IMPACTS OF SEA LEVEL RISE ON ECONOMIC GROWTH IN DEVELOPING ASIA

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ASIAN DEVELOPMENT BANK

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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% (Hinkel et al. 2014; Pycroft, Abrell, and Ciscar 2015). 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) estimates 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.

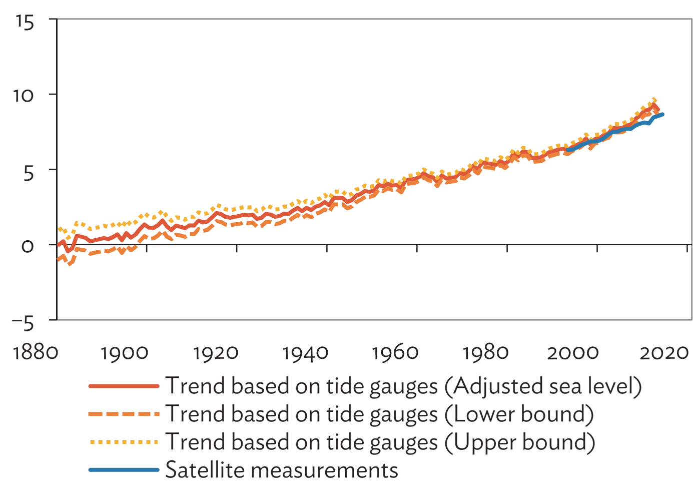
Keywords: climate change, economic growth, sea level rise

JEL codes: Q50, Q54

I. INTRODUCTION

The global sea level during the past few million years' ice age cycles has been varying by more than 100 meters (m).[1] Over the last century, however, sea levels have been rising much faster than in other previous millennia. The National Aeronautics and Space Administration 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.[2] Figure 1 shows the historical global average absolute sea level change.[3]

Figure 1: Global Average Absolute Sea Level Change, 1880–2014
(inches)



Note: Data sourced from Commonwealth Scientific and Industrial Research Organisation (2015) update to data originally published in Church, John A., and Neil J. White. 2011. "Sea Level Rise from the Late 19th to the Early 21st Century." *Surveys in Geophysics* 32 (4): 585–602. www.cmar.csiro.au/sealevel/sl_data_cmar.html; National Oceanic and Atmospheric Administration. 2015. Laboratory for Satellite Altimetry: Sea Level Rise. www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/LSA_SLR_timeseries_global.php (accessed 4 July 2016).
Source: Environmental Protection Agency. Climate Change Indicators in the United States. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level (accessed 22 June 2016).

Church and White (2011) 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. (2012) 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) 2013 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

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1 According to IPCC (2007), 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.

2 National Aeronautics and Space Administration. https://www.nasa.gov/ (accessed July 2016).

3 Environmental Protection Agency estimates the cumulative changes in sea level for the world's oceans, based on a combination of long-term tide gauge measurements and recent satellite measurements.

rise. Recent literature (Kopp et al. 2014) 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. (2016) 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 (Cazenave and Llovel 2010; Levitus et al. 2009; Levitus, Antonov, and Boyer 2005; Levitus et al. 2001). Vermeer and Rahmstorf (2009) 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 ice—glaciers, ice caps, and ice sheets—due to higher temperature (Cazenave and Llovel 2010; Lombard et al. 2005). 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. (2015) 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.

