

RESEARCH ARTICLE

Impacts of sea level rise on economic growth in developing Asia

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Abstract: Global sea level rise (SLR) variations have undeniably begun to make an impact on highly vulnerable economies. These impacts of SLR are a key component of the projected economic damage of climate change, an important input to climate change policies and adaptive measures. This paper considers SLR projections and its impact on the economy and includes a consolidation of various related studies. Estimated global gross domestic product (GDP) loss by 2100 ranges from 0.3% to as high as of 9.3%. Climate change impact should be addressed at the global level through a locally focused effort where education and acceptance by all stakeholders are crucial and warranted. Further, this paper tackles several adaptive strategies as a response to SLR which include retreat, accommodation, and protection. The retreat strategy simulates that SLR causes the loss of inundated land and incurs planned relocation (migration) costs above a certain sea level. The accommodation strategy allows usage of vulnerable areas or land and limits damage by flood-proofing or raising structures. Finally, the protection strategy projects that land will be protected from SLR damage by sea walls or other barriers of a certain height. On the other hand, Diaz (2016) estimated a median adaptation cost from migration at 16% of GDP under the least-cost strategy by 2050. In general, the education of and the acceptance by the concerned local community will be crucial in the successful implementation of SLR adaptation strategies, notwithstanding parallel mitigation efforts on a global scale.

Keywords: sea level rise, climate change, economic growth

1 Introduction

The global sea level during the past few million years' ice age cycles has been varying by more than 100 meters (m). (According to IPCC^[1], the global sea level rose by about 120 m during the several millennia that followed the end of the last ice age (approximately 21,000 years ago) and stabilized between 3,000 and 2,000 years ago.) Over the last century, however, sea levels have been rising much faster than in other previous millennia. The National Aeronautics and Space Administration (NASA) reported that February 2016 had the highest increase in sea height variation at 74.8 millimeters (mm) since 1993 and the global mean sea level change is at 3.4 mm per year. Figure 1 shows the historical global average absolute sea level change. (Cumulative changes in sea level for the world's oceans, based on a combination of long-term tide gauge measurements and recent satellite measurements.)

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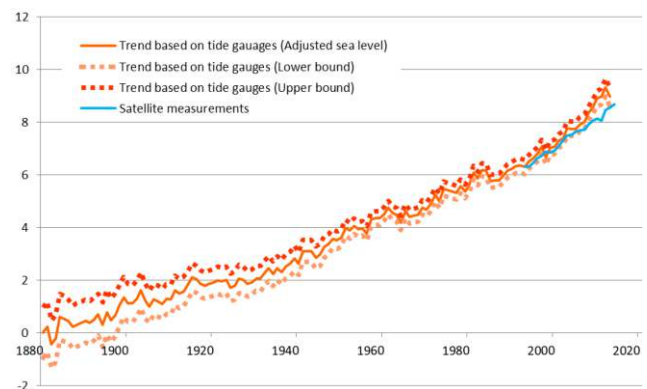


Figure 1. Global average absolute sea level change, 1880-2014 (inches)

Church and White^[6] estimate that the rise in global average sea level from satellite altimeter data is about 0.2 m from 1993 to 2009. Schaeffer *et al.*^[7] use a semi-empirical model, calibrated with sea level data of the past 100 years, and the resulting estimate is about 0.25 m lower with an unmitigated emissions scenario, but 0.15 m above a hypothetical scenario reducing global emissions to zero by 2016. The Intergovernmental Panel on Climate Change (IPCC) estimated that average global sea levels have increased by around 3 mm annually since the early 1990s and are expected to further increase from

0.75 m to 1.90 m during 1990-2100 as temperatures continue to rise. Recent literature^[8] projects 20th century global mean sea level estimates at 0.3-1.2 m using the different Representative Concentration Pathways (RCPs) scenarios. On the other hand, Mengel *et al.*^[9] recognize that the accelerating sea level rise (SLR) is mainly due to anthropogenic climate change and project an anthropogenic SLR of 0.28-1.31 m in 2100 for the different concentration scenarios.

