International Institute for Sustainable Development

Modelling for Sustainable Development

New Decisions for a New Age

International Institute for Sustainable Development

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International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is an independent think tank championing sustainable solutions to 21st–century problems. Our mission is to promote human development and environmental sustainability. We do this through research, analysis and knowledge products that support sound policy making. Our big-picture view allows us to address the root causes of some of the greatest challenges facing our planet today: ecological destruction, social exclusion, unfair laws and economic rules, a changing climate. IISD's staff of over 120 people, plus over 50 associates and 100 consultants, come from across the globe and from many disciplines. Our work affects lives in nearly 100 countries. Part scientist, part strategist—IISD delivers the knowledge to act.

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Preface

Why This Book?

In October 2018, the Economic Law and Policy (ELP) Group of the International Institute for Sustainable Development (IISD) met for a team retreat in Montreux, Switzerland. The agenda for the meeting included a review of the various modelling approaches used by different project groups within the ELP Group. This included the new Sustainable Asset Valuation (SAVi) model on infrastructure development and a new Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) model on tax incentives in the mining sector.

When the group explored further, participants discovered that IISD had been modelling issues ranging from climate change mitigation, fossil fuel subsidy reform and adaptation options, and hunger eradication, to pollution control in the Experimental Lakes Area program and local water issues in Lake Winnipeg (adjacent to the IISD headquarters in Winnipeg, Manitoba). While IISD had come a long way in terms of understanding, using and building models, it also turned out that the people working on these individual projects had not yet connected with each other. Even internally, modelling work was taking place in silos!

This led to a simple question: what would happen if we were able to gather all our modelling work into a more holistic process, building on what everyone is already doing at the project level? Simply put, would pooling what we already do enable us to build an integrated model for sustainable development?

It turns out the question is not that simple. At a subsequent exploratory meeting in December 2018, which included our internal teams and some external modelling experts, it became clear that a single model is not the answer. Nor would simply integrating what was already being done inside IISD amount to an appropriate vision for modelling for sustainable development. Modelling, we concluded, had to be better understood as part of a process of informed decision making, not as an independent tool-based exercise. The process of building a model itself requires many different technical choices that have to be married with the decision objectives at hand. Answering what was thought to be a simple question was in the end not as simple as posing the question, and this book resulted from that realization.

For a one-week Book Sprint, Switzerland, in June 2019, IISD has been incredibly fortunate to be able to bring together some of the leading global experts and modellers, with diversified expertise in policy development and connecting policy to the achievement of sustainable development objectives. What would a shift in paradigm from conventional, single-dimension modelling to a more integrated and holistic concept of sustainable development entail? The goal was to have a collective brainstorm about the concepts, challenges, and opportunities associated with the concept of Modelling for Sustainable Development.

These experts have become the collective co-authors of this book, applying the methodology of an intense, one week drafting process developed by Book Sprints. The Book Sprints process allows a group of authors to conceptualize, draft and edit a book in just five days. These five days have been intense, at times lively, sometimes tough, but always geared towards a creative process of designing a new decision-making framework for a new age of sustainable development centred on human activity. Our agenda has been ambitious, but this ambition has been matched by the time, effort and dedication of all co-authors. IISD thanks these 12 co-authors for their spirited collaboration:

- **Andrea M. Bassi**, Senior Affiliate IISD; Founder & CEO, KnowlEdge Srl; Extraordinary Associate Professor, Stellenbosch University
- **Liesbeth Casier**, Policy Analyst, IISD
- **David Laborde**, Senior Research Fellow, International Food Policy Research Institute
- **Max Linsen**, Consultant, Adaptation to climate change, IISD
- **David Manley**, Senior Economic Analyst, Natural Resource Governance Institute.
- **Nicolas Maennling**, Senior Economics and Policy Researcher, Columbia Center on Sustainable Investment
- **Howard Mann**, Senior International Law Advisor, IISD
- **Morten Siersted**, Visiting Research Fellow, CDS, University of Bath; Director, FAST Standard Organisation; Founder & Director, F1F9
- **Carin Smaller**, Senior Policy Advisor & Team Leader, Agriculture and Investment, IISD
- **Iain Steel**, Independent Consultant
- **David Uzsoki**, Senior Advisor in Sustainable Finance, IISD
- **Johnny West**, Director, OpenOil

Modelling for Sustainable Development: New Decisions for a New Age is available on the IISD website and the websites of the participating organizations. It is freely available for download, and usable by readers under normal fair use and citation rules (cf.).

It is the collective hope of this extraordinary group of authors that this book will stimulate new thinking among our readers that moves decision making for sustainable development forward.

Finally, it has been my own great privilege to be part of developing and designing this process, and to engage with colleagues in producing this remarkable work.

Howard Mann
Senior International Law Advisor, IISD
Montreux, 7 June 2019

Acknowledgements

The co-authors and planners would like to thank all those who have contributed to the production of this book. Rebecca Meaton and Joelle Deschambault from IISD have provided excellent logistical support throughout the project. We are indebted to them for their patience in dealing with us all. We also thank, in advance, IISD's communications team, Sofia Baliño, Stacy Corneau, and Zahra Sethna, for the follow-up communication and dissemination process.

Nathalie Bernasconi, head of the Economic Law and Policy Group at IISD, has been a steadfast support in the development and funding of the process leading to this Book Sprint. Her support and leadership is much appreciated. In this context, we also express our appreciation to the generous support of the Open Society Foundations and to IISD's Economic Law and Policy Program.

The Golf Hotel René Capt in Montreux hosted and fed the team for this week in Montreux, with patience and flexibility to complement their always professional service. We were well rested each morning and well sustained throughout the day as a result.

And last, but not least, the Book Sprints team has been a wonderful partner in this process. The co-authors and planners collectively thank the team. In particular, Laia Ros who led the collective drafting process as facilitator and enabler, turning twelve often headstrong individuals into one collective voice. We thank her for her guidance, support and resolve in ensuring the success of this process.

1. Introduction

1.1 Why a Book on Modelling for Sustainable Development

> The definition of insanity is doing the same thing over and over and expecting a different result.
> *—commonly attributed to Albert Einstein*

Many of the planet's ecosystems are perilously close to collapsing. Multiple social and environmental systems are experiencing massive stresses leading to migration, starvation, and ever-increasing number of refugee camps. Despite this impending catastrophe, governments and corporations continue to implement the same policies and investments that led us to this precipice. To stop this madness, their decisions need to be better informed. Unfortunately, the way information is developed, and the scope of that information, remains largely focused on the traditional metrics of profits and taxes. Until this approach changes, the hope of making better decisions and moving the world back from this precipice remains an illusion.

This book sets out the reasons and processes for changing how governments and corporations make decisions. It focuses on achieving the goal of sustainable development in its holistic form, as the overarching test for all decision making for public policy and major private sector investments: the vehicle for this change being integrated models for sustainable development.

The book builds on the expanding practices of modelling complex decision-making requirements and indicators. It considers the challenges of decision making in the face of incomplete and sometimes inaccurate information, the role of multiple stakeholders, and the capacity of governments and others to use models effectively. The collective ambition reflected in this book is unapologetically high. But so are the stakes in failing to change the nature of the critical public policy and large-scale investment decisions that have been made to date.

1.2 What Is Sustainable Development?

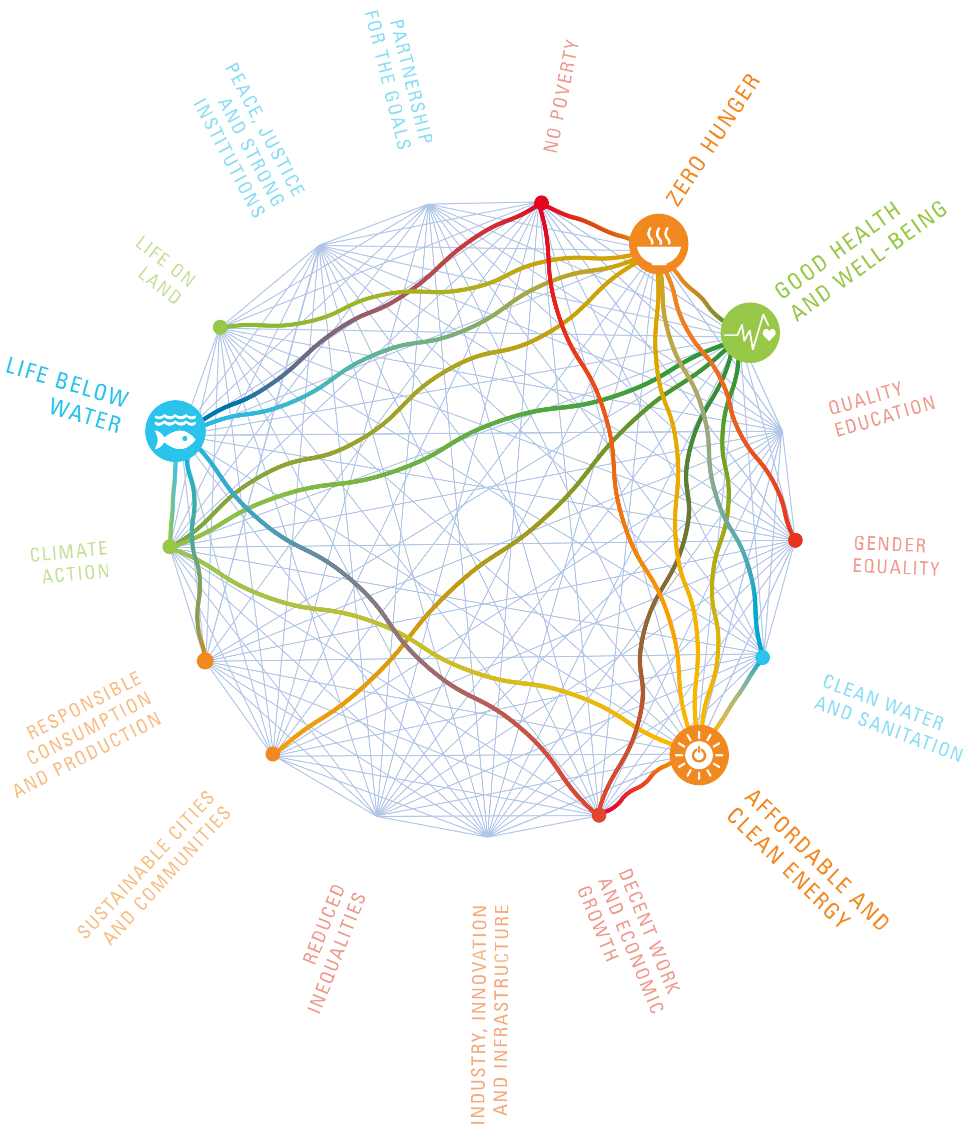
The core of this book combines the world of sustainable development and the world of modelling in order to improve critical public policy and private sector decisions. This first requires an understanding of what is meant by sustainable development.

The global understanding of what sustainable development is, how it can be measured, and how it can be achieved is evolving. This evolution has taken the meaning of sustainable development a long way from it origins in the famous Brundtland Report, *Our Common Future*: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The Brundtland Report focused on promoting economic growth without damaging the environment and without compromising the opportunities for future economic growth. It was, by and large, an environmental concept. Over time, the three-pillar approach to sustainable development became more fully elaborated: environmental, social and economic. Today this approach is understood as requiring decision making that fosters inclusive economic growth, equity and fairness in social development, and maintaining and rebuilding the environmental quality of the planet.

The most recent global articulations of sustainable development show the ongoing evolution of the global understanding of the concept. The Millennium Development Goals (MDGs) were established in 2000. The MDGs included a set of indicators, primarily focused on society and the economy, and included absolute targets for each of the goals. These summed up to a total MDG score for each country. Subsequently, the Sustainable Development Goals (SDGs) were adopted in 2015 by the United Nations. The SDGs provide a longer list of indicators to choose from at the country level, allowing for a customized approach that can be weighted differently for different circumstances. Importantly, the SDGs stress that humans can only develop sustainably if the interconnections among the goals are well understood (see Figure below). Some goals may be weighted more heavily than others, but either way, the 17 goals are seen as indivisible.

Modelling for sustainable development, as conceived in this book, requires a similar focus on indivisibility. This does not mean that all the SDGs, (or every one of the accompanying 169 targets and 232 indicators) have to be assessed in each model. But every major decision implicating any aspect of sustainable development must be considered within the full context of all three of the environmental, social and economic pillars and the extent to which the goals of sustainable development are interconnected within a given context. The objective in such consideration is not simply to avoid harm, but to maximize the benefits of decision making across all three pillars and goals as well.

Figure 1 — The SDGs are an interconnected web of decision-making factors



Source: ICSU, 2017

1.3 What Is a Model?

A model is a set of mathematical equations that describes a number of relations between a number of variables. The objective of the model is to provide a realistic, yet simplified, representation of reality. There is no single method to model for sustainable development. Different methods integrate each dimension of sustainable development differently and each have its own benefits.

A map of a country is a model that can be used to estimate the distance between two towns, choose between travelling by road or rail, and determine the optimal way to travel. But the map cannot be used to travel to a different country if the country is outside the scope of the map. This is the problem with traditional modelling approaches. Important factors for sustainable development have been left outside the map of models, and not taken into account in critical decisions.

Governments and private companies use modelling in their decisions all the time. They model financial, social or environmental problems—but in isolation. The models are too narrow in scope. They lead to decisions that result in unsustainable outcomes. Financial models measure profits for companies and tax revenues for governments. They rarely include the costs of environmental damage and social harm. Climate change models may measure the investment needed to mitigate or adapt, but may not include impacts on access to health care or education.

A key challenge is the need to understand the complex connections and interactions between development goals and hence among the environmental, social and economic parameters included in models. Understanding and modelling these complexities better is needed to inform sustainable development decisions. Models can only impact decisions positively if they are understood and acted upon. The model is not the decision-maker.

1.4 Who Should Read This Book?

This book is intended for those interested in better decision making to support a progressive agenda for achieving sustainable development.

This is a wide audience—and it should be. The audience includes those who commission, design, use and act upon models (see Figure below). It equally includes all those who today do not fall into these categories, but who might do so in the future.

Decision-makers: Decision-makers are those who are primarily responsible for acting upon the results of a model. They include people in positions of authority in government, business, and civil society. If they continue to rely on one- or two-dimensional financial models, their decision making will remain limited. This applies equally to government and corporate decision-makers. Decision-makers therefore have a special responsibility to ensure they consider all relevant environmental, social and economic factors.

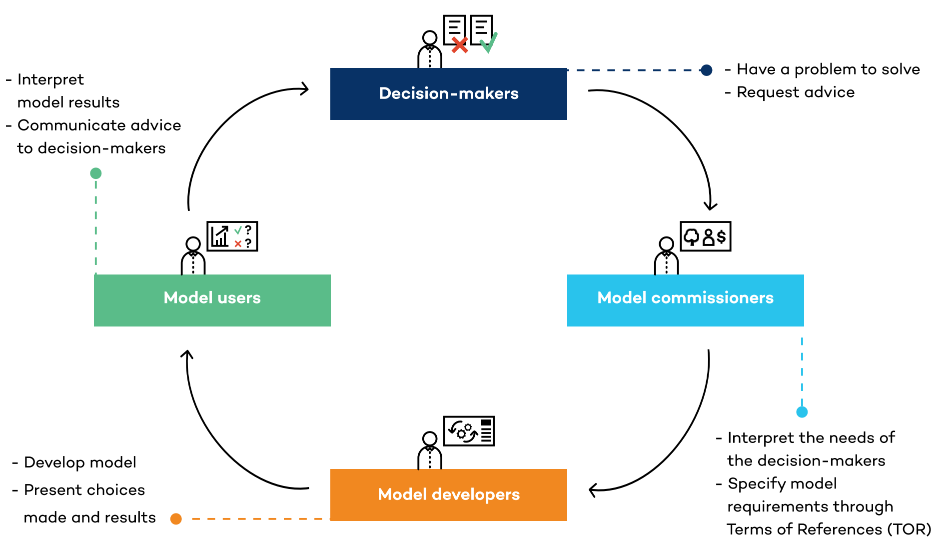
Model commissioners: Models are commissioned by officials in government and managers at different levels in the private sector. They are also commissioned by intergovernmental organizations, civil society organizations, and in some instances by donor agencies. In all these instances it is important that those who commission a model understand the importance of developing its scope appropriately. In essence, they are the gatekeepers of the modelling process and thus determine how broad or narrow it will be and what questions it can answer. This book is essential reading for this group of people.

