ACPC
African Climate Policy Centre

United Nations
Economic Commission for Africa

SOCIOECONOMIC BENEFITS OF CLIMATE INFORMATION SERVICE FOR DISASTER RISK REDUCTION IN AFRICA

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WISER
Weather and Climate Information Services for Africa

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EXECUTIVE SUMMARY

The negative impacts of hydrometeorological hazards on agriculture and food security, water resources oftentimes lead to disasters. Over 90% of natural disasters in Africa are a consecutive consequence of these hazards. There continues to be the in existence in many regions in Africa the ever-looming threats of these climate-induced disasters, (Urama & Ozor, 2010). It is, therefore, incumbent upon policy-makers to formulate appropriate strategies in order to minimize the effects of these devastating hydrometeorlogical hazards on communities. In this regard, there is need to provide communities and organizations with timely, tailored climate-related knowledge and information, as well as products that they can use to reduce climate-related losses and enhance benefits, including the protection of lives, livelihoods, and property (Vaughan and Dessai, 2014). Furthermore, studies indicate that weather and climate services improve smallholders' livelihoods in Africa (e.g. Patt et al., 2005).

As part of the process to demonstrate socio-economic benefits of Climate Information Services (CIS), the African Climate Policy Centre (ACPC) of the United Nations Economic Commission for Africa (UNECA) under the Weather Information and Climate Services (WISER) programme has developed an analysis framework to assess the Socioeconomic Benefits (SEB) of CIS within and across various socioeconomic sectors. The WISER framework assesses the economic and social benefits of climate information services compared to the costs of investments with the aim to provide decision support and information to inform the design of DRR interventions. WISER CIS is one of the key strategies that aim to ensure the utility of timely and accurate weather and climate information vital to the day to day decision making of Africa.

The SEB Framework presents the steps required for the effective identification and use of indicators to support a sectoral and integrated analysis of SEB in CIS for the benefit of DRR. The SEB assessment framework allows the development of an integrated Cost Benefit Analysis (CBA), where social, economic and environmental impacts – as well as policy outcomes – are considered. The CBA considers three main analytical components: investment, avoided costs and added benefits. The integrated CBA includes the economic valuation of environmental consequences.

Climate information Service (CIS) is an important component of the evidence base required to guide decisions regarding appropriate levels of investment to minimize potential impacts on the economy, ensuring uninterrupted delivery of critical services and infrastructure. Investing in the development of early warning systems and contingency planning, reserving contingency funds for emergency use, and potentially subsidizing vulnerable or impacted sectors (such as agriculture) is necessary to help protect socio-economic welfare.

The SEB findings serve as a means to prepare disaster risk adaptation strategies or to expand existing national and sectoral policy and strategies. The study has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to decrease economic vulnerability of the countries to the hydrometeorological risks.

1. INTRODUCTION ON SEB FRAMEWORK MODEL CHOICE

The livelihoods of inhabitants of African continent are highly dependent on weather and climate information. The utility of timely and accurate weather and climate information is vital to the day to day decision making. There is, therefore, a need for weather and climate services to provide people and organizations with accurate, timely, tailored climate-related knowledge and information that people can use to reduce climate-related misfortunes and enhance benefits, including the protection of lives, livelihoods, and property (Vaughan and Dessai, 2014).

However, there is a gap in evidence which remains an obstacle to the level of investment needed to build the resilience of smallholder agriculture and create an enabling environment for climate-smart agriculture at scale. As a result, it is difficult to assess the extent to which individual climate services or weather and climate services in general live up to the promise of benefiting the society at large. This leaves weather and climate service providers, and funding agencies with very little information about the quality and relative value of weather and climate services (Vaughan and Dessai, 2014).

Therefore, the aim of this work is to assess the value for money of these services in order to provide evidence for the providers of these services to determine whether to invest in, or continue investing in the provision of weather and climate information services to improve or perhaps even maintain these services (Anaman, 1995; Freebairn&Zillman, 2002).

Demonstrating the socio-economic benefit of these services can also help potential users of the services to understand the use and benefits of forecasts so that they know how and why they could use weather and climate information, ?? it also helps them in involving and supporting service providers and to understand user needs and values to prioritize the types of information to generate and determine how best to disseminate that information (Zillman, 2007; Lazo et al., 2009). According to Perrels et al. (2013), the societal value of, and benefits from, weather and climate information services can be greatly enhanced by establishing a much closer dialogue and sense of partnership between the provider and user communities at all levels.

According to the World Bank Group, with a current hydrometeorological investment portfolio approximated at US$ 500 million, estimates that globally improved weather, climate, as well as water observation and forecasting could lead to up to US$ 30 billion per year in increases in global productivity and up to US$ 2 billion per year in reduced asset losses, Hallegatte, S., (2012). This scale of improved productivity could be crucial to lifting out of poverty the millions around the world whose livelihoods are at risk of climate shocks. The recognition of these benefits and their contribution to sustainable development, poverty reduction and shared prosperity is motivating the development community to invest more holistically in modernizing hydrometeorological services and ensuring that service providers are better connected with service users, Rogers, D.P. and V.V. Tsirkunov, (2013). As part of the process to demonstrate socio-economic benefits of Climate Information Services (CIS), the African Climate Policy Centre (ACPC) of the United Nations Economic Commission for Africa (UNECA) has developed a framework which assesses the economic and social benefits of climate information services in comparison to the costs of investments.

The framework essentially built a business case for ongoing investment in CIS by showing the impacts of integrating climate information into the policy and resource allocation process. By turning the outcomes of CIS investment into monetary terms, the framework illustrated that the benefits of policies outweigh the amount of money invested in them. In this way, it is easier for policy makers to justify current and future investment in CIS.

The Socio-economic Benefits (SEB) Framework presents the steps required for the effective identification and use of indicators to support a sectoral and integrated analysis of SEB in CIS. The steps presented are largely more relevant to climate vulnerability assessment, while others are more useful for adaptation and policy formulation/assessment. There are steps that lead to the implementation of an integrated Cost Benefit Analysis (CBA), where social, economic and environmental impacts – as well as policy outcomes – are considered. CBA considers three main analytical components:

i. Investment,
ii. Avoided costs, and
iii. Benefits.

The integrated CBA includes the economic valuation of environmental consequences.

Indicators when used to effectively inform decision making, are designed to support the initial and final stages of the development planning process, namely issue identification (stage 1), strategy/policy formulation and assessment (stage 2), and strategy/policy monitoring and evaluation (stage 5) (UNEP, 2014). Decision-making (stage 3) is the point in time when a particular policy recommendation is adopted, based on the comparison of different policy options that were developed under stage 2. Finally, the role of indicators in policy implementation (stage 4), is mainly exercised through monitoring and evaluation (stage 5), when the actual impacts of development plans are monitored both during and after implementation.

Cross-sectoral causal descriptive models can incorporate several of the methods mentioned above, from historical observations to simulation of future scenarios. These models, based on the Systems Thinking and System Dynamics methodology, have been traditionally used to support planning exercises at various levels with the analysis of “what if” scenarios, for instance in the context of climate adaptation. The key features include horizontal integration (i.e. a variety of sectors interconnected with one another) and a fairly aggregated level of detail for each sector. The former allows the inclusion into the model social, economic and environmental indicators; the latter indicates that this approach does not substitute others, but rather complements existing –and more detailed- sectoral modelling efforts with a more comprehensive framework of analysis. As a result, these models can be used to simulate alternative scenarios of action and inaction, using several weather indicators as input and providing insights on both the identification and anticipation of vulnerabilities and the identification and evaluation of interventions to improve resilience to climate change (e.g. based on forecasts of SEB).

Having a shared understanding is crucial for solving problems that influence several sectors or areas of form which are normal in complex systems. Since the process involves broad stakeholder participation, all the parties involved need an inclusive vision to undesrstand the factors that generate problems and those that could lead to a solutions, therefore establishing successful private-public partnerships.

As such, the solution should not be imposed on the system, but should emerge from it. In other words, interventions should be designed to make the system start working in our favour, to solve the problem, rather than generating it. Looking ahead: framework customisation by sector. Following development of the framework, the next stage is customising it for specific sectors, starting with agriculture and disaster risk reduction. This tailoring of the framework will facilitate closer examination of the economic benefit of applying CIS at sector level. This will enable decision makers to make better informed strategies for averting climate-induced disasters; or taking advantage of favourable climatic conditions to help grow their economies.

Agriculture

Here, customisation will be designed so CIS products can be tailored and applied to agriculture, leading to better productivity. This may include enabling use of appropriate seed varieties, containing infestation of pest and diseases, managing agricultural operations, e.g. scheduling weeding and application of fertilizers and hiring of temporary staff for specific tasks necessary to improve productivity.

Disaster Risk Reduction

Policy and institutions. It is critical that decision makers at all levels are committed to disaster risk reduction, so that resources and planning guidance are provided. Just as important is the participation and understanding of individuals at the local level where disasters are felt. This category includes the country's overall policies, the legislative process, and the institutional framework for implementing measures. The tools that have been developed for policy and institutions are aimed at mainstreaming disaster risk reduction into development planning from the national to community level. This aims to bring about a "culture of safety and resilience".

The model output will provide a basis for integrating CIS into disaster risk reduction. This will involve developing and disseminating climate information and prediction products systems that can enable the tracking of hydro-meteorological hazards ahead of time. This will contribute to enable, so that Disaster Risk Managers capacitated in applying CIS can to put in place measures to avert potential weather- and climate-induced disasters. The process will also map out patterns of hydro-meteorological disasters into the future. This will enable planners to invest resources in the areas that are currently more susceptible to flooding and droughts so that, for instance, roads, bridges, dams and housing structures are designed to be as climate proof as possible.

2. DISASTER RISK REDUCTION

Hydrometeorological hazards: floods, storms, droughts, and extreme temperatures strike communities around the globe each year. The top ten disasters of 2004 (ISDR, 2004 ISDR, 2004), in terms of the number of people affected, were all weather and climate-related. Since the 1980's, Sub-Saharan Africa has experienced more than 1,000 disasters (www.cred.be, see 2004 statistics). Tropical cyclones mainly affect Madagascar, Mozambique and some of the Indian Ocean islands.

These have been a major threat to lives and sustainable development, as they frequently reverse development gains. Other adverse impacts hydrometeorological hazards include food insecurity and epidemics mainly, cholera, meningitis and malaria. These types of disasters have occurred throughout history but with total damages amounting to US$130 billion (www.cred.be, see 2004 statistics). It is also estimated that in developing nations losses are typically 10-14 % of GDP, Abramovitz, (2001),. From this and just these ten events across the globe, it is clear that the necessary steps to reduce disasters have not yet been taken.

Sub-Saharan Africa's disaster profile is closely linked to the vulnerability and exposure of its population and economy/community assets, and their often-low capacities to cope with natural hazards. Most African countries have limited resources to invest in disaster risk reduction and minimal fiscal space to fund relief and recovery efforts after major disaster impacts in terms of mortality, morbidity, destroyed livelihoods, infrastructures, capital and disrupted community social networks. Disasters can be a tremendous setback for economic growth and performance.

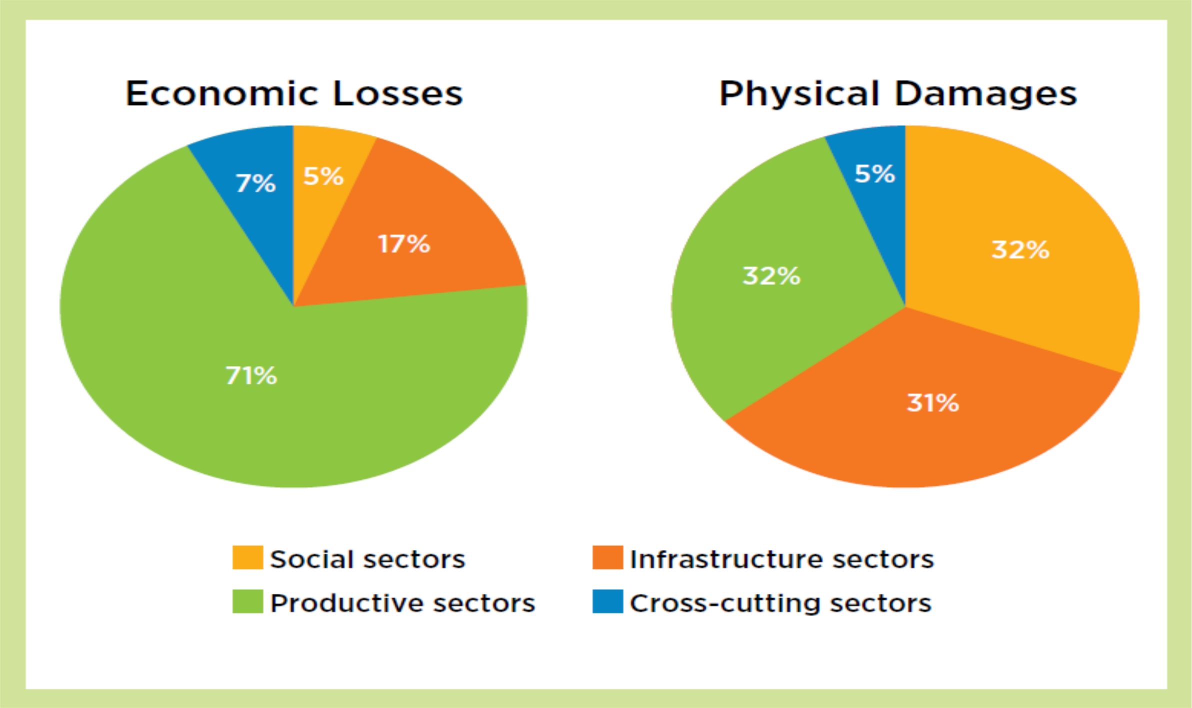

Figure: 2.1 (a) Economic losses and (2) physical damages caused by hydrometeorological hazards (Adapted from ISDR: 2014)

As climate change begins to manifest itself—in the form of increased frequency and intensity of hazards such as floods, storms, heat waves, and drought—the need for communities to address climate risks is becoming urgent. The coming decades are likely to bring, among other changes, altered precipitation patterns so that many areas will experience more frequent floods and landslides, while others will experience prolonged drought and wildfires.

As many communities are not prepared to cope with climate disasters facing them today, an ongoing challenge is to build their resilience. In answer to this challenge, disaster risk reduction aims to address a comprehensive mix of factors contributing to communities' vulnerabilities. There are numerous tools and methodologies that have been developed to put this approach into practice. The value of DRR and the experiences gained by DRR practitioners have been increasingly tapped by organizations active in climate change adaptation. For example, UNDP, OECD, the World Bank, and others have recently explored linkages between the two.

2.1 New Approach to Disaster Risk Reduction

The disaster management community has been evolving. Until the 1990s, disaster management was primarily focused on the response of governments, communities, and international organizations only *after* disasters had struck. This included the humanitarian aspects of relief, such as providing medical care, food and water, search and rescue, and containing the secondary disasters (e.g. fires that occur following an earthquake). Even now, only a tiny amount of humanitarian funding is spent on disaster risk reduction. Although the international community has increasingly realized that countries experience disasters differently, the unfortunate truth is that poorer countries are hit hardest, as they do not have sufficient resources to prepare for disasters. Overall education in terms of the basic knowledge and awareness of disasters, for the people residing in less advantaged areas still needs to be encouraged. In addition, the socio-economic impacts following a disaster may linger far longer in poorer nations. A UNDP report states, "*In 1995, Hurricane Luis caused US$ 330 million in direct damages to Antigua, equivalent to 66 percent of GDP. This can be contrasted with the larger economy of Turkey that lost between US$ 9 billion and US $13 billion in direct impacts from the Marmara earthquake in 1999, but whose national economy remained largely on track.*" The same report found that "*while only 11 percent of the people exposed to natural hazards live in countries classified as low human development, they account for more than 53 percent of total recorded deaths.*"

Disaster risk reduction is increasingly recognized as a major factor in achieving sustainable development, although the systematic integration of DRR into development planning and activities remains a challenge. Time and again, investments in development have been wiped away by disasters, and these damages have only increased as countries grow. According to Munich Re, the recorded economic value of disaster damage has increased from US$ 75.5 billion in the 1960s to US$ 659.9 billion in the 1990s.6 These figures do not account for the losses suffered by communities in terms of lost lives and livelihoods.

To reduce human and economic losses, the *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters,* commits countries and agencies to: integrate DRR into sustainable development; develop and strengthen institutions, mechanisms and capacities to build resilience; and systematically incorporate DRR into emergency preparedness, response and recovery programmes. States have agreed to taking the lead in achieving these goals by:

- Strengthening policies and institutions
- Identifying, assessing ad monitoring risk and enhancing early warning
- Using knowledge, innovation and education to build a culture of safety
- Reducing underlying risk factors, such as environmental degradation

- Strengthening preparedness for effective response

2.2 Focus on communities and vulnerability

One of the underlying principles of DRR is to consider disasters as a result of a community's vulnerability. Vulnerability has been defined as "a set of conditions and processes resulting from physical, social, economical, and environmental factors, which increase the susceptibility of a community to the impact of disasters." Taken from this standpoint and incorporating the resources within the community, risk can be defined as follows:
RISK = HAZARD x VULNERABILITY/CAPACITY

By analyzing vulnerabilities and capacities, a fuller picture emerges of how to reduce disaster risks. The DRR approach considers a comprehensive range of vulnerability factors and aims to devise strategies that safeguard life and development before, during, and after a disaster.

2.3 Disaster Risk Reduction Tools

One common characteristic of DRR tools is the emphasis on taking a holistic view of disaster risk reduction and the importance of linking with diverse stakeholders. Even for those tools with a narrower target group (e.g. climate forecasters or water utilities), the process requires drawing on wide-ranging sources of knowledge for successful risk reduction in the community. This attempt to analyse risk from diverse perspectives makes the tools suitable for climate change adaptation as impacts will affect various sectors and communities.