SLR is caused by the ongoing global climate change such as thermal expansion of ocean waters and melting of land-ice due to higher ambient temperatures. Several studies confirm that increased air temperatures cause thermal expansion of oceans as they absorb 85% of the excess heat trapped by the atmosphere and were the main driver of global SLR for 75-100 years after the start of the industrialization.^[10-13] Vermeer and Rahmstorf^[14] also find a significant relationship between sea level and temperature over the period 1800-2000. Another significant factor that affects global SLR is the faster shrinking of land iceglaciers, ice caps, and ice sheets due to higher temperature.^[10,15] The rise in sea level is accelerating both globally and regionally in many places.

Figure 2 illustrates mean sea level trends of the People's Republic of China (PRC), India, Japan, Kiribati, the Philippines, and Singapore. Davao in the Philippines has the highest mean sea level trend at 5.32 millimeters per year (mm/yr) with a 95% confidence interval of +/-1.30 mm/yr based on monthly mean sea level data from 1948 to 2008, which is equivalent to a change of 0.5 m in 100 years. This is followed by Nagasaki in Japan at 2.2 mm/yr and Singapore at 1.53 mm/yr. Moreover, Strassburg *et al.*^[16] noted that Southeast Asia has one of the highest sea level trends observed by modern satellites and the long-term sea level trends will continue to be affected by global mean sea level rise occurring now and in the future.

Rapid SLR (more than 1 m per century) is adversely affecting the environment, especially the coastal areas. Coastal areas have been used extensively and will continue to increase through the 21st century,^[1] as various settlements were developed due to access for food and livelihood. (The Fourth IPCC Assessment Report (AR4) estimated that 23% of the world's population, or around 10 million people, live within 100 kilometers' distance of the coast. According to the World Resources Institute, in 1995, 39% of the world's population, or 2.2 billion people, lived on or within 100 kilometers of a seashore. Recent studies reveal that up to 600 million people live in low elevation coastal zones and 200 million people live within coastal floodplains.) Ciscar *et al.*^[17] highlighted that, among the most important sectors affected by cli-

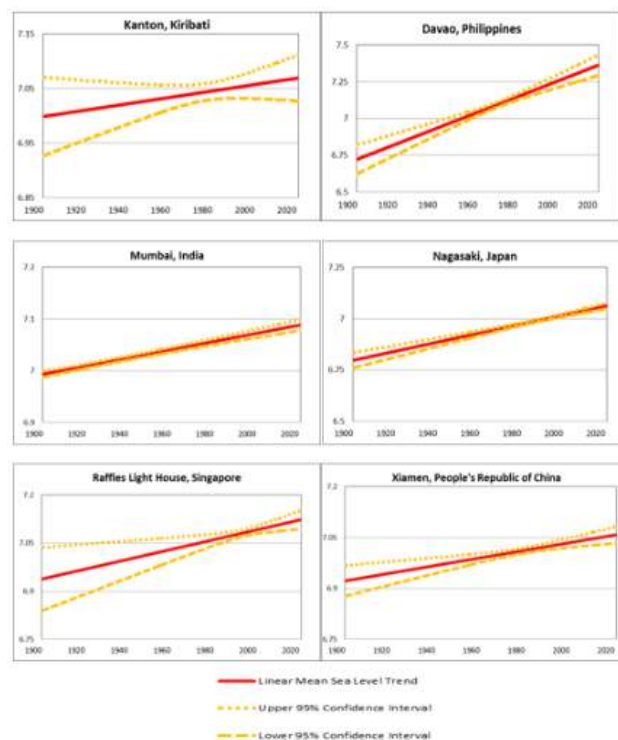


Figure 2. Mean sea level trends in developing Asia (meters)
 Note: Each graph represents a particular location where sea level rise (SLR) is being measured. The mean sea level trend for each location has a certain level of SLR measured in millimeters per year, with a 95% confidence interval based on monthly sea level data from a certain duration of time that is equivalent to a certain sea level change in 100 years.

mate change (such as agriculture, river floods, coastal systems, and tourism), coastal systems are the most negatively affected in all European regions due to increasing sea levels. In fact, Diaz^[18] stressed that coastal sector impacts from SLR are an important component of projected economic damage of climate change. Hauer *et al.*^[19] found that almost 13 million people may be living in vulnerable regions along coasts in the United States (US) by 2100 if sea levels rise by 1.8 m. Moreover, the most vulnerable to SLR are mostly small island states and atoll countries. An example close to the highlighted and anticipated impact of SLR are: one is Kiribati, an island in the Pacific, and another is the city-state of Singapore, where notably, the impact of SLR is slowly being felt in market and non-market areas.