Model developers: Professional modellers use their technical skills to develop models that meet the requirements of model commissioners using data, assumptions and calculations. If the model developer is dedicated to one type of model, or believes new approaches to modelling are not possible for whatever reason, including that they may be too complex, this book will be especially important for them.

Model users: *Users* is a very broad category. It includes, in any given instance, anyone who uses a model to produce analysis or communicate results. This would mean government officials, corporate officials, lawyers and economists advising governments and companies; local community stakeholders in a project; or policy, media, and academics working in various spheres. Civil society organizations, professional organizations, business groups and others may also be users of a model in any given case, especially as regards public policy-oriented models. Users may be interested in providing model inputs, commenting on the methodology, reviewing assumptions, discussing, disseminating and using results.

Beyond this core set of readers, students of modelling and of environmental, development and sustainable development studies will all benefit from this book. Specialists in political economy and related disciplines will also benefit, as will anyone interested in improving the opportunities locally and globally for advancing the cause of sustainable development.

Figure 2 — Information flow between those who commission, design, use and act upon models



2. Why Models Matter for Sustainable Development

TAKEAWAYS

- Models are great at combining many types of knowledge into a meaningful whole. They are a good way of simplifying complexity, and of understanding and managing risks. Models also have many limitations though.
- The critical question should not be whether or not to use models, but rather how better to design, develop and use them to inform decisions in a complex world.
- Governments and corporations use modelling within all spheres of public life. These models are often limited because they fail to take into account the multiple dimensions of sustainable development.
- There is a growing realization of the need for a more holistic approach to planning. Modelling for sustainable development can play an important role in improving decision making and avoiding the emergence of future environmental, social, and economic crises.
- The choice must be deliberate. Unless decision-makers are required to include social, economic and environmental outcomes there will be no pressure to include these outcomes in models.

2.1 Introduction

There is a growing realization that there is a need for a more holistic approach to decision making. This is not a trivial task. Policies and projects always affect the environment, the society, and the economy.

This chapter introduces modelling, and the potential it holds for improving decision making; that is, if modelling is done for the purpose of supporting the achievement of sustainable development objectives. This section explains that reliable and meaningful modelling results are key, but it also emphasizes that the added value of models goes beyond numerical outputs. Modelling can trigger and structure the conversation for stakeholders to achieve sustainable development.

2.2 Why Model Anything?

Modelling is a way of understanding and managing risks. It is a way to identify opportunities. In this respect, humans have always modelled. Consciously or not, the first time a community took the trouble to build a wall, or plan an irrigation system, they took a view about the risks they faced and the costs and benefits of their project.

The essence of a model is that it captures the relationships between many moving parts of a complex system, which can be tested repeatedly under various scenarios, providing a result that is simply understood and can be used to make decisions.

Take weather forecasting as an example of a model. Who hasn't made a decision to stay in or venture out, or to go out with an umbrella, or an extra layer of clothing, based on a weather forecast? The principal parts of the system in this case are temperature, humidity, cloud formations, air pressure, wind, landscape, and so on. Meteorologists take all these inputs in their current state and combine them in weather models to calculate a forecast. The outputs of these complex models provide useful information to address everyday questions such as: is this a long sleeve or short sleeve day? Or: will it rain over the weekend? Indicators that feed into a weather model are now widely understood, and even though forecasts are never 100 per cent accurate, a margin of error is accepted. People still use it on a daily basis. Despite its shortcomings, modelling is used everywhere from space exploration programs to sales strategies for peanut butter.

Models are good at combining many types of knowledge, from the scientific to the less scientific, into a meaningful whole. Measurements, expert judgment, personal experience, the wisdom of elders, or the knowledge captured in proverbs or folklore, are all useful inputs to make an informed decision.

Models can also have many limitations. Big mistakes were based on models just as convincingly as big successes. The global financial crisis of 2008–2009 is an example. Nevertheless, mistrust of modelling as a whole is misplaced. Experience, in fact, tells us that understanding complexity is not something we excel at. Here we make an important distinction between *complicated* systems, which represent a long series of steps in a sequence, such as the production process of a vehicle, which we can handle well; and *complex* systems, which are characterized by the presence of many interconnected parts, which is what we struggle with (i.e. interconnections across domains, time and space). While our education system pushes us to develop deeper knowledge in specific thematic areas, there is an ever-growing need to integrate the specific into global or planetary trends.

Models can help simplify such complexity, because we can model various parts of a complex system until we reach a much more holistic view. We can manage individual parts, but need a model to properly understand how interacting parts lead to the whole. Experiments in clinical psychology have shown that even the simplest statistical models outperform unaided and unstructured "expert intuition" (Paul Meehl, 1954 and 1989 and later Amos Tversky, 2000 and Daniel Kahnemann, 2011).

The critical issue should not be whether to use models, but rather how to develop, design, and use them in a way that promotes a result that is most supportive of decision making in today's complex world. This is particularly the case when looking at the focus area of this book: decision making for sustainable development.

2.3 The Current State of Modelling

Governments and corporations use modelling across all spheres of public life. Models can be used at the policy and project level. Policy-level modelling estimates the impacts of a government intervention, such as estimating how much money would be needed to provide access to electricity for the country. Project models estimate the costs or impacts of a particular project, such as the construction of a hydroelectric dam or mine.

A common limitation is that models tend to analyse each project or policy without taking into account the multiple dimensions of sustainable development. At the policy level, for example, the ministry of energy may develop an energy strategy and develop policy models that assess electrification costs, but do not consider the objectives of the environmental ministry.

Project models often focus on financial and technical aspects. This is especially true for infrastructure and industrial and mining projects, where government might grant access rights to investors. In such cases, the modelling process addresses project finance, and is mostly led by the private sector. Potential investors will model profit levels and often exclude other project impacts and benefits. For governments, the kaleidoscope of public interest issues beyond tax revenues (which are important in and of themselves), often falling within the environmental and social dimensions of sustainable development, are left unmodelled and so, effectively, are left out of government analysis. Profits and taxes are counted, but other public interests simply drop out of sight, whether in terms of minimizing costs in these areas, or maximizing benefits.

For project-level assessments, governments often outsource the modelling component to third parties. This is even the case for prestigious projects touted to have transformative impacts on the economy. As a result, the government may not own the information provided by the model or be able to adapt the model to assess different scenarios. Governments also often rely on models that are submitted by project proponents. However, these models may have missing information and assumptions that are not shared by the government.

2.4 The Case for Modelling for Sustainable Development

The challenge for sustainable development is to tackle complexity, identify entry points for intervention, inform decision making, and improve the state of the world. Modelling can support that challenge at all levels and quantify the costs and benefits. Modelling for sustainable development is not just about avoiding environmental and social *harm;* this element must be combined with seeking to maximize the *benefits*.

There is no lack of ambition for this agenda. There are several ongoing efforts to improve understanding of how the environment, society and the economy are interconnected. For example, the Sustainable Development Goals Acceleration Toolkit provides an online compendium of system-level diagnostics, models, methodologies and guidance for analyzing interconnections among the SDGs.

Despite these efforts, and our improved understanding of sustainable development, most modelling exercises are still sectoral and done in silos. The opportunity for the whole modelling field is therefore to explore, model and quantify the interconnections across different dimensions of sustainable development, across sectoral and economic actors, and over time and space.

The very concept of modelling for sustainable development should break down the silos and lead to a more holistic approach; bring different actors and interests to the table; and in turn permit a more accurate understanding of the trade-offs between different policy or project choices.

These choices must be deliberate. Unless decision-makers are required to include social, economic and environmental outcomes, there will be no pressure to estimate and share information on *all* the expected outcomes of their projects. A model for sustainable development, for example, would ask how to best meet energy needs in a way that ensures environmental and human health are protected.

CASE STUDY

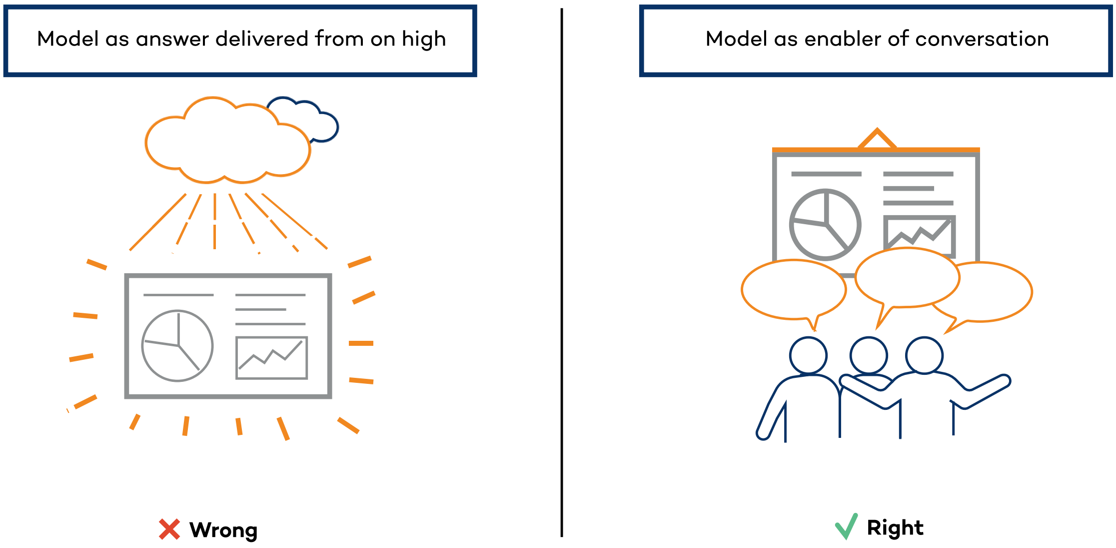
Modelling protected areas versus resource extraction

A typical trade-off question is what are the costs and benefits associated with protecting a certain area of land and promoting eco-tourism vs. allowing extractive industry activities? Traditional planning and modelling exercises would focus on government revenue prospects from the various activities, without sufficiently considering the negative environmental and social externalities associated with these activities. This approach gives preference to the most financially profitable projects, but ignores the other values associated with protecting ecosystem services, biodiversity, culturally significant spaces, and more. When not planned for appropriately, the positive environmental and social impacts that can arise from a holistic decision-making process can be lost forever because of a simplistic revenue calculation. These benefits are excluded from being counted. (Steffen et al., 2015)

2.5 Modelling as a Conversation

One of the major values that lies behind the idea of modelling for sustainable development is the role a good model can play in the creation of conversations among stakeholders and around multiple interests (see Figure below). This implies a number of things about the way models should be built and used when major policy or project decisions are being considered. The process at all stages is as important as the result that is derived at the end, and indeed will significantly impact the substance and legitimacy of that result.

Figure 3 — Models to produce numbers vs models to produce conversation



Consider the case of a potential iron ore mine. Mining projects are complex, and today are generally understood to require a collaboration between government, company and community, each with their own set of interests. For example:

- A traditional potential foreign investor would focus on profitability and bankability. A more enlightened foreign investor would also include a focus on its social licence to operate.

- The government might have several involved agencies. The national mining agency would like the tax regime the government offers to be as attractive as possible to ensure the mine is built in that country and not in another country. The ministry of finance, meanwhile, is concerned about maximizing government revenues. Water, environment and economic development ministries will have a variety of other interests they want reflected in any specific decision. (In Colombia, for example, all mining in a particularly vulnerable environmental area was recently stopped by the government after interventions by local communities and the minister for the environment.)

- Local communities will be concerned about the environmental impacts and loss of environmental uses in the community, preventing medical problems like HIV, maximizing employment benefits and maximizing education benefits in the community for boys and girls.

In a traditional project-level modelling context, the investor would come with its model on revenues and taxation (including royalties) and argue for its share of rents from the project. The mining agency and the ministry of finance may themselves interact to discuss the tax and government revenue regime. The use of a model—often any model—might help government agencies to think of their interests as an indicator with a value. Attractive investment might become a calculation around the Internal Rate of Return (IRR) of the investor, and how high that should be. A solid tax regime might be turned into another widely used metric, such as the combined tax and royalty returns to governments. Each party might then have a conversation about the modelled metrics and have an objective discussion about how the mining revenue should be shared between the private company and the government.

In this traditional process, the investor will have a model. The government may or may not have a model, or may rely on the investor's model, with its limited set of revenue- and tax-related indicators. Communities are generally left without any specific access to a proper model, leaving community-level interests outside any structured conversation.

Now let's move to a sustainable development approach to a model, and how this can, and should, create a process of interactive discussions.

A three-pillar approach to modelling—environmental, social and economic—will necessarily force the inclusion of many other factors into the model. Government, environmental agencies, agriculture ministries, and development ministries may all have interests that need to be factored into any government decision around a mine. These ministries will, essentially, be bringing in other perspectives from the broader set of issues represented in the notion of sustainable development. The agriculture ministry may have concerns over water allocation and water quality and how changes may impact upstream and downstream farming. The environment ministry wants to track levels of air pollution and ensure the sound structure of a tailings dam to prevent any risk of massive water and soil pollution. The tourism ministry will want to ensure that no sludge treatment facility for the mine is built on pristine coastline that tourists visit regularly.

Government interests may closely parallel community interests, and there are also health, employment, and education issues to consider, among others. Just as with a government's social and environmental interests, these issues can be identified and built into the model used for the full analysis of the costs and benefits of the mine to ensure informed decision making. This can be done using a group model-building exercise to create ownership of the process and the model. It also turns out that a company that considers the value of a social licence to operate will want to understand and consider these issues. Articulating all interests through an open discussion, which may include qualitative modelling and the creation of system maps before designing the simulation model, will help in creating a shared understanding of the problem, and eventually of the solution.

Identifying the array of relevant interests is thus the first step in a sound modelling process, and this requires a conversation among all stakeholders. In turn, the broader the model that results from this first level of conversation, the more likely it is that stakeholder engagement will flow to the other stages of the process. In the chapters that follow, the potential role and value of this engagement is discussed in relation to choosing the indicators in the model, determining how to quantify them, review and analyze how they are applied, and finally validate the results of the model.

All of these discussions will enhance both the validity and legitimacy of the resulting decision-making processes. This process can promote coordination among ministries and different levels of government, as well as between government, company and community. It can also help to depoliticize decision making by re-focusing the discussion. Having a clear understanding of who benefits and who bears the costs across all stakeholder groups will help in developing strategies and programs of how the benefits can be fairly distributed and/or how programs can be designed to compensate those who are negatively impacted.

The above is focused on project-related modelling. However, the principles apply equally to policy-related processes, in the context of both of sectoral and national development plans. Relevant stakeholders may change from local communities to civil society and professional organizations concerned with the underlying issues, academics with recognized expertise, and so on. The principle, however, remains the same.

The role of the model should be noted here. It is not to provide a neutral, "technical" answer. It is to frame the terms of the debate based on a common set of assumptions and results. If ministries and/or other stakeholders dispute each other's interests, then that is something that needs to be resolved to form the indicators that go into the model, not simply debated without end. In this way, the model does not impose a magic solution from above. Rather, it helps formalize and clarify the different interests and goals of different stakeholders in a more comparable manner so that a conversation can be had, to understand and resolve differences.

Finally, it is worth noting that inclusive and engaged decision making is in itself a core part of the SDGs. SDG 16 is about "Peace, Justice and Strong Institutions." SDG 17 is about "Partnerships for the Goals." Inclusive modelling processes in and of themselves will make strong contributions to the achievement of these goals.

3. Using Models for Better Decision Making

TAKEAWAYS

- The ultimate test of success is whether a model informs decisions and their implementation. Factors that contribute to success include understanding the needs of the decision-maker, choosing the right time, and selecting the right model.

- The choice of model should fit the question asked. Some models are used to set a target for decision-makers, others help decision-makers choose between options.

- Decisions are made through a cycle of steps. Some types of models are better suited to informing certain steps than others.

- A transparent and participatory process can enhance legitimacy, ensure the model meets critical needs, and include more people's interests.

- Publishing the model itself can also improve technical robustness, grow a knowledge community, and re-balance relationships between stakeholders.

3.1 Introduction

The ultimate goal and measure of success of a model is whether it informs decisions that contribute to sustainable development. Even if a model is technically robust and generates new and interesting results, if it does not meet the decision-maker's needs it will not inform a decision—ultimately missing its core target.

This chapter sets out how to place decision making at the centre of the modelling process, while ensuring that both the model and the decisions that are based on it have policy relevance. It also discusses which practices could enhance the probability of impact.

