Energy Policy Planning for Climate-Resilient Low-Carbon Development

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Introduction

Climate change has emerged as arguably the biggest threat facing human development in the twenty-first century. The current stock of atmospheric greenhouse gas (GHG) is large enough to cause climate change and climate variability. International efforts have been undertaken to stabilize atmospheric GHGs and to limit average global temperature rise to 2 °C (Randall 2010). If current emissions continue unabated, it is expected that the temperature rise will be between 4 °C and 6 °C, that can be reached towards the end of this century. Under this "do nothing" scenario, all nations would be losers. It is, therefore, in humanity's interest to do something about the current state of affairs. Although adapting to climate change and climate variability is important, the safest adaptation would be large-scale reduction in atmospheric GHG emissions. It has been shown recently that limiting global temperature increase to 2 °C above pre-industrial levels could be achieved through the "wedging the gap" approach consisting of 21 coherent major initiatives that together would trigger greenhouse gas emission reductions of around 10 Gt CO_2e by 2020, plus the benefits of enhanced reductions in air-pollutant emissions (Blok et al. 2012). Emissions reductions can be achieved broadly through a combination of: (1) policy measures that provide for financial and economic incentives (e.g., feed-in tariffs for renewable energies) or disincentives (e.g., carbon tax), and (2) market-based

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H. Qudrat-Ullah (ed.), *Energy Policy Modeling in the 21st Century,*
Understanding Complex Systems, DOI 10.1007/978-1-4614-8606-0_8,

mechanisms such as carbon trading, both of which would be required to implement the "wedging the gap" approach. Further, this novel approach would require unprecedented global scale coordination and cooperation.

Global coordination for GHG emission reductions is typically carried out under the aegis of the United Framework Convention on Climate Change (UNFCCC). The use of new market mechanisms (NMMs) for achieving global reductions in GHG emissions was adopted at 16th session of the Conference of Parties (COP16) in Cancun (2010), and further referenced at COP17 in Durban (2011). According to Intergovernmental Panel on Climate Change (IPCC (AR4)), global energy use and supply (26 %), industry (19 %), and transport (13 %) are major drivers of GHG emissions; estimates of CO_2 emissions from agriculture and forestry have a higher level of uncertainty. Since the sectoral scope of NMMs depends, among others, on data availability and low degree of uncertainty in emission estimates the sectors that are recommended for NMMs are: (1) energy supply; (2) industry (e.g., oil refineries, natural gas facilities, iron and steel production, cement production); and (3) transport. Consequently, the case studies presented here place the focus of this chapter squarely on these key sectors.

System dynamics modeling (SDM) provides a useful approach to better understand the multi-dimensional socio-economic and environmental impacts of current climate variability and projected climate change that would be necessary to inform adaptation policies and strategies. Similarly, the system's approach allows the impacts of policies and emission reduction through market-based mechanisms to be investigated. Importantly, it allows energy policy to be tied with emission reduction across all economic sectors, and it also offers a way to investigate novel approaches to NMMs. In this chapter, we will demonstrate the practical use of SDM for policy planning to achieve climate-resilient, low-carbon development pathways, in the context of national development planning. In particular, we will use examples from developing (Mauritius and Kenya) and developed (USA) countries to make the case for the use of SDM for climate proofing of the energy sector and to develop nationally appropriate mitigation actions (NAMAs) as one type of NMM.

The case studies form a part of the work carried out for the United Nations and national governmental agencies, including the creation of cross-sectoral climate mitigation and/or adaptation simulation models for national policy formulation and evaluation. The main objectives of the modeling work presented in this chapter are to: (1) create an innovative simulation model, and to (2) improve policy formulation and evaluation analysis for the elaboration of coherent and comprehensive climate change mitigation and/or adaptation strategies. The models are built up on social, economic, and environmental sectors and integrate the best sectoral knowledge in one single model framework representing a full incorporation of economic and bio-physical variables. In particular, they capture: (a) feedbacks within and across sectors, aiming at identifying both synergies and potential bottlenecks (unexpected side effects); (b) time delays, whereby policies and investment allocations may lead to a "worse before better" situation; and (c) nonlinearity, leading to the identification of potential thresholds and tipping points.

Methodological Approach

Energy is a meta-technology that pervades all aspects of modern societies. Further, the global energy system is so pervasive that it now has a direct impact on the climate system, which in turn impacts all socio-economic sectors including the energy sector. Therefore, energy systems are better understood in terms of complex systems, which are characterized by nonlinear relationships that cause feedback loops to vary in strength, depending on the state of the system (Meadows 1980). In systems built on a variety of feedback loops, nonlinearity creates shifts in dominance of such loops, which become very important in determining how structure defines behavior, even at different times and with different states of the system.

Nonlinearity allows for a clearer interpretation and understanding of the context of analysis. A wide range of scenarios with different assumptions on nonlinear relations existing within the system can be simulated to test and evaluate the impact of various policy choices, and system responses to their implementation. Nonlinear relations highlight the creation of raptures as well as stronger or weaker approaches in response to unprecedented issues. Though this approach may not be perfectly accurate, it provides insights on the potential medium to longer-term impact of policies that cannot be discerned from linear tools. Both dynamic and detailed complexity should be represented to reach improved understanding of the context in which issues manifest themselves and have to be faced. Combining feedback loops, nonlinearity, and delays contribute to the creation of a consistent and coherent framework for the analysis of the properties and structure of complex systems.

System Thinking and System Dynamics

In order to design and evaluate national development policies the structure of the system analyzed (e.g., social, economic, and environmental) should be properly understood. Economic volatility, as well as natural disasters and other unexpected events can have a considerable impact on the effectiveness of policies over time. For these reasons scenarios have to be defined, to reduce the uncertainty coupled with the analysis carried out. Policies would then be evaluated based on the structure of the system analyzed as well as on a variety of possible scenarios. Policies are "shocks" to the system, which in turn responds to these changes. Hence, the system itself should be analyzed focusing on feedbacks and causal relations, with a specific interest on medium to longer-term impacts (which go beyond the implementation delays of policies—i.e., inertia of the system).

The understanding of the functioning mechanism of the system allows for the identification of medium to longer-term sectoral and cross-sectoral implications of policy implementation. These impacts have to be analyzed with the understanding that different sectors are influenced by different key causes defining the success (or failure) of policies. In other words, a policy can have very positive impacts for certain sectors and create issues for others. Furthermore, successful policies in the longer term may have negative short-term impacts, for which mitigating actions may be designed and implemented.

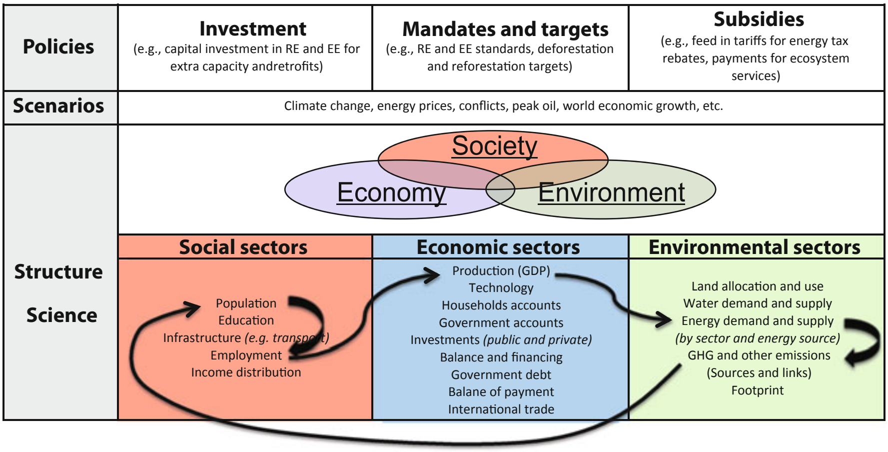

Fig. 1 The three main layers for carrying out integrated policy formulation and evaluation: structure, scenarios, and policies

Simulation models exist which aim at understanding what the main drivers for the behavior of the system are. In the case of system dynamics, this implies identifying properties of real systems, such as feedback loops, nonlinearity, and delays, via the selection and representation of causal relations existing within the system analyzed. This is advantageous for integrated policymaking because, while optimization models are prescriptive and econometric models are heavily relying on the history of the system analyzed, simulation models are descriptive and focus on the identification of causal relations influencing the creation and evolution of the issues being investigated.

Three Layers for Effective Policy Analysis

In order to make progress towards a low-carbon, climate-resilient development in the twenty-first century, an integrated approach that incorporates environmental, social, and economic (ESE) implications of policy implementation is needed. Underlying this approach is the recognition that the algebra among the social, economic, and environmental pillars of sustainable development (how the variables relate and affect one another in context, how they combine towards the equation of sustainable development) is more important than the arithmetic among them (added or subtracted as convenient) (United Nations Environment Management Group 2011).

Figure 1 indicates that policy formulation and evaluation need to be carried out in the context of scenarios (e.g., technological development, natural disasters), and policies (e.g., subsidies, incentives, and/or mandates) have to be evaluated across a variety of indicators (social, economic, and environmental) simultaneously. How these three levels are supported with solid and coherent information and interact with each other will greatly determine the success of any national development plan over the medium to longer term. This information is also crucial to truly understand the drivers of change and to effectively design policies that have the desired impacts.

More specifically, firstly, in order to design and evaluate national development policies the structure of the system analyzed (e.g., social, economic, and environmental) should be properly analyzed and understood. Using the example of the energy sector, this includes the investigation of the main drivers of demand, and how supply can respond to its needs. This is a broad investigation heavily relying on soft and hard data analysis, as we are in rapidly changing times and various cross-sectoral interdependencies are emerging.

