Prepared for:

IPCC WORKING GROUP 2 SECOND ASSESSMENT REPORT

METHODS FOR ASSESSMENT OF MITIGATION OPTIONS
APPENDIX IV: MITIGATION ASSESSMENT HANDBOOK

PART A: ASSESSMENT OF MITIGATION OPTIONS FOR THE ENERGY SECTOR

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SECTION 1:
INTRODUCTION TO THE ENERGY SECTOR APPROACH

In most countries, the energy sector will be a major focus of mitigation analysis. Globally, the energy sector is the predominant source of carbon dioxide (CO_2), the most important greenhouse gas. The combustion of fossil fuels accounts for about 60% to 90% of current net anthropogenic emissions of CO_2 emissions. Under the IPCC's 1992 baseline scenarios, energy sector emissions of CO_2 will grow from 0.6% to 2.4% per year between 1990 and 2020, with faster increases in developing country regions. The energy sector is also a major source for other direct greenhouse gases, methane (CH4) and nitrous oxide (N2O), and potential indirect greenhouse gases, such as other nitrogen oxides (NOx) and volatile organic compounds (VOCs). The production and transmission of coal, oil, and natural gas account for about one-fifth of global methane emissions. (Pepper et al., 1992)

This part of the appendix provides an example of one approach to national level analysis of the mitigation of energy sector GHG emissions. It describes a relatively simple and straight-forward approach to mitigation analysis. It also introduces a computerized accounting and modeling framework, the Long-range Energy Alternatives Planning System (LEAP) that countries can use to implement this approach. The approach is illustrated using a hypothetical example.

Section 1 begins with an overview of the analytical approach: "bottom-up", least-cost, end use analysis. The basic four steps involved in using this approach for an energy sector mitigation analysis are then reviewed. Section 2 provides a brief description of software and modeling options, and explains the essential elements of the LEAP system. In Sections 3 through 5, the four broad steps of mitigation analysis are explained, with reference to how they can be implemented using LEAP and/or complementary tools.

1.1 OVERVIEW OF THE ANALYTICAL APPROACH

The basic approach presented below is typically described as "bottom-up", least-cost analysis. (See Section 5.2.2 of the Technical Report) It involves the comparison of specific mitigation options, usually individual technologies or groups of technologies, based on their relative economic costs to achieve a unit of GHG reduction. This approach gives equal weight to both energy supply- and energy demand-side options. Cost or supply curves can be used along with other screening criteria to identify and rank promising mitigation options. These mitigation options are then combined to create one or more integrated mitigation scenarios. In these scenarios, the interactive effects of the mitigation options are assessed in an accounting or modeling framework that helps to ensure consistent and comprehensive analysis of energy, emissions, and cost impacts. Mitigation scenarios are evaluated against the backdrop of a baseline scenario, which simulates the events assumed to take place in the absence of mitigation efforts. Mitigation scenarios can be designed to meet specific emission reduction targets or to simulate the effect of specific policy interventions.

In addition to the specific bottom-up approach presented here, other approaches have been suggested for mitigation analysis. The most prominent alternative, the top-down approach, relies on economic models that most typically analyze the effect of carbon taxes on the behavior of energy consumers and producers and the resulting emission reductions and costs to national economies. Table 1.1 below summarizes the key features of the bottom-up and top-down approaches. In-depth explanations and reviews of the various bottom-up and top-down approaches, and their relative strengths and weaknesses, are provided in the Technical Report and in the general literature.[1] While this appendix presents a specific bottom-up approach, it should be recognized that top-down analyses can provide important added insights, particularly in terms of assessing macroeconomic impacts. Some

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[1] See for example, the UNEP GHG Abatement Costing Studies (UNEP, 1992; UNEP, 1994a), Grubb et al. (1993), Wilson and Swisher (1993), and Hourcade (1993).

observers have suggested that both top-down and bottom-up approaches should be used, since they tend to provide upper and lower bounds, respectively, on estimated costs of GHG mitigation.[2]

Table 1.1 Approaches to Analyzing Mitigation Options[3]

Top-down	Bottom-up
• Assesses costs/benefits to different sectors of the economy in output, income, or GDP	• Assesses costs/benefits of individual or groups of technologies and policies
• Captures intersectoral feedbacks and interactions, thereby minimizing double counting	
• Implicitly captures administrative, implementation, and other costs	• Can be explicitly designed to include administrative and program costs
• Uses aggregate economic data	• Uses detailed data on technologies and policies
• Assumes markets are efficient	• Does not necessarily assume that markets are efficient

The construction and evaluation of bottom-up mitigation scenarios typically requires an accounting or modeling framework to capture the interactions between mitigation measures, and to ensure consistency in the assessment of energy, GHG emission, and cost impacts. Accounting and modeling methods can vary greatly in terms of their sophistication, data intensiveness, and complexity. As noted in the Technical Report (Section 5.2.2), such models are either descriptive or prescriptive. Optimization models, which can be used to determine the “best” set of options under a given set of objectives and constraints, are the most typical of prescriptive methods. Descriptive methods, on the other hand, simulate the effect of selected mitigation options on overall costs and emissions. While they cannot generate the least-cost mitigation solution, descriptive methods can be used to represent cost-minimizing behavior. At the same time, they reflect the factors that decision makers may wish to consider in evaluating alternative options (e.g. institutional feasibility, equity impacts, cultural factors). In general, they also tend to require less data and expertise, and are simpler and easier to use than optimization models.

