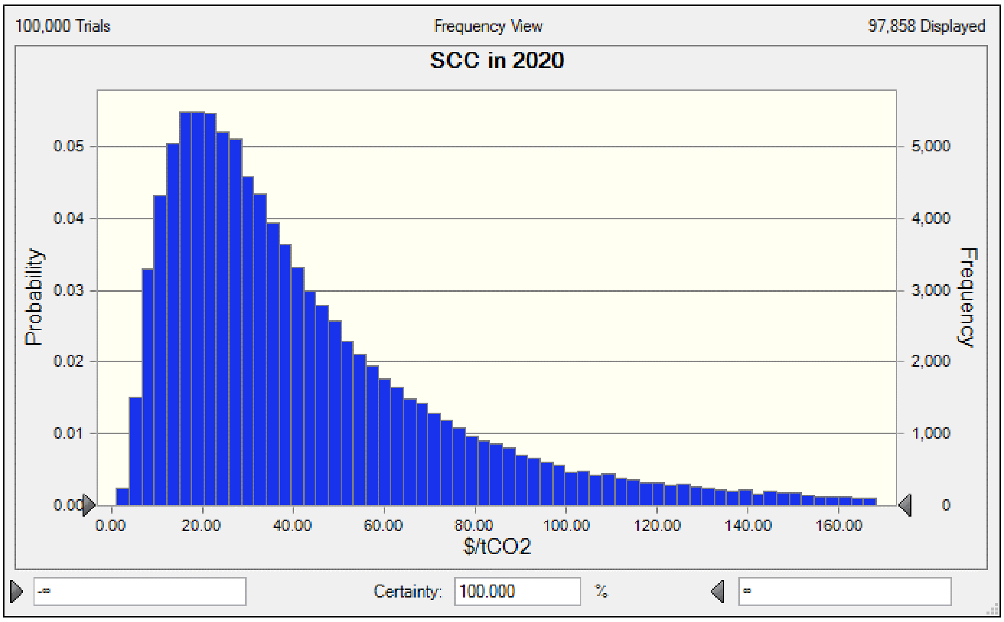
This methodology extends a conventional approach of BCR calculation including economic value of risk reduction. Then risk adjusted BCR (RABCR) equals to the following expression:

$$RABCR = BCR + \frac{P(D_0) - P(D_R)}{Z}$$

As an example we demonstrate application of ROA to calculation of a risk-adjusted value of social cost of carbon (SCC).

Consider the SCC in 2020 calculated with a 3% discount rate. An expected value is \$43 and is \$129 at the 95th percentile. Assuming, that the SCC is a quadratic function of the global average temperature increase above preindustrial levels (like in the DICE model in Nordhaus, 2013), the SCC could be described by a distribution shown in figure 12.[3]

Figure 12: Social cost of carbon in 2020



Certainty: 100.000 %

Source: Estimates by the authors using IWG SCC, 2009.

By definition, the damage from the emission of 1 additional ton of CO2 is equal to the SCC[4] (or loss of future economic output). Let's assume that the adaptation cost is a proxy for damage. This approach captures some of the irreversible losses reflected as a permanent (or at least long term) loss of

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[3] Note: the figure 1 is not an exact replication of an actual distribution from IWG 2013 since we take into account just the shape of damage function from DICE. The IWG considered three different integrated assessment models including DICE.

[4] For the formal definition see IWG (2009)

productivity of the global economy in response to changing climatic conditions. In this formulation the economic consequences of climate change can be fully compensated by higher productivity of the global economy.

Society may invest in carbon intensive, buy very productive technologies and accumulate enough resources to successfully tackle climate change. However, society may decide to abate 1 t of CO2 and save on SCC. How much should society spend on abatement? An average value of SCC $43/tCO2 may be too little, but $129/tCO2 looks like too much at this point in our knowledge.

What would be the market price of hedging risk? If someone sells a share short, then in order to eliminate risk, he needs to create a hedging position by purchasing a call option. Given a distribution of future value (say the value of the share in question has the same distribution as the SCC), at the money call option would cost about $16/tCO2. Then the maximum that the investor would be willing to pay in the future to close the short position is $43+$16 =$59/tCO2. Then the risk of the short position costs $16. Therefore, by emitting 1 t of CO2 society is ready to accept a cost equal to $59/tCO2. If, nevertheless, abatement is less expensive, it makes sense to abate this ton of CO2 instead.

3. Major interventions (with benefit and cost estimations)

Based on consideration of hazards, exposure and vulnerabilities of Bangladesh to climate change and also taking into account various kind of uncertainties we conclude that adaptation should satisfy the following criteria:

- The strategy should be flexible enough to accommodate learning and new knowledge about global climate change and its specific implications for Bangladesh;
- The initial interventions should be robust vis-à-vis imminent adjustment in response to learning;
- Initial interventions should address the most pressing adaptation needs;
- Adaptation strategy should be embedded into the long-term development strategy.

Using World Bank (2010), World Bank (2012) and several other publications on adaptation in Bangladesh and applying above listed criteria we selected six strategically relevant interventions for BCA.

Adaptation alternatives include interim and long-term interventions:

Interim interventions present reactive adaptation interventions:

- Polders reconstruction and setback;
- Foreshore afforestation (mangroves restoration and plantations);
- Multi-purpose cyclone shelters, cyclone-resistant private housing and further strengthening of early warning & evacuation system

Long-term strategy of resilient economic growth, assets diversification and human capital formation:

- Population reallocation;
- Improvements of productivity of agriculture and fishery;
- Manufacturing in the second-tier cities

Interventions generate direct and indirect ancillary benefits that are briefly summarized in Table 7.

Table 7. Summary of major benefits of adaptation

	Relocation of population from the high cyclone risk areas	Construction of cyclone shelters and early warning system	Mangrove protection	Polders set back and selective enhancement	Productivity of agriculture
Reduction of cyclone loss due to mangrove degradation in Khulna		+	++	++	++
Reduction of cyclone loss in Barisal	++	++		++	++
Access to fresh water	+		+		+
Reduction of crop loss due to increased salinity (shrimp farming)	+				
Carbon benefits			+		+
Enhancement of mangrove provisional value	++		++		+
Biodiversity	+		++		+

Source: Summarized by the authors.

3.1. Interim – reactive adaptation interventions

Interim adaptation interventions focuses on two specific climate hazards:

- Storm surges amplified by tropical cyclones;
- Inland flooding and water logging.

Thus we focus on protection of population, property and agricultural land within cyclones prone zone and inundation more than 1 m. Table 8 presents population in inundated areas, as estimated in World Bank (2014).

Table 8. Population living in inundated area (million)

Inundation Depth	At present	In 2050
More than 1 m	16.83	35.33
More than 3 m	8.06	22.64

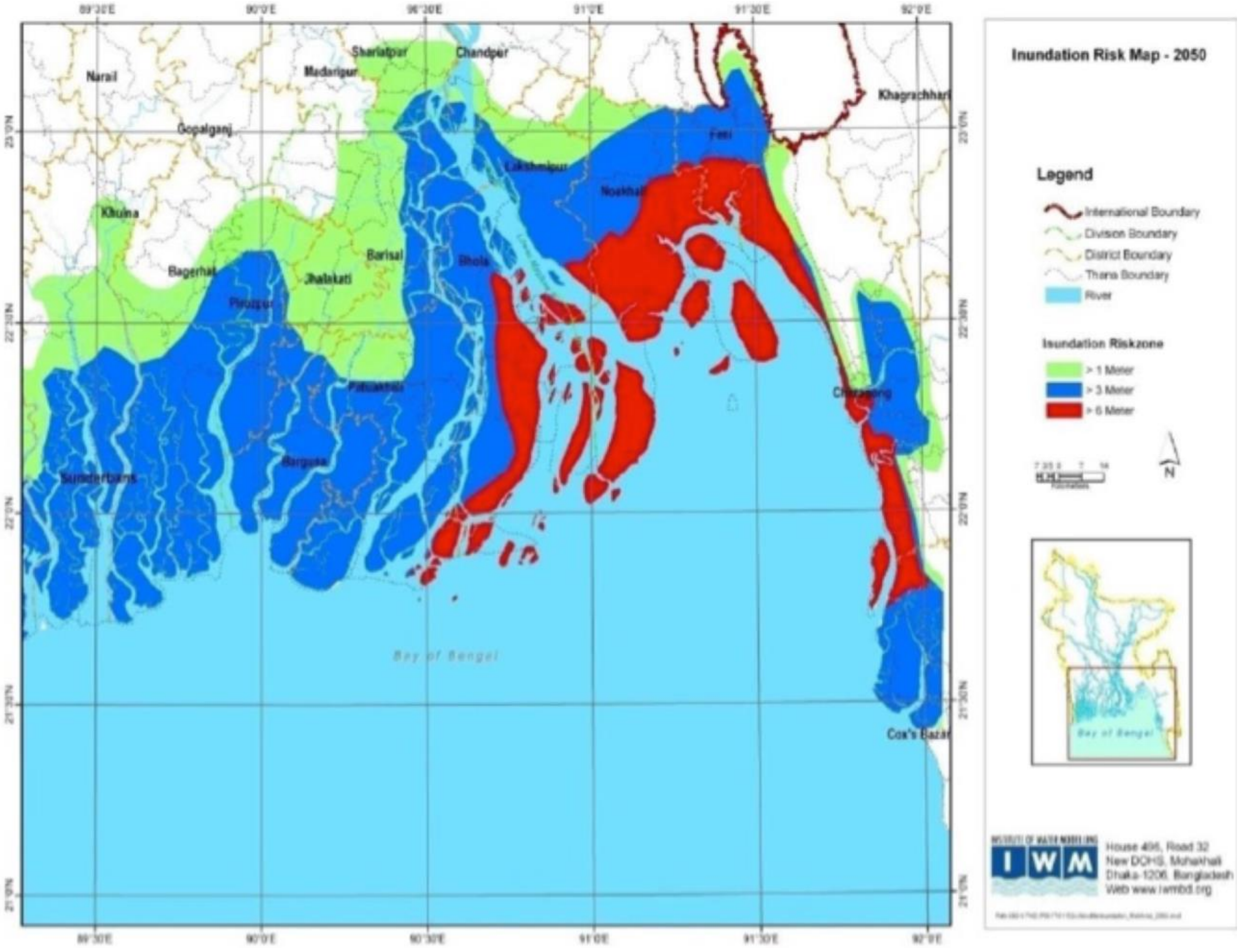
Source: World Bank, 2014

Population in 3 m inundation zone experiences more intensive hazard. Due to geomorphological conditions this population is more exposed to extreme weather events. Figure 12 helps to narrow priority area furthermore. For the BCA we consider near-term interventions in Khulna and Barisal.

Most of the islands of the Bangladesh Sundarbans are inhabited, and the population in The Sundarbans Reserve Forest and Sundarbans impact zone (the SIZ) at present is at about 3.8 million (rural population in upazilas within The Sundarbans and immediately adjacent to it). The major geomorphic features are mudflats, bars, shoals, beach ridges, estuaries, extensive network of creeks, paleomudflats, coastal dunes, large number of islands and saltpans. Figure 13 below presents inundation map of Sundarbans by inundated area. About 8 million population is located in blue area that is more than 3 m inundated during storm surge. This population is expected to almost triple by 2050.

The spatial distribution of the population in The Sundarbans is closely linked with their occupational distribution. Landless and marginal households, who are often directly dependent on the forest and rivers, are concentrated on the river-banks bordering the forest. The landed households are mostly placed in the interiors or towards the mainland.

Figure 13. Projection of storm surge inundation



Source: World Bank, 2014

3.1.1. Foreshore afforestation (mangroves restoration and plantations) and mangrove protection

Mangroves protects coastal zone from storm surge. Benefits and cost of this intervention was calculated for the period 2015-2050. This intervention protects population in Khulna. The range of estimates for affected populations that could be protected by mangrove restoration summarized in table 9.

Table 9. Affected population protected by mangroves restoration (million)

	2025	2050
Low bound	5.51	4.29
Central estimate	6.40	6.40
Upper bound	7.44	9.55

Source: Estimates by the authors.

In order to estimate the protective function of mangroves we model a surge height as a function of mangrove density. A reduction in mangrove density would result in higher storm surge. Increase in Sea Surface Temperature (SST) along with mangroves degradation would be two complimentary factors that increase intensity of cyclone impact in Khulna District. In Barisal District unprotected by mangroves only increases in SST will accelerate impact of storm surge. Cyclone damage is presented as a linear function of surge height (World Bank 2012, World Bank 2014).

This model allowed constructing 5 Business As Usual (BAU) scenarios for Khulna and Barisal Districts. Baseline scenario assumed impact of climate change increases intensity of storms and causes mangroves degradation. Total damage depends on the exposed population. For Khulna three different population change scenarios were considered:

- 1 % population growth;
- Stabilization of population; and
- 1 % of population decline.

Damage per capita is calculated in each BAU scenario taking into account annual per capita GDP growth (5% annually in Sundarbans). In Barisal District only two population dynamics scenarios were considered: 1% population growth and 1% of population decline.

In changing climatic conditions it is very difficult to apply conventional methodology to predict the future cost of cyclones. Frequency and severity of cyclones most likely will increase (AR5, Working Group 2, 2013). Newest development in climatic modeling may allow increasing accuracy of future predictions. In the meantime one should rely on arbitrary built distributions[5] to take into account uncertainty in major cyclones occurrence over 40 years period. Being on the conservative side we assumed that the probability of cyclone occurrence each year is 0.1. It corresponds to a 10 year major cyclone return period in the deterministic model. Cyclone occurrence each year is treated as statistically independent events. Therefore there is some very small probability that no major cyclone occurs over 40 years, as well as there is a small probability that cyclones will return each year. In order to eliminate outliers we consider results in 90 % confidence interval (CI).

