



Framework for Undertaking Socio-Economic Cost-Benefit Analysis for Climate Information Services in the Western Tropical Pacific

Report to the Green Climate Fund Readiness and Preparatory Support (Activity Area 4) for Vanuatu (Readiness Grant Agreement VUT-RS-001)

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Executive summary

Weather, climate and related conditions affect everyone on the planet. The variability of the atmosphere, oceans and land surface, on timescales from minutes to centuries, exerts a major influence on the population and economy. Extreme weather events, prolonged droughts, floods, and other natural weather-related disasters have a financial, social and economic impact on every country.

Developing and emerging economies can be disproportionately affected by the effects of climate and weather. These effects include impacts on human health and well-being, infrastructure (in terms of asset turnover rate, efficiency and direct damage), sector-specific impacts (such as loss of agricultural productivity due to droughts, floods, or changes in growing conditions; energy generation; and tourism through less favourable environmental conditions), and loss of biodiversity and ecosystem services.

Tailored information provided to stakeholders in the form of customised climate products and services, also referred to as climate information services (CIS), can be used to mitigate the effects of climate change and weather events. Such information provides the evidence-base for improved policy development, planning and associated decision-making underpinning national, regional, and household-level adaptation and disaster risk reduction measures. It follows that resources for supporting development and delivery of CIS need to be allocated on a sustained basis concurrently with strategic climate finance investment in adaptation and disaster risk reduction. It is therefore important to analyse socio-economic costs and benefits of CIS as an ongoing process in order to: (1) frame the planning and policy-making dialogue with government and other stakeholders at sectoral and community level; (2) demonstrate the net socio-economic and environmental return on investment; (3) provide a quantifiable decision-making framework through which investment in climate services can be made; and (4) provide a monitoring and evaluation capability for demonstrating the long-term net socio-economic impact of CIS.

To meet the aforementioned requirements for partner Pacific Island Countries and Territories (PICTs) located in the western tropical Pacific, the present study was undertaken as part of the Green Climate Fund Readiness and Preparatory Support (Activity Area 4) for Vanuatu (Readiness Grant Agreement VUT-RS-001). The approach was to adopt and modify the use of well-established methodologies developed by the World Meteorological Organization (WMO) for socio-economic benefit analysis of CIS for initial application in Vanuatu but with potential for application more broadly within partner PICTs.

In particular, the WMO approach identifies the use of economy-wide or general equilibrium economic modelling as a way of analysing the costs and benefits of meteorological and climate services. Consistent with this approach, the present study proposes using Global Trade and Analysis Project (GTAP) computable general equilibrium (CGE) modelling to conduct the analysis. This will be supplemented by ancillary socio-economic data collection strategies (typically from existing national databases), econometric modelling and integrated assessment where needed to bring all elements together. In attempting to quantify key costs and benefits of CIS, the present study also adopts a 'triple bottom-line' approach in order to deliver three integrated perspectives on return on investment, viz:

- **Economic return on investment.** Economic return on investment from CIS comes in the form of avoided economic costs due to climate impacts, and increased economic growth and welfare, improved terms of trade, infrastructure, economic output, economic structure and changes in foreign aid flows. This component will be achieved through GTAP-based economic modelling;
- **Social return on investment.** Social return on investment from CIS comes in the form of enhanced household welfare, including but not limited to changes in household income, real consumption, household savings, education and labour-force skilling. Either through direct modelling and/or econometric analysis, derived changes in welfare for various regions and demographic cohorts (such as women and children) will be estimated; and

- **Environmental return on investment.** Environmental return on investment from CIS will examine things like changes in pollution levels, greenhouse gas emissions, land-use change, natural resource extraction, and stress on key natural resources such as fisheries. This will be achieved through integrated assessment of economic outcomes and environmental impacts. Similar modelling is used to project future climate changes by coupling economic models to simplified climate models.

In summary, the proposed framework for undertaking socio-economic cost-benefit analysis (CBA) developed in the present study will provide a systematic approach to support decision-making relevant to investments in CIS, as well as providing quantifiable benefits of these services for monitoring and evaluation purposes. Such capability is highly relevant to the publically funded climate finance sector including international donors, national governments and civil society in the Pacific and other regional Small Island Developing States around the world. In particular, application of this framework will be highly relevant where the public sector has a need to assess whether a CIS-based project investment will increase aggregate social welfare compared to other market interventions. The assessment methodology is based on placing a value against all the direct and indirect costs and benefits of the proposed CIS project investment and estimating the net result in a manner consistent with neo-classical economic theory. In this context, CBA is used as a decision-making guide (i.e. to provide evidence to inform decision-making) rather than as a decision-maker as such. This approach to CBA is well established in the public sector and has been widely used for analysing feasibility and attractiveness of project interventions in a way that presents to the decision-maker a systematic quantitative analysis of socio-economic benefits for comparing alternative investment options. In the western tropical Pacific specifically, the proposed CBA framework will help decision-makers: (1) identify CIS projects that have the greatest common good; (2) estimate the rate of return on investment; and (3) inform the ongoing monitoring and evaluation of net CIS project socio-economic benefits to target communities.

1 Climate information services and their socio-economic value

Weather and climate impact pervasively on the economies of both developed and developing countries. While the theory and research literature of information economics provide considerable insight into the general role of information in decision-making, there has been relatively little mainstream economic research into the specific contribution of meteorological (both weather and climate) information and services to the overall socio-economic well-being of the world economy (SBI 2013). The informed use of meteorological (weather) and climate information, can deliver enormous benefits to society. Reliable weather and climate services enable individuals, households, organisations and governments to make more informed, evidence-based decisions which reduce the impacts of natural hazards, enhance the safety and convenience of daily life, increase business profitability, address the challenges of public health, alleviate poverty, improve productivity, strengthen regional and national economies, protect the environment and provide a more secure basis for future planning (WMO 2014).

The past 50 years has seen a massive increase in the quantity, quality and availability of information-based weather and climate products and services. The development of advanced delivery technology such as the internet and mobile devices such as smart phones means that billions of people are gaining access to these services and using them in their decision-making, greatly enhancing public and private benefit. However, this is producing new challenges for the development, prioritisation, delivery and investment in the underpinning infrastructure and the creation of new and improved climate information services (CIS) tailored to the specific needs of target users.

The World Bank Group, with a current hydro-meteorological investment portfolio of around US\$500m, estimates that globally improved weather, climate and water observation and forecasting could lead to up to US\$30b/annum in increases in global productivity and up to US\$2b/annum in reduced asset losses (WMO 2015). More specifically, Hallegatte (2012) estimates economic benefit:cost ratio of improving meteorological/hydrological services at national level in weather and climate sensitive sectors ranging between 4:1–36:1 within developing countries. According to WMO (2015), full benefit:cost estimates for investment in science and technology-based enhanced climate services need to incorporate triple bottom line (economic, social and environmental) analysis. As an example, Holland (2014) (*Economic Dimensions of Improved Meteorological Services in the Pacific*) estimates that a 1% reduction in damage from improved information and improved severe weather warnings to the community and business would generate regional cash savings of US\$3.6m; an estimated 6:1 benefit:cost ratio.

Reliable, more extensive analyses have not been undertaken to date in the western tropical Pacific, or indeed in small island developing states (SIDS) more generally. Nonetheless, WMO (2015) asserts that the implementation of the Global Framework for Climate Services (GFCS), which explicitly promotes better access to and use of climate information by users and the free and open exchange of climate relevant data as an international public good, facilitates the “delivery of goods and benefits in key economic sectors such as agriculture and food security, health, energy, disaster risk management, water resource management and urban environments”.

1.1 The present study

Over the past century, numerous studies have provided compelling evidence of the social, economic and environmental benefits of weather and climate services (Zillman 1999; Freebairn and Zillman 2002; Gunasekera 2004; WMO 2015), hereafter referred to collectively as climate information services (CIS).

The present study was undertaken as part of the Green Climate Fund Readiness and Preparatory Support (Activity Area 4) for Vanuatu (Readiness Grant Agreement VUT-RS-001). The purpose of the present study and of this publication is to outline a framework for evaluating and demonstrating the net socio-economic value of CIS. The approach was to adopt and modify the use of well-established methodologies developed by the World Meteorological Organization (WMO) for socio-economic benefit analysis of CIS (WMO 2015) for initial application in Vanuatu, but with potential for subsequent application more broadly within partner Pacific Island countries and territories (PICTs).

First however, it is necessary to introduce some basic concepts in CIS, and identify the key social and economic challenges facing communities. Following on from this, an overall framework for assessing the economic benefit of CIS is described. Accordingly, the main objectives of this study are:

- To provide a rigorous and systematic framework for evaluating the net socio-economic costs and benefits of CIS to decision-makers, including donors, national governments and CIS user groups, funding agencies, internal stakeholders, user groups and the public; and
- To build increased understanding and awareness of CIS costs and benefits between climate scientists, national meteorological and hydrological services and associated CIS user communities.

1.2 Climate information services

Climate information services are usually regarded as falling into the two broad classes of ‘weather services’ and ‘climate services’ based on the characteristic timescales of weather (minutes to weeks) and climate (months to centuries), respectively, albeit with substantial overlap between the two. Climate information services thereby consist of the provision of information-based decision-support tools, communication products and data services relevant to the past, present and future state of the atmosphere, including information on temperature, rainfall, wind, cloudiness, air quality and other atmospheric variables, as well as the occurrence and impacts of significant weather and climate phenomena such as storms, flooding, droughts, heatwaves and cold waves on natural and human systems.

1.2.1 Global Framework for Climate Services

The structure of the Global Framework for Climate Services (GFCS) (WMO 2014), is designed in large part to provide the conceptual framework for society to “... better manage the risks and opportunities arising from climate variability and change, especially those who are most vulnerable to climate-related hazards”. The GFCS goes on to state that “...This will be done through developing and incorporating science-based climate information and prediction into planning, policy and practice”. The expected GFCS long-term high-level outcomes and benefits include “... that user communities make climate-smart decisions and that climate information is disseminated effectively and in a manner that lends itself easily more easily to practical action”.

The five key components or pillars of the GFCS are:

1. *Capacity Development*: to address the particular capacity development requirements identified in the other four pillars and, more broadly, the basic requirements for enabling any GFCS-related activities to occur.

2. *User Interface Platform*: a structured means for users, climate researchers and climate information providers to interact at all levels.
3. *Climate Services Information System*: the mechanism through which information about climate (past, present and future) will be routinely collected, stored and processed to generate products and services that inform often complex decision-making across a wide range of climate-sensitive activities and enterprises.
4. *Observations and Monitoring*: to ensure that climate observations and other data necessary to meet the needs of end-users are collected, managed and disseminated and are supported by relevant metadata.
5. *Research, Modelling and Prediction*: to foster research towards continually improving the scientific quality of climate information, providing an evidence base for the impacts of climate change and variability and for the cost-effectiveness of using climate information.

For the purposes of this report, ‘users’ are further specified and defined as follows:

- **Next-users** are the ‘intermediary’ users of the outputs/deliverables of the project’s activity; typically are key agents, advocates or otherwise ‘enablers’ in the CIS knowledge value chain and associated pathway to impact, and thereby provide critical linkages to ‘end’ users.
- **End-users** are the ‘final’ users of the outputs/deliverables of the project’s activities; typically are the key stakeholders for which Project-level outcomes and impacts are realised as tangible, on-ground benefits in terms of enhanced (more sustainable and resilient) livelihoods and well-being.

For this report, and as broadly adapted from WMO (2014), CIS are defined as information services which:

- encompass a range of activities that deal with generating and providing information based on past, present and future climate and on its impacts on natural and human systems
- include the use of simple information like historical climate data sets as well as more complex products such as predictions of weather events on daily, seasonal or decadal timescales, also making use of climate projections according to different greenhouse gas emission scenarios
- information and support that help the user choose the right product for the decision they need to make and that explain the uncertainty associated with the information offered while advising on how to best use it in the decision-making process.

The inter-dependencies of the five pillars of the GFCS and links to relevant ‘next’ and ‘end’ user communities are schematically represented in Figure 1, noting that in addition to the global context, the GFCS is intended to be strategically and operationally relevant to stakeholders at both the regional and national level where appropriate.

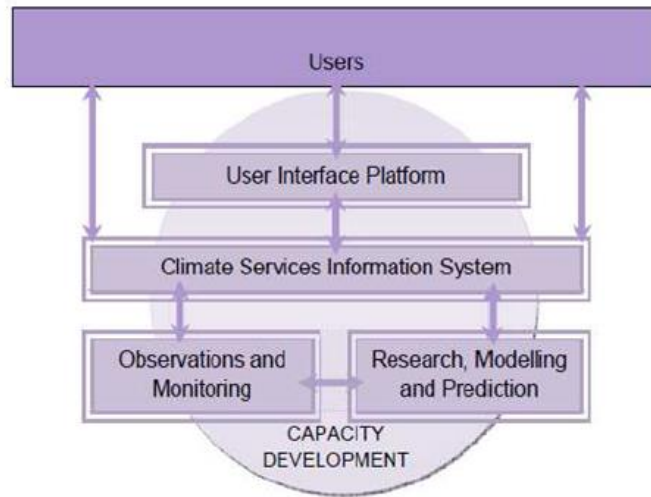


Figure 1. Global Framework for Climate Services

Within this very broad scope, CIS include the use of simple information like historical climate data sets as well as more complex products such as predictions of weather elements on monthly, seasonal or decadal timescales, and also make use of multi-decadal climate projections according to different greenhouse gas emission scenarios. Included as well are information and support that help the user choose the right product for the decisions they need to make and explain the uncertainty associated with the information offered while advising how to best use it in the decision-making process.

The so-called 'knowledge value' chain of CIS is shown in Figure 2. Value chain of CIS; adapted from WMO (2015) report. Consistent with the GFCS, the value chain typically commences with the acquisition of raw data from observational stations and other measurement systems. These basic level historical and/or real-time observations are then assimilated into modelling capability to create longer-term forecasts of future weather and climate conditions. These forecasts are then integrated or further tailored to produce 'application-ready' data products and services for end-users. These elements in the value chain can be further grouped into three main categories of CIS products:

- Basic infrastructure data and products. The basic data collection and processing infrastructure which underpins the provision of the full range of services (and may itself be recognized as the provision of a basic service to present and future generations).
- Basic service. Basic services are those services provided by a CIS provider in discharging its government's sovereign responsibilities to protect the life and property of its citizens, to contribute to their general welfare and the quality of their environment, and to meet its international obligations under the Convention of the WMO and other relevant international agreements.
- Special services. Those CIS beyond the basic service which may include the provision of special data and products, their interpretation, distribution and dissemination, and expert consultative advice.

The net value of the CIS value chain is improved by investment in: (1) basic infrastructure; (2) improvements in basic services and modelling capability; (3) providing specialist services. The entire value chain can also be enhanced through investment in research and development or improved data processing and management of infrastructure and capability.

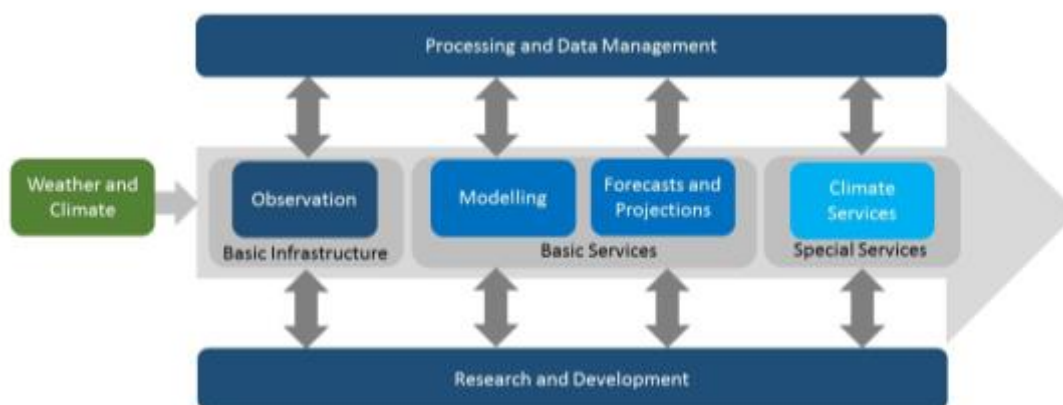


Figure 2. Value chain of CIS; adapted from WMO (2015) report

1.2.2 Delivery of CIS

Climate information services are enabling technologies generally considered to be a public good. They are not generally an end product in themselves. They are inputs at the start of a value chain that can involve many stages of value adding, application development, planning and decision-making that contribute to the productivity, efficiency, value, and resilience of sectors, infrastructure and investment within the economy.

Climate information services, particularly the special services at the end of the value chain, provide information about four main areas of impact upon the economy: human health, rare events and catastrophes, infrastructure impacts, and sector-specific impacts. Details of these areas are covered in more detail in Section 2. The information provided by CIS is then used to improve the productivity of individual sectors, economic factors (such as labour) and infrastructure. These in turn change household welfare, economic growth, foreign aid and investment, environmental outcomes, sectoral efficacy and the sectoral composition of the economy. The trickle through effect of CIS is shown in Figure 3..



Figure 3. Delivery of climate services and the implications for social, economic and environmental outcomes

Any improvements or investments in the CIS value chain (see Figure 2. Value chain of CIS; adapted from WMO (2015) report) will, eventually, result in positive socio-economic outcomes. The full benefit of CIS is determined based on how potential users receive and interpret climate information and how that information impacts or changes their planning, decision-making process and actions. The outcomes associated with user decisions are then compared to the outcomes that would have occurred in the absence of CIS. When assessing benefits, it is essential that there is a good understanding of the components of the

value chain associated with the particular climate service in the context of the sector into which it is being delivered.

1.2.3 Challenges facing CIS delivery

The rapidly growing demand for CIS delivery around the world presents major scientific, operational and public policy challenges for service providers that maintain and operate the US\$10 billion in global infrastructure which makes up the supply chain for climate services (Zillman 2003). In particular, the demand for services suggests the need for major investments in:

- expanded observational networks;
- efficient data collection and management and data exchange;
- improved computational and computing facilities;
- sophisticated data analysis schemes and increased resolution of simulation and forecasting systems;
- efficient delivery of information to end users;
- effective tailoring of services to meet user needs; and
- basic science.

