COMPENDIUM ON GREENHOUSE GAS BASELINES AND MONITORING

NATIONAL-LEVEL MITIGATION ACTIONS

United Nations
Framework Convention on Climate Change

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MITIGATION ACTIONS

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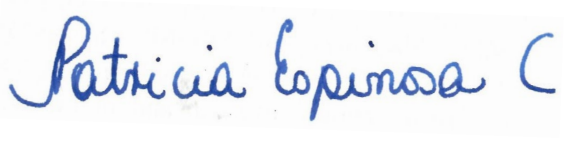
FOREWORD

With the wind of the Paris Climate Change Agreement in our sails, the global community now shifts to an exciting new phase of implementation, turning climate commitments into action. We have on board a huge amount of political will from governments along with willingness from the private sector, civil society and individuals all over the world. Together we are charting the course towards a low-emissions future.

In this context, it is important for countries to have suitable tools and approaches to analyze pathways of development and greenhouse gas emissions under new and existing mitigation policies and actions. This volume aims to support countries in their assessments of emissions reductions from national-level mitigation actions in economies that are dominated by energy-related emissions. It also provides an overview of main approaches for developing baseline and mitigation scenarios at a national level for the entire economy. These scenarios build a bridge between national ambition and the more detailed analysis of options and implementation plans to achieve mitigation targets.

As we work towards a low-carbon future, we must bear in mind that climate change action is really about protecting and improving the well-being of people in all corners of the world. This perspective should help us focus on the big picture and drive us to collectively take more urgent and ambitious action.

All national plans and policies must now align with the course we have set in the Paris Agreement and the Sustainable Development Goals. It is my sincere hope that this volume supports policymakers as they take the next crucial steps to realize a better future for all.



Patricia Espinosa, Executive Secretary
United Nations Convention on Climate Change
Bonn, Germany, December 2016

PREFACE

The adoption of the global Sustainable Development Goals and the landmark Paris Climate Change Agreement in 2015 set the world on a path towards a low-emission and sustainable future. The Paris Agreement for the first time unites all nations in the common cause to undertake ambitious efforts to combat climate change by means of national climate action plans.

In developing these climate action plans, it is essential that policymakers have the means at their disposal to set national targets and goals, estimate the mitigation impact of actions taken to reach these goals and measure progress towards achieving them. With this in mind, this volume gives an overview of tools available for this purpose and provides guidance on the various steps along the way, as well as key aspects that need to be considered to select the most appropriate approach for each country's national circumstances.

The comprehensive guidance contained in this volume can help countries assess national emissions trajectories and make informed choices when setting national emission reduction targets and goals. By preparing informed and ambitious national mitigation actions, every country can make a sound contribution to the global effort to combat climate change and build a sustainable future.

Donald Cooper, Director
Mitigation, Data and Analysis Programme
United Nations Convention on Climate Change
Bonn, Germany, December 2016

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GLOSSARY

Activity data	A quantitative measure of a level of economic activity that results in greenhouse gas emissions. Activity data are multiplied by an emission factor to estimate the greenhouse gas emissions associated with a process or an operation
Base year	A specific year of historical data against which greenhouse gas emissions are compared over time
Baseline scenario	Baseline scenarios are projections of greenhouse gas emissions and their key drivers as they might evolve in a future in which no explicit actions are taken to reduce greenhouse gas emissions
Baseline scenario assumption	A quantitative value that defines how an emission driver in a baseline scenario is most likely to change over a defined future period of time
'Business as usual' (BAU) scenario	A reference case that represents future events or conditions that are most likely to occur as a result of implemented and adopted policies and actions. It is sometimes used as an alternative term for "baseline scenario"
CO_2 equivalent (CO_2 eq)	The universal unit of measurement to indicate the global warming potential value of each greenhouse gas, expressed in terms of the global warming potential of 1 unit of carbon dioxide. It is used to evaluate releasing (or avoiding releasing) different greenhouse gases against a common basis
Cumulative emissions	A sum of annual emissions over a defined period of time
Double counting	Double counting occurs when the same transferable greenhouse gas emission unit is counted towards the mitigation goal of more than one jurisdiction. Double counting includes double claiming, double selling and double issuance of units
Dynamic baseline scenario	A baseline scenario that is recalculated based on changes in emission drivers
Emission factor	A carbon intensity factor that converts activity data into greenhouse gas emission data
Emission reduction	A reduction in greenhouse gas emissions relative to a base year or baseline scenario
Leakage	An increase in emissions outside of the boundary of a mitigation action that results as a consequence of the implementation of that mitigation action
Mitigation scenario	A mitigation scenario represents future greenhouse gas emissions with the assumption of the introduction of certain policies and measures reducing greenhouse gas emissions with respect to some baseline (or reference) scenarios
Model	A framework used to represent the operation and/or the characteristics and/or the reactions of a complex (natural, engineering or socioeconomic) process

Parameter	A variable that is part of an equation used to estimate emissions. For example, “emissions per head of cattle” and “quantity of livestock” are both parameters in the equation “1.5 kg CO_2 eq/head of cattle × 100 head = 150 kg CO_2 eq”
Policy	A set of formally described and adopted legal actions, rules or guidelines to be followed and/or enforced by a government or authority. A policy typically includes its area and date of validity, objectives and implementing organizations
Projection	An estimation of the evolution of certain parameters, indicators or variables (e.g. temperature, rainfall, or emissions) based on a set of assumptions and, optionally, with the use of a model (depending on the approach chosen)
Reference year	A year against which commitments are made and measured, typically in the form of emission abatement. Most frequently it is a year in the past, for example the year 1990 for the commitments under the Kyoto Protocol, but in some cases it can be a future year. It can also to be an average of a period of years
Static baseline	Static baselines use greenhouse gas emissions or estimates of greenhouse gas emissions in a given year or the average of several years as a reference value
Scenario	The description of several key variables in a possible state in the future. A scenario has to be plausible in the sense that under certain assumptions it is likely to occur and should contain consistent and coherent outcomes. A scenario is not a probabilistic forecast, but a deterministic description

ABBREVIATIONS

AFOLU	agriculture, forestry and other land use
BAU	‘business as usual’
BBL	blue barrel (a standard measurement unit in the oil industry)
CGE	computable general equilibrium (a type of model)
CO^2 eq	carbon dioxide equivalent (a unit of measurement)
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre of the European Commission
LULUCF	land use, land-use change and forestry
M	million
Mtoe	million tonnes of oil equivalent
NDC	nationally determined contributions
OECD	Organisation for Economic Co-operation and Development
SSP	shared socioeconomic pathway
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Following the adoption of a new United Nations agenda for sustainable development[1] and a landmark global agreement on climate change[2] in 2015, governments and jurisdictions started charting the course towards low-emissions development and integrating it into national-level planning processes and policies. In this context, it is important for countries to have suitable tools and approaches at hand to analyse pathways of development and greenhouse gas (GHG) emissions under new or enforced mitigation policies and actions. These pathways are then compared to a projected baseline – a reference pathway without the considered mitigation policies and actions – in order to assess the impact of mitigation policies and actions.

This volume of the *Compendium on Greenhouse Gas Baselines and Monitoring* (hereinafter referred to as the compendium) aims at supporting countries in assessing emission reductions from national-level mitigation actions in economies that are dominated by energy-related emissions[3] and provides an overview of the main approaches for developing baseline and mitigation scenarios at the national level (i.e. for the entire economy), considering the main drivers of GHG emissions, technology options, data sources and impacts of mitigation actions. It provides an overview of top-down modelling approaches for mitigation assessment, while other volumes of the compendium deal with bottom-up modelling approaches, which are mostly used for mitigation assessment of individual sectors of the economy. Further, this volume provides guidance in relation to the selection of suitable baseline approaches based on the national circumstances of a country. It also provides guidance on maintaining consistency when integrating bottom-up sectoral baselines into a national economy-wide baseline.

1.2 SCENARIOS AND BASELINES

In the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), a scenario is defined as a possible future pathway with the ability to "capture key factors of human development that influence GHG emissions and our ability to respond to climate change. Scenarios cover a range of plausible futures, because human development is determined by a myriad of factors including human decision making". In addition, the report states that "Scenarios can be used to integrate knowledge about the drivers of GHG emissions, mitigation options, climate change, and climate impacts" (IPCC, 2014).

The AR5 furthermore defines a baseline as "the reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario is used as a reference in the analysis of intervention scenarios". According to the IPCC, a reference scenario or baseline is used as a benchmark to assess alternative scenarios as "Baseline scenarios are projections of GHG emissions and their key drivers as they might evolve in a future in which no explicit actions are taken to reduce GHG emissions. Baseline scenarios play the important role of establishing the projected scale and composition of the future energy, economic, and land-use systems as a reference point for measuring the extent and nature of required mitigation for a given climate goal. Accordingly, the resulting estimates of mitigation effort and costs in a particular mitigation scenario are always conditional upon the associated baseline". For the present volume, the definition of the IPCC is used as a working definition of the term "baseline".

In general, baselines are defined as scenarios that describe future GHG emissions in the absence of defined mitigation efforts and policies. The term "baseline" is often used interchangeably with "business as usual scenario" and "ref-

[1] United Nations. *Transforming our World: the 2030 Agenda for Sustainable Development*. Available at <https://sustainabledevelopment.un.org/post2015/transformingourworld>

[2] Paris Agreement. See <http://unfccc.int/paris_agreement/items/9485.php>

[3] For approaches suitable for assessing emission reductions from mitigation actions in the land use, land-use change and forestry (LULUCF) sector, please see the volume of the compendium titled Land Use, Land-Use Change and Forestry (forthcoming).

erence scenario". However, baseline scenarios may deviate from the expected emissions under 'business as usual' (BAU): in order to evaluate the impact of a specific policy, countries may choose a baseline scenario to represent a hypothetical case that does not include the impact of policies that would otherwise be included in a BAU scenario (see, e.g., Clapp and Prag, 2012).

1.3 USE OF BASELINES

National baselines are the key elements of climate change policymaking and are used to support national climate change policy preparation, set national targets and goals, provide a benchmark for mitigation targets, estimate the mitigation impact and assess progress in implementation (Weyant, 1999). In addition, national baselines are used in determining the amount of allowances in international emissions trading. Furthermore, they can also be used for the construction of the global GHG emissions trajectory.

1.4 TOP-DOWN VERSUS BOTTOM-UP APPROACH

Top-down models are standard tools for assessing the macroeconomic costs of carbon dioxide (CO_2) abatement and its economy-wide feedbacks on prices, commodity and factor substitution, income and economic welfare. Bottom-up models are used to investigate emission reductions delivered by the deployment of portfolios of technologies that make up the supply and demand components of the energy system, in order to identify low-cost abatement opportunities or design technology-based subsidies or emission standards (Wing, 2006).

Top-down approaches to formulate national baselines provide a projection of future emissions trajectories based on macroeconomic projections, where the specific technical and operational properties of the individual sectors and subsectors of the economy (energy, transport, agriculture, industry, waste management, etc.) are not modelled. The focus in a top-down model is the economy as a whole. Top-down models use aggregated data such as consumption, investment, aggregate supply and demand, and price levels to examine interactions between sectors. As a consequence, these models cannot readily incorporate different assumptions about how discrete technologies and their costs are likely to evolve in the future.

In contrast, bottom-up models describe current and prospective technologies in detail. They are therefore well suited to the analysis of specific changes in technology or 'command and control' policies such as efficiency standards. A common shortcoming of the bottom-up analysis is that it fails to account for market failures, price distortions, economy-wide interactions and income effects. The terms "top-down" and "bottom-up" can also be interpreted as aggregated and disaggregated models[4].

A recent development is that the gap between these model types is closing. According to the IPCC, "A new finding in the underlying literature (see, for example, the review in Weyant, 2004) is that the traditional distinction between 'bottom-up' (engineering) and 'top down' (macro-economic) models is becoming increasingly blurred as 'top down' models incorporate increasing technology detail, while 'bottom up' models increasingly incorporate price effects and macro-economic feedbacks, as well as adoption barrier analysis, into their model structures". In this context, some such models are also referred to as "hybrid" models.

[4] These definitions are used differently in varying contexts and are not always consistent for all sectors when referring to data; for example, volume 3 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* on industrial processes and product use refers to chemical sales data as top-down data and market data as bottom-up data.

1.5 VOLUME OVERVIEW

This volume provides guidance on the steps required to develop national-level baseline and mitigation scenarios using top-down approaches. The volume starts with an overview of key preparatory steps for developing national-level baseline and mitigation scenarios. Section 2.1.1 provides information on key aspects that need to be considered in order to select the most appropriate modelling approach. Section 2.1.2 provides guidance on conducting the stocktaking of available resources in order to identify relevant data needed for scenario building and data gaps that may need to be bridged in order to reach set objectives. Using this information as the basis for baseline and mitigation scenario building, the volume provides guidance on the methodological steps of the process and introduces key methodological issues of scenario building (section 2.2), the key drivers of GHG emissions (section 2.3) and considerations related to accounting for policies and measures in baselines (section 2.4). It describes modelling approaches, their key features, advantages and disadvantages (sections 3.1 and 3.2), and provides an overview of sources of data required for modelling (section 3.6) and examples of the application of models (section 3.9). The volume concludes with the comparison of top-down and bottom-up modelling approaches and explains discrepancies in modelling results stemming from the use of both types of approaches for the modelling of GHG emissions in individual sectors, and provides a description of the hybrid modelling approach.

Chapter 2

METHODOLOGICAL ASPECTS OF GREENHOUSE GAS EMISSION SCENARIOS

2.1 PREPARATION FOR SCENARIO BUILDING

In the following sections, the keys steps in preparing for national-level scenario building are outlined. The information gathered at these steps will then inform the subsequent steps in developing national-level baseline and mitigation scenarios.

2.1.1 Needs Assessment

Every baseline and mitigation scenario modelling starts with a thorough needs assessment, which identifies key needs that the modelling should fulfil and forms the basis for the later choice of modelling approach and the data requirements.

The needs assessment may include the analysis of the aspects contained in Figure 1 below:

Figure 1
Assessment of modelling needs

Objetive of baseline setting	What is the intended use of the national-level baseline emissions? Example: Setting national emission reduction targets or domestic mitigation policy planning
Sectoral coverage	Which are the most important sectors to target with mitigation actions and include in the mitigation assessment? Example: Those sectors of the economy that are responsible for the largest shares of total national GHG emissions
Time frame	What time period needs to be considered in the mitigation assessment? This information is relevant for the selection of the base year and the projection period
Accuracy	What level of accuracy, conservativeness and detail is necessary? This information is relevant for the selection of the tier

Abbreviation: GHG = greenhouse gas.

2.1.2 Stocktaking

After the needs assessment, a stocktaking of available information, resources and previous work is conducted. This may include the analysis of the aspects contained in Figure 2 below. The stocktaking exercise helps to obtain an overview of available resources. This may guide the selection of appropriate models for the baseline and mitigation scenario modelling and, subsequently, once data and other resource requirements to fulfil the specific needs of the model are better understood, the stocktaking can be used to identify relevant gaps (e.g. in data and expertise requirements to use a model), in the form of a gap analysis, that may need to be bridged in order to reach the objectives of GHG emission scenario modelling.

Figure 2
Stocktaking of available information and resources

Research capacity	Are there research institutions available with relevant modelling expertise that can support the GHG emission scenarios modelling? Example: Universities, government agencies, researchers and consultants
Data	What data are available? See section 3.2 for an overview of data sources and data requirements of data models
Models	What models are available? See section 3.1.1 and Annex 1 for an overview of models
Studies	What studies on national-level scenario building have been conducted? What can these studies bring in terms of useful information for the GHG emissions scenario modelling that can be used as indicators to the proposed effort? Example: Macroeconomic forecasts, population forecasts and outlined emission projections

Abbreviation: GHG = greenhouse gas.