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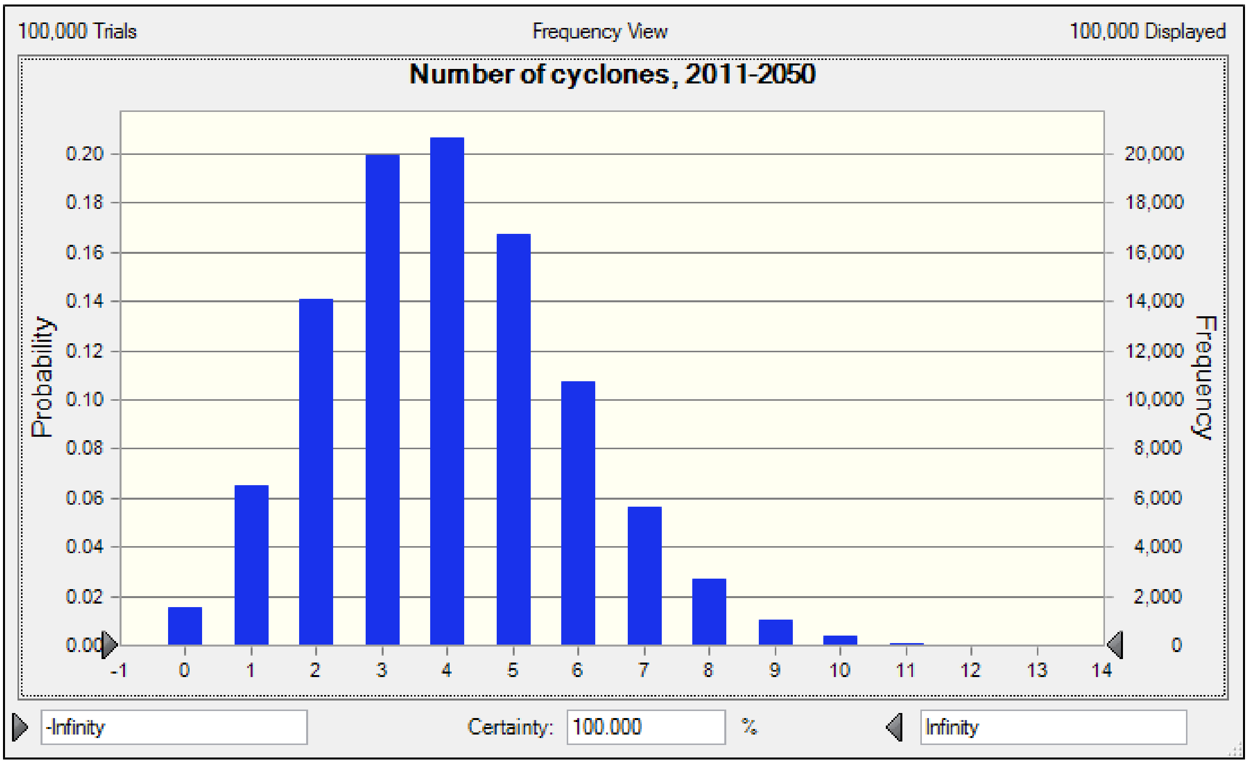
[5] http://www.rff.org/events/pages/introduction-climate-change-extreme-events.aspx

Figure 14 below illustrates distribution of cyclones frequency over the next 40 years. Number of cyclones in 90 % CI is from 1 to 7 over the 40 years period.

Being on the conservative side we assume that probability of major cyclones does not depend on global temperature rise. However, as we mentioned before, cyclone intensity will increase with SST rise that is a function of global temperature in our model. Global temperature depends on the global emission scenario. For the global temperature simulation we use DICE 2013 (Nordhaus), the open source integrated assessment model. The model translates global Greenhouse gases (GHG) emissions into global temperature increase.

Figure 14. Average predicted number of cyclones in Bangladesh in 2011-2050



100,000 Trials

Frequency View

100,000 Displayed

-Infinity

Certainty: 100.000 %

Infinity

Source: Estimates by the authors.

Box 1. Reconstruction of baseline and alternative scenarios for mangroves protection/planting

The baseline scenario assumes on average 1% of mangrove degradation over the period up to 2050. Mangrove protection constitutes an adaptation intervention. We assume that planting of mangroves on 5,530 ha every year during the next 20 years would prevent degradation of mangroves in Sundarbans (the total area of 395,000 ha)[6]. Also, protection of mangroves requires husbandry sedimentation of a shoreline. Total costal line is about 750 km. Annual sedimentation should be

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[6] Planting of forest could be scattered across an entire forested area in order to obtain maximum protecting effect. Also we assume additional 40% of replanting required due to 60% survival rate of seedlings.

completed on about 37.5 km per year. The cost of mangrove planting per ha is US$1,680 (see Dasgupta, 2010); and cost of husbandry sedimentation is estimated at US$1.5 million per km of coastline, assuming 500 m3 of land is needed to reinforce 1m of costal line, and cost of moving 1 m3 is US$3.

Benefits of intervention include direct and indirect benefits of mangroves protection. Mangroves reduces exposure to storm surge and damage from cyclones, mitigating negative impact of relatively frequent and moderately intensive cyclones. The protective value of mangroves is estimated in (World Bank, 2012) and briefly summarized below.

Projection of storm surge inundation in a changing climate (Dasgupta et al, 2010) confirmed an essential protective function of mangroves. Storm surge in mangroves area is projected two times less than in the area without mangroves (marked in red in the map figure 13). Degradation of mangrove forests due to climate change and human activity results in losses of its protective function, while interventions to protect mangroves enhances their protective function and reduces the risk of cyclone damage. Cyclone Sidr that hit the SIZ in 2007 generated substantial damage in Barisal District, unprotected by mangroves, while damage was relatively lower in Khulna District, protected by mangroves (see Government of Bangladesh (GoB), 2008).

In World Bank, 2011 an average per capita damage in Barisal is about US$170 per capita, and in Khulna District – about US$77. Degradation of mangroves results in increased damage calculated as a linear function of reduction mangroves density (based on the reported data for the whole affected area damage. This damage was estimated as a function of storm surge). A 5% per year appreciation coefficient was applied to the base value of damage from cyclone, assuming the values reported in WB 2011 were calculated for the year 2010.

The difference between degradation (reference or BAU) scenario and protection scenario constitutes benefits of proposed adaptation intervention. In addition to protective benefits from cyclones and storm surge, mangroves have several quantifiable benefits that we include in BCA. A detailed description of benefits presented below.

Value of mangrove services in Sundarbans

Proposed intervention allows preservation of various benefits provided by mangroves. We monetized provisional value, recreational value, biodiversity protection values and climate regulation values of mangroves.

1) Provisional values

The study by Islam[7] (2010) quantifies the economics of extraction and sale of marketed products from the Sundarbans Reserved Forest (SRF) that form the basis for an assessment of direct annual use of the various categories of goods extracted from SRF: timber; non-timber forest products; fish; and other aquatic resources. Timber and fuel wood were exclude from the study since the Ministry of Forest put a moratorium on timber felling in 1989 and on fuel wood collection in 1995 (Islam , 2010). Growth of tree volume in the SRF reported in Ministry of Environment and Forests in Bangladesh (2010) suggests that this moratorium is quite effective.

Provisional function of mangroves is valued applying information reported in Islam (2010). This study used a structured questionnaire survey of the SIZ population on the annual extraction of products from mangroves and benefits and costs of their collection. We used only benefits and costs of collectors for the net benefit estimation. Reported data are presented in the table below.

Table B2. Net annual income of the SIZ8 collectors

	Mangrove products extracted	Annual income of each collector, Tk.	Total collectors	Net annual income, million Tk.
Non-timber products	Golpata/Grass (Shon)	23451	78696	1292
Fish	Gura (small) fish	47153	104928	1979
	Sada(white) large fish	63311	67453	2989
	Hilsha	40413	127712	3097
	Shrimp large (galda)	59737	23154	968
	Shrimp large (bagda)	66220	73300	3398
	Shrimp gura (galda)	69833	23154	970
	Shrimp gura (bagda)	62424	73300	3203
	Shrimp fry (galda)	63368	228592	14485
	Shrimp fry (bagda)	46505	179876	8365
Aquatic resources	Crab	86334	75398	3906
Non-aquatic resources	Honey	14830	24583	201
Total			1,080,146	44,853

Source: Islam (2010)

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[7] Islam M. (2010) A Study Of The Principal Marketed Value Chains Derived From The Sundarbans Reserved Forest. IRG, USAID.

[8] Definition of the SIZ in Iqball (2010) is different from the definition that was adopted in this report. However, we accept a conservative approach, utilizing Iqball (2010) information due to the lack of data how different definitions of the SIZ would affect the total number of collectors in the SRF.

Then applying Tk.79 per US$ 1 exchange rate, average provisional value of mangroves in Sundarbans is estimated at US$ 1,646 per hectare.

2) *Recreational values*

Domestic and international tourist flow in the SIZ is reported in Iqball et al (2010).

Table B3. Foreign and domestic tourists in the SRF

	Foreign tourists	Domestic tourists
2004	1,457	46,887
2005	1,298	69,078
2006	1,582	92,632
2007	2,083	94,745
2008	1,861	78,689

Source: Iqball et al (2010)

Expenses of a foreign tourist are estimated at about US$3000 per trip, including US$2000 air ticket, US$500 trip to Sundarbans, and remaining US$500 for hotel in Dhaka and other expenses. Domestic tourist expenses are estimated at about US$50 per person/trip. Total expenses are estimated at 0.6 billion Tk. annually. The expenses reflect a low level of ecotourism development in the SRF. Ecotourism development is one of the ways to improve livelihoods of local population and accumulate conservation funds for the SRF. Recreation value per hectare of forest in Sundarbans is estimated at US$24 per hectare.

3) *Biodiversity values*

There are several meta-analysis studies of ecosystem services values available (Hussain et al, 2011; de Groot et al, 2012). The study by de Groot et al is a background estimate provided by the TEEB project.[9] The study presents meta-analysis of ecosystem services valuation studies from all over the world. It gives a comprehensive summary of reported values of ecosystem services in different ecosystems, including tropical forests. This study presents an average median value of coastal forests that include coastal areas with mangroves. Median nursery service value per hectare of coastal area is estimated at International US$1,127 per hectare or US$376 per hectare; and gene pool conservation values are estimated at International US$ 1,815 per hectare or US$605 per hectare in Bangladesh using PPP conversion of International UD$ into US$.

4) *Climate regulation or carbon pool value*

Carbon sequestration in Sundarbans is estimated in Government of Bangladesh (2011). Only above ground accumulation is taken into account on this report.

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[9] http://www.teebweb.org

Table B4. Carbon sequestered in different mangrove forest in Sundarbans

	Sundri		Gewa		Goran	
	C t/ha	95%CI	C t/ha	95%CI	C t/ha	95%CI
Trees above ground	109	+/-15	56	+/-15	20	+/-4

Source: Government of Bangladesh, 2011

For the whole Sundarbans (Government of Bangladesh, 2011) estimates that average carbon pool for trees aboveground is at about 82 t/ha (+/-11t/ha). Then applying price per tone of carbon as in (Tol, 2011) for the Social Cost of Carbon (SCC) at 5.2US$/t CO2 with discount 5%, average cost of carbon accumulated in mangroves is estimated at US$1,563 per hectare.

Although for deterministic calculations we apply the SCC from Tol 2011, as it was required to establish a “common denominator” with other studies for Bangladesh, for uncertainty analysis we apply DICE 2013 to compute the SCC. For calculating revenues from REDD+ we assumed heavily discounted market price @5/tCO2 in 2015, i.e. about the same as in 5% discount rate scenario.

Then total mangroves values are summarized in the table below

Table B5. Annual mangrove values estimated in the report (US$ per hectare)

Provisional	1,646
Biodiversity protection	981
Recreational	24
Climate regulation	1,563
Total	4,214

Source: Estimated by authors

Results of benefit cost analysis for different discount rates summarized in table 10.

Table 10. Benefits and cost of mangroves protection in The Sundarbans (US$ million)[10]

Discount	3%	5%	10%
Cost	1,788	1,352	783
Provisional benefits, biodiversity, ecotourism values	3,655	2,321	907
Protective services values	2,123	1,218	368
Climate regulation (carbon pool) values	293	194	0-87
Total benefits	6,071	3,733	1,362
BCR	3.40	2.76	1.63-1.74

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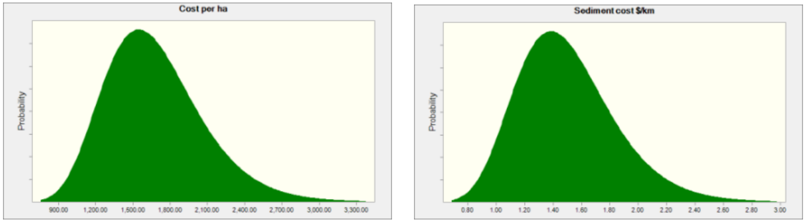
[10] According to Tol 2011 SCC at 10% discount rate is zero, at the same time it is advisable to apply at list a market value of carbon around $5/tCO2. A 5% a year appreciation coefficient was applied to SCC.

If we apply the USEPA recommended SCC at US$11/tCO2 calculated with 5% discount rate[11], then the BCR increases from 2.76 to 2.92.

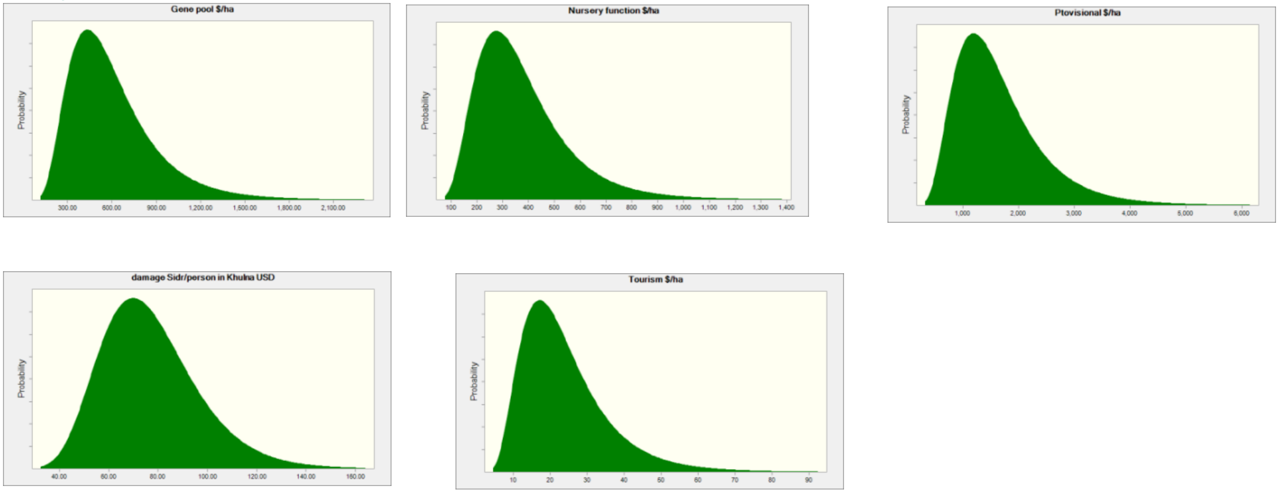
We run Monte-Carlo simulation in order to account for uncertainty and calculate risk adjusted BCR. Selected assumptions for Monte-Carlo simulations summarized in Figure 15, A and B. Estimated distribution of benefits presented in figure 16.