3. CLIMATE INFORMATION SERVICES

According to the Integrated African Strategy on Meteorology (Weather and Climate Services), NMHSs contribute to underpinning economic growth and sustainable development in the African continent. It has been demonstrated that weather and climate services provided by NMHSs significantly contribute to the safety and well-being of the African people and communities and support key economic areas including agriculture, aviation, forestry, fishing, water resources, energy industries, transportation and tourism. In addition, these services are crucial to enhancing resilience to and reducing vulnerability from, natural hazards and the effects of climate variability and climate change.

The strategy should enhance the cooperation between African countries and to ensure that NMHSs have the capacity to fulfil their responsibilities including in the implementation of the Global Framework for Climate Services (GFCS), spearheaded by WMO and its partners in the United Nations to improve climate services, especially for the most vulnerable.

The implementation of the GFCS will enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scales.

CIS, therefore, provides Africa an opportunity to find long term solutions to the effects of the recurrent drought which undermine the development efforts in the Sahara, Sahel, Kalahari deserts and in the Horn of Africa and devastating floods such as those being witnessed in West Africa, for example, Nigeria and others.

As part of the GFCS, Climate Information Services (CIS) builds on continued improvements in climate forecasts and climate change scenarios to expand access to the best available climate data and information. Policy-makers, planners, investors and vulnerable communities need climate information in user-friendly formats so that they can prepare for expected trends and changes. They need good-quality data from national and international databases on temperature, rainfall, wind, soil moisture and ocean conditions. They also need long-term historical averages of these parameters as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios.

Depending on the user’s needs, these data and information products may be combined with non-climate data, such as agricultural production, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socio-economic variables. The aim is to support efforts to prepare for new climate conditions and adapt to their impact on water supplies, health risks, extreme events, farm productivity, infrastructure placement, and so forth.

Expanding the production, distribution and use of relevant and up-to-date climate information can best be achieved by pooling expertise and resources through international cooperation. UN agencies, regional institutions, national governments and researchers will work together through the GFCS to disseminate data, information, services and best practices. This collaboration will build greater capacity in countries for managing the risks and opportunities of climate variability and change and for adapting to climate change.

Multi-time scale forecasting plays a vital role within the framework of CIS. This is shown in Figure 3.1.

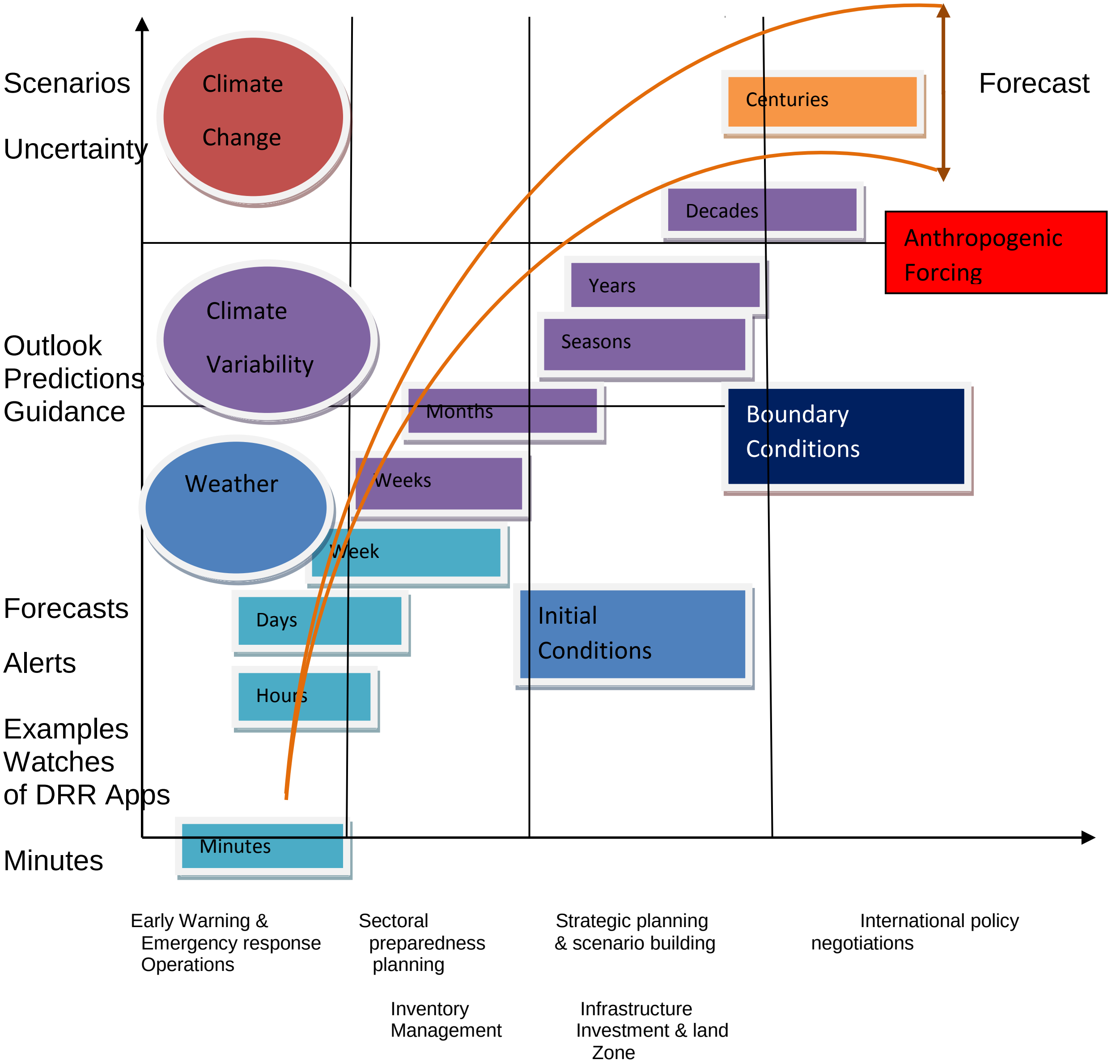

Figure: 3.1 Multi-time forecasting and multi-sectoral utility (adapted from WMO)

Enhanced integration of climate science into Disaster Risk Reduction and Climate Change Adaptation policies and operations in Africa can be achieved by developing appropriate partnerships. Building partnerships is fundamental in establishing a durable and action-oriented dialogue among the climate scientists, operational meteorological and climate services (information providers) at the national level , disaster risk managers and decision-makers in various socio economic sectors (e.g., energy, water resource management, agriculture, health, etc) which is in order to provide relevant climate services for risk reduction measures, community centered Early Warning Systems that leverage national, regional and global coordination, local preparedness, response and recovery..

World Bank study estimated that the benefits of improving hydro-meteorological services in developing countries to standards used in developed ones would lead to an increase of US$30 billion per year in economic productivity and a decrease of up to US$ 2 billion per year from reducing asset losses (Hallegatte, 2012).

4. SEB FRAMEWORK

To adequately capture the SEBs that can be derived from CIS, the assessment has to be conducted from a systems perspective. The SEBs resulting from CIS are multi-sectoral in nature: they can be demonstrated for DRR, Agriculture, Water, Health, Energy and other sectors. These are extensible in the realm of climate change adaptation. It is important to note that these also often depend on a multitude of factors. A systems dynamics approach is a useful tool to demonstrate the inter-linkages of benefits that depend of the application of the climate system. This can be gleaned from the schematic depicting conceptual representation of Systems Dynamics, Figure 4. 1.

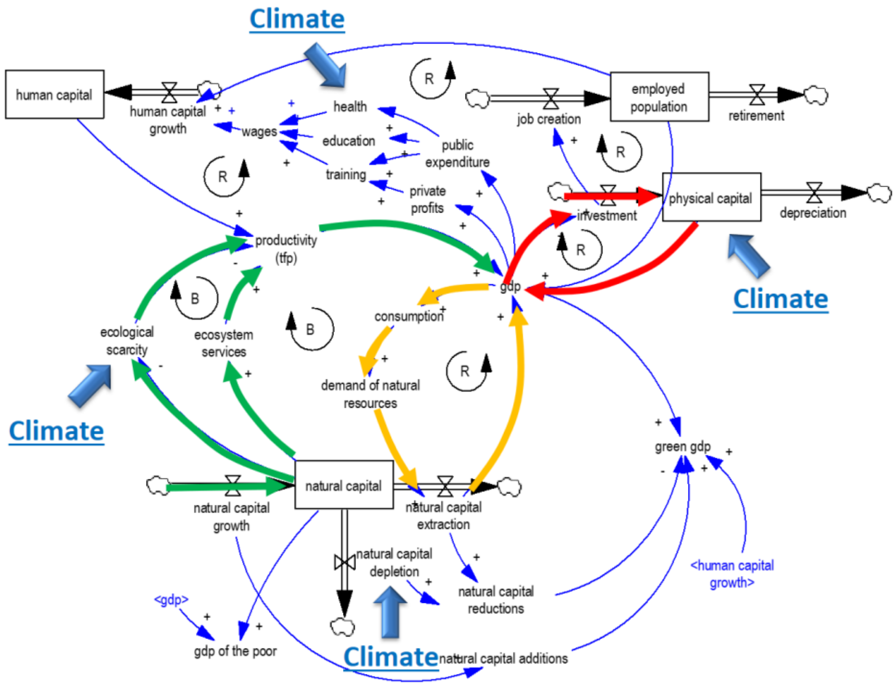

Figure 4.1: – Conceptual representation of the System Dynamics model

Overview

System Dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems — literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.

The field developed initially from the work of Jay W. Forrester. His seminal book *Industrial Dynamics* (Forrester 1961) is still a significant statement of philosophy and methodology in the field. Within ten years of its publication, the span of applications grew from corporate and industrial problems to include the management of research and development, urban stagnation and decay, commodity cycles, and the dynamics of growth in a finite world. It is now applied in economics, public policy, environmental studies, defence, theory-building in social science, and other areas, as well as its home field, management. System Dynamics emerges out of servomechanisms engineering, not general systems theory or cybernetics (Richardson 1991).

System Dynamics is a methodology used to create models that are descriptive and focuses on the identification of causal relations influencing the creation and evolution of the issues being investigated (Sterman, 2000). System Dynamics models are in fact most commonly used as “what if” tools that provide information on what would happen in case a policy is implemented at a specific point in time and within a specific context (Probst & Bassi, 2014).

System Dynamics aims at understanding what the main drivers for the behavior of the system are. This implies identifying properties of real systems, such as feedback loops, nonlinearity and delays, via the selection and representation of causal relations existing within the system analyzed (Sterman, 2000). Potential limitations of simulation models include the correct definition of system's boundaries and a realistic identification of the causal relations characterizing the functioning of systems being analyzed (e.g., relating to the use of causality rather than correlation).

5. RATIONALE FOR USE A SYSTEMS DYNAMICS APPROACH TO ASSESS THE SEB OF CIS FOR DRR

For the assessment, an integrated and systemic CBA methodology is proposed, made of three main analytical components: investment, avoided costs and added benefits. The conceptual framework in use for the analysis is represented in Figure . The assessment of SEBs of CIS is based on the amount of avoided costs and added benefits that investments in generate over time, meaning that cumulative benefits and costs are compared to determine the benefit to cost ratio of CIS implementation. To better illustrate the applicability of this approach, climate change adaptation techniques are employed. For example, sustainability certification (to reduce negative impacts of human activity and improve adaptation and resilience) is presented throughout the report, for selected sectors.

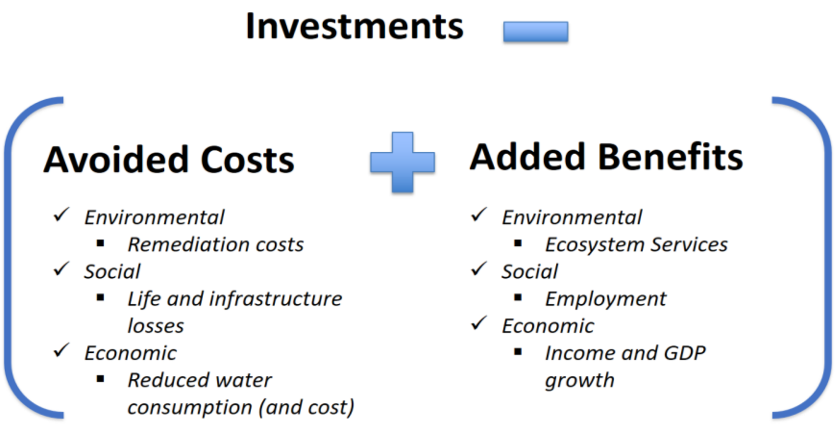

Figure 5.1: – Conceptual framework in use for the analysis

a) *Investment:* from a private sector perspective, investments refer to the monetary costs of implementing a decision, such as complying with sustainability standards, including, for example, annual certification fees, auditing and other management costs related to certification, as well as the costs for greening production (e.g. the purchase of machinery and the transformation of production processes and techniques, potential additional labor and training costs). From a public-sector point of view, investments refer to the allocation and/or reallocation of financial resources with the aim to reach a stated policy target (e.g. create enabling conditions for the development of sustainable businesses in a given country).

b) *Avoided costs:* the estimation of potential costs that could be avoided as result of the successful implementation of an investment/policy. In the case of sustainability principles and processes, these refer to the use of green production practices (as a result of sustainability certification) and may include direct savings deriving from a more efficient use of natural resources, as well as indirect avoided costs, e.g. health expenditure, avoided losses from environmental degradation, and avoided payments for the replacement of key ecosystem services (UNEP, 2012a).

c) *Added benefits:* the monetary evaluation of economic, social and environmental benefits deriving from investment/policy implementation, focusing on short-, medium- and long-term impacts across sectors and actors. In the case of sustainability certification these include enhanced access to markets, or the availability of premium prices for certified products. These are all additional benefits that would not be accrued in a business as usual scenario.

Investment

A set of possible indicators of investment, broadly subdivided into capital and operation & management costs, training costs, certification costs, and government costs. These indicators are selected for the example of sustainability certification, for agriculture, fisheries and aquaculture, DRR and forestry. This set of indicators is neither exhaustive nor in its entirety applicable to all policies and sectoral analyses. It rather reflects a generic portfolio of indicators that can be flexibly customized (i.e. expanded or narrowed down) to the requirements and objectives of specific sectoral assessments.

Avoided costs

A key aspect that is often neglected when measuring the effectiveness of investments in sustainability is the cost saving deriving from such interventions. More specifically, improving the sustainability of a sector has the potential to:

(1) reduce costs currently sustained by public and private actors as result of the current ineffective natural resources management and use, and

(2) avoid potential future costs deriving from the depletion of natural capital and ecosystem degradation.

Consequently, an integrated analysis of the impacts of climate change adaptation interventions should include the estimation of potential (policy-induced) avoided costs, using historical and current data on environmental, social and economic performance. This analysis is particularly relevant from a green economy perspective, where social inclusiveness (i.e. the equitable distribution of costs and benefits across actors) is at the core of sustainable development.

Added benefits

Once the total investment and avoided costs (both public and private) have been estimated, the additional benefits potentially deriving from policy implementation should be properly assessed. In particular, economic, social and environmental benefits should be identified, and adequately measured by means of relevant indicators.

6. ASSESSMENT SOCIO-ECONOMIC BENEFIT IN MODELS

There are methods that allow the quantification and valuation of SEBs from W&CS. These in turn allow the analysis of the economic costs and benefits of these services. Previous studies have shown that weather and climate services do deliver very high economic benefits, and when compared to the costs of investing, they produce a high benefit to cost ratio (i.e. a high economic ranking).

The approach used to quantify SEB looks at the action and outcomes from the use of enhanced weather and climate services, and compares this to a baseline without this additional information: the difference is the quantified benefit. This is often known as the value of the information. In order model and assess SEBs, there are key steps to follow.

The key steps in an SEB analysis are:

- Identify current and future vulnerability to climate variability and climate change. This includes an assessment of the exposure of built capital and infrastructure, of the vulnerability of people and villages to extreme weather events, and of the potential sensitivity of economic activities (e.g. agriculture production) to changing weather patterns.
- Identify indicators that can be used to measure performance and vulnerabilities across social, economic and environmental dimensions. Since not all the impacts of climate change are economic, it is important to identify social and environmental indicators that could potentially be subject to economic valuation.
- Identify the potential benefits of the weather and climate service and how these benefits will arise from the steps in the weather chain (from weather or climate information to end users). This should include all benefits, i.e. financial benefits as well as non-market benefits such as

health. It is also important to note the actors (e.g. the public and private service providers and users) across the chain.

- Review and decide on the potential methods for assessing these benefits vulnerabilities, taking account of your resources and how adequately these methods represent the local context. This may have to involve steps to quantify and potentially value market and non-market sectors. It could include integrated or sectoral modelling, survey and econometric work data analysis or lighter touch qualitative methods. More detail is provided in the Annex.
- Derive a baseline of the current situation without the new information provision. Derive a baseline and, to the extent possible, quantify the potential social, economic and environmental impacts of climate change. This includes an assessment of the impacts across sectors and actors (e.g. households, private and public sector), as well as over time (e.g. short term vs. long term).
- Identify, simulate and analyse alternative scenarios of action (i.e. with different degrees of availability of climate information and uptake from local economic actors) to estimate deviations from the baseline. This allows to assess impacts on vulnerabilities: potential cost reductions and the potential emergence of new opportunities, across social, economic and environmental indicators.
- Identify the potential benefits of the weather and climate service and how these benefits will arise from the steps in the weather chain (from weather or climate information to end users). This should include all benefits, i.e. financial benefits as well as non-market benefits such as health. It is also important to note the actors (e.g. the public and private service providers and users) across the chain.
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- Assess the change from the baseline with the new weather and climate services in place. This should include the potential benefits, but ensure that the efficiency losses along the weather chain are considered. See Annex.
- Assess the costs of the project, including investment in meteorological stations, system operation and information provision (thus capturing equipment and resource (labour) costs).
- Compare benefits against costs, estimating, to the extent possible the economic value of avoided social and environmental impacts, as well as avoided economic costs and benefits. The comparison of costs and benefits should also highlight the improve resilience by sector and economic actor, to better inform decision making.
- .
- Identify omissions, consider bias and undertake sensitivity analysis. When assessing costs and benefits it is crucial to acknowledge any

missing information, or social and environmental impact that could not be monetize. This is to ensure that if a partial analysis is carried out, it is acknowledged that the results may be an underestimation of the SEB brought about by investments in weather information. The use of Multi Criteria Analysis (MCA) may be considered.