Secondly, economic volatility, as well as climate impacts, natural disasters, and other unexpected events can have a considerable impact on the effectiveness of energy and environmental policies over time. For these reasons scenarios have to be defined to reduce the uncertainty coupled with the analysis carried out. Policies would then be evaluated based on the structure of the system analyzed as well as on a variety of possible scenarios.

Thirdly, the implementation of policies for climate change mitigation and adaptation should be tested in the context of longer-term national development, while possibly also taking into account broader issues such as globalization. The issue of globalization may have severe ramifications. For instance, the delocalization of energy intensive industries from developed to developing countries that do not have binding emission reduction commitments under the UNFCCC would have social impacts through job loss (or creation). In order to investigate whether they create synergies, bottlenecks, or unexpected side effects across sectors, the impacts of policies have to be evaluated for a variety of social, economic, and environmental indicators.

Model Development and Validation

The development of a SDM (conceptualization, customization, and validation) proceeds through a variety of tasks, and the generic steps are discussed below:

STEP 1: *Identification of key issues and opportunities*

Definition of key issues in the energy climate change nexus: As every model application is unique, the issues to be analyzed have to be carefully designed and agreed upon. A multistakeholder process (MSP) is adopted to obtain the widest possible stakeholder views. The steps of the MSP adopted are shown in the Appendix. The MSP is used to engage stakeholders during all the steps of model conceptualization, customization, and validation.

Definition of key opportunities and policy options in the energy and trade sectors: the options and opportunities, together with the issues, serve to define the boundaries of the model and always keep in mind the end goal of the project.

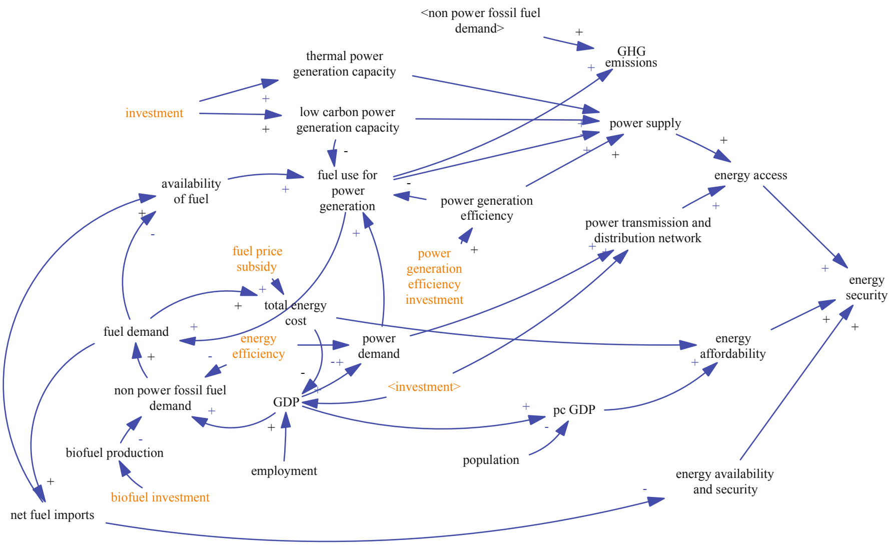

Fig. 2 Causal relations between energy and the environment-economy-society system

STEP 2: *Data collection and consistency check*

This is a time consuming task, and, on top of data mining, cross-sectoral data consistency checks are an essential step.

STEP 3: *Causal mapping and identification of feedback loops*

Causal mapping of system drivers: This step constitutes of creating causal loop diagrams (CLDs) of the issues or sectors that were identified in Step 1. The CLDs provide the high-level system view of issues that would be addressed by the modeling, and its development also draws from the availability of data identified in Step 2. Creating a map of the system analyzed has several purposes. First, it brings ideas, knowledge, and opinions of the core team of modelers together. Secondly, it highlights the boundaries of the model and analysis. Thirdly, it allows all participants to reach a basic to advanced knowledge of the energy sector and how it relates to society, the economy, and the environment. Finally, it serves as a starting point in the development of the mathematical (stock and flow) model.

Identification of key feedback loops in the causal map: Identifying the key drivers and feedback loops in the system allows considering the reinforcing and balancing nature of our complex environment. Also, feedback loops highlight potential side effects, synergies across variables and sectors, to make the best of the available investment and maximize returns. An example of a CLD that was developed to build the energy sector model of Mauritius (see Sect. 3.3) is shown in Fig. 2.

The parameters shown in orange in Fig. 2 are policy interventions. As shown by this CLD, energy security is a combination of energy availability, access, and affordability. Energy affordability is a function of energy costs which in turn depends on energy supply and demand. Energy supply is from a mix of renewable and nonrenewable sources. In the case of power, supply is constrained by generation capacity that depends on investment in infrastructure (e.g., power plants). In the CLD, energy availability and security is dictated by net imports that gives an indication of energy dependence. Once power is generated, its access depends on the network of electricity transmission and distribution. It is worthy to note that energy is a parameter in “total factor productivity” (not shown here) that is used in combination with a standard Cobb-Douglas production with constant elasticities to calculate the gross domestic product (GDP).

STEP 4: *Creation of customized mathematical models*

This step consists of a sequence of iteration involving key stakeholders, and it consists in the translation of CLDs into mathematical models, with numerical inputs and equations. This step adds the quantitative layer to the analysis. At this stage the model is built up on social, economic, and environmental sectors, practically integrating the best sectoral knowledge in one single model framework representing a full incorporation of economic and bio-physical variables, capturing (a) feedbacks within and across sectors, aiming at identifying both synergies and potential bottlenecks (unexpected side effects); (b) time delays, whereby policies and investment allocations may lead to a “worse before better” situation; (c) nonlinearity, leading to the identification of potential thresholds and tipping points. Further, the model is created making use of existing expertise (through the Causal Diagram and participatory modeling), acting as a knowledge integrator of successful—technically valid and already effectively utilized—models for policy analysis, and being fully customized to the national context (with an extensive cross-sectoral dataset and structure, for a more holistic approach to planning in the energy sector).

STEP 5: *Validation and analysis*

- Validation of model (structure): Variables and equations have to be validated to ensure that all experts feel comfortable with the overall structure of the model, reflecting reality. This is done primarily by simulating the base case. This is done by testing the outputs of simulations against historical data (Step 3), and this is done for a multitude of socio-economic and environmental indicators. The confidence that the causal relationships in the model are well established emerges from the ability of the model to replicate historical data. Where necessary the model can be calibrated to obtain a consistent and reliable baseline simulation—i.e., the business-as-usual (BAU) case.
- Simulation of alternative scenarios: Once the BAU is confirmed, scenarios can be simulated to test the impacts of alternative policy options that were identified in Step 1.
- Validation of model (behavior): Simulations (BAU and policy interventions) have to be validated to ensure that all stakeholders feel comfortable with the overall behavior of the model. Here again, the multistakeholder process described in the Appendix is used.

Practical Applications: Three Case Studies

Various energy contexts are unique in different geographical areas. A wide range of properties ranging from political environment to richness of natural resources characterizes these contexts. When reducing them to a simulation model, boundaries are set. These apply to the geographical area analyzed, including the socio-economical dimensions of the society scrutinized. In order to represent such diverse properties of the system, customization is needed. In addition, given the numerous interrelations existing among society, economy, and environment, complexity has to be simplified to account for the key mechanisms influencing the course of events (historical, present, and future).

Different geographical areas can have similar characteristics and show similar behavior while being structurally different. The approach proposed by the authors aims at decoupling the properties of the real systems analyzed, in order to better understand how the underlying structure of the system generates its behavior. Reality is complex, for two reasons: there is a very high level of detail in every real system (i.e., every major process is built up on smaller ones, that contribute to the formation of the aggregated behavior of the system), and there are dynamic relationships existing among both the elements forming the system analyzed and the ones surrounding it. While conventional modeling tools can extensively represent the details of each linear process involved in a real system (e.g., energy transformation from crude oil to refined fuels), a closer investigation of the dynamic relationships contributing to the growth and progress of the system itself is needed.

The studies presented in the next sections provide a diversity of countries covering widely differing geographical scales and levels of socio-economic development. Together, they form a good combination of examples to demonstrate the versatility of SDM for energy policy planning, including the integration of climate change.

The validation of such models takes place in different stages, and the most peculiar tests, when compared to optimization and econometrics, are the direct comparison of projections with historical data, which simulation models can backtrack, and the analysis of structural soundness with respect to reality (Central Intelligence Agency 2011; Barlas 1996). Potential limitations of simulation models include the correct definition of boundaries and a realistic identification of the causal relations characterizing the functioning of systems being analyzed.

United States of America

Under the current state of negotiations under the UNFCCC, developing (nonAnnex 1) countries do not have any binding responsibility for curbing emission reductions. As a consequence, a variety of policy interventions are being evaluated in several countries, including the USA. If this situation were to prevail in the future and the onus would remain on developed countries to carry out significant emissions reductions, the door opens up for the possibility of an exodus of energy intensive industries

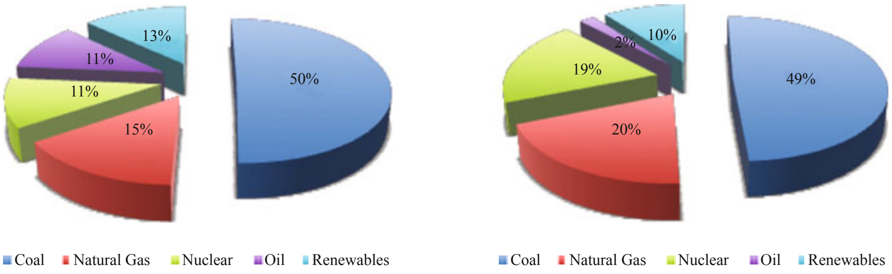

Fig. 3 Power generation shares for *coal, oil, natural gas, nuclear,* and *renewables,* 1980 and 2009. (Source: EIA)

from developed to developing countries, in search for a low-cost solution to their competitiveness problems. The impacts of possible several intervention options to reduce the GHG in developed countries are analyzed, also investigating the potential delocalization of energy intensive industries to developing countries.