Figure 15. Cost of mangroves protection: planting cost US$ per ha (A) and sedimentation cost US$ million per km of coastline (B)



A. **B.**

Figure 16. Benefits of mangroves US$/ha, including gene pool, nursery function, provisional benefits, baseline damage from cyclones (US$ per person), benefits from tourism (recreational benefits)



Source: Authors' assumptions

For Monte-Carlo simulation we consider the base case with discount rate 5%. Results of Monte-Carlo simulations presented in figure 17, A, B and C.

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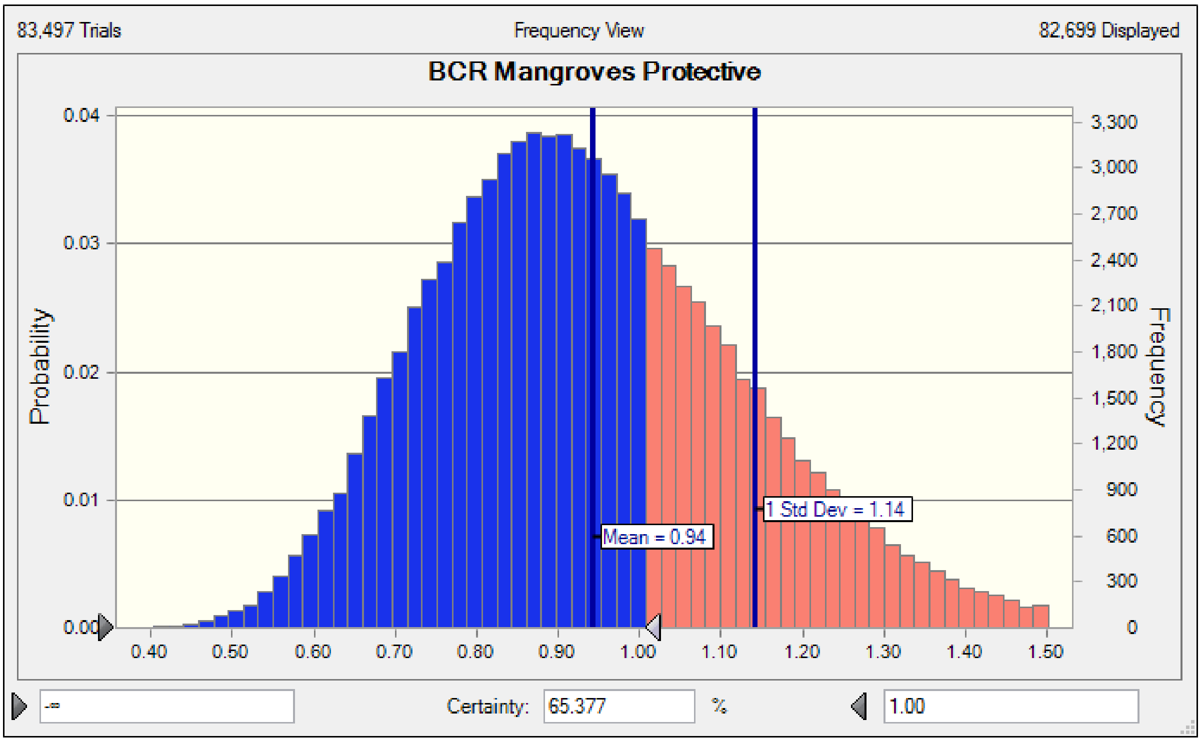
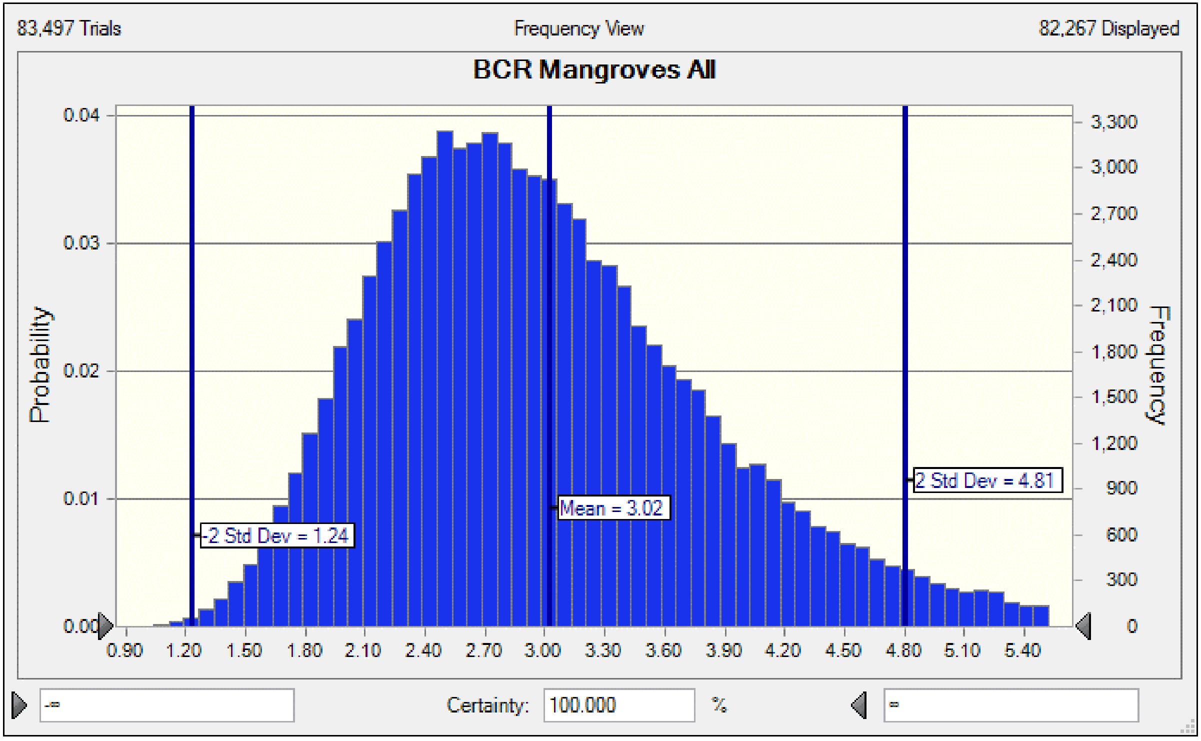
[11] See http://www3.epa.gov/climatechange/EPAactivities/economics/scc.html

Figure 17. A. Distribution of BCR for mangroves protection benefits



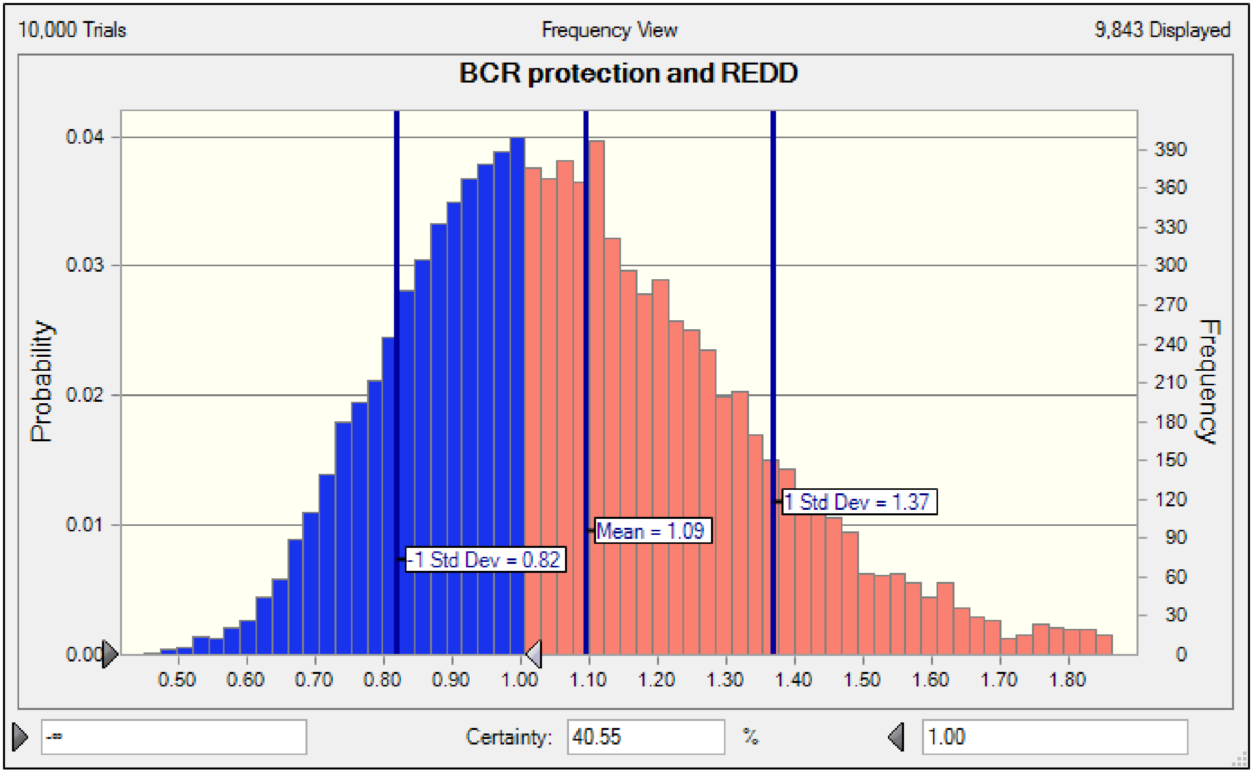
Source: Estimates by the authors.

Figure 17. B. Distribution of BCR for mangroves protection including global carbon benefits, provisional value, biodiversity and tourism



Source: Estimates by the authors.

Figure 17. C. Distribution of BCR for mangroves protection including potential monetizable carbon benefits from participation in REDD+



-∞

Certainty: 40.55 %

1.00

Source: Estimates by the authors.

In all carbon monetization cases, the expected BCR is higher than 1.

In case with all benefits included, the BCR is about 3. With an option value, the risk adjusted BCR is about 10% higher, i.e. it is about 3.3. In the worst case scenario the BCR may not be lower than 1.2. Therefore, mangroves protection could be recommended for implementation. It may take about 20 years to implement the program of mangroves protection. New information on climate change, status of global carbon market, actual efficiency of mangroves to mitigate damage from storm surge, etc. would become available during this period. It allows a narrowing range for the BCR and deciding on acceleration of phasing out the project. Taking into account benefits of flexibilities, the risk adjusted BCR for mangroves protection with REDD+ benefits increases to 1.2.

3.1.2. Multi-purpose cyclone shelters, cyclone-resistant private housing and further strengthening of the early warning & evacuation system

Shelters and an early warning system prevent risk of human health losses, primarily. All other losses may still occur. In 1991 about 190,000 lives were lost. Multipurpose cyclone shelters, which were built mainly after the cyclone of 1991, were found useful in flood and in small intense cyclones from 1991 onward. At present, about 15% of the coastal population is under the coverage of cyclone shelters. About 1.5 million people took shelter during cyclone Sidr. During cyclone Sidr about 3.5 thousand lives were lost (Government of Bangladesh, 2009).

To ensure the safety of the rest of the 85% people in the area with the highest cyclone risk[12], 530 cyclone shelters are needed and with the increase in population, more cyclone shelters will be required. Shelter construction was considered in Barisal district in the areas where population is most exposed to mortality risk from cyclones taking into account relocation of some population. While relocation practically eliminates risk of human life loss, shelter construction significantly reduces, but not completely eliminates this risk due to various reasons related to population response to early warning, efficiency of enforcement of mandatory evacuation, accuracy and predictability of cyclone path, etc. 75 per cent of shelters efficiency was assumed in the study.

Each shelter can accommodate 1,000-1,300 people and 450-500 cattle, and includes separate rooms for men, women and sick people, as well as toilet facilities, a rainwater tank, solar panels, generator and loudspeaker. One million cattle perished during Sidr. Then 530 shelters protect about 2.5 million cows.

The early warning system is critical to increase shelters efficiency, timely dispatching population exposed to the immanent risk of an unfolding extreme event to a nearest shelter will increase its efficiency. According to the (World Bank, 2010) the cost of one shelter is US$ 227 thousand. Maintenance cost is at 5% of capital cost per year.

Multipurpose shelters prevent human lives losses, injuries and losses of animals. We apply data from Table 10 to calculate individual risks to humans and animals from extreme weather events.

Table 10. Damage from Sidr in the most exposed area in Khulna and Barisal

	Most affected zilas	Population, 2007	Cattle, 2008	Deaths	Full house destroyed	House partially destroyed
Barisal	Barguna	984,000	276,280	1264	47%	53%
	Jhalokati	805,000	151460	1290	48%	52%
	Pirojpur	1,289,000	201490	726	27%	34%
Khulna	Bagerhat	1,797,000	292350	854	37%	41%

Source: GoB. 2008; Census of Agriculture 2008.

According to table 10, Barguna and Jhalokati are most exposed and vulnerable to extreme weather events. Therefore we selected these two zilas to estimate the BCA of multipurpose shelters.

Risk of mortality, injuries and losses of animals was estimated assuming 10 years return period for cyclones like Sidr and taking into account statistics on losses and health damage from less devastating, but more frequent extreme weather events. Individual risk estimates are summarized in Table 11.

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[12] Assumed 1 million exposed in Barisal District.