While it is understood that investment in the value chain of CIS provides a greater return of more than an order of magnitude in economic benefits, service providers are continually in need of:

- clearer demonstration of the importance of the underpinning observational and data processing infrastructure and support research needed to provide essential public information, forecast and warning services to their communities;
- more rigorous and widely understood demonstration of the net socio-economic benefits, both public and private, of the services being provided;
- a more systematic basis for prioritising the use of available funding for infrastructure, services, research and development and delivery; and
- stronger economic evidence for the substantial additional investment in CIS infrastructure necessary to support national responsibilities under the various international frameworks such as the United Nations Framework Convention on Climate Change.

A framework for assessing the net socio-economic benefit of CIS must be able to address the aforementioned requirements. A systematic and economically rigorous approach for assessing the economic benefits of meteorological and climate services (Freebairn and Zillman 2002) and an overall economic framework for meteorological services (WMO 2002, 2015; Gunasekera 2004) has been established over the last couple of decades. These more recent developments placed particular emphasis on the characteristic of public good of most meteorological services (Samuelson 1954). The framework presented in the present study draws on this body of work, and expands the framework from meteorological services to include climate services in the context of CIS.

1.2.4 Approach and methodological issues

As the primary focus in the present study is with the socio-economic cost-benefit of CIS, the value of gathering observations, processing, storage and assimilation of this data into weather and climate models to produce forecasts is not considered. Rather, the value chain commences with the generation of basic forecasts of future weather and climatic conditions from existing data. These outputs are generally created

by government and public agencies (such national meteorological and hydrological agencies, regional organisations, research institutions and universities, etc.). These forecasts are generally at a lower resolution than is required by the decision-maker to facilitate informed decisions. As a result, these outputs are generally further processed to create finer (spatial) resolution (also referred to as downscaled) climate and weather projections. The downscaled projections are then packaged into geographical information systems, models and other decision-support systems which deliver products and services that are used by government, industry, researchers, and other decision-makers.

1.3 Economic approach

Estimating the value of CIS presents a number of challenges. Firstly, CIS are a public good, that is they are a service provided without profit to all members of a society, either by the government or by a private individual or organisation. Secondly, CIS are both non-excludable and non-rivalrous in that individuals, producers and consumers cannot be effectively excluded from their use, and use by one individual does not diminish their availability or value to others. Thirdly, the value of CIS improves with the investment in skill, resolution and capability of the basic generating models, the cost of which is generally borne by government or those providing the public good. Finally, the benefits that accrue are to downstream next and end-users.

As a starting point in estimating the value of CIS it is important to clarify what is meant by value. Climate information services are an intermediate good and an enabling technology that value adds to other goods and services. To understand their value, we need to explore the benefits that users draw from CIS.

One approach to assessing the value of CIS is to estimate the consumer surplus through willingness to pay studies. Consumer surplus is the difference between the price a consumer is prepared to pay for a good or service and the price that the consumer has to pay. It represents the value to consumers of a good or service. This approach has been used in a number of studies attempting to value CIS.

An alternative approach is to examine the impact of CIS on productivity of downstream users of the services. This accounts for the fact that CIS are enabling technologies. The productivity impacts are then translated into an increase in value added in a sector. Value added is the difference between the revenue received from the sale of a good or service and the cost of intermediate goods consumed in producing that good or service. Gross value added is the main component of gross domestic product. The productivity impact approach is the preferred method used here.

It is this latter approach that the framework developed in the present study draws on.

1.4 Framework for assessing the benefits of CIS

It is important to view the socio-economic analysis of CIS as an ongoing process of assessment, particularly given that resources for CIS need to be given on a sustained basis. Therefore it is important from an investment as well as a monitoring and evaluation point of view to have a structured framework around which to perform the assessments.

In the present study, this framework is written in a generic way. The initial study area is specific to countries (with emphasis on small island developing states) in the western tropical Pacific; however, this approach can potentially be applied to any region in the world. The framework and economic methodology is aimed at:

- quantifying the economic (productivity and welfare) impacts of historical climate-related events on selected PICTs at both sectoral and community level

- determining the net socio-economic (changes in output, price, economic structure and welfare) effects of CIS where they are directly linked to improved climate adaptation and disaster risk reduction capacity and resilience within relevant sectors, and at community and national levels.

To address the above questions and develop policy-relevant insights, the present study uses a computable general equilibrium (CGE) or economy-wide framework to undertake relevant analysis. Specifically, this includes:

- an economy-wide, multi-region CGE model to measure desired indicators of changes in climate adaptation capacity and resilience. CGE models have been successfully used by governments, international donors such as the World Bank, and other research organisations to perform such analyses elsewhere in the world for different applications, including CIS; and
- an additional modelling-based approach involving plausible scenario analysis. This approach will utilise the Global Trade and Analysis Project (GTAP) Model, which has been used by 400+ government research organisations and a host of private consulting organisations across the world for many decades (see Section 3 for further information).

This economic approach recognises that the choices of different decision-makers and policy-makers are interlinked. It provides a framework for assessing the net socio-economic costs and benefits of a particular CIS on the economy; or the impact of a particular climate-related event on the economy with or without CIS; or a structured framework for comparing alternative CIS interventions.

More specifically, the economic analysis undertaken in this project comprises three econometric project evaluation criteria, namely (i) the benefit–cost ratio (BCR), (ii) net present value (NPV) and (iii) the internal rate of return (IRR). Where appropriate, these three project evaluation criteria will be used in the context of the reference and counterfactual cases described later in this report. The major challenge of using these three project evaluation criteria however is that all the costs and benefits associated with the GCF investment in improving climate services in Pacific Island economies must be measurable in monetary terms.

These project evaluation indicators will enable us to assess the benefits of improved CIS against the cost of providing and using them if additional investment from donors and/or national governments were made to enhance the existing provision and use of CIS in Pacific Island economies.

The BCR is the ratio of benefits to costs and basically compares costs and benefits of the provision and use of improved CIS over time (N.B. the inverse cost–benefit ratio can also be used instead to do the same thing). Any BCR above 1 makes sense from an economic point of view as this indicates that benefits are higher than the costs. The larger the BCR becomes, the better the investment/policy option is judged to be. The estimate of BCR is able to help decision-makers decide which investment/policy option is preferred if there is more than one option that makes economic sense to be implemented.

The NPV is a main output of any benefit-cost analysis. The NPV is simply benefits minus costs calculated at their present value (i.e. using a discount rate for future benefits and costs). If the calculation leads to a positive NPV, then the chosen investment/policy option makes sense from an economic point of view. The better the economic value of an investment/policy option is the larger the NPV becomes.

The third project evaluation criteria is the IRR, which can basically be considered the interest rate an investment/policy option would generate for society. Technically speaking, the IRR is the discount rate at which the NPV becomes zero. Hence, a resulting IRR higher than the discount rate to be chosen is a good sign. However, no distinct value can be provided at which an IRR could be considered economically reasonable. Instead an IRR should exceed the opportunity costs of capital (i.e. the interest rate one might generate through alternative investments, or be higher than an applicable social discount rate).

1.5 Decision-making and cost-benefit analysis

Cost-benefit analysis (CBA) in general terms is a structured and systematic assessment of the desirability of a project. In the present study, the focus is on socio-economic CBA, which is used by the public sector to assess whether a CIS-based project would increase *aggregate social welfare*. This assessment is made by placing a value against all the costs of the project, and all the benefits. Costs will include all the resources required to produce a project, even if these do not have to be paid for directly. For example, even if you already own the land using it for this project will mean it is unavailable for another use. Costs also include non-market damages such as noise and pollution. Similarly the benefits can include both things people pay for, such as food or access to a cinema, and things they don't, such as a more pleasant urban environment. The value placed on costs and benefits is rooted in neo-classical economic theory. In practice CBA is used as a decision-guide, rather than as the decision maker. Broadly, CBA has two main purposes: (1) To determine if an investment/decision is sound (justification/feasibility) – verifying whether its benefits outweigh the costs, and by how much; (2) To provide a basis for comparing projects – which involves comparing the total expected cost of each option against its total expected benefits.

CBA can be used as part of the 'Rationale, Objectives, Appraisal, Monitoring, Assessment and Feedback' (ROAMEF) cycle, which is at the heart of the many funding institutional guidelines for appraisal and evaluation. The following list shows what CBA activities should be performed at the ROAMEF step. This should be understood as a continuous feedback loop cycle, rather than a linear process.

- Rational
 - In CBA, the high-level rationale is always an improvement in social welfare
 - Each project also requires a specific rationale
- Objectives
 - Decide on key objectives
- Appraisal
 - Consult relevant stakeholders in order to decide what the relevant costs and benefits are
 - Produce scoping values for several different approaches
 - Test values and plans with stakeholders
- Monitoring
 - Collect data which will allow ex-post assessment of the costs, benefits and to who these fall
- Evaluation
 - Recalculate costs, benefits and to whom these fall based on what actually happened
 - Discuss with stakeholders and experts how and why the project delivery was different from anticipated (positive and negative)
- Feedback
 - Combine lessons learnt from the evaluation with stakeholder feedback to reconsider new projects and/or the continuation of the project
 - In the light of experience were the initial rationale/objectives, the most appropriate?

At the detailed level, CBA alone cannot provide a rationale, and this must (and does in practice) come from elsewhere. But it is important to remember that at the conceptual level the rationale for CBA is fixed by the method, and this rationale is to increase societal welfare according to economic theory. Specific objectives

will come from previous experience and a wider narrative about problems and opportunities. Other tools will help to refine these.

1.6 Structure of the remainder of this report

There is a close interlinkage between economic growth, climate and climate change. Section 2 of this report focuses on economic exposure and sensitivity to climate change of the world economy in five key areas, chosen either because they make a large economic contribution to a given economy or because the impacts on markets and/or non-market values are expected to be significant. These five key areas are: (1) infrastructure; (2) human health; (3) ecosystems and biodiversity; (4) sector-specific impacts; and (5) rare events and catastrophes. This section briefly reviews these interlinkages and, where possible, provides some estimate of regional and global impacts of climate change on those areas of the economy.

Following on from the overview of the interlinkages between climate and the economy, Section 3 begins by discussing the trade-off between costs and benefits over time, in the context of CIS. Ultimately, the value of CIS is determined based on how potential users receive and interpret climate information and how that information impacts or changes their planning, decision-making processes and actions. To understand the full benefit of CIS, any socio-economic cost-benefit analysis needs to take a triple bottom-line approach, and this is discussed in Section 3.2. Section 3.3 outlines the general equilibrium modelling framework, an economy-wide approach that has been successfully used to calculate triple bottom-line outcomes. This section introduces the Global Trade and Analysis Project (GTAP) model, a commonly used computable general equilibrium model, discusses how scenarios are assessed, and lists some of the key indicators available in the model.

With knowledge as to how socio-economic benefits are calculated, Section 4 presents the main steps in conducting a socio-economic benefit analysis. This section steps through the phases of defining the scope of the socio-economic benefit analysis, identifying the impacts, building the reference and counterfactual cases, conducting the analysis (where the GTAP model is used), and communicating the outcomes to various key stakeholder groups.

Section 5 provides an illustrative socio-economic cost-benefit analysis, around the social and economic impacts of sea-level rise on Pacific Island nations. This is a hypothetical analysis, and will provide the foundation for initial benefit analysis, and allow key stakeholders to become familiar with process.

The refinement, development and deployment of the socio-economic benefit analysis are described in Section 6. This involves taking the initial case studies and engaging key stakeholders in their refinement, as well as capacity-building in relation to modelling capacity, to give more detailed regional, sectoral, and meteorological/climate services oriented analysis.

Section 7 provides the summary conclusions of this publication. The conclusions focus on the current state of knowledge and suggested priorities for future work on improved approaches for assessing the benefits and costs of meteorological, hydrological and related services.

2 Economic impacts of climate change

There is a close interlinkage between economic growth, climate and climate change. This section focuses on economic exposure and sensitivity to climate change of the world economy in five key areas, chosen either because they make a large economic contribution to a given economy or because the impacts on markets and/or non-market values are expected to be significant. These five key areas are: (1) infrastructure; (2) human health; (3) ecosystems and biodiversity; (4) sector-specific impacts; and (5) rare events and catastrophes. In the remainder of this section, we will briefly illustrate how climate change impacts these various areas.

The impacts of climate variability, extremes and change on countries in the western tropical Pacific is provided by Bureau of Meteorology and CSIRO (2014) in detail at a national level, and more generally by CSIRO and Bureau of Meteorology (2015) at a national/sectoral level.

2.1 Infrastructure

Climate change will have wide ranging and significant impacts on the infrastructure critical to the operation of local, regional and global economies. This will occur through changes in the average climate, sea-level rise, and changes in the frequency and intensity of severe weather events.

2.1.1 Building and built infrastructure in coastal settlements

Buildings and infrastructure being constructed will have functional lives of many decades. In the Pacific Islands, between 67% and 98% of infrastructure is within 500 m of a coastline (Kumar and Taylor 2015). The increased magnitude of storm events and sea-level rise under climate change is likely to exert significant pressure on coastal infrastructure through storm damage and localised flooding. This would cause immediate damage to assets, particularly building contents, and accelerate the degradation of buildings, requiring them to be replaced.

2.1.2 Electricity generation and distribution networks

Increased temperatures are likely to have several implications for electricity generation and distribution networks. First, increased temperatures will increase demand for electricity to power air-conditioning and other appliances. Second, increased temperatures increase attenuation within the distribution network, requiring additional generation capacity to meet the existing baseload. Increased temperatures will also increase the degradation of distribution network infrastructure.

2.1.3 Port operations

Sea-level rise and storm surges pose a significant risk to port operations. Damage to key infrastructure or downtime due to flooding reduces the efficiency of ports to effectively load and unload cargo, which could result in increased transportation and storage costs and localised shortages of commodities and other goods. Sea-level rise also places at risk the port infrastructure, which may have to be replaced or reinforced.

2.1.4 Roads and bridges

Roads and bridges are key pieces of infrastructure that are vital for the basic efficiency of the underlying economy. Damage to roads and bridges through increased temperatures, flooding, storms, landslides, sea-level rise and storm surges poses a significant economic and social cost.

2.1.5 Dwellings

A changing climate poses several pressures on dwellings. First, increased frequency and intensity of weather events, and sea-level rise all place pressure on the integrity of dwellings, reducing their longevity and increasing their cost of repair. Second, increased temperatures and changed climatic conditions mean that dwellings may need to be retrofitted to meet new environmental conditions. Failure to adapt dwellings can have significant health and well-being implications.

2.2 Human health and well-being

Climate change is likely to affect the health of millions of people worldwide over this century in many ways. Some climate-related events, such as heatwaves, have direct impacts on the economy through death and loss of productivity. Other climate events indirectly affect the human population through modification of ecological, biological and natural processes, such as the breeding cycle and distribution of a range of disease-carrying mosquitoes. Other health issues such as access to key facilities by remote communities are also important. Each of these areas has significant economic implications. Under-developed economies are most likely to be disproportionately affected. In the remainder of this section, we will touch on some of these issues.

2.2.1 Temperature-related death and serious illness

Exposure to prolonged ambient heat promotes various physiological changes that can lead to death. The elderly and very young are the most at-risk groups. The effects of climate change on temperature-related deaths are highly variable over space and time.

2.2.2 Loss of productivity due to heat stress

Apart from premature mortality, heat stress reduces labour productivity through limiting the amount of work that an individual can do. For example, in labour-intensive sectors of the economy such as construction or agriculture, workers may have to work in 30-minute periods to avoid the adverse effects of heat stress (Dunne et al. 2013). Economic analysis of the proposed changes in work conditions suggest that parts of the world, such as India and Pakistan, may have their labour productivity reduced by as much as 80%, resulting in a 55% reduction in GDP (Newth et al. 2015).

2.2.3 Vector-borne diseases

A changing climate means a change in the distribution of disease-carrying vectors such as mosquitoes. Communities that have never experienced dengue fever, Ross River virus, Chikungunya virus or malaria may become exposed to these diseases. This requires additional resources to be available to treat these diseases, and mitigation strategies to be put in place to limit exposure of the population to these diseases. In addition to the increased health costs to treat these diseases, there is a secondary cost to the economy through lost productivity.

2.3 Ecosystems and biodiversity

Natural biological systems throughout the world have been dramatically changed by human activities. Climate change is likely to exacerbate existing environmental problems, such as the widespread change in ecosystem structure and function, changes in water availability and quality, fragmentation of habitats and ecosystems, and the introduction of invasive species. Each of these aspects has a significant impact on the structure of functioning ecosystems including agriculture, livestock, and tourism.

2.4 Sector-specific impacts

Climate variability has long posed a significant challenge to communities and industries that rely on natural resources. Climate change is likely to increase the variability of the current climate. Forestry, agriculture, mining, and tourism are all likely to be affected by climate change. In the United States, it is estimated that economic output can vary by as much as \$260 billion annually depending on weather conditions (Larsen et al. 2007) and that this can be offset by improved weather forecasting capabilities (Lazo and Chestnut 2002).

2.4.1 Agriculture

Climate change is likely to affect agricultural production through changes in water availability, water quality and temperatures. Crop production is likely to be affected directly by changes in average rainfall and temperatures, distribution of rainfall during the year, and rainfall variability. The productivity of livestock industries will be influenced by changes in the quality and quantity of available pastures as well as by the effects of temperature on livestock. Dairy production is also expected to be impacted, and the locational distribution of production could change as a result of available pastures and rainfall. Higher carbon dioxide concentrations could reduce crop quality (European Environment Agency 2004). Severe weather events including bush fires, droughts and flooding are likely to reduce agricultural production through effects on crop yields and stock losses. Finally, changes in environmental conditions are likely to alter the occurrence of pests and disease outbreaks, further reducing agricultural output.

2.4.2 Tourism

Tourism is a significant contributor to GDP for many countries around the world. For Australia, tourism contributes around 3.7% of GDP. For the Pacific Islands the proportion is a lot larger. In Vanuatu, for example, tourism contributes around 20% of GDP (World Travel and Tourism Council 2015). Climate change could lead to loss of key tourism attractions, such as coral reefs, and increase costs for adaptation, repairs, maintenance and replacement of tourist infrastructure, and developing alternative attractions.

2.5 Rare events and catastrophes

Severe weather events such as cyclones and intense storms, and storm surges, pose a significant security challenge for many parts of the world because of the death and destruction that results and the political, economic and social stresses these events place on even the most developed economies. Island nations are particularly vulnerable. Severe events may call into question the ability of governments to respond and may lead to inter-communal conflicts. Of particular interest are the frequency and intensity of cyclones, El Niño-Southern Oscillation-related events, flooding and drought.