According to the World Bank,^[20] Kiribati is one of the world's most vulnerable countries to climate change and extreme weather. Kiribati is one of the first Pacific islands that will be in danger of becoming uninhabitable due to climate change.^[21] Kiribati is composed of coral atolls and reef islands scattered across a swath of the Pacific Ocean and lies no higher than 1.83 m above sea level. With Kiribati's geographical situation, rising seas and in-

tensifying storms are threats not only to the people but also to their livelihoods, according to government's report to the United Nations. A study conducted by the World Bank^[20] reports that Tarawa, the capital of Kiribati, under the climate change scenarios could experience annual damages of about \$8 million–\$16 million. Moreover, inundation and storm surges can affect Tarawa's coast through shoreline displacement resulting from the rise in sea level (by 0.20.4 meters by 2050). Further, SLR can disrupt socioeconomic activities in Kiribati such as an increase in causeways destroyed, damaged coral reefs, and shoreline erosion. Thus, migration of communities is expected as land will be lost and freshwater supplies become critical. In fact, it has been reported that the Government of Kiribati has encouraged residents to consider moving abroad with job skills necessary to be employed.^[22]

Another small low-lying island-state that is worth noting is Singapore. The rise in sea level poses threats to Singapore as it lies only 15 meters (m) above the mean sea level, with about 30% of the island at less than 5 m above the mean sea level, according to Singapore's National Climate Change Secretariat (NCCS). Navaratnarajah^[23] relates SLR to increases of carbon emissions and temperature and notes that warming can cause Singapore's sea level to increase by 9.5 m, leaving 745,000 Singaporeans' homes submerged. Moreover, Ng and Mendelsohn^[24] examine the impact of SLR in Singapore and explore whether Singapore should defend its coast or allow it to be inundated. Based on their study, the annual cost of protecting Singapore's coasts is estimated to rise over time as the sea level rises and will range from \$0.3 million–\$5.7 million by 2050 to \$0.9 million–\$16.8 million by 2100. Depending on the SLR simulation, the present value of these costs ranges from \$0.17 million to \$3.08 million. Clearly, the regions or countries most vulnerable to SLR include atoll countries and small islands states like Kiribati and Singapore. Hence, there is a need for relevant discussions and consensus on how SLR will be dealt with through adaptation or mitigation.

Global SLR threatens not only the coastal communities as development continues but also national economies. The consequences of SLR can also lead to reduced growth and out-migration. As the sea level rises, there will be threats to food and water security, infrastructure, and public health and safety. Agricultural lands and traditional water sources will be compromised, bringing uncertainty of food and potable water sources. Infrastructure such as roads, bridges, and railways will also be exposed as the sea level rises. According to the Food and Agriculture Organization of the United Nations (FAO), fisheries and aquaculture provide livelihoods to 10%–12% of the world's population which means that healthy oceans rep-

resent jobs, food, and protection. This mounting pressure on existing links of people to economic resources will definitely have corresponding negative impacts on socioeconomic activities and consequently growth in the long run. Furthermore, low-lying and coastal areas will frequently experience more flooding which may threaten the existing public health infrastructure and the general safety of citizens, thus leading to human migration to high islands and continental sites. This paper surveys the potential impacts of SLR to economic growth, tourism, and migration, as well as the probable scenarios of SLR on economic activities for policy making and poverty alleviation in the long run. Moreover, it explores the various adaptive measures and the underlying cost to consider to combat SLR, especially for vulnerable countries, and their implications.

Section II focuses on and summarizes the effects of SLR on economic growth and various economic activities including the effect on tourism and migration. Climate change adaptation due to SLR is highlighted in section III, including the strategies that are important to consider. Sections IV and V present policy recommendations and conclusions, respectively.