Table 11. Individual risk estimates

	Individual mortality risk	Risk of injury	Risk per cattle
Barguna	1.48E-04	2.51E-03	0.1
Jhalokati	1.84E-04	3.13E-03	0.12

Source: Authors' estimates

Bangladesh median age is about 25 years and the average life expectancy in Bangladesh is 71 years (https://www.cia.gov/library/publications/the-world-factbook/geos/bg.html#People). Then an average person dying from a catastrophic event loses about 46 years of life. If these are productive years, then annual GDP per capita could be used as a proxy for the value of life year lost. GDP per capita in Bangladesh in 2014 is at US$1040 (WDI, 2014). Then the average VSL is estimated at US$49 thousand. Cost of an injury is estimated @ $100 per case.

Other assumptions for BCR calculation are summarized in Table 12.

Table 12. Base value of key parameters used in the estimates

Parameters	Value US$ thousands
VSL	12.2 - 49
Injury	0.1
Cattle	0.8
Shelter capacities	Thousand
People	1.3
Cattle	0.5
Efficiency	0.75

Source: Estimated by authors, http://www.irinnews.org/feature/2012/10/16.

Injury value is estimated as the sum of direct and indirect cost. Direct cost is valued at about one day in hospital with minor trauma as recommended in (Doocy et al et al, 2013), and indirect cost is valued at 4 direct cost (https://safetymanagementgroup.com/resources/injury-cost-calculator/)

Calculation of the value of statistical live for a developing country is a challenging issue. Application of DALYs value method[13] includes an assessment of a number of statistical life years loss and utilizes Benefit Transfer method to estimate an economic value of DALYs at $49,000 (applying Ramsey discount rate and relevant adjustment coefficient). Direct calculation of the VSL substituting different discount rates for Ramsey discount rate yields the following VSLs: $30,000 for 3% discount rate; $22,100 for 5% discount rate and $12,200 for 10% discount rate.

For various reasons described in the literature, people are reluctant to seek refuge in shelters during extreme weather events. Building more expensive multipurpose shelters as described above should increase willingness to use them. Nevertheless, we assume 75% shelters' efficiency rate.

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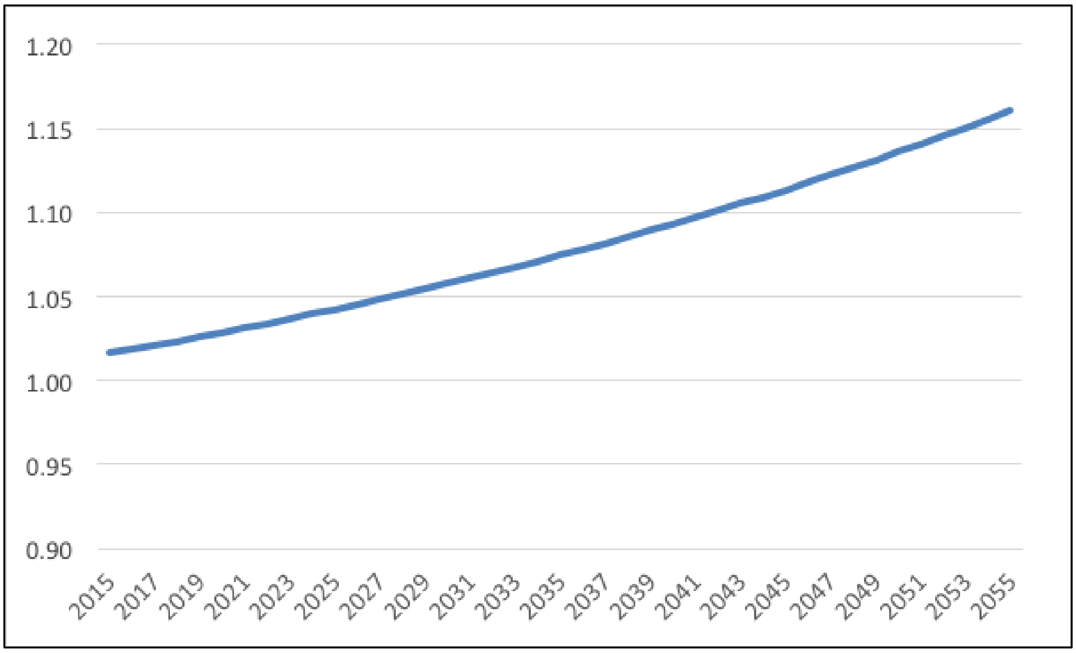
[13] Basically, one value the Value of Statistical life Year (VSLY) lost.

An average incremental capital cost for multipurpose shelter estimated at $277,000, and operation annual cost including maintenance is 5% of capital cost. Cost calculations also include US$40 thousand investment into early warning system and 5% maintenance cost calculated as implied cost per a shelter, based on the cost information presented in (Dasgupta, 2010; World Bank, 2011).

As in the case of mangroves protection, the shelters construction program covers the period 2015-2055. We apply the same model to account for increase in hazard of cyclones due to climate change.

The index of cyclone intensity is calculated assuming 2.15^{0}C of the global temperature increase by 2055. The index of cyclone intensity is presented in figure 18.

Figure 18. Index of cyclone intensity



Source: Estimated by the authors

As before, 5% appreciation of the value of benefits is assumed for BCR calculations.

Summary of benefits, cost and BCR for shelters in Barguna and Jhalokati is summarized in Table 13.

Table 13. Summary of benefit and cost for shelters (calculated per one shelter)

	Discount	3%	5%	10%
PV benefits, US$ thousand	Barguna	3092	1997	856
	Jhalokati	3740	2415	1035
PV cost, US$ thousand	Each region	1419	1090	684
BCR	Barguna	2.18	1.83	1.25
	Jhalokati	2.64	2.22	1.51

Source: Estimated by authors

Table 13A. Summary of benefit and cost for shelters calculated with different VSLs for different discount rates

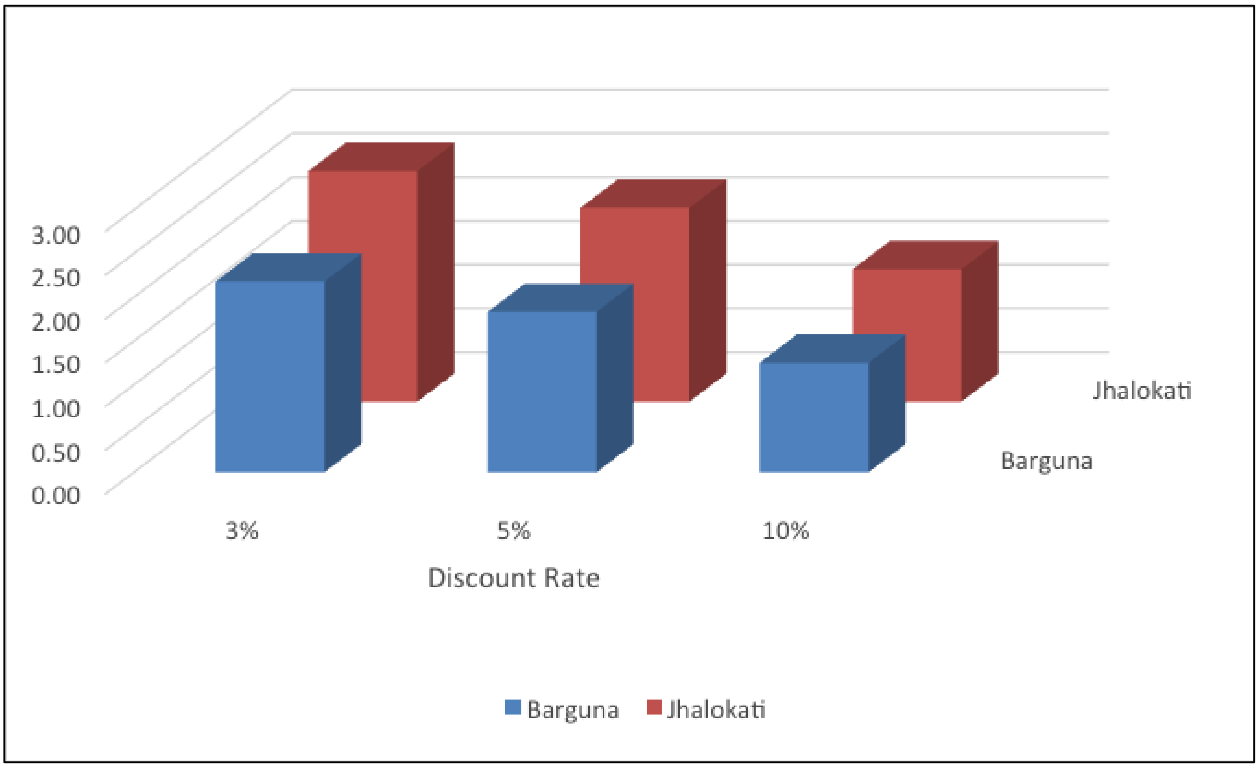
	Discount	3%	5%	10%
PV benefits, US$ thousand	Barguna	2,873	1,790	734
	Jhalokati	3,466	2,157	883
PV cost, US$ thousand	Each region	1,419	1,090	684
BCR	Barguna	2.02	1.64	1.07
	Jhalokati	2.44	1.98	1.29

Source: Estimated by authors

Application of a lower value of VSL drives BCR lower, however it is still higher than unity in all cases. On contrary, application of higher VSL, say $200,000, derives BCR significantly higher. At 5% discount rate the BCR of shelters in Barguna is estimated at 2.9 and in Jhalokati at 3.55.

The BCR in Jhalokati is slightly higher since this region is more vulnerable to climate change (figure 19).

Figure 19. The BCR for Barguna and Jhalokati

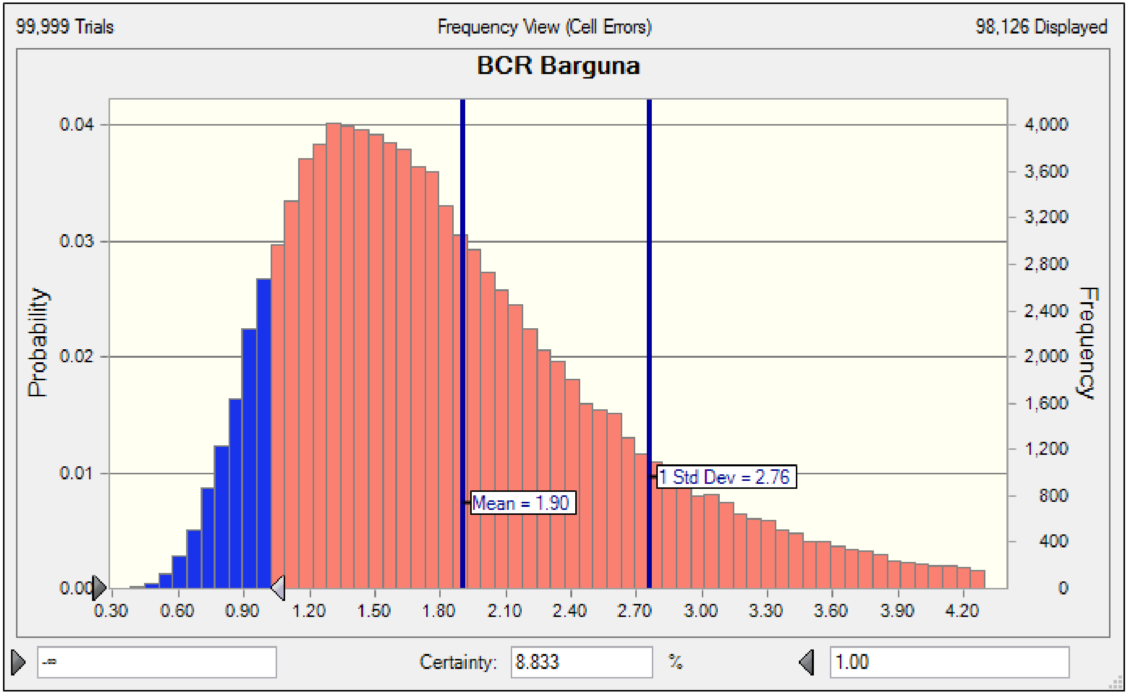


Source: Estimated by the authors

A major factor of uncertainty is frequency of cyclones occurrence. Frequency of cyclone occurrence was modeled in the same way as for the analysis of the mangroves protective function. We use the same assumptions as in case of mangroves describes above. Beta-PERT distribution was applied for efficiency of shelters distribution on the interval 0.65-0.85 that corresponds to the central value 0.75. Shelter construction cost and cost of early warning system were assumed log normal with SD=25%.

Results of Monte-Carlo simulation presented in figure 20 and figure 21.

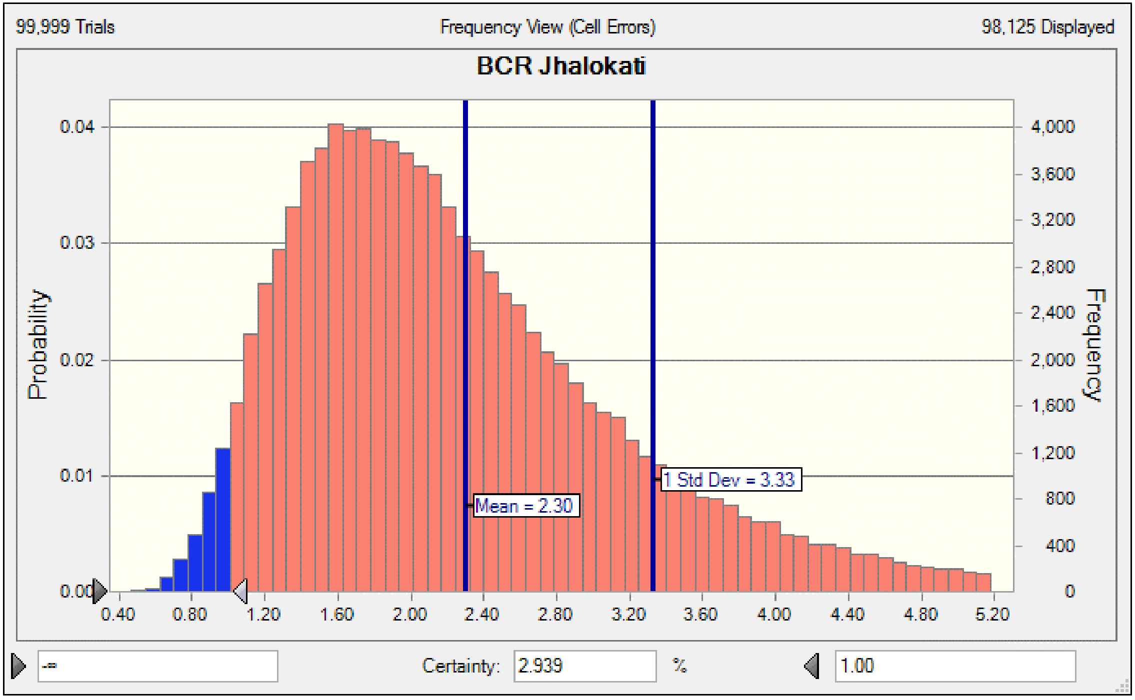
Figure 20. The expected BCR for multipurpose shelter and early warning system for Barguna



Certainty: 8.833 %

Source: Estimates by the authors.