- Explore how benefits could be enhanced through interventions along the weather chain and. through the implementation of complementary interventions across sectors and actors, and over time. It is crucial to identify if there complementarity/synergy between investments in the weather value chain and sectoral development targets, as this would increase the effectiveness of budgetary allocation.

This section summarises the WISER guidance on socio-economic benefits.

The upstream weather and climate services are usually seen as non-technical in nature and people find it difficult to assess their benefits in quantitative terms. This part of the guidance aims to address this problem by outlining how to identify and quantify the benefits of weather and climate services.

There are several reasons why it is beneficial to consider socio-economic benefits.

- It can help to identify the ‘impact’ of the project, and what it is trying to achieve in terms of delivering benefits to users.

- It can help to understand how to maximise user-benefits, looking at how benefits are delivered from initial services down through the user chain;

- It can provide information to for policy makers on the benefits of W&CIS and thus help to justify current and future investment in these services.

How socio-economic benefits can be quantified

There are methods that allow the quantification and valuation (monetisation) of W&CS benefits. These in turn allow the analysis of the economic costs and benefits of these services.

Using such methods, previous studies have shown that weather and climate services do deliver very high economic benefits, and when compared to the costs of investing, they produce a high benefit to cost ratio (i.e. a high economic ranking).

The approach used to quantify SEB looks at the action and outcomes from the use of enhanced weather and climate services, and compares this to a baseline without this additional information: the difference is the quantified benefit. This is often known as the value of the information.

Importantly these benefits include several categories. These are illustrated in the box below, and include direct and indirect benefits, related to both market and non-market impacts. As these are wider than just financial benefits alone, and capture the full economic benefits, they are referred to as socio-economic benefits.

More details on methods are included in the Annex.

The types of socio-economic benefits

A wide range of different benefits may arise from weather and climate services. These include areas where there is an obvious financial benefit, but other areas which provide benefits which are more difficult to value in monetary terms. While the direct losses can usually be quantified and then valued using market prices, the intangibles involve non-market effects, which use economic methods to derive economic values.

7. CUSTOMIZATION OF SEB TO DRR

Studies within the first phase of WISER allowed the quantification and valuation of CIS benefits to the economy. Such studies have shown that CIS do deliver very high economic benefits, and when compared to the costs of investing, they produce a high benefit to cost ratio. It has been established that global disasters are mostly caused by hydrometeorological hazards.

Better weather and climate services leads to improved information, such as better forecasts, early warning systems and seasonal forecasting. In turn, these services provide benefits to users, and lead to positive outcomes from the actions and decisions they subsequently take. As examples:

- Early warning systems can significantly reduce the damages and losses - and reduce loss of life and injuries - caused by extremes and disasters:

- Seasonal outlooks can help improve agricultural production (higher yields) or reduce losses from extreme events.

Taking the above into account, there was need to extend, and customize, SEBs to DRR. The approach used to quantify SEB looks at the action and outcomes from the use of enhanced weather and climate services, and compares this to a baseline without this additional information: the difference is the quantified benefit in DRR. The focus on SEB of CIS with particular reference to DDR helped in maximising the impact of weather and climate services for appropriate interventions along the user chain are included.

There were a set of steps to apply the Socio-Economic Benefit framework developed during the WISER first phase to Disaster Risk Reduction. This resulted in conducting a systemic analysis of sectoral and cross-sectoral vulnerabilities and opportunities.

These were as follows:

- to customize the SEB framework, methods and tools to evaluate their application in Disaster Risk Reduction;
- to establish and test the framework to drive uptake and investments in Disaster Risk Reduction various levels.
- to carry out analytical studies to show the need for investment in CIS and provide strategic guidance for investment in Disaster Risk Reduction;
- to demonstrate the applicability of SEB framework in DRR and to popularize the use and the dissemination of the framework;
- to analyse and develop indicators and trackers for CIS uptake in development of DRR policies; and
- to contribute to the human and institutional capacities strengthening of African countries to plan and optimise investments in DRR.

8. DATA

Countries have established loss-monitoring systems in the past years, largely with the help of external support. However, there are significant concerns regarding the reliability and sustainability of these efforts. In many instances, data coverage is sporadic-meaning loss estimates are missing, data quality is questionable, and operators lack financial resources to maintain loss databases (UNDP/BCPR 2013). On the other hand, equally important data on vulnerability and resilience is largely missing making it difficult to track loss reduction progress in conjunction with resilience.

Better data on losses, both historic and current, are also essential for the attribution of extreme weather impacts to climate change (Basher 1999; Jagger et al. 2011). Being able to recognise that weather patterns and their impacts have changed is crucial for establishing the need for climate adaptation rather than conventional disaster risk management. Consequently, losses (or avoided losses) should be considered a performance measure of risk management, as should resilience.

In order to carry out research necessary for the purposes of solving socio-economic and other problems, there is need to have relevant good-quality data from national and international databases on parameters such as: temperature, rainfall, wind, soil moisture and ocean conditions, Long-term historical averages of these parameters as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios will help in the formulation of strategies necessary to minimize potential impacts of hydrometeorological hazards to communities.Depending on the user's needs, these data and information products may be combined with non-climate data, such as agricultural production, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socio-economic variables, GDP and water resources; land use, vulnerability of communities to hydrometeorolocal hazards, economic damages due to disasters, etc..

Climate information Service (CIS) is an important component of the evidence base required to guide decisions regarding appropriate levels of investment to minimize potential impacts on the economy, ensuring uninterrupted delivery of critical services and infrastructure. Investing in the development of early warning systems and contingency planning, reserving contingency funds for emergency use, and potentially subsidizing vulnerable or impacted sectors (such as agriculture) is necessary to help protect socio-economic welfare.

Since the 1970's, mortality rates from disasters have decreased in some regions as a consequence of the development of multi-hazard early warning systems. Effective early warning systems include risk knowledge; monitoring and warning service; dissemination and communication; and response capacity. Lessons learned from a number of good national practices in multi-hazard early warning systems indicate that these systems enable decisions to protect lives and livelihoods in short- and longer-term timeframes by extending the lead time for contingency planning and preparation. Short-term warnings can enable evacuations and transportation to predetermined shelters, the protection of some assets (for instance, by calling boats to shore and boarding-up buildings, and the pre-positioning of emergency capacities).

Longer-term early warnings provide lead times of a few weeks to several months for slow-onset hazards like drought. They enable individuals and communities to make adjustments for improved agricultural planning, such as select ion of drought-resistant crops and adjustment of planting and harvesting timing and for governments to adjust delivery of health services (for example, pre-positioning of pharmaceuticals and weather-informed vector-control activities).

They also enable longer-term preparedness actions, as described below.
Both short-term weather forecasts and seasonal forecasts can be used to build reliable deterministic or probabilistic risk scenarios and, in turn, to strengthen disaster preparedness.
Warning of a fast-onset hazard enables preparedness capacity to be activated for early response, including by: distributing stockpiles of medicine, food, water, emergency shelter and body bags; dispatching skilled personnel for rescue, and specialists to provide medical, communication, engineering and nutrition services; and accessing contingency funding.

Seasonal forecasts are used in preparedness efforts such as training volunteers, mobilizing the community disaster response teams, pre-positioning of stocks, and logistics planning, including securing visas for international emergency personnel and setting up camps for the displaced. Seasonal forecasts can also be used to secure emergency funding .At community level, longer-term-preparedness includes development of community preparedness plans and related infrastructure, e.g. shelters and raised mounds for flood evacuation, as well as measures such as carrying out other community disaster preparedness activities and micro-mitigation projects.

Seasonal forecasts have been proven invaluable for contingency planning, which are plans to address and respond to specific events or scenarios for different hazards and settings and at various scales, such as citywide flooding or agricultural drought. Similarly, seasonal forecasts enable trans-boundary coordination to manage water resources in countries sharing riverways in order to reduce downstream impacts.

The main data source for disaster profiles is obtained for the UNISDR using DesInventar as a Disaster Information Management System on the following web page; http://www.desinventar.net/data_sources.html.

It is important to note the following challenges with the data acquisition, among others:

1. Disaggregating of data;
2. Identifying all possible data sources for a national effort;
3. Making the information accessible and in many cases;
4. Conciliating multiple data sources report; and
5. Dissimilar figures when describing the effects of the same event.

Hydrometeorological data was obtained from WB sources.

8.1 ***Defining and measuring the data***

In the first phase of the project, SEB, the list of areas of socioeconomic impactsincluded in the model were: Population; Health; Education; Roads; Macroeconomy; Water; Agriculture; Energy sectors. However, due to the non-availability of some of the raw data, there was need to consider the use of proxy data, for the purposes of representing some economic damages in certain sectors as these were deemed to be appropriate, at the same time, some explicit impacts were not necessary to include for the reasons that follow.

- Population
    - Effect of flood on migration

        - This parameter can be removed due to difficulties in isolating the effect of floods or droughts on migration
- Education
    - No direct impacts; Excel spreadsheet quantifies damages from education: however, there was no information on how these occurred
- Health
    - At this stage: additional costs in health care per capita due to adverse weather
        - Intended to capture additional health care costs per capita in case of adverse weather (flood or drought)
- Roads
    - Effect of flood on functioning roads
        - Captures the loss of roads due to floods
        - Is used to calculate the additional costs for re-establishing the roads network
- Macroeconomy
    - Capital erosion due to floods
        - Intended to capture the loss of physical capital in case of floods, and hence affects productivity and total value added
    - Effect of drought on total factor productivity
        - Intended to capture the impact that droughts (and the resulting lack of food) has on total factor productivity and hence total value added
- Water sector
    - Effect of temperature (/drought) on evapotranspiration
        - Intended to capture the impact that higher temperatures have on the evapotranspiration rate of rain. Evapotranspiration is also depending on the saturation of the air with humidity and wind speed, both of which are not included in the model.
    - Effect of temperature on natural vegetation cover
        - Intended to capture the change in percolation rate related to the loss of surface vegetation. Less vegetation leads to the loss of roots in the ground, which makes the ground less permeable and hence causes more water to run off into surface water streams.
- Agriculture
    - Effect of drought on average lifetime of agriculture land
        - Intended to capture the loss of agriculture land in case of droughts. An adjustment process in this part of the structure leads to a continuous renewal of agriculture land, trying to reach pre-disaster levels.
    - Effect of adverse weather on agriculture yields
        - Intended to capture the loss of agriculture production through floods or droughts. This might need to be refined (evtl. in phase III), as the lack of water affects agriculture productivity in a different way than floods do. Also related to our discussion in the team meeting that floods, once the water leaves, make land more fertile, while droughts desert land and it hence takes longer to recover.

- Energy
    - Effect of precipitation and temperature on load factor of conventional power generation capacity
        - Intended to capture the effect of water availability on the capacity of power generation capacity to remain operational (e.g. water for cooling purposes)
        - Also: intended to capture the impact of temperature/water temperature on the operation of thermal power plants
            - Both affect the operations of power plants in a negative way and either lead to more fuel consumption and hence higher emissions, or result in a temporary shutdown of plants due to "overheating"
    - Water flow impact on hydropower load factor
        - Intended to capture the impact of "water availability" on hydropower electricity generation
    - Effect of temperature and drought on the occurrence of forest fires/fires related to the power distribution network
        - In tended to capture the interaction between temperature, drought and power distribution infrastructure, and their combined impact on the occurrence of fires

For the work on the phase on DRR and CIS, data on some of the parameters of impacts have not been considered due mainly to their nonavailability. Proxy data have, instead been used. Additionally hydrometeorological data such as: precipitation, flooding: droughts, storms, tropical cyclones have been acquires and processed for the purposes of ingesting into the model.

8.2 Methods of obtaining data

Data were obtained from the public domain from credible sources such as: UNISDR, IFRC, WB, WMO, FAO, UNDP, etc.

As an alternative to using observed data on fatalities and economic losses to set baselines and determine progress, metrics on expected disaster fatalities and expected economic losses should be developed, and DRR policies tracked through procedures such as identifying the percentage of the population living or working in buildings of moderate and high susceptibility to collapse in high-hazard earthquake zones (see section 4.2). The long-term aim could be for every country to eventually use full catastrophe models to monitor progress. However, these will take time to develop. Both these methods will require the collection of high-resolution exposure information, including that on building locations and values.

In future, detailed data on disaster losses and the attributes of buildings damaged will be important for testing and improving the methodology for measuring assumed relationships between fatality rates and different building styles or evacuation procedures. The occurrence of particular disasters will also test mitigation strategies. Hence, we will need improvements in disaster loss data collection, including the generation of datasets to assess impacts on the poorest (Sections 5.2 and 5.4). It will be important for the collection of both risk and loss data that there be consistent global definitions and methodology.

9. MODEL DESCRIPTION

The modelling effort was carried out on Vensim software, using Systems Dynamics principles.

9.1 Vensim model

Vensim , designed by Ventana Corp., is a visual modeling tool that allows you to conceptualize, document, simulate, analyze, and optimize models of complex dynamic systems. Vensim provides a flexible approach to creating models by allowing you to include ideas, build diagrams and, when appropriate, move into a formal simulation model. Modeling starts with causal loop diagrams, equations, or stock and flow diagrams. Models can also be imported from other applications, providing the user with Vensim's powerful analysis and optimization tools.

For Advanced Modelling, you need Vensim PLE Plus, Vensim DSS and Vensim Pro because you can use arrays in the equation editor. Vensim Model Reader is just for running models, it does not have the capabilities to designing models. The Model Reader can however read arrays.

9.2 Causal relationship

Causal relationship are relationships that show how variables in a Vensim model affect each other. They are interpreted by Causal Loop diagrams. An arrow going from A to B indicates that A causes B. Causal loop diagrams can be very helpful in conceptualizing and communicating structures. By connecting words with arrows, relationships among system variables are entered and recorded as causal connections. Causal relationships can help you analyze your model throughout the building process, looking at the causes and uses of a variable, and also at the loops involving the variable. For an example Figure 9.1 shows several examplesr of relationships used in causal loops. One such example is cis adjustment is affected by,

i. Desired cis coverage,
ii. Time to establish CIS,
iii. CIS investment policy switch, and
iv. Start time of cis investment.

On the other hand cis adjustment affect the rate in change in cis coverage.

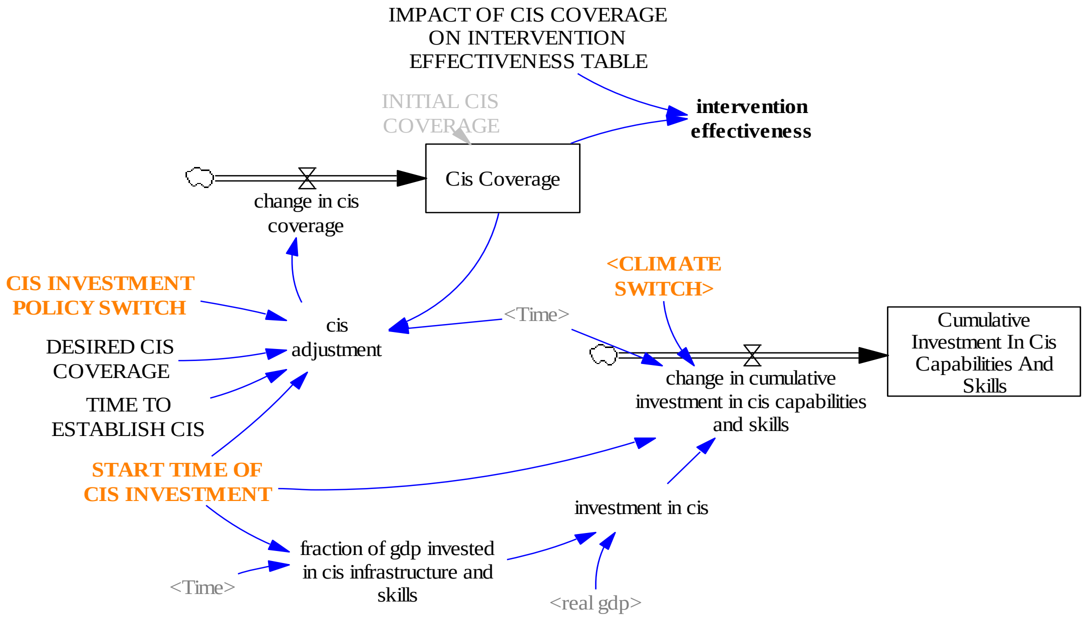


Figure 9.1: Causal loop representation.

9.3. Assumptions

Assumptions (only structural, numerical ones are addressed under parametrization)
Structural

The following are the main structural assumptions used to build the model. The assumptions used in the model are based on available literature and models, as well as on data.

- Climate events and their magnitude are calculated based on average monthly precipitation and predefined threshold values. The threshold values for floods and droughts were provided as follows:
  - Drought: 25% below monthly average
  - Flood: 25% above monthly average
- CIS coverage in the context of the CIS SEB model refers to both infrastructure (observational networks, radars, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). . Assuming a value of 0.6 hence indicates that 60% of infrastructure and skills are available.
- The effectiveness of interventions, and hence damages avoided, is based on CIS coverage. Information on the relationship between CIS coverage and DRR intervention effectiveness was provided by Dr. Garanganga. It is defined as the following, non-linear relationship: It is assumed that extreme weather events affect production (e.g. agriculture) in the short term.