Context

The USA is the largest energy consumer as well as the largest economy in the world (Central Intelligence Agency 2011; US Department of Commerce 2008). America's economic growth, on the other hand, is being challenged by domestic and international events. This is a unique opportunity, where the world's largest economy can serve as example for other countries that intend to move toward a low-carbon path.

The USA experienced the fastest economic development in North America over the last few decades. GDP grew by 63 % between 1990 and 2007 (US Department of Commerce 2008), whereas population has increased by 18 %, reaching 300 million in 2005 (United Nations Population Division 2007). Total energy demand increased by 20 % in the same period, while supply has remained just about flat, leading imports to increase by 56 % (US Department of Energy 2010b). As a consequence of increasing energy consumption, emissions are now 15 % above the 1990 level (see also Fig. 3 for the composition of power supply in 1980 and 2009).

The model used for the US analysis focuses on the impact of various policies and investments allocated to different sectors, such as energy, transport, industry, buildings, and waste management, all aiming at reducing GHG emissions. These include fuel efficiency standards for passenger vehicles (corporate average fuel economy, CAFE), the electrification of the intercity rail system and the expansion of urban rail, the enactment of renewable energy standards (RES) and exploitation of unconventional fossil fuel reserves with carbon capture and sequestration, the introduction of a cap-and-trade mechanism, energy conservation, and waste-to-energy (and reuse)mechanism.

Analysis of Modeling Results

The analysis of increased investments in the USA accounts for the simulation of various policies across sectors. In order to analyze the broader implications of these policies and provisions, two alternative scenarios are examined below: a reference case, with a recovery from the current economic crisis in the next few years, and a peak oil scenario, with world conventional oil production reaching a plateau phase shortly after 2020—or about 10 years earlier than in the reference case.

The key investments and supporting policies simulated in the green economy scenario are as follows:

- Nuclear energy: We assume that 380 GW of capacity will be added between 2015 and 2050. Capital and maintenance costs use International Energy Agency (IEA) assumptions, and are set to US$ 5,500 and US$ 165 per MW respectively (International Energy Agency 2010).
- Renewable energy: We simulate investments in renewable energy to reach a 20 % market penetration in the power sector by 2020. Investments are mostly directed to wind (80 %) and solar (20 %), which are assumed to cost, according to the IEA, between US$ 1,800 and US$ 1,750 per MW and US$ 3,900 and US$ 2,750 per MW respectively in 2015 and 2030 (International Energy Agency 2010).
- Electrification of rail (urban and freight): With this provision we assume the electrification of over 100,000 miles of existing inter-city railroads,[1] with the average cost per mile estimated at US$ 3.5 million and a 70 % shift of long-range freight to rail by 2050. The urban rail investment includes building new urban rail lines, reaching higher density on existing urban rail lines and electrifying current diesel commuter lines for a total of 500 miles per year over the next 40 years. The average cost per mile is estimated at US$ 54.5 million.[2]
- Industrial energy efficiency: Investments are assumed to be allocated to support energy efficiency interventions in energy intensive industries, especially in light of the possible enactment of a cap-and-trade mechanism with rebates declining before 2025. As a result, the energy efficiency of the industrial sector is projected to be 5 % higher than BAU by 2020. Investment estimations are based on IEA's world economic outlook (WEO) 2010 (International Energy Agency 2010), resulting in emissions mitigation costs that average about US$ 68/t of CO_2 over the simulation period, increasing from US$ 64/t on average between 2010 and 2030 to US$ 72/t on average between 2030 and 2050.

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[1] These include 32,421 railroad miles that the Department of Defense has classified as being "strategic" (Military Traffic Management Command 1998), 14,000 miles of grade separated three or four track services (comparable to CSX plans from Washington DC to Miami), with one or two tracks devoted to 100–110 mph passenger and express freight service, and electrification of upgrade of additional 60,000 miles.

[2] It is assumed that, out of the 500 miles built or upgraded each year, 350 will be light rail (costing on average US$ 35 million per mile) and 150 will be metro—or subway—systems (costing on average US$ 100 million per mile). See John Schumann, "Status of North American Light Rail Transit Systems", "8th Joint Conference on Light Rail Transit, Dallas, Nov. 2000; Portland Tribune, 18 June 2002."

- Carbon capture and sequestration: It is assumed that all new plants (coal and gas) starting operations after 2020 will be equipped with carbon capture and sequestration (CCS) capabilities. We account for an efficiency loss of 12 %, assumed to be replaced with new capital and used cost assumptions from the IEA, averaging about US$ 600 per MW (International Energy Agency 2010).

The total investment simulated averages of 1 % of GDP throughout the simulation period. Administrative expenses are assumed to account on average for 30 % of this investment and the remainder is productive, or capital, expenditure. Capital investments amount to US$ 120 billion (Bn), US$ 125 Bn and US$ 238 Bn in 2015, 2030, and 2050 respectively. The capital investment equals on average 3.5 % of total public and private investment throughout the simulation and is divided into the different sectors as follows: renewable energy, 46 %; electrification of rail, 24 %; carbon capture and sequestration, 20 %; nuclear energy, 7 %; energy efficiency, 3 %.

With a baseline scenario (BAU) closely replicating economic and energy projections from the US Department of Energy's Energy Information Administration (EIA), the allocation of the green investments listed above is projected to produce higher GDP growth rates relative to BAU after the recovery, averaging 2.91 % instead of 2.68 % between 2010 and 2050. While each investment will individually impact GDP and emissions, among others, their timing and strength differs. By implementing all of the policies, growth rates will remain around 2.7 % pa in the 2020s and 2030s and rise to over 4 % pa in the 2040s. This development is due to the growing cumulative impacts of investments and the projected increase in fossil fuel prices, especially after the peak of conventional oil. Worth noting, GDP growth could be enhanced or curbed by the financing strategy implemented. Predominant public financing could increase the national debt, while excessive reliance on private financing may not be effective, due to already low savings and very high consumption.

As in the case of GDP, total employment would also be higher than the base case over the whole period, with 1 million and 10 million new jobs created by 2030 and 2050 respectively. Of these, 300,000 and 1 million net additions by 2030 and 2050 are attributable to the energy sector, with an average of 14,600 and 240,000 jobs gained in nuclear and renewable power generation, 50,000 lost in thermal generation and 131,000 gained through CCS.

GHG emissions on the other hand, despite the projected increase in GDP, will be significantly reduced by the policies simulated. The combination of policies would generate a reduction of about 0.5, 0.65, and 1.8 billion t of GHG by 2020, 2030, and 2050 relative to the BAU case. This reduction would be worth US$ 14 Bn, US$ 38 Bn and US$ 287 Bn in the same years using the American Clean Energy and Security Act of 2009 (ACES) and corresponding EIA study (US Department of Energy 2010) as references for emission allowance prices. The total avoided energy cost would reach about US$ 220 Bn, US$ 376 Bn, and US$ 821 Bn in 2020, 2030 and 2050, respectively. These achievements are reached after investing US$ 110 Bn in the energy sector (including energy efficiency, renewable energy, nuclear, and CCS) each year on average between 2010 and 2050.

It is worth noting that the timing of the impacts of the different policies simulated differs. Implementing the higher CAFE standard, a known case and embedded in the BAU case, and CCS have a relatively slow impact. Both policies apply only to newly manufactured cars and thermal power plants in our scenarios, with the average fuel economy of the whole auto fleet and the carbon intensity of the power sector improving gradually as the old is retired and new one built. In the same way as in the CAFE case, where it takes over 15 years for the whole fleet to reach the new standards—and the impact on GHG emissions and oil demand rises slowly over time—, the capital life time of power plants (30 years) has the consequence that the impacts of CCS on US fossil fuel emissions from the power sectors grow slowly but steadily.[3] Increased renewable energy production under a RES has a more immediate impact, being regulated by sharply increasing mandates on renewable energy generation, on jobs and income for the production and installation of new and additional wind turbines, solar panels, and biofuels plants among others. Also, the effect on GHG emissions is more immediate, as renewable energy under a RES would initially both fill the gap between growing demand and supply and gain market share replacing older capital.[4] The electrification of rail would also quickly reduce demand for oil as commuting and freight is shifted to electrified rail, and it would involve infrastructure construction spread over time, which helps job creation and GDP growth. Reduced transport costs will also increase funds available for other consumption. However, this rail transport will increase the demand for electricity, which at the margin would be coal-based, so the impacts on GHG emissions will be more modest.