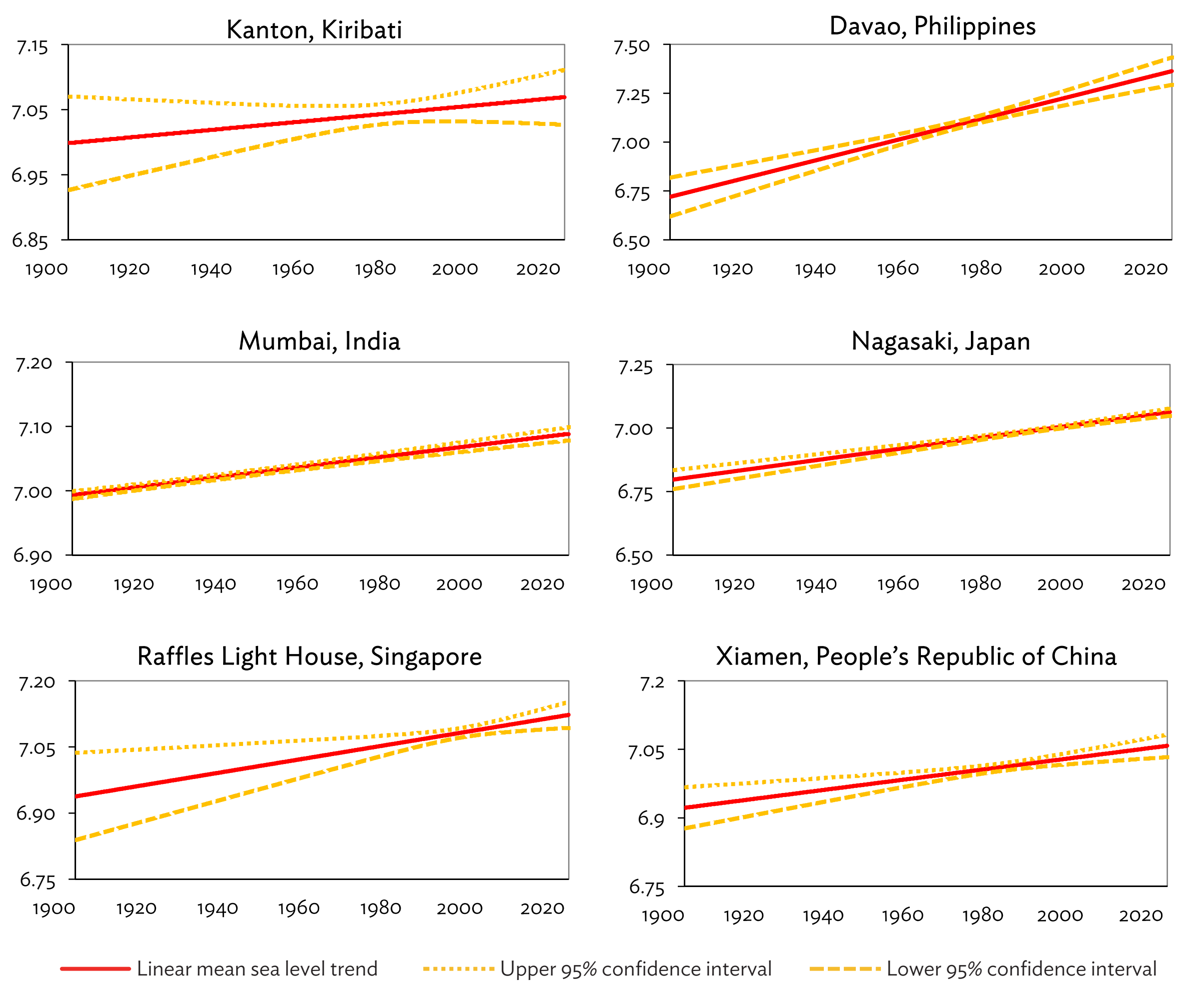
Rapid SLR (more than 1 m per century) is adversely affecting the environment, especially the coastal areas. Coastal areas have been used extensively and will continue to increase through the 21st century (IPCC 2007), as various settlements were developed due to access for food and livelihood.[4] Ciscar et al. (2012) highlighted that, among the most important sectors affected by climate 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 (2016) stressed that coastal sector impacts from SLR are an important component of projected economic damage of climate change. Hauer et al. (2016) found that almost 13 million people may be living in vulnerable regions along coasts in the United States 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 nonmarket areas.

According to the World Bank (2013), 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 (Decloitre 2010). 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

[4] The Fourth IPCC Assessment Report (IPCC 2007) estimated that 23% of the world's population, or around 10 million people, live within 100 kilometers' distance of the coast. Based on the World Resources report, 39% of the world's population, or 2.2 billion people, lived on or within 100 kilometers of a seashore (UNDP et al. 2000). Recent studies reveal that up to 600 million people live in low elevation coastal zones and 200 million people live within coastal floodplains.

level. With Kiribati's geographical situation, rising seas and intensifying 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 (2013) 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 0.2–0.4 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 (*New York Times* 2016).

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.
Source: National Oceanic and Atmospheric Administration. 2016. Tides and Currents. https://tidesandcurrents.noaa.gov/sltrends/globalregional.htm (accessed 22 June 2016).