- It is assumed that agriculture land affected by drought events can be re-established within one year as long as land for conversion is available.
- It is assumed that drought events only affect the share of population that is living in drought-prone areas. The impact of drought events hence depends on the number of people living in these areas and the magnitude of the drought.
- The impact of floods is, opposed to the impact of drought events, based on total population as floods can potentially happen anywhere in case of extreme rainfall over extended periods of time.
- Extraordinary health care expenditure is assumed to only incur for the total number of people affected by events.
- It is assumed that capital (e.g. infrastructure) is damaged by extreme events and that only roads are rebuilt. Other damage to capital is carried over throughout the end of the simulation. Reinvesting the avoided costs from DRR interventions would lead to higher economic growth, however, as damages are avoided, there is no perceived for reinvesting (or investing) money.

9.4. Uncertainties

There are some uncertainties when model assumptions are made. The following are examples of such:

- The extent to which the economy is impacted depends on the structure of the economy (e.g. share of agriculture in GDP, road network availability)
- The model assumes a continuing trend in terms of future weather and climate. Future sensitivity scenarios could assess the performance of the country under different climate change scenarios.
- The strength and magnitude of climate events also depends on spatial factors (e.g. flood in urban areas, loss of a bridge), which implies that customizing the model to a country's context is indispensable for a proper economic assessment
- The abatement of damages and hence related benefits, depends a) on the capability and capacity of the government to disseminate CIS in a timely manner, and b) on the actual uptake of the rural population.
- Forecast accuracy depends on both the available infrastructure and the skill level of the people using the infrastructure. To realize the benefits of CIS, investments must consider both.
-

10. CRITICAL EVALUATION AND DOCUMENTATION OF CAUSAL RELATIONSHIPS

In order to carry out modelling work there is need for critical examination of the causal relationships. This entails that assumptions made, limitations, data requirements and data gaps that may exist are carefully assessed.

10.1. Assumptions

Assumptions (only structural, numerical ones are addressed under parametrization) Structural

The following are the main structural assumptions used to build the model. The assumptions used in the model are based on available literature and models, as well as on data.

- Climate events and their magnitude are calculated based on average monthly precipitation and predefined threshold values. The threshold values for floods and droughts were provided as follows:

-	Drought:	25% below monthly average
-	Flood:	25% above monthly average

- CIS coverage in the context of the CIS SEB model refers to both infrastructure (observational networks, radars, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). . Assuming a value of 0.6 hence indicates that 60% of infrastructure and skills are available.
- The effectiveness of interventions, and hence damages avoided, is based on CIS coverage. Information on the relationship between CIS coverage and DRR intervention effectiveness was provided by Dr. Garanganga. It is defined as the following, non-linear relationship:

- It is assumed that extreme weather events affect production (e.g. agriculture) in the short term.
- It is assumed that agriculture land affected by drought events can be re-established within one year as long as land for conversion is available.
- It is assumed that drought events only affect the share of population that is living in drought-prone areas. The impact of drought events hence depends on the number of people living in these areas and the magnitude of the drought.
- The impact of floods is, opposed to the impact of drought events, based on total population as floods can potentially happen anywhere in case of extreme rainfall over extended periods of time.
- Extraordinary health care expenditure is assumed to only incur for the total number of people affected by events.

- It is assumed that capital (e.g. infrastructure) is damaged by extreme events and that only roads are rebuilt. Other damage to capital is carried over throughout the end of the simulation. Reinvesting the avoided costs from DRR interventions would lead to higher economic growth, however, as damages are avoided, there is no perceived for reinvesting (or investing) money.

10.2. Limitations

There are limitations that arise due to the data used, for instance. The data used for the parameterization of the model was calculated based on a dataset providing climate related impacts across multiple African countries UNISDR: 2017: web page link-http://www.desinventar.net/data_sources.html). The provided dataset was incomplete for many events, which required averaging the information that was available. Consequentially, the model is using average parameters to calculate climate impacts of floods and droughts on various sectors. Furthermore, the model uses monthly averages for precipitation and expert confidence ranges to determine the frequency of adverse climate events.

For a proper assessment of climate impacts and the SEB of CIS, country specific data on macroeconomic variables (e.g. GDP by sector, employment, health care) is necessary to customize the model.

10.3. Data requirements and sources

In order to carry out the Systems Dynamics modelling related to SEB on CIS-DRR, there is need to have climate and socio-economic data: economic damages, people affected, constraints to agricultural production, etc.. These types of data were obtained from the public domain using websites of credible, relevant organizations: such as UN agencies.. These data were from official government compilations, relief organizations, media, etc. The multiple sources enabled some measure of authentication of independent data source.

10.4. Data gaps

Identified data gaps range across all sectors and are mainly related to the lack of post-disaster assessments of the actual damages that occurred during adverse weather events.

Assessment of economic damages

The dataset () provided mainly impacts on physical factors, such as population (e.g. affected, missing, dead), the amount of agriculture land and cattle affected, or lost through the respective event. Information on the economic value of respective events was either not available or provided on aggregate level. Aggregate information of impacts would allow for the estimation of impacts compared to GDP but does not provide information on the economic sectors in which these damages were caused. Consequentially, post-disaster assessment of damages by sector (and actor), such as conducted after cyclone Eline in Mozambique in the year 2000 () are needed.

11. ANALYSIS

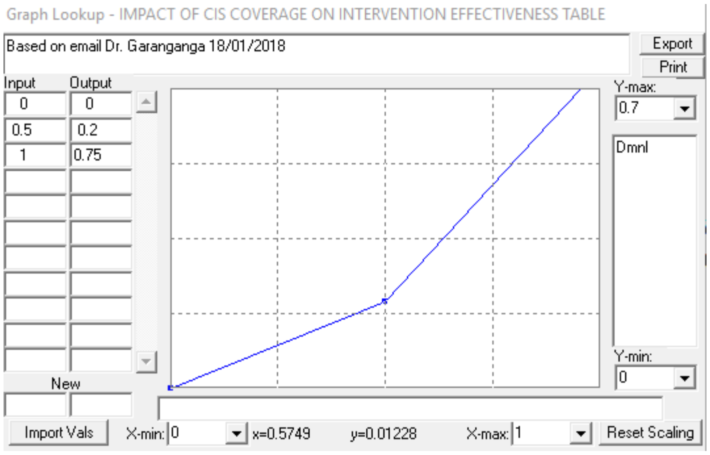
The analysis was done through use of relevant equations and parameters for generating the outputs.

11.1 Relevant equations and parameters determined

Assumptions (only structural, numerical ones are addressed under parametrization)
Structural

The following are the main structural assumptions used to build the model. The assumptions used in the model are based on available literature and models, as well as on data.

- Climate events and their magnitude are calculated based on average monthly precipitation and predefined threshold values. The threshold values for floods and droughts were provided as follows:
  - Drought: 25% below monthly average
  - Flood: 25% above monthly average
- CIS coverage in the context of the CIS SEB model refers to both infrastructure (observational networks, radars, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). Assuming a value of 0.6 hence indicates that 60% of infrastructure and skills are available.
- The effectiveness of interventions, and hence damages avoided, is based on CIS coverage. On the basis of available information on the relationship between CIS coverage and DRR intervention effectiveness , the following, non-linear relationship exists:



Graph Lookup - IMPACT OF CIS COVERAGE ON INTERVENTION EFFECTIVENESS TABLE

Based on email Dr. Garanganga 18/01/2018

Input	Output
0	0
0.5	0.2
1	0.75

Y-max: 0.7

Dmnl

Y-min: 0

X-min: 0

x=0.5749

y=0.01228

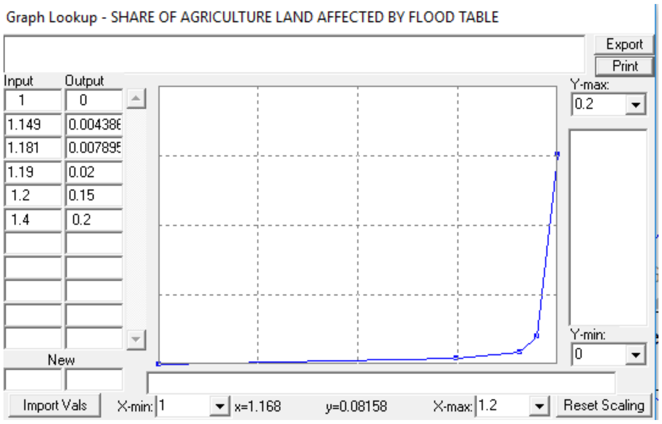
X-max: 1

Figure 11.1: Relationship between CIS coverage and DRR intervention effectiveness

11.2. Model parameterization

Relevant parameters were determined and equations set out for the development of the models. Share of agriculture land affected by flood

Based on the available data (UNISDR: 2017: web page link- http://www.desinventar.net/data_sources.html)), the share of agriculture land affected by floods was determined to range from 0% to 20%. The analysis of the data indicated that, even in months with a relatively high precipitation above average (e.g. 50%), the share of agriculture land affected could be relatively low. Consequentially, a non-linear function was established to determine the share of agriculture land affected by floods. The function is displayed in **Error! Reference source not found.**11.2. The amount of agriculture land affected by flood events is hence determined based on the total amount of agriculture land and the non-linear function of the flood indicator.



Graph Lookup - SHARE OF AGRICULTURE LAND AFFECTED BY FLOOD TABLE

Input	Output
1	0
1.149	0.00438
1.181	0.00789
1.19	0.02
1.2	0.15
1.4	0.2

Y-max: 0.2

Y-min: 0

X-min: 1

x=1.168

y=0.08158

X-max: 1.2

Figure 11.2: Share of agriculture land affected by flood

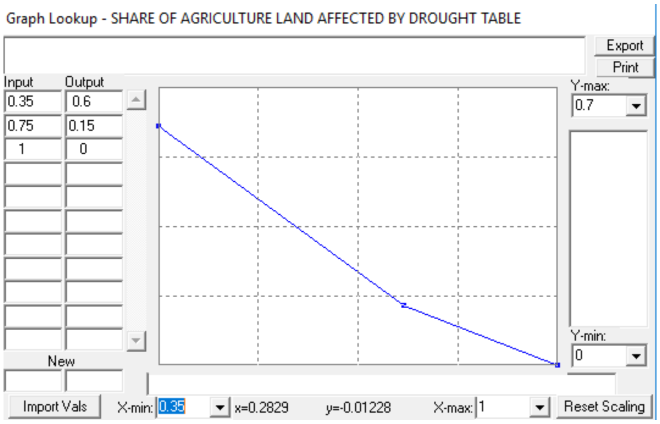
The share of agriculture land affected by flood is hence dependent on the flood indicator, which indicates the magnitude of the event. Subsequently, the total amount of agriculture land affected by floods is calculated by the following equation:

*Agriculture land affected by flood = Total Agriculture Land * share of agriculture land affected by flood*

1.1.1. Share of agriculture land affected by drought

Based on the available data (UNISDR: 2017: web page link-http://www.desinventar.net/data_sources.html)), the share of agriculture land affected by droughts was determined to range from 0% to 30%. The analysis of the data indicated that, even in months with a relatively low precipitation below average (e.g. 15-20%), the share of agriculture land affected could be relatively low. It should be noted that a drought indicator per se does not provide necessarily provide all the information to determine strength and impact of the drought, as discussed in the limitations section. Consequentially, the function assumes a linear increase up to 15% of land affected for precipitation 25% below average, and after that steep increase to 60% to simulate extreme drought events (35% of average monthly rainfall or less).

Based on this information, a non-linear function was established to determine the share of agriculture land affected by floods. The function is displayed in **Error! Reference source not found.**. The amount of agriculture land affected by drought events is hence determined based on the total amount of agriculture land and the non-linear function of the drought indicator.



Graph Lookup - SHARE OF AGRICULTURE LAND AFFECTED BY DROUGHT TABLE

Input	Output
0.35	0.6
0.75	0.15
1	0

Y-max: 0.7
Y-min: 0
X-min: 0.35
x=0.2829
y=-0.01228
X-max: 1

Figure 11.3: Share of agriculture land affected by drought

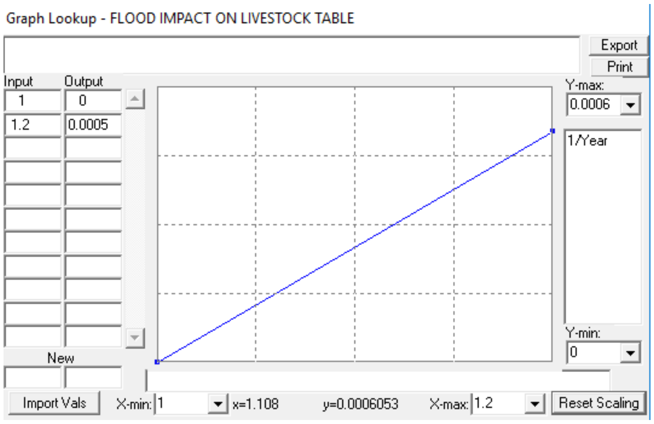
The share of agriculture land affected by drought is hence dependent on the water scarcity indicator, which indicates the magnitude of the event. Subsequently, the total amount of agriculture land affected by droughts is calculated by the following equation:

*Agriculture land affected by drought = Total Agriculture Land * share of agriculture land affected by drought*

1.1.2. Share of livestock affected by flood

The share of livestock affected by floods is assumed to range between 0% and 0.05% per flood event, depending on the magnitude of the event. As discussed in the limitation section, the impact of floods is not bound to a specific region, which implies that the share of livestock affected by floods could be significantly higher, depending on the country context.

Based on the available information (UNISDR: 2017: web page link- http://www.desinventar.net/data_sources.html)), a linear relationship for the share of livestock affected by flood was established. The relationship between the flood indicator and the share of livestock lost is illustrated in **Error! Reference source not found.**4



Graph Lookup - FLOOD IMPACT ON LIVESTOCK TABLE

Input	Output
1	0
1.2	0.0005

Y-max: 0.0006

1/Year

Y-min: 0

X-min: 1

x=1.108

y=0.0006053

X-max: 1.2

Figure 10.40: Share of livestock affected by flood

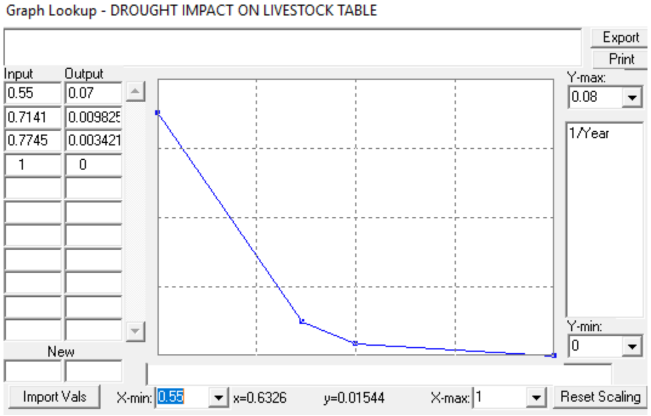
The share of livestock land affected by floods is hence dependent on the flood indicator, which indicates the magnitude of the event. Subsequently, the total heads of livestock affected by floods is calculated by the following equation:

*Loss of livestock due to floods = Livestock * FLOOD IMPACT ON LIVESTOCK TABLE (flood indicator)*

1.1.3. Share of livestock affected by drought

The share of livestock affected by droughts is assumed to range between 0% and 7% per drought event, depending on its magnitude. As discussed in the limitation section, the impact of floods is not bound to a specific region, which implies that the share of livestock affected by floods could be significantly higher, depending on the country context.

Based on the available information (UNISDR: 2017: web page link-) http://www.desinventar.net/data_sources.html)), a non-linear relationship for the share of livestock affected by flood was established. The function assuming that the loss of livestock increases linearly from 0 to 1% as with a decrease in average monthly precipitation from 100% to 75%. As soon as monthly average precipitation drops below 75%, the share of livestock affected increases strongly, assuming a lack of sufficient water to maintain all animals. The relationship between the flood indicator and the share of livestock lost is illustrated in Figure. 11.4.



Graph Lookup - DROUGHT IMPACT ON LIVESTOCK TABLE

Input	Output
0.55	0.07
0.7141	0.009825
0.7745	0.003421
1	0

Y-max: 0.08

1/Year

Y-min: 0

X-min: 0.55

x=0.6326

y=0.01544

X-max: 1

Figure 11.11: Share of livestock affected by drought

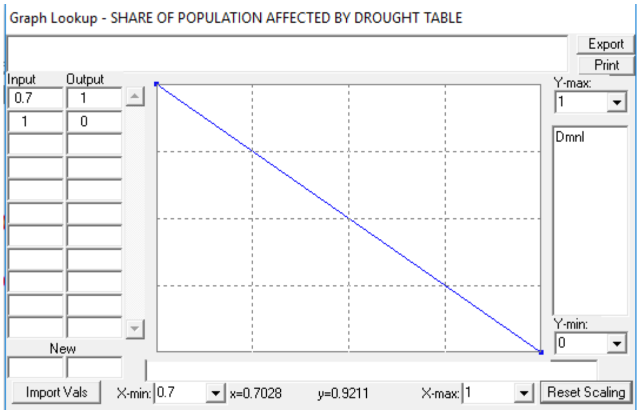
The share of livestock land affected by droughts is hence dependent on the drought indicator, which indicates the magnitude of the event. Subsequently, the total heads of livestock affected by droughts is calculated by the following equation:

---

*Loss of livestock due to drought = Livestock * FLOOD IMPACT ON LIVESTOCK TABLE (flood indicator)*

1.1.4. Share of population affected by adverse weather

The share of population affected by flood and drought is dependent on the flood indicator and the water scarcity indicator and table functions determined based on the analyzed dataset (UNISDR: 2017: web page link- http://www.desinventar.net/data_sources.html)). The share of population affected by drought is estimated based on the *share of population living in drought prone areas* and the *share of population affected by drought*. The latter variable is comprised of a linear relationship which has been estimated based on the available data and is depicted in **Error! Reference source not found.**.