2.2 KEY METHODOLOGICAL ISSUES

Once the needs assessment and stocktaking are completed, the collected information forms the basis for the baseline and mitigation scenario building that starts with the identification of a set of key methodological aspects related to preparing baseline and mitigation scenarios, including the selection of the base year and projections time frame, the national GHG emissions inventory, sectoral coverage, and treatment (inclusion or exclusion) of domestic policy measures, including cross-checking the consistency of the GHG emission projections with the projections of the socioeconomic development of the country, as well as the selection of the projections and modelling methodology (Clapp and Prag, 2012):

- ***The base year*** for the projection[5] can be a single individual year or a set of years (e.g. the average or trend over a number of years). If a single year is chosen, the selection might have a large effect on future projections, if the emissions for that specific year are significantly higher or lower than the typical average for that time period. There might be short-term fluctuations in, for example, gross domestic product (GDP) growth, foreign trade, commodity and energy prices, weather extremes (e.g. exceptionally hot summers or exceptionally cold winters, a year with an El Niño or La Niña pattern), precipitation change, and disasters (e.g. hurricanes, forest fires, floods influencing agriculture and afforestation, war). These factors may lead to a baseline based on a single year that is not representative of the period of projections. Averages over several years (e.g. four to five years) may therefore be more suitable for defining representative baseline values. Furthermore, the selection of the base year can adhere to internationally accepted standards, (e.g. the base year of 1990 for the first commitment period of Kyoto Protocol's can be another year based on the purpose of the use of the baseline emission projections);
- ***The national GHG inventory*** is another important element in the baseline development. It comprises emissions from all sectors of the economy. Inventory emissions are estimated using activity data (e.g. cement production) and emission factors for each type of activity. The GHG inventory provides an overview of the GHG emissions in the base year and also shows the past developments and trends in emissions, which can allow for a validation of the baseline emission projections. Another way of validating baseline emissions is to compare them with the outputs of other models and/or the outputs of an international modelling framework and check for significant differences (see how this approach was applied to India in MoEF, 2009);
- ***Linking socioeconomic and GHG projections.*** Governments typically develop scenarios of socioeconomic development (e.g. GDP forecasts, sectoral projections and population growth forecasts) for planning and designing economic policies and identifying problematic social areas which require government intervention. This is typically undertaken by a specific ministry, agency, or sometimes the central bank. It is advisable to ensure the consistency of the GHG emission projections with the projections of the socioeconomic development of the country in terms of the variables used in both types of projections (e.g. GDP growth rates and population growth rates);
- ***The sectoral coverage***. Besides the respective contribution of economic sectors to total national GHG emissions (and the prioritization of the sectors responsible for the largest shares of total national emissions), the availability of data and costs of acquiring them are the main considerations related to the inclusion of economic sectors in the scope of modelling. In developed and advanced developing economies, the primary focus is on energy-related CO_2 emissions as the main source of total national GHG emissions. In many less advanced developing economies, agriculture, forestry and land-use change are the main GHG-emitting sectors. Non-CO_2 emissions and land-based emissions are in many cases not includ-

[5] The base year for the projections may or may not have a connection to the base year used for setting the national GHG emission reduction targets or goals and is the year from which the model calculates the baseline. However, for both purposes, the same year can be selected to use the projection results for setting national targets or goals.

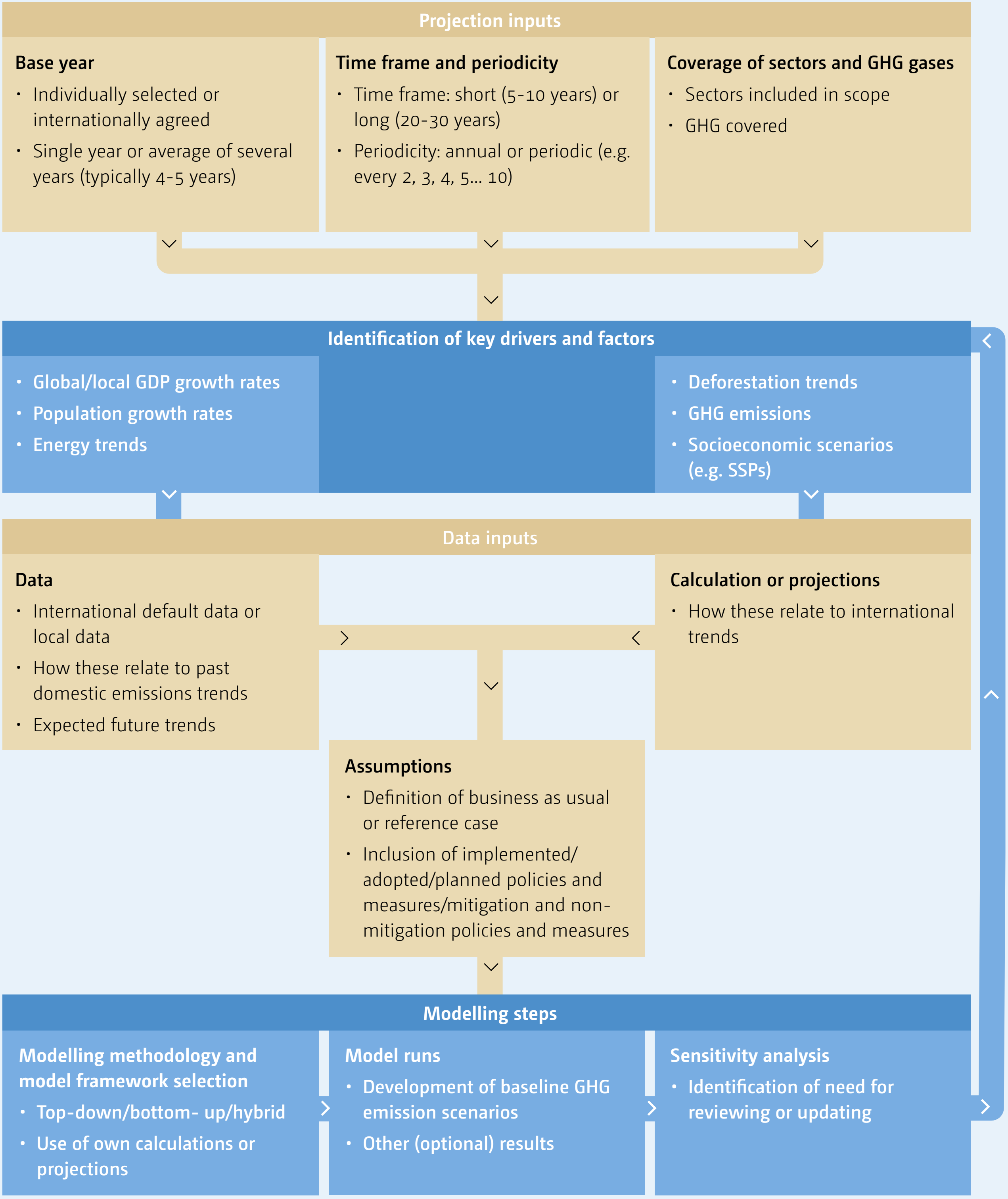
ed in national-level GHG emission scenarios developed with the use of top-down models (since models for these emissions sources are of a bottom-up nature owing to their spatial and temporal variability);[6]

- ***Considering policies and measures.*** Considering climate policies and measures, which target and result in emission reductions, energy efficiency improvement and renewable energy penetration, is important when projecting future baseline emissions. Besides climate change specific policies and measures targeting GHG emission reductions, many non-climate policies affect GHG emissions, such as fuel taxes or subsidies, and industrial or infrastructure development policies (e.g. industry infrastructure subsidies, mass transportation investment and power sector development). Some non-specific policies might have an adverse impact on emissions (e.g. policies targeting the increase of livestock in agriculture). Considerations for accounting for policies when setting national baselines are discussed in section 2.4;

› *Modelling methodology* used for the projection of baseline and mitigation scenarios also has a significant impact on the final results. Projections can be carried out by simple extrapolation using historical GHG emission trends and inventory data, or by more complex modelling. Complex modelling can either be conducted at the national economy level using a top-down approach or on a sector-by-sector basis using a bottom-up approach and aggregating sectoral projections into national-level baseline emissions. The choice of the projection method or model can have a significant impact on the baseline emissions and the resulting mitigation potential. Baseline emissions should also be continuously updated to reflect developments in policy, technology, costs and other aspects. Modelling approaches are discussed in Chapter 3.

[6] Modelling approaches for these sectors are described in detail in the respective volumes of the compendium.

Figure 3
Flowchart for establishing national baseline emissions using top-down methods



Abbreviation: GDP = gross domestic product, GHG = greenhouse gas, SSP = shared socioeconomic pathway.

2.3 DRIVERS AND IMPACTS

There are a number of drivers that impact GHG emissions. The identification and analysis of their relative impact on GHG emissions (see section 2.3.1 for more information) forms the basis for the later selection of a modelling approach that is best suited to simulating the dynamics of these drivers and their impact on baseline and mitigation scenario emission pathways. The analysis of key drivers based on historical data can also be used for developing simple baseline and mitigation scenarios that combine the effect of key drivers, as shown in section 2.3.2. Though simple, such approaches work with limited data and provide transparent (first order) results. More generally, the understanding of drivers and their impacts on GHG emissions is fundamental to all modelling approaches (see section Chapter 3 for more information).

2.3.1 Key drivers affecting emissions

Drivers and their respective importance can vary by country and region. Correctly identifying their relevance and assessing their future evolution forms the robust basis for reliable emission projections. Key drivers that affect future emissions include changes in population growth, changes in economic growth (GDP), the contribution of economic sectors to GDP and energy prices (see Table 1 for an overview of the primary drivers of GHG emissions and key data sources). More detailed guidance on where to obtain data on primary drivers is provided in Annex 2). Secondary drivers include the penetration of new technologies, changes in consumption patterns, and changes in the energy system. Furthermore, the policy framework (incentives, taxes, subsidies, mitigation measures and development plans for specific sectors) also impacts GHG emission trends.

The dynamics of these factors also need to be assessed. The assessment should include how the factors are expected to change over time and how technological development and the penetration of different technologies is expected to evolve, how the economic structure is expected to change (in terms of the contribution of economic sectors to GDP and the associated contribution of economic sectors to national GHG emissions), as well as the evolution of consumer preferences, urbanization, and changes in modalities of transportation, among others. In addition to varying economic activities in different countries, differences in other aspects of the national circumstances[7] impact on countries' emission profiles, resulting in a wide diversity of national emission profiles.

Table 1
Overview of the primary drivers of emissions at the national level

Primary drivers	Examples of sources of data[a]
Population growth	United Nations and government agencies
Economic growth, activity	National statistics, OECD, World Bank, CIA The World Fact Book and IIASA
Structural changes in the economy	National statistics, OECD, World Bank and IIASA
Technological advancement	IIASA and national agencies
Modalities of transportation, infrastructure	National agencies
Efficiency of energy use	IEA, EPA and IIASA
Emission intensity	IEA, EPA and FAO
Intrinsic fossil fuel supplies	BP and Shell reports
Energy prices, energy demand and supply, price and income elasticity of energy demand	National statistics, Bloomberg, IEA and IRENA
Tax system, government policies (climate and non-climate policies)	Government agencies, OECD, IRENA and IEA

Abbreviations: CIA = Central Intelligence Agency, EPA = United States Environmental Protection Agency, FAO = Food and Agriculture Organization of the United Nations, IEA = International Energy Agency, IIASA = International Institute for Applied Systems Analysis, IRENA = International Renewable Energy Agency, OECD = Organisation for Economic Co-operation and Development.

[a] See Annex 2 for a detailed list of data sources.

2.3.2 Constructing simple greenhouse gas emission scenarios

2.3.2.1 The 'Kaya Identity'

After undertaking a qualitative assessment of the drivers of GHG emissions, simple baseline and mitigation scenarios can be derived using a tool called the 'Kaya Identity'. The Kaya Identity is a simple approach to modelling national-level energy-related GHG emissions as the product of the following drivers (Kaya and Yokoburi, 1997; and Blanford, 2008):

- Population;
- GDP per capita;
- Energy intensity (per unit of GDP);
- Carbon intensity of energy use (emissions per unit of energy consumed).

The Kaya Identity is estimated as follows:

Population (N) × per capita income (PCI)= GDP
GDP × energy intensity (EI)=primary energy demand (ED)
Primary energy demand (ED)× carbon intensity (CI)= emissions (EM)

These equations show that in order to have a forecast using the Kaya Identity, it is necessary to have forecasts for the annual values of per capita GDP, population growth and carbon intensity of energy use. If these data are available (see Annex 2 for information on data sources) then a simple multiplicative relationship allows a projection of GHG emissions to be calculated. More information can be found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000).

As the Kaya Identity focuses on emissions from energy use, it is most useful for countries with a relatively high share of emissions from the energy sector. The advantages of the Kaya Identity are its relative simplicity and direct comparability between countries. The energy intensity of the economic activity component in the Kaya Identity captures possible efficiency improvements and structural changes of the economy, if these are expected in the future. For example, the impacts on GHG emissions resulting from the restructuring from a manufacturing-based economy towards a less energy-intensive service-based economy are possible to assess using the Kaya Identity. The Kaya Identity is best established by providing information on the rate of economic restructuring, in other words, by a forecast of the carbon intensity of energy use.

It has to be noted, however, that even though the Kaya Identity can be used to assess the primary driving forces of CO_2 emissions (and possibly other GHGs), there are important limitations to its use. The four factors – population growth, GDP per capita growth, energy intensity of GDP and carbon intensity of energy use – are not always considered to be fundamental driving forces, and they are not generally independent from each other. The Kaya Identity does not take into account the great heterogeneity among populations and the level of industrialization with respect to GHG emissions. Furthermore, the Kaya Identity is not capable of analysing the causes and dynamics behind GHG emission trends. Therefore, additional analysis might be advisable to better understand trends in GHG emissions and model GHG emission scenarios.

2.3.2.2 Activity, Structure, Intensity and Fuel decomposition

The Kaya Identity accounts for assumed structural changes of the economy using the Activity, Structure, Intensity and Fuel (ASIF) decomposition (Partnership for Market Readiness (PMR), 2012). The ASIF decomposition accounts for changes using the following components:

- *Activity*: economic activity, such as GDP growth or sectoral activity (which can be further disaggregated into population growth and per capita GDP growth);
- *Structure*: structure of the economy, such as shares of industry and services, or shares of different technologies in a given sector;
- *Intensity*: energy intensity of the economy and capturing energy efficiency improvements;
- *Carbon content of fuel*: capturing the fuel mix, electrification rate and carbon content of electricity.

[7] For example, a country with extreme climatic conditions is likely to use a relatively large amount of energy for heating (or cooling) in buildings, and is therefore likely to have a profoundly different emissions profile from a country with moderate climatic conditions.

The historical analysis of these components (see section 2.3.1) might provide more precise projections of future emissions (based on projections of the ASIF components) than those derived from the Kaya Identity, although it requires more detailed analytical input. GHG emissions are projected using the following formula:

$$EM = \sum_{k,j} A \times S_k \times I_{kj} \times F_{kj}$$

Where:
- $\boldsymbol{EM}$ = GHG emissions;
- $\boldsymbol{A}$ = activity level;
- $\boldsymbol{S_k}$ = the share of the k^{th} sector (or technologies if the scope of assessment is a sector) in the aggregate output of the economy (or sector, if that is the scope);
- $\boldsymbol{I_{kj}}$ = the proportion of energy used by the k^{th} sector (or technology) from the j^{th} energy source, and;
- $\boldsymbol{F_{kj}}$ = the carbon content of the j^{th} energy source used in the k^{th} sector (or technology). The carbon contents are defined using the IPCC emission factors.

The summation is performed for each sector k and each energy source j for each year.

Examples of the application of this method can be found in Kojima and Bacon (2009) and Janssens-Maenhout *et al.* (2013).