2 The impacts of sea level rise

2.1 Economic growth

The growing evidence of the enormous global impact of rising temperatures on society warrants investigation into the magnitude of such climate impact economic activities. (Dell, Jones, and Olken^[25] and Burke, Hsiang, and Miguel^[26] are few of the studies that investigate and estimate the impact of rising temperature to the economy.) As the temperature increases, the global sea level rises as well. This firmly confirms the need to delve into the effects of SLR on economic activities, losses, and development in general. Hallegatte^[27] reveals that SLR largely affects economic growth and welfare at least on the regional scale and channels through the following: (i) the loss of land, (ii) the loss of infrastructure and physical capital, (iii) the loss of social capital and the additional cost from extreme events and coastal floods, and (iv) an increase in expenditure for coastal protection. Further, Hallegatte^[27] notes that SLR is a progressive and dynamic process and that it requires a continuous adaptation process in order to cope or readily react to it. Moreover, the complexity of SLR and how it can affect economic growth clearly pose a challenge for quantitative analysis in terms of measurement and actuality. The existing literature on the economic impacts of SLR borders on the investigation of its global and local "coastal effects," *i.e.*, countries along the coasts are most economically and

Table 1. Summary of sea level rise impact estimates on global economic growth

Author(s) and Title of Paper	Year Published	Period	Climate Scenarios	Sea Level Projections (meters)	Damage Cost (% of GDP)
Hinkel et al. Coastal Flood Damage and Adaptation Cost under 21st Century Sea Level Rise	2014	2000–2100	RCP 2.6	0.35	0.3–0.5
			RCP 8.5	0.74	1.2–9.3
Pycroft, Abrell, and Ciscar The Global Impacts of Extreme Sea Level Rise: A Comprehensive Economic Assessment	2015	2010–2100	A1B	0.5	0.15
			RAHM	1.12	0.33
			High	1.75	0.5

Notes: A1B is consistent with the A1B IMAGE scenario, which assumes a warming of 2.4°C by the 2050s and 3.8°C by the 2090s. RAHM is from Rahmstorf,^[31] where the sea level rises by 1.4 meters by 2100. RCP are the Representative Concentration Pathways. High is from Lowe and Gregory,^[31] where the sea level rise is projected to be 2 meters by 2100.

environmentally vulnerable and challenged.

Table 1 describes two recent SLR studies that deal with measuring its economic impact as a percentage of gross domestic product (GDP) under different scenarios and models used. Using sea level modeling techniques, SLR projections ranged from a low of 0.35 m under the RCP 2.6 scenario to as high as 1.75 m in 2100. The global impact estimate on GDP by SLR is, on average, from 0.15% to as much as 9.3% of global GDP. Pycroft, Abrell, and Ciscar^[28] even project global GDP loss of 0.5% under the highest SLR scenario, (According to Lowe and Gregory,^[29] the sea level will increase by 2 m by 2100.) with a loss of welfare (measured in equivalent variation) at 1.91% worldwide by 2100, which is equivalent to \$2.82 trillion by 2100. (Using the Diaz^[18] global GDP estimate of \$147.6 trillion under RCP 8.5.)

2.2 Migration

SLR is expected to bring significant changes in migration patterns in vulnerable areas. Future SLR is projected to reach 0.9 m by 2100^[32] to as high as 1.75 m under the high sea-level scenario in the 21st century.^[28] According to Perch-Nielsen,^[33] the impact of SLR would increase flood frequency, erosion, inundation, and rising water tables to vulnerable communities, creating risk to food security and livelihood of the population. However, Raleigh, Jordan, and Salehyan^[34] stress that international migration might be quite limited since less developed countries lack abilities to mitigate climate change and instead try to incorporate physical and social hazards into their livelihoods as their coping mechanism.^[35–38]

Pycroft, Abrell, and Ciscar^[28] estimate the impact of migration on GDP and find that the PRC, the Republic of Korea, and Indonesia have the highest estimated to-

