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Delta Economics and Sustainability

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8.1 Introduction

Deltas are exposed to multiple climatic and environmental factors such as sea-level rise, subsidence, storm surge and temperature and rainfall changes. These environmental risks frequently translate into harm to populations, depending on the sensitivity of the economic activity on which populations depend. Economic characteristics are, of course, heterogeneous across deltas. In absolute terms, the deltas located in East and South-east Asia, Gulf of Mexico, and the deltas of the rivers Rhine, Nile and Parana have a higher GDP per capita compared to the economies in which they are located. The opposite is found in deltas located in less developed regions and in Africa in particular. Developed regions often have significant assets that indicate the financial capacity to cope with environmental change (Tessler et al. 2015). Consequently, regions

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with significant economic activity and infrastructure have been commonly designated as having low vulnerability to environmental risks as investing in infrastructure represents a major element of adaptive capacity (Engle 2011; Tessler et al. 2015).

The economies of deltas are heterogeneous in relation to their structure and evolution. The contribution of agriculture and fisheries to the GDP in deltas located in lower income countries is in general higher than in industrialised countries. Activities such as transportation, tourism, and in some cases oil and gas extraction are present across most deltas to varying extents. While the size and structure of delta economies are, in general, stable, some deltas in emerging economies are growing and diversifying rapidly. This is the case for the Bangladeshi section of the Ganges-Brahmaputra-Meghna (GBM) Delta. Some other delta regions such as the Mekong within Vietnam are, by contrast, shrinking in relation to the economy of the rest of the country.

The evolution of deltas in the Anthropocene era is highly influenced by economic and environmental dynamics at different scales. A significant challenge to deltas is how different potential climate futures affect economic options and pathways and how these in turn affect vulnerability and sustainability, the availability of jobs and livelihoods, and potential population movements in the wider regions. In this chapter

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the current and potential future economies of the GBM, Mahanadi and Volta Deltas are therefore analysed. Possible economic trajectories under climate change through macro-scale economic model and scenario simulations, highlighting both the economic activities and the labour implications of diverse futures, are explored. The chapter also introduces a framework to assess the economic impacts of climate change on individual deltas (as defined in Chapters 2–4) and presents summary findings and conclusions on the future of the deltas in a changing environment.

8.2 The Current Socio-Economic Context of Deltas

Analysing discrete geographical regions within national economies is often restricted by the availability of detailed data on economic activities, not least when some parts of the economy involve informal transactions and labour markets. National statistical institutes of all countries report on a regular basis the main economic aggregates and structure of their economies, as well as some economic indicators at sub-national level. The latter information is often limited and reporting units, provinces or districts, do not necessarily match the geographical area of interest. Furthermore, in some cases such as the GBM Delta, deltas cross national boundaries. While it is desirable to address transnational deltas as a single unit, macroeconomic analysis usually differentiates between the countries' economic systems because they are governed by distinct political, institutional and cultural rules. The circulation of goods, labour and capital are also constrained by geopolitical borders.

The first step to understand the current socio-economic context of deltas consists of compiling relevant information available for the administrative regions within the delta from economic accounts, census and statistics on employment, trade, agriculture and forestry and fishing. This information is used to develop multiregional input-output (MRIO) tables for each delta (see Cazcarro et al. 2018 for methods and data sources). The MRIO table represents the socio-economic structure of the country where it is located, divided into the delta and non-delta parts of the economy. It describes the flows of goods and services

between all the individual sectors of the delta and non-delta regions and the use of goods and services by final users, quantified in monetary terms. The distinction between the delta and non-delta is especially relevant for the study of labour and populations movement, since decisions by individuals to relocate across economic sectors and places are primarily driven by differences in the economic conditions of delta and non-delta areas. The MRIO tables are also used to analyse the biophysical and socio-economic conditions and change within deltas. Combining a Computable General Equilibrium (CGE) model with changes in the provision of natural resources, for example, reveals their potential effect on the economies of the deltas and linked regions, and how this in turn affects economic vulnerability and sustainability in these regions.