Graph Lookup - SHARE OF POPULATION AFFECTED BY DROUGHT TABLE

Input	Output
0.7	1
1	0

Y-max: 1

Y-min: 0

Dmnl

X-min: 0.7

x=0.7028

y=0.9211

X-max: 1

Figure12.12: Share of population affected by drought

This linear function is based on the assumption that drought impacts gradually affect the population living in drought prone areas, and that all people living in drought prone areas are affected starting from precipitation levels of 30% below average. The *population affected by drought* is calculated as

---

Population affected by drought =

*Population living in drought prone areas * share of population affected by drought*

Further, while the value 1 represents 100%, this share applies to the *population living in drought prone areas* only, meaning that the number of people would be equivalent to the share of total population living in these areas. The amount of people living in drought prone areas is calculated through the following equation

---

Population living in drought prone areas=

*Population * SHARE OF POPULATION LIVING IN DROUGHT PRONE AREAS*

11.3. Simulation of the model

Time

, The projections of the model depend on the correctness of climate forecasts, which indicates that the degree of uncertainty in the projections increases over time. In addition, the CIS SEB model does not capture daily precipitation, but uses monthly average precipitation to determine the number and magnitude of climate impacts. This implies that events causing floods (e.g. 3-day spills of heavy rain) are not and cannot be considered in the analysis. In the same line, the model does not look at the number of months during which average precipitation is below the monthly average, which could be used as an additional indicator for droughts, together with the month during which the drought occurs.

The magnitude of impacts varies between countries and depends on a variety of factors, such as the structure of the economy, the share of people living in disaster-prone areas, and the strength of climate change impacts. At this stage, the CIS SEB model represents average climate impacts derived from events across multiple African countries. The magnitude of impacts on this model is hence calculated based on the initial parameterization of the model (Mauritius) and the average parameters derived from the dataset as described in section 11.1.1. This implies that the simulation results obtained from the model provide information about the SEBs of CIS on general level, and that the assessment of actual benefits requires the customization of the model to a country context. Space

Climate related impacts and damages are often related to landscape attributes and depend on geographical factors, such as slope, land cover, soil type, and regional climate conditions. Consequentially, only certain areas of the country are affected by climate events, although the impacts of these events (e.g. food scarcity) can be on national level. At this stage, the CIS SEB model is set up to calculate climate impacts based on country level, however, it could be calibrated to the subnational level if data were available. The proper assessment of climate impacts in a specific country context would account for the share of agriculture land located in drought prone areas, share of population living in drought prone areas, national food imports and other important variables that provide information about the magnitude of impacts.

In addition, the current formulation of the model does not allow for droughts and floods to happen simultaneously. Both event types occur if average monthly precipitation exceeds or undercuts predefined threshold values (<75% and >125% of normal average). A flood and a drought can hence occur in two subsequent months, but not at the same time.

11.4. Model validation

Model validation, i.e. Comparison of simulation with data on events and impacts were done up to 2018. **Error! Reference source not found.** represents the number of extreme adverse weather events that occurred between 1980 and 2015. Between 2000 and 2015, the model indicates a flood event almost every other year, and 3-4 severe drought events (including some minor drought events) in both scenarios, which is consistent with the frequency and impacts indicated in the dataset (UNISDR: 2017: web page link- http://www.desinventar.net/data_sources.html). According to the data UNISDR: 2017: web page link- http://www.desinventar.net/data_sources.html), Ethiopia, Mozambique and the Niger experienced between 3 and 5 drought events between 1980 and 2015 with a significant number of people affected. Furthermore, the dataset indicates that, since the year 2000, almost all countries are experiencing flood events on an annual basis.

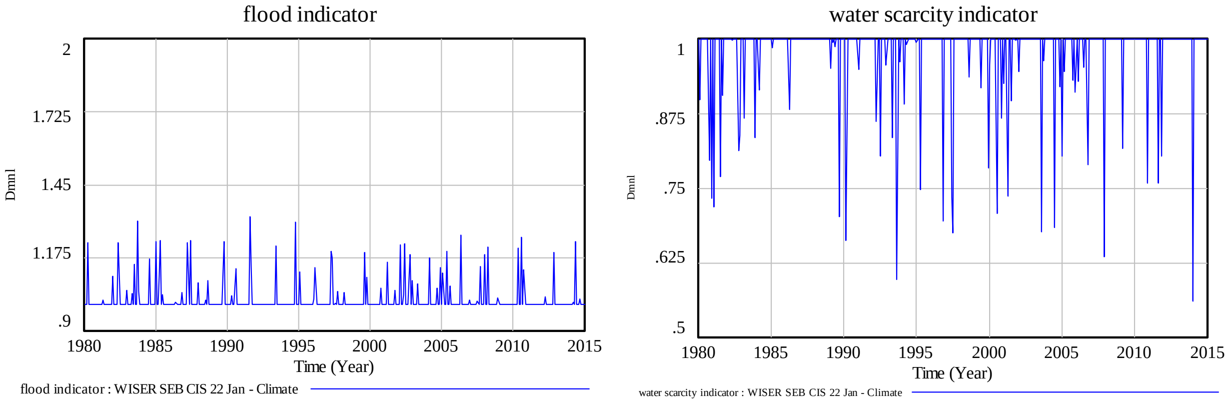


Figure 12.13: Flood indicator and water scarcity indicator 1980 to 2015

Impact of floods / drought on land (magnitude)

Table 11.8 provides an overview of the shares of agriculture land affected by floods and droughts. The simulations indicate that major events affecting large amounts of land happen on average every 3 to 5 years. Based on the available dataset, the frequency of events is comparable to the data provided for Ethiopia and Mozambique. Further, the model generates an average amount of land devastated by floods of 1.4% per year in the Climate scenario, which is in the range of the calculated averages from the dataset. According to the data, the average amounts of land devastated in case of a flood event range from around 1% to 1.5% for Senegal and Ethiopia, to around 4% to 6% for the Niger and Mozambique. This indicates that flood impacts are captured moderately in the model.

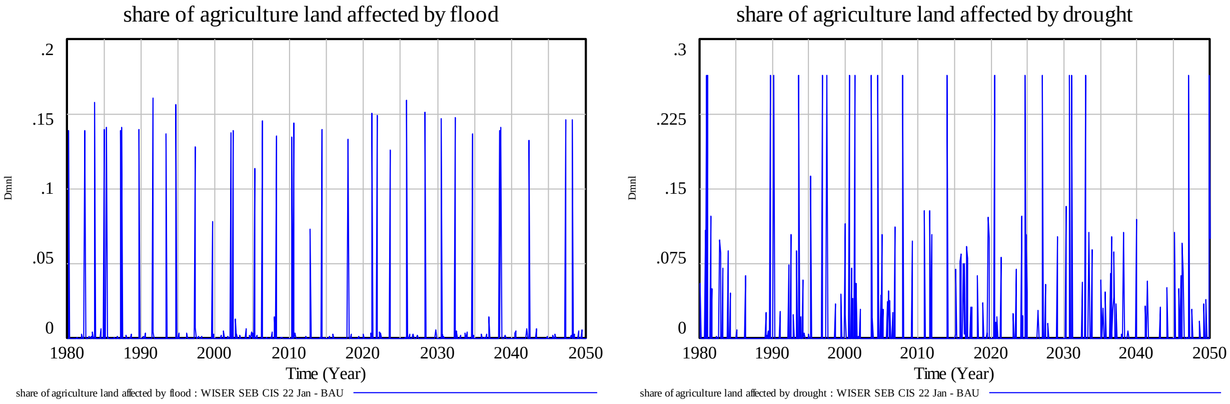


Table 11.8: Impact of floods and droughts on agriculture land 1980 to 2015

Regarding the impacts of drought on agriculture land, the data analysis provided a range from 0.5% for moderate events to more than 40%-60% of farmland damaged in case of a severe event. For the years 2010/2011, the model generates a 12.8% and 10.4% share of farmland damaged on average, which means that also drought impacts are captured moderately and could be much more severe in case of extreme events.

Impact of floods / drought on GDP

Compared to the baseline scenario, the generated behavior in the Climate scenario shows the impacts of adverse events. Over a period of 35 years (1980 to 2015), total real GDP is 3.68% lower as a consequence of capital erosion due to adverse weather. The difference in total GDP is equivalent to MUR 5.4 billion, or roughly USD 168 million by 2015.

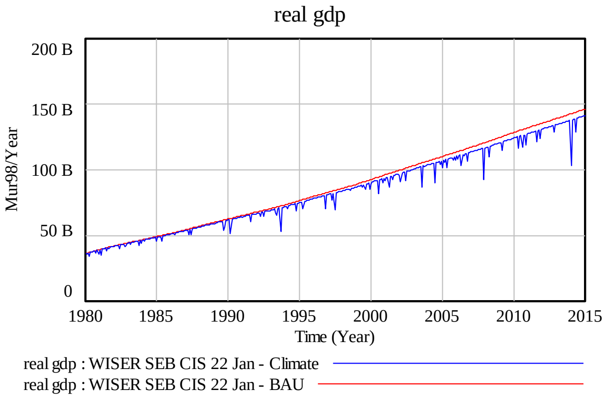


Table 11.9: Real GDP in BAU and Climate scenario 1980 to 2015

Population affected

The total affected population is in the range of 50,000 to 150,000 people, which is equivalent to 5% to 15%, of total population, depending on the magnitude of climate events. These numbers are in line with to the numbers in the available data sets, although only general validation is possible at this stage. The total share of population affected by droughts depends on the share of people that live in drought-prone areas, which is assumed to be 13% for the current simulations. This indicates that the number of people affected can be significantly higher, especially in countries with a high percentage of subsistence farmers in rural areas.

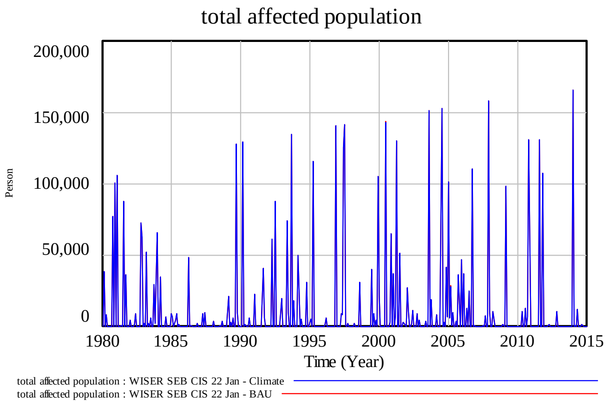


Figure 12. 16: Total affected population in the BAU and Climate scenario 1980 to 2015

1.1.5. Sensitivity analysis (how much results change when you modify assumptions)

12. QUANTITATIVE MODEL RESULTS

Agriculture: impact on land and productivity

Climate impacts on agriculture distinguish between the share of agriculture land affected by floods and agriculture land affected by droughts. The causal relationships used to determine the impact of climate hazards on the amount of affected agriculture land are displayed in Figure 12..

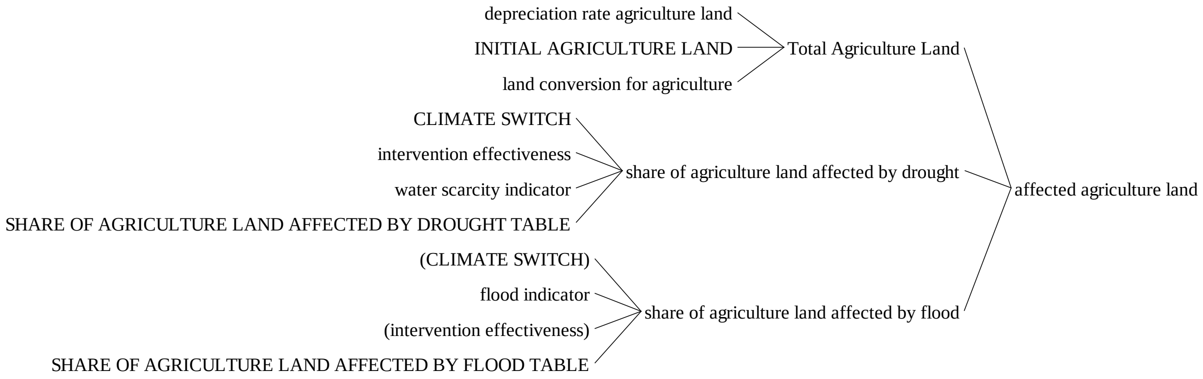


Figure 12.1: Climate impacts on productive agriculture land

The amount of *affected agriculture land* depends on the magnitude of climate events. According to the Food and Agriculture Organization of the United Nations (FAO), droughts can reduce total agriculture productivity by 70% (FAO , 2015). The CIS SEB model uses two different variables for yield. The first one is the regular production *yield*, which is affected by total factor productivity and the elasticity of agriculture yield to total factor productivity. In addition to the normal agriculture yield, the model considers a reduced yield for production on affected agriculture land, which is equivalent to 30% on the baseline yield and hence captures the 70% indicated by the FAO. Figure 12. illustrates the causal relationships used to calculate total agriculture production into the model.

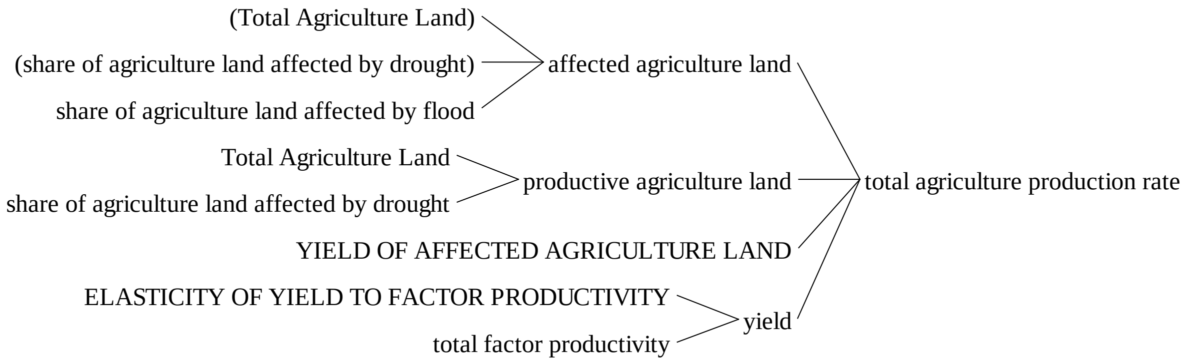


Figure 12.2: Climate impacts on total agriculture production

Livestock: losses due to climate change

The causal relationships used to implement the impact of floods and droughts on livestock is into the model are illustrated in Figure 12.3. The *change in livestock* is an inflow to the stock of livestock and calculated based on an exogenous annual growth rate. Floods and droughts pose different threats to livestock and the model assumes two separate impacts to ensure that both types of events affect livestock differently. The impacts of adverse weather are hence captured through the outflows *loss of livestock due to floods* and *loss of livestock due to droughts*.

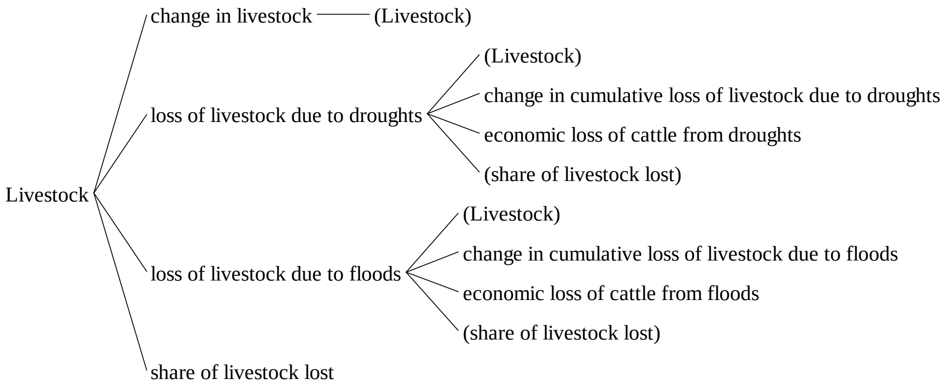


Figure 12.3: Climate impacts on livestock

Whereas the loss of livestock due to floods and droughts are physical flows of animals that are affected by adverse weather, these flows inform the assessment of economic impact of such events. The number of animals lost per event is used to determine the economic value (loss) per event, which then serves for the assessment of avoided costs and added benefits of CIS interventions.

Population number of people affected by climate events:

An additional variable introduced to the model is the number of people that are affected by adverse weather events. The proper assessment of population-related additional costs requires an estimation of the number of people affected by flood and drought events respectively. The estimation of the number of people affected is based on

i) The share of people that are living in flood- and drought-prone areas respectively, and

ii) The magnitude of the climate event, or in other words, the share of people within these areas that are affected by a certain event. At this stage, regionalization (share of people in areas prone to adverse weather) is only assumed for drought events, as flood events can potentially occur anywhere in case of extreme rainfall.

Figure 12.4 illustrates the factors determining the number of people affected by climate events.