2.5.1 Cyclones

Climate change is predicted to change the frequency and intensity of tropical cyclones, making the economic costs even larger over the rest of the 21st century. The US Climate Prospectus (<http://climateprospectus.org/>) estimates that over the next century the monetary value of losses due to cyclone, will be around US\$9.7 trillion worldwide. Further analysis suggests that the impacts of cyclones are long lived and there are huge gains to be had through improved forecasting capability, leading to improved policies and mitigation strategies.

2.5.2 ENSO events

El Niño-Southern Oscillation (ENSO) events can have a significant effect on global weather and climate. Changes in the frequency, intensity and duration of hurricanes, cyclones, monsoons, droughts, wintertime storms, rainfall patterns and warmer temperatures are associated with ENSO events. This has significant implications for agriculture and construction sectors.

2.6 Climate information services

Weather- and climate-sensitive industries directly impacted by weather (such as agriculture, construction, energy distribution and tourism) account for nearly 10% of GDP. Further, weather and climate indirectly impact an even a larger portion of the global economy, extending to finance and insurance, services, retail and wholesale trade, as well as manufacturing. Some analysts estimate that nearly 25% of GDP, or \$2.7 trillion, is either directly or indirectly impacted by weather and climate (WMO 2015).

The effect of climate change on the world's population and natural assets will depend on exposure to changes in the climate system, sensitivity to those exposures and the capability to adapt to the changes to which we are sensitive. Regional exposure and sensitivity to the impacts of climate change is highly variable. The extent to which these impacts are realised will depend on the success and timing of greenhouse gas emissions mitigation and regional adaptation efforts. This requires the delivery of timely information to key users and stakeholders.

Climate information services aim to bring together all the required information for decision-makers to make well informed choices about the pathway to adaptation as well as to assess location options for greenhouse gas mitigation. Making informed decisions can result in net reductions in various climate-induced economic impacts and in some cases even result in net benefit.

3 Costs and benefits of CIS

Some of the impacts of climate change can be diminished by mitigation and adaptation measures taken by individuals and firms, and by policies that support adaptation activities. Effective adaptation requires strong, high-quality information tailored to the region and sector in question to enable policy- and decision-makers to construct good markets for reallocation of resources, goods and services, and capital for investment in infrastructure and new productive capacity that is more suitable to the new environment. Climate information services aim to provide this, underpinned by high-quality environmental intelligence for all decision makers.

The costs of improved CIS will generally come early, when development and implementation costs are incurred, and the benefits from reduced impacts of climate change impacts will occur later. In the remainder of this section, we will outline how to measure these costs and socio-economic benefits.

3.1 Measuring the CIS benefits against the costs

Ultimately, the value of CIS is determined based on how potential users receive and interpret climate information and how that information impacts or changes their planning, decision-making process and actions. The outcomes associated with user decisions are then compared to the outcomes that would have occurred in the absence of CIS. When assessing benefits, it is essential that there is a good understanding of the components of the value chain associated with the particular CIS in the context of the sector in which it is being evaluated.

The costs and benefits of CIS fall on and accrue to different groups in the community. They are also felt and valued in various ways by different groups of people. An overall assessment of whether a particular CIS is worthwhile will depend on the distribution of costs and benefits across the entire community.

As an illustration, let's plot our expectation of regional or national utility or welfare over time in the absence of CIS (see Figure 4.(a), orange curve). Utility will generally grow over time through the accumulation of wealth, infrastructure, savings and investment. Now, let's plot on the same graph, our expected utility over time of improved decision-making due to CIS (see Figure 4.(a), blue curve). As shown in Figure 4.(a), the utility curve without CIS is initially above the utility curve with CIS in the early period. Climate information services have a cost attached to them. However, in cases in which they are associated with benefit to the economy, at some point the utility curve will cross the utility curve without CIS and continue to rise. The point at which the two utility curves meet is called the utility crossover point.

The two curves illustrate the shape of a fish. The body of the fish covers the time period in which the net benefits of CIS are negative. The area inside the 'fish body' represents the excess cost of CIS (e.g. building information systems, setting up networks, acquisition of hardware to increase capability, employing more staff etc.) in the time periods to the crossover point. The tail of the fish covers the years in which the net benefits of CIS are positive. These benefits continue to grow with time.

As shown in Figure 4., CIS are the result of a long value chain involving research and development, scientific infrastructure, information technology and information dissemination. The quality of CIS can be improved through investment in various elements within that value chain. The benefit of such investment is shown in Figure 4.(b), which shows utility curves for three cases: (1) expected utility without CIS, (2) expected utility with CIS, and (3) expected utility with enhanced CIS.

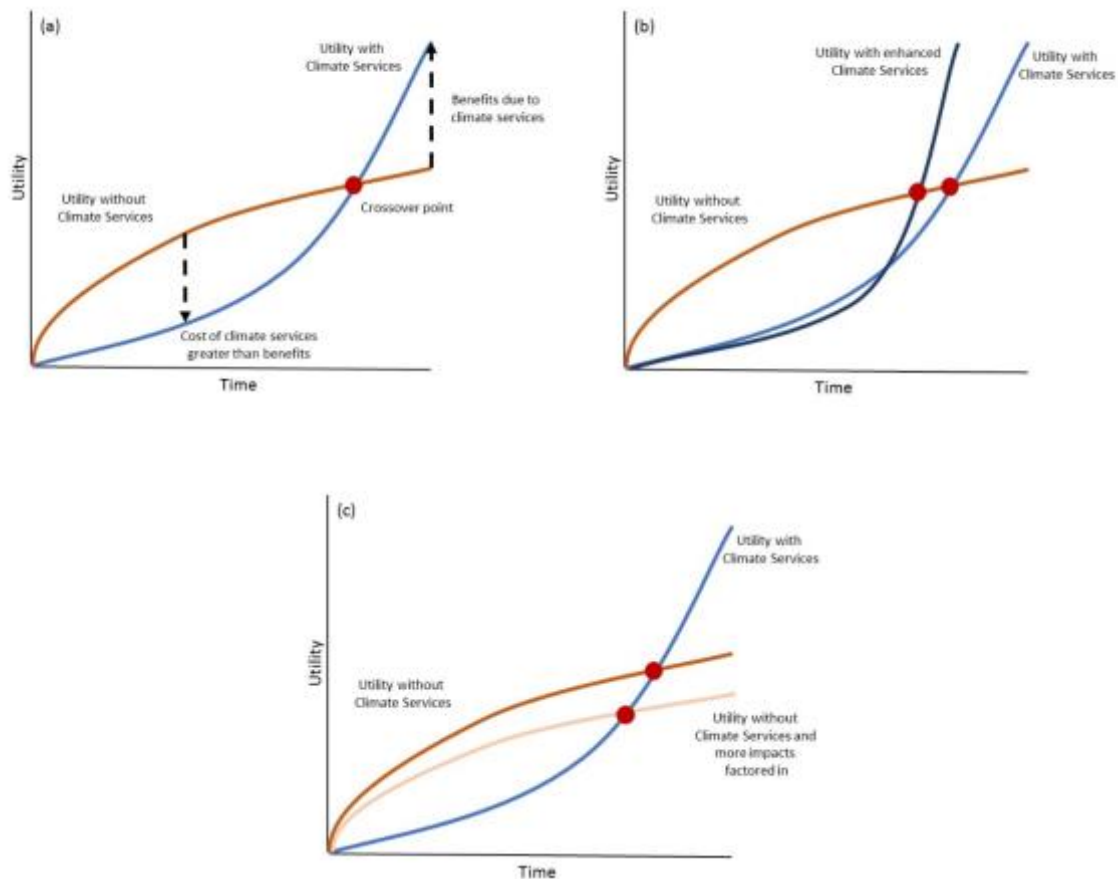


Figure 4. Illustrating the costs and benefits of alternative courses of action over time.

Figure 4.(b) shows the utility curves for with and without climate services and for an enhanced climate services scenario. For the enhanced climate services case, the fish will have a ‘fatter’ body and tail, as both the costs and benefits are increased, compared to the ‘normal’ climate services case. Figure 4.(c) shows the utility curves for cases where additional impacts from a lack of climate services are taken into account. As more climate impacts are quantified and taken into account, the utility curve for increased impacts is shifted downward. The body of the fish becomes thinner, the crossover point occurs earlier and the tail grows faster. This implies a higher net benefit for climate services.

For any chosen investment, development, implementation and rollout strategy for CIS, there will be an optimum distribution of the costs and effort over time. For simplicity, we assume that the ideal deployment strategy, including ideal allocation of effort and resources over time, is known and chosen for implementation.

3.2 Accounting for the full suite of CIS benefits

As Figure 4.(c) illustrates, to determine the total economic value of CIS it is important that all benefits be identified, regardless of to whom they accrue or where they might be realised. This includes the financial benefits to a specific sector or country, as well as any environmental and social benefits that may result. This can include improved household welfare, reduced exposure to pollutants, and more. The inclusion of environmental and social implications is referred to as triple bottom-line accounting. Table 1, modified from and based on Lazo et al. (2008), outlines some of the triple bottom-line considerations.

Table 1. The triple bottom-line approach accounts for the benefits of CIS

BENEFITS	EXAMPLES
Social	Avoided loss of life, injury and illness from rare events, catastrophes, and natural disasters
	Improved safety and security
	Access to clean water and air
	Improved access to luxury goods
	Improved household welfare
	Improved food, energy nutritional security
	Improved information and data access
	Improved infrastructure and investment decisions
	Continuity of employment
	Improved governance and continuity of governance
	Contributing to the day-to-day safety, comfort, enjoyment and general convenience to: recreation, travel and commuting, preparation for severe weather, direct and indirect health and societal benefits, event management, avoided climate-related illness including vector-borne diseases, and heat-related illnesses
Environmental	Long-term monitoring and basic indicators of the state of the environment
	Minimisation of release of toxic substance and other pollutants
	Management of local environmental quality
	Support for addressing major environmental issues
	Water savings
	Other natural resource savings
	Reduced runoff and cross contamination of fertiliser application, resulting in improved water and air quality
Economic	Avoided loss of productivity due to heat stress
	Increased agricultural productivity
	Increased manufacturing efficiency
	Increased manufacturing efficiency
	Increased transportation efficiency
	Minimised drought and other relief programmes
	Avoided loss of infrastructure
	More efficient planning of energy production and delivery
	Avoided loss of infrastructure
	Increased efficiency of operation of infrastructure and labour
	Minimized search and rescue costs
Reduced health costs of vector-borne diseases and heat-related illnesses	

Source: Lazo et al. (2008)

3.3 Economic modelling

Various economic modelling approaches can be used to assess the benefits of CIS. These models rely on data on the production and consumption of goods and services across different economies, trade data, taxes and tariffs, and decision-makers' policies and settings. Within the context of CIS, economists use models to determine the value of CIS for households, firms, producers and consumers, as well as to determine how the broad use of CIS can impact regional and national governments. As it is important to capture as many costs and benefits, we adopt an economy-wide approach to analysing the implications of cost-benefit analysis. In the remainder of this section, this approach is outlined.

3.3.1 Economy-wide modelling or general equilibrium modelling

General equilibrium theory attempts to explain the behaviour of supply, demand, and prices in a whole economy with several or many interacting markets, by assuming that the set of prices exist that will result in an overall equilibrium, where supply equals demand. General equilibrium theory is distinguished from partial equilibrium theory by the fact that it attempts to look at several markets simultaneously rather than a single market or sector of a market in isolation. As an example, in the agricultural sector, if producers use seasonal forecasting to improve the productivity (both in terms of quantity and quality) of the production of agricultural commodities, then producers will have a competitive advantage over competitors. This allows them to maintain or increase supply.

The major advantage of general equilibrium modelling is that it tracks all the relationships between supply side factors (such as availability of inputs, costs, labour and infrastructure and technology) and demand side factors (prices, change in quantity demanded). A number of studies have used CIS to assess the implications of a changing climate on agricultural productivity (Cai et al. 2015), labour productivity (Newth et al. 2015), changes in patterns of crop production (Porfirio et al. 2016), and the impact of ENSO on agricultural productivity (Araújo et al 2015).

In Section 4, we will outline the methodology used to design an integrated analysis of climate services and economic modelling. In the rest of this section we will outline the methodology used to calculate costs and benefits within the general equilibrium modelling framework. This discussion will include a description of the Global Trade and Analysis Project (GTAP) model, a widely used general equilibrium model; development of a reference case; and key socio-economic indicators of the costs and benefits.

3.3.2 The Global Trade and Analysis Project (GTAP) model

The GTAP model is a multi-commodity, multi-regional computable general equilibrium model, with detailed economic theory and producer and consumer behaviour. The standard GTAP model employs the simple, but robust, assumptions of constant returns to scale and perfect competition in all markets with Walrasian adjustment to ensure a general equilibrium. As represented in Figure 5. (Brockmeier 2001), the regional 'household' (e.g. the EU) collects all the income in its region and spends it over three expenditure types – private household (consumer), government, and savings, as governed by a Cobb-Douglas utility function. A representative firm maximises profits subject to a nested Constant Elasticity of Substitution (CES) production function which combines primary factors and intermediates inputs to produce a final good. Firms pay wages/rental rates to the regional household in return for the employment of land, labour, capital, and natural resources. Firms sell their output to other firms (intermediate inputs), to private households, government, and investment. Since this is a global model, firms also export tradable commodities and import the intermediate inputs from other regions. These goods are assumed to be differentiated by region, following the Armington assumption, and so the model can track bilateral trade flows.

Land is imperfectly mobile across uses. Labour and capital markets are segmented, allowing for differential returns between the agriculture and non-agriculture sectors and immobile across countries. Government spending is modelled by using a Cobb-Douglas sub-utility function, which maintains constant expenditure shares across all budget items. The private household consumption is modelled with a non-homothetic Constant Difference of Elasticity (CDE) implicit expenditure function, which allows for differences in price and income elasticities across commodities. Taxes (and subsidies) go as net tax revenues (subsidy expenditures) to the regional household from private households, governments, and firms. The rest of the world gets revenues by exporting to private households, firms and governments. In the GTAP model, this rest of world composite is actually made up of many other regions – with the same utility and production functions as for the regional household at the top of Figure 5.

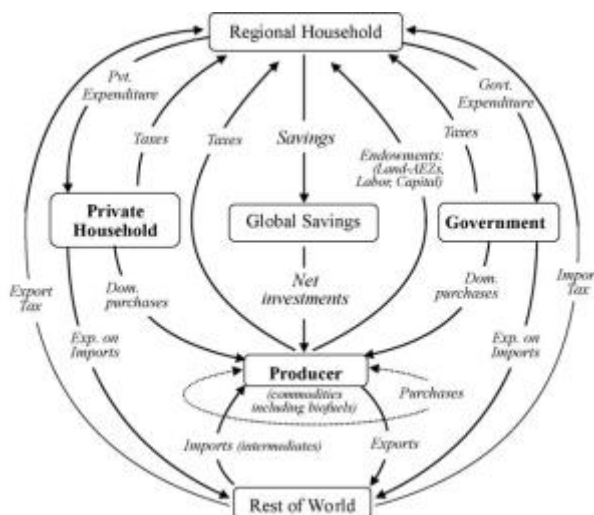


Figure 5. Schematic of the flows in the GTAP model. For each region in the model, this schematic is replicated with regions connected via the ‘Rest of World’

3.3.3 Beyond the GTAP Model

The GTAP model can be thought of as the standard on-the-shelf model for conducting general equilibrium analysis. For the purposes of studying the impact of climate change, it is worth considering several logical extensions to this model. These are: (1) The MyGTAP model; (2) the inclusion of a climate services sector; and (3) the disaggregation of island economies. These extensions can be considered as part of the proposed analytical framework and would be used where appropriate in the cost benefit analysis.

3.3.3.1 The MyGTAP Model. The MyGTAP model is identical to the GTAP model but has several useful extensions. First, MyGTAP has multiple representative households. This allows the analysis of the consequences of changes to the economy on different cohorts within the population, for example the effects of improved climate services on the rich versus the poor. Second, MyGTAP includes foreign aid flows; this is important as it shows how the reduced aid burden flows back through the global economy due to CIS. This could be used to answer questions such as: What is the impact of a reduction in donor-funded aid to Pacific Islands? What if more was invested in improved CIS to mitigate sea-level rise and associated storm surges?

3.3.3.2 Inclusion of a CIS sector. Meteorological, weather and climate services are a public good and generally funded via government and donor support, then used by sectors of national economies to improve productivity and safety and well-being of local communities. Currently the modelling would assume that all changes to CIS are exogenously driven, that is, the basic costs and benefits are calculated off model and then used to form the reference case and the counterfactuals. An alternative approach is to create a CIS sector, and then further activate that sector directly with changes in policy (e.g. increased funding, new

infrastructure and investment, etc.). The model would then endogenously calculate the productivity changes. This approach would still require exogenous calculations of the impacts of climate phenomena such as the impact of sea-level rise on infrastructure. This expansion would allow us to explore questions such as: What is the implication of reduced/increased government funding for CIS on the mitigation of sea-level rise?

3.3.3.3 The disaggregation of island economies. The GTAP database used to drive the GTAP model has 147 countries and regions. These regions can be aggregated and disaggregated in appropriate ways to answer key policy and economic questions. The Pacific Islands are aggregated together to form 'Rest of Oceania' or XOC for short. Disaggregation of XOC into smaller economies is possible and it would allow a more robust analysis of the beneficiaries of different types of CIS. This can be done in one of two ways. First via creating regional households within the MyGTAP framework, where we could see the household-level effects; this is highly doable as the required information such as the Vanuatu Household Expenditure survey is freely available. Second is to split Pacific Island Countries out so they have a distinct country and sectoral representation. This may be difficult, as the detailed data required may not be available, but it should be possible to construct a good representation of any island nation economy based on reliable proxy data.

3.3.4 Assessing scenarios

The analysis of costs and benefits of CIS requires an assessment of the benefits that may be attributed to their use in the future. When assessing the impact of CIS it is important to address the questions of attribution and additionality:

- Attribution means the extent to which CIS have added value to the overall benefit.
- Climate information services are enabling technologies for other systems, sectors and services, and cannot be credited with all of the benefits that might arise from the use of the services.
- Additionality means the extent to which CIS have added additional value to that which would have otherwise occurred with alternatives to the service being offered.