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 (2015) 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 (2005) 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 (2014), fisheries and aquaculture provide livelihoods to 10%–12% of the world's population which means that healthy oceans represent 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.

II. THE IMPACTS OF SEA LEVEL RISE

A. Economic Growth

The growing evidence of the enormous global impact of rising temperatures on society warrants investigation into the magnitude of such climate impact on economic activities.[5] 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. Hallegate (2012) reveals that SLR

[5] Dell, Jones, and Olken (2012) and Burke, Hsiang, and Miguel (2015) are few of the studies that investigate and estimate the impact of rising temperature to the economy.

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, Hallegate (2012) 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 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 (2015) even project global GDP loss of 0.5% under the highest SLR scenario,[6] with a loss of welfare (measured in equivalent variation) at 1.91% worldwide by 2100, which is equivalent to $2.82 trillion by 2100.[7]

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

GDP = gross domestic product.
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 (2007), where the sea level rises by 1.4 meters by 2100. RCP are the Representative Concentration Pathways. High is from Lowe and Gregory (2010), where the sea level rise is projected to be 2 meters by 2100.
Sources: Jochen Hinkel, Daniel Lincke, Athanasios T. Vafeidis, Mahé Perrette, Robert James Nicholls, Richard S. J. Tol, Ben Marzeion, Xavier Fettweis, Cezar Ionescu, and Anders Levermann, 2014. "Coastal Flood Damage and Adaptation Costs under 21st Century Sea Level Rise." *Proceedings of the National Academy of Sciences of the United States of America* 111(9): 3292–3297. Jonathan Pycroft, Jan Abrell, and Juan-Carlos Ciscar. 2015. "The Global Impacts of Extreme Sea Level Rise: A Comprehensive Economic Assessment." *Environmental Resource Economics*. doi: 10.1007/s10640-014-9866-9

B. 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 (IPCC 2001) to as high as 1.75 m under the high sea-level scenario in the 21st century (Pycroft, Abrell, and Ciscar 2015). According to Perch-Nielsen (2004), 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 (2008) stress that international migration might be quite limited since less developed

[6] According to Lowe and Gregory (2010), the sea level will increase by 2 m by 2100.
[7] Using the Diaz (2016) global GDP estimate of $147.6 trillion under RCP 8.5.

countries lack abilities to mitigate climate change and instead try to incorporate physical and social hazards into their livelihoods as their coping mechanism (Mula 1999; Maxwell 1999; Meze-Hausken 2000; Findley 1994).

Pycroft, Abrell, and Ciscar (2015) estimate the impact of migration on GDP and find that the PRC, the Republic of Korea, and Indonesia have the highest estimated total 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. (2006) estimate that there are around 8.7 million people expected to be displaced by 2050 due to rising sea levels. ADB (2013) 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 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.[8] Estimates from FUND3.6 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 (2013) 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 emissions scenarios.

Table 2: Migration Impact Estimates on Developing Asia
($ billion)

Region/Country	A1B	RAHM	High
People's Republic of China	5.7	4.5	4.5
Republic of Korea	0.0	3.8	1.0
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	**11.0**	**75.0**	**64.0**

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 (2007), where the sea level rises by 1.4 meters by 2100; RCP are the Representative Concentration Pathways; High is from Lowe and Gregory (2010), 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.
Sources: Jonathan Pycroft, Jan Abrell, and Juan-Carlos Ciscar. 2015. "The Global Impacts of Extreme Sea Level Rise: A Comprehensive Economic Assessment." *Environmental Resource Economics*. doi: 10.1007/s10640-014-9866-9

[8] FUND3.6 is an integrated assessment model originally developed by Tol (1997) 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 2013). 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 (Hope 2010).

C. Tourism

Based on IPCC (2014), coastal tourism has been the largest component of the global tourism industry. Burke et al. (2011) 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 (Nicholls 2014).