It is also worth noting that with this combination of policies, but excluding CCS, the total amount of CO_2 emissions from fossil fuels will still increase by 0.5 % per year on average between 2010 and 2050, with a short-term decline and stronger longer-term increase relative to BAU. With the introduction of CCS for all new plants coming on stream after 2020 instead, emissions are projected to decline to 5.4 Bn t/year in 2050, reaching 1995 levels and scoring a 35 % reduction when compared to BAU (see Fig. 4a and Table 1). Results of the simulation show that the share of plants with CCS will steadily grow to 54 % of gas turbines and 50 % of coal-fired plants by 2050. With no CCS investment, per capita CO_2 and GHG emissions instead will stabilize after 2020, with GHG emissions reaching 17.5 t/person/year, to slowly pick up after 2040 due to higher GDP and energy consumption and climb up to 18.2 t/person/year. With the CCS investment though, the decline of emissions will be prolonged throughout the simulation horizon, reaching 13.95 t/person/year in 2050. Considering emission allowance price projection published by the EIA and used by the US Congressional Budget Office (CBO) (US Congressional Budget Office 2009; Yudken and Bassi 2009) and a 5 % yearly increase after 2030 (see Fig. 4b), CCS

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[3] Worth noting, on top of requiring more water (NETL 2009), thermal power plants with CCS capabilities suffer a 12 % efficiency loss (IEA 2008), which increases capital investment, fuel input, and emissions, but also employment.

[4] It is assumed that the grid would be able to support a 20 % RES by 2020 and that thermal or nuclear plants would still be preferred for base load supply.

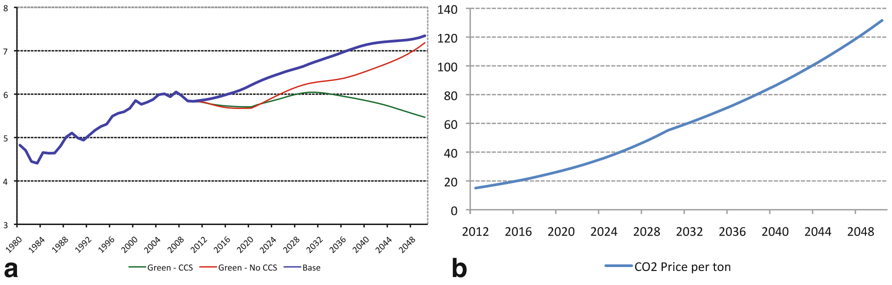


Fig. 4 Fossil fuel CO_2 emissions in Gt for the BAU, green case with and without CCS (**a**); emission price, US$ 00/t of CO_2 (**b**)

Table 1 Key indicators for comparative analysis across countries: USA

	Unit	2010	2020		2030		2040		2050	
		BAU	BAU	Low GHG	BAU	Low GHG	BAU	Low GHG	BAU	Low GHG
Real GDP per capita	US$/person	37,198	44,089	44,323	53,731	54564	64,144	66,663	81,571	89,461
Emission per capita	ton/person/year	18.62	18.05	16.59	18.06	16.30	18.23	14.92	17.85	13.27
Emission per GDP	kg/year/US$	0.50	0.41	0.37	0.34	0.30	0.28	0.22	0.22	0.15
Energy intensity	Btu/US$	8,311	6,770	6,685	5,562	5616	4,839	4,818	4,200	4,188

costs are going to be fully offset by avoided emission charges starting from 2035, while positive employment impacts remain and grow over time.

When analyzing the impact of a cap-and-trade mechanism— of a similar impact of other interventions on energy costs—on energy intensive industries (primary and secondary aluminum, steel, paper and paperboard, petrochemicals, and alkalies and chlorine), a highly debated topic in the US Congress, results of the simulation indicate that the manufacturing sector will likely have to face higher—policy-driven—costs, and that these could be fully offset, at least until 2020/2025, by the free emission allowanced once considered by the Government (see ACES bill, US Congress 2009). In this scenario, the emissions cost will start impacting the profitability of these industries as soon as the free allowances will decline, to be only partially offset by a proposed border adjustment fee (Yudken and Bassi 2009). The efficiency gains required to offset losses related to the implementation of moderate and high-CO_2 prices are in the range of 5 % by 2020 and 10 % by 2030 with the planned allowance allocation, assuming that no major energy efficiency investments will be made by the industries by then (Yudken and Bassi 2009). It is worth considering that, in the absence of free allowances, the energy efficiency improvement required to offset increasing energy prices could reach up to 30 % for iron and steel production, and over 20 % for paper and paperboard. These are sectors with historically low profit margins, implying that the former may relocate to less stringent countries (a growing trend, not only for the USA, in recent years), and the latter (being traditionally related to a localized production system) may slowly vanish and disappear from the American soil (Bassi et al. 2009; Bassi and Yudken 2011).

Summary

The case study of the USA indicates that the allocation of investments aiming at reducing GHG emissions may well result in higher GDP growth and employment relative to BAU, generating double and triple (social, economic, and environmental) dividends. This indicates that the investment required to implement the interventions simulated will have a positive socio-economic return on investment, especially when taking into account avoided energy costs and the potential to generate employment and reduce the economic vulnerability to the volatility of fossil fuel prices. GHG emissions, the primary objective of the interventions analyzed, are projected to decline and reach the 1995 level by 2050 thanks to the implementation of both demand and supply-side interventions.

It is worth noting that the timing of the impact of the green investments simulated differs. Indeed, implementing CCS has a relatively slow impact on the creation of jobs and reduction of emissions, as opposed to the enactment of a federal Renewable Portfolio Standard (RPS). Further, the implementation of a cap-and-trade mechanism, such as the ACES bill, would allow CCS costs to be fully repaid by 2035 and, with a provision to allocate free allowances to energy intensive sectors in early years, would greatly limit potential negative consequences on the profitability of manufacturing sectors.

Concluding, the use of a system dynamics model customized to the USA has allowed the simulation and analysis of the impact of simultaneous policies and investments at the source (such as the expansion of renewable energy and the introduction of CCS), as well as interventions to improve energy efficiency on the demand side. The results of the analysis, carried out across social, economic, and environmental indicators, indicate the potential generation of social and economic medium and long-term benefits, while considerably improving energy and national security.

Kenya

Kenya is a developing country member of the East African Community (EAC). Development in the EAC is constrained by power supply, and historical extreme events have shown that the large hydro-electric component of the Kenyan power sector is highly vulnerable to variability in precipitation. Energy security is therefore a concern for the economic growth and overall development of the country. Using the integrated SDM that has been developed for Kenya, scenarios to build climate resilience into the power sector and the development of Kenya according to Vision 2030 are investigated.

Context

Kenya is already prone to cyclical droughts and flooding because of its geographic location and it is likely to see an increase in the intensity and frequency of these events as global climate continues to change. In Kenya, where about 75 % of the population depends directly on land and natural resources for their livelihoods, the impact of climate change and related disasters on land and natural resources have the potential to severely affect the lives and livelihoods of most Kenyans. This expectation was expressed in the First National Communication of Kenya to the Conference of the Parties to the United Nations Framework Convention on Climate Change, and the State of the Environment Report 2006/2007, which stated that adverse environmental, economic, and social repercussions are anticipated as the impacts of climate change become increasingly manifested. Some of the adverse impacts include water and food shortages, famine, energy shortages, desertification, forced mass migration, diseases, and overall economic, environmental, and human degradation. Existing climate variability has significant economic costs in Kenya. With increasing climate variability in the future, aggregate models indicate additional (on top of existing climate variability) net economic costs which could be equivalent to a loss of almost 3 % of GDP each year by 2030 in Kenya (Stockholm Environment Institute 2009).

This case study forms part of a larger adaptation project to provide the Government of Kenya (GOV) with a dynamic, quantitative, and transparent planning tool for climate adaptation defined here as strategies, policies, programs, projects, or operations aimed at enhancing resilience or reducing vulnerability to observed or plausible changes in climate. It includes activities implemented to create changes in decision environments as well as actual adjustments to address climate risks (Adger et al. 2007). Since there is convergence between climate change and human development, the dynamic planning tool also serves to carry out integrated or multisectoral development planning over the multidecade time horizon, while offering the capacity to carry out scenario analyses of strategies and actions under uncertainty. A system dynamics model has been developed for Kenya that integrates the analysis of the risks and impacts of climate change across the major sectors in the economy, society, and environment, in order to inform coherent national development policies that encourage sustainable development, poverty eradication, and increased wellbeing of vulnerable groups, especially women and children, within the context of *Vision 2030* (Government of Kenya 2007). Four priority sectors—i.e., energy, agriculture, water, and health—have been identified for detailed analysis.

The Kenya model is composed of 50 modules (see Table 2). These modules are regrouped under 18 sectors (6 social sectors, 6 economic sectors, and 6 environmental sectors) based on their functional scope. The strength of system dynamics model is its

Table 2 Modules, sectors and spheres of the Kenya system dynamics model

Society	Economy	Environment
Population sector	**Production sector**	**Land sector**
1. Population	15. Production and income	34. Land
2. Fertility	16. Agriculture	
3. Mortality	17. Husbandry-fishery-forestry	**Water sector**
	18. Livestock	35. Water demand
Education sector	*19. Fisheries*	36. Water supply
4. Primary education	*20. Forestry*	
5. Secondary education	21. Industry	**Energy sector**
	22. Services	37. Energy demand
Health sector	*23. Tourism*	38. Energy supply
6. Access to basic health care		
7. HIV/AIDS	**Households sector**	**Emissions sector**
8. HIV children and orphans	24. Households accounts	39. CO_2 and GHG emission
9. Nutrition		
	Government sector	**Sustainability sector**
Infrastructure sector	25. Government revenue	40. Ecological footprint
10. Roads	26. Government expenditure	
11. Irrigation	27. Public inv. and consumption	**Extra modules**
	28. Gov. balance and financing	*41. MDGs*
Labor sector	29. Government debt	*42. HDI and GDI*
12. Employment		*43. Indicators*
13. Labor avail. and cost	**ROW sector**	*44. Climate impacts*
	30. International trade	*45. Climate interventions*
Poverty sector	31. Balance of payments	*46. Climate investments*
14. Income distribution		*47. Malaria transmission*
	Investment sector	*48. IVM interventions*
	32. Relative prices	*49. Malaria treatment*
	33. Investment	*50. Malaria cost accounting*

flexibility to accommodate additional modules or sectors depending on new issues to be analyzed, and also in its structural nature, being able to integrate economic sectors with biophysical variables for the environment and society. Using the MSP discussed in "Model Development and Validation", over 15 specific climate impacts were modeled across sectors. While climate adaptation can reduce the economic costs of climate change, it has a cost as well. The costs of adaptation are still emerging. Over 18 categories, accounting for more than 25 specific interventions, have been identified and included in the Kenya country model that relate to the balance between development and climate change. To highlight the potential results of the analysis and the value addition of the projects, several scenarios were simulated. The main results of the analysis are discussed below for the energy sector, while results of the full analysis can be found elsewhere (Bassi et al. 2011).