3.2 From Models to Decision Making

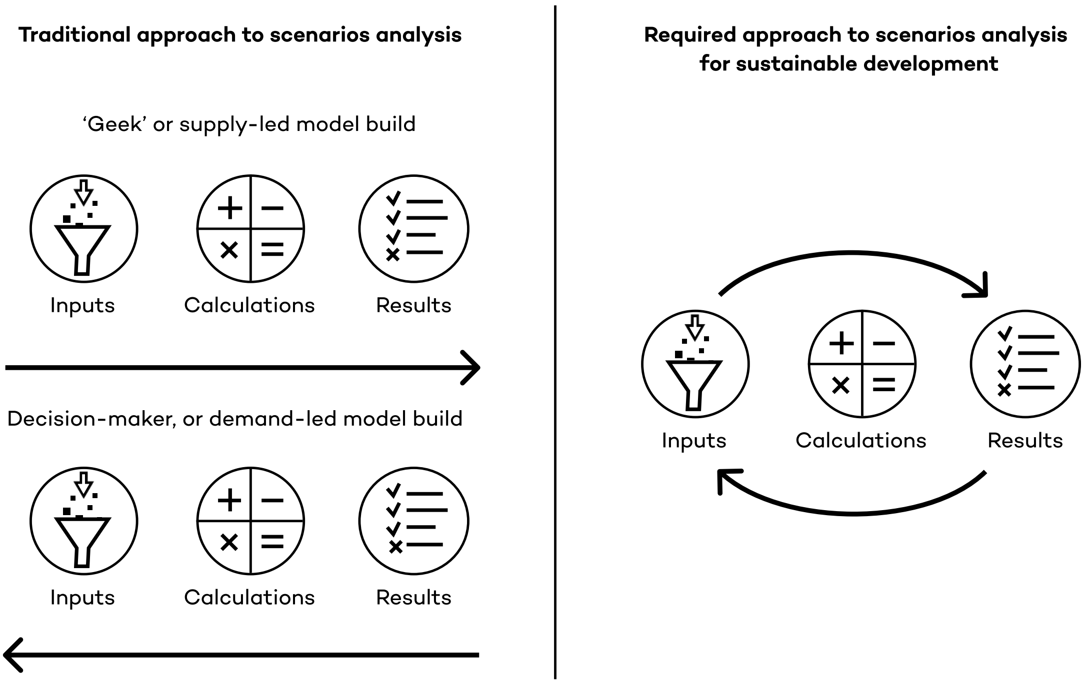
The ultimate test of success for any modelling exercise is whether the results inform decisions and their implementation. This is challenging in itself as it requires communications between modellers and decision-makers about their need to act and the potential consequences of their actions. These challenges are multiplied in the context of sustainable development because they may:

- Involve multiple departments (who might not be used to working together, not want to share information, or worse, be working at cross-purposes).
- Require trade-offs across different parts of society or from one generation to the next.
- Lead to some impacts that are measurable in the short-term, and others that are either not measurable or will only emerge in the longer-term.

There are several steps to factors that can contribute to more policy-relevant modelling:

Understand the needs of the decision-maker. Being clear on the needs of the decision-maker will inform the way the results are presented. If a government has already decided to build a road, there is no point in developing or using a model for which the outcome is whether or not to build a road. In this case, what the government may need are options for how to build that road in a way that minimizes the costs and maximizes the benefits. Typically, decision-makers would start with a target and ask the model to determine what actions are required to achieve this target. For a modeller, the starting point is to define the inputs for the model and obtain an estimate of the cost of such investment. When modelling for sustainable development, these approaches have to become iterative in order to estimate the many potential outcomes of interventions and use this information to further improve the inputs in the model.

Figure 4 — Sequence of model building



Engage the decision-makers and all relevant stakeholders early in the modelling process. While models are often commissioned by a specific decision-maker, the ability to turn the results into decisions will require the support of a range of other actors. These can often create obstacles to executing a decision based on the modelling. This is particularly common with modelling for sustainable development, since by its nature the decision being modelled affects a diverse set of people and the circumstances in which they live. A carefully developed communications and engagement strategy will help ensure the right actors are involved throughout the process (see Chapter 8: Communicating Modelling Results).

Choose the right time. Perhaps the most important factor for success is timing. In this regard it is important to know at what stage in the political cycle your model is intervening. This will determine the model that you use, the degree of sophistication, and the trade-offs that need to be made. If a decision is to be taken within weeks, there is no point spending time developing a new model. In this case, you may need to either abandon the idea of a modelling exercise altogether or focus on whether other existing models are available. In some instances, decisions are not only made at a single moment in time but are being taken throughout the life cycle of a project or a policy process. Being aware of the full life cycle of decision making and identifying the single or multiple entry points for the modelling work in that cycle will ensure that the model's results have the greatest impact and usability.

Select the right model. The desire to "run a model" can often lead to the wrong model being selected. A poor understanding of the different modelling options and how models work can be major factors in the choice of the wrong type of model. An initial step is to assess the suitability of modelling methodologies, and then to identify available models or consider the potential benefit of creating a new one that fits the situation's needs and the relevant stakeholders' objectives.".

3.3 The Choice of Model Should Fit the Question

Some modelling processes result in a single number or set of numbers that set a target for a decision-maker. For example, in one instance a founder wanted to know how much additional public spending was needed to end world hunger. The model was able to produce a result that showed that international donors would need to spend an extra USD 4 billion per year from 2016-2030 to achieve the target (IISD & IFPRI, 2016). Using this approach, a given target and set of constraints are defined, and the model identifies the optimal solution (e.g. investment amount, policy ambition and related target). A discussion may be necessary to question the structure and assumptions of the model, but the discussion is about improving the accuracy, and perhaps credibility, of that number.

Other modelling processes are about helping decision-makers set a policy or invest in a project, or for governments to allow a project to proceed. They are usually context and location specific, such as "Shall I build a road in this place?" (WWF, 2013) or "What type of irrigation scheme ensures the maximum environmental, social and economic outcomes?" (TEEB, 2018). The modelling results alone may be insufficient and other sources of information may be required before decisions are made. For example, when planning to build a mine, consider how the mine might affect agriculture, river water quality, and HIV rates in the local area. In this context it is difficult, if not impossible, to optimize for a given outcome, given the many consequences involved and the different priorities each stakeholder might give to each factor. If such consequences are built into the model, and *simulation* (of a *what if* analysis) is used that highlights the likely outcomes of interventions, it is possible to spark a conversation about the relevance of including such impacts to create a more comprehensive strategy. In these cases, a more integrated model can help identify unintended, or unconsidered consequences and the contribution of the model goes well beyond the numbers generated.

Some questions can be answered with a relatively generic model, while others require a more customized model. The degree of customization required depends again on the question. A relatively generic model can be helpful for choosing between broad policy options or understanding the impact of policy in a representative case. For example, the IGF mining tax incentives model can be used to assess the impact of tax incentives typically used in mining projects in a representative case but could not be used to assess the impacts on a particular mine without being customized further. More customized models can be used to answer questions in a specific context, such as how setting a project or implementing a policy in a particular geographical location may affect results. For example, System Dynamics models were used to inform national climate change adaptation and energy efficiency strategies in Mauritius and Cambodia respectively. As each model was customized to the local context it could be used to identify local priorities, support project and policy formulation, assess options, and monitor and evaluate outcomes. The process of customizing models is also an opportunity for local communities and others to participate in the process, giving a sense of ownership and trust in the results.

Whether a model is used to optimize or choose between options, and whether generic or customized, it will need to include all three pillars to be a sustainable development model.

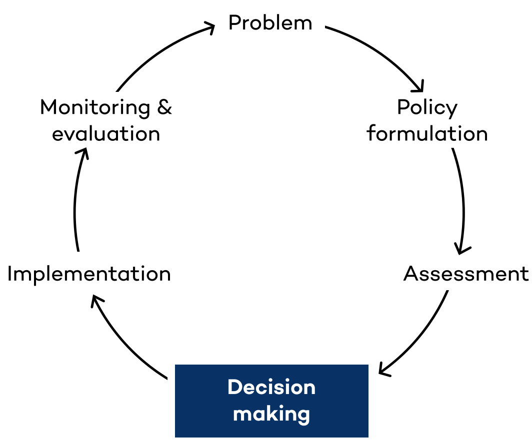
REUSING, RECYCLING AND REPURPOSING MODELS

The life of a model often ends after its original intended purpose. Although models are developed to answer specific questions, they can be reused, recycled and repurposed.

Reusing models

Models can be commissioned to inform a particular step of the decision-making cycle (see Figure below). If a model is sufficiently flexible, it can be used again at a different step. So, a model used to assess different options can also be used a few years later to evaluate the impact of the chosen option. This can be a relatively simple exercise, for example by updating the assumptions that were made at the time of assessment with data observed a few years later. The results may identify a problem and need or policy change, which can be assessed again using the same model.

Figure 5 — The decision-making cycle

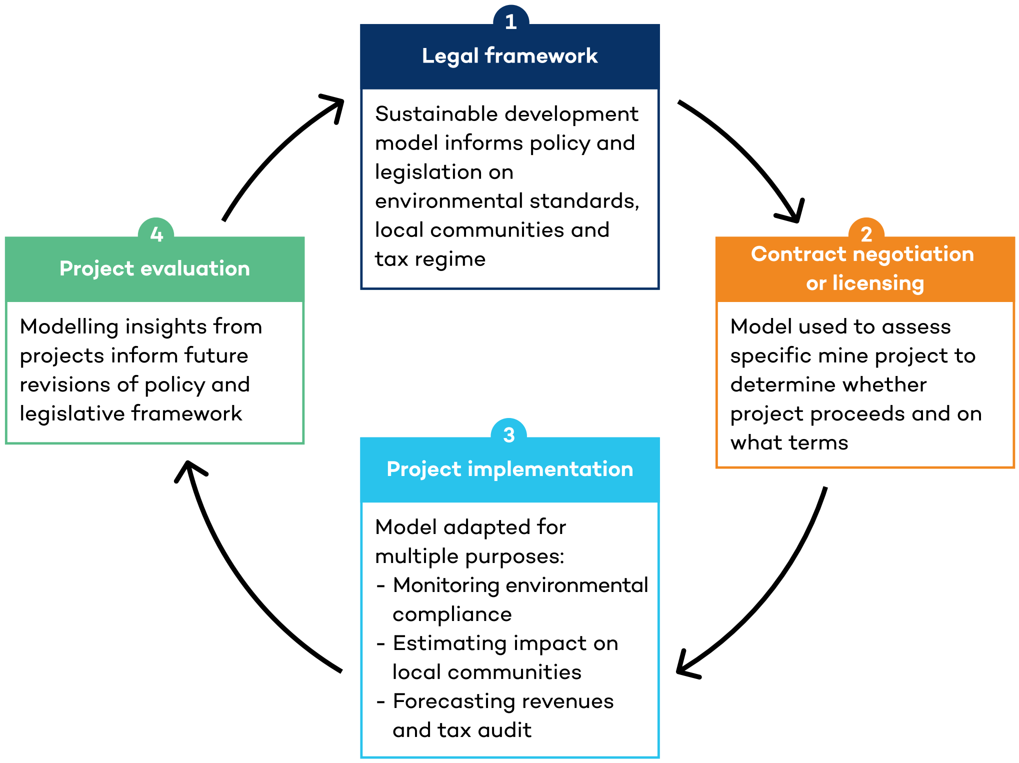


Recycling and repurposing models

Models can also be recycled and repurposed to answer different questions. One way to do this is to take a model used to answer a broad policy question and customize it to answer a specific project question. For example, a model used to set environmental, social and tax policy in the mining sector could be customized to apply to a specific mining project. This could be as simple as ensuring data and assumptions are based on the specific project or could require further development of the model to incorporate local factors that were omitted from the model.

Another way is to adapt the model to different, or even multiple, purposes. For example, a mining project model could be customized and used for monitoring environmental impacts, forecasting tax revenues, and auditing the mining company. As these functions are often done by different government agencies, the original model might then be distributed to each agency for their own specific purpose. The insights from these new models could identify problems in the legal framework, which could then be assessed using the original model (see Figure below).

Figure 6 — Recycling and repurposing a model for sustainable mining



3.4 Publishing Models

Publishing models strengthens the transparency of the modelling approach and its legitimacy. It also improves the capacities of all relevant stakeholders to design, use, and understand models. The benefits of publishing a model are:

Testing the robustness of the mechanics: The greater the number of people that *can* look at a model, the more likely the discovery of errors in the inner workings of the model. This principle is valid even if in practice the number of people able to look at the inner workings of any given model in an informed way is limited. It only takes a small number of people to make a difference, whether they are applying a model in a negotiating or policy-making context, or finding the model on the Internet for their own needs.

Robustness of data and assumptions: Leaders of local communities, for example, might not be modellers themselves, but they are more likely to be able to hold an informed view about whether some of the *assumptions* relating to their own circumstances going into the model are robust. Is it really true that there are no major roads in the district now and that the new project will transform local economic possibilities? Are the number of livelihoods jeopardized by the project—a potential risk—being accurately estimated? Only when the data and assumptions are known and subject to review can the accuracy, and hence legitimacy, of the model be confirmed. A model is not a magic box: it cannot transform bad inputs into good results.

Setting of policy priorities: Ensuring that a model incorporates the interests of stakeholders is critical for the legitimacy of the final decisions. If models are supposed to provide results in given metrics, such as share of profits, numbers of jobs created, or a combination of different criteria which guide policy-makers through informed decisions, the question is then: has that metric, or combination of metrics, been correctly identified by those policy-makers? In practice, that's harder to know if the model hasn't been published. There are many project models in which the metric, which effectively means the overall policy goal, has been selected by one government agency or ministry in isolation from others, but this cannot even be known because the model was kept secret.

Growth of the knowledge community: Developing technical capacity to design, build and operate a model is a key factor in how viable modelling can be. One of the cheapest and most effective ways to help build the community of people in a country who can understand and act upon models is to increase the number of fully featured models that are freely available. Few things elevate the level of capacity expected in government like a public example of best practice from within the home country. As many aspects of best modelling practice are common across all economic sectors, it may not even matter which sector the model deals with. Once it is published, it helps set "the new normal." It also helps entice and engage future generations of modellers.

Rebalancing relationships between stakeholders: One of the key arguments given against publishing models is that they may contain proprietary or privileged information. Companies prefer to keep terms of business secret. Asymmetries of information are a potential asset. Making a model public reduces the value of such asymmetries. Contract terms often require confidentiality around commercially sensitive issues. Madagascar has implicitly circumvented this by setting a financial model as an official project document attached to its model oil contract. Should any dispute arise about the impact of changes in law affecting investor interests, this model can be used to define potential levels of loss and restitution.

Avoiding disinformation: Modellers are often reluctant to publish models out of fear that they then can be modified and used for questions they were never designed to answer. That may lead to the generation and dissemination of disinformation. However, models can be made public in a way that is protected against such abuse. For example, a blockchain allows a model, or indeed any compliance-level document, to be verified and committed to public record.

4. Building a Model

TAKEAWAYS

- Building a model for sustainable development requires mapping the concerns of, and interactions between, stakeholders.
- Quantifying and monetizing the environmental, social and economic indicators to produce a single metric could help decision making.
- Adjusting values for time and risk is critical.
- Given imperfect scientific knowledge and lack of agreement on how to value non-financial information, not everything can be modelled today.
- There is no single method to model for sustainable development. Various methods integrate each dimension of sustainable development differently and each has its own benefits and limitations.

4.1 Introduction

Building a model for sustainable development is not a *business-as-usual* exercise. The outcome of such a model should lead to measuring all three dimensions of sustainable development. The action of a government or company can result in numerous, interrelated outcomes on the environment, society and the economy. Information on these outcomes is rarely quantified in a way that provides simple insights for decision making.

This chapter sets out how to start the modelling process with a mapping exercise of needs and expectations, then discusses the challenges involved when trying to quantify the various dimensions of sustainable development and provide an overview of relevant modelling techniques.

4.2 The Context and the Stakeholders

Before starting to model, it is crucial to understand the context, the cause of the problem, and the obstacles to solving the problem. This requires engaging with all stakeholders, from government and companies to civil society and academia. Speaking to these groups reveals what they are concerned about, as well as who the project or policy might affect, why, and how. Collecting this information determines the *boundaries* of the model: the indicators to include and exclude.