2.4 ACCOUNTING FOR POLICIES AND MEASURES IN NATIONAL BASELINES

It is deemed to be good practice that national GHG emission baselines take into account all policies that impact GHG emissions. Policies that are aimed directly at reducing GHG emissions or those that have an indirect impact on the reduction of GHG emissions should be identified and accounted for. The inclusion of some policies in the baseline (e.g. those regarding renewable energy or energy efficiency), may lead to lower baseline emission levels and, in turn, diminish the estimates of emission reductions attributable to planned mitigation efforts. The date of adoption or actual implementation of a mitigation policy is very important when establishing national GHG emission baselines. The decision to include certain policies in the baseline may lead to perverse incentives for countries to evade or adjourn the adoption of policies that result in GHG emission mitigation. This issue has been debated in the context of national communications and even international market mechanisms (e.g. under the clean development mechanism (CDM)[8].

The Danish Energy Agency (DEA) (DEA *et al.*, 2013) highlights that subjectivity and politically driven elements may be involved in the decision on which policies to include in the GHG emission baseline scenario. Furthermore, it is not always an easy task to isolate and model the potential effects of a particular policy. It is therefore important to acknowledge that national-level baselines always contain a certain degree of subjectivity, as different assumptions and approaches in including (or excluding) national policies in baselines lead to different projection results.

Considering the impact of interaction between different policies is also important when setting baselines. An example is provided in the publication by PMR (2015), accounting for the impact of the summation of policies, which would be different if the same policies were evaluated in isolation. This example shows that in the case of combining the effects of the removal of fuel subsidies on fuel prices and a policy for energy efficiency, the resulting decrease in GHG emissions would be higher than in the case where the effects of both policies were evaluated in isolation. Table 2 provides an overview of approaches to accounting for policies in establishing baselines in different contexts (UNFCCC, 1999; PMR, 2015; World Resources Institute (WRI), 2014; and CDM Executive Board, 2005).

[8] For a detailed discussion, see: <http://www.energimyndigheten.se/globalassets/klimat--miljo/cooperation/carbon-limits---national-policies-and-cdm.pdf> and <http://www.cdmpolicydialogue.org/research/1030_impact.pdf>

Table 2

Overview of approaches to taking national policies into account in establishing baselines

Aspect	National Communications	Mitigation Goal Standard[a]
Objective of baseline	Communication of national progress in climate change mitigation	Development of baseline scenarios for national or subnational greenhouse gas (GHG) emission reduction goals
Types of policies to be taken into account in baselines	• Policies that are planned, adopted and/or implemented by governments at the national, state, provincial, regional and local levels • 'With existing measures' (WEM) scenario includes adopted and implemented policies • 'With additional measures' (WAM) scenario includes planned policies over WEM scenario policies • Policies may also include those adopted in the context of regional or international efforts	To reflect the most likely future emission pathway under a baseline scenario, users should include all policies and actions that • Have a significant effect on GHG emissions, either increasing or decreasing them; and • Are implemented or adopted in the year in which the baseline scenario is developed
Baseline scenario	Includes all policies and measures planned, adopted or implemented after the year chosen as the starting year for the projections ('without measures' scenario)	Relevant for baseline scenario goals; users shall report: • The cut-off year for the inclusion of policies; that is, the year after which no new policies or actions are included in the baseline scenario • Key policies and actions included in the baseline scenario • Any additional methods and assumptions used to estimate the effects on GHG emissions of key included policies and actions • Any significant policies excluded from the baseline scenario, with justification
Mitigation Scenario	• WEM scenario projections shall encompass currently implemented and adopted policies and measures • WAM scenario projections also encompass planned policies and measures	This is determined by calculating the allowable emissions in the target year, based on the specifics of the goal

[a] See <http://ghgprotocol.org/mitigation-goal-standard>

[b] Interpretation from the document *Checklist on Establishing Post-2020 Emission Pathways* (PMR, 2015).

Aspect	Partnership for Market Readiness – World Bank	Clean Development Mechanism
Objective of baseline	National-level baselines for the development of (intended) nationally determined contributions ((I)NDCs)	Project-level baselines in the clean development mechanism (CDM) (crediting for international offsetting under the Kyoto Protocol)
Types of policies to be taken into account in baselines	• Existing and committed or planned policies • Choices need to be made as to which existing policies are included in the baseline and which are part of the emission reduction scenarios • There is no single universal rule with regard to where to draw a line between baseline and emission reduction scenarios, but it is useful to make such choices transparent and justified in the (I)NDCs or any other nationally determined mitigation contribution	A baseline shall be established taking into account relevant national and/or sectoral policies and circumstances, such as sectoral reform initiatives, local fuel availability, power sector expansion plans, and the economic situation in the sector where a CDM project is planned to be implemented
Baseline scenario	• Existing and implemented policies should be included • Policies that are approved and legally binding, but not yet fully implemented, may not be included in the baseline scenario	• Only national and/or sectoral policies or regulations that lead to the increase of GHGs (E+) that have been implemented before the adoption of the Kyoto Protocol (11 December 1997) shall be taken into account when developing a baseline scenario • If such national and/or sectoral policies were implemented after the adoption of the Kyoto Protocol, the baseline scenario should refer to a hypothetical situation without the national and/or sectoral policies or regulations being in place • National and/or sectoral policies that lead to the reduction of GHGs (E-) that have been implemented after the adoption by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol of the CDM modalities and procedures (11 November 2001) need not be taken into account in developing a baseline scenario
Mitigation Scenario		• Policies and actions being assessed • Policies that are approved and legally binding, but not yet fully implemented, may be included in the mitigation scenario[b]

Chapter 3

MODELLING GREENHOUSE GAS EMISSION SCENARIOS

This chapter provides an overview of different modelling approaches for projecting baseline and mitigation scenarios, and discusses their characteristics and typical applications in (section 3.1). To assist in choosing a modelling approach that meets the modelling objectives and corresponds to national circumstances and data availability, all models are categorized into tiers (3.2) and decision-making flowcharts and guidance are provided to assist in selecting an appropriate modelling approach (3.3). Lastly, data availability is an important consideration in selecting an appropriate model: on the one hand, data availability (sections 2.1.2 and 3.6) limits the range of available models; while on the other hand, the chosen modelling approach also defines the data needed for its application (section 3.6).

3.1 OVERVIEW OF TOP-DOWN MODELS

A critical dimension in developing GHG baseline and mitigation scenarios is the selection of a model for a specific modelling task, as the model defines the data requirements and associated transaction costs for data collection, as well as the level of expertise required for its use. For the latter purposes, existing models are classified into tiers, allowing for a choice of a model that corresponds to the available resources and time. This volume focuses on top-down models for GHG scenario building. Although there is no generally accepted classification of top-down models, the following types can usually be identified (Wei *et al.*, 2006; Böhringer, 1998):

- Trend analysis;
- Macroeconomic models;
- (Computable) general equilibrium models;
- Partial equilibrium models.

These models require inputs which are typically macroeconomic aggregates or indicators such as data on consumption, investment, capital inflows to the country, interest rates, savings rates, population growth rates and exchange rates. They typically forecast macroeconomic aggregates, sectoral activity levels, GDP growth and GHG emissions. Further details on the specificities of each type of model and their typical applications are provided below. Table 3 provides examples of the application of top-down models and highlights the key advantages and disadvantages inherent in each model type.

A trend analysis is typically used for short- or medium-term projections. Simple time series models can also be assigned to this model type. The Kaya Identity is an example of applying trend analytical data to forecast GHG emissions.

Macroeconomic models deal with macroeconomic aggregates such as consumption, investment, savings and output growth based on some assumptions made on the behaviour of economic actors (e.g. rationality, profit maximization or consumption smoothing). In order to calculate emissions from a macroeconomic model, it is necessary to have additional conversions from the model results (e.g. consumption of goods and services) to the energy use and emissions.

General equilibrium models establish the conditions that allow for simultaneous equilibrium in all markets of individual products and services, and deal with the determinants and properties of such an economy-wide set of equilibria. In this sense, general equilibrium models use a microeconomic, individual market-based approach. Economic equilibrium methodologies simulate very long-term growth paths and do not apply econometric relationships, but are tested against a given year in order to ensure consistency (Beeck, 1997).

Partial equilibrium models do not deal with emissions outside of the modelled sector(s). In other words, they do not cover the complete set of interactions in an economy. Aside from that, they are similar to the general equilibrium models.

Table 3
Overview of top-down models

Model type	Key features[a]/range of time periods considered	Example of applications and models used	Advantages	Disadvantages
Trend analysis	Extrapolates past trends, has less stringent data requirements than other model types listed below **Short or medium term (1–10 years)**	Intended nationally determined contributions (INDCs) of Benin, Djibouti and Gabon[b]	Requires highly aggregated data, and thus is less demanding to use	• Limited application to policy analysis • Interactions between energy use and economic sectors cannot be modelled
Macroeconomic models	Macroeconomic models focus on the entire economy and on the interaction between the sectors. Often, macroeconomic models do not concentrate on energy specifically, but on the economy as a whole, of which energy is only a (small) part **Short or medium term (1–10 years)**	INDC of Trinidad and Tobago (MACRO)	Good forecasting potential, and good linkage to the sectors of the economy	• Lack of technology representation • Requires high expertise to use • Provides a static representation of the economy • Typically provides an indirect connection to energy use and emissions
General equilibrium models	General equilibrium models consider simultaneously all the markets in an economy, allowing for feedback effects between individual markets. Such models are used to study the energy sector as part of the overall economy and focus on interrelations between the energy sector and the rest of the economy[c] **Medium or long term (5–30 years)**	INDC of Kenya, shared socioeconomic pathway scenarios (regional level) (computable general equilibrium, 3ES and GEM-E3)	Comprehensive analytical strength: good for energy policy assessment (regulation, taxation, etc.)	• Highly sensitive to accurate estimation of substitution elasticities • Lacks detailed technological data • Places restrictive assumptions on production functions • Understates transition costs when a switch from one technology to another is modelled

Model type	Key features[a]/range of time periods considered	Example of applications and models used	Advantages	Disadvantages
Partial equilibrium models	Partial equilibrium models only focus on equilibria in parts of the economy, such as the equilibrium between energy demand and supply. Aside from that, they are similar to the general equilibrium models **Medium or long term (5–30 years)**	Sectoral modelling (e.g. EuroCARS) or emission baselines (e.g. POLES modelling in the Joint Research Centre of the European Commission Covenant of Mayors Programme (European Commission, 2012), or the baseline presented in the sixth national communication of Italy)	Comprehensive analytical strength, good suitability for energy policy assessment (regulation, taxation, etc.)	• Highly sensitive to accurate estimation of substitution elasticities • Lacks detailed technological data, and places restrictive assumptions on production functions • Understates transition costs when a switch from one technology to another is modelled

Note: The models presented in Table 3 do not necessarily generate GHG emission forecasts as outputs; some of them generate energy demand forecasts or macroeconomic aggregates (see table 13 in Annex 1 for further information). In order to develop GHG emission scenarios, the modelling results of such models have to be translated into GHG emissions by multiplying energy-related activity indicators projected with the use of the model with corresponding emission factors for energy use.

Abbreviations: 3ES = Macroeconomic, Energy and Environment sub-model – 3Es-Model. GEM-E3 = General Equilibrium Model for Energy-Economy-Environment interactions. POLES = Prospective Outlook on Long-term Energy Systems.

[a] A detailed description of the models can be found in Annex 1.

[b] INDC submissions are available at <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>

[c] Giannakidis *et al.*, 2015; Li *et al.*, 2003.

In conclusion, although all these types of models are capable of providing forecasts of GHG emissions (outputs that can be converted into forecasts of GHG emissions), their analytical capabilities differ, and thus these models have different ranges of suitable applications. More specifically, the trend analysis can be applied in situations where no specific knowledge is available on either the structure of the economy or interactions between economic actors, markets, key industries and their products, and emission factors, whereas macroeconomic models and general or partial equilibrium models require detailed knowledge of the economy. Although using more sophisticated models is more resource-intensive than the use of simpler models, more sophisticated models offer the potential to capture

Box 1

Availability of models

The majority of the models presented in section 3.1 are developed by government agencies, research institutions or international organizations, typically under the framework of an international cooperation initiative.[a] In most cases, the availability of these models is not clearly stated in public sources, and the documentation on models is not very transparent and/or up to date. Thus, to obtain the model and information about it, it is advisable to contact the model owners/developers. There are also models that are easily and freely available and are accompanied by adequate documentation[b].

[a] For example, the General Equilibrium Model for Economy, Energy, Environment (GEM-E3) was developed on behalf of the Joint Research Centre of the European Commission, in cooperation with three European universities.

[b] An example is the Greenhouse Gas Abatement Cost Model (GACMO), which is a simple trend analysis tool that can be downloaded at <http://www.cdmpipeline.org/publications/GACMO.xlsm> and the VATTAGE general equilibrium model developed in Finland, which is also freely available and can be adapted to the respective national economy; available at <http://www.vatt.fi>

the evolution of market conditions, economic development, the appearance and closure of industries, and trading links.

3.2 CATEGORIZATION OF MODELS INTO TIERS

The range of modelling approaches provides flexibility of choice. Since there is a wide variability of country needs, national circumstances, availability of required data, and size of potential mitigation actions, all modelling approaches are categorized into tiers, consistent with the categorization used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereinafter referred to as the 2006 IPCC Guidelines). This is helpful in selecting an appropriate approach that corresponds to the needs, availability of data and expertise, thus helping to focus available resources, time and human resources to achieve optimal results. As a general rule, tier 1 models are the simplest, with the smallest resource and data requirements, and tier 3 models include the most elaborate and sophisticated models, with the highest data and resource requirements. There is a link between the tiers and the level of accuracy or uncertainty level achieved – the higher the tier level, the lower the uncertainty and the higher the precision of modelling results. The models used for projecting national-level emission scenarios are classified according to the following tiers[9]:

- **Tier 1:** Simple trend analytical models using global or external forecasts for major macroeconomic variables (e.g. obtained from models such as PRIMES[10]) reference technological data (if available, national-level data can be used) and IPCC emission factors. In this case, future emission factors, growth factors and prices are sourced from external data sources (see Annex 2 for information on sources of data). Such an approach is easily verifiable, trackable, transparent and simple. Its disadvantage is that it might not provide a full coverage of trends, and model outputs are only approximate (i.e. they have high uncertainty);
- **Tier 2:** Top-down simulation, computable general equilibrium (CGE), and econometric models that use endogenous development of prices, demand and supply. In some cases, technological development in terms of sectoral or aggregate energy efficiency improvements can also be modelled;
- **Tier 3:** Bottom-up or hybrid models using a top-down framework coupled with technology-level breakdown of processes, fuel use, thermal efficiency and emission intensity (CO_2/kWh), among others. This approach is highly detailed and highly sensitive to assumptions, but potentially more reliable and results in higher accuracy.

In cases of very limited data availability and resources, tier 1 approaches following simple trend analysis or simpler spreadsheet models may be considered. In Table 1, the key drivers of GHG emissions are provided. When checking for the feasibility of modelling, critical (minimum required) data include an estimation of economic growth, population growth, energy intensity of the economy and emission intensity of energy use. This choice could be the first step when a country attempts to model its national emissions. Once data are collected and expertise built, the country may gradually move to more sophisticated methods that provide more precise and reliable results that allow for the capturing of additional economic trends and processes to understand their impacts on GHG emissions. Table 4 summarizes the relevant characteristics and data requirements of key types of models classified into tiers.