For the deltas analysed, the MRIO tables reveal the structure of the economies of the delta in relation to the rest of the country. For example, the Bangladesh GBM represents one quarter of the economy of Bangladesh. The Volta represents, by contrast, only 3.5% of the economy of Ghana, while the deltas in India are a small fraction of the national economy. These differences are also reflected in terms of income per capita. In India and Ghana, the GDP per capita (measured in purchasing power parity) is lower in the delta than in the non-delta region suggesting that deltas are economically marginalised and are not growth poles within those countries. In Bangladesh, by contrast, the delta has a GDP per capita higher than the rest of the country. These descriptions are dependent, inevitably, on the presence or absence of large urban centres within the deltas: in the Bangladesh case, the higher GDP per capita is explained by the inclusion of Chattogram (formerly known as Chittagong) and Khulna cities within the region.

Differential income levels in delta and non-deltas areas and the size of the economies of both regions partially explain migration patterns across the deltas, as discussed in Chapter 7. Of the deltas analysed here, the lowest GDP per capita appears in the Volta Delta (USD 1048 compared to USD 1215 per capita nationally); GDP per capita in the Indian deltas is substantially greater being USD 1958 per capita in the Mahanadi Delta and USD 2347 per capita in the Indian section of the GBM (also termed the Indian Bengal Delta [IBD]). In both cases though, the average income per capita in the delta remains

lower than for the whole country (USD 3172 per capita). Conversely, in Bangladesh the GDP per capita in the delta (USD 1607) is notably higher than in the whole country (USD 1444 per capita).

The MRIO tables also show the sectoral contribution to GDP. Generally, economies in which a high share of the GDP is linked to sectors whose activity relies on environmental conditions, such as agriculture or fishing, are more likely to suffer the impacts of climate change. Figure 8.1 shows the sectoral structure of the GDP and the employment in the deltas; the tertiary sector is revealed as the main source of income in all deltas. In the three Asian deltas the contribution of services, trade and transportation represents more than half of the total GDP of the economy; in the Volta, while lower, they still contribute 40%. However, the contribution of the primary sector remains significant, ranging between 16 and 29%. The majority of the primary sector contribution corresponds to agriculture, with fisheries making a more

Fig. 8.1 Percentage distribution of GDP and employment by sector and delta in 2011

modest contribution (3–4% of GDP, except in the Volta where it represents 7%). In the Bangladesh GBM the construction sector is relatively high compared to the other delta areas (15%), while industrial activities such as transformation of agricultural goods in the food industry or salt-mining are especially relevant in the Volta (almost 20%). In terms of employment, however, the role of the primary sector in the economy is more relevant than in terms of GDP. The share of the employment engaged in the primary sector ranges from 32% in the IBD to 58% in the Mahanadi. This difference is the consequence of the low productivity of the agricultural sector, in which subsistence production dominates, compared to other economic activities.

In addition to the information shown in Fig. 8.1, the MRIO tables can be used to provide some insights on the importance of each sector in the economy from a systemic view (i.e. including information on the economic activities indirectly linked through supply-chains). In this sense, a way of measuring the relevance of the economic activities exposed to the impacts of climate changes, such as agriculture, is the measurement of the potential impact, in terms of GDP, of their hypothetical disappearance. This impact, which includes both the direct GDP loss in the sector that hypothetically disappears and the cascading or indirect effects in other sectors, is computed using the Hypothetical Extraction Method (Strassert 1968; Meller and Marfán 1981; Cella 1984; Clements 1990). This method hypothetically extracts a sector from an economic system and examines the influence of this extraction on other sectors in the economy. For the Mahanadi Delta, where agriculture is not well-integrated with other sectors, apart from the (hypothetical) direct loss within the sector itself (17% of the GDP), the effect on GDP from other sectors would be relatively low (0.36% of the total Delta GDP). In the IBD direct losses would amount to 15% of the GDP and, as integration is slightly higher, the hypothetical indirect loss in other sectors would be greater (1.23% of the total Delta GDP). In the Bangladesh GBM, direct losses would total 12% of the GDP and indirect would go above 5% of the GDP. The effect is greatest in the Volta Delta where there is a potential direct and indirect reduction in GDP of around 22% and 8% respectively. In the Volta Delta, the relatively higher indirect impact is linked to the