For these and other reasons, a descriptive, bottom-up modeling framework, the Long-range Energy Alternatives Planning (LEAP) system, was selected for the illustrative purposes of this appendix. LEAP possesses several specific characteristics, summarized in Table 1.2, that make it suitable for mitigation scenario analysis in many countries. It has been widely used in developing (and industrialized) countries since 1980 for a variety of integrated energy analyses, a few of which are described in Section 2.1. and Attachment A. In recent years, applications have included a number of GHG mitigation studies.

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[2] See Grubb et al, 1993. The UNEP GHG Abatement Costing Studies (UNEP, 1994) and other efforts have sought to integrate the two approaches.

[3] Excerpted from the Technical Report.

Table 1.2 Key Characteristics of LEAP

- Comprehensive, integrated system covering both energy demand-side and supply-side mitigation options and providing cost and emissions analysis.
- Model-building system and accounting framework rather than a fixed model.
- Flexible and expandable data structures; can be used under conditions of limited data.
- Choice of modeling methodologies, e.g., end-use and/or econometric demand relationships; load curve dispatch or fixed plant shares for electric system.
- Associated Environmental Data Base contains extensive emission factor data.
- Easy-to-use, menu-driven interface and straightforward data entry screens.
- Integrated context-sensitive help and full documentation; flexible reporting system including built-in graphics.
- Runs on standard PCs under MS-DOS (requires 640K RAM and a hard disk with at least 6 MB free space).
- Off-the-shelf training exercises; on-site training available.
- Used in numerous developing and industrialized countries over past 15 years.

Due to its flexible structure and relationships, LEAP can be applied in different local circumstances, and, in particular, where data and modeling expertise are limited. At the same time, it offers a comprehensive, integrated framework that enables the consideration of most demand-side and supply-side energy sector mitigation options and the calculation of costs and emissions impacts. The structure of LEAP, its applications, and its use for mitigation analysis are described in more detail in Section 2.

1.2 STEPS OF THE ANALYSIS

There are three steps to the mitigation analysis procedure presented here. These steps encompass the major elements of the analytic process described in Section 2.1 of the Technical Report. As noted there, the manner in which the steps are performed will reflect each country's resources, objectives, and decision-making process. Since they are interlinked, the steps are not necessarily sequential, and often require iterations. For instance, the design of a mitigation scenario (Step 3) will often influence data collection and model design (Step 1).

The three main steps of the procedure, each with several sub-steps, are as follows:

(1) **Design and Set Up the Analysis:** Mitigation analyses require physical and economic data about the energy system, emissions, socio-economic variables, and specific mitigation options. An approach or set of approaches for evaluating mitigation options needs to be established. If appropriate, a model of the energy sector needs to be set up and calibrated to base year conditions. In general, this step includes the following actions:

  - Select base year and time horizon for the analysis.
  - Assess data requirements and collect relevant information.
  - Select/design model/accounting approach. The <u>data structure</u> used will depend on the availability of disaggregated energy data, the selected model relationships, the relative importance of sectors and end-uses in terms of current and projected GHG emissions, and the mitigation options that will be considered. The <u>model relationships</u> or formulations are the algorithms or equations that relate activities (e.g. value added, population growth, etc.) to energy use on the demand side, and that dictate the operating characteristics of energy conversion and supply facilities. These relationships will depend on local conditions and perceived behavioral and functional relationships.

- Calibrate base year energy balance. The disaggregated energy data should be normalized to yield the more accurate national energy supply totals for the base year.
- Decide which gases to consider, specify emission factors, and calibrate base year emissions with existing GHG inventories, as available.

(1) **Develop the Baseline Scenario:** The baseline scenario projects energy use and emissions over the time horizon selected, reflecting the assumed development of the national economy and energy system if no steps are taken to reduce emissions. The baseline scenario must include sufficient detail on future energy use patterns, fuels production systems, and technology choices to enable the evaluation of specific mitigation options. The construction of a baseline scenario generally involves the following elements:

- Define baseline scenario and develop baseline assumptions for economic and demographic parameters, changes in the patterns of energy use, fuel prices, and technological change. These assumptions can be based on available macroeconomic modeling projections, government and energy sector investment plans, and/or analyst judgment.
- Assemble baseline scenario, assess the ramifications for GHG emissions, and review the reasonableness and consistency of assumptions.

(1) **Create and Evaluate Mitigation Scenarios.** This step involves the identification and evaluation of specific mitigation options, the combination of selected options, and the construction of a mitigation scenario. The comparison of mitigation and baseline scenarios should reveal the net costs and impacts of the selected mitigation options. The results need to be assessed with respect to reasonableness and achievability, given implementation concerns and the exact policy instruments that might be used (taxes, standards, permits, etc.). This step includes several key elements:

- Establish the objective of the scenario(s). Mitigation scenarios can be defined to meet particular emission reduction targets, to assess particular policies or technologies, or to match other objectives.
- Decide on whether CO_2 or all GHGs will be targeted.
- Define key parameters and considerations, such as the discount rate and the costs and benefits to be included.
- Identify, screen, and select mitigation options to include in each scenario.
- Estimate the penetration rates for each mitigation option.
- Construct integrated scenarios, and run an energy sector model or accounting framework (e.g. LEAP) to calculate costs and impacts over the time horizon considered.
- Present estimates of total mitigation potential and costs.
- Account for uncertainty. Conduct sensitivity analysis of key input variables.
- Review impacts not captured by LEAP analysis that may have an effect on overall GHG emissions. Integrate with macroeconomic analysis, if appropriate.