Analysis of Modeling Results

The following climate impacts were studied for Kenya: (1) reduced hydropower generation during droughts and floods; (2) damage to power infrastructure (e.g.,

Table 3 Summary of adaptation measures, including timeframe for implementation and annual investments

Policy interventions	Timeframe (years)	Investment per year (billion KSh)
Accelerated development of geothermal power by the government and its development partners	10	20.3
Accelerated development of geothermal power by the private sector (GDC will take up if there are no suitable investors)	10	12.1
Accelerated development of green energy (solar, wind, renewable biomass, etc.) by the govt. and its development partners	5	15
Accelerated development of green energy (solar, wind, renewable biomass, etc.) by the private sector	5	22.5
Provision of efficient (fluorescent) bulbs to domestic consumers	10	0.36
Water catchments protection programmes e.g., afforestation	10	0.375
Provision of improved jikos	10	0.075
Promotion of low-end solar devices including solar drip irrigation, solar water heating, etc.	10	3

power cables during floods); and (3) increased demand for electricity for services like refrigeration, air conditioning, and irrigation (due to increase in evapo-transpiration). The policy interventions that were simulated to climate-proof the energy sector against these impacts are summarized in Table 3.

The BAU assumes that no climate change adaptation measures would be implemented, including green energy measures. However, the reality is that climate variability and climate change will have an impact on power generation. In the BAU, electricity generation is assumed to be solely from hydro, geothermal, and thermal power generation. In the climate change adaptation scenario, the energy sector includes both promotion of renewable energy on the supply side and use of efficient bulbs on the demand side with a total investment of 73.71 billion KSh per year (see Table 3).

With the use of efficient bulbs, the actual residential lighting will be 2,441.88 GWh by 2030 compared to 3,860.96 GWh if efficient bulbs were not used, translating to 36.75 % of energy saved. By 2050, this will have reduced to 2,186.37 GWh compared to 5,975.07 GWh if the old bulbs are used (see Fig. 5). This translates to a saving of 63.4 % of energy with the use of efficient bulbs. Reduction in electricity demand puts less pressure on the need to increase electricity generation, and constitutes an adaptation strategy in the face of climate vulnerability.

On the supply side, construction of geothermal generations by the government and the private sector would lead to geothermal power capacity to increase from 0.1 GW to 1.33 GW, compared to 0.66 by the year 2031 without the interventions. Further, the government and private sector interventions on green energy development would boost the green energy power generation capacity from 0.01 GW to 0.7 GW and thus have a net increase of 0.7 GW by the year 2017, since the investment is proposed to take five years (2012–2017).

Fig. 5 Residential lighting energy consumption

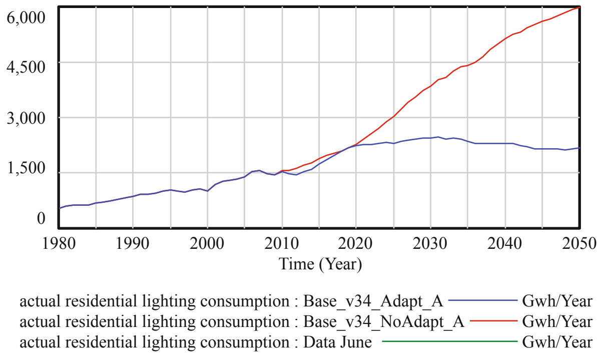
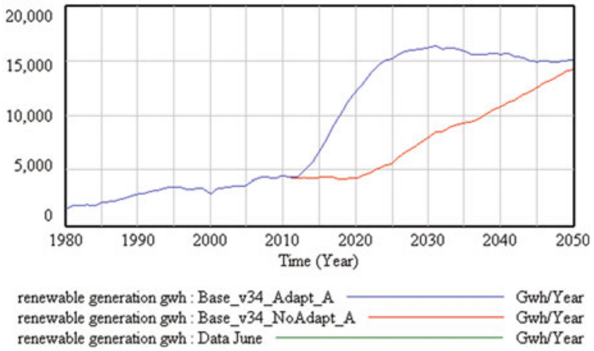


Fig. 6 Total renewable (geothermal, wind, and PV) power generation



Total renewable power generation increases with the addition of solar and wind power generation by 104 % in 2030, by 44.2 % in 2040 and by 6.8 % in 2050 (Fig. 6). The decline in percentage increase in renewable power generation is due to installed plant for wind and solar generation reaching its maximum lifetime.

As a result of these combined mitigation measures, the climate change adaptation scenario (Adaptation) is projected to reduce total CO_2 emissions to 33.6 Mt per year in 2050, compared to 36 Mt in the BAU case.

Summary

This case study has demonstrated the use of system dynamics modeling to climate-proof the power sector in Kenya that is highly vulnerable to current climate variability and projected climate change. Once climate vulnerabilities have been established using a MSP process, policy interventions have been identified to reduce the vulnerability of the power sector. In the climate adaptation scenario, a total investment of US$ 2.7 Bn per year between 2011 and 2030 in climate adaptation and mitigation measures among a number of sectors in Kenya including agriculture (crop cultivation, livestock, fishery, and forestry), energy, and tourism have been simulated. Results of this study show that adaptation has potentially very large benefits in reducing present and future damages.

In the energy sector, CC investment to the tune of 73.71 Bn KSh per year leads to energy savings through efficient bulbs and expanding energy production from renewable sources, both also reducing power cuts. The intervention of using efficient bulbs from the energy demand side would result to a net total energy saving of 1,843 GWh from the current level of 8.54 GWh. On the supply side, public and private sector interventions would increase geothermal power capacity from 0.1 GW now to 1.34 GW by 2031 (compared to 0.66 in the BAU), and green energy power generation capacity from 0.01 GW to 0.7 GW by the year 2017. Despite the fact that wind and solar generation would reach their maximum lifetime, total renewable power generation will increase with the addition of solar and wind power generation by 104 % in 2030, by 44.2 % in 2040, and by 6.8 % by 2050. As a result of these combined mitigation measures, the CC scenario is projected to reduce total CO_2 emissions to 33.6 Mt per year in 2050, 7 % lower than the BAU case (36 Mt). Correspondingly, the total ecological footprint will decline to 1.25 by then relative to 1.4 in BAU, and the ratio of footprint to biocapacity will be 8.3 to 9.3 in the CC and BAU scenarios, respectively.

Mauritius

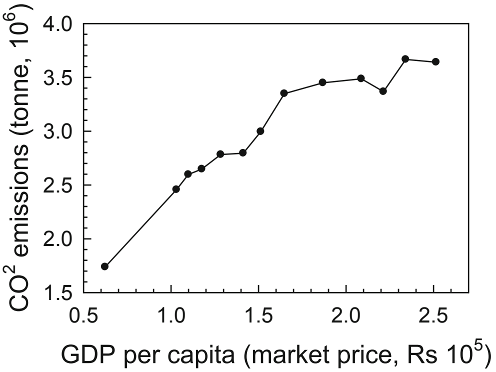
Mauritius is an upper-middle-income country and a Small Islands Developing State (SIDS). A SDM has been developed for the power and transport sectors, and this section will demonstrate how the tool can be used to develop NAMAs for the power sector. In addition, we will show that SDM is a versatile tool for sectoral carbon crediting under dynamic baselines. Since development of NAMAs will require stringent measurement reporting verification (MRV), countries under the UNFCCC would be required to submit their GHG inventories every second year. We will show how relevant indicators can be built into the SDM so that the model can also be used for monitoring and evaluation of policy implementation. This can be achieved dynamically while being in line with IPCC guidelines for national GHG inventories.

Context

Mauritius is classified as a small island developing state (SIDS) within the UN system. A commonality of SIDS is their inherent vulnerabilities to external shocks including extreme weather events that would be made worse by climate variability and projected climate change, and energy security due to the volatility in the price of oil and lack of indigenous supply of hydrocarbons. It is an upper-middle-income country that has witnessed substantial economic growth over the past 3 decades. The rapid economic growth has been accompanied by an increase in its dependence on imported fossil fuels, and correspondingly on GHG emissions (see Fig. 7).