Figure 21. The expected BCR for multipurpose shelter and early warning system for Jhalokati



Certainty: 2.939 %

Source: Estimates by the authors.

The expected BCR is estimated for Barguna and Jhalokati at 1.9 and 2.3 respectively (discount rate is fixed at 5%). It makes shelters an attractive option for implementation in the most risk prone zilas with some mangroves protection already in place. The risk adjusted BCR in Barguna is 2.22 and in Jhalokati is 2.68 because shelter construction is flexible over time depending on learning about climate change and other important uncertain parameters that determine return of multipurpose shelters. However in other regions, the value of shelters is significantly lower.

3.1.3. Polders reconstruction and setback

The least efficient intervention includes set back and enhancement of sea facing and inner polders along with establishment of mangroves green belt, and special fund creation for cyclone resistant private housing encouragement. This intervention just partially mitigates damage from cyclones that remains significant.

While multipurpose shelters and an early warning system primarily prevent human life losses, injuries and, to some extent, property losses, polders mainly prevent damage to agriculture housing, infrastructure, etc. Even after reconstruction, polders would create little protection from super cyclones. As reflected in figure 6, by 2050 large number of polders will be overtopped. There is an uncertainty on degree of sea level rise, storm surge, frequency and intensity of cyclones, etc. Polders are exposed to an increasing risk of overtopping and dykes failure. Existing reconstruction projects (World Bank, 2010) do not meet criteria of acceptable risk of failure. For example, in the Netherlands an acceptable risk criteria for inundated areas requires probability of 10^{-5} for an accident with more than 100 fatalities (in other words, once per 5000 years)[14].

For numerical analysis we apply following data summarized in table 14

Table 14. Benefits and cost of polders reconstruction and setback project

Length	Sea facing polders	1207	km
	Inner polders	1100	km
Cost	Polders	4472	Million US$
	Mangrove protection sea facing	101	Million US$
	Cyclone resistant private housing	200	Million US$
Benefits	Khulna	2934	Million US$
	Barisal	472	Million US$

Sources: Dasgupta, 2010; World Bank, 2014, author estimates

The project cost is calculated based on (Dasgupta, 2010), and (World Bank, 2014). Benefits with 5% discount rate in the table above are calculated using the same model we applied for calculating of benefits of mangrove restoration and benefits of multipurpose shelters.

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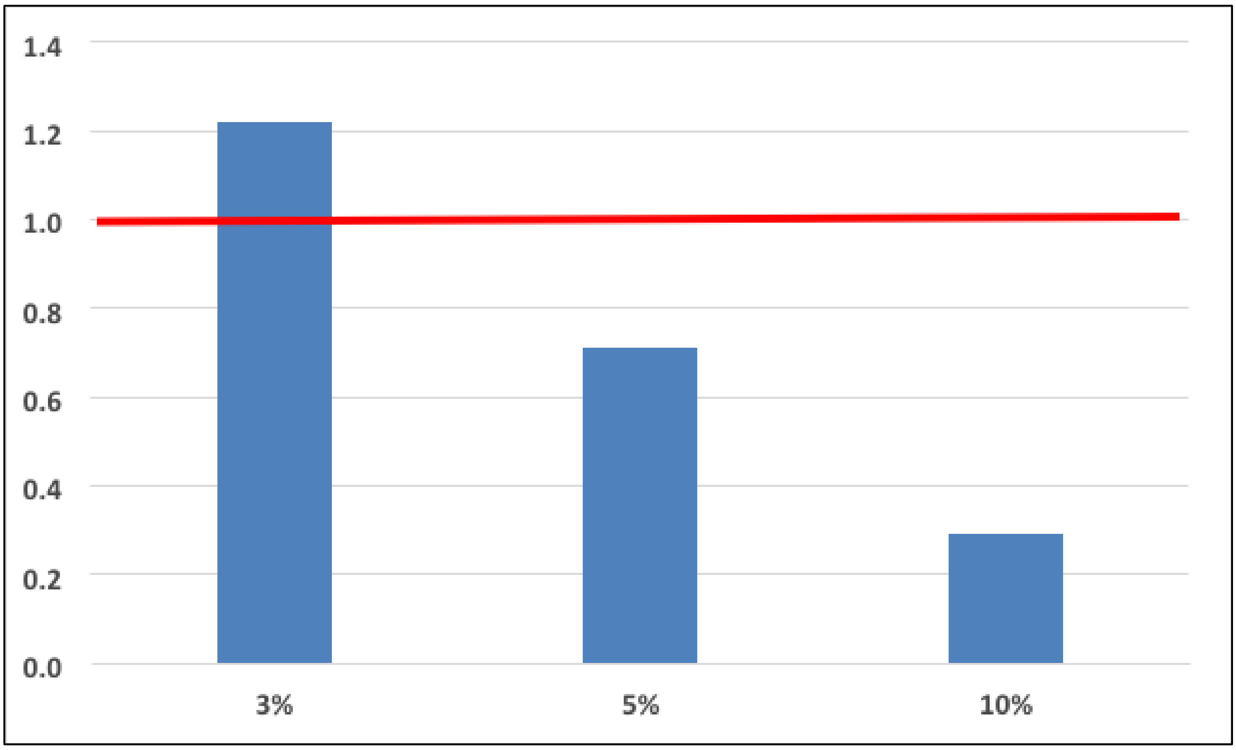
[14] See Veiling et al 2005

In other discount rates are applied, then the BCR of the entire polders reconstruction and setback project is above unity just for discount rate 3%.

Polders reconstruction and setback project is an expensive and not very reliable intervention to protect delta from extreme weather events. Maximum polders efficiency is 80% for Khulna District protected by mangroves, and 50 % for Barisal district (World bank, 2011).

Despite a significant cyclone risk, the estimated BCR for the entire region is not sufficient to justify polders set back and enhancement as an area wide intervention (figure 22). However, some local improvements could be viable. As Pethick (2011) suggests more analysis is required to elaborate an embankments enhancement program that should be considered along with other interventions.

Figure 22. The BCR for polders reconstruction and setback calculated with different discount rates



Source: Estimates by the authors.

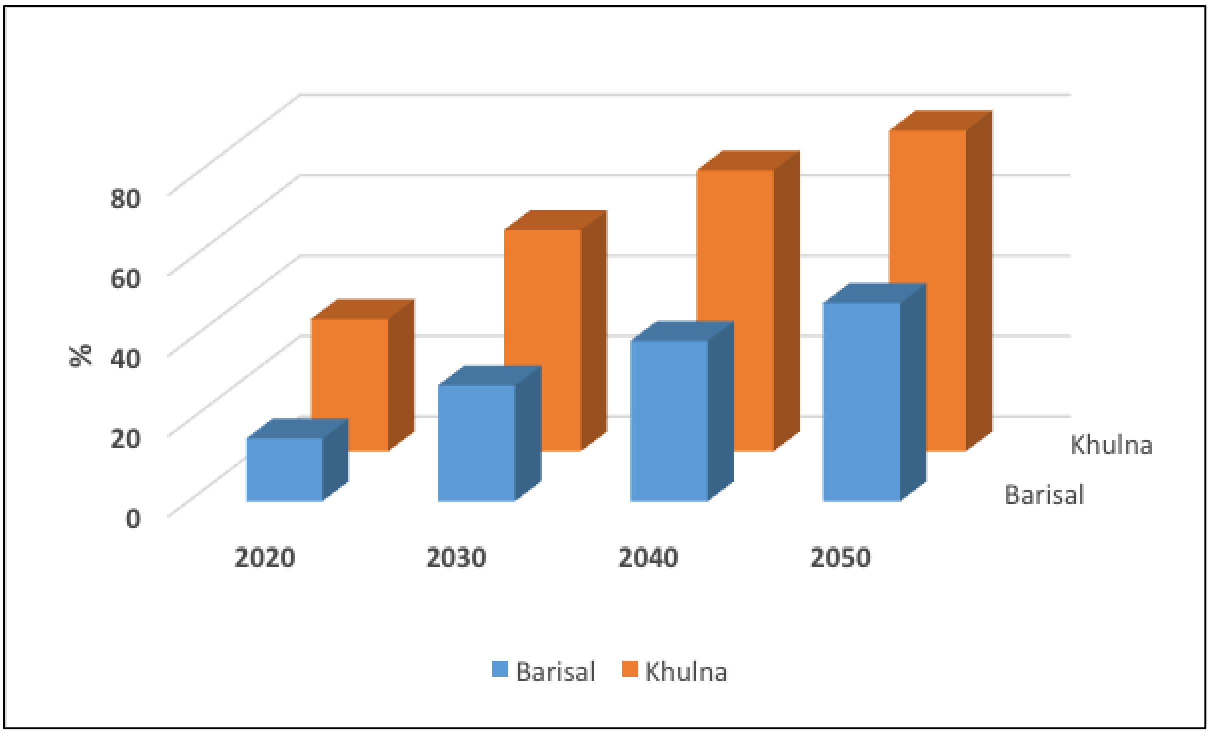
For example, more selective approach to polders reconstruction focusing on areas with inundation less than 3 meters will increase efficiency of polders project, rising BCR above 1 (figure 23).

Effectiveness of this intervention increases with an increase in intensity and frequency of cyclones and height of storm surge. Existing polders already protect affected territory from relatively “mild” events. Incremental benefits are harvested only with an increase of intensity, frequency and severity of the future extreme weather events. However, even enhanced polders will not protect from a mega storm like Sidr. Therefore, for a given height of dikes, their protective efficiency is represented as a function of time with a reversed U-shape

Selective approach to polders reconstruction yields a higher BCR. For example, reconstruction of interior polders costs disproportionally less than the entire project we discuss above (table 14). Using the same assumptions as in (Dasgupta, 2010) on cost of polders reconstruction in two areas of inundation, the attributable share of the entire polders set back and reconstruction project cost in the area with inundation less than 3 m, is estimated at about 20% of the total project cost, while attributable fraction of the benefits (proportionally to population leaving onshore and inland) is estimated at 65% in Khulna and at 45% in Barisal.

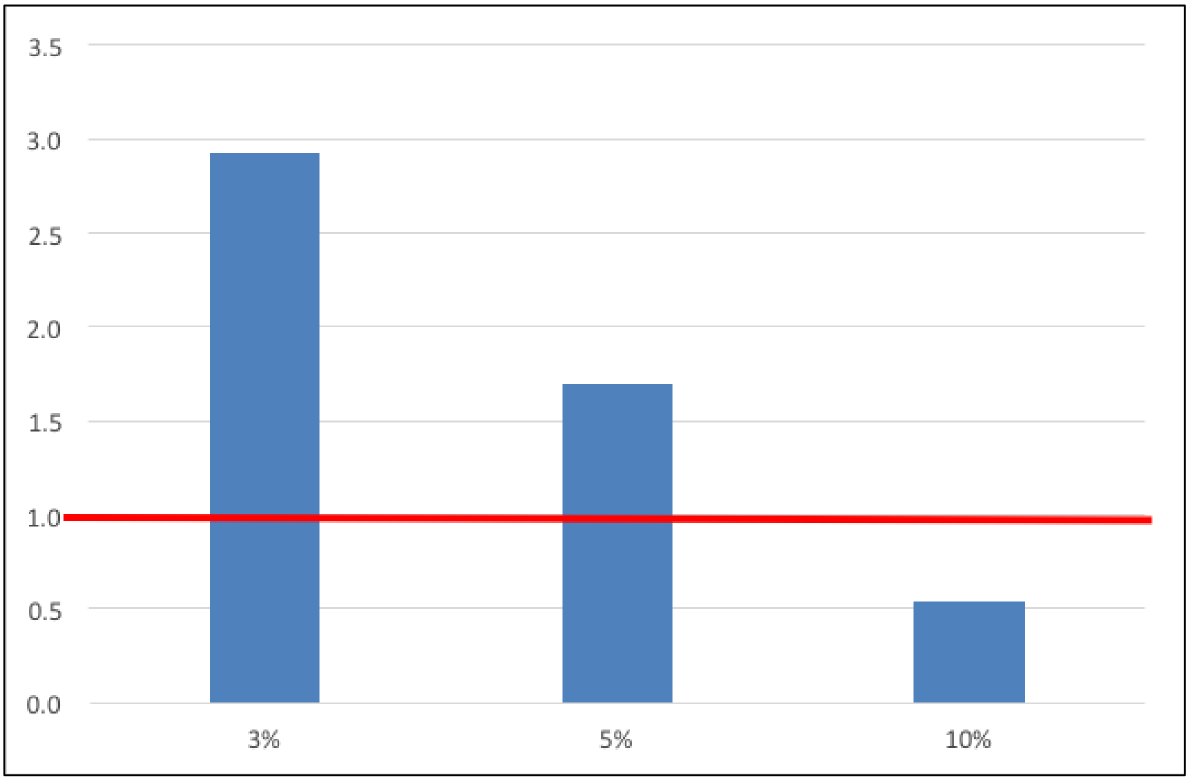
The estimated BCR for reconstruction and setback in the less than 3m inundation area (see figure 24) is higher that for the entire project as presented in figure 22.

Figure 23. Effectiveness of polders reconstruction and setback for the selected polders in the less than 3m inundation



Source: Estimates by the authors.