tal impact among the region at a combined \$6 billion, or almost 10% of the world's estimates under the high scenario by 2080 (Table 2). Ericson *et al.*^[39] estimate that there are around 8.7 million people expected to be displaced by 2050 due to rising sea levels. ADB^[40] also reaches a similar conclusion, stating that SLR is projected to significantly impact the Pacific region, damaging infrastructure and human habitats. The ADB results are based on the IPCC Special Report on Emissions Scenarios (SRES) and are interpreted as percentage deviations from a baseline situation without projected changes in climate conditions. The two integrated assessment models Framework for Uncertainty, Negotiation and Distribution 3.6 (FUND3.6) and Policy Analysis of the Greenhouse Effect 09 (PAGE09) estimate the total costs of climate change as a percentage of GDP increase every year. (FUND3.6 is an integrated assessment model originally developed by Tol^[41] which aims to advise policy makers on the characteristics of an optimal policy rather than to evaluate the economic and climate consequences of proposed policies (ADB^[18]). PAGE09 is a new version of the PAGE integrated assessment model that values the impacts of climate change and the costs of policies to abate and adapt to it.^[42]) Estimates from FUND 3.6 indicate that costs range between 2.7% and 3.5% of annual GDP equivalent in 2050 and increase to 4.6%–10.9% by 2100. PAGE09 provides lower estimates of economic costs ranging between 2.2% and 2.8% of annual GDP equivalent in 2050 and higher estimates by 2100 ranging between 2.9% and 12.7% depending on the emissions scenarios. ADB^[18] finds that, regardless of which model is used, the results suggest the Pacific will be greatly affected by climate change by 2050 and losses are projected to rise over time under all scenarios, and would be largest with high emis-

sions scenarios.

Table 2. Migration impact estimates on developing Asia (\$ billion)

Region/Country	A1B	RAHM	High
China, People's Republic of	5.7	4.5	4.5
Korea, Republic of	0	3.8	1
Indonesia	0.1	0.6	0.5
India	0.7	0.5	0.6
Rest of South Asia	0.4	0.8	1.2
Rest of Southeast Asia	1.2	6.6	2.4
World	11	75	64

Notes: A1B is consistent with the A1B IMAGE scenario, which assumes a warming of 2.4°C by the 2050s and 3.8°C by the 2090s; RAHM is from Rahmstorf, where the sea level rises by 1.4 meters by 2100; RCP are the Representative Concentration Pathways; High is from Lowe and Gregory, where the sea level rise is projected to be 2 meters by 2100. While cumulative migration in high SLR scenarios is always higher, this research takes the average values for the 2070s, 2080s and 2090s. In some high SLR cases, e.g. the People's Republic of China, much migration has already occurred in earlier decades, so the additional migration in these three decades is lower in the high SLR scenarios than the A1B scenario.

2.3 Tourism

Based on IPCC,^[43] coastal tourism has been largest component of the global tourism industry. Burke *et al.*^[44] discovered that more than 100 countries benefit from the recreational value provided by their coral reefs, which contributed \$11.5 billion to global tourism. The tourism industry is one of the world's largest industries, accounting for about 9% of global GDP and provides jobs to people worldwide. The sector is particularly important for some of the world's poorest countries, especially some of the small island states.^[45]

Tourism is a low-lying fruit that any coastal community can take advantage of to promote domestic jobs. Thus, tourism is an important economic growth driver. In fact, the World Tourism Organization^[46] announced that 2015 international tourist arrivals grew by 4.4%, about 1.2 billion arrivals, almost reaching the projection of 1.6 billion by 2020. Many developing countries depend on tourism as a main driver of economic growth. However, climate change poses many challenges to the development of tourism and to the gains that tourism has already garnered in many coastal scenic cities and communities.

An appropriate example of the impact of SLR on tourism is the Maldives. Some researchers find that the country is very vulnerable to SLR and that it faces the very real possibility of the majority of its land area being inundated by 2100. (See Tol;^[47] United Nations Office for the Coordination of Humanitarian Affairs;^[48] Pfeffer, Harper, and O'Neel;^[49] Anthoff, Nicholls, and Tol.^[50]) According to Climate Hot Map,^[47] the white sand beaches and extensive coral reefs of its 1,190 islands draw more than 600,000 tourists annually. The Maldives relies on its marine life and beaches to sustain a tourism industry that contributes over 30% of total GDP.

Moreover, Pfeffer, Harper, and O'Neel^[49] estimate that

the sea level could rise 0.8–2.0 m, depending on the amount of carbon emissions released. Their study revealed that the Maldives will experience a rise in sea level of 0.50 m by around 2100 and would lose 77% of its land area by the end of the century.^[47] If the sea level were to rise by 1.0 m and no further coastal protection mechanism is instituted, the country would be nearly completely inundated by about 2085.^[51] This obviously paints a stark future for the Maldives.