In Sections 3 through 5 of this appendix, the application of LEAP to each of the above steps is described, using a hypothetical country example.

SECTION 2:
TOOLS FOR MITIGATION ANALYSIS, AN OVERVIEW OF LEAP

2.1 APPLICATION OF SOFTWARE AND MODELS

While this appendix focuses on LEAP, other software options are available for mitigation analysis. These range from simple spreadsheets to more sophisticated and data-intensive models. The choice of software and models depends on the desired analytical method, which in turn depends on the specific circumstances of each country and each assessment.

Some countries with considerable technical expertise and data availability, especially those that wish to emphasize technological options, might opt for the use of optimization models, such as EFOM or MARKAL. Optimization models compute an estimate of the economically optimal mix of technologies for a set of inputs under given constraints. This approach can be rich in technical detail and forward-looking in its technological assumptions. At the same time, many policy and behavioral variables and constraints are difficult to parameterize and incorporate in these analyses.

Others with a particular interest in the interaction between prices and the behavior of energy consumers and suppliers might opt for econometric and equilibrium modeling approaches, such as ENPEP, MEDEE or others. If econometric models are based upon historical relationships, they may have difficulty reflecting changes in the variety of technologies available, or other structural shifts that differ from historical trends. In addition, due to their usual high level of sectoral aggregation, econometric models often forego detail about changes specific to subsectors and energy end-uses such as lighting or process heat. Such changes can have major effects on overall energy use.

Some econometric and equilibrium models allow the estimation of feedbacks between, for example, energy prices and economic production. This can be important in estimating the overall effects of policies on a nation's economy or on the economic outlook in particular sectors. Unlike equilibrium models, LEAP does not simulate price and income interactions to seek a `market equilibrium' between supply and demand for each scenario. For instance, a reduction in fossil fuel demand due to improved energy efficiency, and could result in decreases in fossil fuel prices, possibly limiting the cost-effective penetration of competitive non-fossil supplies. Likewise, as the cost of energy services is reduced by the use of least-cost technologies, the demand for energy can, in turn, rise somewhat.[4] Such interactive relationships between price and demand are notoriously difficult to accurately quantify, and the high variation among elasticities can lead to dramatically different results. However, where there are sufficiently detailed data available to properly and reliably calibrate econometric and/or equilibrium models, application of these models can yield useful insights.

Some countries might choose to apply two or more models to gain further understanding of the nature of costs and impacts of mitigation strategies, while others might rely on spreadsheet software to develop accounting models adapted to their own needs and capabilities. In addition to LEAP, energy-sector modeling and analysis tools include: STAIR, ENPEP, MARKAL, MEDEE, ENERPLAN, ENERGY TOOLBOX, MESAP, TEESE and others. (See the Technical Report and World Bank (1991) for more details on these and other approaches.) Some of these tools have been used for GHG mitigation or scenario analyses, while others could be applied for such analyses in the future. Several criteria -- such as user friendliness, comprehensiveness (energy demand, supply, emissions, and costs; and coverage of major mitigation options), data intensiveness, sophistication (required levels of expertise), transparency,

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[4] A related concept, often referred to as the `take-back effect' may occur in cases where more efficient technologies (e.g., compact fluorescent bulbs) decrease the cost of an amenity (e.g., lighting), leading to additional use (leaving the light on longer). Whether such an effect actually occurs is subject to debate in the literature. See UCS et al 1991, p.33-34.

robustness of results, treatment of uncertainty, and flexibility -- can help to judge whether a particular tool can be implemented locally and yield meaningful results.

Regardless of the approach, the assumptions and judgments that define the analysis -- from projections of future technology costs, benefits, and availability to expectations regarding consumer response and policy effectiveness -- are major determinants of its outcome. All such analyses should be reviewed and evaluated with this point in mind.

2.2 LEAP APPLICATIONS, DESIGN AND STRUCTURE

LEAP represents a relatively easy to use and flexible accounting and modeling framework developed by the Stockholm Environment Institute - Boston Center at the Tellus Institute. (SEI, 1993a; SEI, 1993b)

As a “bottom-up”, end-use modeling system, LEAP's principal elements are the energy and technology characteristics of end-use sectors and supply sources. The end-use approach, embodied in LEAP, enables the incorporation and simulation of several important factors that can have significant effects on future GHG emissions. Such factors include technological improvements and transitions, the limits imposed by saturation of energy-intensive activities, and structural shifts among economic sectors and subsectors.

LEAP contains a full energy system accounting framework, which enables consideration of both demand and supply-side technologies and accounts for total system impacts. For example, a reduction in electricity requirements, will lead to a decrease in the operating and fuel costs for the electric plants operating on the margin, and a decrease in fuel imports or local energy production requirements. With its links to the Environmental Data Base, LEAP can track the pollution resulting from each stage of the fuel chain, including the reduction in GHG emissions from extraction, processing, distribution, and combustion activities that might result from more efficient use of electricity or other fuels.