relevance of the food processing industry, while in the Bangladesh economy it is due to the food processing industry and textiles and leather transformation. These figures provide a preliminary overview of the vulnerability of the delta economies to impacts such as those originated from climate change which may generate economic losses. However, the comprehensive analysis of the economic impacts of climate change for the future requires further integration between present and future climatic, biophysical and socio-economic drivers under different scenarios.

8.3 Modelling the Economic Impacts of Climate Change in Deltas

Overview of the Integrated Modelling Framework

The analysis of the economic impacts of future climate change in the deltas involves two sources of uncertainty. First, uncertainty arises because of the complexity of functioning of and interactions between complex socio-economic and natural systems. Second, there is intrinsic uncertainty because of the indeterminate nature of future climatic and socio-economic pathways.

Figure 8.2 shows the integrated modelling framework, consisting of a set of scenarios and models operating in different spheres that are used to analyse the impacts of climate change in deltas and to assess different adaptations options, especially migration. The framework follows the typical sequential or cascading structure (Ciscar et al. 2011) linking future climatic projections, changes in environmental conditions, biophysical impacts and economic impacts.

The starting point of the integrated modelling framework is the scenario framework developed by Kebede et al. (2018) (top of Fig. 8.2). This framework uses global narratives for the climatic, socio-economic and adaptation pathways (Representative Concentration Pathways [RCP] [van Vuuren et al. 2011], Shared Socio-economic Pathways [SSP] [O'Neill et al. 2014], and Shared Policy Assumptions [SPA] [Kriegler et al. 2014]). The large-scale global circulation models (GCMs) simulate climate across the World and assess the impacts of

Fig. 8.2 Integrated modelling framework (Adapted from Arto et al. [2019]. Red text indicates link node with Fig. 8.3)

increasing greenhouse gas concentrations on the global climate system. The simulations assume concentrations of greenhouse gases and temperature increases in line with the worst case scenario (i.e. the RCP 8.5). The results of the simulations of various GCMs are downscaled using regional climate models (RCMs).

In the second stage of the modelling chain, the hydrological model takes information from the climate models and provides future pathways for hydrology parameters. Hydrological models such as the INCA model (Whitehead et al. 2015a, b, 2018) are conceptual representations

of a part of the hydrologic or water cycle, primarily used for hydrologic prediction and for understanding hydrologic processes. The information reported by this hydrological model is passed, together with information from the RCM, to the biophysical models in order to explore the impacts of climate change on crop productivity and fisheries.

The FAO/IIASA Agro-Ecological Zoning (AEZ) modelling (Fischer et al. 2012) is a comprehensive framework accounting for climate, soil, terrain and management conditions matched with specific crop requirements under different input levels and water supply. It provides information of crop yields and potential production for current and future scenarios for major crops. In the case of fisheries, the Plymouth Marine Laboratory (PML) POLCOMS-ERSEM biogeochemical model and the Dynamic Bioclimate Envelope Model (DBEM) (Cheung et al. 2009) report projections for key marine species using inputs from the RCM and the INCA model. The output from the crop and fisheries models enters as input into the economic model.

The economic sphere is analysed using, for each delta, a dynamic CGE model (Delta-CGE) that interacts at several stages with other models. The model consists of two components: a comprehensive economic dataset of the case study areas assembled in a Social Accounting Matrix (SAM), and a relatively flexible model (systems of equations) in the form of a dynamic CGE. The former represents the flows of all economic transactions that take place within the economy (an extension of the MRIO tables) and the latter aims to represent the flows of goods and services in the economies of the deltas and their relation with the rest of the country at a given point in time. In this regard, the Delta-CGE model uses actual economic data to estimate how the economy might react to changes in external factors.