There is a lingering uncertainty in the tourism sector amid the anticipated threats of climate change, particularly the impact of SLR. While there is a large amount of literature on climate impacts, there is uncertainty surrounding tourist behavior and it is difficult to draw overarching conclusions due to lack of consistency and, often, conflicting information.^[52] However, these issues clearly point to the obvious urgency to prepare and adjust to the impacts of SLR on global tourism.

3 Sea level rise adaptation strategies

With the urgent need to address extreme weather and climate change-related events such as SLR, adaption strategies to manage the various risks are very crucial to how different countries that are vulnerable to these specific risks connect and become ready and resilient to the economic impacts such events bring.

Dronkers *et al.*^[53] outline several options to adapt for SLR and divide these into three categories: retreat, accommodation, and protection.

3.1 Retreat

Retreat involves no effort to protect the land from the sea or refers to the planned movement of the population from hazard-prone sections of the coast,^[30] and, in extreme cases, the entire area may be totally abandoned. Researchers often emphasize how people in degraded or disaster-prone areas incorporate risk into their livelihoods through individual and community coping mechanisms. In this case, climate migration is used as a coping strategy and is a frequent response to both economic and environmental hardship.^[34]

Generally, climate migration is presented as one of the most dramatic consequences of global warming. However, empirical research shows that migration can be a strategy if the affected population is given the means to do so in order to adapt to the degradation of their immediate environment.^[55] Results by Diaz^[34] present economies with significant adaptation costs from migration due to SLR, and median spending is projected to be about 16% of 2050 GDP. Nauru has the highest adaptation cost at 40%, while Tonga has the lowest at 2%. It is also fit-

ting to note that the Maldives (31%); Hong Kong, China (29%); and Tuvalu (22%) have considerably huge costs compared to other developing Asian economies included.

In general, Dronkers *et al.*^[53] describe the different implications for the “retreat” strategy. This specific strategy will have obvious environmental impacts through ecosystems migrating landward as sea levels rise and thus potentially remaining largely intact, although the total area of wetlands would decline. Economic implications include that coastal landowners and communities would suffer from loss of property, resettlement costs, and the costs of rebuilding infrastructure. Resettlement could create major problems and is by and large difficult socially as it could lead, among others, to language barriers, racial and religious discrimination, and difficulties obtaining employment. Even when they feel welcome, the disruption of families, friendships, and traditions can be stressful.

3.2 Accommodation

Accommodation refers to the continued use of land at risk with no attempts to prevent the land from being flooded. In this strategy, the impacts to humans are minimized by adjusting the use of the coastal zones via flood-resilience measures.^[6] The community, in order to adapt, will build emergency flood shelters, elevate buildings on piles, convert agriculture to fish farming, or grow flood- or salt-tolerant crops.^[56] Other additional strategies are early warning and evacuation systems, improved drainage systems, and hazard insurance points under the accommodation strategy.^[57]

There have been listed economic benefits to inundation and flooding under the accommodation strategy as it provides opportunities for land to be used for new purposes. Dronkers *et al.*^[53] suggest changing property values, increasing damage from storms, and costs for modifying infrastructure as among some of the economic impacts under accommodation.

3.3 Protection

Protection strategies normally refer to construction of dikes and sea walls. Hillen *et al.*^[58] give a reference cost of \$6.02 million per kilometer of coastline per vertical meter of protection. Diaz^[18] posts the results of the protection strategy, and among the developing Asian economies in the estimates, Tonga (65%), Viet Nam (52%), Sri Lanka (48%), the PRC (37%), Bangladesh (33%), India (31%), and Singapore (30%) have the highest protection costs. (Total protection costs (as percentage of 2050 GDP): Bangladesh, 33%; Cambodia, 0%; PRC, 37%; Fiji, 0%; Georgia, 0%; Hong Kong, China, 0%; India, 31%; Indonesia, 8%; Japan, 19%; Kiribati, 0%;

Malaysia, 12%; Maldives, 5%; Marshall Islands, 0%; Federated States of Micronesia, 2%; Myanmar, 2%; Nauru, 0%; Pakistan, 2%; Palau, 0%; Papua New Guinea, 0%; Philippines, 7%; Samoa, 0%; Singapore, 30%; Solomon Islands, 0%; Sri Lanka, 48%; Thailand, 31%; Timor-Leste, 0%; Tonga, 65%; Tuvalu, 20%; Vanuatu, 0%; and Viet Nam, 52%.) Protection from SLR can be cost-effective for richer countries vulnerable to SLR rather than poorer countries threatened by rising sea levels.