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[9] See volume 1 of the compendium for further information on tiers

[10] See, for example, <https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf>

Table 4

Key characteristics of models and their attribution to tiers

Modelling approach	Tier 1	Tier 2	Tier 3
Trend analysis	++	+	-
Macroeconomic models, general or partial equilibrium models	+	++	++
Bottom-up or hybrid models with CGE or macroeconomic elements	-	+	++
Data needed	Minimum: gross domestic product, population, energy intensity	Structural data, market/ sectoral data, elasticities	Efficiency, technology data, plant data, agent behaviour data
Resource needs (assumed costs)	Low	Medium to high	High
Institutional needs (trained experts, etc.)	Low	Medium to high	High
Time to develop scenarios (estimated)	9-12 months	12-36 months	18+ months
Need for sensitivity scenarios/ uncertainty	High	High to medium	Low to medium
Expected quality of forecast	Low to moderate	Medium to high	High
Potential to assess mitigation policies and measures	Low	Moderate	High

++ Always applicable
\+ Applicable with limitations (e.g. less data, less precision)
\- Not typical

After understanding the key characteristics of the modelling approaches, an appropriate model that corresponds to a country's needs and resources is selected.

The next section provides guidance and an overview of key considerations related to selecting an appropriate modelling approach.

3.3 SELECTION OF AN APPROPRIATE MODEL

When deciding about the modelling approach to be applied, fundamental characteristics of the national conditions, including the structure of the economy, industrialization level and population size, are the primary deciding factors. Depending on the structure of the economy and the scale of economic activity on the one hand, and the level of expertise, institutional background (e.g. existing agencies, existing research initiatives and past modelling experience) and data availability on the other hand, the choice can be made between simpler and more complex models.

The use of the baseline and mitigation scenarios, as well as the expected magnitude of emission reductions, also need to be considered. If the expected emission reductions from the planned mitigation actions are relatively small compared with the total baseline emissions, a higher precision in estimating the baseline emissions may be required, and a robust estimation is necessary (i.e. a more detailed modelling approach is required). On the other hand, a more detailed modelling approach is often more data-intensive, which leads to higher transaction costs for data collection. Consideration therefore needs to be given to whether the magnitude of emission reductions and the importance of mitigation action justify the resources needed to use a detailed model to estimate the expected emission reductions from that mitigation action. Moreover, the emission projection period, whether short-, medium- or long-term, has an impact on the selection of the model. The key factors that influence the choice of the model can be summarized as follows:

- Objective of developing the baseline and mitigation scenarios;
- National circumstances (sectoral breakdown, carbon intensity and population size);
- Relative magnitude of emission reductions compared with total baseline emissions.

The more complex an economy, the more complex the model required to obtain reliable results. This is illustrated in Table 5, where suggestions for typical choices of models are outlined.

Table 5

Examples of model choices suitable for different national circumstances

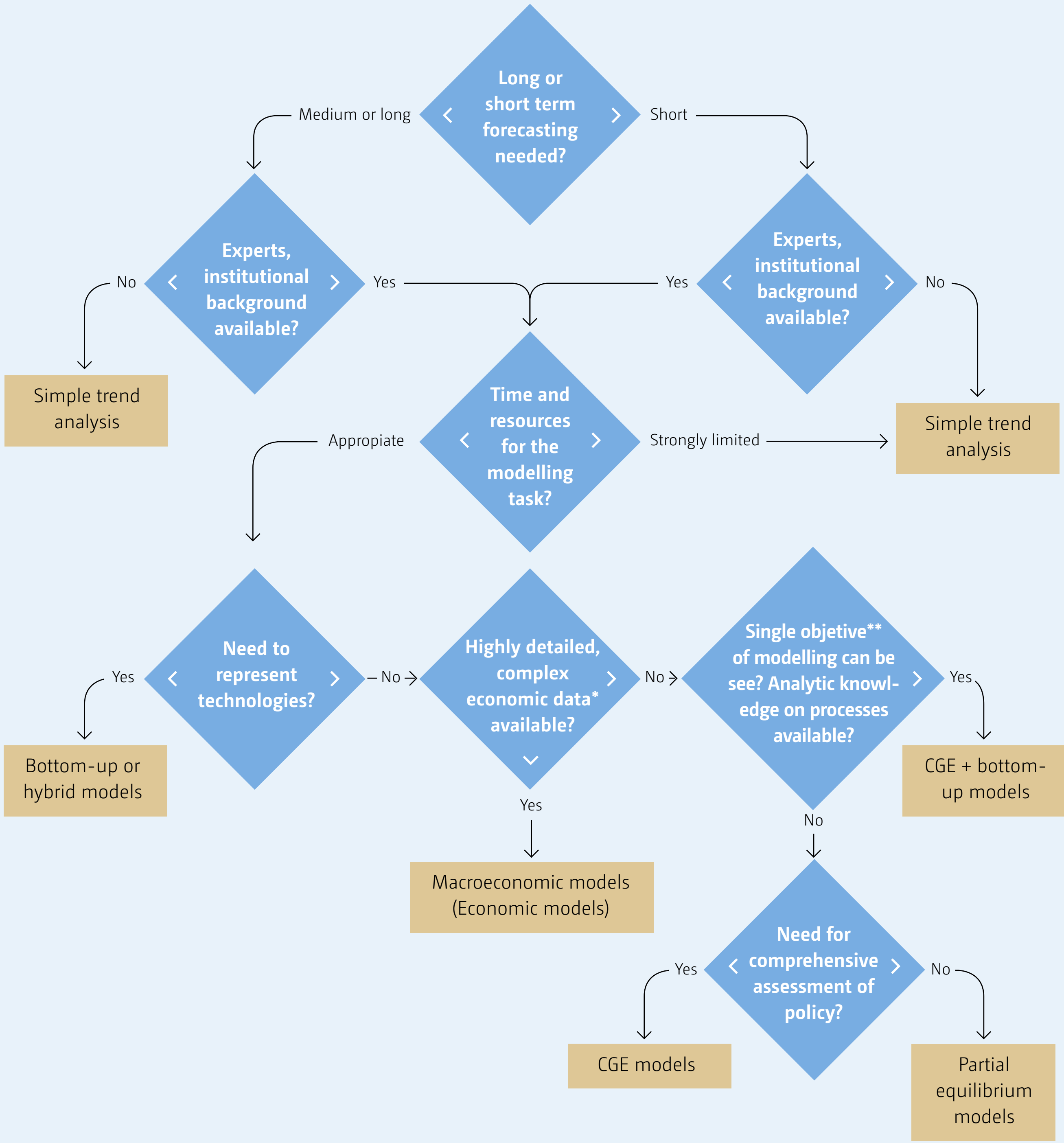
National circumstances	Suitable models	Main sources of data[a]	Costs of input data and time required for data collection
Developing country with low carbon intensity (low GDP/capita and high share of agriculture)	• Trend analysis (simple models)	• United Nations agencies, World Bank, IEA and OECD • National statistics	Low (3–6 months)
Developing country with growing carbon intensity of economy (low–medium GDP/capita, growing share of industry or services sector, e.g. tourism)	• Trend analysis • Macroeconomic models	• United Nations agencies, World Bank, IEA and OECD • National statistics • National data development (measurements and modelling)	Low to medium (3–12 months)
Advanced developing countries with high carbon intensity of economy (industry not diversified, but a few major industries)	• Trend analysis • Macroeconomic models • Equilibrium models	• United Nations agencies, World Bank, IEA and OECD • National statistics	Low (3–6 months)
Countries transitioning from high carbon intensity to a services-oriented economy (polluting industries, transforming economies, and growing services sector)	• Macroeconomic models • Equilibrium model	• National statistics • Specialized technical agencies (IRENA and IEA) • National data development (measurements and modelling)	Low to medium (3–12 months)

Abbreviations: GDP = gross domestic product, IEA = International Energy Agency, IRENA = International Renewable Energy Agency, OECD = Organisation for Economic Co-operation and Development.

[a] More information on data sources can be found in Annex 2.

After identifying the appropriate model that matches the economic complexity of the country, there is still a range of possibilities to choose from. Figure 4 provides a flow chart for selecting an appropriate model that matches the modelling needs and economic complexity of a country, as well as the national circumstances.

Figure 4
Flowchart for selecting an appropriate modelling approach



* Data on the structure of the economy, interactions of markets, price elasticity of demand, international trade balance, consumer preferences and other data.

** For example, minimal social cost of complying with emission cap, attainment of an emission cap for the economy or the industries that the cap covers, and least cost expansion of the power system.

Abbreviation: CGE = computable general equilibrium.

The concept behind Table 5 is that for a country whose economy has a less complex structure, a simpler model (e.g. trend analysis or simple simulation model) might not present significant bias from that which a more complex and sophisticated model would predict. In more complex economies, macroeconomic and equilibrium models are more appropriate, which can represent this increasing complexity to a sufficient extent. In addition, resource requirements should be commensurate with the chosen complexity of the model.

It is also worth noting that even though more detailed tier 3 models might provide a more adequate simulation of GHG emission scenarios, it is not guaranteed that higher-tier models always provide more robust results. Sometimes, simpler tier 1 approaches based on actual data can provide more robust results than tier 3 models built using limited data and many assumptions. Therefore, it is always recommended to adapt the choice of a model to data availability. The following section provides an overview of data sources and introduces ways of overcoming data scarcity.

3.4 DEALING WITH SCARCITY OF DATA

Using complex models is challenging when data are scarce and available data do not meet the data requirements of a model to project baseline and mitigation scenarios. In such cases, simple forecasts of GHG emissions based on population growth forecast, a per capita energy demand forecast and carbon intensity forecasts (e.g. through the Kaya Identity or the ASIF decomposition described in section 2.3.2 above) may be the best option.[11] If more sophisticated models are not available due to a lack of detailed data required for their use, another approach to forecasting GHG emissions is to assume that the trends in the reduction of the carbon intensity of the economy (e.g. reducing CO_2 emissions per unit of GDP) are constant or to follow historical trends. An example of using this approach is the GACMO[12] model of the United Nations Environment Programme (UNEP) Technical University of Denmark (DTU) Partnership.[13] This simplified approach – although not entirely accurate as changes in the carbon intensity of the economy are influenced by many factors – yields relatively robust results in cases where few structural changes are likely to occur in the economy of the respective country during the projected period.

A more sophisticated approach can be taken if local or national data on the expected GDP growth rate or trends in energy intensity (e.g. from the forecast of structural changes) or carbon intensity (e.g. from inclusion of renewable energy in the future energy mix) are available. These data can be used to refine the extrapolation of the historical trends by including an autonomous improvement factor in energy intensity. Such data can be obtained from various sources, for example from the International Institute for Applied Systems Analysis (IIASA) Scaling Dynamics of Energy Technologies (SD-ET).[14] The SD-ET analysis uses historical examples of scaling at the level of both individual technologies and entire industries for a number of key markets and selected energy supply and end-use technologies over the last 100 years. The SD-ET results can be applied to examine future mitigation scenarios in terms of their consistency with observed historical technological scaling and market growth dynamics.

3.5 NON-ENERGY RELATED EMISSION SCENARIOS

In countries with widespread deforestation or where agriculture is responsible for a significant share of total na-

[11] Examples of the application of the Kaya Identity and the ASIF decomposition can be found in: IPCC. E*missions Scenarios*. p.92. Available at <https://www.ipcc.ch/pdf/special-reports/emissions_scenarios.pdf> See also Kojima M and Bacon R. 2009. *Changes in CO_2 Emissions from Energy Use: A Multicountry Decomposition Analysis*. World Bank. Available at <http://siteresources.worldbank.org/EXTOGMC/Resources/co2_emissions1.pdf>

[12] Greenhouse Gas Abatement Cost Model – GACMO.

[13] See <http://www.cdmpipeline.org>

[14] See <http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/Scaling-Dynamics-of-Energy-Technologies1.en.html>

tional GHG emissions, mitigation actions in reducing deforestation (such as through REDD-plus[15]) or measures in the agriculture sector may offer a large mitigation potential. In such countries, the agriculture, forestry and other land use (AFOLU) sector needs to be included in the national GHG baseline emission scenarios in order to quantify the mitigation effect of these actions. Detailed guidance on developing GHG emission scenarios for the AFOLU sector is provided in volume 7 of the compendium.

Non-energy related emissions from the industrial processes, agriculture, or waste sectors are often neglected when national GHG emission scenarios are built for countries where these sectors do not represent a significant emissions source. It is also possible to use simplified bottom-up models for modelling emissions from these sectors using sector-specific indicators such as agricultural activity levels (e.g. arable land size, land-use change, livestock, manure management), forestry management indicators and industrial activity indicators, etc. (Schönhart *et al.*, 2012). Detailed guidance on constructing GHG emission scenarios for these sectors is provided in the respective volumes of the compendium.

3.6 DATA SOURCES

To develop national GHG emission scenarios, an appropriate model needs to be selected, which, in turn, has specific data requirements. The more sophisticated the model, the more complex and extensive the required data. An overview of the data requirements of key model types is presented in Table 6.

Table 6
Data requirements of key model types

Model type	Data requirements
Trend analysis	• Data on the structure of the economy (e.g. the relative importance and added value of economic sectors, past trends, activity rates, population growth rates, unemployment rates, energy data (sectoral, sources), forecasted growth rates, forecasted energy prices, exchange rates, basic energy conversion data) • Constraints, caps from policies and measures
Macroeconomic models	• Structural data (e.g. population, gross domestic product (income, production, expenditure breakdown), capital, foreign direct investment, price level, wages, inflation) • Prices of different energy types (electricity, district heating, natural gas, etc.) • Prices of consumer goods or services • Assumed autonomous energy efficiency improvement • Total private consumption (e.g. consumer goods, services and durable goods) • Investments (increase in productive capital) • Products (real inventories and inventory/sales ratios of enterprises) • Data on foreign trade (volume and value of exports/imports) • Interest rates (e.g. depending on model requirements, risk-free rate, market rate and prime rate) • Exchange rates and stock price indices • Constraints, caps from policies and measures

[15] In decision 1/CP.16, paragraph 70, the Conference of the Parties encouraged developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following activities: reducing emissions from deforestation; reducing emissions from forest degradation; conservation of forest carbon stocks; sustainable management of forests; and enhancement of forest carbon stocks.

Model type	Data requirements
General equilibrium models	• Tables of transaction values, showing, for example, the value of one sector's output used by another sector as input (e.g. refined oil used in the chemical industry), commodities, primary factors of production and types of household • Price elasticities (of substitution), dimensionless parameters that capture behavioural response (e.g. export demand elasticities specifying the extent to which export volumes might fall, if export prices increase) • Costs of production, costs of implementation measures, market imperfections, macroeconomic relationships (multiplier effects, price effects) and macroeconomic indicators (gross national product, employment) • Bilateral imports, factor demands (e.g. inputs used for production: capital, labour and natural resources) • Taxes, sales taxes, export/import taxes, income taxes and other taxes • Complex preferences, intangible costs, capital constraints, attitudes to risk, uncertainty and market barriers. These data are typically based on an economic analysis of market actors and characteristics and are specific to the given sector/economy • Constraints, caps from policies and measures

To gain a better understanding of the relative data intensity of key types of models so as to select an appropriate model that matches data availability, Table 7 provides a schematic comparison of the data requirements of the model types described above.

Table 7
Comparison of the data requirements of key model types

	Trend analysis	Macroeconomic models	Partial or general equilibrium models
Gross domestic product growth (aggregate and/or sectoral)	•		
Interest rates	•	•	•
Exchange rates	•	•	•
Stock price indices		•	•
Economic data (structural data, added values)	•	•	•
Population, employment	•	•	•
Capital		•	•
Foreign direct investment flows		•	•
Market data		•	•
Prices, price forecasts	•	•	•
Macroeconomic relationships (multipliers, price effects)		•	•
Behavioural data (preferences, risk aversion, uncertainty)			•

After selecting the model to be applied and understanding the data requirements associated with its use, the demanding task of data collection begins. Data collection should start with an initial assessment of available data sources in order to achieve a comprehensive overview of available data for projecting GHG baseline and mitigation scenarios.