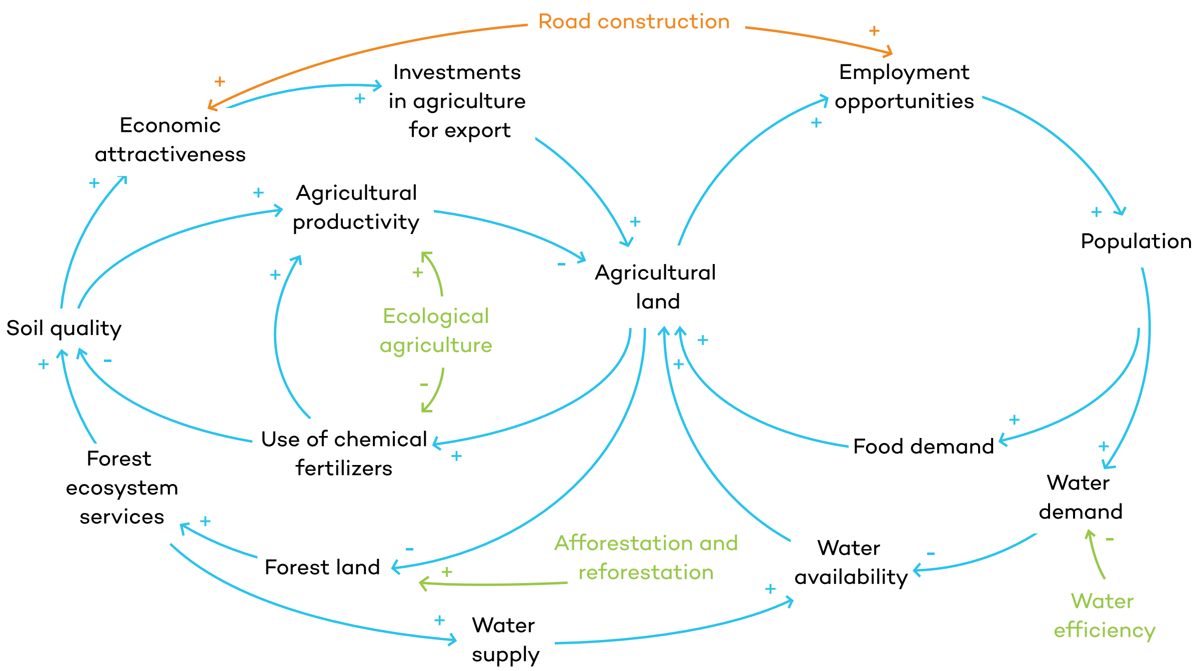
Taking an example of an actual process illustrates the usefulness of this approach. In 2013, the governments of Thailand and Myanmar were planning to build a road between Bangkok (Thailand) and the coastal city of Dawei (Myanmar). The governments hoped that it would help people and businesses deliver their goods faster and at lower costs to new markets across southeast Asia, while the road construction work itself would create jobs.

The World Wildlife Fund (WWF) was brought in to evaluate the road project. WWF first organized meetings to bring government, construction companies, the business community, affected communities and other civil society organizations together to share information about expected benefits, unexpected synergies and the costs that might emerge. Thirty participants were involved, representing local actors with a stake in the road: townspeople, farmers, researchers with interest in land productivity, and landowners concerned about the value of land (Bassi et al., 2016). The goal was to have as many voices as possible, to identify any conflicting priorities and find shared approaches to mitigate such conflicts.

To support this engagement with stakeholders, WWF used a system map (also referred to as a Causal Loop Diagram, CLD). A system map is a way to explore and graphically represent the interconnections between the key indicators of a system, in this case a system of groups that might be affected by the road project (Probst and Bassi, 2014). A system map is a form of qualitative modelling. The stakeholders first build the map through their ideas and opinions gathered at meetings. This then defines the boundaries of the analysis, and helps the stakeholders better understand how the system responds to the implementation of a project or policy.

WWF drew a system map (see Figure below) based on the meetings with stakeholders. Participants said that the road (in orange) was to be implemented for two reasons: jobs and access to markets. Participants also thought that building the road would create jobs and therefore increase the population in the area. This in turn would increase demand for food, and thereby increase agricultural production. The participants also identified that the increased access to markets would encourage local landowners to invest and buy more land, with the prospect of higher revenues, including from exports.

Figure 7 — System map of the Dawei Road construction outcomes



However, people also identified costs from the road project. The farmers emphasized the importance of increasing productivity to supply the new demand, but this would necessitate increasing chemical fertilizers and pesticides. Civil society said that to expand the areas of land devoted to farming would mean cutting down forests, which would threaten tigers and other endangered species. This would also lead to a reduction in available water and would erode soil quality, exacerbated by the use of chemical fertilizers and pesticides. By mapping these factors, the WWF team saw new dynamics in the system: factors that might undermine the potential economic benefits of the road. For example, the reduced water supply could limit the expansion of agricultural production (especially irrigated land) and the diminished soil quality would eventually reduce farming yields. This led to a new discussion about what complementary intervention options could be identified to maintain the positive outcomes of road construction while at the same time avoiding its side-effects (see variables highlighted in green) (Bassi and Gallagher, 2013).

By mapping these factors and the relationships between them, the system map exercise clarified the indicators to include a quantitative assessment (road construction, employment, agriculture land, deforestation, waste availability and soil quality) as well as options for alternative scenarios (e.g. investments in water efficiency, support in the adoption of sustainable agriculture practices and reforestation). From here, the quantitative modelling could begin.

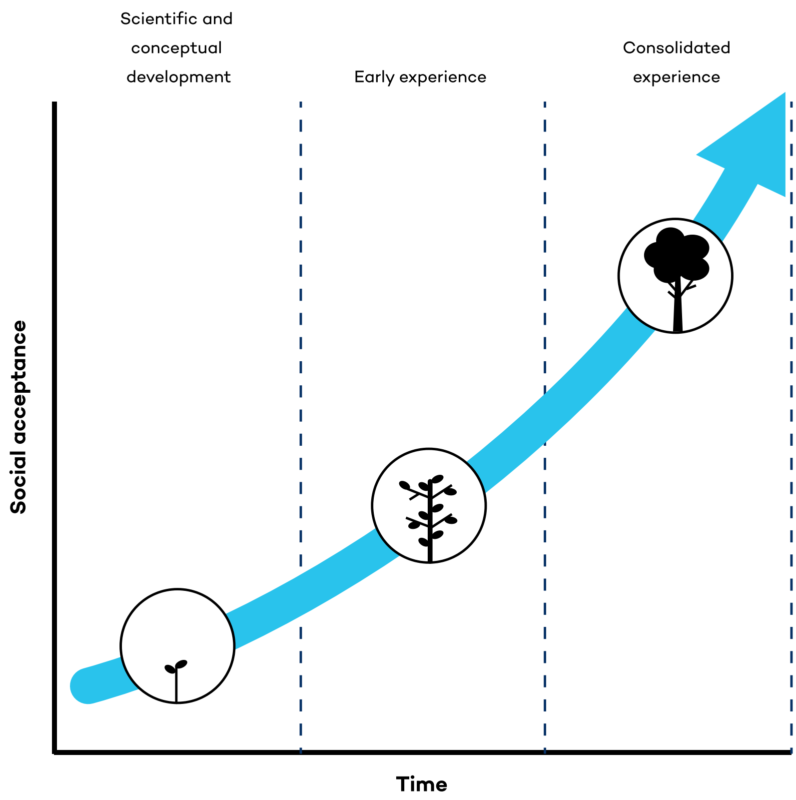
4.3 Converting Environmental, Social, and Economic Metrics to a Common Unit of Value

The unique advantage of the sustainable development approach is that it provides the conceptual means to be explicit and inclusive about environmental, social and economic outcomes. Modelling for sustainable development needs to consider two steps. First, a modeller must quantify the different outcomes, and may convert them into a common unit of value—often a monetary value. Second, because these outcomes might happen in the future, the modeller must adjust these values for both time and lack of certainty.

QUANTIFYING AND CONVERTING OUTCOMES

The way to quantify and monetize environmental, social and economic indicators depends on the state of scientific knowledge and the social acceptance of the findings of the science (see Figure below). It evolves with developments in science, artificial intelligence, machine learning or open source access to models. In the early stages, models that combine indicators from multiple disciplines may have a strong scientific backing, but it does not mean that they are accepted by society. The same goes for monetizing indicators: there may be scientific consensus on the quantification, but not on the weight of the monetary value. It is because of the absence of consensus that mapping the interactions with the right stakeholders is crucial. The modelling is the starting point of a conversation around how to represent the three dimensions of sustainable development. The discussion that follows illustrates the limits of what modelling can and can not do for sustainable development.

Figure 8 — Acceptance of a common unit of measure over time



VARIABLES THAT ARE RELATIVELY EASY TO QUANTIFY AND MONETIZE

Traditional modelling techniques, used in economic and financial analysis, start from economic variables for which prices are the basic metrics—in some cases observed in the market. The quantification and monetization processes are relatively straightforward and includes traditional economic variables such as income flows and costs.

The main challenge is to guarantee that the economic and financial models used are consistent with assumptions and concepts about the value of time. It is also important to track and explain differences between public and private costs and benefits, as well as externalities.

VARIABLES THAT ARE RELATIVELY EASY TO QUANTIFY BUT NOT TO MONETIZE

Many environmental indicators and some social indicators are relatively easy to quantify but difficult to monetize. Social and environmental disciplines have a long history of monitoring and modelling with their respective metric systems. The key challenge for this category is to find the right conversion factor to monetize the quantitative values. For example, integrating the value of a clean lake in the price of real estate requires that the value of a clean lake be converted into a monetary term.

An important caveat is the extent to which the market is used to process these indicators. Even as markets for ecosystem services are slowly emerging, current market and policy failures could lead to strongly biased interpretations of prices.

The conversion of greenhouse gases into monetary value using the European Union's Emissions Trading System is an example of a market-based price. Still, capturing the financial value of inequalities or the value of a human life is much more challenging.

VARIABLES THAT ARE DIFFICULT TO QUANTIFY AND MONETIZE

Today, some issues stand at the frontier of existing knowledge and techniques in their respective disciplines. Environmental processes encompass all disciplines related to natural sciences. Social processes are equally complex and introduce political elements such as migration, gender inequality and distribution of wealth in relation to well-being. The heterogeneity and complexity of environmental, social and economic processes make the quantification, and eventual monetization, of these variables more difficult. This includes the challenge of converting qualitative measurement to quantitative measurement.

Examples in this category are models for nature-based infrastructure, ecosystem services for adaptation to climate change, thermal pollution in natural water systems and the valuation of these systems. Similarly, while finding proper metrics for natural capital still requires some efforts, valuing this capital could be done through various approaches, monetary or non-monetary, either at the national or project levels (e.g. hedonic valuation, shadow prices).

Several efforts are emerging to harmonize approaches and facilitate the sharing of information across different development disciplines. In the environmental dimension, the creation of environmental accounts that gather environmental data in a format used for national economic accounts is an important step forward. This is the System of Environmental Economic Accounting (SEEA). The Secretariat of the Convention on Biological Diversity (CBD) and the Economics of Ecosystems and Biodiversity (TEEB) are also working towards consensus in the quantification and monetization debate on ecosystem services.

KNOWING WHEN TO STOP

Sometimes existing knowledge and social consensus may be too limited to provide a robust quantification or monetization. There are variables where there is little or no consensual way, currently, to define how to convert them into monetary values. This is illustrated in the figure above. This can be due to the lack of societal agreement, or simply because there is not enough science to measure or quantify the issue at stake. While modelling can offer some techniques, such as comprehensive or discrete sensitivity analysis to push the boundaries of what is possible, it will have to acknowledge its limitations. When such limitations exist, other chapters of this book provide strategies to protect the utility of the model without necessarily reducing the scope of factors included.

For example, an investor plans to build a new factory farm and wants to analyze the risks to human health, economic benefits, and environmental costs. They know that antimicrobial resistance is now a major threat to human health and development. The misuse of antibiotics for human populations and the role of antibiotics in livestock production are drivers of this threat. The long chain of causality is not yet well captured by science. Thus, quantifying the health risk of this farm for humans, as well as the societal and environmental costs, is challenging or subject to uncertainty.

In addition, it is also important to remember the suggestions within this book in relation to transparency and stakeholder engagement. These become important safeguards to address the legitimacy of the overall conversion process in each specific circumstance.

CONVERTING FUTURE AND UNCERTAIN VALUES

The benefits and costs of sustainable development do not emerge at the same time. For example, the jobs created in the first year of a road construction project may appear as a significant benefit, but that gain is diminished when weighed against the car fumes which pollute the air for decades. The value of job creation today and air pollution in the future needs to be converted to a common unit of measure in a present value to make a comparison. The financial concept of discount rate allows us to do this. This discount rate is sometime referred to as the *time value of money*. The higher the discount rate, the lower the future value compared with the present. This is assumed or estimated in various ways.

For example, to choose between receiving USD 90 today or USD 100 next year we need to convert the future USD 100 into what it is worth today. With a discount rate of 5 per cent, the present value of receiving USD 100 next year is USD 95 (the calculation is USD 100/1.05). Based on that discount rate, it is a better choice to wait until next year.

As well as valuing time, it is equally important to value risk. Events and values of things in the future are unknown. Some events and values will be more certain than others, so to compare we need to adjust for this difference. For example, instead of receiving USD 100 next year for certain, the option is now risky. We might get USD 100 next year, but we might also receive nothing. Given this risk, which option should we choose?

To compare the prospect of possibly receiving USD 100 with the certainty of receiving USD 90, we need to adjust the USD 100 for the uncertainty that we might not actually get the money. A common approach is to assume how much we dislike risk (the risk aversion). This risk preference is often included within the discount rate. So, to account for the risk preference, a risk-included discount rate from 5 per cent to 15 per cent could be used. Applying this discount rate to the USD 100 now results in a present value of USD 87 (the calculation is USD 100/1.15). Based on this discount rate, it is a better choice to receive USD 90 today.

There are ways to estimate how different groups of people consider risk. The risk preference is always an assumption in the model.

THE DISCOUNT RATE IN SUSTAINABLE DEVELOPMENT MODELLING

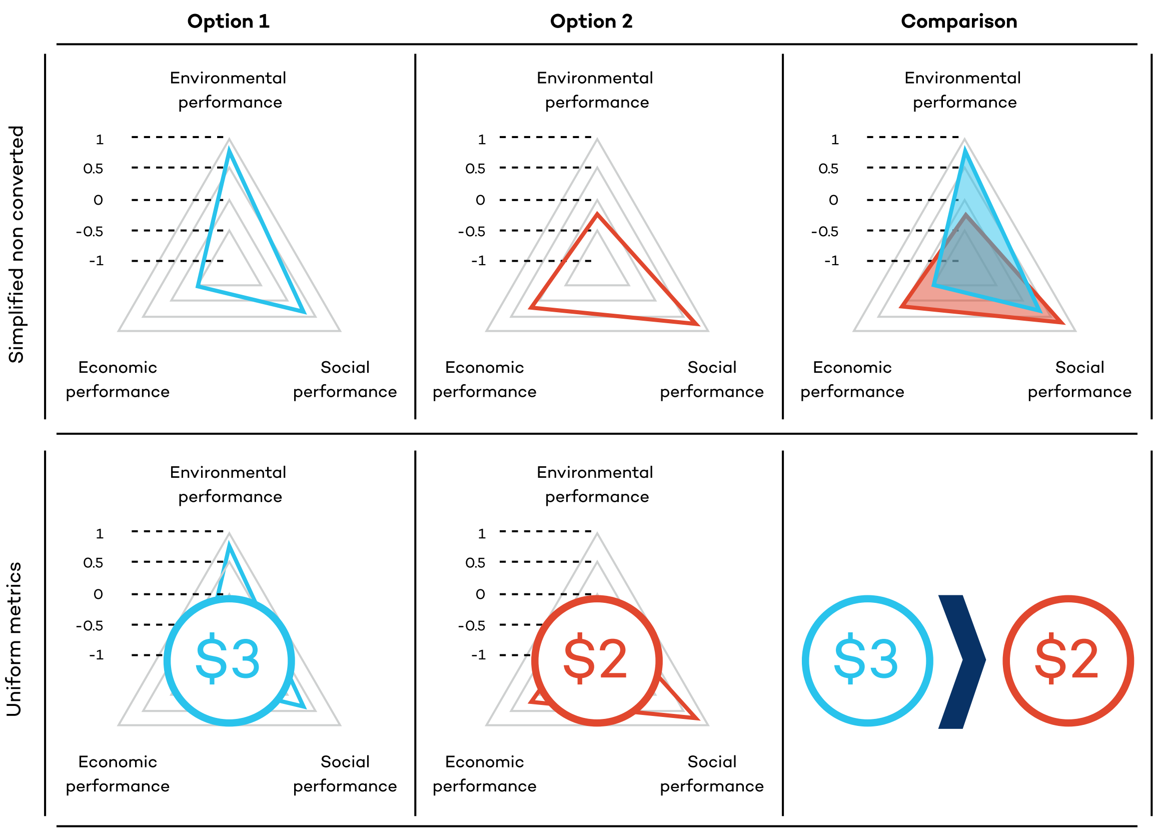
The notion of a discount rate is particularly important in sustainable development modelling because the time spans and lack of certainty involved are so large. Still, because of the complexity involved in adjusting values for risk, the discussion on the discount rate is sometimes omitted. Types of modelling that are able to forecast risks using bio-physical indicators are helping modellers to treat risk more explicitly.