The starting point of the economic modelling are three scenario storylines up to 2050 inspired by the SSP2, SSP3 and SSP5 narratives (Moss et al. 2010; van Vuuren et al. 2011; O'Neill et al. 2012; Kriegler et al. 2014; Riahi et al. 2017). At the national scale, the socio-economic scenarios for the three countries (Ghana, India and Bangladesh) are based on the publicly available SSPs (IIASA, 2018). These data provide historic trends and future projections of the changes in urban and rural populations, and GDP for each country under the different SSP

scenarios. These data are used as one of the boundary conditions to develop the scenario at the delta-level in collaboration with regional and national experts and stakeholders.

The Delta-CGE model (Arto et al. 2019) acts as an interface between the climate and biophysical models and the integrated model of migration, in the sense that it translates the biophysical impacts of climate change, such as reduction of crop productivity, into changes in some key socio-economic drivers of migration, such as wages. It is important to highlight that the Delta-CGE model does not seek to directly translate changes in climatic conditions into migration flows. Rather, it aims at taking advantage of the superiority of the biophysical models to capture the impacts of climate change in some critical variables affecting specific economic processes and translates them into economic impacts.

The economic model also interacts with the four different adaptation trajectories elaborated through combining expert-based and participatory methods. The four adaptation trajectories are termed Minimum Intervention, Economic Capacity Expansion, System Efficiency Enhancement and System Restructuring (see Suckall et al. 2018 for further details). The combination of the three different socio-economic scenarios, the four adaptation trajectories and the impacts of climate change from the biophysical models results on a set of possible socio-economic trajectories under climate change.

This information is further passed to the Integrated System Dynamics models and Bayesian Network model (see Lázár et al. 2017) where, in combination with the outputs of other models, it is used to assess the impact of climate change on human well-being and to evaluate different coping strategies. The integration of the results of the economic model into the migration models is done through a statistical emulator, which approximates the results through statistical relationships based on a Monte Carlo analysis of the economics results, without the need of integrating all the sets of equations of the Delta-CGE. At the same time, partial assessments of these integrated models provide the Delta-CGE with an ex-ante exogenous default set of migration figures (without yet accounting for migration changes estimated in the economics model), represented as dotted lines in Fig. 8.2.

(i.e. wages). Households consume goods and services coming from the delta, the rest of the country or the rest of the World. Income is distributed between consumption and savings/investments. Households also interact with government by paying taxes and receiving transfers. A similar interaction applies to firms and government. It is also via firms that the returns of capital are further invested within companies or distributed to households. The income of households in the delta also includes remittances from migrants in other regions.

The model also has a migration module in which migration is driven by economic factors using a Harris-Todaro model type of decision rule (Harris and Todaro 1970; Todaro 1986; Gupta 1993; Espíndola et al. 2006). According to this rule, migration is triggered in response to differences in expected earnings between regions. The specification may look oversimplified, but other factors affecting migration are modelled in the Integrated System Dynamics models and Bayesian Network model (Lázár et al. 2017) and linked to the Delta-CGE model. The dominant thinking in the economics literature of labour migration highlights how better economic opportunities typically drive migration; this has been found in the deltas analysed (Safra de Campos et al. 2016) (see Chapter 7). Arto et al. (2019) provide a detailed description of the migration module of the Delta-CGE model.

8.4 The Socio-Economic Future of Deltas in a Changing Environment

Baseline Socio-Economic Scenarios

Socio-economic scenario modelling, together with climate and environmental analyses, is one of the key elements in the study of climate change and its possible implications in the mid-term. Several approaches have been taken in the literature, such as Participatory Scenario Development (e.g. Bizikova et al. 2014), also sometimes linking stakeholder survey, scenario analysis, and simulation modelling to explore long-term trajectories (e.g. Keeler et al. 2015). The scenario

framework (see Kebede et al. 2018), integrates knowledge from scenario design, modelling and surveys, being stakeholder participation a central element of the framework. This was done with the triple purpose of engaging stakeholders in the project, understanding the capacity of the governance system to support migration in the context of other adaptation options, and leaving a policy and practical legacy from the research.