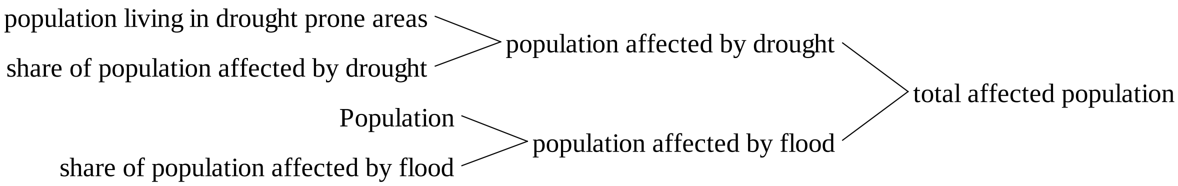


Figure 12.4: Climate impacts on population

At this stage, the number of affected people is used to determine the additional health care expenditure. In later iterations of the model, this number can potentially be used to determine disaster relief payments, such as for example payments for food and water delivery to affected areas or resettlement costs.

CIS investment and impact

The impact of CIS coverage on intervention effectiveness was implemented into the model. More data is needed to adequately parameterize this effect, however the structure for including this impact is in place and operational. Figure 12. represents the structure used to capture the impact of CIS coverage on intervention effectiveness. This structure allows for the adjustment of CIS coverage based on a desired coverage value. Further, it is capable of calculating the necessary investment for the increase in CIS coverage over time.

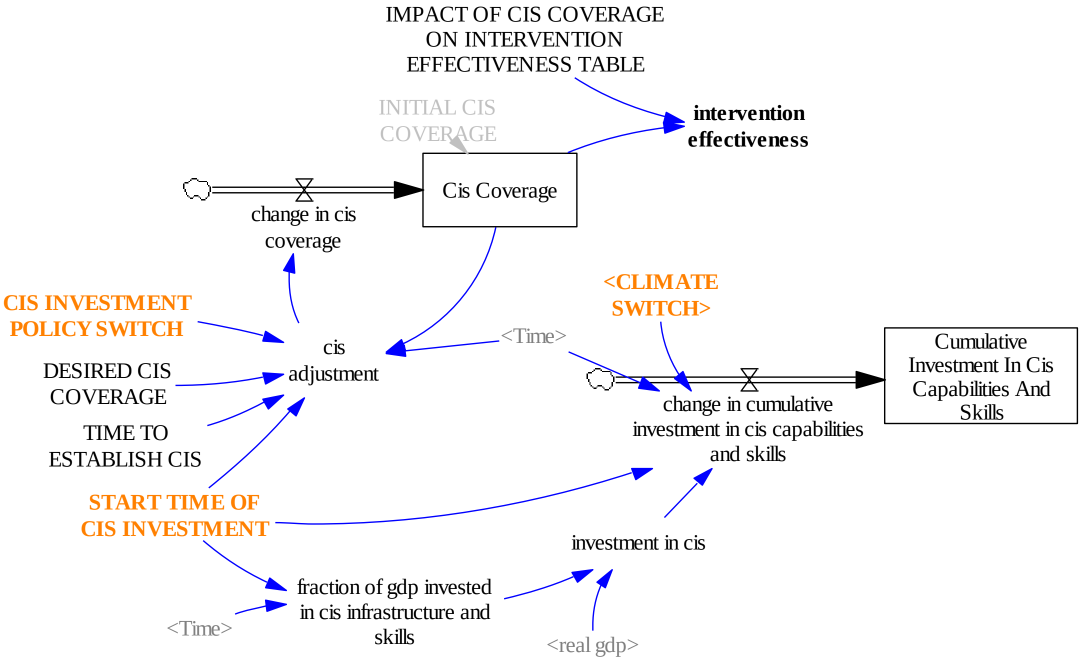


Figure 12.5: Structure in use to represent CIS coverage in the CIS SEB model

DRR indicators

A sketch providing an overview of the main DRR indicators has been implemented into the model. It displays graphs of key variables in the model for each of the simulated scenarios to enable users to see the generated behavior and hence the impact of investments in CIS. The sketch will be refined based on input from the intended end users concerning desired variables to be displayed and their mode of representation (e.g. graph, bar chart, table) to ensure the usefulness of the outputs for various audiences.

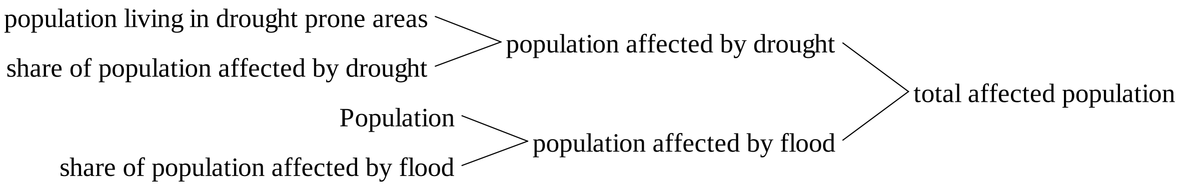


Figure 12.6: Climate impacts on population

The dataset () provided mainly impacts on physical factors, such as population (e.g. affected, missing, dead), the amount of agriculture land and cattle affected, or lost through the respective event. Information on the economic value of respective events was either not available or provided on aggregate level. Aggregate information of impacts would allow for the estimation of impacts compared to GDP but does not provide information on the economic sectors in which these damages were caused. Consequentially, post-disaster assessment of damages by sector (and actor), such as conducted after cyclone Eline in Mozambique in the year 2000 () are needed.

Assessment of impacts by sector

In addition to the number of people affected by adverse climate events, information on physical impacts on infrastructure and capital are needed. Floods have detrimental impacts on roads, real estate, power distribution and mobility, and information on the loss of physical variables is very scarce or not available. The assessment of changes in different capital stocks is crucial to assess the full range of impacts, since replacement or rebuilding requires additional capital investment and stimulates economic activity.

Positive spillover effects from adverse climate events

Next to information on the physical (and economic) impacts of adverse weather events, information on potential positive impacts would benefit the analysis. While floods destroy land and capital, they can potentially contribute to increasing agriculture land fertility and hence productivity in subsequent years. The assessment of potentially positive impacts from adverse weather events would add an additional perspective to the DRR assessment of adverse weather.

2015

SEBs of CIS

Increase agriculture share in GDP

The current setup of the model assumes that agriculture holds a share of 5-7% in total GDP. The sensitivity scenario increases the value of damages to agriculture to 50% assuming a country where agriculture production makes up a large share of GDP. A tenfold increase in the value added per ton of agriculture produce is assumed. The change in value added per ton affects the calculation of foregone agriculture production, which implies that no GDP impacts are assumed. To capture the implications on real GDP, the model would need to be recalibrated, which is beyond the scope of this sensitivity analysis.

Figure displays the cumulative economic value of foregone agriculture production and the total cumulative impacts of climate events. The increase in value added per ton of agriculture produce increases the cumulative economic value of foregone agriculture production from MUR 1.45 billion to MUR 14.5 billion in 2050. The increase in value added from agriculture production increases the total cumulative impacts of adverse climate events by 5%[1].

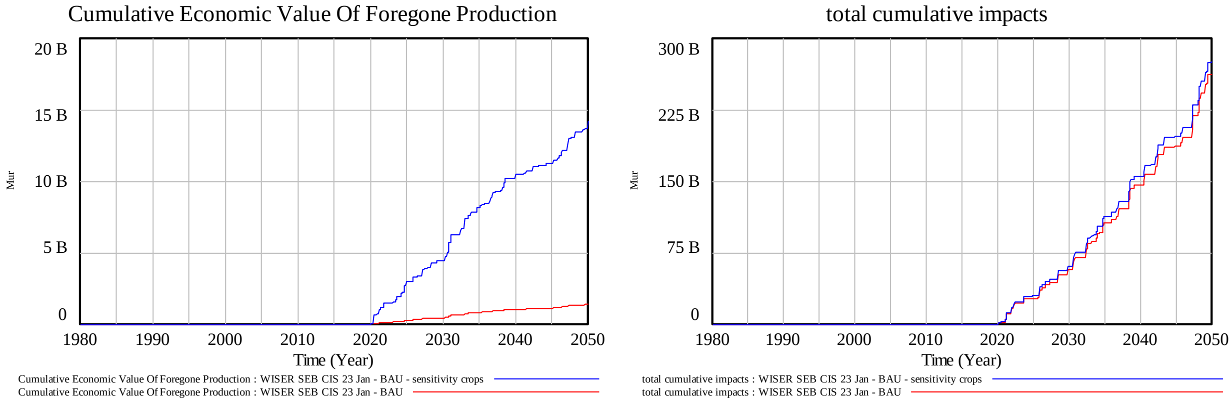


Figure 12.7: Sensitivity scenario – Agriculture

Value of infrastructure damage – Road network

Increase the value of damages to roads for countries with high infrastructure. The costs per kilometer of road is currently assumed to be roughly 300,000 USD, which is quite low compared to international averages on paved roads. For the sensitivity scenario, the costs per kilometer of road will be increased by factor four, to approximately USD 1.2 million per km.

The results for cumulative additional costs for roads construction and total cumulative impacts from adverse weather are displayed in Figure 12.8. The increase in costs per kilometer of road increases the cumulative additional costs for re-establishing roads from MUR 13.2 billion to MUR 52.8 billion in 2050. The increase in additional costs for maintaining the road network increases the total cumulative impacts of adverse climate events by 15%

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[1] Note that losses from agriculture is captured through the loss in capital. Consequentially, this sensitivity scenario addresses losses related to reductions in value added from agriculture output.

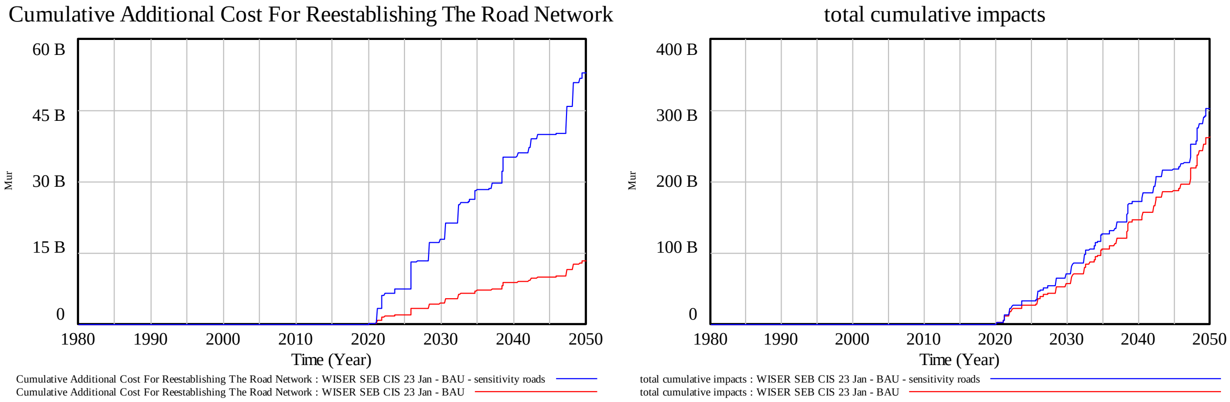

Figure 12.8: Sensitivity scenario – Roads

2. Quantitative results (model results)

The CIS SEB model determines the SEBs of climate information services between 2020 and 2050. The following four scenarios serve for the quantitative assessment of the SEBs of CIS:

1) The **No Climate** scenario
…assumes no climate impacts and no investments, and hence represents the current state of macroeconomic planning models.
2) The **Reference** (or baseline scenario)
…assumes 0% coverage throughout the simulation, which implies no anticipation of climate events and hence 100% of damages.
3) The **Business as usual** (**BAU)** scenario
…assumes 30% coverage throughout the simulation, which translates into an intervention effectiveness of 12%. This means that only 88% of the damages incur.
4) The **CIS investment** scenario
5)
…assumes an increase in CIS coverage from 30% to 95% between 2020 and 2030, and a further increase from 95% to 100% coverage between 2030 and 2040. This translates into an intervention effectiveness of 68% and 74.5% by 2030 and 2040 respectively, which implies that 74.5% of damages can be avoided by 2040.

The No Climate scenario does not consider climate impacts and serves for the assessment of climate impacts on various sectors, since, if climate change is not considered, then the projected results will be higher (e.g. GDP). The Reference scenario provides the full impact of climate events and provides a baseline for the assessment of SEBs of CIS. Considering that are already CIS in the BAU scenario indicates savings in the BAU case. Given that the application of CIS is beneficial for DRR and the abatement of climate change related damages to various sectors, the CIS investment scenario with full coverage is simulated to assess the full range of potential SEBs that could be obtained through CIS.

Scenario	Total impacts (million USD)	Total SEBs (million USD)	Total investment (million USD)	Cost to benefit ratio
Reference (0% CIS coverage)				
Full climate impacts	9'160.55	-	-	-
BAU (30% CIS coverage)				
Impacts climate	8'159.32	1'001.23	208.31	4.81
CIS investment (100% coverage by 2035)				
CIS investment	3'027.19	6'133.36	845.14	7.26

provides an overview of the assessment of the SEBs of CIS in the current model. It summarizes the total impacts, avoided impacts, investments and the total SEBs generated by the respective investment over its lifetime (30 years assumed). The No CIS scenario serves as a baseline that provides the total damages in case that no climate information services are provided[2]. More detailed results on impacts by sector are provided at the end of this section.

Scenario	Total impacts (million USD)	Total SEBs (million USD)	Total investment (million USD)	Cost to benefit ratio
Reference (0% CIS coverage)				
Full climate impacts	9'160.55	-	-	-
BAU (30% CIS coverage)				
Impacts climate	8'159.32	1'001.23	208.31	4.81
CIS investment (100% coverage by 2035)				
CIS investment	3'027.19	6'133.36	845.14	7.26

Table 12.1: Overview of SEBs of CIS between 2020 and 2050 by scenario

The following sections provide an overview on the three simulated scenarios.

2.1. Parameterization of precipitation

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[2] Climate impacts in the No CIS scenario will be the strongest all the time (12% higher than in the Climate scenario), while the behavior will be comparable the Climate scenario. Illustrations through this section therefore only contain graphical information of the Climate scenario and the CIS investment scenario.

The annual rainfall uses seasonality and a baseline medium to longer term trend. The left graph in **Error! Reference source not found.** illustrates precipitation in the year 1980, to highlight assumptions on seasonality. The graph on the right of **Error! Reference source not found.** shows precipitation in the baseline scenario over the full range of the simulation (1980 – 2050).

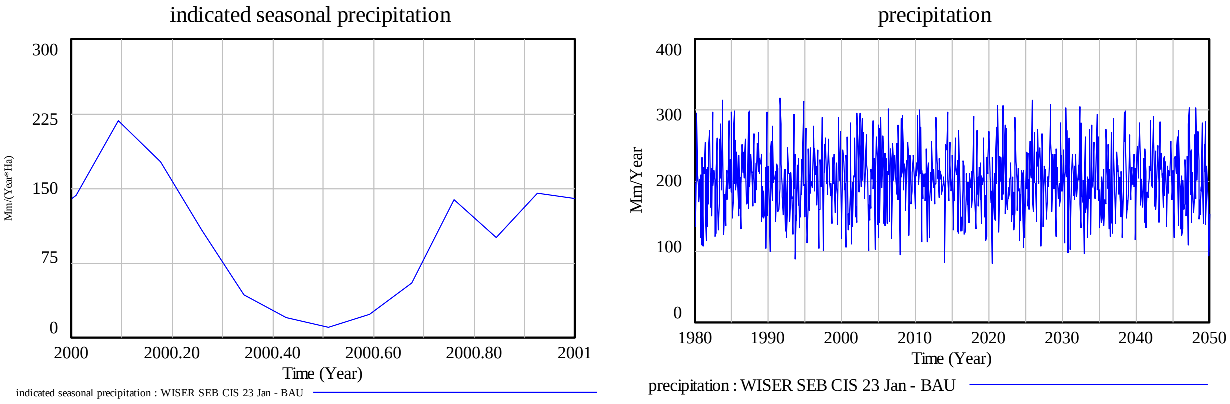


Figure 12.9: Seasonal precipitation and precipitation

Capturing seasonality in precipitation is necessary to understand the dynamics i) of the sectors that are dependent on rain, and ii) the probability of adverse weather events (e.g. floods and droughts). As an example, the agriculture sector is heavily dependent on rainfall for growing crops, which implies that changes in the amount of seasonal rainfall or a shift in the rainy season can have detrimental consequences on production, especially if farmers are prepared for it.

CIS coverage

Figure 12.110 illustrates the development of CIS coverage and DRR intervention effectiveness in the BAU and the CIS investment scenario. The BAU scenario assumes a continuation of historical trends, which implies a constant share of CIS coverage through the whole simulation and hence a DRR intervention effectiveness of 12%. The CIS investment scenario assumes an increase in CIS coverage from 30% to 100% between 2020 and 2040, which simultaneously increases the effectiveness of DRR interventions from 12% to 75% during the same period.

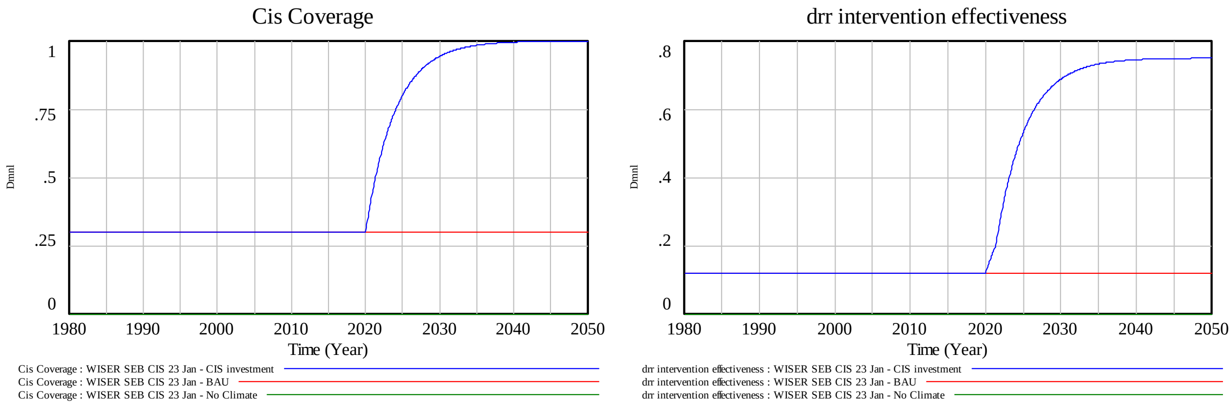


Figure 12.11: CIS coverage and DRR intervention effectiveness all scenarios

CIS coverage is used to determine the effectiveness of DRR interventions that contribute to the generation of CIS-related SEBs through the simulation. The successful planning and implementation of DRR interventions contributes to abating climate related damages and generating added benefits, as illustrated in the subsequent paragraphs.