Again, Dronkers *et al.*^[53] are of the view that, under the protection option, a much larger proportion of these ecosystems would be lost; hence, protective structures should be designed to avoid adverse environmental impacts. On the economic impact of climate change, countries and communities would face the costs for the necessary structures that would protect economic development but could adversely affect economic interests that depend on recreation and fisheries. The estimated total cost of defenses would amount to about \$500 billion over the next 10 years (which only includes the marginal or added costs and is not discounted). Thus, the overall protection costs will be considerably higher.^[53] Therefore, decisions should be based on both long-term and short-term costs and benefits to ensure sustainable coastal development.

Moreover, the loss of traditional environments which normally sustain economies and cultures and provide for recreational needs could disrupt family life and create social instability under the protection scenario. Regardless of the response eventually chosen, community participation in the decision-making process is the best way to ensure that these implications are recognized. Again, the protection efforts may need regional and global cooperation to maximize their impact.

More importantly, it is crucial to distinguish and identify the various types of costs associated with SLR. Typically, SLR costs are either adaptation cost, which is the cost of protecting the coastal regions or the cost of moving people to higher regions, and the economic costs brought about by the flooding or inundation of land. Diaz^[18] segregated the different SLR costs into either protection, retreat, or flood costs, covering what are typically the types of SLR costs using new open-source optimization model, Coastal Impact and Adaptation Model (CIAM). The CIAM assesses coastal impacts by disaggregating the least-cost adaptation decisions and determines an efficient strategy for adaptation at the local level. Thus, the advantage is that it not only produces aggregate or global cost levels but also describes the impacts at a local level, where retreat is often defined as a more cost-efficient adaptation strategy than merely protection.

Table 3 outlines the national adaptation cost estimates

Table 3. Sea levels rise impact estimates on selected countries in developing Asia and the Pacific

Country	NPV (\$ billion)	2050 Total (% of GDP)	Protection (% of total)	Retreat (% of total)	Flood (% of total)	Residual (% of total)
Marshall Islands	1.2	7.6	0	17	0	83
Maldives	9.8	7.5	50	31	0	64
Tuvalu	0.1	4.6	0	18	0	82
Kiribati	0.5	4.1	0	20	0	80
Tonga	0.9	2.5	65	2	0	32
Palau	0.3	1.9	0	15	0.1	85
Micronesia, Federated States of	0.6	1.8	2	20	0.1	77
Nauru	0.1	1.7	0	40	0	60
Median Country	1.1	0.1	0	16	0	79

Notes: GDP = gross domestic product, NPV = net present value.

of selected countries in Developing Asia and the Pacific for the least-cost strategy in RCP8.5. Note that the columns from left to right describe the net present value (NPV) of SLR impacts from 2010 to 2100 and the annual cost in 2050 as a percentage of national GDP, first as total cost and then decomposed into protection cost, (Protection construction costs are assumed to be linear to coastline length and quadratic to sea wall height, reflecting the increasing need for a structural foundation. There is also an annual maintenance cost and an opportunity cost to the occupied land.) retreat cost, (Gradual retreat incurs adaptation costs associated with redeveloping and relocating the affected people and infrastructure further inland.) expected flood cost, (The expected cost of flooding is computed as the integral overall sea level extremes that exceed the current adaptation level.) and the residual cost of inundation and wetland loss. (The incremental inundation of unprotected coastal land causes damage based on the extent of national land endowment lost and assumed to correspond in value to interior land. Wetland loss is an increasing function in the annual rate of SLR; permanent loss occurs when the rate exceeds a critical threshold for vertical accretion or if protection is chosen, as this physically prevents the natural migration of inhabitants.) Many small Pacific countries are included in the top 15 national adaptation cost estimates for SLR. The PRC, Indonesia, Malaysia, and India belong to the top 15 countries that have high national adaptation cost estimates based on NPV between 2010 and 2100.