2.2.1 LEAP APPLICATIONS

LEAP was initially developed as part of the Kenya Fuelwood Project, one of the first major integrated energy planning exercises conducted in a developing country.[5] Since that time, LEAP has been used in over 30 developing and industrialized countries for a wide range of tasks, including, most recently, GHG mitigation analysis. Government ministries and planning units, such as those in Tanzania, Zambia and Zimbabwe have focused on building institutional capacity for energy planning, with LEAP used as a training and analytical tool, assisting in the formulation of energy master plans (Mrindoko and Lazarus, 1992). Some LEAP applications, such as in the Philippines, have emphasized decentralized rural energy planning, while in other applications, planners have used it for energy scenario analyses that emphasized modern use of biomass resources, as in the state of Minas Gerais in Brazil. (van der Werf, 1992; Ackerman and Fernandes de Almeida, 1990) In Hungary, LEAP was used to compare coal and nuclear-based energy futures, and is now being used to consider a wider range of supply options. Researchers in India used LEAP to look at options for minimizing air pollution from the transport sector in Delhi (Bose and Mackenzie, 1993). LEAP has also provided the analytical framework for two global energy and climate change studies (Sinyak and Nagano, 1992; Lazarus, Hall, Greber, et al., 1993).

Most recently, LEAP has been used directly for mitigation scenario analyses. As part of the UNEP Greenhouse Gas Abatement Costing Studies project (UNEP 1994a), it was used by analysts in Senegal and Venezuela. It has also been used for greenhouse gas-related scenario analyses in the U.S.

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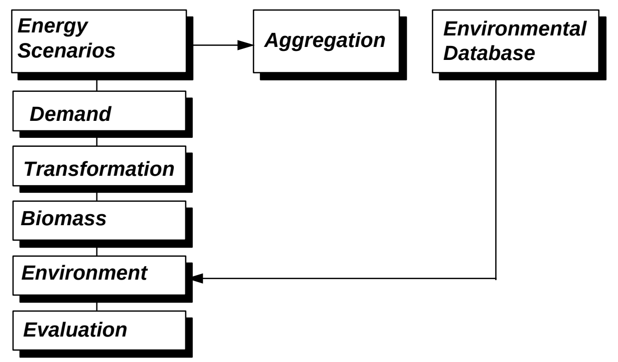
[5] Details of these and other early LEAP studies can be found in volumes 1,2 and 9 of *Energy, Environment and Development.* (Beijer Institute and Scandinavian Institute of African Studies, 1984-1986)

and Costa Rica. (UCS et al., 1991; von Hippel and Granda, 1992) Attachment A briefly describes a few of these LEAP-based mitigation analyses and their findings.

2.2.2 LEAP STRUCTURE AND DESIGN

Figure 2.1: LEAP Program Structure



The structure of LEAP is presented schematically in Figure 2.1. LEAP consists of three blocks of programs: Energy Scenarios, Aggregation, and the Environmental Data Base (EDB). Four of the Energy Scenario programs address the main components of an integrated energy analysis relevant to mitigation analyses: energy demand analysis (Demand), energy conversion and resource assessment (Transformation), emissions estimation (Environment), and the comparison of scenarios in terms of costs and physical impacts (Evaluation). These four programs and EDB are described below. The optional Biomass program is available to assess the relationship between biomass energy demands, supplies, and land use changes. (For a more detailed description of LEAP structure, capabilities, and algorithms, see SEI-B, 1993a and SEI-B, 1993b).

The LEAP system is *demand driven*. That is, demand requirements drive the calculations of the Transformation program, and the results of the Transformation program, in turn, drive the calculations of the Biomass, Environment, and Evaluation programs. Supply constraints and feedbacks are managed by the analyst through modifications of the demand scenarios.

The LEAP Demand program provides a disaggregated, end-use approach to the analysis of energy requirements. Rather than a rigid pre-set model of energy demands, the Demand program is a flexible *model-building* tool that enables the construction of a wide range of models to reflect local conditions. The user can create a four-level “branch structure” to represent a desired model of energy use, as illustrated in Figure 2.2.[6] This branch structure can be relatively simple or more elaborate, depending on data availability and the analyst’s modeling preferences.

When creating baseline and alternative scenarios, the future values for each branch -- activity levels, percentage shares, and energy intensities -- are determined. For example a projection might be based on changes in sectoral driving variables (e.g., growth in numbers of households), subsector breakdowns (e.g., income distribution), end-uses (e.g., space cooling), and device usage (e.g., the mix of more and less efficient air conditioners and their levels of usage).