3.6.1 National data sources

The basic data needed for modelling using top-down approaches usually comes from national statistical institutions and agencies, and government bodies, which are specific to each country. Depending on the sectoral scope and the model applied, large sets of additional data might be required. In general, national official data and statistics may be more reliable because government agencies and statistical offices have an obligation to conform to given standards. Thus, data from such agencies may be of higher quality and more representative. The drawback is that official statistics take a relatively long time to develop and become available. However, preliminary data sets might be available (e.g. GDP statistics).

After identifying the sectors that are the largest contributors to total national GHG emissions and including these sectors in the scope of modelling, the sector-specific data requirements can be formulated. Typical national data sources for modelling a baseline scenario in the energy sector are listed in Table 8.

Table 8
Typical national sources of data required for modelling the energy sector using a computable general equilibrium model

Typical data requirements	Typical sources of data
Energy balance: for each sector	• National energy balance published by the Ministry of Energy
Energy intensity of the economy: for each sector	• National energy balance published by the Ministry of Energy • Power consumption data from national grid operators • National production statistics • National input–output-tables • Plant-level data from manufacturers
Structure of energy supply (energy source, main characteristics of energy policy, institutional structure, ownership of installations, identification of policymakers, regulators and energy project owners)	• National energy statistics • National energy regulatory office • Ministry of Energy • Non-governmental organizations • Annual energy bulletins of the government offices (if applicable)
The market structure for electricity and heat (whether prices are free or regulated, who can participate on the supply side and as intermediaries, and whether energy is traded in derived forms)	• National energy regulatory office • Ministry of Energy
Structure of consumption by end-use	• National energy statistics • National energy regulatory office • International energy-related databases
Importance of other country-specific factors such as local climate (heating/cooling), district heating, etc.	• UNFCCC national communications;

Source: Adapted based on International Atomic Energy Agency, 2001.

3.6.2 Alternatives to national data sources

If countries do not have national sources for use as input data, they may rely on data sets produced by acknowledged international organizations such as United Nations organizations, the World Bank, the International Monetary Fund (IMF) , the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA). International sources of data are listed in Sources of default data, including details of the institutions that provide them.

Most of the models contain a reference technology database, which includes technological parameters, and emission factors for processes, sectors, energy production and power generation. One such example is the DECADES[16] modelling system developed by the International Atomic Energy Agency (IAEA), which uses a comprehensive, harmonized set of technical parameters, economic characteristics and environmental data for energy chains (IAEA, 1995; and IAEA, 2000). Another example is the renewable energy technology cost and performance assessment system and database provided by the International Renewable Energy Agency (IRENA) as part of its REmap programme[17] (renewable energy road map), which provides a tool and assessment methodology for assessing accelerating renewable energy uptake to 2030. The tool also includes inputs from IRENA databases such as the Global Atlas and costing database that contains data from over 9,000 utility-scale projects collected from its Renewable Costing Alliance.[18]

A more recent and updated example is the TIMES model,[19] which uses reference technology data (Energy Technology Database (ETDB)).[20] An obvious advantage of using such a source of reference technology data is that it allows for a quick start and faster development of scenarios. Moreover, it can be considered as a well-established, peer-reviewed data set. In cases where developing countries aim to use state-of-the-art technologies, and the technology in itself is not significantly country-specific, this allows international technology data to be adapted to the national circumstances. However, the validity of the international data in the specific context of a host country has to be cross-checked with available local data or proxy information (e.g. data on local maintenance practice, fuel quality and other parameters).

The new reference scenarios developed by the IPCC for socioeconomic development can also be applied to national circumstances (e.g. IPCC shared socioeconomic pathways (SSPs)[21]). While these scenarios are designed over a long time frame until 2100, they provide an internationally recognizable source that may help to improve coherence among GHG emission baselines for countries over time.

Data from the national GHG inventory of a country's national communication can be used where available. If such data are not complete, new estimates of emissions using default values can be calculated using default IPCC emission factors and relevant activity data (e.g. total fuel use in a country). Where local data are not available, data on energy use from international organizations (e.g. IEA,[22] WRI[23] or the Emissions Database for Global Atmospheric Research (EDGAR))[24] may be used to fill gaps. Historical data for population and GDP may be used from international organizations (e.g. IMF[25] or the World Bank[26]).

The checklist for establishing post-2020 emission pathways developed by PMR (PMR, 2015[27]) of the World Bank Group[28] provides useful sources of information from international organizations such as the World Bank, IEA and the United States Department of Agriculture,[29] which provide future estimates of population, GDP, energy demand and supply, and commodity markets.

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[16] DECADES is the inter-agency joint project on data bases and methodologies for comparative assessment of different energy sources for electricity generation. For more information on the project, see IAEA (1995) and IAEA (2000).

[17] See <http://www.irena.org/remap/>

[18] See <http://costing.irena.org/>

[19] TIMES stands for the Integrated MARKAL-EFOM System. MARKAL (MARket Allocation model, Fishbone *et al.*, 1981, 1983, Berger *et al.*1992) and EFOM (Van Voort *et al.*, 1984) are two bottom-up energy models, which inspired the structure of TIMES. For more information, see <http://iet.jrc.ec.europa.eu/>

[20] This is an online centralized database for sharing technical and economic characteristics of energy technologies between technology experts and modellers at JRC in Ispra, Italy. Further information is available at <https://www.iea.org/media/workshops/2014/egrdmodellingandanalyses/3_Sgobbi.pdf>

[21] See <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about>

[22] See <http://www.iea.org/statistics/>

[23] See <http://www.wri.org/resources/data_sets>

[24] See <http://edgar.jrc.ec.europa.eu/#>

3.7 UNCERTAINTY AND SENSITIVITY ANALYSIS

During the development of baseline and mitigation scenarios, experts often face a trade-off between resources used and time available for the tasks, and the accuracy and reliable forecasting ability of the models used. In all models, input parameters are, to a certain extent, uncertain owing to measurement problems or other problems that increase the uncertainty of the parameters. The modeller is likely to be aware of the uncertainty of the current values and the future values used; this applies to factors such as prices, costs, productivity and technology. In general, the sensitivity analysis is defined as the study of how uncertainty in the output of a model can be attributed to different sources of uncertainty in the model input. If the parameters are uncertain, the sensitivity analysis can provide information such as:

- The sensitivity of the model outputs to changes in parameter values;
- The size of the change that would be necessary to alter the optimal solution (or the ranking of solutions);
- How the values of key parameters and indicators influence the optimal solution;
- The extent of the negative consequences if the decision makers ignored the changed circumstances and continued to use the originally selected strategy.

Besides the uncertainty of the parameters, modelling is always subject to uncertainties that result from the assumptions and approaches used in the model design. These "model uncertainties" or "systematic uncertainties" may be as important as the above parameter uncertainties and need to be taken into account in interpreting model results. For these reasons, a sensitivity analysis is frequently used (see, e.g., Saikku and Soimakallio, 2008). More sophisticated means also exist to estimate the combined effect of multiple input variables (e.g. the Monte Carlo simulation). More detail on the sensitivity analysis and uncertainty is provided in Annex 3.

3.7.1 Example of uncertainty analysis

An example of the sensitivity analysis is the analysis conducted for the 2012 GHG emission projections of Northern Ireland.[30] Throughout the analysis, several parameters were varied, namely: gross value added, the future levels of renewable electricity generation, assumptions on European Union (EU) legislation to control fluorinated GHG emissions, fuel prices in the domestic sector, assumptions on building regulations policy, vehicle policy, fuel prices in the transport sector, cattle numbers, and afforestation rates.

The analysis found that a 0.5 percentage point increase in annual average gross added value growth lowered the overall projected 2025 emission reduction by 2.6 percentage points. Conversely, a 0.5 percentage point decrease in annual average economic growth led to an additional 2.4 percentage point emission reduction. This would suggest that variable economic conditions could lead to an emission reduction in the range of 30.7–35.7 per cent between 1990 and 2025. With such an analysis, modellers can estimate the uncertainty of the modelling results. This can be used to select variables that have a large impact on emissions, and adapt policies that target these variables.

Another example of informing policymaking with the results of the sensitivity analysis is the sensitivity analysis of the energy sector undertaken in South Africa in the framework of the development of the country's long-term mitigation scenarios (Hughes *et al.*, 2007). The sensitivity analysis of energy prices has been undertaken for oil, gas and petroleum prices. For coal, natural gas and nuclear fuel prices, the price ranges were quite broad (e.g. for oil from USD 55/bbl in 2003 rising to USD 100/bbl in 2030, and similar rates for other fuels). Surprisingly, only changes in coal price had a significant impact, as an increase in coal price reduced emissions by around 1,400 Mt CO_2 eq, mainly by reducing the capacity of synfuel[31] plants (Winkler, 2007).

[25] See <http://www.imf.org/external/pubs/ft/weo/2015/01/weodata/download.aspx>

[26] See <http://databank.worldbank.org/data/home.aspx>

[27] See <https://www.thepmr.org/>

[28] See <https://www.thepmr.org/>

[29] See <http://www.fas.usda.gov/commodities> and <http://www.usda.gov/oce/commodity/index.htm>

[30] See <http://www.doeni.gov.uk/ni-ghg-projection-tool-sensitivity-analysis-2014.pdf>

[31] Plants in the petrochemical industry that produce synthetic fuel.

3.8 CONSIDERATIONS FOR DEVELOPING COUNTRIES

3.8.1 Coverage of sectors and greenhouse gases

The scope of a baseline and mitigation scenario involves decisions on which GHGs to include in the projection (e.g. CO_2 only, the GHGs covered by the Kyoto Protocol, or the GHGs included in the UNFCCC reporting guidelines)[32] Further, it is important to decide which emitting sectors or sources to include. National emissions can be broken down in a number of ways, for example by economic sector or according to emission sources, as recommended in the 2006 IPCC Guidelines.[33]

Developing countries face a number of challenges, including limited capacity, experience and human resources, as well as weak or absent institutional arrangements. One of the ways to deal with these challenges and use available resources most effectively could be to focus on those sectors of the economy that are major contributors to total national GHG emissions or on those sectors where most mitigation actions are planned to take place.[34]

To identify the sectors that are major contributors to total national GHG emissions, the GHG emission contribution of each sector needs to be estimated, the sectors need to be ranked according to their relative contribution to total national GHG emissions, and the sectors of the economy that are cumulatively responsible for 80, 90 or 95 per cent of total national GHG emissions are selected for inclusion in the baseline GHG emission projections.[35] This approach is similar to the key category analysis in IPCC inventories (IPCC, 2006).

Another key element to consider when defining the coverage of sectors and/or gases in a national GHG baseline and mitigation scenario is the range of existing or planned mitigation actions. Economic sectors in which mitigation actions are planned should be included in the baseline scenario in order to estimate and track the mitigation impact of these actions compared with national GHG baseline emissions. It is important to highlight that for some mitigation actions, sectoral baselines may not be appropriate for estimating and monitoring emission reductions, and the baseline for a specific mitigation action should be developed using more detailed and disaggregated data than that used for constructing sectoral baselines (for more information, see the volumes of the compendium that cover individual sectors).

3.8.2 Ways of addressing gaps in national data and expertise

A source of good examples of addressing gaps in the national data and expertise required to develop national GHG emission scenarios is contained in the Low Emission Capacity Building Programme (LECBP)[36]. Under this programme, data sets for emissions from energy and non-energy sectors have been developed using the LEAP[37] model and data from international sources. Data sets covering historical data for the period 1990–2009 were used to develop simplified projections of GHG emissions for the period 2010–2040 for 22 countries, for which international data were available. The projected national baseline GHG emissions were developed to support mitigation assessment in each of the 22 countries serving as a starting point for the assessment. The international data sources used include IEA, the World Bank, the IPCC, the World Energy Council, EDGAR[38] and United Nations organizations.

Since the national GHG inventory is one of the key methodological aspects of GHG emission scenario building (see

[32] See, for example, the Guidelines for the preparation of national communications from Parties not included in Annex I to the Convention available at <http://unfccc.int/resource/docs/cop8/07a02.pdf#page=2> and the Biennial update reporting guidelines for Parties not included in Annex I to the Convention available at <http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf#page=39>

[33] <http://www.ipcc-nggip.iges.or.jp/public/2006gl/>

[34] In the ideal scenario, the entire energy system should be covered.

[35] An example of the application of this approach is Guyana, which focuses on the forestry sector (and associated baseline GHG emissions) as the most important economic and GHG-emitting sector in its Low Carbon Development Strategy (2010); available at <http://www.lcds.gov.gy/>

[36] See <http://www.undp-alm.org/resources>

[37] Long-range Energy Alternatives Planning.

[38] See <http://edgar.jrc.ec.europa.eu/#>

[39] See <http://www.undp.org/content/dam/undp/documents/projects/ZMB/00061806_Low%20Emissions%20Capacity%20Building%20Project.pdf>

section 2.2 for more information), the case of Zambia[39] can serve as a good example of addressing the gap related to the absence of formalized institutional arrangements for GHG inventory management, poor data quality and lack of expertise. More specifically, in addition to the absence of formalized institutional arrangements, the country faced the following limitations when calculating national GHG emission projections:

1. Lack of quality data and associated poor data management during the preparation of the GHG inventory as part of the preparation of the second national communication;
2. Lack of reliable data for the land use, land-use change and forestry (LULUCF) sector and relevant default emission factors;
3. Lack of expertise and resources to undertake the GHG inventory work.

The example of Zambia shows that capacity-building support provided in the framework of LECBP can assist countries in establishing institutional arrangements and collecting data for reliable GHG emission projections. LECBP has involved training on the use of software based on the 2006 IPCC Guidelines for determining GHG emissions from the AFOLU sector and has supported the development of the GHG inventory management plan, data collection methodologies, and quality assurance/quality control guidelines. In addition, Zambia benefited from the work undertaken in the framework of the European Space Agency's Greenhouse Gases Climate Change Initiative.[40]

Another good example of addressing gaps in data is the case of Malaysia,[41] where a national GHG emission baseline scenario has been prepared with support from LECBP. To address data gaps, a number of international data sources were consulted to collect data on population, GDP and economic variables, and energy demand and supply, which were then used as inputs to the LEAP model to project energy use and emissions in the agriculture, industry and services sectors. Further information on the sources of data for each type of input is provided below. Demographic data were obtained from the United Nations *World Population Prospects* report (United Nations, 2010[42]). Macroeconomic data were sourced from the World Bank's World Development Indicators (WDI) (World Bank, 2012). In addition, a number of data sets were extracted from the World Bank WDI database, including historical estimates of GDP, estimated both in terms of market exchange rates and purchasing power parity. Units for both types of data are in constant international dollars. In addition to overall GDP estimates, the WDI also provide historical data on how GDP has been calculated from the economic value added from the agriculture, industry and services sectors. The data were used to calculate the historical value added shares for these three "macro sectors", which, in turn, were used as inputs in the LEAP model to project energy use and GHG emissions in the agriculture, industry and services sectors. Finally, comprehensive historical data on energy demand and supply for the period 1990–2009 were obtained from the IEA database of world energy balances (IEA, 2011). These data included information on final energy consumption by fuel in each major energy demand sector, namely households, services, industry, transport, agriculture, and non-energy/non-specified uses. All of the data sets were used as input parameters to prepare the GHG emission baseline scenario of Malaysia[43] and enabled the country to address the gaps related to the absence of good quality national data.

3.9 EXAMPLES OF APPLICATIONS OF TOP-DOWN MODELS

The following examples introduce case studies that help illustrate the application of models of different levels of complexity and data requirements to develop national GHG emissions scenarios.