To address these issues we have utilised the concepts of evaluation scenarios and counterfactual or reference scenarios.

- The evaluation scenario is the case with CIS (the blue line is counterfactual in Figure 6.)
- The counterfactual is the situation where the best alternative to CIS is deployed in its absence.

Within the framework we explore several counterfactuals to explore the scope of uncertainties around the effectiveness of CIS and their uptake; as well as the potential to deliver further benefits through enhanced CIS.

It is acknowledged that in some cases, services and commodities could not be delivered without CIS. In such cases the counterfactual would be based on the level of service that might have been delivered even though it would have been ineffective or significantly less effective.

When assessing the difference between the evaluation and the counterfactual scenarios it is important to take into account the marginal changes in economic welfare. This will be done by clearly identifying the evaluation and counterfactual scenarios for each case study.

The difference between the evaluation scenario and the counterfactual is illustrated in Figure 6.. The economic value is defined as the difference between the evaluation case and the counterfactual shown as the accumulated impact as at 2016. In the following section we will outline some of the key variables in the model and explain their importance in understanding the costs and benefits of CIS to a given economy.

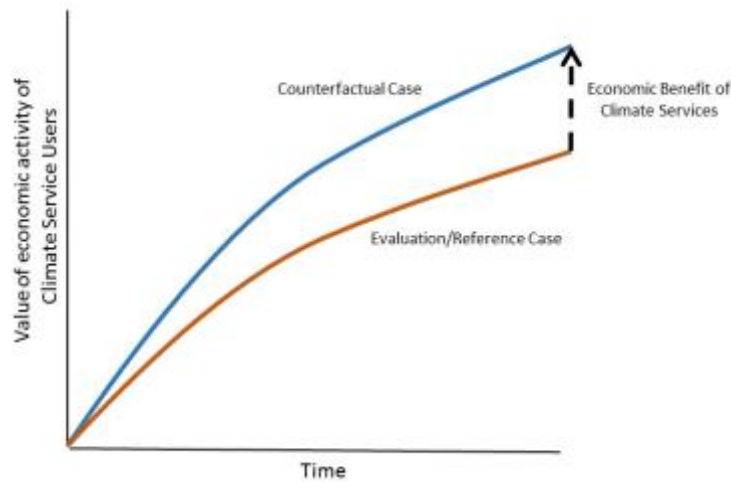


Figure 6. Evaluation of reference cases and counterfactual scenarios of CIS

3.3.5 Key indicators

Here we briefly define some key GTAP model indicators (Figure 7).

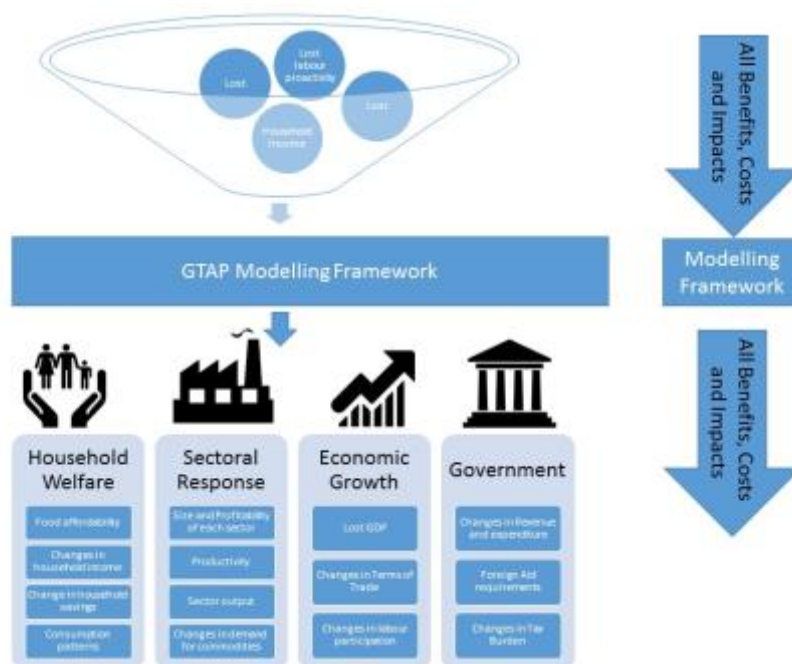


Figure 7. Resulting economic analysis from the GTAP model

3.3.5.1 Household welfare: equivalent variation. This is a money-centric measure of the value to the consumer of the price changes due to an economic shock (e.g. the deployment of CIS)? It is calculated as the difference in income required to achieve the new versus the initial levels of the utility when goods are valued at base-year prices.

3.3.5.2 Household welfare: real consumption. This is a money-centric measure of the value to the consumer of the price change due to an economic shock? It is calculated as the difference in income required to buy the new basket of goods versus the initial basket of goods when both baskets are valued at base-year prices.

3.3.5.3 Terms of trade. Measures the import purchasing power of a country's exports. Any change in the terms of trade therefore affect an economy's welfare, by changing its consumption possibilities. Terms of trade are calculated as the ratio of the price of a country's exported goods to the price of its imported goods.

3.3.5.4 Quantity of output. Measures the change in output of a particular sector in response to an economic shock. Improvements or reductions in efficiency or changes in the availability or price of intermediate inputs can change the supply profile for a given commodity, so a change in policy setting can stimulate or retard the level of production within an economy.

3.3.5.5 Change in prices. Measures the change in prices, due to an economic shock. As prices of intermediate inputs change, the cost of production for a given commodity does as well. Increased demand also places upward pressure on prices, so changes in prices reflect the relative affordability of a particular commodity.

3.3.5.6 Change in imports and exports. Changes in imports and exports reflect on a region's ability to accumulate wealth and be competitive on the international market.

3.4 Closing comments

The following section outlines a framework for conducting a socio-economic benefit study. The modelling capability described in the current section provides the analytical framework through which benefits can be calculated, once the study question has been identified and all the required inputs have been sourced. The following section also outlines the need for stakeholder engagement in the development of a study, as well as the need for a well-defined communication strategy.

4 Framework for assessing the benefits of CIS

There are many reasons for studying the costs and benefits of CIS. The previous section outlined the need to understand the full set of benefits attached to CIS, an economic approach to calculating those benefits, and several extensions to get a more robust set of benefits. The purpose of this section is to outline a framework for conducting a CIS-based cost-benefit analysis.

A socio-economic cost-benefit analysis is a comprehensive investigation of the benefits and costs of a potential project intervention. Socio-economic analysis of CIS takes into account not only financial costs and revenues, but also the wider range of benefits and costs of a CIS program (such as change in household welfare), from various perspectives including the end user, the household, sector, the environment, and society as a whole. For example, these may include direct impacts such as reduced or avoided costs of sea-level rise, and non-market costs and benefits such as the preservation of natural features and biodiversity.

Conceptually, the development of a socio-economic cost-benefit analysis for CIS in the present study consists of five main parts. These steps are shown in Figure 8. Initially, the CIS and the climate impacts that are to be assessed need to be identified. Following on from this, we need to develop a reference case. The business as usual or reference case serves as an anchoring point or a baseline for determining the costs and benefits. Once the reference case is established counterfactual cases need to be identified. This is the set of costs and benefits of deploying a given CIS for mitigating particular climate impacts. With the reference case and the counterfactuals established, the next step is to analyse these two alternative outcomes and determine the net socio-economic benefits. The final phase is to review and communicate the benefits to stakeholders and then identify whether the study needs adjustment or consider an alternative set of CIS and impacts.



Figure 8. The main phases of a socio-economic cost-benefit analysis

Socio-economic cost-benefit analysis is used to determine whether significant programmes should proceed, as well as for monitoring and evaluating the effectiveness of the programme. Socio-economic cost-benefit analysis involves a systematic appraisal of the programme’s overall benefits and costs in order to quantify the full range of social, economic, welfare and environment benefits in monetary terms (where possible). Some of these benefits may not be fully acknowledged or appreciated, in part because they are of a less tangible, less quantifiable nature. All of these benefits need to be considered to determine the overall viability of a particular project. Omitting some benefits can lead to an erroneous conclusion that benefits are outweighed by costs, when in fact the opposite might be true.

4.1 Steps to conducting a socio-economic benefit analysis

Figure 8 showed the five main phases of conducting a socio-economic benefit analysis for CIS. The bulk of the detail in conducting a socio-economic benefit analysis is in phases 2–5. In the remainder of this section more detail is outlined for the steps in each of the phases. Figure 9 provides a summary for each of the steps and the sequence in which they should be conducted. For some analyses, certain steps may not be feasible with the amount of information that is available, or necessary, or both. This material is based on Lazo and Peacock (2007), Lazo et al. (2008), WMO (2014) and other source material cited in that work. The process consists of four key parts: (1) stakeholder engagement; (2) study design and data collection; (3) analysis of the benefits and costs; and (4) communication and outreach. The remainder of this section looks at each of the main parts.

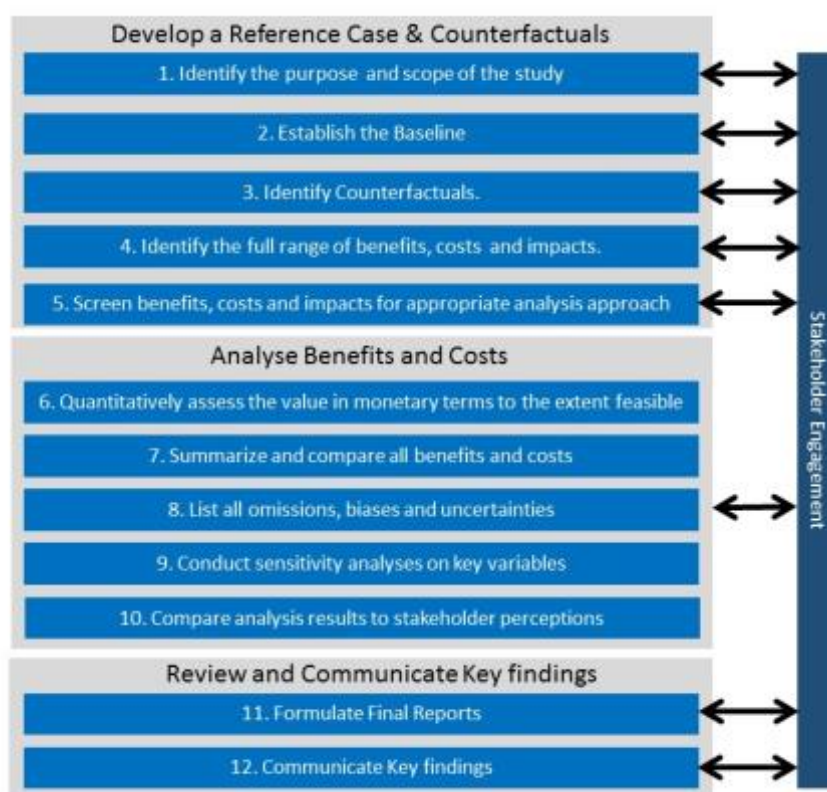


Figure 9. Steps in conducting a socio-economic analysis for climate information services

4.2 Stakeholder engagement

Rather than attempting a whole-of-service study, in many cases it will be easier to both measure and illustrate the economic value generated by a specific CIS (or climate and weather-related event) on a specific sector, user group or segment of the economy. The benefits and costs from a CIS are easier to define than those associated with the range of decisions that are also affected by a set of climate services. As a result, there is an opportunity to tell a comprehensive story about the economic benefits derived from investing in CIS.

The economy-wide framework allows for rich and robust narrative to be constructed that will engage a wider cross section of stakeholders, and those who will directly benefit from the CIS. For example, the use of an economy-wide framework for the analysis of how sea-level rise and storm surges will affect shipping and port operations will also show how costs are incurred by upstream/downstream sectors of the economy. A decrease in port operations will increase shipping costs, making (for example) exports of agricultural goods

more expensive. More expensive agricultural goods mean that the agricultural sector is less competitive internationally, meaning that demand for that region's agricultural goods will decline. This results in lower returns to local agricultural producers.

The effective construction of such narratives requires an effective working relationship with the sectors, stakeholders and beneficiaries. The development of the analysis and scenarios must be a two-way process and involve focus from all parties. The stakeholders need to understand not just the potential afforded climate services but also the limitations of such guidance. Therefore, it is necessary for the socio-economic analysis to be conducted with deep engagement with both the CIS team and the key stakeholders. The engagement with both teams should lead to a high level of user satisfaction. There should also be ongoing monitoring of key stakeholder participation to ensure that a high level of stakeholder satisfaction is achieved. Both the climate services team and the key stakeholders should be engaged with all steps outlined in the flow diagram in Figure 9.

4.3 Development of reference case and counterfactuals

Steps 1 to 5 in Figure 9 focus on designing the study, and building the reference case and counterfactuals. The remainder of this section describes what is involved in each of these steps.

4.3.1 Step 1. Identify the purpose and scope of the study

The study design phase is the most crucial step in creating a successful cost-benefit analysis. During this phase, it is decided what exactly the study will be about, its purpose and scope and boundary. This phase requires stakeholder engagement to ensure that the study will deliver the required analysis. Within the context of CIS, the economic modelling framework outlined in the previous section can be used to in one of three main ways:

- To analyse the costs and benefits of a particular CIS. For example, we could seek answers to key questions such as: what is the net socio-economic benefit of investing in advanced tropical cyclone early warning systems?
- To analyse the net socio-economic impacts of climate-related phenomena, and consider how we target CIS to minimise such impacts. For this type of analysis, we would be aiming to answer questions such as: what is the net socio-economic benefit of improving a tropical cyclone early warning system from 12 hours to 36 hours lead time?
- To provide analysis and compare the net socio-economic benefits of alternative policy settings and investment strategies for alternative CIS. In this mode, we could answer questions such as: what are the net socio-economic benefits of investing in tropical cyclone early warning systems versus sea-level rise decision support systems?

Identifying the purpose of the study is the most important step in designing the study. It sets the boundary, initial scope, and key questions to be addressed. This information may be provided in a briefing note or via stakeholder workshops. Once the purpose is identified, auxiliary questions can be added, via stakeholder elucidation, to ensure the study meets the requirements of a wider group of stakeholders and decision makers.

Once the purpose of the study is identified it is necessary to identify the scope of the study. That is, to identify what the study will, and won't, cover. This includes regional, sectoral, and welfare considerations. This is an important step that requires significant stakeholder engagement, as stakeholder expectations need to be traded off against the complexity of the overall project.

4.3.2 Step 2. Establish a baseline or reference case

The baseline, or reference case, establishes the accounting stance within which we evaluate and compare the CIS. It also determines the problem-solving context within which we consider alternative CIS investments and outcomes. The baseline then must be defined carefully. It is the pivotal foundation for conducting the socio-economic benefit analysis itself, as well as for framing the policy-making dialogue with government, customers, stakeholders and the wider community.

From the perspective of establishing a suitable accounting stance for the economic analysis, we typically define the baseline as the status quo or business as usual alternative to a particular system or services being evaluated. For example, in the context of, say, a tropical cyclone forecast CIS, the business as usual scenario would be to evaluate the impact of the current forecasting system within the context of future tropical cyclone events. The baseline should reflect the future situation for the community, assuming that the CIS continues in its current form. In other words, we view the future with the current CIS through the lens of likely future conditions. Even in a relatively simple context, the baseline must reflect the future. The reference case must draw on economic growth projections, demographic shifts and changes, climate outlooks, environmental outcomes, societal preferences, future policy settings, and international policy settings.

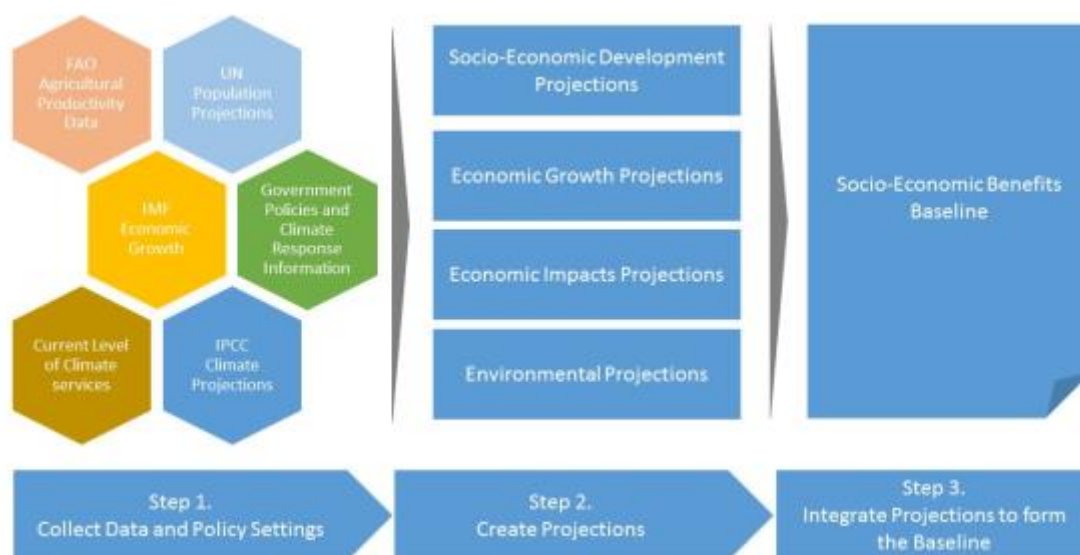


Figure 10. Development of baseline

The development of a baseline (see Figure 10) has three main steps: (1) Collect all relevant information such as local and global economic growth projections, key government policies, climate projections and demographic projections; (2) Create a series of social, economic; environmental and impact projections to represent a business as usual future world; (3) Integrate the projections into the GTAP modelling framework to create an internally consistent baseline.

4.3.3 Step 3. Identification of counterfactuals

To determine what is being valued, we must work out the primary options being considered and what potential alternatives should also be considered in the analysis. Within the scope of CIS, options can include improvements to any part of the supply chain (as shown in Figure 2. Value chain of CIS; adapted from WMO (2015) report). These improvements can include: enhanced basic infrastructure (such as additional observational capacity, new computer facilities), improved basic CIS (such as improved modelling and data assimilation capability), or more tailored specialised CIS (such as climate-based decision support tools).

Extending this framework, CIS may involve improvements or implementation of new or better responses to information including improved forecasting and information delivery, and government policies and response measures to severe weather and rare events.