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 (UNWTO 2016) 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.[9] According to Climate Hot Map, 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 (2008) estimate that the sea level could rise 0.8–2 m, depending on the amount of carbon emissions released. Their study revealed that the Maldives will experience a rise in sea level of 0.5 m by around 2100 and would lose 77% of its land area by the end of the century (Tol 2007). If the sea level were to rise by 1 m and no further coastal protection mechanism is instituted, the country would be nearly completely inundated by about 2085 (Anthoff, Nicholls, and Tol 2010). 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 (IPCC 2013). However, these issues clearly point to the obvious urgency to prepare and adjust to the impacts of SLR on global tourism.

III. 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. (1990) outline several options to adapt for SLR and divide these into three categories: retreat, accommodation, and protection.

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[9] See Tol (2007); United Nations Office for the Coordination of Humanitarian Affairs (2007); Pfeffer, Harper, and O'Neel. (2008); Anthoff, Nicholls, and Tol (2010).

A. 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 (Alexander, Ryan, and Measham 2012), 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 (Raleigh, Jordan, and Salehyan 2008).

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 (Gemenne 2010). Results by Diaz (2016) 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 fitting 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. (1990) 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 societally 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.

B. 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 (Nicholls 2011). 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 (Knecht 1975). Other additional strategies are early warning and evacuation systems, improved drainage systems, and hazard insurance points under the accommodation strategy (Sterr, Klein, and Reese 2003).

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. (1990) suggest changing property values, increasing damage from storms, and costs for modifying infrastructure as among some of the economic impacts under accommodation.

C. Protection

Protection strategies normally refer to construction of dikes and sea walls. Hillen et al. (2010) give a reference cost of $6.02 million per kilometer of coastline per vertical meter of protection. Diaz (2016) 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.[10] 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. (1990) 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 (Dronkers et al. 1990). Therefore, decisions should be based on both long-term and short-term costs and benefits to ensure sustainable coastal development.

Moreover, the degradation of environment could disrupt family life and create social instability under the protection scenario and community participation in the decision-making process is the best way to ensure that these implications are recognized, regardless of the response eventually chosen (Dronkers, et al 1990). 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 (2016) 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 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 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, retreat cost, expected flood cost, and the residual cost of inundation and wetland loss.[11] Many small Pacific countries are included in the top 15 national adaptation cost estimates for SLR. The PRC, Indonesia,

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[10] Diaz (2016) also estimated total protection costs (as percentage of 2050 GDP) for the following economies: 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%.

[11] 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. Gradual retreat incurs adaptation costs associated with redeveloping and relocating the affected people and infrastructure further inland. The expected cost of flooding is computed as the integral overall sea level extremes that exceed the current adaptation level. 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 (Diaz 2016).

Malaysia, and India belong to the top 15 countries that have high national adaptation cost estimates based on net present value between 2010 and 2100.

Table 3: Sea Level 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	0.0	17.0	0.0	83.0
Maldives	9.8	7.5	50.0	31.0	0.0	64.0
Tuvalu	0.1	4.6	0.0	18.0	0.0	82.0
Kiribati	0.5	4.1	0.0	20.0	0.0	80.0
Tonga	0.9	2.5	65.0	2.0	0.0	32.0
Palau	0.3	1.9	0.0	15.0	0.1	85.0
Federated States of Micronesia	0.6	1.8	2.0	20.0	0.1	77.0
Nauru	0.1	1.7	0.0	40.0	0.0	60.0
Median Country	1.1	0.1	0.0	16.0	0.0	79.0

GDP = gross domestic product, NPV = net present value.
Source: Diaz, Delavane B. 2016. “Estimating Global Damages from Sea Level Rise with the Coastal Impact and Adaptation Model (CIAM).” *Climatic Change* 137 (1): 143–56. doi:10.1007/s10584-016-1675-4

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

On the global scale, the Institute on Science for Global Policy (ISGP 2015), 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. (1990) 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 aspects 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.

V. 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. Worldwide 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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Impacts of Sea Level Rise on Economic Growth in Developing Asia

This paper examines the impact of global sea level rise (SLR) on the economic growth, migration, and tourism from various empirical studies and consolidates several sea level projections by 2100 under different scenarios. The paper points out that the regions or countries most vulnerable to SLR include atoll countries and small islands states like Kiribati and Singapore. In addition, it tackles several adaptation cost estimates for selected countries in developing Asia and summarizes adaptive strategies and mitigation as a response to SLR which include retreat, accommodation, and protection. The paper also presents policy recommendations for developing Asia to cope with increasing sea levels.

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