Figure 24. The BCR for reconstruction and setback in the less than 3m inundation area with different discount rate for project costs

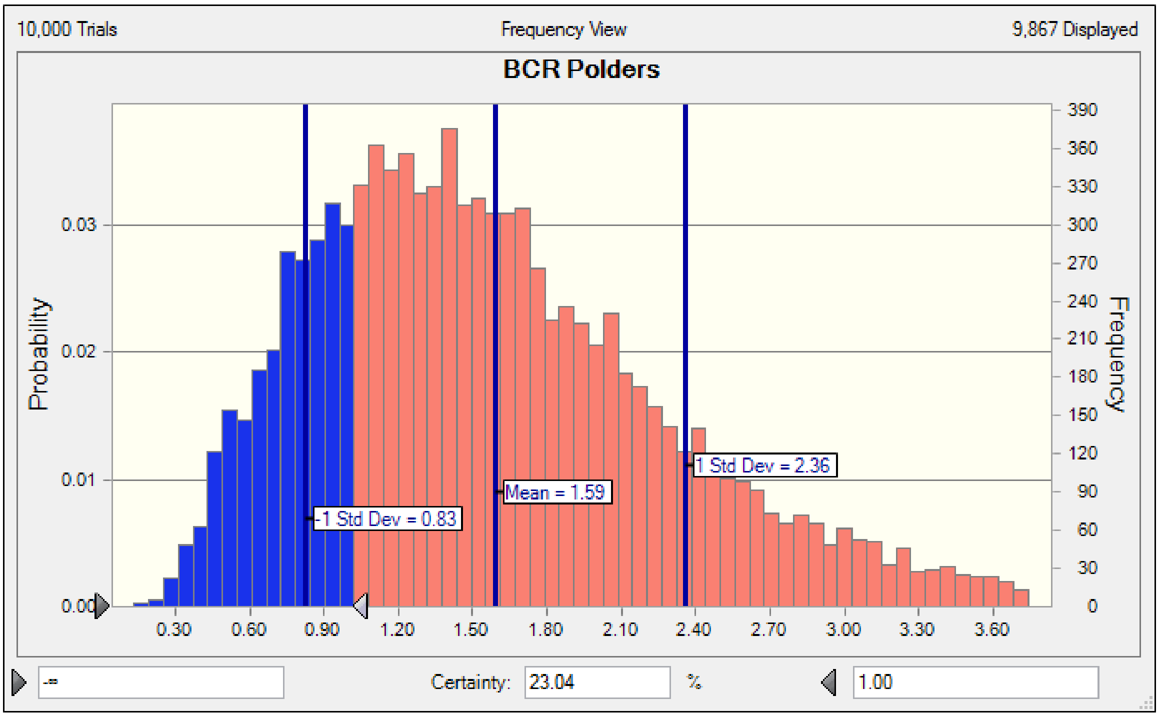


Source: Estimates by the authors.

Thus, a selective approach demonstrates an efficiency of the polders reconstruction and setback project in the selected areas with inundation less than 3 m.

The probabilistic model of damage from cyclones is calibrated to take into account uncertainties. Base value of cyclone damage in Khulna District is assumed log normal with SD=25% and SD=50% in Barisal District. Coefficient of cost attribution between Khulna and Barisal is also uncertain. We applied a lognormal distribution with mean value at 0.2 and SD=0.07. An additional maintenance cost (5% of the capital cost) is included to account for damage to dikes from climate change, if temperature increases above the reference level. For example, in 2055, the global temperature rise reaches 3^{0}C, an additional maintenance and repair cost reaches 10% of the capital cost. Then distribution of the BCR in the selected inundation area (less than 3 m) is presented in Figure 25. Mean BCR is estimated at 1.59.

Figure 25. Distribution of the BCR for the polders setback and enhancement in the selected inundation area



-∞

Certainty: 23.04 %

1.00

Source: Estimates by the authors.

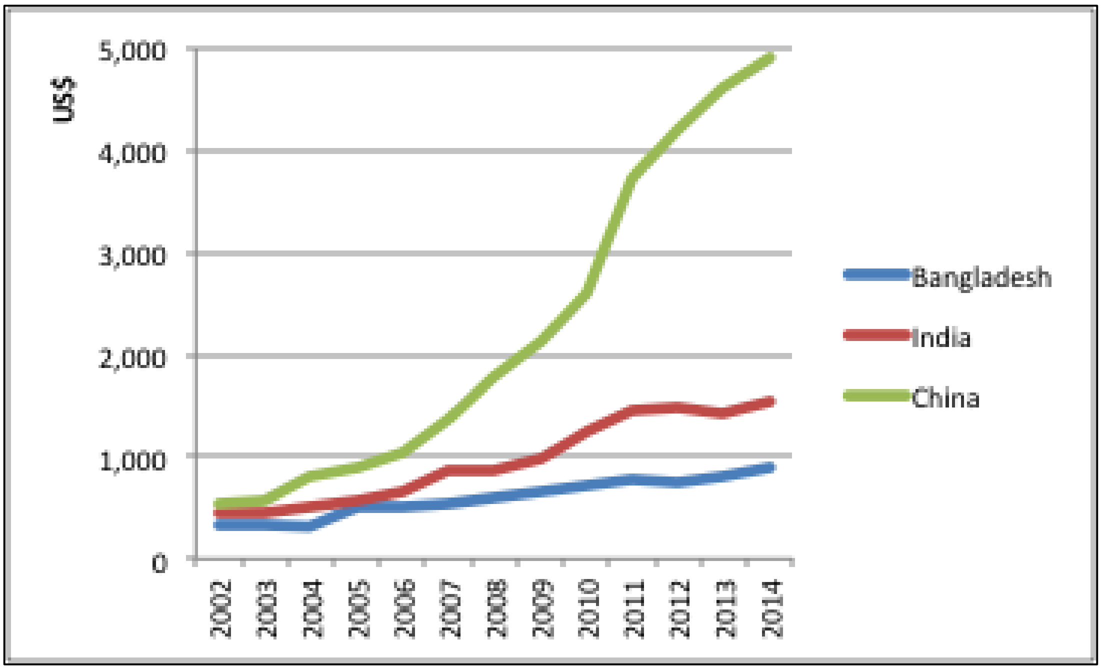
In contrast to previous interventions that are scalable and do not require a large upfront investment, polders reconstruction and setback requires a significant upfront capital cost. Risk adjusted value of the BCR should include a forgone value of deferral option on this investment. Taking this into account, the BCR for this intervention is estimated at 1.29.

3.2. Long-term strategy of resilient economic growth, assets diversification and human capital formation

In this section we go beyond a traditional definition of adaptation interpreted as an intervention to react to various hazards attributed to climate change. As we discussed in Section 1.2, climate change could become an important barrier for long-term economic growth. Moreover, Bangladesh is facing a significant risk of sliding into an “adaptation trap”. To avoid this risk, adaptation should be embedded into a development strategy. Proposed interventions have a comprehensive impact on Bangladesh economy including adaptation to climate change and building economic potential to improve resilience of Bangladesh to climate shocks.

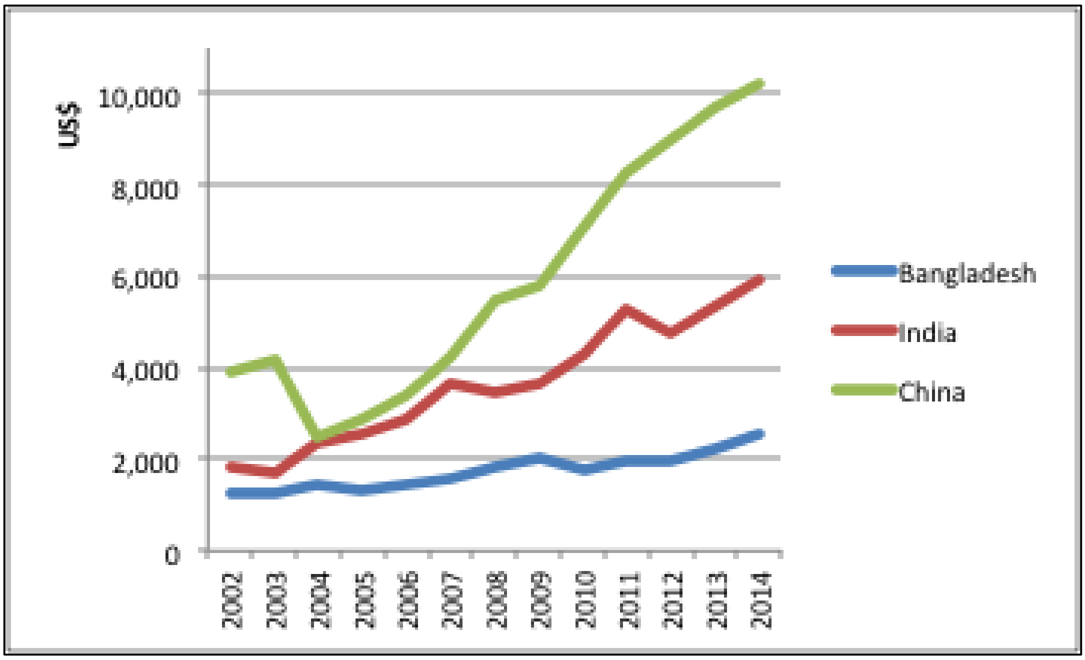
An increase in productivity of the labor employed in agriculture, manufacturing and service sectors is the only way to increase the resilience of Bangladesh to climate change and to meet long-term development goals. Bangladesh has significant reserves to improve productivity while catching up with other developing and middle-income countries. Figures 25.A and 26.B demonstrate a gap in value added in agriculture and manufacturing per employee in Bangladesh compared to India and China (about US$3,300-7,500 in industry and US$650-4,000 in agriculture).

Figure 26. A. Value added per employed in agriculture (current US$)



Source: Estimates by the authors using WDI, 2016.

Figure 26.B. Value added per employed in industry (current US$)



Source: Estimates by the authors using WDI, 2016.

There is also a room for improvement in the weighted average productivity of the economy shifting labor from agriculture to manufacturing and services. The next intervention demonstrates the economic benefits of population reallocation and population reallocation with simultaneous increase in productivity. According to (IMF, 2013) Bangladesh suffers from “disguised unemployment”. The disguised unemployed are engaged in agriculture and informal services. At present, about 40-45% of labor force is involved in agriculture. With an increased productivity it constitutes a significant reserve for more productive manufacturing and service sectors. Table 15 illustrates one possible composition of the labor force and goals for productivity increase by 2050 in order to meet a development goal and read GDP at about US$ 7,000 per capita (see table 1). According to the World Bank study on green growth in Bangladesh (Hossain et al, 2012) “…sustained increases in Bangladesh’s growth will require significant increases in the investment rate, to at least 33 percent of GDP, as well as efforts to increase labor force participation and worker skills through schooling.” (Hossain et al, 2012 p. 4).

Table 15 presents one possible scenario of reaching a development goal of about US$7,000 GDP per capita by 2050. We assume that domestic agricultural production per capita increases 20% over the period from 2015 to 2050. We also assume 0.5% annual growth rate in labor participation. Over the next few decades, Bangladesh should adopt more productive and less climate change vulnerable technologies. Yet a residual damage from climate change estimated as percentage of output would likely reach a double-digit figure (see Burke et. al., 2015). For table 15 we adopt moderately optimistic assumptions on climate change damage. In-depth review of economic growth and climate change paths requires an application of the Integrated Assessment Model coupled with the Computable General Equilibrium model. Such analysis is beyond the scope of this paper.

Table 15. Structural changes, increased productivity and climate change by 2025

Sector	Target share	Target increase of productivity, %	Residual damage from climate change, %	Gross output per employed, US$	Net output per employed after accounting for climate change damage, US$	Total output, US$ million
Agriculture	0.2	4.5	25	3,990	3,192	47,942
Manufacturing	0.3	6	15	15,500	13,478	337,393
Services	0.5	5.5	10	26,500	24,091	1,045,291
Total production US$ million						1,430,626
GDP per capita, US$						7,075

Source: Estimates by the authors.

3.2.1. Productivity increase in agriculture

The productivity gap in Bangladesh agricultural sector could be explained by several factors. Climate change plays an important role. Due to extreme weather event like cyclones, floods, droughts, etc. accumulated economic assets (livestock, equipment), infrastructure and harvest is regularly literary being wiped out. Salinity is another critical problem, partly attributed to climate change (Dasgupta et al, 2016). Over the next decades, agriculture will suffer from reduction of agricultural land (sea level rise and salinity) and from outflow of labor. Radical increase in productivity is the only way to ensure some food security. Agricultural production per capita should stay at least at the same level.

Manmade and human capital are adequate substitutes for reducing agricultural land. Accumulation of manmade and human capitals coupled with adoption of new technologies also increases resilience to climate change.

In order to study benefits and cost of continuous transformations in agriculture we calibrated production function of the following form:

$$Y(K, L, S) = \rho k^{\alpha} s^{1-\alpha} L,$$

where k denotes capital per labor in agricultural sector (capital cost also includes fertilizers and other material expenses, capital cost them self-calculated as a rental value of equipment, livestock, etc.);
s stands for land per unit of labor;
L is total number of employed in agriculture;
α stands for capital productivity;
ρ denotes total factor productivity.

For calibration we use data from USDA[15]. Calibrated production function is presented in Figure 27.

For calibration we used USDA data for South Asia. At present, intensity of capital and material resources per labor employed in agriculture in Bangladesh is almost 8 times less than in China, while labor concentration per 1 ha of land is about 2.4 times higher. According to the development scenario in table 15 and assuming minimum net losses of agricultural land as in (Dasgupta et al, 2016), by 2050 the maximum ratio of land per one employed is 1 Ha.