4.3.4 Step 4. Identification of full range of CIS costs and benefits

In this step, we develop a thorough inventory of all the likely costs and benefits associated with the proposed CIS programme. In general, costs and benefits should be included regardless of to whom they are accrued or where they might be realised. In some circumstances a government may only be concerned with benefits and costs to the citizens of its own country. If decision-makers elect to include only a limited set of benefits or costs in an analysis, this should be made explicit in the discussion. Figure 11 illustrates an example of efforts to identify stakeholders and potential beneficiaries of investment in decision support tools to support better planning around sea level rise.

The advantage of the GTAP modelling framework, as outlined in Section 3.3.2, is that once the initial impacts and costs are identified, the modelling framework can capture all of the remaining knock-on implications.

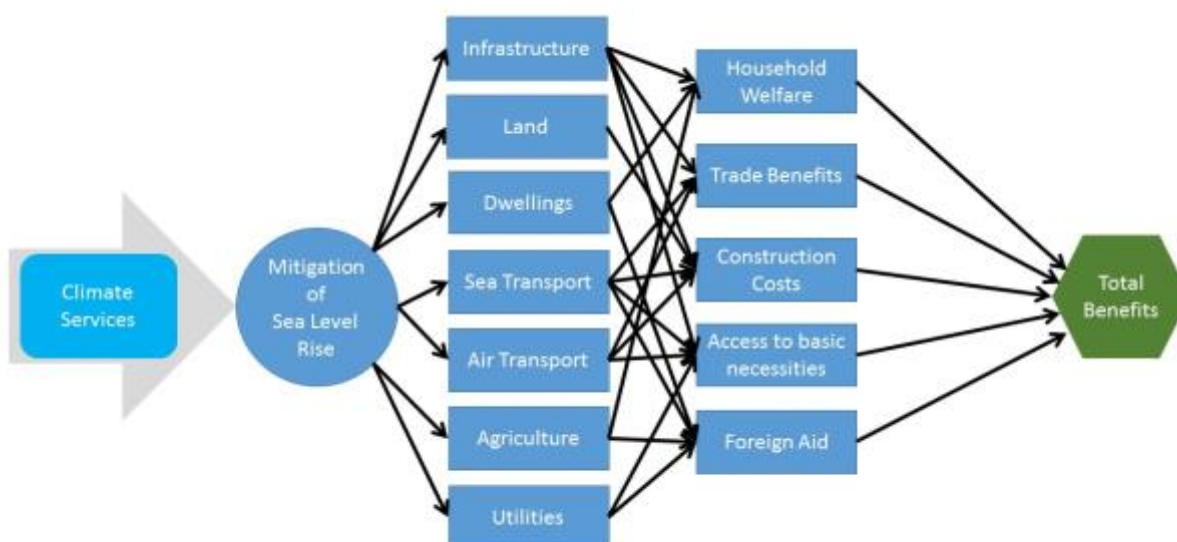


Figure 11. Interconnections between mitigation of sea-level rise and downstream impacts

There are three main ways to help identify the full spectrum of CIS costs and benefits:

- **Econometric analysis.** Econometric analysis involves the development of regression and other statistical models to estimate the relationships between (in this case) weather and climate events and changes in economic output, factors of input, and productivity.
- **Expert elucidation.** Expert elucidation involves obtaining expert opinion as to the potential impact of particular climate or weather events, or how CIS may benefit a particular sector of the economy. This approach also is an active way to engage key stakeholders in the development of the socio-economic analysis.
- **Historical accounts.** Historical records of the impacts of various climate and weather-related events can be used to assess the socio-economic impact of the event, for example, the impacts of Tropical Cyclone Pam can be used to determine the net socio-economic impact on Vanuatu.

Using this information, counterfactual scenarios can be constructed to show how improved CIS and mitigation strategies associated with the improved information benefit the region.

4.3.5 Step 5. Screen benefits and costs for appropriate analytical approach

In the screening step, we determine which costs and benefits can and should be analysed quantitatively and which should be described only qualitatively. Those costs and benefits that are insignificant can be eliminated from the analysis.

4.3.6 Establish the counterfactual cases

Steps 3 to 5 develop the counterfactual cases, that is, what improvements we can expect once the CIS being assessed are deployed. The inputs into this include the costs and benefits that have been identified, the reference case as an anchoring point for the analysis, and any government or other policy responses likely to arise due to the adoption of a given CIS.

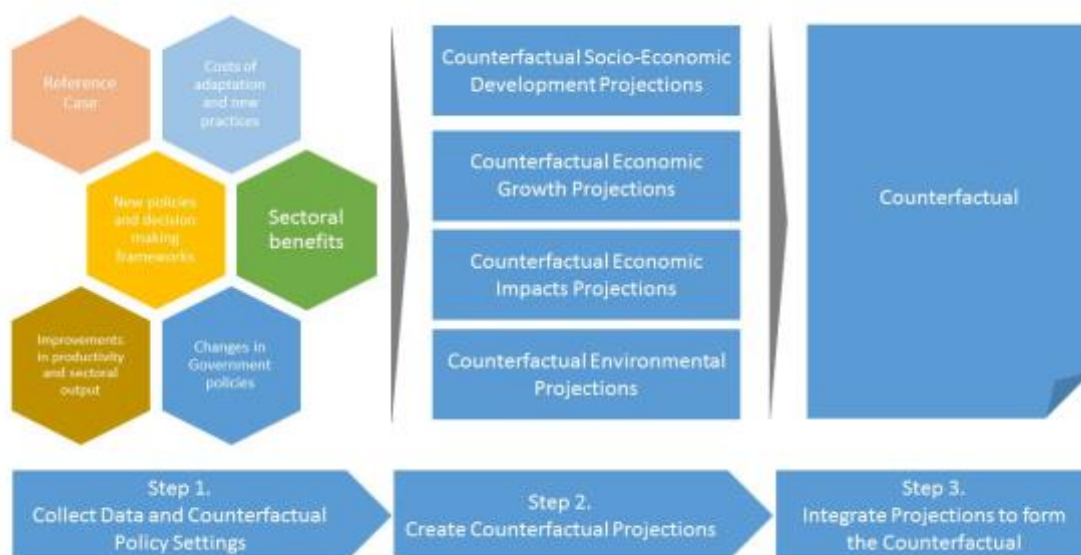


Figure 12. Development of a counterfactual

The development of a counterfactual (see Figure 12) has three main steps: (1) All the relevant information such as local and global economic growth projections, key government policies, climate projections and demographic projections is collected; (2) A series of social, economic; environmental and impact projections are created to represent a counterfactual related future world; (3) The projections are integrated into the GTAP modelling framework to create an internally consistent counterfactual.

4.4 Analysis of the benefits and costs

For any CIS delivery, costs are typically the monetary costs of funding the programme. Some initial costs, including those for capital items, will be required to get the programme started. Once the programme has been launched, there will be continuing costs for running it.

The benefits of a CIS programme typically arise from information the programme produces. We can usually characterise this information directly (e.g. a precipitation forecast with a certain time horizon and accuracy). It is more difficult, though ultimately more important, to characterise the information in terms of its potential

users and what they use information for in decision-making. For example, a long-range precipitation forecast would have uses in agriculture and water resource management, and likely in other areas as well. Although it may be difficult to determine the ultimate impacts of a CIS programme on users, we must understand the causal link in order to assign an economic value to such efforts.

To determine the benefits of a project, then, we must understand the following aspects of the valuation problem:

- The type of information being delivered;
- The types of decisions being made using the information and how the information affects these decisions;
- The beneficiaries of the climate services (where the benefit is being accumulated); and
- The temporal and spatial scales of the values being generated.

We must also understand the CIS delivery process and the associated value chain – as shown in Figure 2. Value chain of CIS; adapted from WMO (2015) report – before we can estimate economic value. Although CIS programmes focus mainly on activities related to mitigation and adaptation to a changing climate, much of the value added or lost occurs in communication and decision-making. Ultimately, value accrues from the subsequent change in behaviour and practices of users and the outcomes of their decisions.

4.4.1 Step 6. Assess the value of benefits and costs in monetary terms

In this step, to the extent possible, we express the costs and benefits of a proposed CIS programme in monetary terms (quantitatively). Costs are typically already in monetary terms, but expressing where those costs are carried and placing a monetary value on benefits is the central challenge for establishing the benefits of a CIS programme.

The outputs of a CIS programme typically have more than one use (and more than one user). Climate information services can also be transformed or augmented before final users receive the information. Ideally, we should identify all uses and determine the benefit accrued from each use. This often requires both expertise or understanding with respect to specific uses (e.g. sea-level rise, tropical cyclones) and proficiency with respect to methods used to value information.

Valuing information essentially requires that we understand how users of information would act, both with and without access to the information, and how the wider economy would respond to those user decisions. Next, we must find a way to estimate the increase in value produced, or the reduction in costs incurred, that results when the information is available and used.

One commonly used method to estimate value of information in the climate context is the economic modelling of the situation in which the information is used (see Section 3). Economic modelling involves mathematically representing decision-making and the value or cost outcomes that result, both with and without information. This makes it possible to calculate the value increase or cost reduction attributable to the information.

Figure 13 shows the conceptual flow of the present study. The baseline and counterfactual are codified into the GTAP modelling framework. The output of the model is a series of economic projections that are the result of implementing alternative CIS.



Figure 13. The analysis framework where baseline and counterfactuals are analysed through the GTAP model

4.4.2 Step 7. Summarise and compare all CIS benefits and costs

The result of step 6 is that all the quantitative and qualitative information on the costs and benefits that have been estimated for the change in climate information services. Step 7 involves two distinct calculations. First, all costs and benefits must be adjusted and aggregated into present value terms employing a discount rate specified in regulations or agreed to by the stakeholders or government decision-makers. The second calculation is to compare the alternative present value terms, typically by applying the net benefits or the BCR decision criterion.

4.4.3 Step 8. List all omissions, biases and uncertainties

In this step, we explicitly document all omissions, biases, and uncertainties associated with the estimated benefits and costs. The impact that these may have on the final outcome of the analysis (e.g. in terms of their likelihood of increasing or decreasing net benefits, or an uncertain direction of change in net benefits) should be noted.

4.4.4 Step 9. Conduct sensitivity analyses on key variable values

Here, we conduct sensitivity analyses on key variables or benefit and cost estimates, with the aim of exploring and communicating the impact of assumptions, uncertainties, or natural variabilities. We use sensitivity analyses to identify which assumptions or uncertainties have the largest impact on the outcome of the analysis (e.g. to identify which assumptions might change the net benefits of an option from positive to negative or to alter the ranking of options in terms of their relative net benefits). We discuss this further in the next section.

4.4.5 Step 10. Compare analysis results to stakeholder perception of value

In this step, we compare the quantitative and qualitative values that result from the analysis and from the various sensitivity analyses with stakeholder expectations of values. This comparison can be informative both as a check on the reasonableness of the analysis results and as a process for working with stakeholders to help them realise (or at least better articulate) the values they obtain from the project. This understanding of values can become the basis for cost-sharing agreements with stakeholders according to the relative shares of benefits derived from the project.

In the CIS context, stakeholders are typically the users of the outputs that are produced by the programme under consideration. These users will often be diverse and perhaps hard to identify. Sometimes, they will not yet have developed the systems or behaviours that will allow them to take advantage of new information.

4.4.6 Analysis from the GTAP model

As outlined in Section 3.3, the GTAP model is a very rich analytical framework which can be used to provide triple bottom-line costs and benefits at the household, regional, national and international scales. Figure 14 illustrates some of the benefits and costs that can be assessed from the model at these various levels.

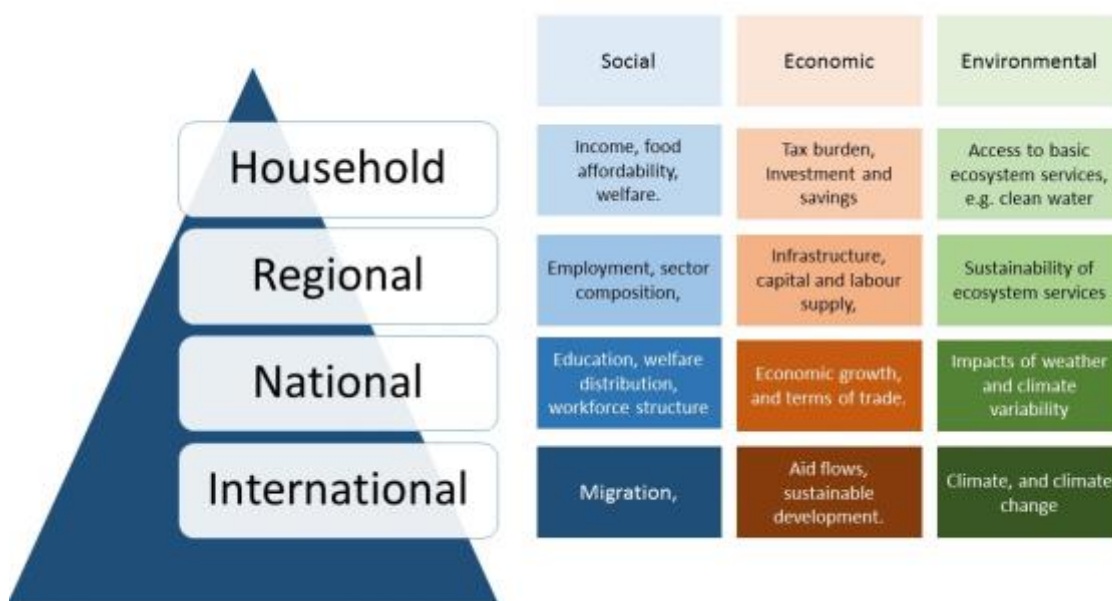


Figure 14. Areas of impact that the GTAP model can help quantify

4.5 Review, evaluate and communicate key findings

4.5.1 Step 11. Formulate the final report and communicate findings

In this final step, we compare and document the quantitative and qualitative values that result from the analysis and from the various sensitivity analyses against stakeholder expectations of values. This comparison can be informative both as a check on the reasonableness of the analysis results and as a process for working with stakeholders to help them realise (or at least better articulate) the values they obtain from the project. This understanding of values can become the basis for cost-sharing agreements with stakeholders according to the relative shares of benefits derived from the project.

In the CIS context, stakeholders are typically the users of the information that is to be produced by the programme under consideration. These users will often be diverse and perhaps hard to identify. Sometimes, they will not yet have developed the systems or behaviours that will allow them to take advantage of new information.

Any socio-economic analysis must be carefully planned, starting with the initial scope of the study and finishing with the delivery of a detailed report. It is tempting to think of the publication of the final report as the end of the process. The outcomes of a socio-economic analysis are likely to be of interest to several different audiences. As a result, it is necessary to have tailored outputs to engage them appropriately. The successful communication of the final results will build a wider support and funding base for CIS.

4.5.2.1 Internal audience. Managers of CIS will be some of the first users of the outcomes of a socio-economic cost-benefit study. They are likely to be instrumental in commissioning the development and deployment of CIS, as well as in directing the socio-economic analysis. They will need to pick a clear and consistent message from the study outcome so that they can argue for resources for sustainable development and the delivery of CIS.

4.5.2.2 External audience. Government agencies, especially finance and public service ministries, will be a key target for effective communication of socio-economic benefits of CIS. With CIS being primarily a public good, these government agencies need to engage with, and have a full understanding of, the benefits of climate services on the economy and society. This will require a proactive approach, with tailored products and presentations given to the appropriate ministries. For example, the Ministry of Finance will want to see the ‘hard economic’ implications of improved climate services, whereas a Ministry of Health would want to see how net household welfare would improve and how quality of life would change. Ideally, the information would be delivered by presentations in which the key messages are presented, with the details readily available, and the questions and concerns of the officials could be answered and teased out in discussion afterwards.

4.5.2.3 Donors and other funding agencies. While all the communication strategies and plans are important, those aimed at donor support and the like are perhaps the most important, as they can leverage significant benefits and provide additional funding for CIS beyond that which national governments can typically provide as part of developing economies. Communicating with donors does not exist in a vacuum, and mainstream media coverage will affect donor perceptions of the benefits of CIS. However, this information needs to be supported by specific information on the key benefits.

4.5.2.4 End users. The publication of the socio-economic analysis is an opportunity to broaden and deepen engagement with key stakeholders and end users. Initially this can be done via the dissemination of key information through existing channels such as newsletters, where the interested reader can be directed to a summary document or the complete analysis. Opportunities should be created, such as workshops and seminars, for the user community to meet with the socio-economic analysis team and relevant climate services team members to allow users to ask questions and to probe the findings. This also provides an opportunity for the socio-economic analysis team to explore additional concerns of the users, and gain a greater awareness of the range of benefits which may be afforded by more targeted or more advanced analysis.

4.4.2.5 Academic audiences. This is a very specific community which may be interested in both the methods and results of the socio-economic analysis. To ensure the scientific and intellectual rigour of the analysis it is important that the findings be disseminated in peer-reviewed journals.

5 Case study of mitigating the impacts of sea-level rise

Pacific Island nations are among the most vulnerable countries in the world to the effects of climate change and natural disasters. According to a World Bank report, eight Pacific Island countries are among the 20 countries in the world with the highest average annual disaster losses scaled by gross domestic product (World Bank, IFC, and MIGA 2016).

5.1 The risk from sea-level rise

Roughly 44% of the world's population – more than 3.13 billion people – live in coastal areas. Coastal regions and large areas of low-lying land, such as Pacific Island nations, are particularly vulnerable to rising seas and coastal storm surges. The risks to these communities include:

- **Shoreline erosion and degradation.** Rising sea levels allow waves to penetrate further inland, even during calm conditions, increasing the potential for erosion.
- **Amplified storm surges.** Coastal storms often cause storm surges, which occur when high winds push water inland. With rising seas, storm surges occur on top of an elevated water level and reach farther inland, with potentially catastrophic damage to homes and infrastructure.
- **Permanent inundation.** Many low-lying coastal land areas are expected to be gradually submerged by rising sea levels.
- **Saltwater intrusion.** Saltwater can reach further into coastal groundwater sources as sea level rises, increasing the salinity of fresh water used for drinking and agriculture.