The socio-economic projections also include a modest exercise of expert-based questionnaire about the future of the deltas regarding rural/urban population, GDP growth and composition, inequality, or education. These expert insights are treated with caution, and put in context in relation to other knowledge, literature and complementary analyses as benchmarks for comparison. In particular, key reference data at the country level are the GDP and population levels projected by the SSP Public Database Version 1.1 (see Riahi et al. 2017). Looking at the future GDP growth (in purchasing power parities, PPP) (see Fig. 8.4), for Ghana the experts' views lie in between the SSP2 and SSP5 projections. In India, experts envisage a lower GDP growth path for deltas than those of SSP3. However, for Bangladesh (both for the delta and non-delta) the experts' visions on GDP are quite above the scenario of the highest growth (i.e. SSP5). This becomes similarly clear when looking at the projected GDP per capita, which would reach close to USD 8000 per year in Bangladesh under the high growth scenario. In the case of Ghana, also the high growth scenario implies even clearer increases in GDP per capita, reaching over USD 8000 per year, due to the clear cut slower population growth under this scenario. In the case of India, the point of departure is much higher; the experts' views from the questionnaires are relatively less pro-growth than in other deltas, being around the projections from SSP3. Still, in those lower-case options the projections are of a GDP per capita around USD 11,000 going up to around USD 30,000 per capita in the SSP5.

As with all projections, these figures should be taken with care. The responses to the questionnaires are sometimes too "pro-GDP growth optimistic", as witnessed in past literature, and are often based on early trends which then were proven to deviate downward, due to the fact that, for example, continuous GDP growth has rarely been sustained for

Fig. 8.4 Country GDP (PPP) and GDP (PPP) per capita projected by SSPs (IIASA) and delta questionnaires (please note differences in vertical scales)

long periods for any country. On the other hand, it is true that SSP projections for Bangladesh on GDP, and more importantly on GDP per capita, seem to be low compared to current trends, so these types of paths are also worth considering, especially if they are likely to be associated to other processes of urbanisation, migration, environmental degradation, etc.

Economic Impacts of Climate Change in the Deltas

In this section the outcomes of simulations for different scenarios with the Delta-CGE model are summarised. The results show the change in the GDP per capita due to climate change with respect to the baseline scenario. In particular, the impacts analysed include shocks on agriculture (losses in terms of land availability and crop yield), fisheries and infrastructure, with and without adaptation options.

The results show that the Bangladeshi side of the GBM would suffer the highest economic impact from climate change, with a cumulative loss up to 2050 of 19.5% in terms of GDP per capita, mostly due to the impacts in agriculture and infrastructures. The Volta Delta would be the one with the lowest GDP per capita losses (−9%), mainly from impacts in the agriculture sector. In the case of the Mahanadi Delta, the main shocks are found in infrastructure, representing about three times the GDP per capita loss of the agricultural and fisheries sectors; the cumulative losses due to climate change up to 2050 would represent 12% of the GDP per capita of the delta (0.25% of the GDP per capita of the whole India). Finally, in the IBD, damages in infrastructure up to 2050 would generate losses equivalent to 7% of the GDP per capita, losses driven by the impacts of climate change in the agricultural sector would affect about 8% of the GDP per capita, and fisheries losses would clearly stay below 1%. Table 8.1 summarises these cumulative losses in terms of GDP per capita up to 2050 without adaptation options.