Extreme events / frequency

The frequency and magnitude of events is assumed to remain unchanged compared to past behavior. As illustrated in Figure 12.1111, minor flood and drought events happen every other year, with an underlying frequency of 2 to 3 major events, both flood and drought, per decade. This represents a continuation of the average historical trend that was obtained from the data and described in section 11.3.

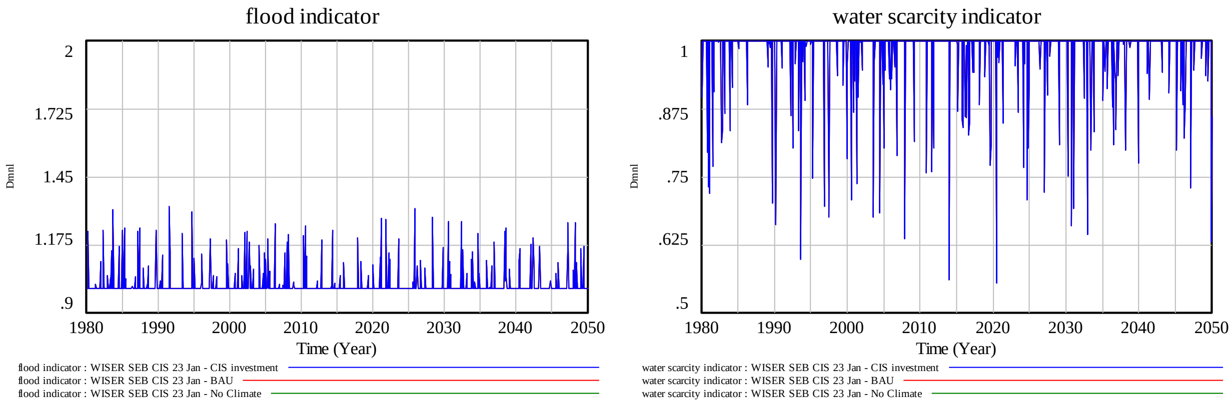


Figure 12.11: Flood indicator and water scarcity indicator 1980 to 2050

Impact of floods / drought on land (magnitude)

The impact of floods and droughts in the BAU scenario behaves according to the historical trends described in section, based on the assumption that CIS coverage remains constant. Figure 12.1212 illustrates the development of the share of agriculture land affected by floods and droughts respectively in the BAU and CIS investment scenario. As a result of an increase in DRR intervention effectiveness through investments in CIS coverage, both shares start to decrease from the year 2020 forward.

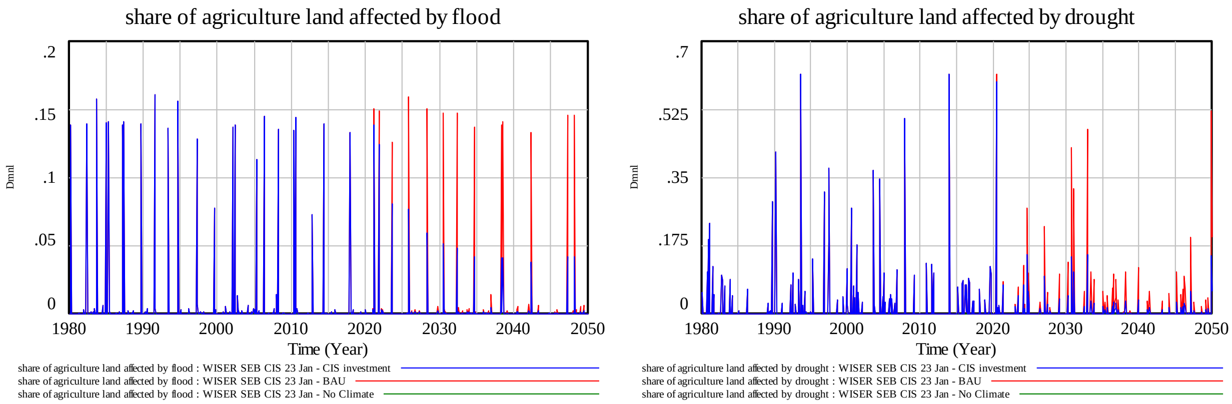


Figure 12.12: Share of agriculture land affected by flood 1980 to 2050

The annual and cumulative amounts of agriculture land for the BAU and the CIS investment scenario are displayed in Figure12.13. Investments in CIS increase CIS coverage and hence DRR intervention effectiveness. Consequentially, annual impacts of adverse weather events on agriculture land decrease with investments in CIS, as illustrated in Figure 12.11. The model increase of CIS coverage contributes to a significant reduction in the amount of agriculture land affected and contributes to a 583,800-hectare reduction in the cumulative amount of agriculture land affected by adverse climate events between 2020 and 2050.

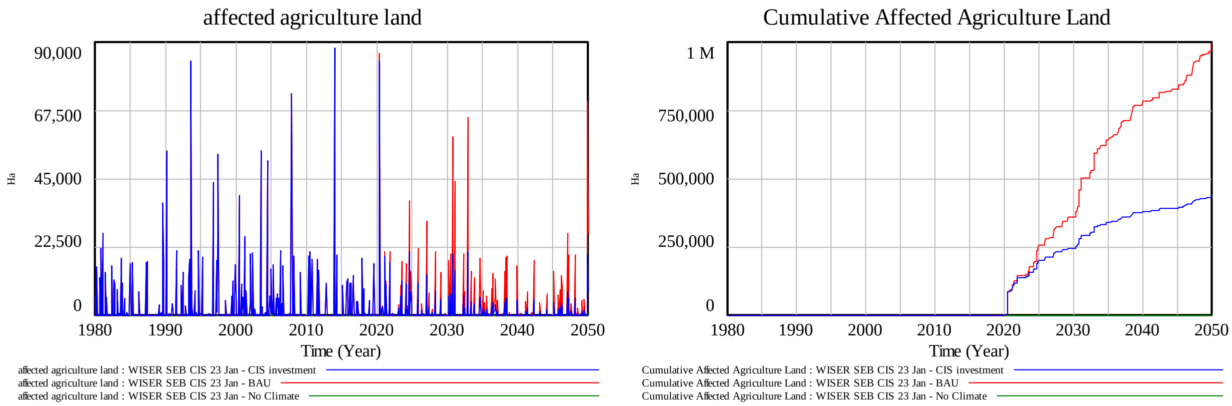


Figure12.13: Affected agriculture land and Cumulative agriculture land affected in all scenarios 1980 to 2050

Total agriculture production and cumulative agriculture production for the No Climate, BAU and the CIS investment scenario are illustrated in 14. In the CIS investment scenario, total agriculture production becomes more resilient towards climate events as results of increasing DRR intervention effectiveness. The increase in resilience is indicated through the reduction in the observed dips in total agriculture production rate. The cumulative loss of agriculture production between 2020 and 2050 totals 2.7 million and 1.4 million tons for the BAU and CIS investment scenario respectively. The respective losses are equivalent to 2.5% and 1.3% of cumulative agriculture production in the No Climate scenario.

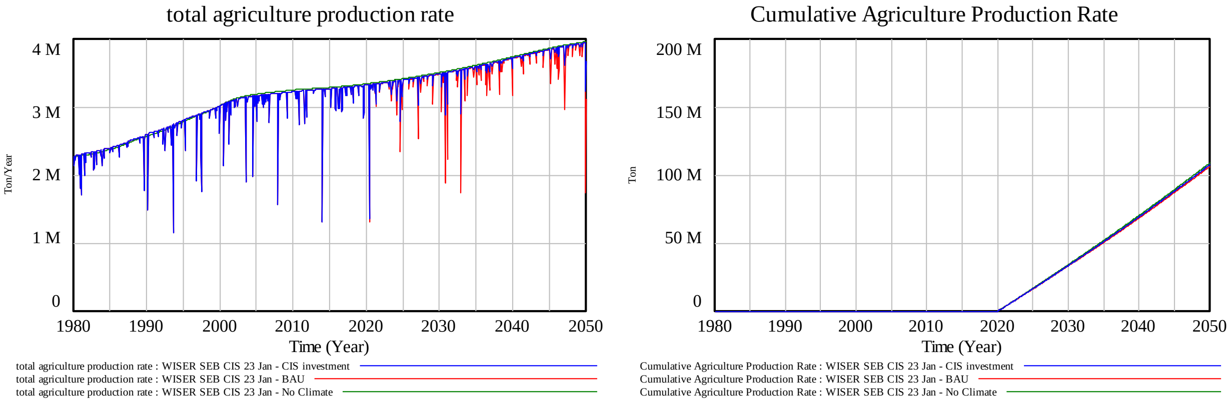


Figure 12.14: Annual and cumulative agriculture production in all scenarios 1980 to 2050

Impact of floods / drought on GDP

Both, the Climate and the CIS scenario show a lower economic performance compared to the No Climate scenario. Compared to the baseline, total real GDP in 2050 is 3.5% and 2.25% lower for BAU and CIS investment scenario respectively. By 2050, the cumulative difference between the No Climate scenario and the BAU totals MUR 348.2 billion, and MUR 252.5 billion between the No Climate and the CIS investment scenario. The development of total real GDP and cumulative GDP are displayed in **Error! Reference source not found.**.

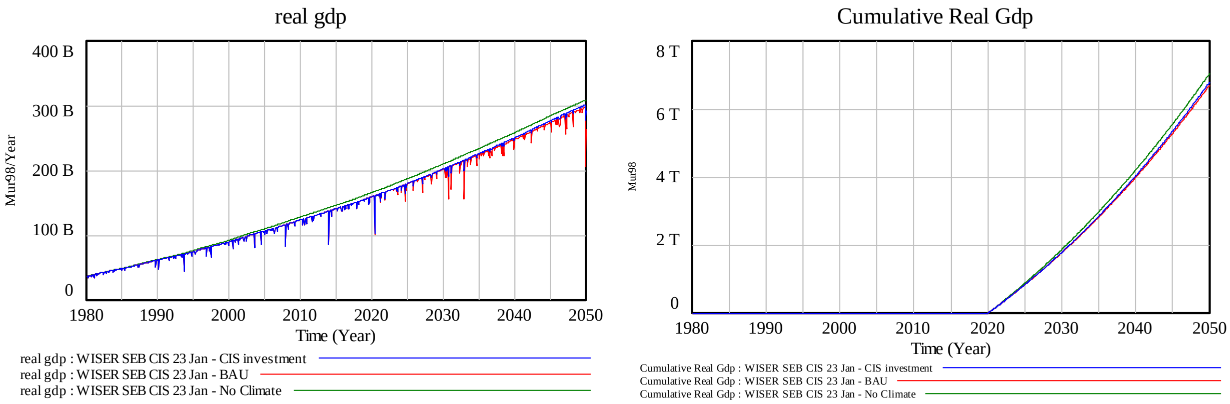


Figure 12.15: Real GDP and Cumulative real GDP in all scenarios 1980 to 2050

The difference in annual real GDP translates into a cumulative total reduction of USD 10.82 billion and USD 7.85 billion for the BAU and CIS investment scenario respectively, or an average annual reduction of USD 360.7 million and USD 261.6 million between 2020 and 2050. During that period, the reductions in GDP represent on average 7.46% of GDP in the BAU, and 5.41% of GDP in the CIS investment scenario, which indicates that investments in CIS can potentially contribute up to 2% to GDP growth.

Population affected

Error! Reference source not found.16 compares the annual and cumulative number of people affected through adverse climate events in the No Climate, the BAU and the CIS investment scenario between 1980 and 2050. Investments in CIS after 2020 lead to an increased DRR intervention effectiveness, which significantly reduces the share of people affected by 69% by 2030 and up to 75% from 2045 forward. Cumulatively, investments in increasing CIS coverage in the CIS investment scenario reduce the number of affected people between 2030 and 2050 by almost 2.74 million.

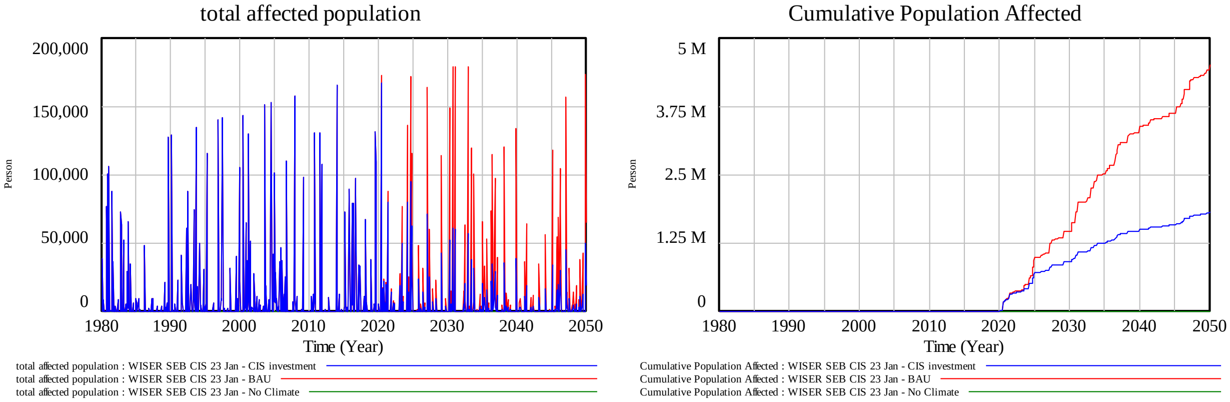


Figure 12.16: Total affected population and Cumulative population affected in all scenarios 1980 to 2050

Economic assessment of CIS related impacts

This section provides an overview of the cumulative climate-related impacts in the Reference, the BAU and the CIS investment scenario. For this section, the Reference scenario is used to assess the contribution of current CIS practices in the BAU scenario.

Figure12. 17 illustrates the cumulative economic value of foregone agriculture production and losses from livestock between 2020 and 2050 for all three scenarios. The results indicate that added benefits generated by current CIS practices in the BAU scenario total approximately MUR 159.5 million, or USD 4.95 million. Additional investments in CIS coverage, as assumed in the CIS investment scenario generate

added benefits of MUR 884 million, or USD 27.5 million, in addition to the savings achieved in the BAU scenario[3].

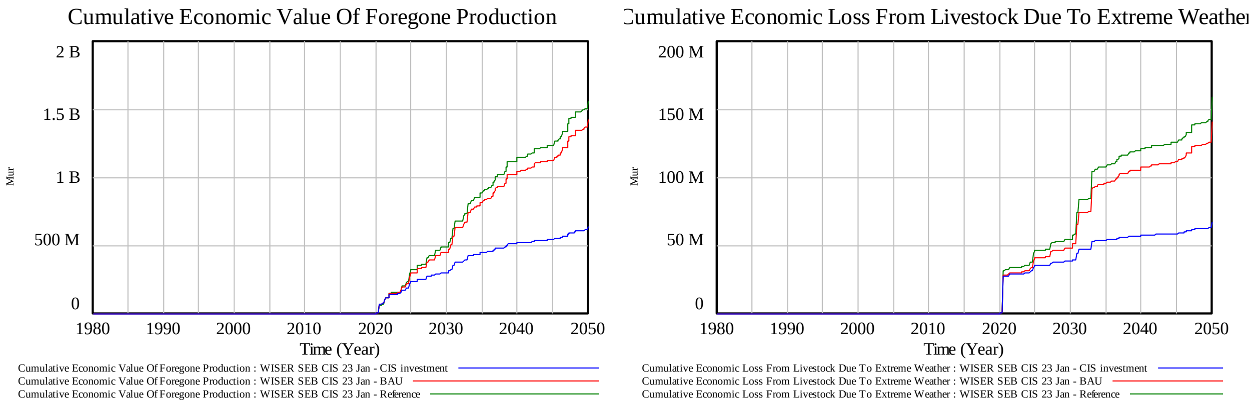
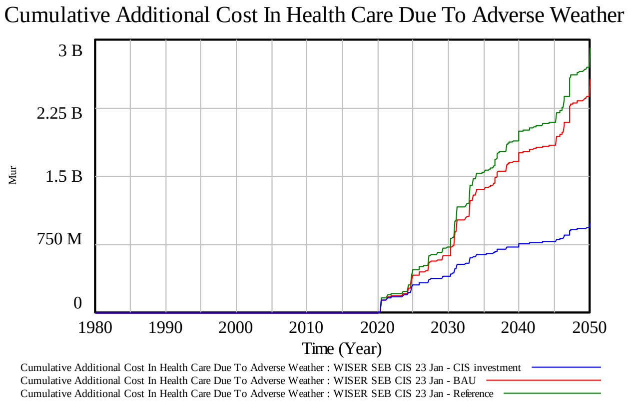


Figure12. 17: Cumulative value of climate impacts in the agriculture sector 2020 to 2050

CIS coverage determines the success of DRR interventions and ultimately the number of people in need of additional medical assistance as a consequence of suffering hardship from adverse climate events. The more people affected, the more extraordinary spending on health care is required to avert the crisis. Figure 12.18 illustrates the additional health care expenditure resulting from the impact of adverse climate events on human health. The current CIS practices in the BAU scenario contribute to a reduction of MUR 365 million, or USD 11.35 million, in cumulative health care expenditure between 2020 and 2050 compared to the Reference scenario. The results indicate that an increase in CIS coverage could generate savings of MUR 1.67 billion (USD 51.76 million) in addition to the savings achieved in the BAU scenario. Comparing cumulative extra health care to cumulative population affected yields 90USD per person over 30 years in additional health care expenditure, which is equivalent to USD 3 per person per year on a levelized basis



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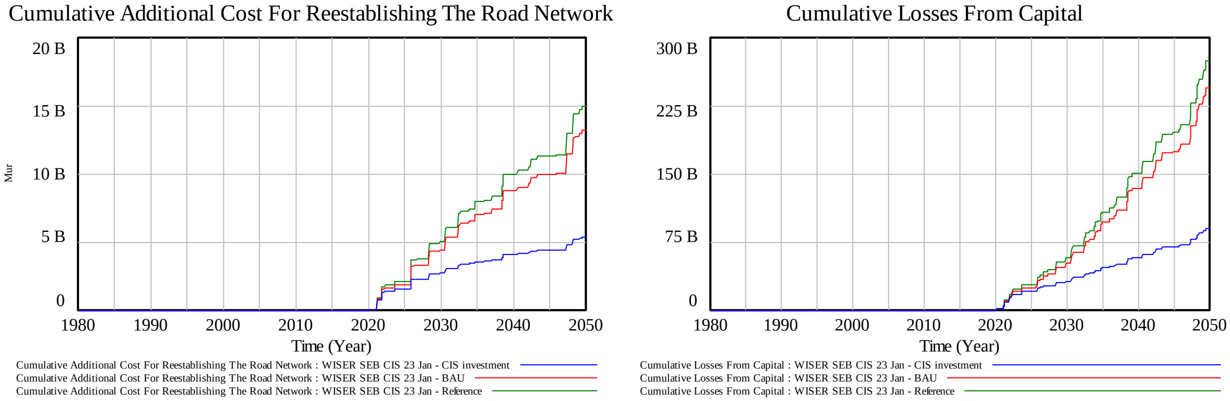
[3] Note that these results are based on the economic structure of Mauritius where agriculture holds between 5-7% in total GDP. For economies with 40% to 50% on agriculture, this value can increase significantly (by up to factor 10, depending on value added per unit of output).