Figure 15 shows the effect of sea-level rise on coastal settlements, how storm surges and flood plains will shift over time. Sea level sets the baseline for storm surge, the potentially destructive rise in sea-level height that occurs during a coastal storm. As local sea level rises, so does that baseline, allowing coastal storm surges to penetrate farther inland. With higher global sea levels in 2050 and 2100, areas much further inland would be at risk of being flooded. The extent of local flooding also depends on factors such as tides, natural and artificial barriers and the contours of coastal land.

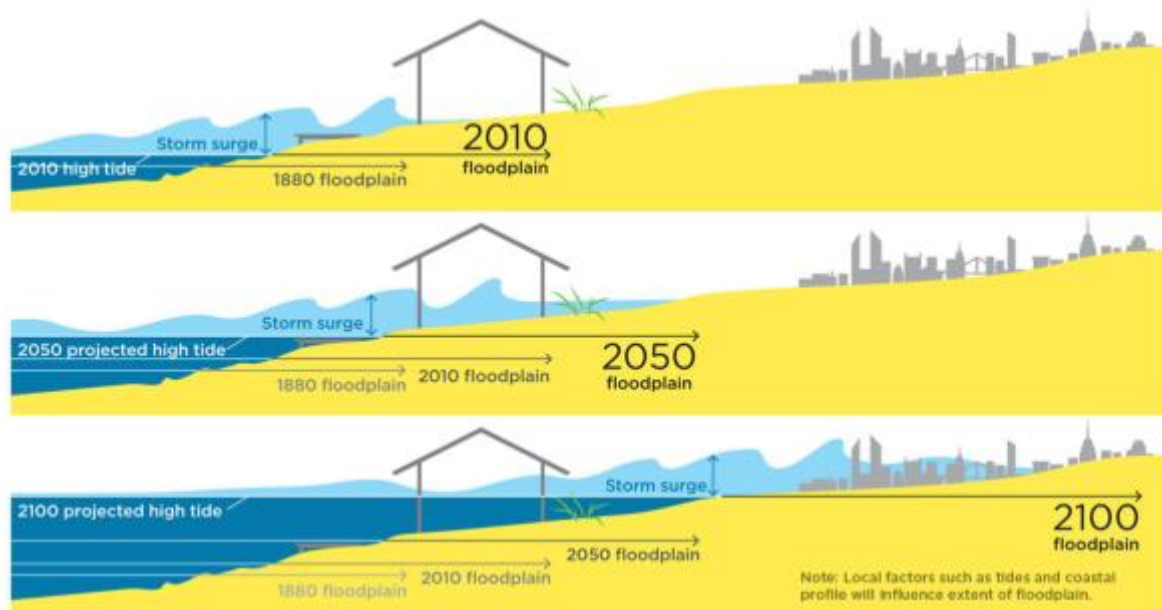


Figure 15. Impact of sea-level rise on storm surges, infrastructure and floodplains. Source: Union of Concerned Scientists (2015)

To mitigate the effects of sea-level rise, communities must weigh the costs and risks of accommodating rising seas, retreating from them, or trying to defend coastal properties and infrastructure with protective measures. These measures can include:

- Traditional defensive approaches, such as building seawalls and levees, or replenishing sand along eroded beaches. This can help protect against flooding and damage but may not provide adequate or sustainable long-term protection.
- Maintaining or restoring natural buffers, such as barrier islands, tidal wetlands, and mangroves, can also help defend coastlines.
- Measures like elevating and flood-proofing structures can help accommodate temporary flooding and gradual inundation.

The most vulnerable coastal communities may increasingly need to consider the stark option of some form of retreat from the rising seas.

To limit the long-term risks of sea-level rise and the costs of adapting to it, we must work toward deep reductions in the global warming emissions that are the primary cause of rising sea levels.

5.1.1 Infrastructure at risk

Pacific island countries have highly populated urban centres that are located on the coastal margin. As a result, the built infrastructure (such as dwelling, businesses, resorts, ports and airports) required to support these urban centres is also located within close proximity to the coastlines. The close proximity of the infrastructure to the coastline exposes them to a variety of natural and climate change-related hazards. Kumar and Taylor (2015) undertook a comprehensive analysis of the exposure of built infrastructure assets to climate risks for a number of Pacific Island countries. They found that 57% of the assessed built infrastructure for countries surveyed was located within 500 m of their coastlines, and estimated a total replacement value of US\$21.9 billion. Eight of the countries surveyed had 50% or more of their built infrastructure located within 500 m of their coastlines. Kiribati, Marshall Islands and Tuvalu have over 95% of their built infrastructure located within 500 m of their coastlines.

Figure 16 shows the breakdown of the replacement value of built infrastructure (percentage of country total) within each interval from the coastline for 12 Pacific Island countries.

Beyond the replacement cost, the loss of this infrastructure would cause significant disruption to utilities, port operations, fisheries, and other sectors of the economy. Coastal adaptation costs will require substantial financial resources, which may not be available in developing countries. Climate services can tailor information products that can help decision-makers make more informed decisions about the construction, replacement and defence of coastal assets.

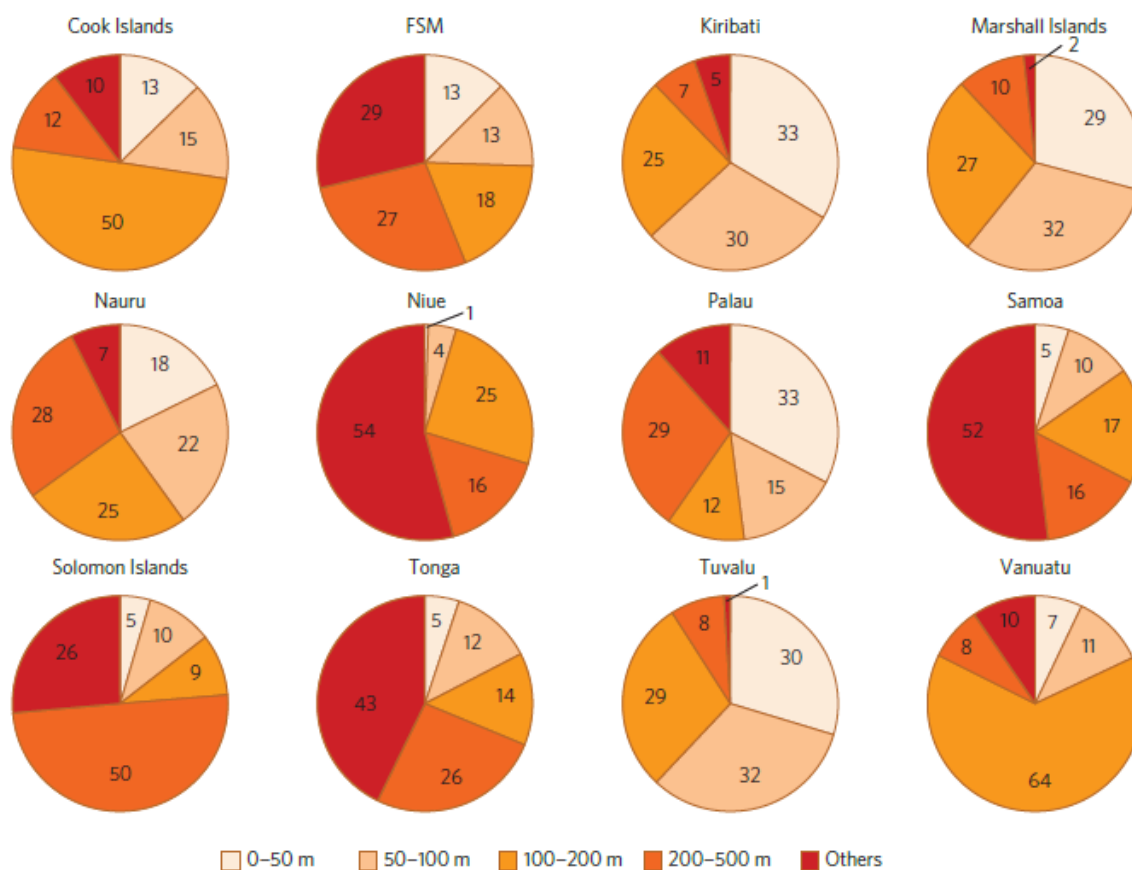


Figure 16. Replacement value of built infrastructure (percentage of country total) within each interval from the coastline. From Kumar and Taylor (2015)

5.1.2 Climate services and decision-making

Climate model simulations of sea-level rise and LiDAR topographical surveys of coastlines can be combined within a geographical information systems framework to produce a decision-support tool. This tool can help planners, policy-makers and other key decision-makers make key investment decisions around the impacts of sea-level rise and how to mitigate its affects. This can include future planning of the location of key infrastructure development, developments of barriers or any of the other mitigation measures listed in the previous section.

An example of such a decision-support tool, the Coastal Risk Dashboard (<http://coastalriskdb.com/>) is shown in Figure 17. This tool allows policy-makers to explore the impacts of sea-level rise and identify at-risk areas under alternative sea-level rise and storm surge scenarios.



Figure 17. The Coastal Risk Dashboard allows decision-makers to explore the impacts of sea-level rise by combining climate change projections with LiDAR information into a GIS platform. (Source: <http://coastalriskdb.com/>)

5.2 Case study design

The key focus of this case study was to estimate the socio-economic benefit of CIS-based improved decision-making around investment and protection of coastal assets and infrastructure in Pacific Island nations. There were three main steps in conducting the study:

- Develop a model aggregation that represented the key sectoral and regional economic activities;
- Establish a reference case, against which the counterfactuals will be evaluated; and
- Establish the counterfactual scenarios.

In reality, these steps would be conducted with detailed engagement with key stakeholders from regional governments and sector representatives. Due to the resource and time constraints of the present study, the stakeholder engagement was limited to two in-country stakeholder meetings in Vanuatu. This means that the full implications of the study may not be realised, but for the purposes of illustration the level of consultation was adequate.

5.2.1 Regional and sectoral aggregation

The GTAP model is based on the GTAP database, with economy-wide information for 140 regions of the world across and 57 sectors of the economy. To make the analysis more tractable, it is necessary to aggregate the sectors and regions into larger regions. As we are interested in the impacts of sea-level rise on Pacific Island countries, we have created an aggregation that has Pacific Island countries as a separate region, although this is itself an aggregate region, its main trading and foreign aid partners, and similar collection of island nations (for comparison) and other major geographical and economic regions. The aggregation is described in Table 2. We have aggregated the economy into 14 sectors, listed in Table 3. We note that alternative aggregations are possible, and aggregations should be determined by the question under investigation.

Table 2. Regional Aggregation for the GTAP model

Region Name	Code	Countries composing region
Oceania	XOC	American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Futuna
Australia	AUS	
New Zealand	NZL	
Asia and the Subcontinent	ASC	China, Hong Kong, Japan, Mongolia, Taiwan, Democratic People's Republic of Korea, Macao, Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Myanmar, Timor Leste, Bangladesh, India, Nepal, Pakistan, Sri Lanka, Bhutan, Maldives
Caribbean	CAR	Jamaica, Puerto Rico, Trinidad and Tobago, Anguilla, Antigua & Barbuda, Aruba, Bahamas, Barbados, Cayman Islands, Cuba, Dominica, Grenada, Haiti, Montserrat, Netherlands Antilles, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Turks and Caicos Islands, British Virgin Islands, US Virgin Islands
USA	USA	
Canada	CAN	
Korea	KOR	
Russia	RUS	Russia, Tajikistan, Turkmenistan, and Uzbekistan
Developed and Emerging Nations	DEN	Mexico, Argentina, Brazil, Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Poland, Portugal, Slovakia Slovenia, Spain, Sweden, United Kingdom, Saudi Arabia, South Africa
Rest of the World	ROW	Rest of the world not elsewhere classified

Table 3. Sectoral Aggregation for the GTAP model

Sector Name	Code	Composition
Crops	CRP	Paddy rice, Wheat, Cereal grains nec, Vegetables, fruit, nuts, Oil seeds, Sugar cane, sugar beet, Crops nec
Livestock	LIVSTK	Cattle, sheep, goats, horses, animal products nec
Agricultural products	AGPRD	Plant-based fibres, Raw milk, Wool, silk-worm cocoons
Forestry	FOR	
Fisheries	FISH	
Manufacturing	MFG	Meat products nec, Vegetable oils and fats, Dairy products, Processed rice, Sugar, Food products nec, Beverages and tobacco products, Textiles, Wearing apparel, Leather products, Wood products, Paper products, publishing, Petroleum, coal products, Chemical, rubber, plastic prods, Mineral products nec, Ferrous metals, Metals nec, Metal products, Motor vehicles and parts, Transport equipment nec, Electronic equipment, Machinery and equipment nec, Manufactures nec
Transport	TRNS	Transport nec
Sea Transport	STRNS	Sea transport

Air Transport	ATRNS	
Natural Resources	NRES	Coal, Oil, Gas, Minerals nec
Water Services	H ₂ O	
Trade	TRADE	
Energy Sector	ELY	Electricity
Services	SER	Construction; Communication; Financial services nec; Insurance; Business services nec; Recreation, Tourism and other services; Public Administration, Defence, Health, Education, Dwellings

5.2.2 Reference case

The reference case has been defined as the current situation with data from existing meteorological services including the basic infrastructure and basic services as described in Section 1. The reference case assumes that sea-level rise, storm surges and inundation are externalities and have no effect on the economy.

5.2.3 Counterfactuals

To illustrate the economic implications of sea-level rise and the potential avoided socio-economic damages, we will make use of two counterfactuals. The first counterfactual assumes that the current level of investment in basic CIS is maintained, and that based on this information decision-makers are able to make a decision about future infrastructure, economic investments and coastal adaptation measures. These decisions are far from optimal. We will refer to this case as the 'sea-level rise scenario'.

The second counterfactual assumes there is an additional investment in tailored CIS to support sectoral decision-making around coastal adaptation and infrastructure investments. These decisions are better than those made under the sea-level rise scenario, but there are still unavoidable impacts from sea-level rise. We will refer to this as the 'mitigated sea-level rise scenario'. This scenario assumes that there is additional government investment in CIS, which is invested into the existing CIS sector, and additional payments to the construction sector to implement the required mitigation steps.

Table 4 lists the key economic shocks and policy changes analysed in the GTAP model. It should be realised that these values are purely illustrative, and that in accordance with the framework outlined in Section 4, these shocks would be developed in consultation with key stakeholders and decision-makers. This selection of values was obtained via limited stakeholder engagement, and a literature survey.

Table 4. Economic shocks used in the experiment

Economic shock or policy setting	Sea-level rise scenario	Mitigated sea-level rise scenario
Reduction in infrastructure due to storm surges damage, flooding and loss of infrastructure	7%	4%
Reduction in sea transport efficacy, due to lost infrastructure and reduced operating conditions of harbours	6%	4%
Reduction in air transport efficiency, due to flooding and storm surge damage to infrastructure	3%	2%
Reduction in transport efficiency due to storm surge and flooding damage to roads, bridges and infrastructure	2.5%	1.5%
Reduction in the productivity of fisheries due to reduced operating capacity of harbour and ports	5%	3%
Reduction in crop output due to inundation and flooding	4%	2%
Reduction in forestry output due to inundation and flooding	3%	2%
Reduction in shipping efficiency, to Oceania from other regions, due to change harbour productivity	8%	6%
Increase in government funding to climate services	–	1%
Increase in government funding to mitigate sea level rise	–	3%

5.3 Results

5.3.1 Gross domestic product

The gross domestic product (GDP) of Oceania in the reference year of 2015 was around US\$44 b. Under the sea-level rise scenario, the GDP of Oceania is expected to fall by almost 8%, by contrast the mitigated sea-level rise would see a 3.5% reduction in GDP (Figure 18). This equates to net economic losses of around US\$3.5 b and US\$1.5 b respectively. At the aggregate region level, mitigation of sea-level rise will save US\$2 b. As this is an aggregate region, the impacts will vary across individual countries, with some countries receiving disproportionately higher impacts than others – so an important step in future development is to disaggregate the region into individual countries and economies.

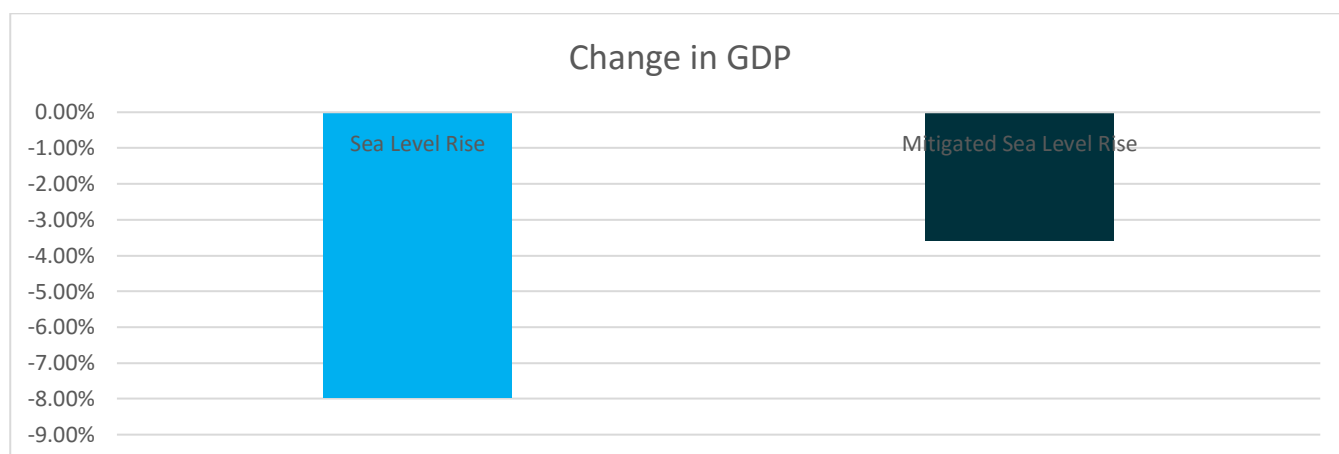


Figure 18. Comparison of the GDP outcomes for the two counterfactual scenarios

5.3.2 Changes in economic output

The GTAP model tracks both the prices and output of each sector of the economy. Figure 19 and **Error! Reference source not found.**, respectively, show the changes in commodity prices and sectoral output for each sector of the Oceania Region. These changes are shown relative to the baseline for each counterfactual.