4 Policy recommendations

SLR and its impact on economic efficiency have been studied, and the probable impact on global GDP is known. The CIAM has also projected local or country-level im-

pacts that are very important to consider moving on with adaptation strategies.

On the global scale, the Institute on Science for Global Policy,^[59] through its Climate Change Program put forward how to mitigate and/or adapt to the anticipated impact of changing climates (*e.g.*, drought, SLR, severe storms, warming seas, and oceans). In particular, the ISGP recommends the following for issues concerning SLR. Recognizing the historic records and current projections indicating that the sea level can rise significantly within a short period of time (*e.g.*, life cycle of a mortgage), it is of vital importance for the economic health and sustainability of the world that policy makers at all levels develop long-term anticipatory plans that

(i) create metrics-driven benchmarks for the implementation of policy actions;

(ii) identify strategies for addressing the overlapping issues of health, freshwater, food, shelter, infrastructure, and safety; and

(iii) consider the potential relocation and/or restructuring of affected communities. Policies need to be developed through extensive community education and engagement, and need to consider social, environmental, and economic issues related to societal inequities and vulnerable communities.

Dronkers *et al.*^[53] put forward three aspects of policy making regarding SLR: (i) national coastal planning; (ii) international cooperation; and (iii) research, data, and information. In the area of localized coastal planning, coastal nations are encouraged to implement comprehensive coastal zone management plans. To increase the likelihood of success against SLR, coastal areas at risk should be identified and known clearly. More importantly, countries should ensure that coastal development does not increase vulnerability to SLR. The different as-

pects required to help coastal development to be environmentally aligned to coastal protection plans should be secured. Moreover, emergency preparedness, coastal response mechanisms, and disaster relief schemes should be reviewed and further strengthened.

In international cooperation, a continuing effort to put in the forefront the effects and potential impact of SLR needs to be maintained. Technical assistance and capacity-building measures should be implemented to help better prepare vulnerable nations. Furthermore, international organizations should continuously support local efforts to contain population growth in coastal areas. Finally, research, data, and information dissemination should continuously be made crucial in the campaign to help vulnerable countries and other stakeholders protect themselves from the various impacts of SLR. SLR research and studies should be strengthened and maintained. The network of global ocean observatories should be continuously developed and seriously implemented. Data and information on sea level change and various adaptive options should be made widely available.

The application at local levels where SLR impacts so far are being felt by communities is important and crucial to the success of these recommendations. Note that the “localization” of education campaign and the relevance and accuracy of data to educate the local communities will play a huge role in making the SLR reality a personal responsibility of each person eventually affected by climate change through SLR.

5 Conclusions

This survey of SLR and its economic impacts provides a clear window to the effects of SLR on future economic activities, not just globally but also particularly on some developing Asian countries. The global perspective of some of the models considered here provide insight into the possible losses brought about by the increasing sea level. By 2100, economic losses may account for as much as 9.3% of global GDP and, as discussed, may vary by country.

Developing Asian countries that have been widely studied were included to provide a local context for the discussions. Specifically, the examples of Kiribati and Singapore have been highlighted to bring to the fore the immediate impact of SLR as it is now. A locally focused adaptation strategy is very important as every single member of the population directly affected by SLR will have to take responsibility in one way or another. The education of and the acceptance by the concerned local community will be crucial in the successful implementation of SLR adaptation strategies, notwithstanding parallel mitigation

efforts by everyone. The local authorities take on the role of emphasizing the need for long-term coastal adaptation strategies as central to addressing SLR.

The effects of SLR are undeniable. Low-lying countries are now experiencing what the scientists and other scholars have widely studied and researched. Thus, international efforts to put the impacts and potential effects of SLR in the forefront are important and need to be continued. Technical assistance and capacity-building measures should be carried out to help prepare the most vulnerable economies for catastrophic impacts. World-wide efforts, through international organizations, must continue to support the localization of efforts to alleviate the impacts of climate change through SLR. Research and consequently the data that it will further produce should be made available and information dissemination intensified for vulnerable countries and other important stakeholders to be protected from the impacts of SLR.

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