Table 8.1 Cumulative GDP per capita percentage losses due to climate change by type of impact in selected deltas up to 2050, average and range assuming no adaptation

	GBM		Volta	Mahanadi
	Bangladesh	IBD		
Agriculture ^a	12 (8–14)	8 (6–9)	6.5 (3–9)	3 (1–6)
Fisheries ^b	0.36	0.33	0.85	0.09
Infrastructure	7.5 (6–9)	7 (4.5–9)	1.5 (1–2)	9 (7–11)
Total	19.5 (14–24)	15.5 (10–19)	9 (4–13)	12 (8–16)

^aConditioned on whether CO₂ fertilisation and good management practices take place or not

^bAverage of three climatic models implemented with the fisheries modelling POLCOMS-ERSEM

Adaptation options, in particular embankments and protection and restoration of mangroves would contribute to buffer these effects. In the case of the Mahanadi Delta, losses in terms of GDP per capita could be reduced by 2%. For the IBD, from the 15% reduction in terms of GDP per capita due to climate change, about 2% could be buffered with adaptation interventions (Fig. 8.5).

In the case of the Volta Delta, the effects from the expected climate impacts on fisheries are the most important across all studied deltas (9–17% of decrease in potential catch up to 2100, and 4–8% in 2050), implying around 1% GDP per capita loss up to mid-century. This could be buffered by adaptation activities such as housing for fishing communities, establishment of fish seed hatcheries and further development of retail fish markets and allied infrastructure. The Bangladesh GBM is a delta without a development gap with respect to the rest of the country and with lower specialisation in agriculture. However, the impacts of climate change in the

Fig. 8.5 Economic impacts of climate change for the four delta economies. Percentage change with respect to the baseline scenario

agricultural sector are still the highest of the areas analysed, reaching a reduction of about 12% GDP per capita in 2050. This result arises from the expected reduction in crop yield that may reach 30% by 2050, and even with CO₂ fertilisation and good management practices still could reach 20%. This decline in yield also translates into GDP per capita reductions for the rest of the country (non-delta region) of about 2% in 2050.

As previously indicated, the socio-economic analysis of fisheries impacts builds on fisheries modelling for both the Gulf of Guinea and Bay of Bengal (Fernandes et al. 2016; Lauria et al. 2018). The expected impacts of climate change on fisheries up to the year 2050 are entered as input in the Delta-CGE model as fisheries losses (based on likelihood of fisheries changes, which may involve growth of stock of some species, and higher losses in others) for each deltaic region. In 2050 under current management practices losses are estimated to be about 8% for Ghana and 4% for the Bay of Bengal. This implies losses in the whole GDP per capita of the deltas of about 0.1% for the Mahanadi Delta, 0.35% for the whole GBM Delta and 0.85% for the Volta Delta. This potential fish decline could be reduced to a third mitigated if sustainable management practices are undertaken (see Barange et al. 2014; Fernandes et al. 2016).

8.5 Conclusions

The vulnerability of deltas is a complex phenomenon characterised by many environmental, social and economic drivers interacting at multiple geographical and temporal scales. Using an integrated biophysical-economic approach, this chapter explores the potential economic impacts of climate change in the deltas of the GBM, Mahanadi and Volta to 2050. A CGE model is used together with information from biophysical models to assess the impacts of climate change on the economies of the deltas and linked regions.

The results from the model simulations show the economic importance of these deltas. Assuming no adaptation, losses in terms of GDP per capita range from an average of 9% in the Volta Delta to 19.5%

in the Bangladeshi section of the GBM. These impacts mainly constitute damages to infrastructure and losses in crop production and, to a lesser extent, due to losses in fisheries. For all these deltas, impacts of agriculture and fisheries represent key livelihoods for the poorest and more vulnerable, and hence the consequences of these purely macroeconomic impacts are expected to be large in terms of livelihoods and food security.

The simulations also provide key information for the development and implementation of successful adaptation options in deltas (Chapters 9 and 10). For example, impacts on agriculture in all the deltas analysed represent around 8% decline in production, though such impacts could be potentially halved through effective management practices. In addition, the results also show the potential effect of interventions aimed at reducing disaster risks such as building multipurpose cyclone shelters or constructing embankments in terms of avoiding economic and social costs of extreme events. This macro-economic analysis and diverse studies of economic behaviour and investments suggest that sustaining people and livelihoods in place in delta regions involves significant challenges, but also offers multiple benefits to the regions and countries within which they reside.

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