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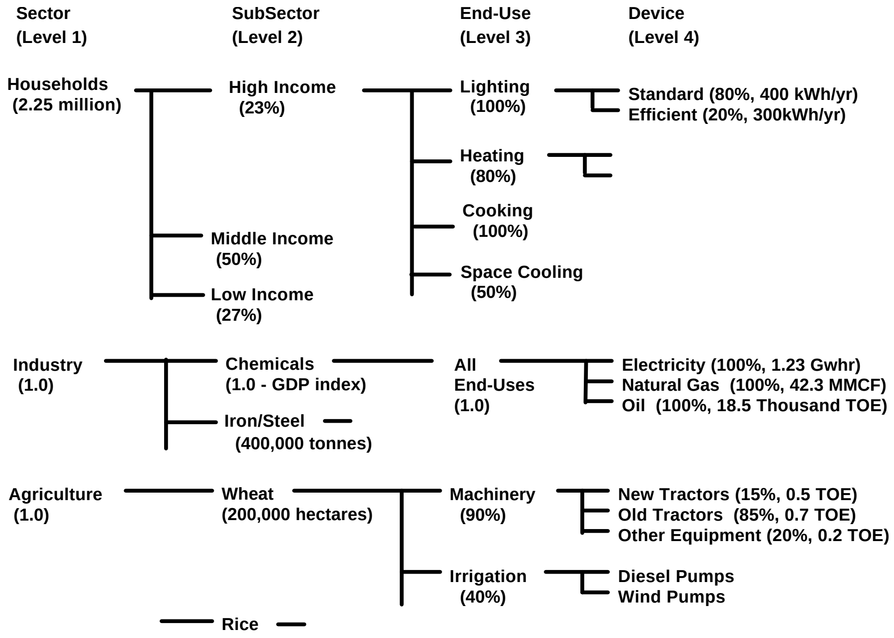
[6] The four level titles in the LEAP Demand program -- *Sector*, *Subsector*, *End-Use*, and *Device* -- are merely for guidance, and the user need not abide by them. For instance, under subsector, a given user may enter end-uses, crop types, housing types, income categories, or whatever type of disaggregation deemed appropriate for the analysis.

Figure 2.2: Schematic of a Sample LEAP Demand Structure



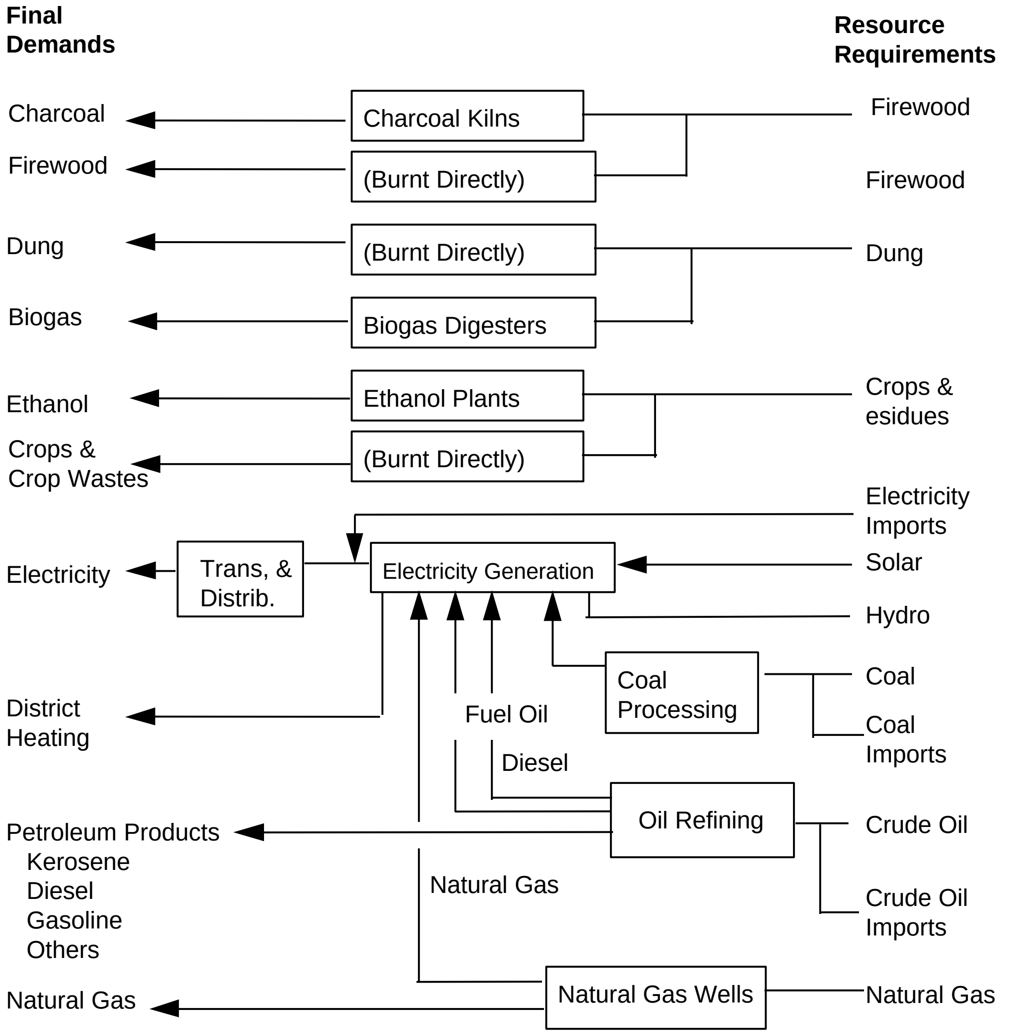
Each sector, subsector, end-use, or device is referred to as a "branch". From right to left, each branch refers to the branch of the preceding level. In the example shown, there are 2.25 million households in the sample area, 23% of these are in the high income group, all of these households have lighting, and 80% use standard (incandescent) electric lighting at an average consumption of 400 kWh/year per household.