3.9.1 Simple spreadsheet-based model

The GACMO model is a simple spreadsheet-based model that can be used to prepare national baseline and mitigation scenarios and assist in the analysis of GHG mitiga-

[40] See <http://www.esa-ghg-cci.org/>

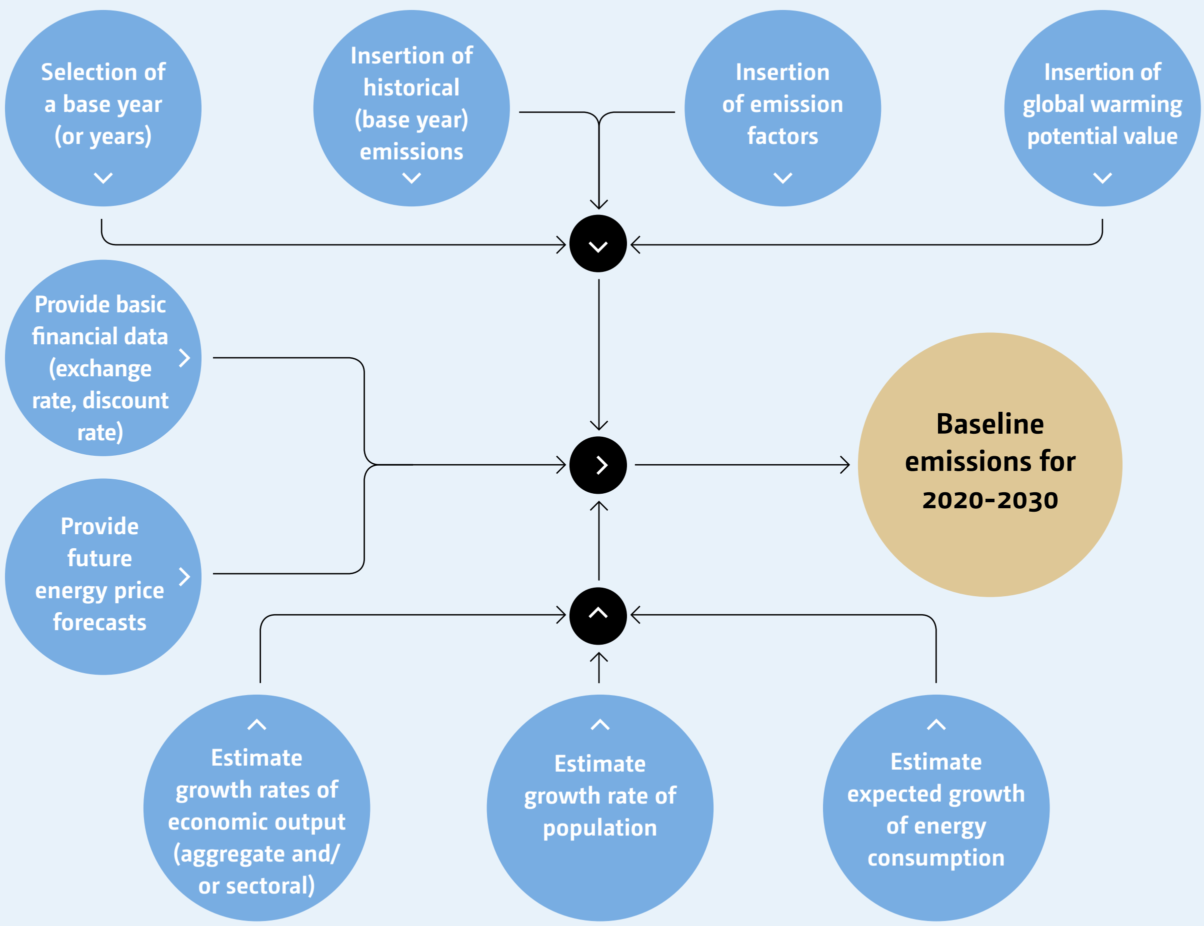
[41] See <ftp://forums.seib.org/LECB/CountryReports/Malaysia_3.0.docx>

[42] See <http://www.un.org/en/development/desa/population/publications/pdf/trends/WPP2010/WPP2010_Volume-I_Comprehensive-Tables.pdf>

[43] United Nations Development Programme Environment and Energy Group. Live Report on Basic Reference Emissions Scenario for Malaysia. See <www.undp.org>

tion options for a country. The input required to run the model is a GHG balance for the country in question and the key output of the model is a table with an overview of emission reductions and abatement costs of different mitigation actions that can also be generated in the form of an abatement cost curve. Figure 5 illustrates a typical flow chart for applying the GACMO model. The choices in approaches to using the GACMO model include assumptions about the growth rates of economic output – which can either be the projections of the aggregate national-level GDP growth rate, or disaggregated into sectoral forecasts of GDP growth rates in individual sectors – and the choice of developing and including sub-scenarios of socioeconomic development and technology development. These parameters are multiplied by the relevant emission factors (country-specific or IPCC default values) to develop the national-level baseline emission scenario. Box 2 provides further detail on the modelling steps and examples of data sources to be used in the modelling.

Figure 5
Flow chart for applying the GACMO[a] model to project national greenhouse gas baseline emissions for a country with emissions dominated by the energy sector.



[a] Greenhouse Gas Costing Model.

Box 2

Steps to develop national baseline emissions using the GACMO[a] model

The first modelling step includes entering data into the model on the national greenhouse gas (GHG) emissions in the base year. A possible source of these data is the national GHG inventories reported under the Convention, historical emissions of the World Resources Institute, or other sources such as the Emissions Database for Global Atmospheric Research. Emission factors for various fuel types are obtained from national data, or emission factors defined by the Intergovernmental Panel on Climate Change could be used. The global warming potential values also need to be entered if values other than the default values available in the model are used.

The next step is to enter into the model the estimated population and GDP growth rates for the projected periods (2010-2020, 2020-2025 and 2025-2030). Possible sources for these data are United Nations population forecasts and macroeconomic forecasts from the World Bank, such as the World Development Indicators (World Bank, 2012). The expected growth in energy consumption then needs to be entered for the respective sectors.

Other data needed for modelling are the currency and exchange rate, discount rate, and energy prices for the projected period. Energy price forecasts can be obtained from international sources, including the International Energy Agency and the International Institute for Applied Systems Analysis (information on additional international data sources is provided in annex 2).

Based on these data, the GACMO model calculates the GHG emission baseline for the years 2020, 2025 and 2030. The GACMO model is available through the United Nations Environment Programme/Technical University of Denmark Partnership (see <www.cdmpipeline.org> or <www.namapipeline.org>).

[a] Greenhouse Gas Abatement Cost Model.

3.9.2 General equilibrium model: NCAER-CGE model

The NCAER-CGE[44] model is a CGE model developed by India's National Council of Applied Economic Research (NCAER) and used by the Government of India to develop a baseline emission forecast for India (MoEF, 2009). The NCAER-CGE model is a top-down, non-linear general equilibrium model, simulating central government interventions and market conditions with profit and utility-maximizing agents. The model includes sectoral interactions and feedbacks and iterates simulations of the economy to equilibrium. The model's main inputs are population, global energy prices, foreign capital inflows, savings rates and labour participation rates. The main outputs are emissions in tonnes of carbon dioxide equivalent (CO_2 eq),[45] GDP, energy and CO_2 eq intensity, final demand for goods, and costs of mitigation policies. The country is assumed to be an open economy on the global market; nonetheless, domestic prices are endogenous in the model. The NCAER-CGE model is aimed at simulating the effects of a particular policy and parameter assumptions. There is no economy-wide objective function. The key attributes of the model are as follows (MoEF, 2009):

- Primary energy sectors consist of fossil, renewable and nuclear energy sources; it is possible to include dynamic supply constraints for each energy form;
- GHG emissions are estimated using fixed emission factors for each energy source (where applicable) and for individual industrial processes;
- Factors of production (labour, capital and land) are included for the agriculture and forestry sectors;
- Consumers maximize utility and producers maximize profits;
- 'Armington' aggregation is used for domestically produced and imported commodities, as well as for different energy sources;
- Government expenditure is modelled with a fixed share of income, which can be varied dynamically;

[44] A computable general equilibrium (CGE) model of India's National Council of Applied Economic Research (NCAER).

[45] CO_2 eq consists of CO_2 and nitrous oxide (N_2O) emissions converted into CO_2 eq using global warming potential values.

- Technological change is an exogenous model input described in terms of "total factor productivity growth" (TFPG) and "autonomous energy efficiency index" (AEEI);
- Policy variables include a full set of direct and indirect taxes, subsidies, and export and import taxes.

Table 9 provides an overview of the data requirements of the NCAER-CGE model and data sources used to forecast India's national GHG emissions. The modelling results obtained using the NCAER-CGE model to project India's national GHG emissions are presented in Table 10 below.

Table 9

Data requirements of the NCAER-CGE model and data sources used for modelling the national greenhouse gas emissions of India

Population	Global/domestic energy price projections	Gross domestic product growth rate	Foreign savings projections	Domestic savings rate	Greenhouse gas emission factors
Registrar General of India (until 2026, extrapolated at same rates until 2030)	International Energy Agency (World Energy Outlook 2007) for International projections, endogenous (i.e. calculated by the model) for domestic projections	Endogenous, (i.e. calculated by the model)	Expert studies	National account statistics	National communication of India

Source: Ministry of Environment and Forests of India, 2009.

Table 10

Forecast of India's national greenhouse gas emissions using the NCAER-CGE model

GHG emissions in 2030-2031 (billions of tonnes of CO_2 or CO_2 eq)	Per capita GHG emissions in 2030-2031 (tonnes of CO_{2e} eq per capita)	CAGR of GDP up to 2030–2031 (%)	Commercial energy use in 2030–2031 (Mtoe)	Fall in energy intensity (%/year)	Fall in CO_2 (or CO_{2e}) intensity
4.00	2.77	8.84	1087	3.85	From 0.37 kg CO_{2e} to 0.15 Kg CO_2 eq to 0.15 kg CO_2 eq per USD GDP at PPP from 2003-2004 to 2030-2031

Source: Ministry of Environment and Forests of India, 2009.

Abbreviations: CAGR = compound annual growth rate, GDP = gross domestic product, GHG = greenhouse gas, PPP = purchasing power parity.

3.9.3 General equilibrium model: ENPEP-BALANCE

The application of the ENPEP-BALANCE[46] model to project the national baseline GHG emissions for the Czech Republic is another example (for more information, see Pajter and Havlas, 2001). The key assumptions used for the projections are presented in Table 11. and Havlas 2001). The key assumptions used for projections are presented in Table 12.

Table 11

Key assumptions used for projecting the greenhouse gas baseline emission scenario of the Czech Republic using the ENPEP-BALANCE model

Aspect	Assumptions
Base year/end year	• 1999/2020
Political framework	• Fast accession to the EU • Membership in 2004
GDP growth total and split by sector	• Moderate growth rate (about 2.5%)
Structural changes in the economy	• Moderate structural changes
Real household income	• Moderate real income growth
Population growth	• Common scenario: stabilization
Housing stock growth split by dwelling category	• Low growth rate (only two thirds of demand is covered)
Transport performance by mode	• Moderate growth rate • Small structural changes
Development of commercial and public services	• Moderate growth rate (2.9%/annum)
Discount rate	• Common scenario set by the central bank models
World energy prices	• Growth rate (USD 25 per barrel of oil in 2020)
Energy pricing and taxation policy	• Fast opening energy market
Government environmental protection policy, emission restrictions and reduction targets (except CO_2 emissions)	• Fast harmonization with the EU
Power and heat generation assumptions	• Baseline assumptions as set in the national energy plan • A new nuclear power plant is commissioned

Source: Pajter and Havlas, 2001.

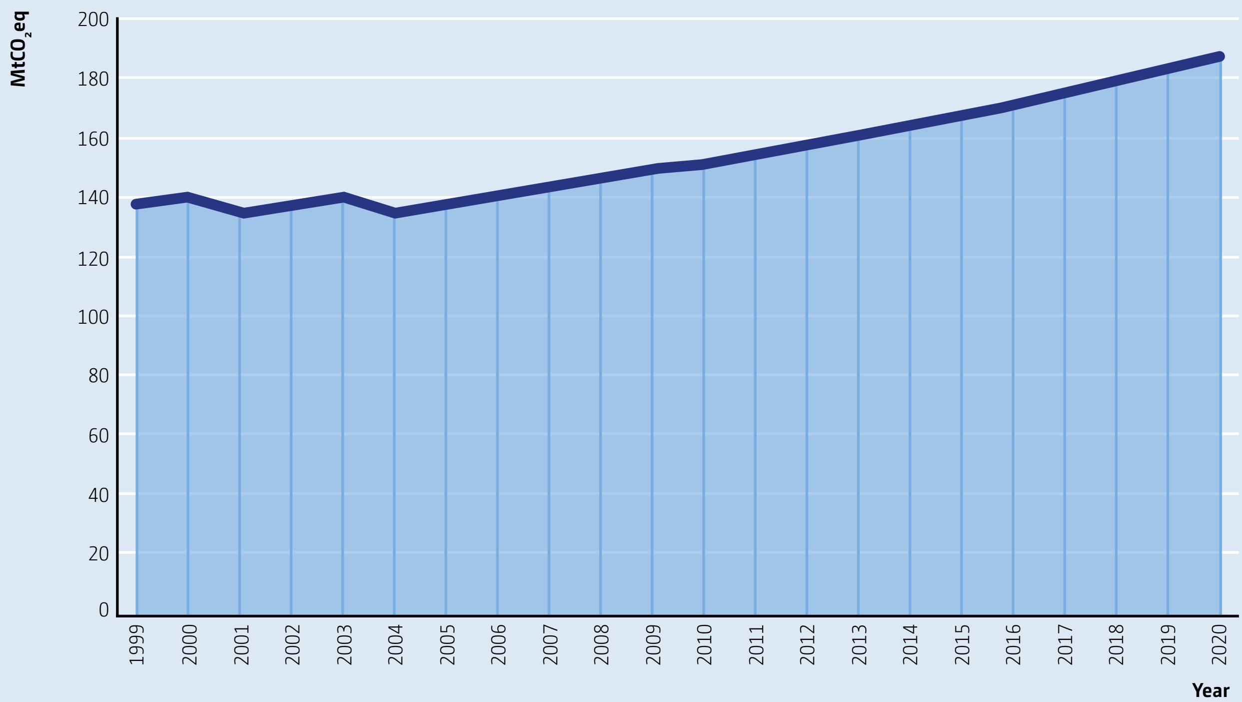
Abbreviations: EU = European Union, GDP = gross domestic product.

[46] BALANCE module of the Energy and Power Evaluation Program (ENPEP) model.

In addition to the assumptions mentioned in Table 11, inflation rate, interest rate (discount rate) and exchange rate forecasts were developed and used in modelling. A network of energy sectors, including supply, conversion and demand, were then modelled. In addition to developing the detailed grid of sectoral interconnections, a forecast of production of selected energy-intensive products was developed for the most important Czech industries. Based on these inputs, the national GHG baseline emissions were projected, as presented in Figure 6 below.