The main GHG in Mauritius is CO_2, and arises from the burning of fossil fuels (coal, fuel oil, diesel oil, gasoline, and kerosene). Although the national emission for Mauritius is small by global standards, it, nevertheless, has a relatively significant

Fig. 7 Variation of GDP per capita and CO_2 emissions in Mauritius, 1995–2011



per capita CO_2 emission. For instance, emissions amounted to 3957.4 kt CO_2 in 2010, while removal by sinks was 250 kt CO_2. The energy industries contributed around 54.6 % of this emission, followed by the transport sector which contributed 31.9 % of the total emissions and the manufacturing industries with 9.1 %. Probably of more importance here is the relatively high per capita CO_2 emission of 2.8 t CO_2 for Mauritius in 2011 (Central Statistics Office 2012). Figure 7 shows that the per capita emission is 2.5 times higher than the per capita emission of Africa ($\sim$ 1.1 t CO_2/person), and 1.8 times higher than that of India ($\sim$ 1.5 t CO_2/person) (Flavin 2008). If the equivalent emissions of methane and nitrous oxide are taken into account, the net per capita GHG emission in 2010 was 3.8 t CO_2e. Figure 7 does not take land use, land use change, and forestry (LULUCF) into account. Including LULUCF the increase of per capita emission is expected to be higher. As an example, a comparison of the national annual emissions statistics is compared with the GHG inventory carried out under the second national communications (SNC) under the UNFCCC. After carrying out detailed emissions from LULUCF, the SNC reports a per capita emission equal to 3.6 t CO_2e in 2006 (Government of Mauritius 2010). Using the annual emission statistics that does not include emissions from LULUCF, the per capita emission in 2006 is found to be just over 3 t CO_2e.

Mauritius is categorized as a nonAnnex 1 country under the UNFCCC and does not have any responsibility or duty to reduce its GHG emissions. However, there are several reasons why emission reduction would be justified in the case of Mauritius:

1. *Energy security*: Development cannot be carried out without the access to reliable sources of energy. From a strategic perspective, reducing dependence on fossil fuel sources over which Mauritius has little control is desirable, especially in a context of rising fuel prices (over a long term), price volatility, and issues related to the geopolitics of fossil fuels (Kuik et al. 2011).
2. *Ethical considerations*: The UNFCCC calls for the “common but differentiated” approach to stabilizing GHG emissions to levels that would limit the long-term rise in temperature to 2 °C. The “common but differentiated” approach recognizes that developed countries are primarily responsible for the bulk of atmospheric GHGs (i.e., the historical perspective) and that countries do not all have the same capacity

to carry out emission reductions or adapt to the consequences of climate change. However, as emissions emanating from developing countries exceed those from developed countries,[5] and considering that: (1) the atmosphere has a fixed budget as a sink for GHGs, and (2) all sentient beings share the only one and same atmosphere, a case can be made on ethical considerations for an equal emissions entitlement—i.e., equal per capita emissions (Moellendorf 2012). Under future contraction and convergence (Global Commons Institute 2010) or common but differentiated convergence (Höhne et al. 2006) scenarios, Mauritius will have to reduce its per capita GHG emissions.

3. *Access to carbon finance*: As a nonAnnex 1 country, Mauritius can benefit from carbon credits by implementing projects that reduce GHG emissions. Further, nonAnnex 1 countries are encouraged to formulate low-carbon development strategies. Investigating the potential of leverage carbon finance as a supplementary flow of foreign direct investment to support the sustainable development of Mauritius is desirable, especially considering the increasing importance of NMMs and NAMAs (Hinostroza et al. 2012).

Analysis of Modeling Results

In the case of Mauritius, the two scenarios that were analyzed are the BAU and government's official long-term energy strategy (LTES) (Ministry of Renewable Energy and Public Utilities 2009). The BAU assumes that current trends will continue and that current policies and decisions will take their course (e.g., planned investments in the construction of new energy supply), while the LTES scenario simulates the policy interventions of the LTES. Table 4 summarizes the main assumptions of the scenario analyses.

This case study being limited to economy-wide GHG emissions calculated in terms of emission of CO_2 does not provide any discussions of the social and economic impacts of scenario analyses. Such results can be found in another recent study that has used system dynamics modeling to investigate the impacts of green investments in several sectors (energy, water, and agriculture) of Mauritius, especially on the creation of green jobs (Bassi and Deenapanray 2012). The total energy consumption in the BAU scenario is shown in Fig. 8, and it reveals that the model simulation (red) can very well replicate historical data (blue). This was the case for a host of socio-economic and environmental indicators that are not shown here.

Figure 9 shows the simulations of GHG emissions for the BAU (red) and LTES (blue) scenarios. Since the modeling can capture dynamic complexity, the BAU simulation represents a dynamic baseline of what would happen in the absence of any policy interventions. Hence, the net emission reductions arising from the

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[5] Total carbon dioxide emissions by developing countries are expected to surpass that of developed countries by 2015. Please see http://www.epa.gov/climatechange/emissions/globalghg.html—accessed 30 July 2011.

Table 4 Main assumptions used in scenario analyses

BAU scenario
GDP growth is calculated endogenously and it follows the declining trend of GDP over the last 18 years (1.8 % average between 2009 and 2025, with 2009 and 2025 at 2.2 % and 1.1 %, respectively). Simulations to 2040 have assumed constant GDP growth rate at 1.1 % after 2025
Maintenance of existing electricity production capacity through 2025, with a net increase in 70 MW between 2010 and 2011 in thermal power plants burning heavy fuel oil (HFO); construction of a 100 MW pulverized coal plant in 2013; in the baseline case only, the construction of additional 100 MW of HFO capacity after 2020 to supply peak power, demand is assumed (this investment is not necessary in the policy case, which projects lower energy demand)
Domestic retail prices of imported primary energy sources (fossil fuels) are exogenous in the model. Historical data use those published by the Central Statistics Office (CSO), Mauritius and projections are calculated applying a future growth rate to the anchor price of 2008 in Mauritius. Projections on the yearly price change for fossil fuels and end-use petroleum-derived fuels are taken from the EIA of the US Department of Energy
Long-term energy strategy (LTES) scenario
Energy efficiency
Applied to electricity consumption, for the domestic, commercial, industrial, irrigation sectors and other uses. Energy efficiency is projected to increase by 2 % in 2010, 4 % in 2015, 6 % in 2020 and 10 % in 2025, relative to 2008
Renewable energy, power sector, and fossil fuels
Efficiency increase in the use of bagasse for electricity generation, to reach 600 GWh of output by 2013
Construction of three wind farms for a combined production capacity of 70 MW (20 + 20 + 30 MW). The project is assumed to start in 2011, with full operational status being reached in 2012
Construction of about 4 MW of small solar energy (2016) and 1 MW of small hydro generating units (2010), for a total of 5 MW installed by the SIPP—an amount considered safe for the grid according to Central Electricity Board (CEB)
Construction of a waste-to-energy plant of 20 MW capacity at La Chaumière. This plant will start producing electricity in 2013
Construction of a landfill gas plant, for 3 MW of capacity (as indicated by CEB) at Mare Chicose. This plant will start producing electricity in 2013 and will be operational for 6 years
Cost-reflective electricity prices
A feed-in tariff for wind is set at Rs 5/kWh, while the one for large scale solar is set at Rs 8/kWh; small scale solar is assumed to receive instead an Rs 15/kwh feed in tariff
The maximum load factor of the various units is assumed as follows: wind 33 %, solar 30 %, waste 80 %, hydro 16 %, landfill gas 76 %, geothermal 70 %, gas turbine 20 %, HFO 56 %, coal 75 %, cogeneration 80 %
The capital lifetime of the various plants is assumed to range between 20 and 30 years
The base load share of electricity demand is set at 60 %
Transport
Reduction of the vehicle age between 2009 and 2025, reaching a 5 % yearly depreciation of the vehicle stock by the end of the period of analysis
Reduction of the age of buses to 10 years, by 2020
Increase in the efficiency of all road vehicles, 20 % between 2008 and 2025, due to the lowered age of vehicles and improvements in fuel efficiency and tuning of engines and tires
Construction of the bus way (for which costs and capacity are not defined yet)
A subsidy to public transportation, of Rs 5/vehicle/day
A congestion charge, of Rs 5/vehicle/day
Capacity of the bus way, assumed at 25 buses
Effectiveness of public transportation subsidy, congestion charge and bus way, each, 5 % in 2012 and 7.5 % in 2015

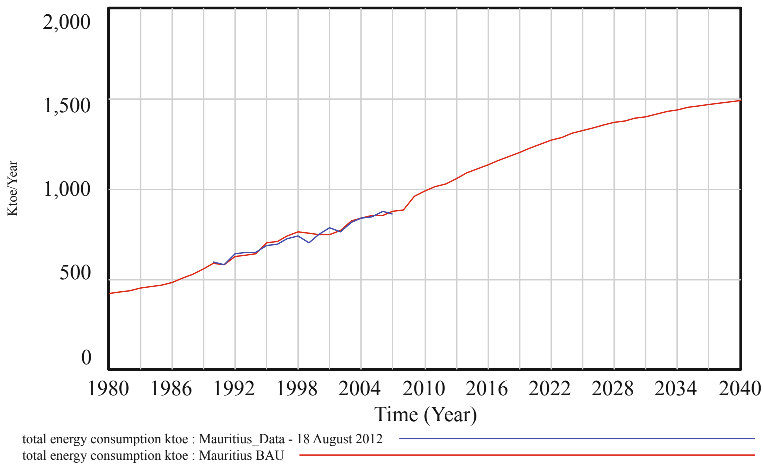

Fig. 8 Total energy consumption—historical data (*blue*) and BAU (*red*) simulation