The **Demand program** contains several options for projecting future changes in activity levels and energy intensities: interpolation/extrapolation of values determined exogenously (i.e. outside of LEAP); econometric relationships; or user-specified growth rates. Exogenous values can be incorporated from other analyses, using the various forecasting methods -- such as expert judgment, trending analysis, or content analysis -- that are discussed in Section 5.2 of the Technical Report. For instance, projections of value added for the iron and steel industry could be taken from a macroeconomic analysis of sectoral performance or from a government production target. As with all LEAP programs, the Demand program contains a flexible report writing and graphing facility that enables the detailed review and presentation of scenario results in different formats and energy units, and at different levels of disaggregation.

The **Transformation Program** simulates energy supply and conversion processes and enables the assessment of primary resource requirements, needs for facility expansion, and import and export levels. Like the Demand program, it is designed as a model-building tool rather than a fixed model. The user can tailor the design of the supply system simulation to match the resources and facilities in a given region, and their general operational rules and characteristics.

The Transformation system is defined at two levels of detail: the *module* level, which represents energy industries or sectors such as grid electricity generation, industrial cogeneration, oil refining, district heating, or charcoal production; and the more detailed *process* level, which describes the cost and performance characteristics of individual energy conversion and production technologies such as electric plants, oil refineries, or coal mines. The analyst has a variety of options for simulating the operation of energy production and conversion systems. For instance, the electric facilities can be dispatched to meet an annual load curve or refineries can be specified to operate at maximum production levels with the export of excess (and import of unmet) petroleum product demands. Other options include alternative policies for specifying the availability of fuel imports, for dealing with shortfalls in production, for setting priorities between domestic consumption and export targets, for handling surplus production of energy products, for specifying waste energy recovery, and for modeling cogeneration.

Figure 2.3: Schematic of Sample LEAP Transformation Structure



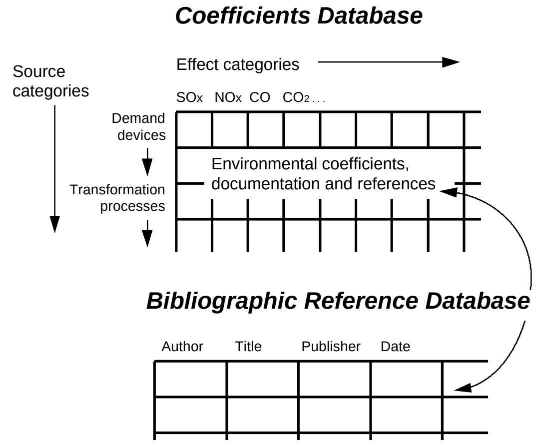
The boxes above refer to LEAP Transformation "modules". Modules can be added, removed, or modified to suit local conditions.

In addition to modules describing energy production and conversion activities, the Transformation program also allows the user to define the available base year stocks and additions to reserves of primary indigenous fossil fuel resources. The calculations in the Transformation system track the depletion of reserves over the analysis period. The Transformation program produces a wide variety of reports and graphs, including energy balances.

The **Environment program** calculates the environmental emissions and on-site health and safety impacts associated with a particular energy scenario. These estimates are based on emission coefficients contained in EDB (the Environmental Data Base) that are matched with specific sectors, end-uses, and/or technologies in the Demand and Transformation programs of LEAP. LEAP can optionally calculate the emissions from the full fuel chain, providing that the proper Transformation modules for the fuel chain are specified in the LEAP data set. As an example of fuel chain emissions, the consumption of electricity might result in the emissions of GHGs from natural gas combustion at an electric generating facility. There may also be leakages of methane from transmission of the natural gas from the gas production site to the power plant, as well as emissions of methane and carbon dioxide at the gas production site itself. These potentially important effects can be accounted for, if the distribution and production of natural gas and appropriate emission factors are specified in the Transformation program and EDB, respectively.

The **Environmental Data Base (EDB)** contains a wide range of technology-specific emission factors for all major greenhouse gases. In addition, users can add data appropriate to local facilities or to specific studies.[7] To date, EDB data have been gathered from over 60 references. EDB contains emission factors for both modern technologies (e.g. electric generation facilities, refineries, boilers) and traditional devices used in many developing countries (e.g. biomass stoves). The coverage of EDB is currently being expanded as part of the UNEP/SEI Fuel Cycle Analysis project. In addition, specific country studies continue to contribute to the database.

Figure 2.4: EDB Program Structure



The **Evaluation program** compares the physical impacts, the economic costs and benefits, and the comparative environmental emissions of one scenario relative to another, e.g. a mitigation scenario relative to the baseline scenario. Capital and operating and maintenance costs are entered in the Demand, Transformation and Biomass programs, and together with per-unit resource costs and optional environmental externality costs they are used in conjunction with the physical results of the other LEAP programs to calculate the comparative costs of different energy-environment scenarios. Reports of the physical, energy, and cost differences between scenarios can be displayed for the whole energy sector, or for selected elements of the energy system, in nominal, real, or discounted terms.

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[7] Global climate change is but one of many important energy-related environmental problems. LEAP and EDB can also be used to examine other environmental consequences that may be of more immediate concern in many areas, such as the emissions of local air pollutants.

SECTION 3:
DESIGNING AND SETTING UP THE ANALYSIS

The first step in conducting a mitigation analysis is to select appropriate analytical approaches and tools and to begin the collection of relevant data. The initiation of a mitigation analysis also requires the definition of several key parameters that will guide data collection and analysis, such as the base year and the time horizon of the study. Collected data are then assembled in a modeling or accounting framework, which should be designed to reflect local conditions and priorities. Finally, in order to ensure consistency, the detailed data should be calibrated to match official aggregate energy supply totals and any existing GHG inventory analyses.