Figure 6

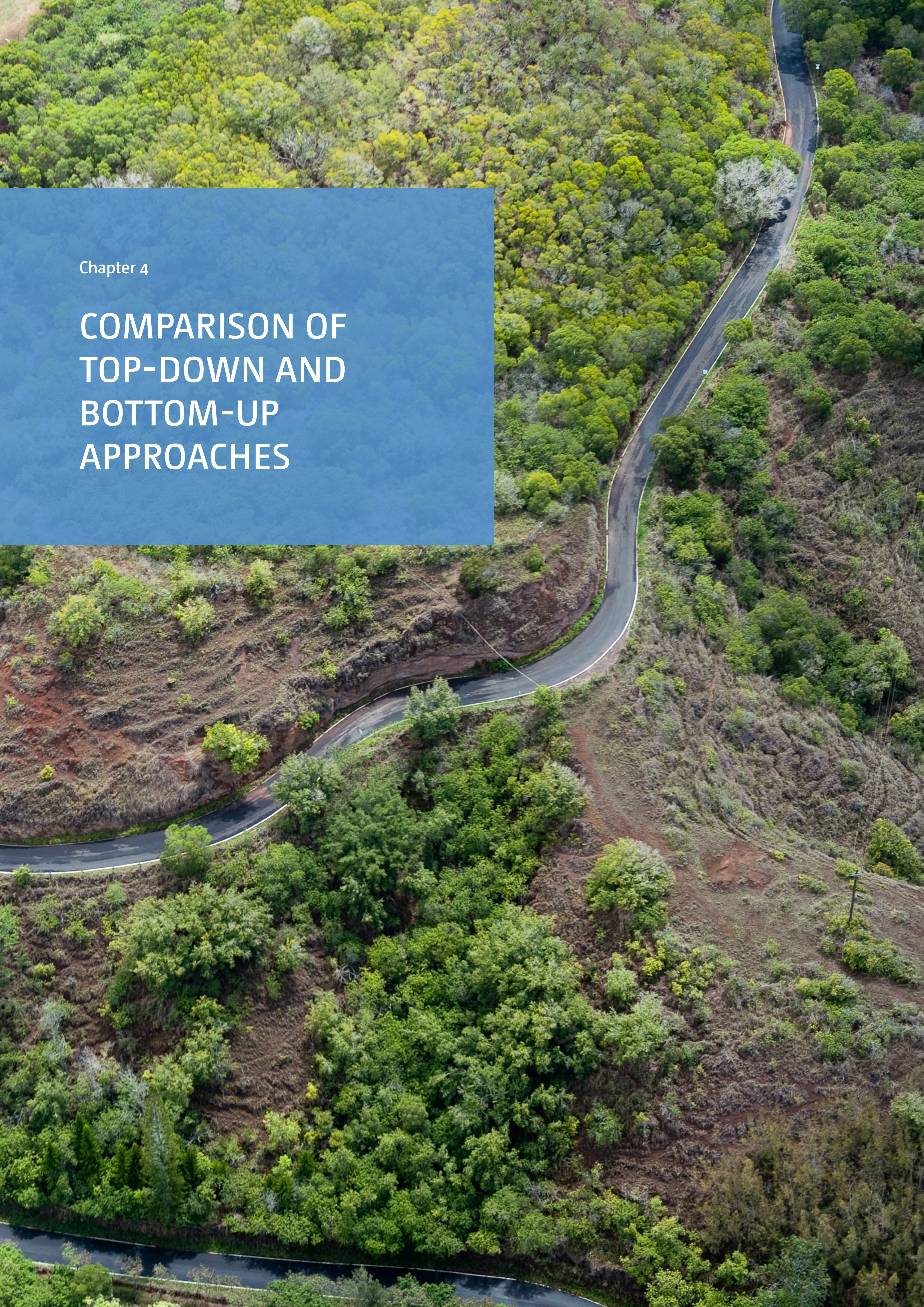
Projections of the national baseline emissions of the Czech Republic using the ENPEP model



Source: Pejter and Havlas, 2001.

Chapter 4

COMPARISON OF TOP-DOWN AND BOTTOM-UP APPROACHES



Top-down models incorporate an economic model based on economic indices of energy price and elasticity. They present the relationship between energy consumption and aggregate production, which in turn can be used for macroeconomic analysis and energy policy programming (Pan, 2005). Bottom-up models integrate detailed descriptions of technologies used for energy consumption and production (Jacobsen, 1998). Thus, bottom-up models typically predict a lower energy demand and higher energy efficiency than top-down models, leading to the notion of the energy efficiency gap. An extensive comparison can be found in Hoogwijk *et al.* (2009). At the global level, the two approaches provide comparable results. However, at the sectoral level, the results do not necessarily match.

As stated in van Vuuren *et al.* (2009), bottom-up models include more energy-system detail and insights into technology development and allow for the evaluation of a wider range of policy options. However, they lack macroeconomic feedbacks between the energy and other economic sectors, such as energy price induced changes of macroeconomic production and consumption. Top-down models add a broader economic context and the associated interactions (feedbacks and spillovers). In addition, they use a more comprehensive costs concept (i.e. income loss for the total economy versus costs for the energy system only) and, generally, the baseline scenario is consistently developed within the model. The disadvantages of this approach are that, as model calibration factors (elasticities) are determined on the basis of historic evidence, historic behaviour is assumed to be relevant for future systems as well. By definition, the representation of specific technologies and other physical parameters is poor, which makes it difficult to analyse other policies than introducing emission prices (Rutherford and Böhringer, 2006; Sugandha *et al.*, 2009). Some discrepancies between the application of top-down and bottom-up modelling approaches in specific sectors are presented below (IPCC 2001).

4.1 ENERGY SUPPLY

The most comparable results for the two approaches can be found in the energy sector, since this sector is well-defined and a high level of detail is available in the modelling tools. Furthermore, the potential to implement technologies is relatively high, and therefore technical options and market responses are not that distant compared to other sectors.

The top-down models generally tend to indicate a higher emission reduction. This may be explained in part by differences in the mitigation options that are included in the top-down models but not included in the bottom-up approach. Examples are reductions in extraction and distribution, reductions of other non-CO_2 emissions, and reductions through the increased use of combined heat and power. Further, different estimates of the inertia of the substitution are expected to play a role. In bottom-up estimates, fuel substitution is assumed only after end-use savings, whereas top-down models adopt a more continuous approach. Lastly, the top-down estimates include the effects of energy savings in other sectors and structural changes. For example, a reduction in oil use also implies a reduction in emissions from refineries. These effects are excluded from the bottom-up estimates (Koopmans and te Velde, 2001; Müller, 2000).

4.2 BUILDINGS

Top-down models often provide estimates of reduction potentials from the buildings sector, which are lower than those calculated from bottom-up assessments. This is because the top-down models examine only responses to price signals, whereas most of the potential in the buildings sector is thought to be from ‘negative cost’ measures that would be primarily realized through other kinds of interventions (such as buildings or appliance standards). Top-down models assume that the regulatory environments of baseline and mitigation cases are similar, so that any negative cost potential is either neglected or assumed to be included in the baseline.

4.3 TRANSPORT

In the transport sector, top-down methods are based on data on 'fuel sold' and part of the energy balances. The fact that fuel sales are monitored in most countries for tax purposes makes this a seemingly simple and easy way to design an energy balance. Countries also report their overall energy balance sheets to IEA. Top-down approaches, especially if based on internationally consistent data sets, also allow for comparison between countries.

The top-down approach is often considered to be more accurate in terms of total GHG emissions than the bottom-up approach because the number of assumptions and data requirements are fewer. However, a top-down approach neglects fuel adulteration, the use of fuel for non-transport purposes such as diesel generators and fuel smuggling (i.e. fuel purchased in one country and used in another) (Bongardt *et al.*, 2013). Further, it does not provide any details on emissions by subsector, mode or vehicle type. A further limitation of top-down models in the transport sector is that they only generate CO_2 emissions. For the determination of other GHGs and air pollutants, information on vehicle technology, fuel and operating characteristics at the technology level is required (Füssler *et al.*, 2016). Top-down models in the transport sector have the same issues related to mitigation measures that have 'negative cost', such as most vehicle efficiency measures, leading to an underestimation of mitigation effects.

4.4 AGRICULTURE AND FORESTRY

In the agriculture and forestry sectors, the estimates from bottom-up assessments tend to be higher than those found in top-down studies, particularly at higher cost levels. These sectors are often not well covered by top-down models owing to the spatial and temporal variability of emissions sources in these sectors that favour the use of bottom-up modelling approaches. An additional explanation is that the data from the top-down estimates include additional deforestation (negative mitigation potential) owing to biomass energy plantations. This factor is not included in the bottom-up estimates.

4.5 INDUSTRY

The top-down models tend to generate higher estimates of emission reduction potentials in the industry sector than the bottom-up assessments. One of the reasons is that top-down models allow for product substitution, which is often excluded in bottom-up sector analysis. Moreover, top-down models may have a greater tendency to allow for innovation over time.

4.6 HYBRID MODELLING APPROACHES

Hybrid approaches exist to bridge the gap between bottom-up engineering and top-down macroeconomic models by integrating the energy technology detail of the former into the macroeconomic framework of the latter. The construction of hybrid models is complicated by the need to numerically calibrate them to multiple, incommensurate sources of economic and engineering data. The differences in structure and scope of the approaches imply that each has its dedicated typical field of application in energy and climate policy analysis.

There are various hybrid modelling efforts that aim at combining the technological explicitness of bottom-up models with the economic richness of top-down models. These efforts can be broadly classified into two approaches. The first approach attempts to couple existing large-scale bottom-up and top-down models (see, e.g., Hudson and Jorgenson, 1974; and Bergman, 1990). The second approach places strong emphasis on overall economic consistency and therefore makes use of a single integrated modelling framework in order to 'hard-link' bottom-up and top-down features. Hybrid approaches are often selected once basic top-down and bottom-up modelling has been carried out and more advanced approaches are sought.

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Annex 1

MODELS AND APPLICATIONS

The models described below are well suited to national-level mitigation assessment. In most of the cases, the models can provide greenhouse gas (GHG) emissions as outputs. In some cases, indirect outputs are provided, such as energy consumption or fuel demand, which need to be multiplied with relevant emission factors to convert these outputs into GHG emissions. Table 12 provides an overview of the key outputs of the listed models, and a detailed description of each model is provided below.

Table 12
Key outputs and availability of models

Model	Tier 1/2/3	Primary output	Availability	Open source/free
3ES-MODEL	Tier 2	Energy use, emissions	NA	NA
MACRO	Tier 2	Macroeconomic aggregates	Y	Y
MAED	Tier 2	Energy use	Y	Y
ENPEP/BALANCE	Tier 2	Energy use, emissions	Y	N
GTAP-E	Tier 2	Emissions, energy use	Y	Y
EnergyPlan	Tier 2	Emissions, energy use	Y	Y
GEM-E3	Tier 2	Energy use, emissions	Y	N
VATTAGE	Tier 2	Energy use, emissions	Y	Y
LEAP	Tier 3	Energy use, emissions	Y	Y
CETM	Tier 3	Energy use, final macro-level demand	N	NA

Abbreviations: N = no, NA = not applicable, Y = yes.

- **LEAP**[47] is an integrated, scenario-based modelling tool that can be used to compare GHG impacts of alternative scenarios and assess the impact of an individual policy or measure and different combinations of multiple policies and measures. LEAP is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data input. The key advantage of LEAP is its low initial data requirements. The model provides a choice of modelling methodologies and many aspects of LEAP are optional, which allows for the creation of simple scenarios using limited data and the addition of further detail and complexity in later iterations once more data are available.

- **3Es-Model**[48] is an integrated econometric model, which consists of a macroeconomic sub-model, energy sub-model and environment sub-model. It enables simulation of the relationship of macroeconomic processes, energy and environment, and forecasting of the trend of the economy, energy and environment, under the scenarios of various emission saving targets, carbon taxes and improvements in energy efficiency.[49] The resultant output of the model provides information for decision makers when planning the long-term energy strategy and policy. The output of the models includes final energy demand and GHG emissions.

- **MACRO**[50] is a macroeconomic model, which describes the relationship of energy consumption, capital, labour force and gross domestic product (GDP) by production function (IIASA, 2004). Its objective function is the total discounted utility of a single representative producer–consumer. The maximization of this utility function determines a sequence of optimal savings, investment and consumption decisions. The model's outputs are macroeconomic aggregates which need to be converted into emissions.

- **MAED**[51] is a simulation model with a scenario development approach. In the MAED model, the structure of the final energy consumption of the country is broken down in a consistent manner, subdividing the economy into major consuming sectors and subsectors (e.g. agriculture, residential and transport). Energy consumption in each subsector is disaggregated into a multitude of end uses (e.g. space heating (services, residential), steam (industry), cooking (residential), motor fuels (transport) and others). The set of social, economic and technical factors which influence each category of end-use energy demand is then identified and the scenarios describing the evolution of social, economic and technical factors are constructed based on these inputs. These scenarios enable the evaluation of the energy demand in the economic sectors of the country.

- **REmap**[52] is an Excel-based accounting and analytical framework, which allows for the identification of renewable energy options in addition to existing energy plans up to 2030. In the REmap framework, the energy system is divided into supply sectors (power and district heat) and end-use consuming sectors (buildings/commercial, industry, transport), and technology options beyond a 'business as usual' scenario are considered for each sector, also allowing sector coupling. 'Business as usual' is determined by the national plans of countries, and the targets and policies in place and under consideration. Technology options are characterized by their energy service cost, but exclude system constraints, path dependencies, and competition for resources or infrastructure. The analysis also includes estimates of the technology choice for carbon dioxide (CO_2) and air pollutant emissions, renewable energy capacity investments, and support needs for investment by technology, sector and country. The result is a perspective on technology choice for renewable energy, costs and benefits, which, when coupled with more expert-oriented longer-term energy planning or energy system models, can provide users with perspectives on renewable technology choice.

- **GTAP-E**[53] is an extension of the GTAP model, allowing for energy substitution. The standard GTAP model is a multiregional, multisectoral, computable general equilibrium model, with perfect competition and constant returns to scale. Innovative aspects of the GTAP-E model include:
  - The treatment of private household preferences;
  - The explicit treatment of international trade and transport margins;
  - A global banking sector which intermediates between global savings and consumption.

[47] Long range Energy Alternatives Planning System (LEAP). More details about LEAP and examples of its application can be found at <http://www.energycommunity.org/default.asp?action=45>

[48] Macroeconomic, Energy and Environment sub-model (3Es-Model).

[49] The model is used to forecast China's GHG emissions until 2030. See <https://www.etde.org/etdeweb/details.jsp?osti_id=20340418>

[50] Top-down macroeconomic model (MACRO).

[51] Model for Analysis of Energy Demand (MAED). More information on the MAED model and its applications can be found at <www-pub.iaea.org/MTCD/publications/PDF/CMS-18_web.pdf>

[52] Renewable Energy Roadmap (REmap). For more information, see <https://www.irena.org/remap/REmap_energy_system_models_chapter_3_2015.pdf>

The GTAP model may be selected if these are important emission drivers in the country. The GTAP model also provides users with a wide range of closure options, including unemployment, tax revenue replacement and fixed trade balance closures, and a selection of partial equilibrium closures (which facilitate the comparison of results to studies based on partial equilibrium assumptions). While the GTAP-E model can be applied to multiregional analysis, it is possible to limit its use to one country.

- **GEM-E3**[54] is a full-scale computable general equilibrium model for the world economy, which provides details on the macroeconomy and its interaction with the environment and the energy system. The model has multinational, multi-agent, multisectoral and dynamic features. It primarily provides a top-down approach on the world economy. At equilibrium, prices expect to clear all the markets of goods, services, labour, capital, finance, energy, and atmospheric emissions and pollution abatement in all regions that are connected through flexible bilateral trade flows. The aim of the GEM-E3 model is to study the relationship of an economy, energy and environment, both at the global and at the European Union level. This model has been initially used to explore the economy, energy and environmental policy planning; and with improvement and upgrade, it may be used to analyse the impact of energy reform and investment on sustainable development and the environment in Europe[55] (Mayeres and van Regemorter, 1999).

  The model is modularly built, allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study. The GEM-E3 model includes projections of full input-output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants.[56]

- **(ENPEP) BALANCE**[57] is a model that can be used to simulate the energy market and determine the energy supply and demand balance over a long-term period of up to 75 years. To achieve this goal, the BALANCE module of ENPEP processes a representative network of all energy production, conversion, transport, distribution and utilization activities in a country (or region), as well as the flows of energy and fuels among those activities. The environmental aspect is also taken into account by calculating the emissions of various pollutants and GHGs. In addition to energy costs, the model also calculates the environmental costs. The main purpose of the model is to provide analytical capability and tools for the various analyses of energy and environmental systems, as well as for the development of a long-term energy strategy of a country or region. For example, it is possible to assess the impact of a new policy, identify the lowest social cost expansion plan for the energy system and calculate the impact of emission taxes.