Figure 12.18: Cumulative additional health care expenditure 2020 to 2050

In addition to added benefits from agriculture production and avoided costs in the health care sector, an increase in CIS as assumed in the CIS investment scenario generates significant benefits from avoiding damages to roads and capital. CIS practices in the BAU scenario cumulatively avoid MUR 31.7 billion in damages to road and capital between 2020 and 2050, which is equivalent to roughly USD 985 million. The results of the CIS investment scenario indicate that, compared to the BAU case, an additional MUR 162.8 billion (USD 5.05 billion) in damages to roads and capital can be avoided during the same period. The development of cumulative losses from capital and cumulative additional costs for roads construction for all three scenarios are displayed in 199.



19: Cumulative climate impacts on roads and capital 2020 to 2050

Economic analysis

This section first provides an overview of the total climate related impacts by sector for the Reference, BAU and CIS investment scenario. Subsequently, the benefits of CIS coverage and DRR intervention effectiveness will be presented.

Table 2 presents the cumulative economic impacts related to adverse weather events by sector between 2020 and 2050 for each of the scenarios. Values indicated for the reference scenario assume that there no CIS coverage, which is not representative for current practices, but useful to benchmark the performance of current practices to their potential. In the reference scenario, cumulative economic impacts total USD 9.16 billion, while cumulative impacts in the BAU and CIS investment scenario total USD 8.16 billion and USD 3.03 billion respectively. In all scenarios, the largest portion of damages stem from the loss of capital, such as sawn area, equipment, buildings, and other productive assets.

Sector	**Costs of adverse weather by scenario and sector**

	Reference (million USD)	**BAU** (million USD)	% of Reference	**CIS investment** (million USD)	% of Reference
Roads	465.6	410.3	*-11.88%*	166.1	*-64.33%*
Health Care	94.8	83.4	*-11.98%*	31.7	*-66.58%*
Total agriculture	54.8	49.8	*-9.05%*	22.3	*-59.21%*
Livestock	*5.3*	*4.7*	*-11.45%*	*2.2*	*-58.91%*
Agriculture production	*49.5*	*45.2*	*-8.79%*	*20.2*	*-59.25%*
Capital	8'545.3	7'615.8	*-10.88%*	2'807.1	*-67.15%*
Total	**9'160.5**	**8'159.3**	**-10.93%**	**3'027.2**	**-66.95%**

Table 12.2: Climate related impacts between 2020 and 2050 by sector and scenario

Table 3 provides an overview of the SEBs generated by CIS in the BAU and the CIS investment scenario. The column 'BAU to Reference' summarizes the net benefits generated through CIS in the BAU scenario, when compared to the reference. The next column, 'Added benefits CIS investment', provides information on the SEBs that are realized in addition to the SEBs generated in the BAU scenario. 'Total SEBs' represents the sum of both, SEBs generated by CIS in the BAU and in the CIS investment scenario.

The difference in impacts between the Reference and the BAU scenario can be regarded as the SEBs of CIS in the BAU scenario. In the BAU scenario, CIS contributes to reducing climate related impacts between 2020 and 2050 by roughly USD 1 billion cumulatively. Assuming an annual investment of 0.1% of GDP, investment costs total USD 211.3 million for the same period. This implies that the CIS SEB model generates a benefit to cost ratio of 4.74 for the BAU scenario, which indicating that investments pay back more than four times in avoided damages and added benefits.

Sector	**BAU to Reference** (million USD)	**Added benefits CIS investment** (million USD)	**Total SEBs** (million USD)	**Total investment (in BAU)** (million USD)
Roads	55.3	244.2	299.5	211.3
Health Care	11.4	51.8	63.1	
Total agriculture	5.0	27.5	32.4	
Livestock	*0.6*	*2.5*	*3.1*	
Agriculture production	*4.4*	*25.0*	*29.3*	
Capital	929.6	4'808.7	5'738.3	
Total	**1'001.2**	**5'132.1**	**6'133.4**	**211.3**

Table 12.3: Added benefits by scenario and sector

The results indicate that an increase in CIS coverage as proposed in the CIS investment scenario could potentially add cumulatively USD 5.13 billion to the USD 1 billion in benefits generated in the BAU scenario by 2050. Assuming that BAU investment would quadruple, assuming a fraction of 0.4% of GDP, then the benefits generated in addition to the BAU scenario yield a **Benefit to Cost Ratio of 6.07**[4]**, which is almost 3 times as high as the BCR of CIS in the BAU** case.

The SEB against CIS has been shown to have great potential for weather- and.climate-sensitive sectors. The benefit-cost ratios are consistent with those in literature. It has been demonstrated that when there is fully function CIS, its utilization typically achieves 2 to 4 times return on investment. .The SEB findings serve as a means to prepare disaster risk adaptation strategies or to expand existing national and sectoral policy and strategies. The study has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to decrease economic vulnerability of the countries to the hydrometeorological risks.

13. CONCLUSION AND RECOMMENDATIONS

The SEB findings serve as a means to prepare disaster risk adaptation strategies or to expand existing national and sectoral policy and strategies. The study has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to decrease economic vulnerability of the countries to the hydrometeorological risks. Seasonal climate prediction with long lead times enable decision-makers and communities in general to protect property and infrastructure; reservoir operators, for example, can reduce water gradually to accommodate incoming floodwaters. Early warning can also provide information on the occurrence of a public health hazard and enable a more efficient response to seasonal drought and food insecurity. Effective systems, therefore, require a combination of government leadership, multiagency coordination to ensure effective responses based on pre-agreed operating procedures, and community participation (Rogers and Tsirkunov 2013).

From the SEB framework in the current study, applying CIS has immeasurable benefits for preparedness efforts. Seasonal forecasts can also be used to secure emergency funding. It has been conservatively estimated that upgrading all hydrometeorological information production and early-warning capacity in developing countries would save an average of 23,000 lives annually and would provide between US$3 billion and US$30 billion per year in additional economic

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[4] The calculation assumes USD 5.132 billion in added benefits through investments in CIS coverage, assuming that investment doubles (211.3 * 2 = 422.6), which yields:

5,132 million / 845.12 million = 12.14

benefits related to disaster reduction (Hallegatte 2012). NMHSs are a small but important public sector—with budgets of usually about 0.01–0.05 percent of national gross domestic product (Hallegaite, 2012). Consistent with the current study findings, assessments elsewhere, show high economic returns from better NMHSs—with cost-benefit ratios of 1:4–1:6, (Tsirkunov et al. 2007).Therefore, there is need for appropriate investment in CIS in order to have capacity necessary to reduce disasters that are triggered by hydrometeorological hazards. It is important to note that countries in Africa also have challenges in the development of data set of fatalities, economic losses due to disaster. There is clearly need for the formulation of appropriate polices.

The following recommendations are deemed necessary for purposes of achieving the goals of maximizing SEBs in CIS for DRR:

1. Setting baselines and determine progress, metrics on expected disaster fatalities and expected economic losses with appropriate DRR policies that can be tracked through procedures such as identifying the percentage of the population living or working in buildings of moderate and high susceptibility to collapse in high-hazard zones
2. Clear and measurable definition of each indicator to be collected: The definition of each indicator (e.g. number of people in an area covered by an effective action plan) needs to be both precise and simple such that all countries are able to follow and adhere to the same global norms.
3. Transparent methodology to calculate or compile the indicator: Rigorous methods that describe the calculation of expected economic and human losses should be tested and set out in guidelines to help national and regional bodies compile this information. The guidelines must be workable in all the different situations in terms of resources and capabilities.
4. Ensure validity and independent quality of data. All efforts should be made to ensure the accuracy of the data collected and the sustainability of the collection procedures. Moreover, there needs to be a transparent method for data validation. Key at-risk cities should be prioritised in terms of data collection and validation.
5. Incentives be identified that may constitute tipping points for behavioural change towards prospective disaster risk management and risk-sensitive choices at a significant scale thereby increasing the political, social and economic saliency of disaster risk management.
6. Following the validation of the model, there is need for a series of hands-on training sessions on economic assessments of weather and climate forecast and their applications decision making in different sectors to the user community, Regional Climate Centres and National Meteorological and/or Hydrological Services. This

should lead to formulation of appropriate policies for establishing a community of practice on economic utility of weather and climate forecasts in Africa

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15. ANNEXES

THEORY OF SYSTEM DYNAMICS

Modeling and Simulation

Mathematically, the basic structure of a formal System Dynamics computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations,

$$\frac{d}{dt}\mathbf{x}(t) = \mathbf{f}(\mathbf{x}, \mathbf{p})$$

where x is a vector of levels (stocks or state variables), p is a set of parameters, and f is a nonlinear vector-valued function.

Simulation of such systems is easily accomplished by partitioning simulated time into discrete intervals of length dt and stepping the system through time one dt at a time. Each state variable is computed from its previous value and its net rate of change x'(t): x(t) = x(t-dt) + dt * x'(t-dt). In the earliest simulation language in the field (DYNAMO) this equation was written with time scripts K (the current moment), J (the previous moment), and JK (the interval between time J and K): X.K = X.J + DT * XRATE.JK (see, e.g., Richardson and Pugh 1981). The computation interval dt is selected small enough to have no discernible effect on the patterns of dynamic behaviour exhibited by the model. In more recent simulation environments, more sophisticated integration schemes are available (although the equation written by the user may look like this simple Euler integration scheme), and time scripts may not be in evidence. Important current simulation environments include Vensim (Ventana Systems, www.vensim.com), STELLA and iThink (isee Systems, www.iseesystems.com), PowerSim (www.powersim.com), and AnyLogic North America, LLC. (AnyLogic, www.anylogic.com).

Forrester's original work stressed a continuous approach, but increasingly modern applications of System Dynamics contain a mix of discrete difference equations and continuous differential or integral equations. Some practitioners associated with the field of System Dynamics work on the mathematics of such structures, including the theory and mechanics of computer simulation, analysis and simplification of dynamic systems, policy optimization, dynamical systems theory, and complex nonlinear dynamics and deterministic chaos.

The main applied work in the field, however, focuses on understanding the dynamics of complex systems for the purpose of policy analysis and design. The conceptual tools and concepts of the field — including feedback thinking, stocks and flows, the concept of feedback loop dominance, and an endogenous point of view — are as important to the field as its simulation methods.

Feedback Thinking

Conceptually, the feedback concept is at the heart of the System Dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system and for communicating model-based insights. Intuitively, a feedback loop exists when information resulting from some action travels through a system and eventually returns in some form to its point of origin, potentially influencing future action. If the tendency in the loop is to reinforce the initial action, the loop is called a positive or reinforcing feedback loop; if the tendency is to oppose the initial action, the loop is called a negative or balancing feedback loop.

The sign of the loop is called its polarity. Balancing loops can be variously characterized as goal-seeking, equilibrating, or stabilizing processes. They can sometimes generate oscillations, as when a pendulum seeking its equilibrium goal gathers momentum and overshoots it. Reinforcing loops are sources of growth or accelerating collapse; they are disequilibrating and destabilizing. Combined, reinforcing and balancing circular causal feedback processes can generate all manner of dynamic patterns.

Loop Dominance and Nonlinearity

The loop concept underlying feedback and circular causality by itself is not enough, however. The explanatory power and insightfulness of feedback understandings also rest on the notions of active structure and loop dominance. Complex systems change over time. A crucial requirement for a powerful view of a dynamic system is the ability of a mental or formal model to change the strengths of influences as conditions change, that is to say, the ability to shift active or dominant structure.

In a system of equations, this ability to shift loop dominance comes about endogenously from nonlinearities in the system. For example, the S-shaped dynamic behaviour of the classic logistic growth model ($dP/dt = aP - bP2$) can be seen as the consequence of a shift in loop dominance from a positive, self-reinforcing feedback loop (aP) producing exponential-like growth to a negative balancing feedback loop ($-bP2$) that brings the system to its eventual goal. Only nonlinear models can endogenously alter their active or dominant structure and shift loop dominance. From a feedback perspective, the ability of nonlinearities to generate shifts in loop dominance and capture the shifting nature of reality is the fundamental reason for advocating nonlinear models of social system behaviour.

The Endogenous Point of View

The concept of endogenous change is fundamental to the System Dynamics approach. It dictates aspects of model formulation: exogenous disturbances are seen at most as triggers of system behavior (like displacing a pendulum); the causes are contained within the structure of the system itself (like the interaction of a pendulum’s position and momentum that produces oscillations). Corrective responses are also not modeled as functions of time, but are dependent on conditions within the system. Time by itself is not seen as a cause.

But more importantly, theory building and policy analysis are significantly affected by this endogenous perspective. Taking an endogenous view exposes the natural compensating tendencies in social systems that conspire to defeat many policy initiatives. Feedback and circular causality are delayed, devious, and deceptive. For understanding, System Dynamics practitioners strive for an endogenous point of view. The effort is to uncover the sources of system behaviour that exist within the structure of the system itself.

System structure

These ideas are captured in Forrester’s (1969) organizing framework for system structure:

- Closed boundary
    - Feedback loops
        - Levels
        - Rates
            - Goal
            - Observed condition
            - Discrepancy
            - Desired action

The closed boundary signals the endogenous point of view. The word closed here does not refer to open and closed systems in the general system sense, but rather refers to the effort to view a system as causally closed. The modeller's goal is to assemble a formal structure that can, by itself, without exogenous explanations, reproduce the essential characteristics of a dynamic problem.

The causally closed system boundary at the head of this organizing framework identifies the endogenous point of view as the feedback view pressed to an extreme. Feedback thinking can be seen as a consequence of the effort to capture dynamics within a closed causal boundary. Without causal loops, all variables must trace the sources of their variation ultimately outside a system. Assuming instead that the causes of all significant behavior in the system are contained within some closed causal boundary forces causal influences to feed back upon themselves, forming causal loops. Feedback loops enable the endogenous point of view and give it structure.

Levels and Rates

Stocks (levels) and the flows (rates) that affect them are essential components of system structure. A map of causal influences and feedback loops is not enough to determine the dynamic behaviour of a system. A constant inflow yields a linearly rising stock; a linearly rising inflow yields a stock rising along a parabolic path, and so on. Stocks (accumulations, state variables) are the memory of a dynamic system and are the sources of its disequilibrium and dynamic behaviour.

Forrester (1961) placed the operating policies of a system among its rates (flows), many of which assume the classic structure of a balancing feedback loop striving to take action to reduce the discrepancy between the observed condition of the system and a goal. The simplest such rate structure results in an equation of the form NETFLOW = (GOAL – STOCK)/(ADJTIM), where ADJTIM is the time over which the level adjusts to reach the goal.

Behavior is a Consequence of System Structure

The importance of levels and rates appears most clearly when one takes a continuous view of structure and dynamics. Although a discrete view, focusing on separate events and decisions, is entirely compatible with an endogenous feedback perspective, the System Dynamics approach emphasizes a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them. Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behavior. It is that underlying tide of policy structure and continuous behaviour that is the system dynamicist's focus.

There is thus a distancing inherent in the System Dynamics approach — not so close as to be confused by discrete decisions and myriad operational details, but not so far away as to miss the critical elements of policy structure and behaviour. Events are deliberately blurred into dynamic behavior. Decisions are deliberately blurred into perceived policy structures. Insights into the connections between system structure and dynamic behaviour, which are the goal of the System Dynamics approach, come from this particular distance of perspective.

The System Dynamics approach involves:

- Defining problems dynamically, in terms of graphs over time.
- Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
- Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioral model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights.

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