This section begins with the issue of time horizon and base year, and then briefly lists the typical types of data required for a bottom-up LEAP analysis and where they might be obtained. The exact data requirements for a given study will depend on the structure and relationships of the energy demand and supply models that the analyst develops. The development of the model structure and relationships, in turn, depends upon the availability of disaggregated data, local circumstances and priorities, the relative importance of sectors and end-uses in terms of current and projected GHG emissions, and the specific mitigation options that will be considered. As a consequence, data collection, the specification of model structure and design, and the analysis of mitigation options (part of Step 3 here) are highly interdependent, and are thus iterative tasks.

This section includes a general explanation of how one would use LEAP to set up demand and supply analyses with reference a the hypothetical country. The key characteristics of this fictitious country, referred to here as “Country X”, are described in Box 3.1 below. While the data, results, and country profile can be considered somewhat typical, they are neither intended nor recommended for actual use in a real mitigation analysis. Several parameters for the baseline and mitigation scenarios for Country X are drawn from the guidelines of the UNEP GHG Abatement Costing project (1994b), including projected fuel prices and the goal of the illustrative mitigation scenario: 12.5% reduction in baseline CO_2 emissions by 2010, and 25% reduction by 2030.

Box 3.1 Key Characteristics of Hypothetical Country "X":

- a middle-income developing economy of 40 million people. (~$600 GDP per capita);
- GDP is expected to grow at 3.5% per year through, while population is expected to grow at 2.5% per year;
- as of 1990, 30% of the country's 8 million households reside in urban areas, a fraction which is expected to rise to 45% by 2030. Due to decline numbers of persons per household from 5 to around 4, the number of households increases at 3.0% per year, faster than population;
- low but growing per-capita energy use (7.5 GJ total end-use energy per capita in 1990);
- a relatively diversified economy, with significant commercial and manufacturing activity, and energy-intensive, basic materials industries (iron and steel, cement, chemicals, and paper and pulp);
- a mostly oil-based energy system, with considerable use of traditional fuels, particularly in rural areas;
- a current stock of electricity generation facilities that includes hydroelectric (25% of 1990 generation), oil-fired (25%), and coal-fired (50%) plants;
- expected increasing reliance on indigenous coal to fuel a growing electricity demand;
- access to imported gas and some indigenous renewable resources;
- irrigated agriculture, which accounts for about 10% of base year electricity demand;
- currently modest but rapidly growing demand for personal transportation services; and,
- an ongoing program of rural electrification, with 95 percent of the households in the country expected to have electricity service by 2030, compared with 65 percent in 1990.

3.1 SELECT BASE YEAR AND TIME HORIZON

A base year and time horizon need to be defined. In most energy analyses, the base year is the most recent year for which relatively complete and reliable energy data are available[8]. In the case of GHG mitigation analyses, however, 1990 may be a preferable base year, since the IPCC requests that countries complete GHG inventories for that year. (IPCC/OECD, 1994)[9].

The time frame for GHG scenarios is generally long, extending from 50 to 100 years into the future. The 1990 IPCC Response Options document developed scenarios for a 100-year time frame with intermediate points at 30 and 60 years from the base year. For mitigation options analysis, it is useful to consider a somewhat shorter time horizon, since the projection of macro-economic variables and the characterization of technologies beyond 20-40 years becomes quite uncertain. Analysts have generally used the period up to 2020 or 2030 as a relevant time frame to analyze the economics of mitigation options.[10] The base year and time horizon for the hypothetical country example are thus 1990 and 1990 to 2030, respectively.

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[8] In specifying a base year, it is important to choose a year in which there were no (or minimal) unusual or abnormal occurrences, such as a drought or a sudden change in GDP, that would make the base year not representative of the energy sector. Since most analysis starts from base year data, choice of an unrepresentative base year can skew the results of scenario analyses.

[9] In LEAP, the analyst can also enter data for both 1990 and a more recent base year, if appropriate.

[10] LEAP is capable of considering up to a 110-year time horizon, e.g. up to the year 2100.

3.2 ASSESS DATA REQUIREMENTS

Regardless of the approach taken and analysis tool used, the collection of reliable data is a major and relatively time-consuming aspect of mitigation analyses. Furthermore, the end-use approach, as in LEAP, can be among the most data-intensive of methods. In order to keep data constraints from becoming a serious obstacle to the analysis, two points are essential. First, modeling tools should be sufficiently flexible to adapt to local data constraints. Second, the data collection process should be as efficient as possible. Efficiency can be maximized by focusing the detailed analysis on sectors and end-uses where the potential for GHG mitigation is most significant, and avoiding detailed data collection and analysis in other sectors.

Using LEAP, or other flexible modeling tools, there are few strict data requirements. Data collection generally begins with the aggregate annual energy use and production figures typically found on a national energy balance sheet. The remaining data requirements will depend largely on (a) the disaggregated structure of the analysis; (b) the specific mitigation options considered; and (c) local conditions and priorities.

The typical types of data needed for an end-use approach to mitigation analysis are shown in Table 3.1. They tend to fall within five general categories: macroeconomic and socioeconomic data; energy demand data; energy supply data; technology data; and emission factor data.