- **VATTAGE**[58] is a dynamic, applied general equilibrium (AGE) model of the Finnish economy. The model can be adapted to any country's needs and applied to study the effects of a wide range of economic policies. The VATTAGE database contains detailed information about commodity and income taxes, as well as the expenditures and transfers of the public sector, and thus covers most policy instruments available to the government. The model provides both economic variables and GHG emissions as output.

- **EnergyPLAN**[59] is a spreadsheet-based model designed to compare and analyse the energy, environmental, and economic impact of various energy strategies in order to support the development of national or regional energy strategies based on alternative energy system expansion plans and economic assumptions. The model covers heat and power supply, transport and industries. The user has to provide information on technologies and specify costs as inputs to the model, which allows for a wide

[53] An energy-environmental version of the Global Trade Analysis Project (GTAP) model (GTAP-E). For more information, see <https://www.gtap.agecon.purdue.edu/resources/download/181.pdf> More details and a free downloadable copy of the GTAP-E model are available at <https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=923>

[54] General Equilibrium Model for Energy-Economy-Environment interactions (GEM-E3).

[55] See <http://ftp.jrc.es/EURdoc/JRC83177.pdf>

[56] More information on the GEM-E3 model is available at <https://ec.europa.eu/jrc/en/gem-e3.P>

range of implementations. The model is an input–output model based on deterministic variables; typical inputs are product demands, renewable energy sources, generating capacities, costs and a number of optional regulation strategies (constraints or targets). Outputs are energy balances, fuel consumption, trade account and costs of electricity.

- **GREEN**[60] is an AGE model that focuses on the energy sector and identifies links between fossil fuel use, energy production and CO_2 emissions. Besides major fossil fuel sources, the model also allows for a secondary energy source: electricity. An important feature of the model is the possibility to insert backstop technologies (new technologies capable of completely replacing old ones), assumed to be available simultaneously in all regions.
- **CETM**[61] is a model that strives to close the gap between top-down and bottom-up models by attempting a partial link (Rutherford *et al.*, 1997). This is undertaken by first developing a partial equilibrium model of the energy sector, followed by linking to the MACRO general equilibrium model. The equilibrium is reached through a series of iterations until convergence to the MACRO model's outputs are reached in terms of energy price and quantities.

[57] BALANCE module of the Energy and Power Evaluation Program (ENPEP) model. More information about the ENPEP model is available at <http://www.energyplan.eu/othertools/national/enpep-balance/> as well as at <http://www.adica.com> Examples of the application of the ENPEP-BALANCE model can be found in Molnár and Takács (1995).

[58] Valtion taloudellinen tutkimuskeskus (VATT) applied general equilibrium (AGE) model (VATTAGE). More information about the VATTAGE model is available at <www.vatt.fi>

[59] More information about the EnergyPLAN model is available at <http://www.energyplan.eu/> Examples of its application can be found at <http://www.energyplan.eu/category/scientific-literature-with-energyplan/>

[60] GeneRal Equilibrium ENvironmental model. Examples of its application can be found at <http://www.oecd.org/dev/1919148.pdf>

[61] A Dynamic General Equilibrium Model of Global Energy Markets, Carbon Dioxide Emissions and International Trade.

Annex 2

SOURCES OF DEFAULT DATA

Table 13
International data sources

Institution	Primary output	Website
OECD	Broad range of socio-economic data, including data on population, trade, economy, education, health care, for developing and developed countries	<http://www.oecd.org/dev>
World Bank	Global and regional economic trends, energy data, environmental data, global and regional climate data	<http://data.worldbank.org/topic>
IEA	Important source of relevant background data for long-term projections to derive assumptions from various regional forecasts, oil and gas price forecasts, energy trends, and the Mobility Model (MoMo) for the transport sector	<http://www.iea.org/statistics/> <http://www.worldenergyoutlook.org/> <https://www.iea.org/etp/etpmodel/transport/>
IMF	Global economic forecasts, world economic outlook	<http://www.imf.org/external/pubs/ft/weo/2015/02/weodata/download.asp>
EIA	Energy forecasts, trends of energy consumption and greenhouse gas (GHG) emissions	<http://www.eia.gov>
ITF	Historical databases, analysis and indicators for the transport sector	<http://www.internationaltransportforum.org/>
ICCT	Data on trends, GHG emissions and energy efficiency implications of different policy options in transport	<http://www.theicct.org/global-transportation-roadmap-model>
GIZ	Fuel prices	<www.giz.de/fuelprices>
IIASA	Extensive range of energy-related data, forecasts, modelling scenarios, technologies, population forecasts, agriculture, and land use, land-use change and forestry data	<http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/PFUDB.en.html> <http://www.iiasa.ac.at/web/home/research/modelsData/PopulationProjections/POP.en.html> <http://www.iiasa.ac.at/web/home/research/modelsData/LandUseMetaData.en.html>
BP	Past and recent trends of energy consumption	<http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html>
IRENA	Renewable energy data and statistics, country studies, renewable energy policies and targets, renewable energy road maps, renewable energy technology information (e.g. costs)	<http://resourceirena.irena.org/gateway/> <https://www.irena.org/remap/> <http://costing.irena.org> <http://irena.masdar.ac.ae/>

Institution	Primary output	Website
ICAO	Data on transport and infrastructure	<https://www4.icao.int/newdataplus>
IMO	Data on transport and infrastructure	<https://webaccounts.imo.org/Common/WebLogin.aspx?App=IMODOCS&ReturnUrl=https%3A%2F%2Fdocs.imo.org%2F>
Shell	Scenarios of technological development	<http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html>
FAO	Agricultural data, forest cover data, emission factors and mitigation data	<http://data.fao.org/collection?entryId=ec68c738-e1e8-4bac-aebc-ac2a6af16937> <http://data.fao.org/collection?entryId=8c97cd48-47bf-4d05-9629-728ae99e7481>
UNIDO	Technological advancement data	<http://www.unido.org/en/resources/statistics/statistical-databases.html>
United Nations	Population forecasts	<http://www.un.org/popin/data.html>
EPA	GHG emission data and past trends	<http://www.epa.gov/climatechange/economics/downloads/DataAnnexes.zip> <http://www.epa.gov/climatechange/economics/downloads/GlobalAnthroEmissionsAppendices.zip>
Bloomberg	Energy price information, market analysis and forecasts	<http://www.bloomberg.com/energy>
CARMA	Plant-level data	<http://carma.org/plant>
WRI	Historical GHG emissions and projections	<http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator[]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator[]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year[]=2012&sortIdx=NaN&chartType=geo>
EDGAR	Historical GHG emissions and forecasts	<http://edgar.jrc.ec.europa.eu>

Abbreviations: OECD= Organisation for Economic Co-operation and Development, IEA= International Energy Agency, IMF= International Monetary Fund, EIA= United States Energy Information Administration, ITF=International Transport Forum, ICCT=International Council on Clean Transportation, GIZ= Deutsche Gesellschaft für Internationale Zusammenarbeit, IIASA= International Institute for Applied Systems Analysis, BP=British Petroleum, IRENA= International Renewable Energy Agency, ICAO= International Civil Aviation Organization, IMO= International Maritime Organization, FAO= Food and Agriculture Organization, UNIDO= United Nations Industrial Development Organization, EPA= United States Environmental Protection Agency, CARMA=Carbon Monitoring for Action, WRI= World Resources Institute, EDGAR=Emissions Database for Global Atmospheric Research.

Table 14

Data sources categorized by scope of interest

Scope of interest	Data source
Population data	United Nations: <http://www.un.org/popin/data.html> OECD: http://stats.oecd.org/> IIASA (population projection): http://www.iiasa.ac.at/web/home/research/modelsData/PopulationProjections/POP.en.html>
Economic growth, activity	OECD: http://stats.oecd.org/> (see, e.g., “Economic Projections”, “Industry and services”, “Environment” and “Transport”) World Bank: <http://data.worldbank.org/topic/economy-and-growth> CIA The World Fact Book: <https://www.cia.gov/library/publications/the-world-factbook/> IIASA: <http://www.iiasa.ac.at/web/home/research/modelsData/Models--Tools--Data.en.html> Tradingeconomics (statistics, current account and forecasts): <http://www.tradingeconomics.com/>
Technological advancement	IIASA (substitution, scaling): <http://www.iiasa.ac.at/web/home/research/modelsData/LSM/LSM2.en.html> <http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/Scaling-Dynamics-of-Energy-Technologies1.en.html> UNIDO: <http://www.unido.org/en/resources/statistics/statistical-databases.html> Shell scenarios: <http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html> IRENA: REmap: <http://www.irena.org/remap>, costing: <http://costing.irena.org/>
Transport and infrastructure	OECD: <http://stats.oecd.org/> ICAO: <https://www4.icao.int/newdataplus> IMO: <https://webaccounts.imo.org/Common/WebLogin.aspx?App=IMODOCS&ReturnUrl=https%3A%2F%2Fdocs.imo.org%2F> ITF: <http://www.internationaltransportforum.org/> ICCT: <http://www.theicct.org/global-transportation-roadmap-model> IEA: transport: MoMo: <https://www.iea.org/etp/etpmodel/transport/> GIZ: <http://transport-namas.org/reference-document-on-measurement-reporting-and-verification-mrv-in-the-transport-sector/> IRENA: <http://irena.masdar.ac.ae/>
Energy	IIASA: <http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/PFUDB.en.html> IEA: <http://www.iea.org/statistics/> IEA World Energy Outlook: <http://www.worldenergyoutlook.org/> IRENA REmap: <http://www.irena.org/remap> BP Statistical Review of World Energy: <http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html> BP Energy Outlook: <http://www.bp.com/en/global/corporate/about-bp/energy-economics/energy-outlook.html>
Energy prices	IEA: <http://www.iea.org/bookshop/650-Energy_Prices_and_Taxes_-_ANNUAL_SUBSCRIPTION <http://www.iea.org/statistics/> Bloomberg: <http://www.bloomberg.com/energy>
Agriculture, and land use, land-use change and forestry	IIASA: <http://www.iiasa.ac.at/web/home/research/modelsData/LandUseMetaData.en.html>

Scope of interest	Data source
Taxes and fiscal incentives	OECD: <http://www.oecd.org/tax/> Tradingeconomics.com: <http://www.tradingeconomics.com/country-list/corporate-tax-rate>
Emission factors, mitigation data	FAO (land use and agriculture, respectively): <http://data.fao.org/collection?entryId=ec68c738-e1e8-4bac-aebc-ac2a6af16937> <http://data.fao.org/collection?entryId=8c97cd48-47bf-4d05-9629-728ae99e7481> US EPA: <http://www.epa.gov/climatechange/economics/downloads/DataAnnexes.zip> <http://www.epa.gov/climatechange/economics/downloads/GlobalAnthroEmissionsAppendices.zip>
Historical greenhouse gas emissions	WRI: <http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator[]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator[]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year[]=2012&sortIdx=NaN&chartType=geo> EDGAR: <http://edgar.jrc.ec.europa.eu>

Abbreviations: OECD= Organisation for Economic Co-operation and Development, IEA= International Energy Agency, ITF=International Transport Forum, ICCT=International Council on Clean Transportation, GIZ= Deutsche Gesellschaft für Internationale Zusammenarbeit, IIASA= International Institute for Applied Systems Analysis, BP=British Petroleum, IRENA= International Renewable Energy Agency, ICAO= International Civil Aviation Organization, IMO= International Maritime Organization, FAO= Food and Agriculture Organization, UNIDO= United Nations Industrial Development Organization, EPA= United States Environmental Protection Agency, WRI= World Resources Institute, CIA= United States Central Intelligence Agency, EDGAR=Emissions Database for Global Atmospheric Research.

Annex 3

SENSITIVITY ANALYSIS

Uncertainty is one of the primary reasons why a sensitivity analysis is helpful in making decisions or recommendations based on forecasts. Throughout the process of sensitivity analysis, the degree of sensitivity of a model (or system it models) to certain parameters is identified. The assessment sheds light on the relative importance of the variables and answers the question of how the uncertainties in model assumptions and input parameters translate into the uncertainty of the model results.

To perform a sensitivity analysis, multiple model runs should be performed while varying the input data parameters in a typical range. For example, the gross domestic product (GDP) growth rates are varied on a relative +–10 per cent scale, and the change in output (greenhouse gas (GHG) emissions) is monitored.

Typical sensitivity analysis methods are as follows:

- Simple sensitivity analysis: (Semi-) manual perturbation of parameters, while monitoring changes. This is a simple method and is easy to perform, but is not capable of measuring model-level uncertainty;
- Monte Carlo method: Algorithmic, random perturbation of parameters based on assumed statistical qualities, identification of sensitivity and the measure of uncertainty. The method has more demanding time and computation requirements, and might not consider co-variations of variables, but provides realistic, exact results and a good measure of uncertainty;
- Taylor-series expansion: Estimation of the variance of the output as a function of input uncertainty. This can be a rapid method to perform, but is only an approximation, so for more complex models, the results can be biased. This method requires the knowledge of standard deviations of parameters.

Various tools are available to perform sensitivity analysis. The Monte Carlo method is one of the more popular approaches and is briefly presented below (for a more detailed discussion, see Mokhtari and Frey (2005).

Monte Carlo simulation

The Monte Carlo method uses a range of values – a probability distribution – for any variable which has inherent uncertainty. The results are recalculated many times using an alternative, random value which fits the variable's assumed probability function. Recalculations (so-called 'iterations') can be performed tens of thousands of times by computer and the output (tens of thousands of results from the iterations) is also a probability distribution, a range of possible outcome values.

With the application of probability distributions, variables can have different statistical qualities, and outcomes can have different probabilities. It is generally agreed that this is closer to a more realistic analysis. In other words, a Monte Carlo simulation not only shows what could happen, but also how probable it is to happen.

Summarizing the advantages over a single-point estimation, the Monte Carlo simulation method provides:

- Results with probabilities;
- An option to graphically display results by mapping outcomes on a chart;
- Selection (and ranking) of parameters with the largest impact on the outcome;
- Scenario analysis; mapping of outputs to certain occurrences of input;
- Modelling of interdependent relationships between variables to identify simultaneously changing factors.

There are commercially available software packages to assist in performing a Monte Carlo sensitivity analysis (e.g. CrystalBall[62] for use in spreadsheet-based modelling).

Steps to conduct a sensitivity analysis

If a sensitivity analysis is applied to outline an optimal strategy, the following steps are suggested (this is a simplified version adapted from Pannell (1997), section 6, "Strategy B"):

1. Select the relevant parameters to be varied. Identify a range for each parameter which accurately reflects its possible range. For example, use maximum and minimum values, or an 80 per cent confidence interval. The use of a uniform 10 or 20 per cent interval on either side of the expected value is not recommended. Also identify other possible scenarios requiring changes to the model assumptions, structure or formulation (e.g. changes in the objective to be optimized, inclusion of additional constraints);

2. Conduct a sensitivity analysis for each parameter individually, using two parameter values (high and low or maximum and minimum). Conduct a sensitivity analysis for each discrete scenario individually;

3. Identify parameters and scenarios to which the resulting key decision variables are relatively unresponsive, using one of the sensitivity indices;

4. Unresponsive parameters and scenarios may be excluded from further analysis. For the remaining parameters, check whether they are likely to have high positive, high negative or low correlation with each other. If it is intended to use probability distributions for random sampling of scenarios or for summarization of results, estimate the distribution for each parameter and, for cases of high correlation, estimate the joint probability distribution. Possibly also estimate probabilities for the discrete scenarios selected in step 1;

5. Summarize results and draw conclusions. For each key decision variable, calculate the values of a sensitivity index for all parameters and discrete scenarios, and rank them by absolute value. These results can be reported directly or used to select which parameters will be examined in graphs and tables (e.g. spider diagrams). This approach helps to prioritize the presentation of results, which is essential to avoid an overload of graphs and tables. It also allows the decision maker to focus on important parameters and relationships. Calculate break-even parameter values for particular circumstances of interest.

[62] See <http://www.oracle.com/us/products/applications/crystalball/overview/index.html>

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