Under the sea-level rise scenario, trade, fisheries, forestry, air transport and sea transport all have significant price increases for their goods and services. This is reflected in the change in sectoral output. These changes are driven by the loss in efficiency and productivity, and increased transport costs. Labour-intensive sectors that require relatively little capital investment such as services, see a net decrease in prices, as labour is transferred from the other sectors. The natural resources sector also follows this trend, but this could be limited as flooding could limit the productivity of resource extraction.

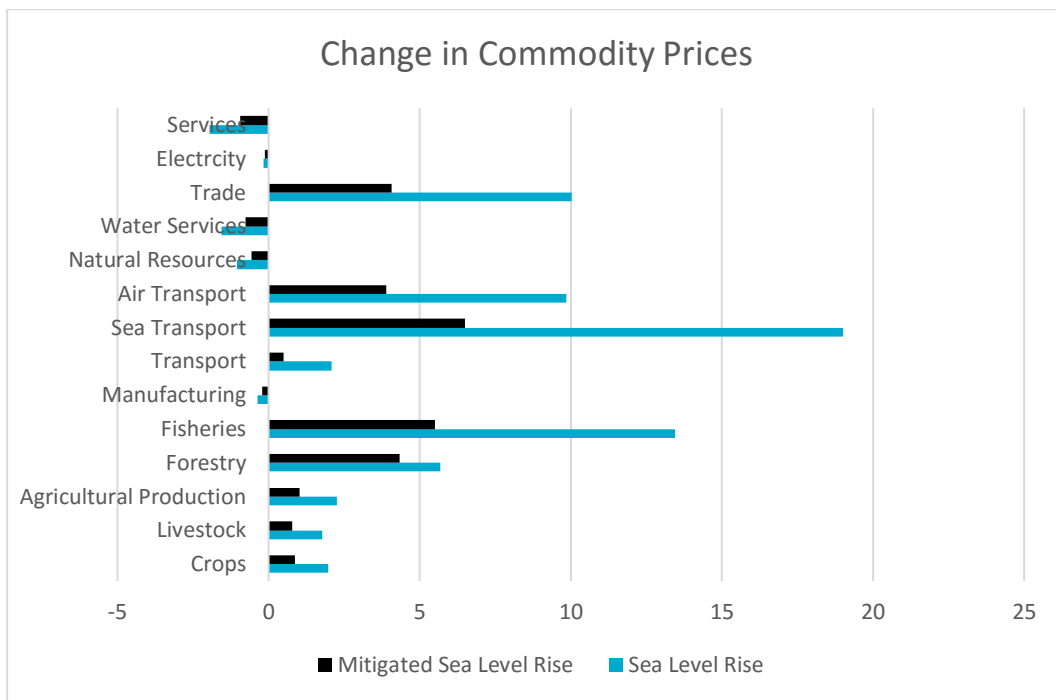


Figure 19. Changes in commodity prices relative to the baseline

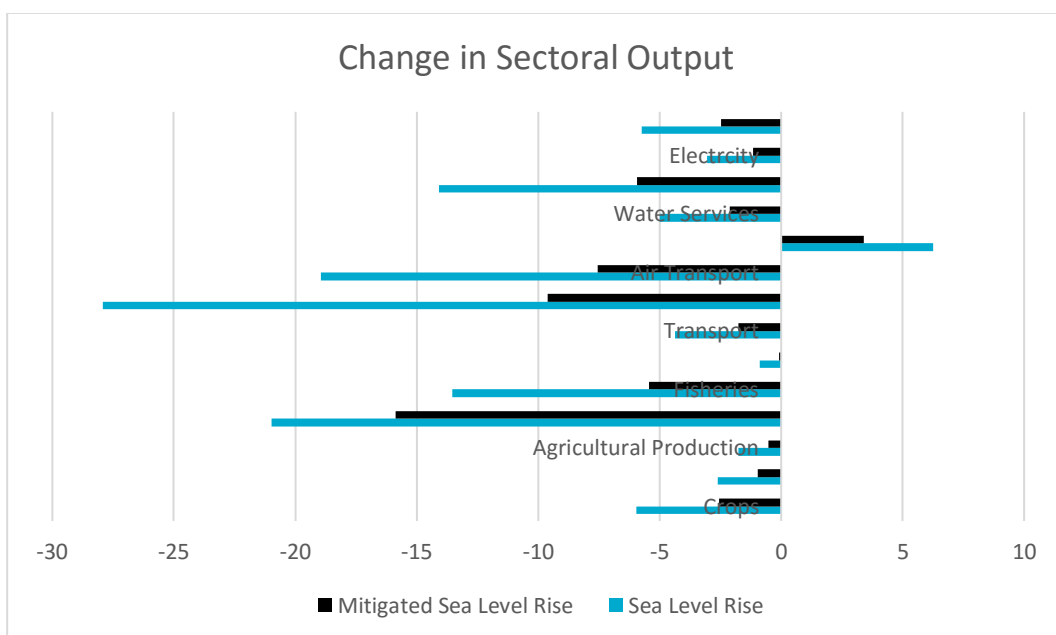


Figure 20. Changes in sectoral output relative to the baseline

5.3.3 Change in imports and exports

Figure 21 and Figure 22 show that there are significant changes to the imports and exports of the region due to sea-level rise.

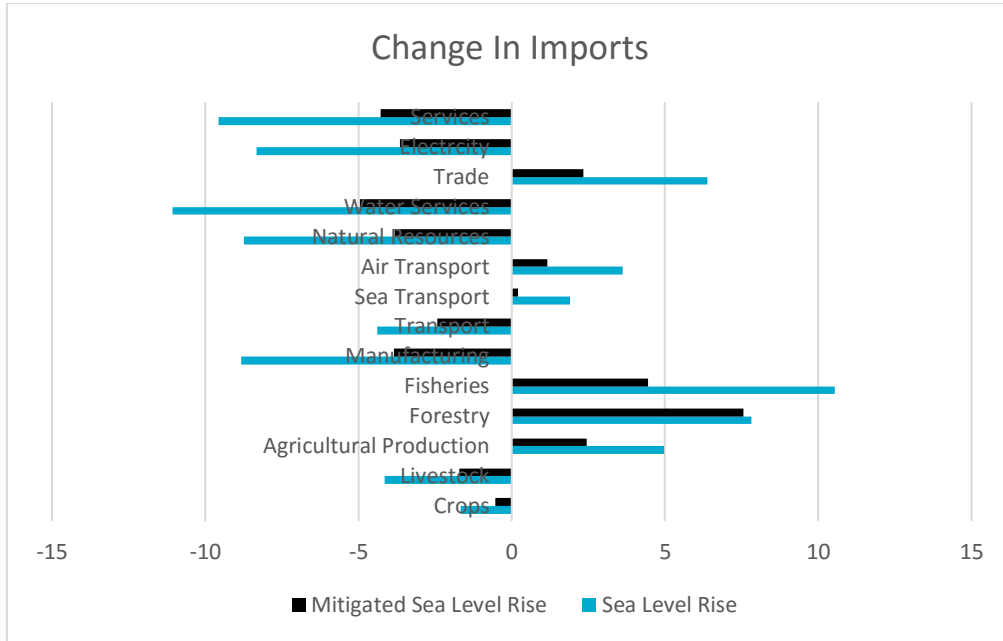


Figure 21. Changes in regional imports

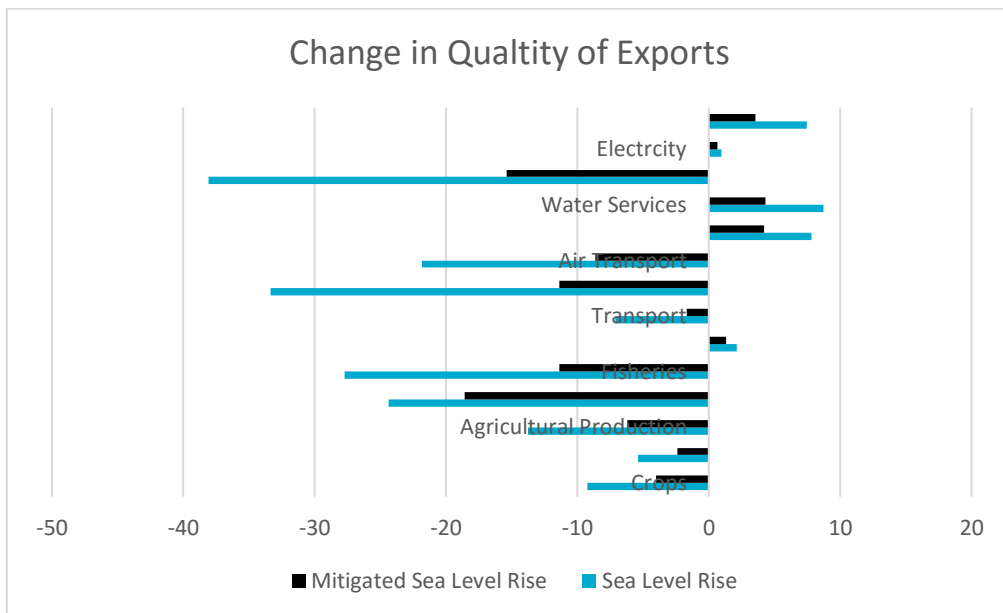


Figure 22. Changes in regional exports

5.3.4 Household welfare

Figure 23 illustrates the changes in household incomes for the two counterfactual scenarios. Under the sea-level rise scenario, household income is reduced by an average of US\$612 per household, while under the mitigated sea-level rise scenario the reduction is estimated to be US\$276 per household. This in turn has a significant impact on household income, as the Vanuatu household income expenditure survey (Vanuatu

National Statistics Office 2012) lists the average household income to be between \$US8,511 and US\$10,585. Again, this reduction in household income is at the aggregate region level; impacts will vary across individual countries, with some countries receiving disproportionately higher impacts than others.

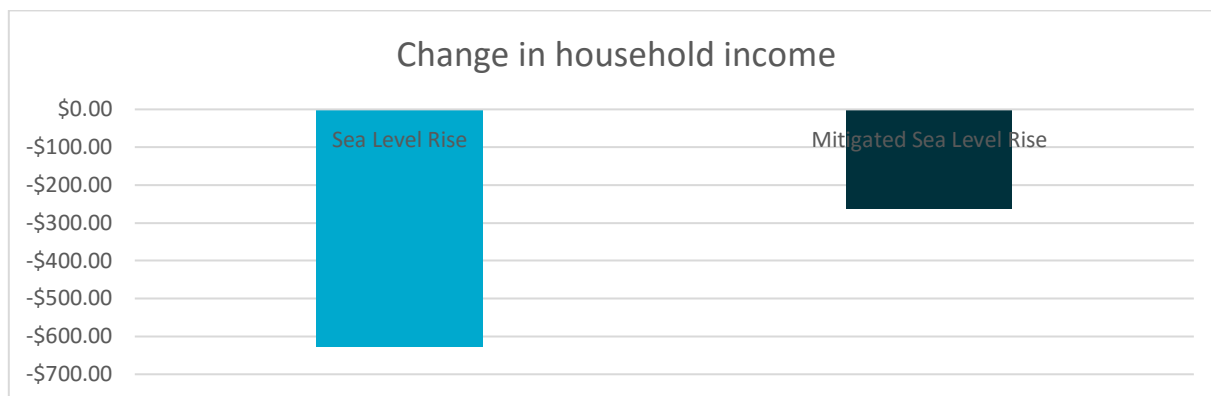


Figure 23. Change in household incomes

5.4 Key messages

The two counterfactuals used here to assess the impact of sea-level rise and storms surges, and the net benefit of improved decision-making through CIS to limit the impact of these events on the economy, have illustrated that even modest reductions in the impact of such events have significant social, economic and welfare implications for the regions affected.

6 Useful steps in undertaking socio-economic cost-benefit analysis of CIS

6.1 Basic steps

The previous section provided a sample case study, and illustrated the type of analysis that is possible with the GTAP modelling framework. As there is likely to be ongoing investment in climate services it is therefore important from an investment, as well as a monitoring and evaluation, point of view to have a socio-economic cost-benefit analysis programme that demonstrates the value of CIS as they are being developed and rolled out. This will require three main steps that will proceed concurrently: (1) Continual stakeholder engagement; (2) Extending the case studies and study scope into real-time, on-ground applications; and (3) Expanding the modelling capability.

6.1.1 Continual stakeholder engagement

As identified earlier, the purpose of a socio-economic analysis in the present study is in part to engage a wide cross section of stakeholders so that there is 'buy-in' and support for CIS, as the stakeholders can see what the value of particular climate services is to them. Beyond the socio-economic analysis, stakeholder participation in the process can help:

1. Guide the required data collection. Identify any gaps in the data that is being collected, and help direct future data collection efforts.
2. Explain and validate the likelihood of the estimated socio-economic changes and why we are likely to observe certain socio-economic outcomes. Nearly every policy lever/tool available to decision-makers is available within the GTAP modelling framework. The framework is also transparent, so as certain interventions and policy decisions are made, the implications of the decisions can be traced through from decision to likely socio-economic and welfare outcomes.
3. Help shed light on core dynamics of the analytical approach. This will help stakeholders understand interlinkages between various parts of the economy that are not directly obvious.
4. Promote a quantitative approach to policy development and decision-making. Through a robust modelling framework, stakeholders can experiment with certain decisions, and explore various economic, social, trade, production, and welfare outcomes of their decisions.
5. Discover new points of intervention. Through participation in the socio-economic benefit analysis, stakeholders are exposed to how their local (e.g. sector-specific) decisions are connected to outcomes in the rest of the economy. The modelling framework can be used to help show policy- and decision-makers that increased investment in other parts of the economy have a significant co-benefit for their sector of interest and general economic and social welfare.
6. Offer a structured and transparent methodology for decision-making. As practitioners become more familiar with the methodology and approach, they can begin to ask questions and explore the trade-offs they may make with respect to their decision-making process.
7. Discipline the policy dialogue. As the proposed modelling framework is economy-wide, it forces policy- and decision-makers to understand the full range of socio-economic outcomes, identifying

winners and losers, and directing their attention to the formation of robust policies, including how to compensate for the losers to undergo the required adjustments

8. Participatory ownership of the process. As the previous points show, stakeholders who actively engage in the socio-economic benefit analysis will benefit from not only output of the analysis (understanding the costs and benefits), but also from participating in the process.

6.1.2 Extending the case studies and study scope

As more and improved CIS become available, it is important that the socio-economic cost-benefit analysis is extended to cover these CIS, and climate-related events in real-time, on-ground situations. Initial stakeholder meetings will help identify the key sectors and parts of the economy that are most vulnerable to climate and weather events that may correspond to these new CIS. A few examples of these sectors are explained below.

1. **Tourism.** For the Pacific Islands, tourism is a major economic activity. Any reduction in tourism will have significant implications for the economic activity and welfare of the region. From a climate perspective, this includes loss of access to the region due to loss of air and sea transport, loss of attractions such as coral reefs (through bleaching events) and beaches (through sea-level rise and inundation), as well as changes in tourists' preferences due to changing weather patterns.
2. **Infrastructure.** As illustrated by the case study in Section 5, infrastructure is particularly vulnerable to sea-level rise. To assess the socio-economic benefits of protecting infrastructure from climate and weather events, it will be necessary to develop inventories and vulnerabilities of at-risk infrastructure by sector and by climate event. Loss of infrastructure has a direct cost to the economy and welfare through the financial costs of replacement, and an indirect cost through loss of productivity. Hence, the protection of key infrastructure assets is very important for the sustainability of the regional economy of the Pacific Islands.
3. **Dwellings.** Loss or damage to dwellings will have significant social welfare implications. Cost of repair and rebuilding, cost of relocation and resettlement of occupants and related costs of emergency shelter and support will have significant economic and social costs.
4. **Ports and transportation.** The Pacific Islands are reliant on international shipping to support their economies. Sea-level rise, storm surges, cyclones, flooding and other climate-related phenomena will reduce the capacity of these major pieces of infrastructure to function efficiently, reducing the overall productivity of the economy.
5. **Agriculture and fisheries.** The production of crops, livestock and fisheries is a fundamental part of almost every economy in the Pacific, and this is among the most sensitive to climatic changes. Improved seasonal forecasting and other climate services can help farmers and fishers plan for future cropping and harvesting regimes and ensure food security.
6. **Improved forecasting capability.** Beyond the sector-specific impacts listed above, improved predictive and forecasting capability such as improved early warning systems can have a significant economic and social benefit through avoided damage. Federal US expenditure in response to hurricanes Katrina, Rita and Wilma was US\$109 billion. Lazo and Waldman (2011) found that US households were willing to pay US\$13 for an improved hurricane forecasting system.

6.1.3 Expanding the modelling capability

The socio-economic benefit analysis is underpinned by a quantitative approach to socio-economic benefits. As Section 3.3 points out the basic GTAP model only has certain capability, and is not specifically designed to

provide a detailed socio-economic benefit assessment of CIS. As more case studies are undertaken and stakeholder engagement increases it will be necessary to extend the modelling capability to include:

1. Increased regional resolution. This will allow, for example, the analysis to drill down and see the net socio-economic impact of sea level rise on (for example) Vanuatu versus Tonga, or between islands within an archipelago such as Vanuatu. This will aid in identifying more 'at-risk' and vulnerable regions, further allowing for more targeted regional delivery of climate services.
2. Increased sectoral resolution. The Pacific Islands are dependent on key sectors of the economy that are not well represented in the basic GTAP modelling framework. This will require obtaining national level data about the key sectors, and creating new sectors within the GTAP database, as well as calibrating key economic parameters to reproduce the prevailing economic structures.
3. Improvement of key economic processes. Public goods such as CIS are not presently represented within the basic GTAP modelling framework. Expanding the GTAP framework to include meteorological supply chain is important as the focus of this work is on CIS. This will create a unique modelling capability. Also, foreign aid flows and multiple representative households should be included within the framework to help better assessment of welfare changes across different household groups, and different demographic cohorts in the regions.

6.2 Implementation of CIS socio-economic analysis programme

The development of a structured framework for CIS-based socio-economic analysis will require a multi-year effort. We envisage the development and implementation of the framework to proceed in five phases. Each phase will need to include elements from each of the three areas listed in Sections 6.1.1 to 6.1.3. Each phase of the project aims to increase the skill, capability, stakeholder engagement in and awareness of climate services.

6.2.1 Phase 1: Basic socio-economic analysis and engagement

In this first phase the aim is to engage and educate (i.e. build capacity in) key stakeholders around socio-economic benefit analysis. This first phase is around building stakeholder and climate service modelling team engagement as well as highlighting the incorporation of the needs of local communities.