An important debate has emerged at the global level concerning what discount rate to use for the value of economic and non-economic values. William Nordhaus, a Nobel Prize winner in economics, proposed a 2.5 per cent discount rate—a value much lower than the rates typically used for financial investment analyses (sometimes 10 to 15 per cent). Some scientists have even argued for using a negative discount rate. Applying different discount rates to the same future value can result in large differences in present values. This makes debates around what the discount rate should be important in sustainable development modelling.

ILLUSTRATING THE CONVERSION PROCESS

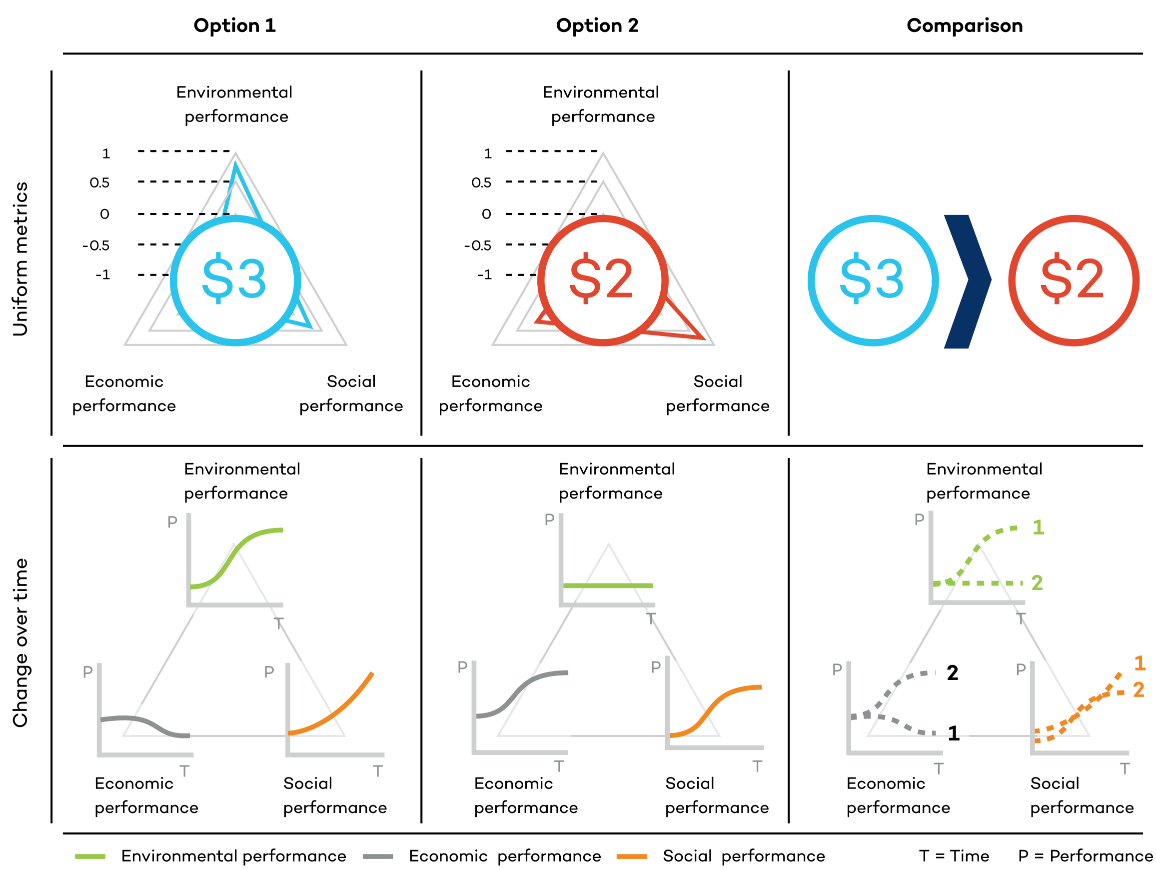
The figure below illustrates the multi-dimensional approach to valuing a project or policy. Option 1 has a strong environmental performance while option 2 has a strong economic performance. Until you can monetize the two options, you cannot know whether the outcome is better. It is only when you monetize the performance that you can compare options. Converting all variables into a monetary equivalent allows you to more easily communicate a message to decision-makers.

Figure 9 — From multi-metric to common currency comparison



When assessing sustainable development outcomes, it is not sufficient to provide a single monetary value. Given the decision-making context, including political cycles, elections, and short-term performance assessments in the private sector, it is important to assess impacts over time. The figure below shows the original two options as a single dollar value, and how the economic, social and environmental performance changes. With this information it is possible to improve decision making because, with the anticipation of change, new projects and policies can be designed that complement original ones.

Figure 10 — Common currency comparison with time dimension added



4.4 Modelling Methods

For the purpose of this book, a model is a set of mathematical equations that describes a number of relations between a number of variables. The objective of the model is to provide a realistic, yet simplified, representation of reality. There is no single method to model for sustainable development. Different methods integrate each dimension of sustainable development differently and each has their own benefits.

Econometric methods are generally used to *estimate* a mathematical relationship based on current or historical data. They provide strong evidence and can be useful for informing forecasting assumptions and relationships. However, they are of limited use for answering forward-looking policy and project questions. By contrast, *optimization* methods generate an optimal outcome for a desired target (e.g. cost of ending hunger), and are subject to chosen constraints (e.g. limited CO2 emissions). Finally, *simulation* methods generate results on the likely impact of various policy or project options.

DIFFERENT TYPES OF MODELS

Models range from relatively simple spreadsheets focusing on a single project or market, to large-scale, global models with hundreds of thousands of equations and variables. Models have their roots in different academic disciplines along with a wide variety of theoretical interpretations of reality. This section describes the most common types of models used in sustainable development.

Economic vs bio-physical

Economic models use economic variables (e.g. GDP, income, employment) and track economic performance, for either a project or policy. While some economic variables can be translated into social impacts, the environmental dimension is typically omitted.

Bio-physical models focus primarily on biological relationships, physical flows, and how these impact the natural environment. Such models are, for example, used to forecast climate change or to simulate growth dynamics of crops under certain agro-ecological conditions and practices. Economic or social dimensions are typically omitted.

Because of the limitations of these models, good practice for sustainable development requires their integration.

Top-down vs bottom-up

Many environmental, social and economic systems have interactions between their micro and macro levels. For example, these interactions are evident when assessing how a forest affects the global weather system, and vice versa. There are two ways to model these interactions, and often using both approaches is useful.

A top-down model operates at a high level of aggregation, the macro-level either in terms of space, sectors, products, or categories of people. From there, results can be disaggregated down to a lower level (e.g. from country to regions) using *scaling down* techniques. However, the disaggregated analysis will not provide results at the aggregated outcome level. By contrast, a bottom-up model keeps track of the detailed, disaggregated variables at the micro-level, and then aggregates this micro-level information to interact with, and provide insights about, macro-level performance.

A top-down approach provides more insights about the likely outcomes at the national level (e.g. how achieving a national emissions target will impact poverty outcomes). A bottom-up approach allows us to have a better understanding of the dynamics that trigger change at the local level (e.g. where to build a road to improve access to health care for a specific community).

Another scaling issue is time. For instance, a community may be sufficiently fed throughout most of the year, but may experience extreme hunger for a few months each year. Therefore, modelling hunger as an annual average may miss these details. At the opposite end, some health or environmental issues will manifest after decades and therefore also requires a longer-term perspective.

Spatial vs. non-spatial models

Environmental issues are normally spatially specific (e.g. water and air pollution, flood risk). These are often analyzed with spatially explicit (i.e. high resolution) data or maps, while economic and social issues are often analyzed within a political boundary (national or city level).

Spatially explicit models simulate changes on a map to varying degrees of resolution (e.g. blocks of one square kilometre). They focus primarily on land use, for example to assess where the expansion of agricultural land use is more suitable or where deforestation might occur as a result of a road being built. Spatially explicit models can also be used to analyze changes in the provision of ecosystem services, for example carbon sequestration, soil erosion, water supply, and water quality.

By contrast, non-spatially explicit or spatially low-resolution models analyze average values for their particular geography, typically at a national level. For instance, instead of estimating air quality for each square kilometre of land in a particular country, and hence for specific urban and rural areas, a non-spatially explicit model would estimate the average value of air quality for the country as a whole based on national trends in air emissions and carbon sequestration.

So just as with top-down and bottom-up models, sustainable development analysis is likely to require both spatially high and spatially low types of models in order to result in a suitably holistic assessment.

Structural vs reduced form models

There are different ways to model the relationship between variables. One approach, usually called structural models, describes the relationship based on a prior understanding of the processes. The other approach, usually called reduced form models, describes the relationship based on the empirical correlations between the observed variables.

For example, we want to model how pressing the accelerator pedal in a car makes a car goes faster. A structural model will describe the physical process. The pedal releases more gasoline into the engine, the engine combusts the gasoline in the cylinders and moves the drive shaft. Moving the drive shaft makes the wheels turn faster. The car accelerates. This approach requires understanding each part of a car's engine, or at least having a theory on how the engine works.

A reduced form model uses the observation that when you press the accelerator pedal down by one centimetre, the car goes 10 per cent faster. The reduced form model uses this correlation – one centimetre to 10 per cent more speed.

Both approaches have advantages and disadvantages. The structural model explicitly lays out the process, which can support an understanding of what is going on. If this process is not clear, this is difficult to do. The reduced form approach does not require understanding of the process but because it does not describe the process, it becomes a *black box*: it will be less helpful in understanding how the process works.

Usually models will use a structural form for the core issues, for which you are likely to have a good understanding of the process. They will then use reduced form for secondary issues, for which you are likely to have a poorer understanding of the process.

DISCONTINUITY VS LINEARITY

One of the challenges of sustainability is the existence of discontinuity, tipping points, and irreversibility. For example, environmental, social and economic histories have been marked by episodes where these systems have been brought to their limits, leading to extreme outcomes from global economic crisis and civil war to major extinction. However, most existing models fail to capture these events. So, until better models have been developed, for now, bear in mind that linear models may generate overly optimistic or pessimistic results.

5. Choosing Model Inputs

TAKEAWAYS

- To get good outputs, models need good inputs. The quality of the input data changes over time and location. Types of inputs include data and parameters.

- Inputs are numerical, but this does not mean that they are facts. Inputs are the results of observation, or generated through various assumptions. Understanding the extent to which the input is an assumption is important for understanding the robustness of the results.

- Sustainable development requires collecting and using data from various fields and disciplines.

- Performing scenario and sensitivity analyses is an important part of checking the robustness of the modelling results.

5.1 Introduction

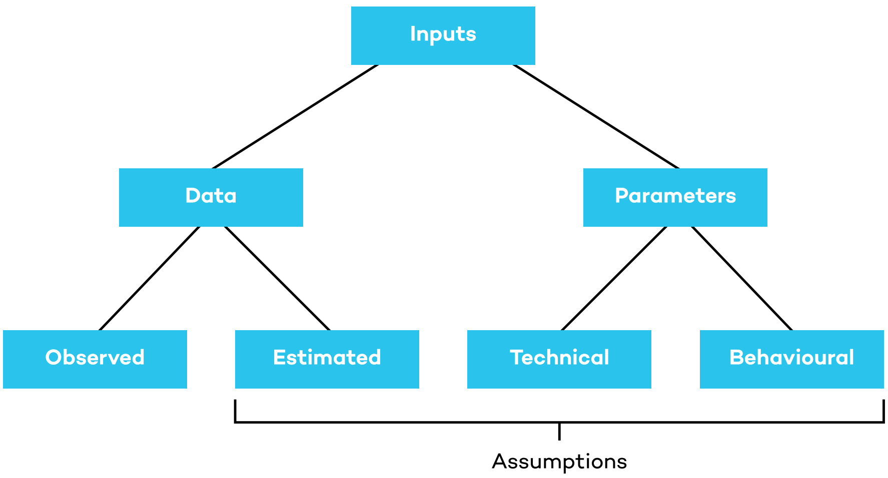
To produce outputs, all models need inputs. Inputs go into a set of equations describing relations between environmental, social and economic model components. In an ideal world, a model would work off perfect information to make its results more reliable. In the real world that is rarely, if ever, the case.

This chapter looks at the scope, quality and completeness of the inputs required by models, and explains what model parameters are and how they should be treated.

5.2 Types of Input

There are two types of input for any model: *data* and *parameters* (see Figure below). Data comes from measurements, observations or estimates that are translated into numbers. The population of Switzerland is data. The census in 2017 counted 8.4 million people. If we want to use the population of Switzerland today in a model, we need to make an estimate based on the 2017 census and the best information available on what has happened to the population since then.

Figure 11 — Model inputs



We separate data and parameters for three reasons.

1. **Conceptually**, they are used to represent different elements within a model, as described above.

2. **Methodologically**, parameters can be estimated—by the modelling team or by third parties—through statistical techniques, or calibrated based on past or present data.

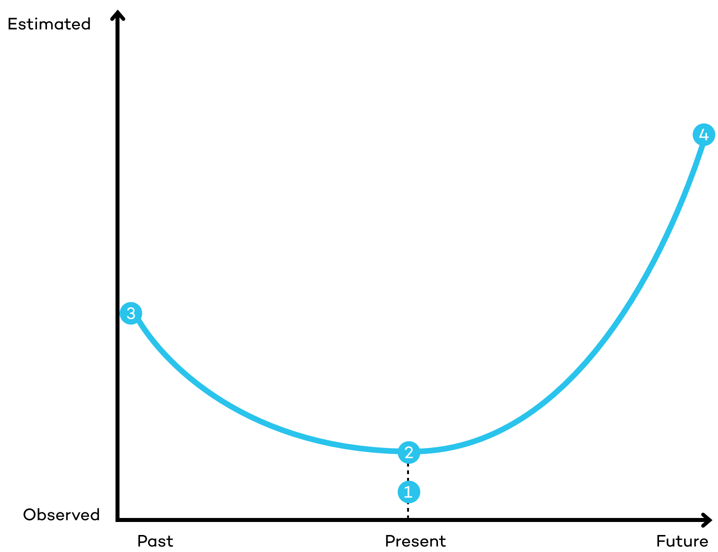
3. **Practically**, behavioural parameters are associated with a higher level of uncertainty than observed data and require assumptions regarding their future evolution. Therefore, they are important for sensitivity analysis.

The numerical character of both data and parameters makes it easy to confuse them with facts. It is important to remember that all data is the result of some interpretation—even accurate measurements. A conceptual relation between data and facts is presented in the figure in the next section. Although different from data, parameters can face similar challenges in terms of how uncertainty and time affect them.

5.3 Observation Versus Estimation of Data

The figure below illustrates the difference between observed and estimated data over time. Observation is more accurate than estimation. Observation is more closely associated with facts, while estimation requires a greater degree of assumption. The figure below shows that when measuring data in the present there is more observation and less estimation, while in the past and future it is the inverse.

Figure 12 — Observed versus estimated data



1. *Actual rainfall today.* Collected at a single weather station.

2. *Estimate of the rainfall today based on measurements from several weather stations.* The meteorological service will present the amount of rainfall for a city or region based on available data collected from various weather stations. This is slightly less accurate than 1 *(actual rainfall today)* because it assumes that all weather stations are well-

calibrated and the average amount of rainfall occurred in the locations in between the weather stations.

3. *Estimate of the rainfall in the past based on historical data.* Using past rainfall data to re-calculate the total amount of rain for a day in the past would most likely lead to less accurate results. This may be because fewer weather stations were installed and the accuracy was less exact.

4. *Weather forecast.* Forecasting weather is consistently improving, but there is still uncertainty that increases over time. Modelling rainfall 10 years from now will by necessity be based on a greater number of assumptions.

Rainfall is just an example, but this figure could apply to any type of model input. Past and future estimates are less exact than those at the date of observation. Future estimates are likely to have greater margins of uncertainty than historical ones. For example, the perimeter of the earth is unlikely to change in the future—it is a constant. At the other end of the spectrum, commodity price forecasts are highly volatile.

5.4 Data

To get the most reliable data for a model, it is important to consider the *sources*, *scope*, *quality* and *completeness* of the data.