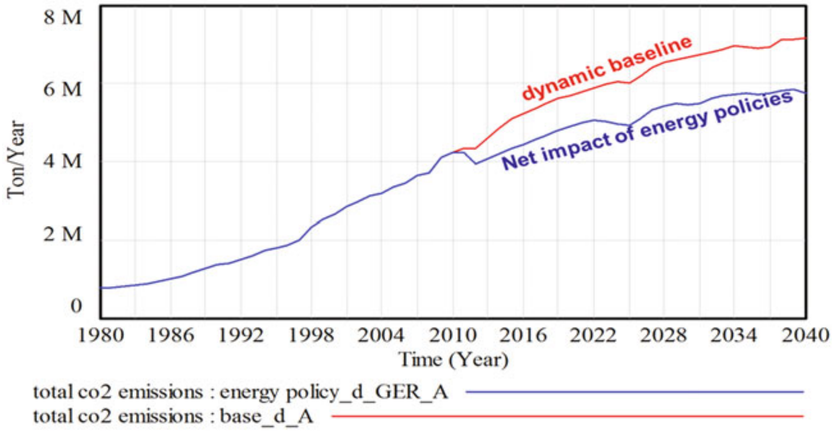

Fig. 9 Emissions reduction through policy implementation against a dynamic baseline

implementation of LTES, which is represented by the curve shown in blue in Fig. 9, can be obtained from the difference between the two curves. Existing baseline-and-credit approaches typically use static baselines that are determined predominantly *ex-ante* (i.e., before a project has been implemented), and are generally applicable to stand-alone projects or program of activities where the activities are of the same type (Beaurain and Schmidt-Traub 2010). There are also cases where the baseline can be updated periodically based on *ex-post* (i.e., after a project has been implemented) observations and emission reductions are calculated based on the most current baseline (Kollmus et al. 2008). For all practical purposes the baseline is considered as counterfactual or hypothetical—i.e., the real future baseline cannot be known once the low-carbon project is implemented. In contrast, system dynamics modeling

Table 5 Emission reductions from policy interventions are calculated against a dynamic baseline, 2015–2040

Year	2015	2020	2025	2030	2035	2040
Emission reduction (million ton CO_2)	0.758	0.786	1.100	1.205	1.190	1.417

allows emission reductions, and hence carbon credits,[6] to be calculated using a dynamic baseline, which would represent a significant advantage of calculating real emission reductions, albeit at the added difficulty of model development. The simulated reductions in emission of CO_2 are summarized in Table 5 as would happen if all elements of the LTES depicted in Table 4 were implemented. The results shown in Table 5 are related to the absolute level of GHG emission reduction. A MRV framework would still need to be put in place for assurance purposes which is discussed later. Further, an assumption is made here that any absolute emission reduction relative to the dynamic baseline would be additional to what would have happened in the absence of the implementation of energy policies.

The simulations shown in Fig. 9 offer two additional advantages that would support NAMAs and NMMs, with the intention to catalyze larger-scale emission reductions beyond what can be obtained from existing project-based or programmatic approaches. The usefulness of system dynamics modeling as a tool to develop: (1) sectoral crediting (under a dynamic baseline), and (2) NAMAs are discussed broadly, while noting that there are several outstanding issues that go beyond the scope of this chapter.

It was discussed in the introduction that stabilizing atmospheric GHGs to levels that would prevent irreversible climate change would require profound emission reductions that would need to go well beyond what can be realistically achieved using the project-based or programmatic approaches. This juncture has led to the proposal for sector-wide emission reductions that are mediated by economy-wide energy policies and strategies as leverage points. In this approach, called sectoral NAMAs, multiple policy-induced emission reduction interventions are implemented across an entire sector (van Asselt et al. 2010; Klein et al. 2009). The policy instruments would be of the sort listed in Table 4, and any sectoral carbon credits generated by emission reductions may be used to support any combination of the sector-specific policies or policy instruments. The decomposition of the total CO_2 emission reduction (Fig. 9) into sectoral emission reductions is given in Fig. 10. In this case, most of the emission reductions are generated in the power sector that contributes around 55 % of the total national CO_2 emissions (see "Context"). The difference between the power sector (green) and dynamic baseline (blue) curves represents the emission reduction from interventions in the power sector, while the difference between the red and green curves give the emission reductions in the transport sector. Thus far, the analysis has shown how system dynamics energy modeling can be used to potentially establish sectoral NAMAs under a dynamic baseline, which may or may not be credited.

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[6] One carbon credit is equal to the reduction in the emission of 1 t of carbon dioxide equivalent.

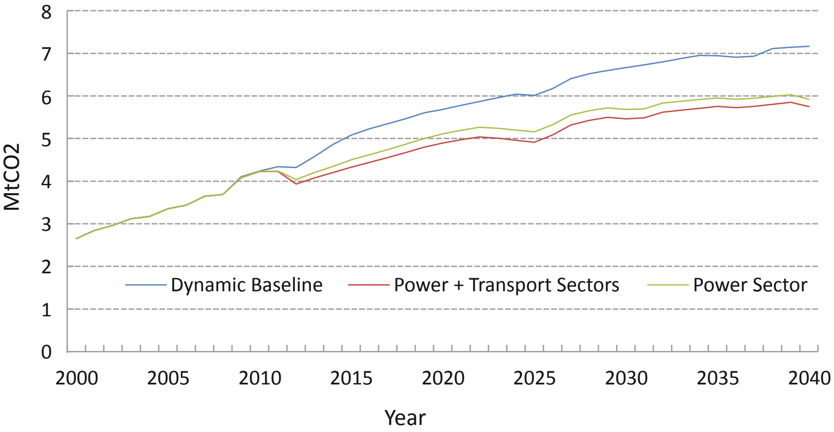

Fig. 10 Sectoral decomposition of total emission reductions from LTES scenario

The next step would be to determine which actions at the sectoral level could be credited. For this, a categorization of sectoral activities will have to be carried out, involving the necessary government agencies, based on the typology provided under the UNFCCC for NAMAs (Hinostroza et al. 2012; Klein et al. 2009):

- ***Unilateral NAMAs***—NAMAs that a country intends to implement completely on its own but for which recognition of this effort is desired. Here the host country sustainable development may not be necessarily driven by the need for emission reductions. Instead, emission reductions could be the result of improving energy security to increase the resilience of the country against externally driven energy shocks or for the generation of green jobs through green investments (Bassi and Deenapanray 2012).
- ***Conditional (or supported) NAMAs***—NAMAs that will only be implemented with the help of international assistance, in the form of financing, technology transfer, and/or capacity building. These NAMAs would typically go beyond unilateral efforts and represent greater emission reduction ambitions for which assistance would be needed for the incremental effort. Actions that contribute to the "no lose or no regrets" goals of the host country would be classified as conditional NAMAs. In this case, the necessary support would have to be specified.
- ***Credited NAMAs***—NAMAs that are eligible for support through full or discounted crediting in the carbon market for activities beyond the BAU scenario.

The categorization of the sectoral interventions as NAMAs is beyond the scope of the work presented here. The process by which a developing country would officially declare its NAMAs has yet to be determined, but it has been proposed that each developing country put forward a climate plan or low-carbon development strategy, such as the LTES, that would also describe the NAMAs that it intends to implement. Generic steps have been developed (GIZ 2011) and best practices (Center for Clean

Table 6 Cumulative investments and O&M costs, and emission reductions for actions in the power sector

Sectoral action	Cumulative investment (capital and O&M)—million Rs		Cumulative emission reduction (Ton CO_2)		In-country capacity
	2011–2025	2011–2040	2011–2025	2011–2040	
Hydro	0	0	0	0	Exists
Wind	12,094	31,216	3,095,318	10,420,031	Does not exist
Waste energy	6,340	8,905	1,604,613	3,391,653	Exists
Cogeneration	0	0	1,554,004	3,232,159	Exists
Solar	615	669	116,925	284,460	Does not exist
Energy efficiency	12,045	29,757	1,762,900	6,932,600	Exists to varying degrees
Total	*31,095*	*70,548*	*8,133,760*	*24,260,903*	

Air Policy 2011) identified that can nevertheless assist countries to develop NAMAs. Sectoral programs could be a part of the developing country's plan or strategy, since they allow any country to grow their economic sectors in a more climate-friendly manner without compromising the country's sustainable development (Klein et al. 2009). The added benefit is that the sectoral approach takes a more systemic view of low-carbon development, and hence offers the opportunity for accelerated energy transformation. Although there are no clear guidelines for categorizing NAMAs, it is expected that cost and technical capacity would be key considerations. Table 6 shows the cumulative investment and operation and maintenance (O&M) costs of various interventions in the power sector, as well as the corresponding emission reduction potentials. The status of available capacity is also given for each intervention. So, the system dynamics modeling could also be used as a useful tool to guide the categorization of NAMAs once the criteria and indicators for that categorization are defined either at the international or national level.

Finally, the MRV of these mitigation actions is important to generate transparency on their effectiveness and facilitate decision making, especially in the case of credited NAMAs. MRV can be thought of as a knowledge management system for tracking GHG emissions, actions to reduce GHG emissions, and climate change mitigation support (GIZ 2011). The system dynamics model can also be used as a monitoring and evaluation tool since, as shown in Fig. 8, the simulation of scenarios can be compared to historical or measured data. Hence, by defining what to measure (i.e., indicators such as direct and indirect emissions, electricity generated by renewable sources, or electricity saved by energy efficiency, etc.) and how to measure the necessary indicators (i.e., what methodology needs to be adopted), the modeling tool can calculate the indicators using the predefined methodologies. In fact, the definition of indicators to monitor and evaluate policy interventions is an integral part of Step 1 in the model development process (see "Model Development and Validation"). For instance, the model used here is fully compliant with the guidelines used for preparing national GHG inventories using the guidelines of the Intergovernmental Panel on Climate Change (IPCC) that are used for national communications under the UNFCC. Not all requirements of a MRV system can be captured by the tool, such as how often, and who should be responsible for MRV.