Key activities in Phase 1:

1. Delivery of real-time, in-country/on-ground sectoral demonstration case studies such as described from Section 5. This is to demonstrate the core capability and to engage stakeholders to refine the key inputs.
2. Participatory modelling exercise to gain expert elucidation of the potential impacts of climate events on various sectors of the economy. In a workshop environment, participants would be surveyed for their views on how climate will impact various key sectors of the economy and gauge their expected level of mitigation. These inputs would then be fed into the model to provide feedback to stakeholders in the form of net socio-economic implications of climate change given their mitigation and adaptation choices.
3. Development of key focused case studies, either around climate events or the delivery of CIS.

Deliverables and Outcomes of Phase 1:

1. Increased awareness of the socio-economic benefits of the use of improved CIS.

2. A synthesis report on the participatory modelling exercise, its outcomes, key findings, and direction setting for the socio-economic benefit analysis.
3. Refined set of case studies, with a clear scope and boundary for those case studies. These case studies will replace the initial conceptual case study described in this document.

6.2.2 Phase 2: Regional and sectoral specific analysis

Building on from the outcomes of Phase 1, this phase aims to provide more detailed sectoral and regional analysis. Phase 1 will identify the key climate-related concerns and vulnerable regions and sectors. This phase will start developing the modelling capability, in conjunction with input from key sectoral stakeholders.

Key activities in Phase 2:

1. Following on from Phase 1, establish the key regional and sectoral needs of the study;
2. Expand the GTAP database to include the new sectors and regions of the economies;
3. Update the scenarios using the new and updated version of the model and database; and
4. Engage stakeholders with the new regional and sectoral socio-economic analysis.

Deliverables and outcomes of Phase 2:

1. A new functional model specification for the regional and sectoral structure of the GTAP model;
2. An updated GTAP economic database that reflects the new structural specification;
3. Refined scenarios that reflect the new regional and sectoral structure; and
4. Synthesis reports communicated to key regional and sectoral stakeholders.

6.2.3 Phase 3: Development of a climate services sector

This phase aims to include an endogenous CIS sector that has a detailed value chain of the production and delivery of CIS into the economy. This will allow stakeholders to see how investment in basic infrastructure, services and advanced climate services benefit the wider economy. Also, this will allow for the more detailed modelling of the net socio-economic impacts of sector-specific CIS. This phase would be executed concurrently with Phase 2. As the focus of this is on CIS delivery, it will involve engagement with regional meteorological services and relevant delivery partners from other countries as well as organisations such as the World Meteorological Organization. This phase is enabling capacity development, and would require only updates as the socio-economic benefit programme is rolled out to other countries under Phase 5 (see below).

Key activities in Phase 3:

1. Engage key meteorological organization to develop a supply chain of climate services;
2. Develop a prototype version of the GTAP model that includes a climate services sector; and
3. Demonstrate this capability to key organizations.

Deliverables and Outcomes of Phase 3:

1. A conceptual economic model and database of the supply chain of climate services;
2. A version of the GTAP model and database that contains a climate services sector; and

3. A synthesis report and presentations demonstrating the return on investment in climate services, targeted towards government agencies and meteorological services.

6.2.4 Phase 4: Continued monitoring and evaluation

With the major model developments completed, the two main tasks remaining are: (1) to combine the climate services model and higher resolution impacts versions of the GTAP model developed in Phases 2 and 3; and (2) to continue to provide socio-economic analysis to new and ongoing projects.

Key activities in Phase 4:

1. Combine the higher resolution and climate services versions of the GTAP model into a new model;
2. As needed, define and analyse new case study examples to match the portfolio of climate services as they are unrolled;
3. As needed, develop new modelling capability that matches regional, sectoral and meteorological advancements.

Deliverables and Outcomes of Phase 4:

1. A new version of the GTAP model combining the elements developed in Phases 2 and 3;
2. As needed, deliver new and refined version of case studies to key stakeholders; and
3. As needed, deliver updates of the GTAP modelling capability.

6.2.5 Phase 5: Replication of the socio-economic analysis to other regions

In this final phase, it is envisaged that Phases 1 to 4 would be replicated across other countries and regions, with initial emphasis on other SIDS regions such as the western Indian Ocean and other SIDS at risk from climate variability, extremes and change. This phase is also a feedback and refinement phase, where the overall socio-economic framework and modelling approach are evaluated and refined before it is replicated to other countries/regions.

7 Moving forward

Climate information services enhance economic development and will no doubt play a crucial role in how we adapt to changes the future brings. A recent report (Global Commission on the Economy and Climate 2014) reminds us that over the next 15 years global production (defined as GDP) will increase by more than half, the global population will move towards nine billion people, with an additional one billion more people living in cities and urban areas, and rapid technological advance will continue to change businesses, lives, lifestyles and livelihoods. These challenges already put pressure on our ability to achieve the sustainable development goals. Climate change is already having serious economic consequences, especially in more vulnerable areas of the world. Those countries of the world that are facing the largest development issues are among those countries most at risk from climate change. The socio-economic cost-benefit analysis framework described in this publication can help identify priority needs for investments to provide reliable CIS and ensure those most at risk are better positioned to manage the consequences of climate change.

7.1 Supporting sustainable development

Climate information services play a key role in building more resilient societies and should be recognised as such. However, public funding of CIS in general, is under increasing pressure and will likely continue to be for the foreseeable future (IMF 2014). This increases the need for well-designed, rigorous and accessible socio-economic studies on the benefits of CIS in order to justify the investment in the face of competing priorities. The economic context in which CIS operate should be understood by the commissioning body, and CIS cost-benefits should be assessed in conjunction with the CIS sector to ensure that the commissioning body regularly reviews how it uses its limited resources to improve the cost efficiency of CIS delivery while meeting priority user demands.

However, beyond the obvious appeal for advocating with financial decision-makers, public sector decision-makers and the general public, the core value of socio-economic analysis of CIS lies in the process rather than the final numerical results. The application and utilisation of such socio-economic analysis should be a continuous process that leads not only to improvement of the effectiveness of CIS, but of performance in conducting the analysis itself. The process of conducting a socio-economic analysis is a valuable source of information for improving the effectiveness of services in all phases of the value chain and prioritising focal areas of service innovation, highlighting areas for increased R&D, and showing the potential for new infrastructure (Perrels et al. 2013).

Countries that are most at risk to climate change would benefit from their CIS providers' routine participation in national development, poverty reduction and climate adaptation planning and policy development. If national accounting systems and economy-wide models and analytical approaches consider potential, realised and avoided climate and weather 'damages', government budgets and financial plans will be more likely to include provisions for providing, enhancing and extending climate services. This situation is currently not the case; however, the integrated economic modelling is available to facilitate such an approach. Generally the results of multidisciplinary integrated modelling studies show that the inclusion of climate and weather damage is essential when developing future policies and making investment decisions.

Better socio-economic studies will therefore not only send a strong message of the need for adequate resource for the delivery of CIS, but will also contribute to guaranteeing the sustainability of such services as a part of a longer term development strategy. This also emphasises that government commitments to sustained financing of operation and maintenance of basic CIS is needed.

7.2 Developing a strong decision-making framework

This publication has outlined a framework for conducting a CIS-based socio-economic analysis. This framework is reliant on data and information availability and this will always be a limiting factor for defining the scope, boundary and level of detail contained within the socio-economic analysis. To build confidence with stakeholders in processes and results, three important approaches should be employed:

1. Recognise some of the limitations of the analysis from the beginning;
2. Transparently justify and document assumptions used to address any shortcomings within the data;
3. Cross-validate results through application of alternative methods; and
4. Take an integrated participatory approach to developing the analysis.

For a study to be undertaken successfully, long-term commitment and investment are needed to ensure reliable and regular acquisition of socio-economic information and data. Systems are needed for data quality management and consistency, and a transparent open approach helps ensure reliability.

If climate services aren't being used then they have no value. The value chain shown in Figure 2. Value chain of CIS; adapted from WMO (2015) report illustrates that the value is only realised once information is collected, processed and delivered to the decision-maker for action. It follows that the more a climate service is used, the more value it has. Therefore meteorological and other related service providers should also support the delivery, training and use of the CIS provided.

Despite delivering clear contributions to social welfare and positive public and private externalities the notion that using public financing to provide free weather data, basic services, and CIS increases economic benefits is not always immediately apparent to governments. However, experience shows that an open-data policy, meaning information is both technically accessible and legally licensed to permit commercial and non-commercial use and reuse without restrictions (World Bank 2014), tends to lead to a dramatic increase in the use of such data. But just because CIS are being accessed and used more frequently does not necessarily mean the information is being fully exploited. If information is misunderstood in some way, it could even lead to poor decision-making, resulting in the information having a net negative value. Training and support for the use of CIS is as important as the need to further develop the CIS themselves. This is reflected as a key element of the GFCS (WMO 2014).

The higher the quality of climate services, the more value they can deliver. In a mutually reinforcing strategy, socio-economic benefit analysis will help inform the design and implementation of investments to improve CIS delivery leading to increased recognition, use and therefore value of CIS. Scientific and technological advantages should be operationalised to maximise benefits. For example, probabilistic forecasts enable better decision-making than deterministic forecasts in the case of early warning systems, by allowing false alarm rates to be set to levels that reflect the stakeholder level of risk aversion.

Programmes such as the WMO World Weather Research Programme's High Impact Weather Project (HIWeather), which aims to increase resilience by improving impact forecasts and enhancing their communication and utility in social, economic and environmental applications, should be pursued to increase meteorological/hydrological service benefits at local, national, regional and global levels. Global models provide input for regional models which, in turn, provide guidance for national/local forecasting. Such cascading approaches ensure that all meteorological services have access to the latest technology and methodologies, without burdening the services with the high costs of maintaining and operating global and regional numerical modelling systems. Currently, the viability of such global CIS depends on the voluntary contributions of advanced service providers. The structure is under increasing stress from budget constraints, especially in the major traditional provider countries. To support these systems and improve the weather

and meteorological/hydrological services available to the developing world, it would be worth exploring public financing models for global public goods.

7.3 Linking communities

Socio-economic benefit analysis of CIS requires an interdisciplinary approach that brings together a number of different expert groups and stakeholders. The strengthening of linkages between the climate, weather and socio-economic analysis communities is of particular importance, as are joint approaches to communicating results externally. Associated with the partners and efforts engaged in the development of this publication, it is planned to facilitate ready, web-based accessibility to the framework, and associated methodologies and case studies, and more importantly to provide a platform for the exchange of ideas, experiences and new studies.

7.4 Monitoring and evaluation

Analysis of CIS-based socio-economic cost-benefits should form an integral component of the monitoring and evaluation of program-level CIS initiatives. Existing systems may need to be adapted to better capture the relevant baselines and the user decisions being made utilising existing CIS resources. Monitoring must, therefore, include outcomes and impacts, not just results/outputs such as the number of forecasts made or warnings sent. In most cases, this last phase of the value chain is a shared responsibility across multiple stakeholders and so monitoring and evaluation partnerships are thus needed at regional, national and sub-national level.

New technologies to monitor and assess uptake, use, satisfaction and ultimately the benefits of CIS should be employed where possible, such as so-called 'big data' and cloud computing. The further along the value chain that CIS can be captured (referring again to outcomes and impacts), the better informed the socio-economic analysis will be.

The tools, assumptions, and processes of socio-economic cost-benefit analysis can always be improved. Ex-post socio-economic cost-benefit studies on CIS are therefore needed to improve future performance. This could involve, among other activities, continuous monitoring, collection of data to revisit methodologies, integration with non-economic methods (for example, other social sciences), and identification of new benefits, all under a continuous process.

7.5 Closing comments

As the delivery of CIS becomes more important prevalent over time, socio-economic analysis will become increasingly important to inform planning and investment by CIS funders and providers with the ultimate goal of enhancing flow of benefits to end-users. Considering this growing interest and demand in CIS, it is hoped that the framework developed in the present study and described in this publication will be applied in as many countries as possible throughout the Pacific region and beyond. This effort will generate more experiences and case studies, eventually providing a rich knowledge base covering all relevant sectors and contexts. The focus on Pacific SIDS will provide a unique insight into the impact of climate change on some of the world's most vulnerable nations.

To achieve these goals, the analysis teams need to engage with people across multiple disciplines and the availability of technical support and training should be widened. Relevant managers and staff will benefit from the integration of the training of socio-economic benefit analysis methodologies within WMO and other development partners. It would be particularly valuable if basic training in meteorological economics was offered to a range of policy and decision makers, to help educate and inform the policy development to

further support national capacity, and for lower capacity partner countries to benefit from the expertise of higher capacity delivery partners.

None of the above will be possible without dedicated financial resources, and such resources can only be made available if the socio-economic analysis agenda is considered a priority by the involved parties. Climate information service providers, climate research agencies, regional and government R&D organisations and their governing ministries will need to allocate resources, as will development partners in their overseas development assistance (ODA) programmes and projects. The effective demonstration of the net social, economic, and environmental outcome of climate services, along with effective monitoring and evaluation of their performance, will encourage further investment in climate services. WMO (2015) presented 10 case studies on the socio-economic benefits of meteorological services, and found returns on investment that ranged from 2-to-1 to 36-to-1, and clearly there are great benefits in assessing and understanding how to optimise the value of meteorological and climate services. According to WMO (2015), it is therefore worth investing in a better understanding of how to invest in CIS.

References

- Araújo P, Féres J, Reis E, Braga MJ, 2015: Assessing the Impacts of ENSO-related weather effects on the Brazilian Agriculture. *Procedia Economics and Finance*. 24: 146–155. doi:10.1016/S2212-5671(15)00635-8
- Brockmeier M, 2001: A graphical exposition of the GTAP model. GTAP Technical Paper No. 08. Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=311
- Bureau of Meteorology and CSIRO, 2014: *Climate variability, extremes and change in the Western Tropical Pacific: New science and updated country reports*. Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia
- Cai Y, Newth D, Finnigan JJ, Gunasekera D, 2015: A hybrid energy-economy model for global integrated assessment of climate change, carbon mitigation and energy transformation. *Applied Energy*. 148, 381–395. doi:10.1016/j.apenergy.2015.03.106
- CSIRO and Bureau of Meteorology, 2015: *Climate Change in Australia. Information for Australia's Natural Resource Management Regions: Technical Report*. CSIRO and Bureau of Meteorology, Australia
- Dunne JP, Stouffer RJ, Jasmin G, 2013: Reductions in labour capacity from heat stress under climate warming. *Nature Climate Change*. 3 (6): 1758-678. <http://www.nature.com/nclimate/journal/v3/n6/abs/nclimate1827.html#supplementary-information>
- European Environment Agency 2004: Crop-yield variability. European Environment Agency. <http://www.eea.europa.eu/data-and-maps/indicators/crop-yieldvariability/crop-yield-variability-assessment-published>
- Freebairn JW, Zillman JW, 2002: Economic benefits of meteorological services. *Meteorological Applications*, 9: 33–44.
- Global Commission on the Economy and Climate, 2014: *The New Climate Economy: Better Growth, Better Climate*. Available at <http://newclimateeconomy.report/2014/>
- Gunasekera D, 2004: *Economic Issues Relating to Meteorological Service Provision*. BMRC research report No. 102. Melbourne, Bureau of Meteorology.
- Hallegate S, 2012: *A cost effective solution to reduce disaster loses in developing countries: Hydro-meteorological services, early warning, and evacuation*. Policy research working paper 6058. Washington D.C., World Bank.
- Kumar L, Taylor S, 2015: Exposure of coastal built-infrastructure assets in the South Pacific to climate risks. *Nature Climate Change*, 5: 992–996, doi:10.1038/nclimate2702
- Lazo JK, Chestnut LG, 2002: *Economic value of current and improved weather forecasts in the US Household Sector*. Report prepared for the National Oceanic and Atmospheric Administration, Stratus Consulting Inc., Boulder, Colorado.
- Lazo JK, Peacock WG, 2007: Social science research needs for the hurricane forecast and warning system: an introduction. *Natural Hazards Review*, 8(3):43–44.

- Lazo JK, Bushek NF, Laidlaw EK, Raucher RS, Teisberg TJ, Wagner CJ, Weiher RF, 2008: Economic valuation and application of services. *WMO Bulletin* 57(4): 222–226.
- Lazo JK, Waldman DM, 2011: Valuing improved hurricane forecasts. *Economics Letters*. 111(1): 43–46.
- Newth D, Valenzuela E, Cai Y, Gunasekera D, 2105: Welfare and Production Implications of Climate Change-Induced Impacts on Labour Capacity: Assessment of outputs from 30 CMIP5 Earth System Models. In: 18th Annual Conference on Global Economic Analysis; 12–19 June 2015; Melbourne, Australia. Global Trade Analysis Project, Purdue University.
- Perrels A, Harjanne A, Nurmi V, Pilli-Sihvola K, Heyndricx C, Stahel A. 2013: *Sector specific and generic impacts of enhanced weather and climate services in a changing climate*. Report for deliverable 2.2. ToPDaD Consortium
- Porfirio L, Newth D, Harman IN, Finnigan JJ, Cai Y. 2016: Patterns of crop cover under future climates. *Ambio*, 46: 265. doi:10.1007/s13280-016-0818-1
- Sustainable Business Institute, 2013: *Climate information as an object of economic research: state and perspectives*. Climate Change, Financial Markets and Innovation. Germany.
- Samuelson PA, 1954: The pure theory of public expenditure. *Review of Economics and Statistics*, 36: 387–389.
- World Bank, IFC and MIGA. 2016: *World Bank Group Climate Change Action Plan 2016-2020*. World Bank, Washington, DC.
- World Meteorological Organization (WMO), 2014: *Implementation plan of the Global Framework for Climate Services*. World Meteorological Organization, WMO-No. 1153, Geneva, Switzerland.
- World Meteorological Organization (WMO), 2015: *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services*. World Meteorological Organization, WMO-No. 1153, Geneva, Switzerland. 286 pp.
- World Travel and Tourism Council, 2015: *Travel & tourism economic impact 2015: World*. World Travel and Tourism Council, London.
- Zillman JW, 1999: The National Meteorological Service. *WMO Bulletin*, 48: 129–159.
- Zillman JW, 2003: The state of National Meteorological Services around the world. *WMO Bulletin*, 52: 360–365.

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