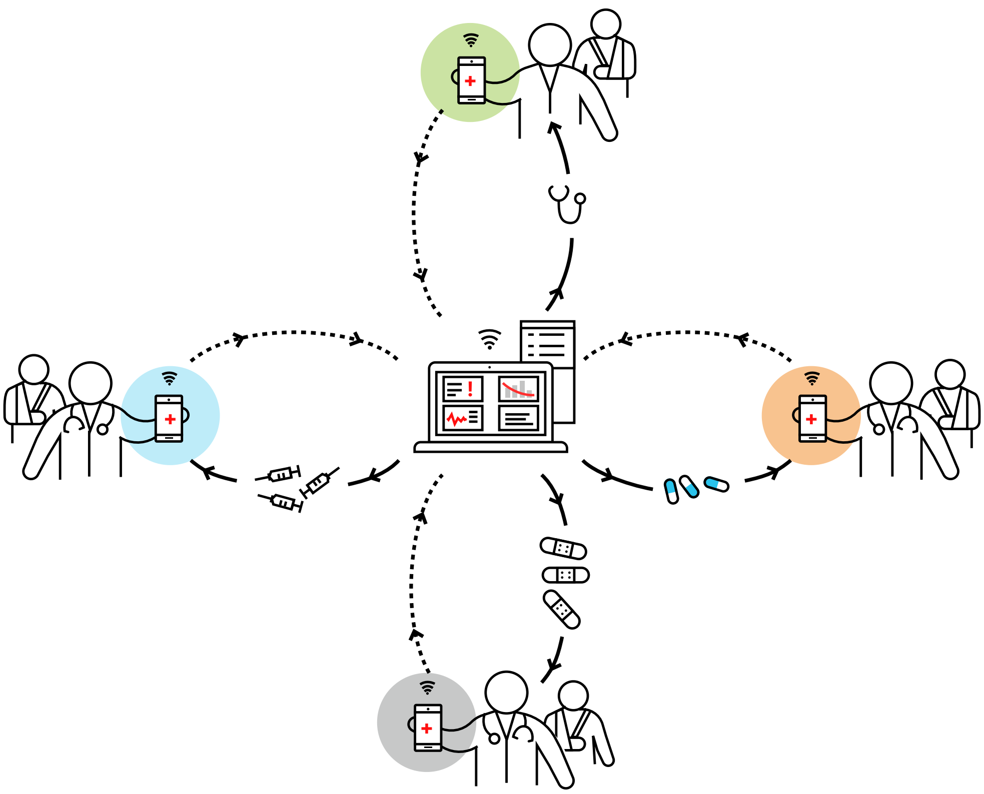
SOURCES

The data needed for a modelling exercise can come from a variety of sources. In relation to sustainability, what matters is knowing that most of the data will be scattered across different agencies and actors. This is why it is essential to bring various stakeholders to the table. Each will own or have access to different parts of the data needed: environmental, social, economic and project-related data.

The availability of data will improve over time. As much as the Millennium Development Goals (MDGs) helped to create good data on indicators to measure the achievement of the MDGs, their successor, the Sustainable Development Goals (SDGs) can be expected to create and improve sustainability-related data on many indicators. To date, the indicators are available, but few governments have been able to fully report on them.

Technological advances have lowered the time and cost of collecting data. This has lead to an abundance of *real-time* data. Global commitments to initiatives like the SDGs have led governments and international organizations to collect and publish, for free, more data on sustainable development. Satellite imagery can be used to collect data on environmental changes in areas that are remote and unmeasured. The abundance of mobile phones has generated vast amounts of data. For example, in Nigeria rural health workers use a simple mobile phone platform to register patient visits, symptoms and treatments. This data is uploaded into a centralized, open-source system that the government can use in models to detect disease outbreaks more quickly, plan how best to distribute and stock medicines, and develop emergency responses (see Figure below).

Figure 13 — Real-time data to improve health care in rural Nigeria



SCOPE

Deciding the scope of data to collect is often both a top-down and a bottom-up process. The top-down process starts from the desired model outputs. What data is required to produce modelling results that (1) consider the three sustainable development pillars, (2) give the decision-maker sufficient and reliable information to make a decision, and (3) enable the decision-maker to explain and justify that decision to multiple stakeholders? Excluding issues of interest to one stakeholder diminishes the value of that model, and calls into question the legitimacy of the decision making. This relies on open and inclusive discussions to ensure transparent and legitimate decisions.

The bottom-up process starts from what data is available and affordable, which then determines the type of modelling and analysis that can be done.

QUALITY

Poor-quality data is so pervasive, and leads to such poor results, that it even has its own acronym: GIGO, meaning "garbage in, garbage out." So, how to make sure not to feed garbage to the model?

First, the threshold for what is considered accurate data will depend on its use (see Dealing With Inaccurate Data below). Some issues require granular data, while others can use broader bands. If a friend asks me how I am I might reply "I'm fine, thanks," and that's sufficiently accurate for my friend. But if a doctor asks me how I am, "I'm fine, thanks" is not going to help her to make a diagnosis. She will likely ask me more questions to gather better-quality data on my well-being. In this sense, the quality of data required will depend on the needs of the user.

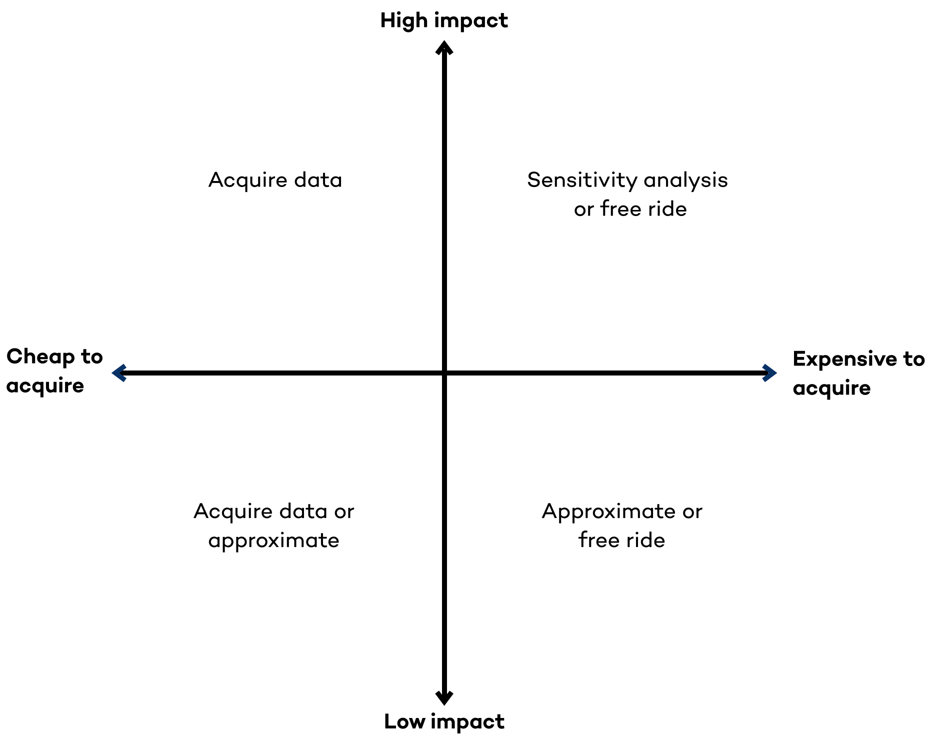
Second, the quality of data also depends on the stakeholders involved in the modelling process. An example of quality improving during the modelling process is the role of traditional knowledge in relation to historical changes in the local environment. The ability to collect this data will depend heavily on the engagement process with the traditional knowledge holders.

Third, the methods used to collect data should be known and preferably published. Standards and benchmarks can improve data quality. Independently verified data that complies with an established standard increases the quality of the modelling results.

COMPLETENESS

What if data is missing? This is not necessarily a problem. Reducing the scope in response to incomplete data is not a good idea, because the objective of a model is to get the best possible model, and an important input category may get lost. Instead, the issue of incomplete data has to be treated in a deliberate and transparent way. One way to do this is to conduct a sensitivity analysis to understand the consequences of missing data. The figure below shows different ways of dealing with incomplete data. The decision is based on the importance of the data for the model output and the cost.

Figure 14 — Dealing with incomplete data



1. Acquire data: collect new data or purchase data from somebody else.

2. Approximate: use comparable data or a proxy and be transparent about the assumptions made.

3. Free ride: find somebody else willing to acquire the data for their needs and ask to share.

4. Sensitivity analysis: be honest, report the results of a sensitivity analysis, and decide how to proceed.

This approach can also follow the logic that a poor decision leads to particularly bad results. If a poor decision could lead to catastrophic damage that is irreversible, the problem of incomplete data must be addressed.

The availability of more data can improve modelling for sustainable development and decisions. While data is not always available everywhere—high-income countries and cities still tend to have more data sources than low-income countries and rural areas—innovative ways of combining different data sources or estimating proxies can be used. When doing so, a sufficiently large and representative sample should be used to infer results infer results that apply to a larger population or area. As the number of data sources increases, care needs to be taken to ensure that data from any given sources are reliable and unbiased.

CASE STUDY

Dealing with inaccurate data

Water pollution is measured in parts per million (ppm). For example, 10 ppm means 10 parts in every million are contaminants. If 100 ppm is a safe level of contaminant for fish, animals and human health, but above that is dangerous, water pollution can be regulated at 100 ppm.

Data on contaminants is accurate to +/- 10 ppm. If the data shows contaminants of 95 ppm, is the water safe or unsafe? This is unknown because the data is not sufficiently accurate. There are two ways to address this. First, include a margin in the regulation to ensure water is safe by limiting pollution to 90 ppm. Second, collect better data that is more accurate than +/- 10 ppm.

5.5 Parameters

Alongside data, the other inputs to models are parameters. There are two types: *technical* and *behavioural*. Technical parameters are those originating outside the model (exogenous), whereas behavioural parameters are those calculated within the model (endogenous). Running a sensitivity analysis of parameters is highly recommended.

TECHNICAL PARAMETERS

Technical parameters can include a wide range of elements. They can include a set of coefficients that are defined by:

1. International convention, such as a conversion rate from kilograms to pounds.
2. The laws of nature, such as the carbon content in a tonne of coal.
3. Social practices, such as the number of working hours per day.

Technical parameters could be constant or change over time due to broader trends that are outside the model (exogenous). These trends could be technological, such as the yield of a solar panel that increases over time as technology gets better, or they could be environmental, such as the number of days of extreme heat increasing due to climate change. In the field of social sciences it includes trends such as the rate of social housing in a city, or the savings rate of the poor.

Depending on the scope of a model, some of these broad trends could be determined within the model (endogenous) even if they would normally be considered exogenous. For example, to model pension costs, life expectancy could be an input—an exogenous parameter. But life expectancy could become an endogenous parameter if atmospheric pollution on health outcomes is used to determine life expectancy.

Depending on the model, some parameters are triggered by events. A dam will either burst or not. The model will estimate likely impacts by using the probability that the event will happen—the dam is 20 per cent likely to burst. Setting this probability requires an assumption which could be based on a different model for hydraulic conditions.

In the real world, technical parameters, and their level of uncertainty, can interact with each other. Choosing the value of these parameters needs to be done in a consistent way.

BEHAVIOURAL PARAMETERS

The second category is behavioural parameters, which guide how model variables behave and respond to one another. Traditionally, they are estimated by using statistical techniques on an existing data set. These parameters need a proper identification of the studied phenomenon to capture a meaningful relation and not a mere correlation. For example, suppose a model simulates how people in Mexico City save money. This model will use a behavioural parameter, the saving rate, that can vary across household categories (people with incomes below USD 10,000 a year save on average 5 per cent of their income).

The frontier between technical and behavioural parameters could be thin, and the differentiation may change depending on the model. A technical parameter, such as the electricity yield of a solar panel, could be purely technical and linked to improvement in innovation. It could also be replaced with a behavioural parameter showing how the yield changes based on the amount of R&D investments.

These correlations between parameters are complex, and it's important to get them right. They should not be based on one study but rather a broad review of existing literature. This approach needs to be documented so others can review and assess the assumptions.

6. Integrating Models

TAKEAWAYS

- Traditional models tend to focus on financial and economic dimensions. Sustainable development, however, is about integrating multiple dimensions: environmental, social and economic.
- The first step is to integrate the body of research and knowledge from across the various disciplines of sustainable development.
- The second step is to decide whether to expand an existing model, combine the inputs and outputs from multiple models, or develop a new integrated model. Each option has pros and cons.
- Modelling integration allows modellers to operate at various levels of scale and combines project-based and policy-based models.
- To facilitate model integration, having common modelling standards is critical.

6.1 Introduction

Sustainable development calls for the integration of environmental, social, and economic factors in decision making. Models, too, should integrate these three dimensions. Without this, policies and projects will continue to be developed in isolation. For integration to happen, those building and using models need to have open minds and a willingness to expand their horizons.

This chapter sets out the options for integrating knowledge on sustainable development throughout the modelling framework.

6.2 Why Integrate?

Sustainable development decisions should seek to maximize benefits and minimize harm across environmental, social and economic outcomes. Better sustainable development decisions require better modelling across all three pillars. Often the models that are used to make decisions fail to incorporate all three pillars.

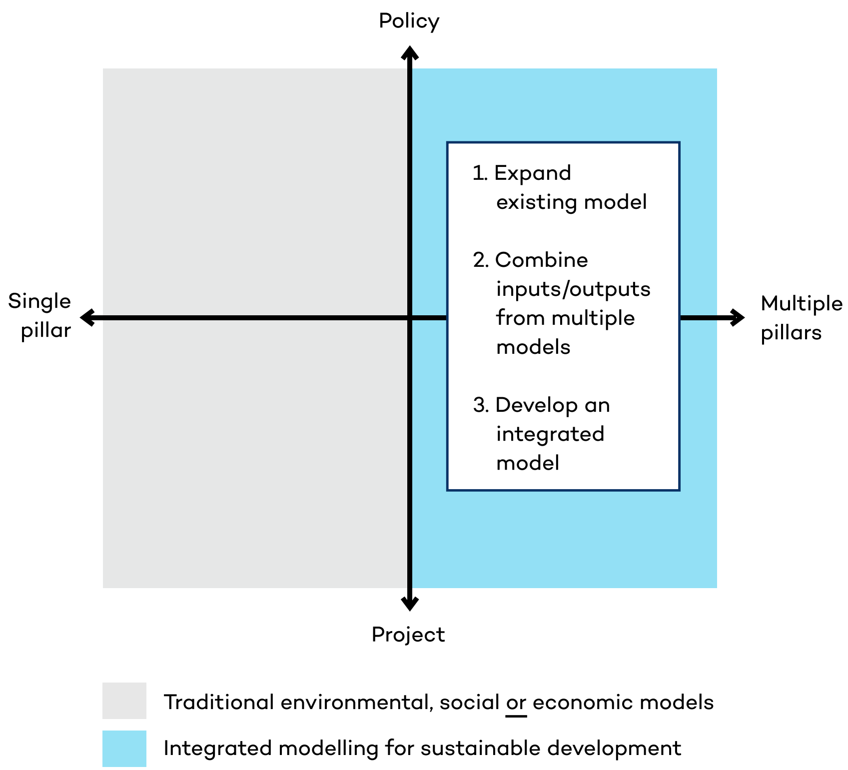
Traditional approaches to modelling mining projects, which focus on economy-wide growth and government revenues, illustrate these failures. In Ghana, traditional modelling was used to decide the taxes levied on gold mining companies. However, the model did not take into account the harm caused by gold mining to local farmers, whose fields suffered from mine pollution. A subsequent study that integrated social and environmental pillars into the traditional approach found that the losses farmers suffered due to pollution were larger than the tax revenues collected (Aragon and Rud, 2016). Had modelling integrated social, environmental and economic factors from the start, the government could have chosen to better regulate mine pollution, increased taxes to clean up pollution, or even decided not to proceed with some projects.

Including environmental, social and economic outcomes requires a level of horizontal integration in modelling. There are options for how to implement this: (1) expand an existing model, (2) combine the inputs and outputs from multiple models, or (3) develop a new integrated model. The pros and cons of each choice are set out below.

The example also demonstrates the need for vertical integration between the policy and project level. Models can better link environmental regulations at the policy level with environmental impacts at the project level. A top-down approach could have factored environmental policy in the project model. A bottom-up approach could have made the case for stronger environmental policy by aggregating the harm from multiple projects to the agriculture sector as a whole.

Modelling for sustainable development requires a shift from single- to multiple-pillar models that link policies to projects and vice versa (see Figure below).