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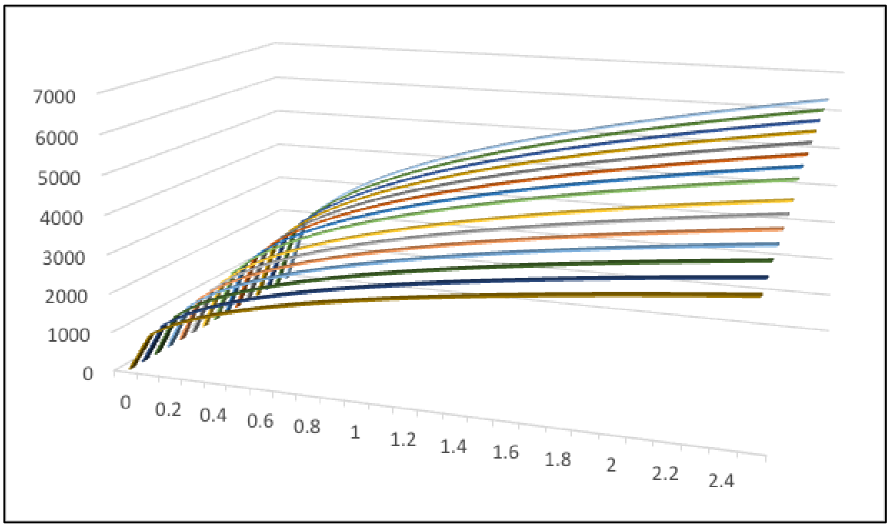
[15] Data on factor productivity, agricultural land etc. are from USDA website: http://www.ers.usda.gov/data-products/international-agricultural-productivity.aspx

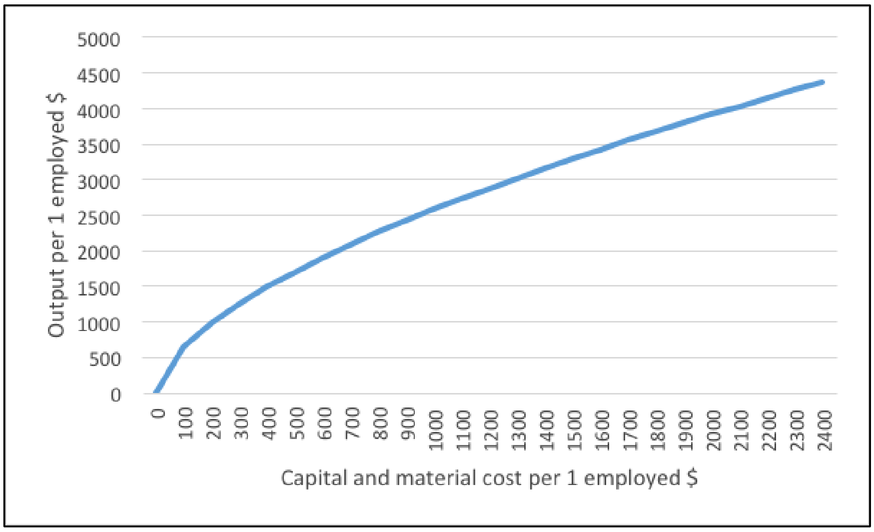
Figure 27. Multifactor production functions for agriculture (US$)



Source: Estimates by the authors.

Figure 28 demonstrates that if a land per employed ratio is set equal to one, then capital and materials intensity should be about US$2000 in order to reach a target level of production per worker employed in agriculture.

Figure 28. Production function assuming land per employed ratio equals one (US$)



Source: Estimates by the authors.

For the benefit cost analysis we assumed an interim goal of increase in capital and operation cost up to US$1000 per employed in agriculture, increase of land per worker up to 0.8 ha and 10% of TFP increase. Climate damage in an "anticipated" scenario is 20% of total output. The net output after subtracting climate damage is US$2,086 per worker. Required capital investment is US$8330 (including $400 for training). Annual operational and maintenance cost is assumed 10% of capital cost. Time horizon for calculations is 20 years. The BCR is estimated in the range of 2.48-4.04, with 3.46 at 5% discount rate.

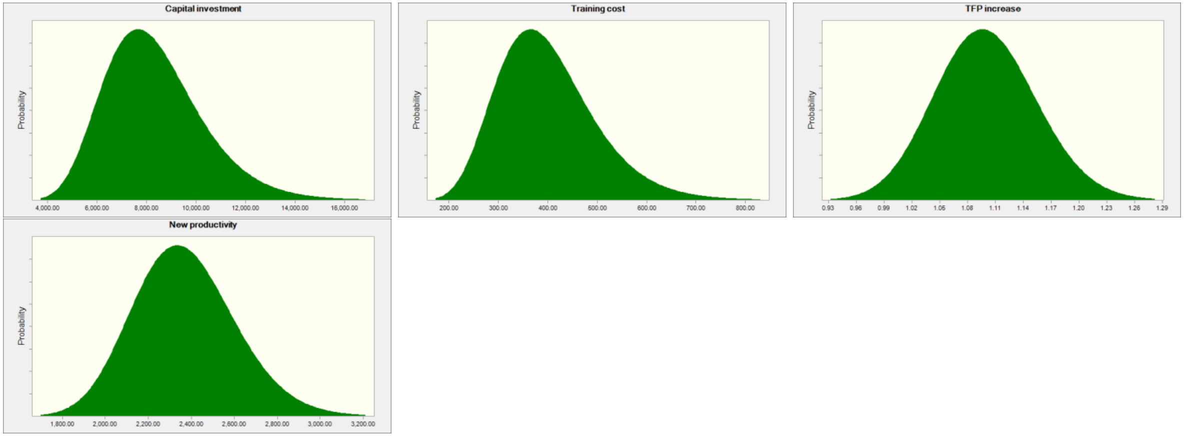
Table 16. BCA for improvement of productivity in agriculture

	3%	5%	10%
PV cost, US$ per one employed	9,352	9,029	8,398
PV benefits, US$ per one employed	37,800	31,220	20,804
BCR	4.04	3.46	2.48

Source: Estimates by the authors.

Probabilistic model of productivity in agriculture increase is calibrated to take into account economic and climatic uncertainties. The new agricultural practice is still vulnerable to climate change, also it is not clear how fast and how successful it will be implemented. Cost parameters are also uncertain. In order to take into account all these uncertainties, we run Monte-Carlo simulations with the following assumptions: summarized in Figure 29.

Figure 29. Assumptions for Monte-Carlo simulations



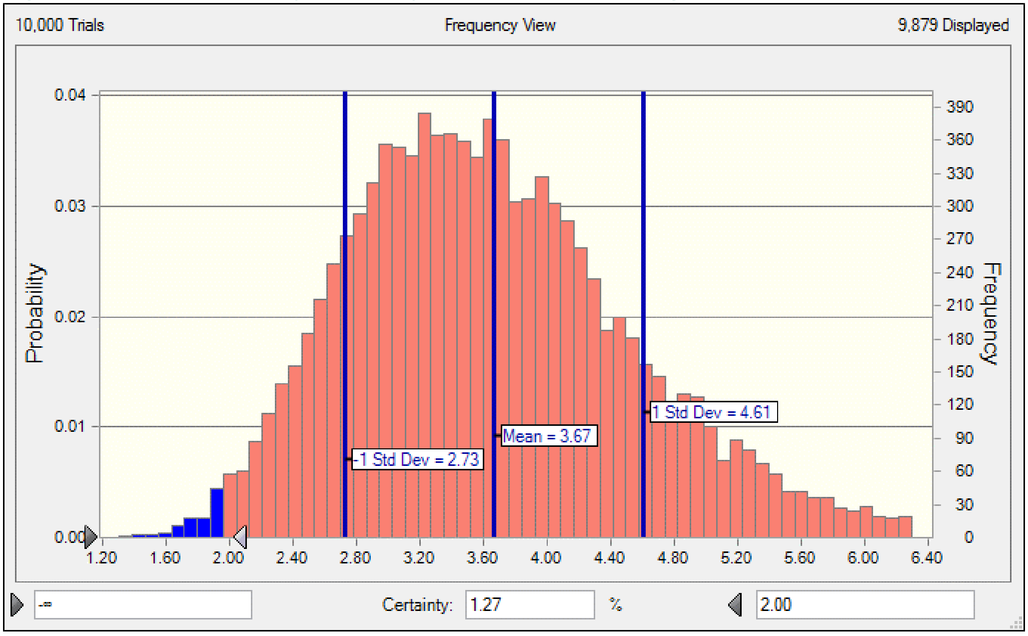
Source: Assumptions for the analysis.

Climate damage is quadratic function of the global temperature increase above preindustrial level with scaling constant equals 0.05. The agricultural sector in Bangladesh is already suffering from a weather related damage that is included into the damage function. Temperature increase is computed using the DICE model (Nordhaus, 2013) like in case with Monte-Carlo simulations for mangroves protection.

Then distribution of the BCR is presented in figure 30. Mean BCR is estimated at 3.67. With probability 98.5% BCR is higher than 2. Taking into account an option value, risk adjusted BCR is estimated at about 4.

High benefit cost ratio indicates relative importance of this intervention. Proposed intervention is scalable and could be replicated over the next 20 years to converge entire agricultural production in Bangladesh. However, if during this time a better technology becomes available, there is a possibility of an easy switch to the next generation technology, more productive and more resilient to climate change.

Figure 30. Distribution of the BCR for interventions in agriculture



Source: Estimates by the authors.

3.2.2. Population relocation

Relocation of population inland is the most efficient risk mitigation intervention. Over the next 20 years around 1 million people currently exposed to a high cyclone threat should be relocated. Relocation reduces total damage from cyclones in this area, which is not protected by mangroves. In addition to damage from cyclones, the population of Barisal District experiences losses from degradation of agricultural lands due to increased salinity, and losses from shortage of fresh water. Lower productivity of agriculture and saline soils, as well as time spent for water search reduces labor productivity. Also, there are some biodiversity losses, by-catch losses from larvae collection and mangroves productivity losses associated with their economic activity in the SRF. According to World Bank 2014, the BCR of relocation is 1.27.

Such a low BCR seems discouraging, however, relocation of about 1 million people from the most vulnerable areas in Barisal district is a matter of necessity. The only way to increase efficiency of relocation is to ensure that the relocated population will have new employment opportunities in more productive sectors of the Bangladeshi economy. Therefore in this section we coincide relocation in combination with job creation in manufacturing and service sector. For numerical analysis we focus on manufacturing sector, but the same methodology could be applied to the service sector.

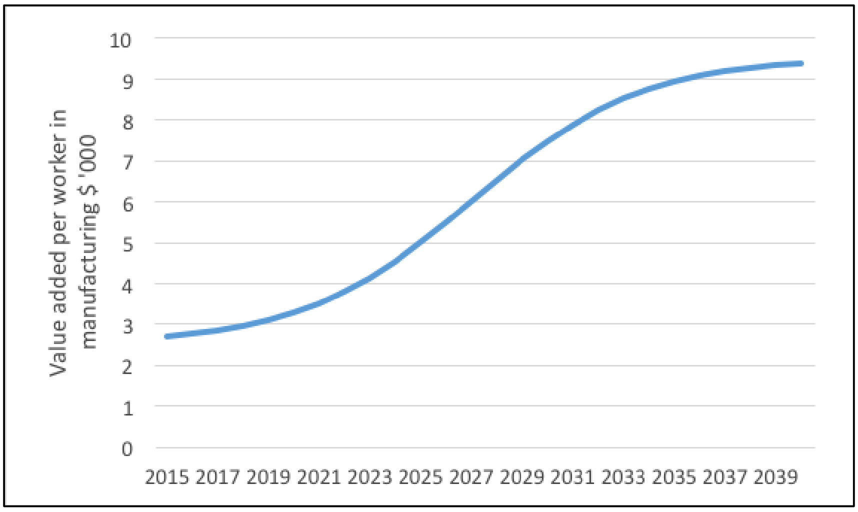
Reallocation is a scalable intervention. Initial experience with reallocation allows narrowing uncertainties, and scaling it up if actual return on investment is higher than expected. According to table 9, by 2050 up to 22 million may be residing in more than 3 m inundated area. Relocation of this population in the second tier cities coupled with training and better education creates a potential for productivity growth of the Bangladeshi's economy crucial to improve resilience to climate change. Applying an average household size in Bangladesh at 4.7 (BBS, 2011) and assuming that 1-2 people in the family will receive an adequate education and training for getting a high productive job in manufacturing sector, we calculate the benefits of relocation. We also assume a logistic learning that results in increase of value added per employed worker in the manufacturing sector (see Figure 32).

The one-time cost of relocation for a family (including help with housing etc.) is estimated at US$ 10,000. It may take on average up to 3 years for a family to settle and receive a relevant training to get a more productive job in manufacturing sector. It requires another US$2,000 per year per family (support and expenses for education). Being on a conservative side we assume that probability to find this more productive and better-paid job is around 0.75 (otherwise a "conventional" employment in manufacturing or agriculture could be available). Also, we assume that in addition to that expense, creation of a new workplace requires US$7,500 (taking into account probability to get the new job mentioned above, job creation investment per family estimated at US$ 15,000 for 2 workplaces).

Attributed benefits include tangible revenues from additional productivity in manufacturing sector (see Figure 32) and avoided damage from extreme weather events estimated similar to the case of shelters construction. This estimate takes into account an increase in intensity of natural disasters and annual appreciation of the base value of benefits. Calculations represent benefits of relocation of most vulnerable population from Barisal. We applied the base value of the annual avoided damage per person at US $170 (World Bank, 2014).

Estimates of central values for the BCA analysis are summarized in Table 17.

Figure 32. Net increase in value added per employed worker in manufacturing sector



Source: Estimates by the authors.

Table 17. Benefits and cost of relocation per person (relocation from Barisal)

	3%	5%	10%
PV cost, US$ thousand	22.5	16.0	7.6
PV benefits, US$ thousand	6.0	5.6	4.9
BCR	3.76	2.85	1.56

Source: Estimates by the authors

For relocation from Khulna, benefits are slightly lower due to the lower base value of damage from cyclones since the population in Khulna is better protected from storm surge by mangroves[16] (see table 18).