Summary

The main objective of this case study was to demonstrate yet another novel application of system dynamics modeling. Using the long-term energy strategy of Mauritius as example, it has shown how scenario analysis of energy policy could potentially be used for the following:

1. Quantify GHG emission reduction under a dynamic baseline. The dynamic baseline is generated under the BAU scenario (i.e., absence of policy interventions) and captures the complex interactions between key social (e.g., population dynamics and disposable income), economic (e.g., GDP growth), and environmental spheres (e.g., GHG emissions) of sustainable development.
2. Develop sectoral GHG emission reduction or sectoral NAMAs based on the implementation of sector-wide strategies. The case study was used to show how total GHG emission reductions could be decomposed into sector-wide emission reductions in the power sector and transport sector separately.
3. Although the modeling tool alone cannot be used to categorize sectoral mitigation actions into unilateral-, supported-, or credited-NAMAs, it can provide some of the information such as investment and O&M costs and action-specific GHG emission reductions to assist in this categorization. Further, it has been shown elsewhere that the modeling tool can also be used to calculate other key indicators like green job creation, reduction in the bill of imported fossil fuels and contribution to economic growth, among others, that may also be relevant to categorize NAMAs (Bassi and Deenapanray 2012).
4. Predefined indicators and methodologies to calculate the indicators based on agreed international benchmarks can be embedded in the system dynamics model to provide key elements of a stringent MRV system. The use of the model as a monitoring and evaluation tool has been discussed, especially in the context that the scenario analyses allow the simulations of the model to be compared directly with historical or measured data.

Conclusions

Climate change has emerged as arguably the biggest threat facing human development in the twenty-first century. It is, therefore, in humanity's interest to do something about the current state of affairs.

Global coordination for GHG emission reductions is carried out under the aegis of the UNFCCC. The use of NMMs for achieving global reductions in GHG emissions was adopted at COP16 in Cancun (2010), and further referenced at COP17 in Durban (2011). Since the sectoral scope of NMMs depends, among others, on data availability and low degree of uncertainty in emission estimates, the sectors that are recommended for NMMs are: (1) energy supply; (2) industry (e.g., oil refineries, natural gas facilities, iron and steel production, cement production); and (3) transport.

In this chapter, we have demonstrated the practical use of system dynamics modeling for policy planning to achieve climate-resilient, low-carbon development pathways, in the context of national development planning. In particular, we have used real examples from developing (Mauritius and Kenya) and developed (USA) countries to make the case for the use of SDM for climate proofing the energy sector and to develop (NAMAs) as one type NMM.

In all cases, the impacts of policy interventions was discussed for several cross-sectoral indicators, highlighting the strengths of system dynamics models in analyzing broader impacts of policy implementation and in identifying potential double and triple dividend interventions. This advantage of SDM also makes these models relevant to analyze energy issues in the context of national development, be it climate adaptation and/or mitigation, or a broader framework such as the green economy.

Appendix: Multistakeholder Process for Model Development

It is widely acknowledged now that the knowledge required to articulate what would constitute sustainable development in any given context (i.e., country or subregions therein) is often dispersed within the system boundary (i.e., country and its subregions), which is why a multistakeholder approach is necessary for successful outcomes. In other words, the complex system of socio-economic conditions existing within the natural ecosystems characterising any given territory can only be seen collectively for the adequate response to the increasing demands for policy-relevant interventions. MSPs can also help ensure better coordination between different institutions and agencies, in addition to ensuring that knowledge is combined and properly utilized by sharing common mental models. MSP is also an appropriate means to achieve consensus and ownership of the modeling tool for planning and decision-making purposes.

The five sequential steps of a generic MSP are illustrated in Fig. 11 (Hemmati 2002). Each step involves specific actions to ensure maximum ownership of the process by the beneficiary stakeholders and ensuring them that climate change related actions are discussed through dialogue and consequently integrated in the national and local agenda. Briefly, the steps of the MSP are defined in generic terms while noting that the central issues are related to climate change:

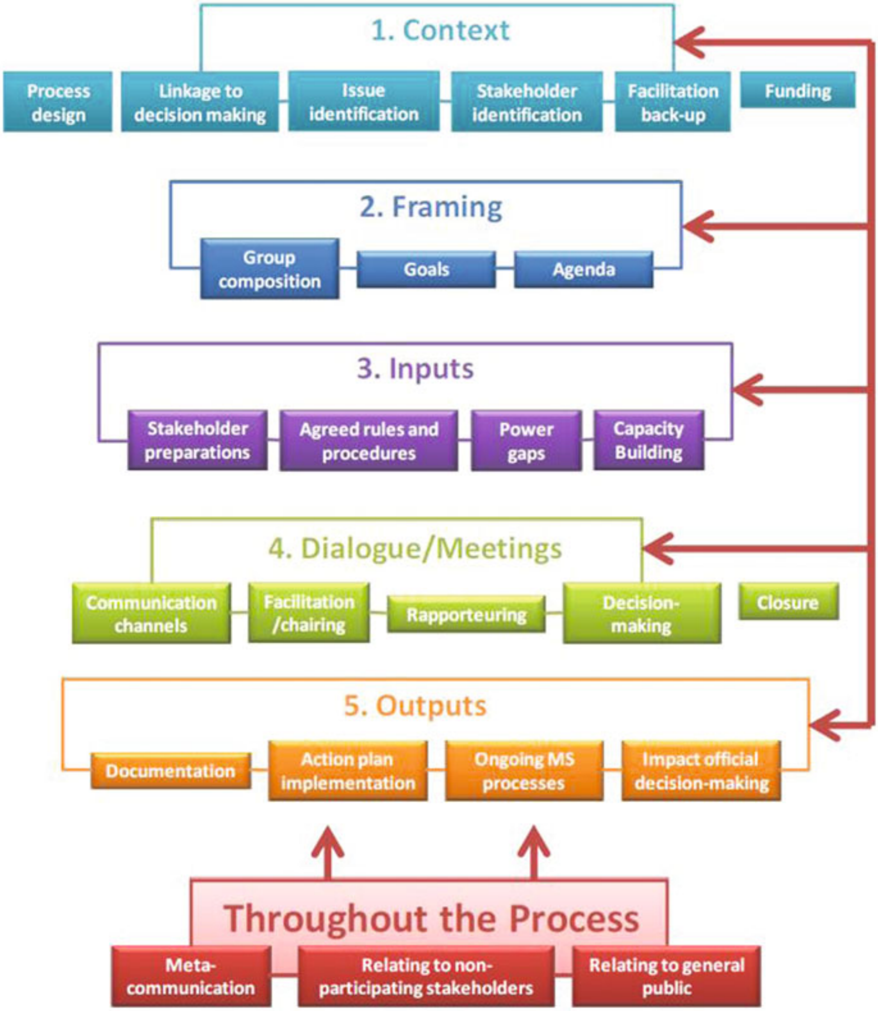

Fig. 11 The five sequential steps of the multistakeholder process used in model development

1. *Context*—Setting the context is probably the most critical step in the process, and the "one-size-fits-all" cannot be applied. After the key stakeholders have been identified based on principles of inclusiveness, diversity, and size, they should be involved in every aspect of the design process to generate legitimacy, credibility, and trust. This does not mean that conflicts will not arise, but that any conflicts may be better dealt with later on. In designing the process, it should be made very clear how the output of the dialogues will permeate the policy decision-making process. Productive dialogue can only take place when all participants share a common understanding of the agenda of the MSP. This requires a clear definition

of what issues the MSP will address. Successful MSPs require facilitation and organizational back up, also implying the need for adequate financial resources.

2. *Framing*—MSPs need precisely defined issues before them. The questions to be addressed and the goals of the process need to be very clear to all the participants and agreed by them. Possible changes over the course of an on-going process also need to be agreed on by the group, allowing for consultations within constituencies if necessary.
3. *Inputs*—In order to facilitate dialogues, several inputs must be in place or be made available to participants. First, all participants must have equitable access to all information, and they should be given sufficient preparation time. The ground rules for the purpose of dialogue must be agreed on within the group, while noting that no one has all the answers but that the output required will be the collective wisdom and knowledge of the participants. Fundamental differences exist between stakeholders in such things as knowledge and information, communication skills, size, nature, and the amount of resources that define significant power gaps and unfair distribution of bargaining and negotiating power. Care must therefore be taken to identify and address power gaps, and this is also a reason why facilitation of dialogues is critical. Bilateral meetings can be used where necessary to prepare participants for plenary sessions.
4. *Dialogue*—MSPs are about creating a space where dialogue can take place. An atmosphere that cultivates equity, respect, dignity, humility, and hope will create a space where people can interact in such a way that their differences and their commonalities become clear so that they can begin to explore possible ways forward.
5. *Outputs*—MSPs should be transparent all the way. So, they should not only publish and communicate their deliberations and outcomes but also keep record of their design. A critical aspect is to be able to demonstrate to stakeholders how the outcomes of their dialogues impacted policy decision-making. One of the key initial outputs of the dialogues is the development of CLDs that are then translated mathematically into system dynamics models.

MSP was adopted for the conceptualisation, customization, and validation of system dynamics models developed in the three case studies presented in this chapter.

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