Figure 15 — Integrating knowledge and models for sustainable development



6.3 Horizontal Integration

Integrating the pillars of sustainable development into models requires an open and collaborative process with multiple experts and stakeholders. This might include environmental scientists, sociologists and economists, as well as government officials, the private sector and representatives of civil society. It can create a shared understanding of why and how issues or opportunities emerge. Group model-building exercises help in this regard.

There are three options for expressing integrated knowledge:

1. **Expand** an existing model to include other dimensions

2. **Combine** the inputs and outputs from several models

3. **Develop** a new integrated model

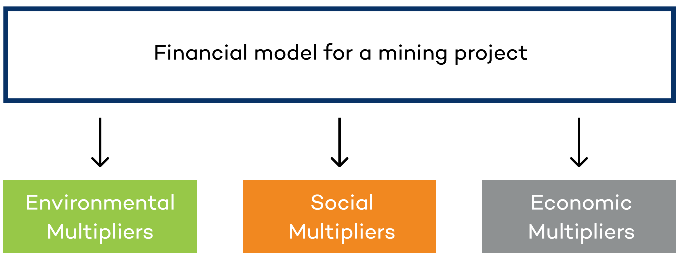
The appropriate choice depends on the:

- Application of the model to the context
- Ease of customization and use
- Capacity of local modellers to continue to use the model
- Transparency of the model and the potential to include various stakeholders in the modelling process
- Data needs and gaps
- Time and budget
- Available models

EXPAND AN EXISTING MODEL

The first approach is to use an existing model and expand its scope by including additional indicators. This is a relevant option when models are already available, trusted and used to support decisions. It is important to build on existing knowledge, improve the analysis, and assess the extent to which the results of the analysis change when integrating the additional variables. For example, an existing financial model for a mining project could be used to integrate the three pillars to help answer questions such as: How does production impact the water flow in the river? How does production impact immigration in the region? How does production impact induced employment in surrounding communities?

Figure 16 — Expanding the domain expertise of one model

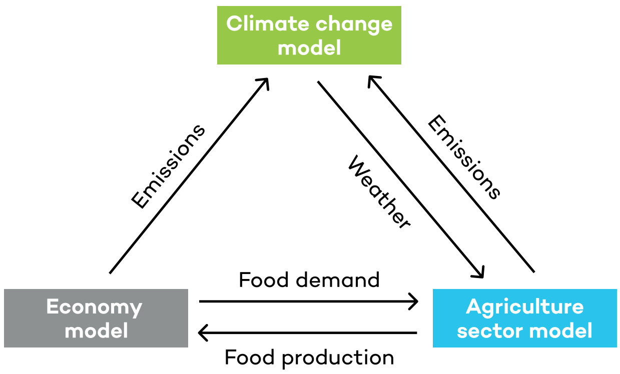


The advantage is that this option uses existing models. The disadvantage is that there is no feedback between the indicators measuring the various dimensions of sustainability. For example, there is no feedback to the financial models on how the water flow will impact the production of the mine.

COMBINE SEVERAL MODELS

The second option uses existing models and combines them to cover other pillars of sustainability. Modellers from different disciplines need to work together, with missing indicators added based on models in their respective field. This approach can involve one- or two-way interactions between models, where the output of one model becomes the input of another.

Figure 17 — Combining several models



As in the figure above, the agriculture sector model interacts with the economy-wide model to define the level of food demand and production. The latter has a direct impact on the amount of emissions generated by the agriculture sector. These emissions, combined with those of the rest of the economy, impact the global climate. The climate change model estimates the weather conditions under which agricultural production takes place, and this will impact crop yields. New crop yields impact agriculture production, the food market and the food security of the population —a key social indicator.

The advantage of this approach is that it combines the knowledge of various experts and provides the possibility of integrating feedback between the environmental, social and economic indicators. It also makes use of existing models, thus becoming less costly or time-consuming.

The disadvantage is that it may become less transparent and too complex. Each individual model was originally intended for a separate purpose so their combination may not make sense. It may also be difficult to see if the models interact coherently and logically.

DEVELOP A NEW INTEGRATED MODEL

The third option is to develop a model that encompasses the interactions of the various pillars of sustainability into one model (see Figure below).

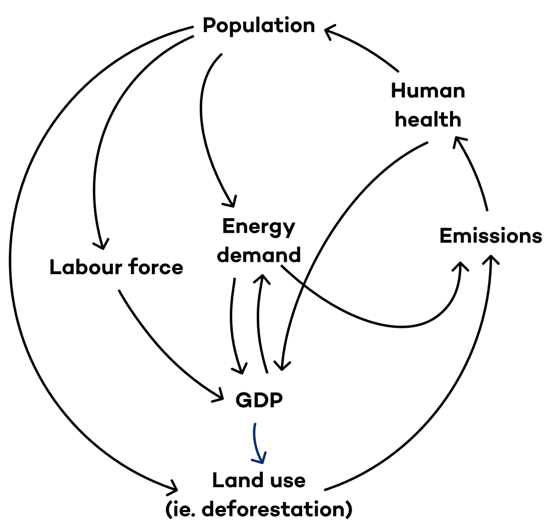
This approach emphasizes integrating subject area rather than detail in any one area. It may rely on simplifying complex relations. Take the example of a dam. The project may impact electricity availability, water supply, fish and crop production. An integrated model could be built to capture all these components, and create feedback loops, delays and non-linear effects.

This approach is relevant when there are several environmental, social, and economic factors to consider simultaneously, and where simply linking models becomes too challenging from a technical point of view.

The advantage of an integrated model is that it captures the value of knowledge integration for sustainable development in its theoretical structure.

The disadvantages are the extensive data requirements and the complexity of explaining and documenting the model, and the interpretation of the results due to the numerous interactions at play. This can affect uptake of the model results.

Figure 18 — Developing an integrated model



6.4 Vertical Integration

Policies are being designed and implemented at various levels of government, and it is key that these policies align. This applies for modelling too. At the global level, there are efforts to cost the SDGs. The European Union models the impacts of policies at the regional level. In decentralized countries where sub-national governments have significant resources and policy decision-making power, modelling is often done at a departmental or municipal level.

Then there are projects that can impact a sub-section of a population in a department or municipality, or projects that span across various countries and therefore have impacts at a regional level. An example of a regional project is an EU-funded road. It is important for there to be interaction and consistency between project and policy models when one impacts the other. The impact can be bottom-up (from project to policy modelling) and top-down (from policy to project modelling).

FROM POLICY TO PROJECT MODELLING

Policy models can inform project models to support decisions. For example, climate change models that help governments set emissions targets can be used to decide what types of energy project should be prioritized. If there were no national model that had set an emissions reduction target, then the project choice may be a coal-fired power plant. If the project decision takes into account the results of the policy model, it may lead to a different choice of project. In this case, the policy model helped define the project boundaries.

FROM PROJECT TO POLICY MODELLING

Project models can also inform policy models. For example, if the government of Tanzania has a policy to increase rural incomes by 20 per cent, the results from modelling a food storage facility that could help increase food production, or from modelling a rural road that could help increase access to markets, could be a useful part of supporting the modelling of the policy question.

The project model can be complemented by a policy model to assess the wider outcomes of the project. If achieving the policy objective requires investing in an infrastructure project, such as an irrigation scheme, power plant or road, you might need to connect project and policy models. Project modelling on its own will be insufficient, since the policy objective will also require other government interventions not related to the infrastructure project itself, such as cash transfers, extension services, research and value chain development to ensure that the infrastructure investments are complemented by better access to markets and opportunities to increase incomes.

6.5 Standards

Standards can help ensure that assumptions, data and model methodologies are applied in a consistent manner and therefore easier to integrate. They are also helpful because they:

- Provide a framework for what data should be used to measure sustainable development.
- Limit the discretion of the modelling team and room for mistakes.
- Reduce the risk of the model being used to support policy decisions that have already been made, rather than as a tool to debate and assess different policy options.
- Allow for comparability between models and limit the discussion among stakeholders on assumptions.
- Can save time.

A drawback of standards may be that they create an additional barrier to entry. Not having access to the relevant data, software, or the expertise to implement more complicated methodologies may prevent governments from including sustainable development components in modelling exercises altogether. To balance these conflicting factors, it may therefore be useful to develop guidelines on best practices for the inclusion of sustainable development components in modelling rather than requiring standards and benchmarks at the outset.

SOFTWARE-SPECIFIC STANDARDS

Models range from relatively simple spreadsheets focusing on a single project or market, to large-scale, global models with hundreds of thousands of equations and variables. Software is used to build these models. Software choice should largely be determined by the modelling task and available resources. Ensuring the model is built robustly and according to a good standard is crucial, whatever the software used to build the model. The means of maintaining and enforcing standards are different for each platform.

Spreadsheet-based standards

Spreadsheets were the software world's "killer app" back in the 1980s. They took the heavy lifting out of calculations, so that it was possible for one person, within a few hours, to successfully structure tens of thousands of numbers and apply mathematical functions to them, from the basics such as summation, averaging or classifying, to statistical functions such as mapping distributions and correlations. The level of mathematical manipulation possible today used to require a computer of a scale only massive organizations like NASA or IBM could afford. Now sophisticated mathematical manipulation can quite comfortably run from a standard laptop in a cafe.

The main reasons for the ubiquity of spreadsheets (compared to other software options for modelling) are:

1. **Affordability:** it is a relatively cheap, sometimes free, software platform.
2. **Ease of access:** little or no training is required to get started.
3. **Transferability:** spreadsheets are a commonly used tool across multiple disciplines, meaning that the people involved in modelling will likely be familiar with their approach and use.

The spreadsheet is flexible because the user interacts with it through a non-technical interface: the cells, rows and columns to input numbers and formulae. When a user opens Excel everything is possible. This might seem great, but ease of access is also problematic because it enables anyone with little or no training to create, or appear to create, a model. This has led to many awful spreadsheets in the world, some of them used to make major decisions.

This is not theoretical, nor limited to institutions perceived to have low capacity or human resources. In 2013, JP Morgan Chase misstated value at risk in a trading portfolio by about USD 400 million due to a mistake in a spreadsheet. In 2010 the U.S. Federal Reserve miscalculated figures for Consumer Revolving Credit by USD 4 billion.

In response to this, spreadsheet professionals developed a range of best practices for modelling. But the benefits rely exclusively on self-enforcement. Few people have sufficient education and training when it comes to making a transparent and robust numeric argument using a spreadsheet. Below are selected spreadsheet guidelines and standards.

Spreadsheeting guidelines & standards

A comparison of spreadsheeting standards is discussed in Grossman, T. & Özlük (2010) and useful links are provided here:

- 20 Principles of Good Spreadsheet Practice
- Best Practice Spreadsheet Modelling Standards
- FAST Standard

- Financial Modelling Code
- Practical Financial Modelling
- SMART Guidelines

FULL-PROGRAMMING BASED STANDARDS

Fuller modelling platforms can provide some protection against the risks linked to spreadsheets. Programming languages such as R and C++ offer more data type control to begin with, and commercial packages may build interfaces which are more constrained.

Take the example of a number for inflation. In Excel, the user needs to change the cell formatting when inputting percentages. If this is not done and the user inputs "3," the model could interpret this number as 300 per cent rather than 3 per cent. In the case of estimating the effect of future inflation on the costs of a project, this would drastically alter the outcome. In a custom-built software program this mistake could be consciously avoided, because the ordinary user would never be able to enter a value that is not formatted appropriately.

These are the theoretical gains of using a "full" programming platform. It requires high quality programmers in the first place. Because the barriers of entry to using these programs are high—such software packages tend to be expensive to build or buy, and more difficult to learn—there is a risk that project models are not thoroughly or regularly audited for mistakes. On the other hand, the high cost of entry may lead to a dependence on one programmer's understanding. This makes public decision making more fragile.

Full-programming applications also tend to be able to handle higher volumes of data more easily, processing millions or even billions of separate numbers, whereas Excel can start to creak with more than a few thousand values.

The choice of platform, and the standards used to maintain model integrity on that platform, could well evolve as a project continues. Because a key principle of modelling is to iterate—to keep refining inputs and features—a project might often start with a light version of programming and move to another one at a later stage once longer-term financial and human resources are secure.

7. Checking Modelling Results

TAKEAWAYS

- Having a clear understanding of the scope of a model and its key indicators is a critical requirement for interpreting results.
- The notion of a model's accuracy should be treated with care. It is better to be broadly right than precisely wrong.
- Interpreting results starts with challenging them. Models are made by humans and humans make mistakes.
- Results should be compared with past findings and any inconsistencies explained.
- Performing sensitivity analyses on key assumptions is a way of checking the robustness of the findings.

7.1 Introduction

There are often mistakes in models, especially in their initial versions. These can include technical mistakes, inconsistent assumptions or poorly designed scenarios. Checking for mistakes is a standard part of the modelling process. There are two types of check: external and internal. External checks involve "sense checking" the model results against information from elsewhere, such as other models, studies or expert opinion. Internal checks use modelling techniques to understand how assumptions impact model results, and determine the certainty of those results.

Before we can run external and internal checks, the model user first needs to know:

1. **The scope of the model.** Modelling results should be interpreted in a given context. When interpreting model results, summary fact sheets and proper documentation should be reviewed to understand the scope of the model.

2. **Indicators definition.** Without knowing what indicators mean in the specific context of the model it is not possible to interpret model results. This is a key issue for sustainable development-related modelling because different disciplines sometimes use the same terms in different ways. This can lead to misinterpretation and misunderstanding.

3. **Acceptable accuracy of the model.** Various modelling techniques will handle accuracy differently. A common misunderstanding is the mistake of false accuracy. It is often better to be broadly right across the three dimensions of sustainability than be precisely accurate in just one dimension but demonstrably wrong in the others.

7.2 External Checks

After producing the first set of results, it is important to check these with other model results, analyses and expert opinion. If the model results are very different from what has been found elsewhere, the model user will have to try to understand why. There are various possible explanations:

- Other models or analyses may be trying to answer a different set of questions.

- The level at which the analysis was made is different (policy versus project-level modelling, for example).

- A different set of assumptions have been made in other models.

- There are mistakes in the inputs, assumptions or coding in the model.

The very first iteration of a model is likely to have mistakes, and this external stress test is a key tool to identify these.

Once the model user is certain that the model does not have any major flaws, the results should be interpreted alongside other results. This approach may provide complementary insights to the analysis and help explain where the results fit in with other model results. This assessment will also be key to explaining to decision-makers and those who provided the other analysis why the results may be different.

Having many models can confuse politicians and decision-makers, especially when models focus on the same issue but take different approaches. For example, there have been various efforts to estimate the cost to end world hunger. In comparing just five of these models, estimates ranged from USD 7 billion to USD 265 billion a year (Fan and al., 2018).

Such a wide range reduces the usefulness of the results and the confidence in using these models to inform policy. But a closer comparison showed that these two models used (1) different modelling approaches (sectoral versus economy-wide models), (2) different assumptions about the role of economic sectors in reducing hunger, and (3) different targets (ending poverty by 2030 vs ending undernourishment by 2050). It is not surprising that the results were so different.

Two types of models that are often used to answer the same question are general equilibrium models and partial equilibrium models. The confusion arises because partial equilibrium models assume that the changes taking place at the sectoral level will not impact the rest of the economy. Conversely, general equilibrium models assume that any intervention will have an impact on the rest of the economy, which in turn will feed back into the inputs of the model. For example, a government is planning to introduce a carbon tax. A partial equilibrium model of the oil industry may show only the negative consequences of the tax, while a general equilibrium model will capture both the negative and positive outcomes on other sectors across the entire economy.

Understanding these differences is crucial not only to avoiding confusion, but also to increasing confidence in model results.

7.3 Internal Checks

Model results are often presented for a single set of assumptions. Would those results still apply if different assumptions were chosen? If not, does this mean we can't trust the results?

The previous section discussed how assumptions can be validated using information and resources outside of the model. This section sets out what to do when it's not possible to validate assumptions with a high degree of certainty.

IDENTIFYING WHICH ASSUMPTIONS ARE IMPORTANT

Models can have many different assumptions. While all assumptions will impact the results, they won't all impact results equally. Sometimes the model developer will indicate which assumptions have the largest impact on results. If not, it is usually possible to determine through intuition or by inspecting the model. For example, in a policy model that analyzes education interventions, the student/pupil ratio assumption is likely to be more important than the cost of pencils.

Once the key assumptions have been identified, there are three approaches to understand how those assumptions affect results: scenario analysis, sensitivity analysis, and Monte Carlo simulations.