Table 18. Benefits and cost of relocation per person (relocation from Khulna)

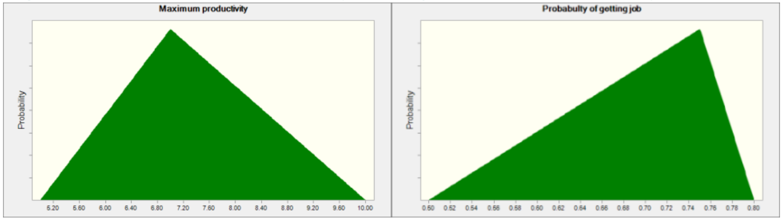
	3%	5%	10%
PV cost, US$ thousand	5.99	5.63	4.88
PV benefits, US$ thousand	18.5	13.0	5.91
BCR	3.09	2.31	1.21

Source: Estimates by the authors

The BCR of relocation and creation of jobs in manufacturing sector could be even higher since we intentionally conduct analysis on conservative assumptions of a success rate of relocation with corresponding increase in productivity. These assumptions reflect existing socio-economic and institutional barriers that may be difficult to overcome. Also, over time the situation may change in a positive way. Initial efforts to support relocation have a significant learning effect. If two family members are able to find a better job in the manufacturing sector, then the BCR will increase up to 3.4 (with 5% discount rate).

For the Monte-Carlo simulations we apply the same assumption as above, and few additional assumptions on productivity in manufacturing sector and probability to gest a new job (see Figure 33 below)

Figure 33. Additional assumptions for relocation analysis



Source: Assumptions for the analysis.

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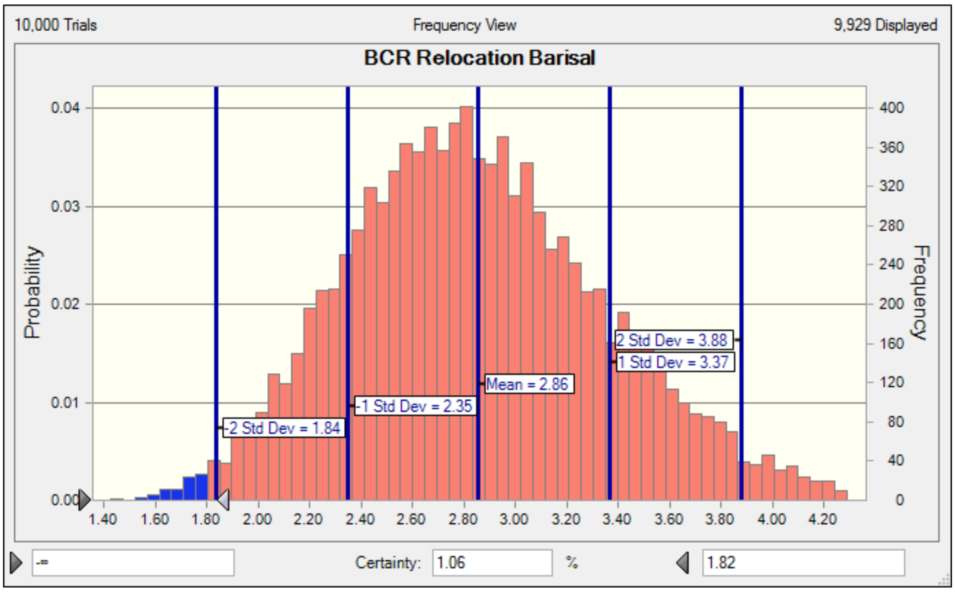
[16] Assuming no mangroves degradation

The expected PV of benefits per relocated person is US$8,600 and US$12,300 in 95th percentile, while an expected cost are estimated US$5,230 and US$6,700 in 95th percentile. The cost includes assistance with settlement, education cost and the cost of job creation.

Figure 34. Benefit cost ratio for relocation to the second tier cities from Barisal

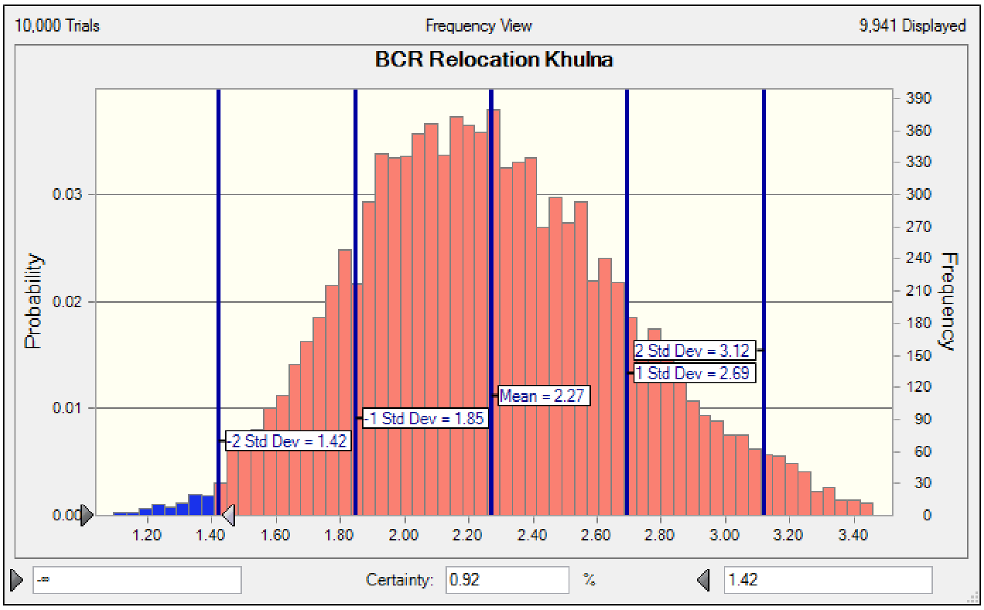


-∞ Certainty: 1.06 % 1.82

Source: Estimates by the authors.

Even with conservative assumptions about benefits and cost of relocation into the second tier cities, the expected BCR is relatively high (mean BCR is 2.86). Moreover, the BCR is always positive and not less that 1.8 within two standard deviation interval. Taking into account option value, the BCR reaches 3.06.

Figure 35. Benefit cost ratio for relocation to the second tier cities from Khulna



-∞ Certainty: 0.92 % 1.42

Source: Estimates by the authors.

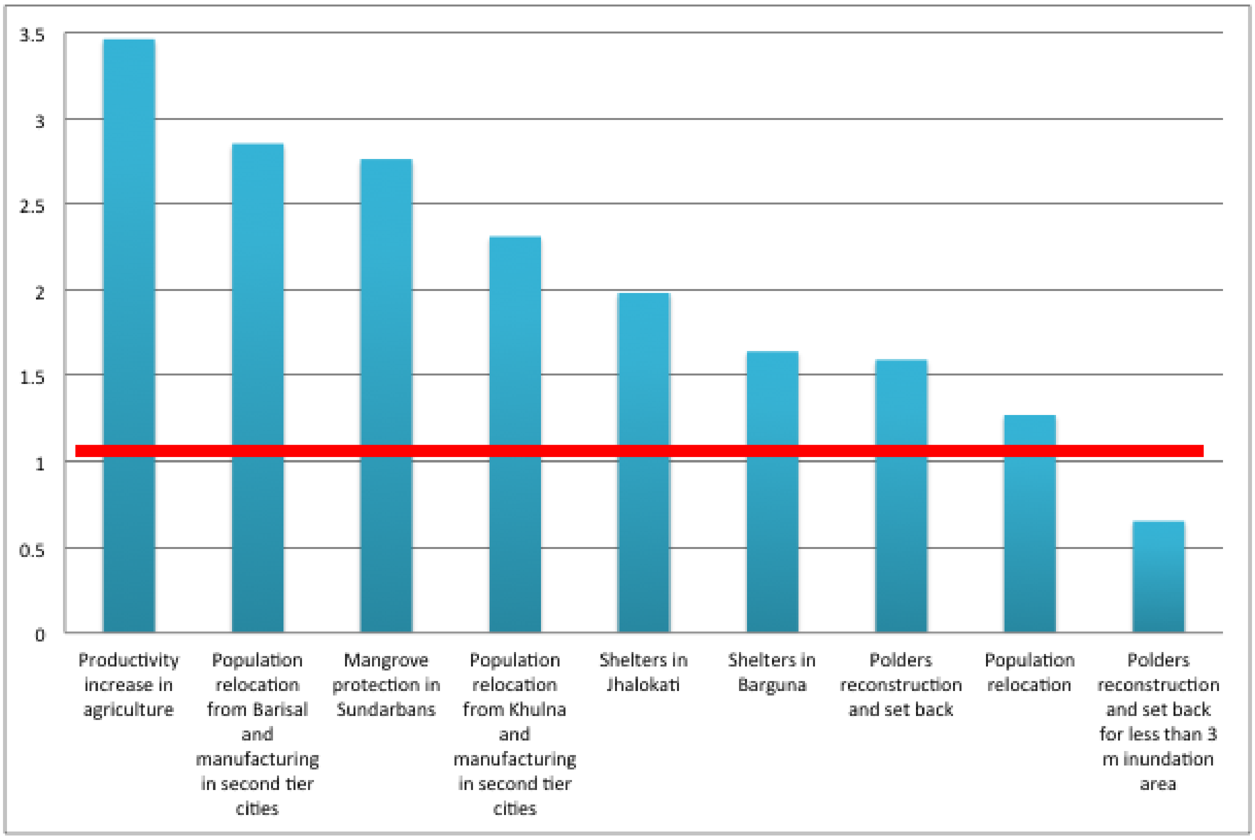
The BCR for relocation from Khulna is slightly lower. Including an option value, the BCR for relocation from Khulna is 2.44.

Adoption of the strategy of structural transformations of employment in Bangladesh in favor of manufacturing sector is a fundamental precondition to build resilience to climate change.

4. BCA – results, recommendations and discussion

The BCA results are summarized in figure 36. For comparison only, central value of the BCR calculated with 5% discount rate is presented in this figure for each intervention.

Figure 36. BCR for adaptation interventions in Bangladesh



Source: Estimates by the authors.

The study demonstrated that taking into account high uncertainty of climate change with non-zero probability of catastrophic events in Bangladesh, most interventions execute the BCR greater than unity.

Increase of productivity is critical for economic development in Bangladesh. Agriculture has a significant room for improvement and this intervention yields the highest BCR. Most of the benefits in agriculture are monetizable, but there are significant barriers for the adoption of new more productive technologies. Institutional changes to promote deployment of new technologies are crucial for climate change resilience.

Relocation of population into second-tier cities with simultaneous training and investment into education is the most promising intervention:

- It has one of the highest BCRs
- It is scalable.

It simultaneously reduces exposure and increases resilience of Bangladesh to climate change. Population relocation also has a relatively high BCR, especially when relocation is coupled with training for the manufacturing sector. Adoption of a structural transformation strategy of employment in Bangladesh in favor of the manufacturing sector is another fundamental precondition to build resilience to climate change.

Mangroves protection is an important interim intervention. It yields the third highest BCR. In contrast to agricultural productivity increase, a sizable share of benefits is external. However, this intervention is important in the mid-term:

- It helps by buying time for gradual reallocation;
- Carbon benefits potentially could be monetized.

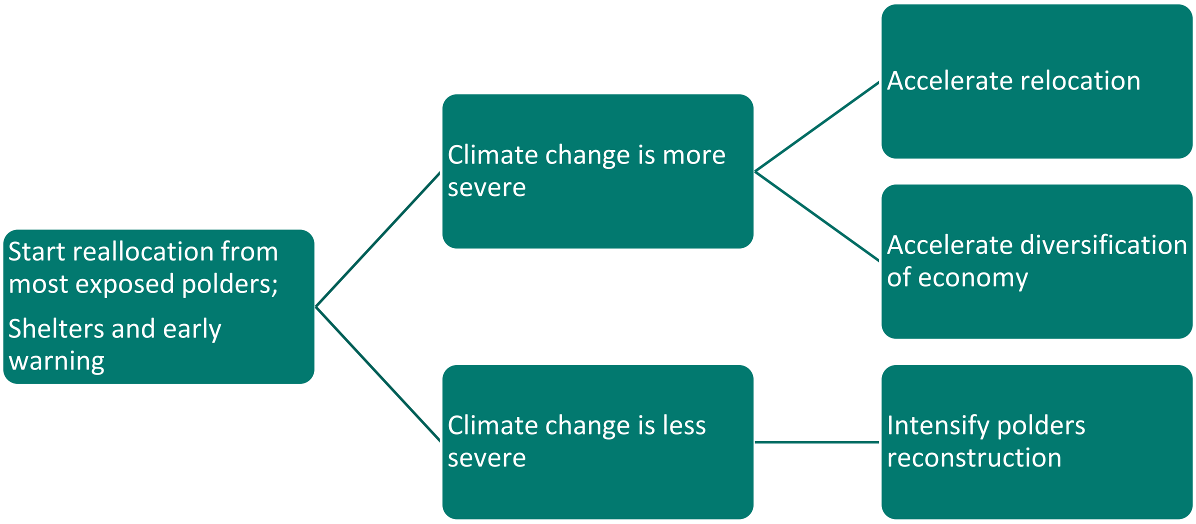
Shelters yield reasonably high BCR; this intervention also should be considered for implementation, especially in Jhalokati.

Polders reconstruction and reinforcement requires a selective approach. Also, large investments should be delayed until major uncertainty on intensity of future climate change is resolved or significantly narrowed.

Flexibility and learning has an economic value that should be taken into account in BCA. Calculation of an option value helps to quantify risk. In contrast to alternative risk metrics, Real Options Analysis offers a valuation methodology consistent with BCA. Moreover, application of ROA helps to build a flexible investment strategy, taking into account potential learning on climate change. An example of a corresponding decision tree is presented in Figure 37.

The decision tree in Figure 37 illustrates a dilemma between relocation of vulnerable population and protection of inundated lands. Relocation is scalable and could be scaled up in response to more severe climate or (and) in response to higher increase of productivity in agriculture and in the manufacturing sector.

Figure 37. Decision tree for adaptation interventions



Source: Summarized by the authors.

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Bangladesh, like most nations, faces a large number of challenges. What should be the top priorities for policy makers, international donors, NGOs and businesses? With limited resources and time, it is crucial that focus is informed by what will do the most good for each taka spent. The Bangladesh Priorities project, a collaboration between Copenhagen Consensus and BRAC, works with stakeholders across Bangladesh to find, analyze, rank and disseminate the best solutions for the country. We engage Bangladeshis from all parts of society, through readers of newspapers, along with NGOs, decision makers, sector experts and businesses to propose the best solutions. We have commissioned some of the best economists from Bangladesh and the world to calculate the social, environmental and economic costs and benefits of these proposals. This research will help set priorities for the country through a nationwide conversation about what the smart - and not-so-smart - solutions are for Bangladesh's future.

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