Scenario analysis

Scenario analysis involves defining different sets of plausible assumptions and producing results for each scenario. Often a base case is defined based on what is considered most likely, and then a better case and worse case defined on either side. This can be used to answer the question, "what if" the assumptions in the base case were too optimistic or too pessimistic. One or more assumptions can be varied in each scenario, but the assumptions used within each scenario should always be plausible and consistent with each other. Modellers use this technique to explain to decision-makers what might happen if things turn out better or worse than expected.

Sensitivity analysis

Sensitivity analysis involves usually changing only one key parameter at a time. Unlike in scenario modelling, the range of values used in sensitivity analysis should be broader, extending beyond those used in the better- or worse-case scenarios. This can be used to understand what happens if the assumptions turn out to be very different than expected.

Monte Carlo simulations

Monte Carlo simulation is another technique to understand and present the impact of uncertainty on modelling results. It involves running the model multiple times with one or more assumptions generated randomly each time. Usually those random assumptions are restricted to a plausible range based on probabilities to ensure the results are realistic. By running the model enough times, a plausible distribution of results can be presented.

8. Communicating Modelling Results

TAKEAWAYS

- Communicating model results is as important as generating them. It requires answering three questions: who the audience is, what they need to know, and how to present the results.
- It is a two-way process between the modeller and the decision-makers.
- Simplify the message without being simplistic.
- Use various media to disseminate results.

8.1 Introduction

Communicating model results is as important as the technical aspects of modelling. A model that is technically good put poorly communicated will have less impact than a model that is technically poor but communicated well.

This chapter sets out three aspects of communicating model results: who is the audience, what do they need to know, and how to present the results.

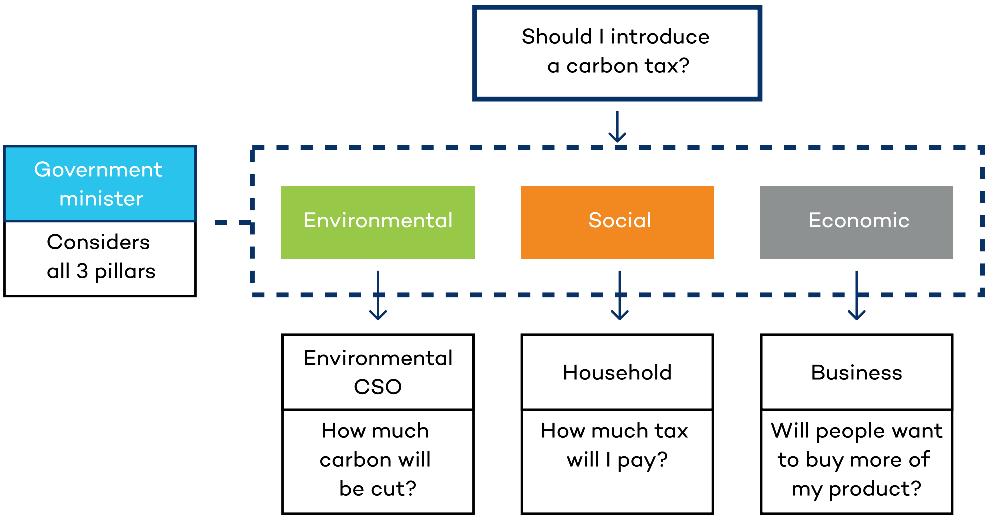
8.2 Who Needs to Know?

A sustainable development model can be used to answer the same question in different ways, depending on who the audience is. To do this though, the potential audiences and their interests need to be identified right at the start. So, the person commissioning the model will need to anticipate who will be interested and what they will be interested in.

In the figure below a government minister is considering introducing a carbon tax. The minister wants to know what impact the tax will have on the environment, society and economy. The modeller will need to communicate key insights on all three dimensions for the minister to decide.

The minister will need to explain and justify her decision to people affected by the tax. The people are diverse and have their own specific interests. Different model results may need to be presented. An environmental CSO may be interested in the impact on carbon emissions and may be less interested in tax revenues. A household may want to know how much the carbon tax will cost. Businesses may want to know the impact on profits.

Figure 19 — Same Question, Different Audiences



Before the start of the modelling process, initial discussions between decision-makers and modellers should develop shared expectations, establish the credibility of the experts, and create trust in the model. This will also help the decision-maker to eventually take ownership of the model results and share them with others.

Having generated the results, the first step is to communicate modelling results to the decision-maker so that they can make an informed decision. Presenting simple but not *simplistic* messages is important.

The second step is to communicate to other ministries who are not involved in the origin of the decision but might be affected by it or could hold up the process. The results that speak to their interests need to be selected and presented.

The third step is to communicate to all stakeholders. They are likely to have an even wider range of interests. It will require additional efforts to explain modelling results.

8.3 What Do They Need to Know?

Models can produce all sorts of complex looking indicators, charts and numbers. The amount of information can be overwhelming. Communicating modelling results is the art of being selective about what is presented. Selecting what information to present should be based on what the audience needs to know for their purposes. The principle of *less is more* applies as this will focus communication on key messages.

Complexity and depth are desirable features of a model but become a burden when presenting results. Too much detail is the fastest way to lose people. The target audience should not have to invest time to understand detail but should be presented with a clear message. For example, a council of ministers debating whether to introduce a carbon tax will be interested in the impact on carbon emissions, the revenues it will raise, and the impact on the economy and the poor. They do not need to know that the modellers combined the inputs and outputs from an emissions model, macroeconomic model, and household microsimulation model to answer these questions. These technical approaches are of little interest to ministers and indeed most people.

It is important, however, to be prepared to answer technical questions, but only in response to a question from the audience. Not being prepared to answer technical questions can undermine credibility and the key message.

Decision-makers need a high level of certainty, or confidence, to act. But a key part of modelling is to measure the uncertainty of outcomes. How can a modeller communicate uncertainty without undermining confidence? Modellers can use different scenarios to communicate some of the underlying uncertainties of a model. It is a fine balancing act to make sure that this does not result in blurring the key message.

8.4 How Can We Present Model Results?

People make judgments based on presentation as much as substance. A modeller will quickly undermine people's confidence in the model and the message if they poorly present the results with inconsistent formatting or unclear charts. Conversely, they will enhance the credibility of their results by using plain language and well-designed charts.

The skills needed to present effectively are not the same as those needed to develop and use models. Still, they are just as important to the effectiveness of modelling for sustainable development. These skills include not just oral presentation and writing but equally the creation of clear graphics, tables and charts.

Often the model can be published, either in full or through an online interface that enables people to produce their own results. This can risk people misusing the model to deliberately undermine the results, but in many other situations, publishing models empowers people to hold decision-makers to account.

9. Resourcing the Modelling Process

TAKEAWAYS

- A good model for sustainable development depends on organizational capacity (budget, organizational mandate) and human capabilities (skills, education).
- Applying modelling standards helps model design, is crucial for sustainable modelling, and ensures that models can be easily understood and transferred.
- Embedding modelling in an organizational culture needs to go hand in hand with investing in human resources.
- Modelling can be done in-house, outsourced, or partly outsourced. But all options require some in-house modelling expertise.

9.1 Introduction

Modelling for sustainable development is not only about methods and modelling tools. The long-term viability of modelling requires skills and organizational capacity. This chapter discusses how to resource the modelling process.

9.2 Modelling Culture

A great deal flows from the modelling culture that an organization and its people adopt. While this should be a conscious choice, in practice it is often chosen subconsciously by the default state of affairs.

Modelling culture is the importance attached to modelling in the decision-making process, the approach taken to modelling as a profession, and the resources available. At opposite ends of the spectrum, modelling culture can be described as either *individualistic, closed,* and *black box* or as *team-based, open,* and *transparent*.

Whether modelling is seen as individualistic or team-based in turn depends on whether the model is regarded as simply a software tool there to produce the "right answer," or whether it is seen as a way to facilitate a conversation around the assumptions, concepts, and expected outcomes of a decision-making process. The difference is between seeing modelling simply as a tool or seeing it more as a process to achieve a result.

9.3 Model Readability and Modelling Standards

Modelling culture sets the expectations about model readability—who can and should use a model. At one end of the spectrum, a single modeller will have access to the model. Only this modeller will know how to operate the model and challenge the results. At the other end of the spectrum, usually in relation to spreadsheet-based models, many team members can get access to the model and are equipped to do the same things. The team members need appropriate model documentation, easy to use model interfaces or dashboards, and training.

To support the team-based approach requires building models in a reasonably standardized way. Standardization supports the ability to build capacity. In the case of spreadsheet-based models, the current state of affairs is unfortunately one of highly individualistic, unstructured, and hard to understand models, making it harder to develop an open modelling culture. Still, there is now a range of highly developed best practices and standards available for spreadsheet-based modelling that will allow for changing practices in the future.

9.4 Transferring and Maintaining Models

Modelling standards can also enhance the wider sharing, adoption and use of models for sustainable development. Standards not only expand internal readability, they also mean that models can be shared with other sustainable development actors. In this way a modelling standard can be compared to a human language. When people use a shared language, they not only understand each other but also collaborate with each other. By adopting a modelling standard, an organization has the opportunity to promote modelling capacity both within its organization and among the wider sustainable development community.

Sustainability in turn can be applied to the modelling process itself. Models that are sustainably embedded in the decision-making process of an organization are likely to have more positive and longer-term impacts on decision making around sustainable development. Achieving this longer-term impact depends on models being used, maintained, and improved over time. Conversely, unsustainable modelling processes may lead to unsustainable policy decisions, as the ongoing insights that they can provide are in effect lost to the organization when modelling is not a continuous practice. In other words, the modelling capacity should be considered a long-term asset that requires maintenance to continue to have value. The models themselves are living documents that can evolve; preferably as the world itself changes.

Models that become well embedded in organizations are likely to have a strong feedback loop between building and interpreting models. Techniques such as agile development—a process of iterative and adaptive development pioneered in the software industry—can help.

9.5 In-House Versus Outsourcing

Because modelling is a process, an organization can choose to outsource some parts of that process and keep others in-house. How much to retain in-house and how much to outsource has implications for in-house expertise, data ownership, and budgets. Two examples illustrate different degrees of outsourcing:

- When considering whether to fund a renewable energy project, a development finance institution might choose to commission an external party to build a model, interpret the results, and advise on the investment decision.

- A ministry of economic affairs that needs a model for carbon emissions may choose to outsource the development of the model, which requires a more unique type of expertise, but decide to train its staff to operate and interpret the model in-house, skills more easily replicable across different models and applications.

How much of the modelling process to outsource and how much to do in-house is an important decision. The best approach will depend on specific circumstances. Still, there are some general factors to consider:

- If a model is required for a routine, *core business* activity or a decision which needs to be repeatedly taken, then a high degree of internal resourcing is appropriate. If, on the other hand, a model is used for a one-off decision, then it might make sense to outsource more of the process.

- If existing modelling capabilities in an organization are low and the costs of making a poor decision are high, outsourcing is likely to be better. It will certainly be better than no modelling at all, leading to a poor decision. For example, natural resource projects have significant environmental, social and economic impacts that are locked in over a long time through contracts. Modelling here is critical to making the best possible decisions.

- If an organization wants to develop its human capabilities and organizational capacity for modelling it might choose to retain more of the process in-house to learn by doing, even if the results in the short-term might not be as good as from outsourcing. This approach is more appropriate when the costs of poor decisions are relatively low or can later be corrected without penalty.

Appendices

A.1 Glossary

- **Base Case** – The scenario used as the starting point, or frame of reference, against which other possible outcomes are compared. This is sometimes referred to as the Base Scenario, Reference Situation, or Central Case.

- **Bio-physical** - Attribute of a model, relation or indicator that belongs to the field of natural sciences.

- **Black Box** – A modelling approach which emphasizes the end result and does not expose the methods used to arrive at it.

- **Boundaries / model boundaries** – The boundaries of a model are the lines between what is and is not in the scope of the model.

- **Causal Loop Diagram (CLD)** – A diagram, or map of the system, that visualizes interconnections (i.e. causal relations) existing among the elements of a system.

- **Computable General Equilibrium (CGE) model** – A large-scale model that simulates the interactions in an economy and what happens when a policy such as a tax cut, or an increase in health care, is introduced.

- **Discount Rate** – The main traditional way in which models translate potential future outcomes into a present-day value.

- **Econometric modelling** – Modelling techniques using statistical methods to quantify economic relations based on current and past data. It is also used to provide forecasts with confidence intervals.

- **European Union's Emissions Trading System -** European trading market for carbon emission allowances. Allowances are limited and fines are imposed if a company does not have sufficient allowances to cover its emissions.

- **Externalities** - Situations when the effect of production or consumption of goods and services imposes costs or benefits on others outside the transaction which are not reflected in the prices charged for the goods and services being provided.

- **GIGO – Garbage In, Garbage Out** – An acronym originating in the software industry to describe the importance of quality control in inputs to a program, since bad quality inputs will lead to bad quality results.

- **Hedonic valuation** – A method to price a good or a service based on the value to the user of its characteristics.

- **Horizontal integration** – The inclusion of the three sustainable development pillars (environmental, social and economic) within a single model or across multiple models working together.

- **Household microsimulation model** – An economic model that simulates the impact of government policies, such as taxes, on the finances of households.

- **Internal Rate of Return (IRR)** – A measure of the profitability of an investment or expenditure against future benefits or revenues.

- **Killer app** – A software application, such as Excel, which has achieved mass use, and changed the paradigm of what is possible in computing.

- **Macroeconomic model** – A model that addresses questions at the level of a whole national, or international economic system, such as country-wide unemployment rates, or GDP.

- **Millennium Development Goals (MDGs)** – In 2000 all United Nations member countries agreed to meet a set of eight goals by 2015. The goals ranged from eradicating extreme poverty and hunger to establishing global partnerships for development.

- **Monte Carlo Simulation** – A technique to understand and present the impact of the lack of certainty on modelling results. It involves running the model multiple times with one or more assumptions generated randomly each time.

- **Optimization** – Simulation that aims at identifying the best solution (with regard to some criteria) from a set of available alternatives.

- **Partial Equilibrium Models** – Simulation models, used in economics, applied to one or several markets. These models do not describe the full economy.

- **Parameter** – A numerical value, based on data, that captures a relationship between two or more variables in a model.

- **Policy model** – A model that estimates the impacts of public policies, such as a tax rate.

- **Project model** – A model that estimates the costs and benefits of a particular project, such as a hydroelectric dam.

- **Qualitative modelling** – A modelling approach that represents relationships without underlying numerical values.

- **Scenario analysis** – Scenario analysis involves defining different sets of plausible assumptions and producing results for each set.

- **Scope (of a Model)** – All of the real-world values and relationships that are represented within the model.

- **Sensitivity analysis** – An assessment of the extent to which model results change when model inputs are changed.

- **Shadow price** – An estimation of the market-value of a good or service for which no actual price exists.

- **Simulation model** – A mathematical model that simulates the impact of a scenario on selected variables.

- **Spatially explicit model** – Models that compute results with an explicit representation of space (i.e. maps).

- **Sustainable Development Goals (SDGs)** – In 2015 all United Nations member countries agreed to meet a set of 17 goals by 2030, though some individual targets have earlier deadlines. The goals include, among others, no poverty, zero hunger, and responsible consumption and production.

- **Sustainable Development Goals Acceleration Toolkit** – Online compendium of system-level models, diagnostics, guidance and methodologies for analyzing interconnections among the SDGs.

- **System Dynamics Modelling** – A methodology to create models that focus on the identification of causal relations between elements within a system. Its main pillars are feedback loops, delays and nonlinearity through the explicit representation of stocks and flows.

- **Systems (or systemic) models** – A model that accounts for multiple components of the system, including various sectors (e.g. economy, energy, water) and social, economic and environmental dimensions of such system.

- **Validation / model validation** – The process of testing whether the structure and behaviour of a model are acceptable as descriptions of reality.

- **Variable** – An element of models that changes when you use the model.

- **Vertical integration** – An approach to modelling where models are combined to achieve a high depth of detail within a sector or region.

A.2 Acronyms

- **CSO** – Civil Society Organization

- **GDP** – Gross Domestic Product

- **GHGs** – Greenhouse Gases

- **IFPRI** – International Food Policy Research Institute

- **IGF** – International Governmental Forum

- **IISD** – International Institute for Sustainable Development

- **IRR** – Internal Rate of Return

- **IT** – Information Technology

- **MDGs** – Millennium Development Goals

- **NRGI** – Natural Resource Governance Institute

- **R&D** – Research and Development

- **SDGs** – Sustainable Development Goals

- **TEEB** – The Economics of Ecosystems and Biodiversity

- **WWF** – World Wildlife Fund

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