The full listing of potential data requirements may appear rather daunting to the uninitiated analyst. In practice, however, much of the data needed may already be available in the form of national statistics, existing analytical tools, and data developed for previous energy sector studies. The development and agreement on baseline projections of key variables, the identification of mitigation options relevant to local conditions, and, if not already available, the compilation of disaggregated energy demand data are typically the most challenging data collection tasks facing the analyst. The latter step can be somewhat simplified by focusing on the most promising sectors and end-uses for GHG reduction.

Table 3.1 Data Sources for a Bottom-up Mitigation Analysis

Data Categories	Types of Data	Common Data Sources
Macroeconomic Variables		
Sectoral driving variables	GDP/value added, population, household size	National statistics and plans; macroeconomic studies; World Bank (1993a&b); World Resources Institute (1994)
More detailed driving variables	Physical production for energy intensive materials; transportation requirements (passenger-km/year); agricultural production and irrigated area; changes in income distribution, etc.	Macroeconomic studies; UN FAO Agrostat database; transport sector studies, household surveys, etc.
Energy Demand		
Sector and subsector totals	Fuel use by sector/subsector	National energy statistics, national energy balance, energy sector yearbooks (oil, electricity, coal, etc.), International Energy Agency (1994)
End-use and technology characteristics by sector/subsector	Energy consumption breakdown by end-use and device: e.g. energy use characteristics of new vs. existing building stock; vehicle stock; breakdown by type, vintage, and efficiencies; or simpler breakdowns	Local energy studies; surveys and audits; studies in similar countries; general rules of thumb from end-use literature; see e.g. Geller (1991); Reddy (1991); Schipper and Meyers (1992)
Response to price and income changes (optional)	Price and income elasticities	Local econometric analyses; energy economics literature
Energy Supply		
Characteristics of energy supply, transport, and conversion facilities	Capital and O&M costs, performance (efficiencies, unit intensities, capacity factors, etc.)	Local data, project engineering estimates, Technical Assessment Guide (US EPRI, 1993); IPCC Technology Characterization Inventory (US DOE, 1993)
Energy prices		Local utility or government projections; for globally traded energy products, see World Energy Council (1992); UNEP (1994a); US DOE/IEA (1994); BP (1994)
Energy supply plans	New capacity on-line dates, costs, characteristics;	National energy plans; electric utility plans or projections; other energy sector industries (refineries, coal companies, etc.)
Energy resources	Estimated, proven recoverable reserves of fossil fuels; estimated costs and potential for renewable resources	Local energy studies; World Energy Council (1992); Johannson et al. (1993)
Technology Options		
Technology costs and performance	Capital and O&M costs, performance (efficiencies, unit intensities, capacity factors, etc.)	Local energy studies and project engineering estimates; technology suppliers; other mitigation studies (UNEP, 1994); IPCC Technology Characterization Inventory (US DOE, 1993)
Penetration rates	Percent of new or existing stock replaced per year; overall limits to achievable potential	
Administrative and program costs	For efficiency investment, often expressed in cost per unit energy saved (fixed amount or % adder to CSE)	
Emission Factors	Kg GHG emitted per unit of energy consumed, produced, or transported.	National inventory assessments; IPCC Inventory Guidelines (IPCC, 1994b); Environmental Data Base; CORINAIR; AIR CHIEF; IPCC Technology Characterization Inventory (US DOE, 1993);

In general, emphasis should be placed on locally-derived data, but where unavailable, these can be supplemented with judiciously selected data from other countries. For example, current and projected cost and performance data for some mitigation technologies (e.g. high-efficiency motors or combined cycle gas units) may be unavailable locally, if the technologies are not presently in wide use. For this purpose, technology data from other countries (e.g. U.S. DOE, 1993) provide indicative figures and a reasonable starting point. For data on energy use patterns, such as the fraction of electricity used for motor drive in the textile industry, the use of external data can be somewhat more problematic. In general, it may be possible to use estimates and general rules of thumb suggested by other country studies, particular data from other countries with similar characteristics (see Technical Report, Appendix 1, Section 5.2).

3.3 SELECT/DESIGN MODEL

The process of developing demand and supply modeling (or accounting) structures is generally performed in parallel with the data collection process, since one process tends to define the other. The principal objectives in developing a model structure are: (a) to represent the national energy system and the major factors that influence its development, and (b) to include a sufficient level of detail to permit the analysis of selected mitigation options. For instance, where irrigated agriculture accounts for a significant share of electricity consumption and related energy sector GHG emissions, the model structure might include greater end-use detail in the agricultural sector to enable the evaluation of mitigation options such as improved pumpsets or more effective water delivery. In other countries, such model structure and data requirements might be irrelevant. In LEAP, as with spreadsheet analysis and some other models, modeling (or accounting) structures can be tailored to local circumstances.

High levels of disaggregation and detailed data structure are characteristic of end-use approaches. While disaggregated data can help in identifying and evaluating specific technological options (e.g., data on the amount of electricity used for lighting will help to better estimate the potential impacts of a lighting efficiency improvement program), excessive data disaggregation can be an analytical burden. As noted in the Technical Report, where local data are scarce or unreliable and are augmented by the use of secondary data or assumptions, “the better resolution otherwise provided by disaggregation is lost in the fuzziness caused by the data. An efficient solution can be to use higher resolution disaggregated approaches in key sectors or subsectors where the potential for cost-effective GHG mitigation appears high. Less detailed methods can be used to provide a broader overview in other sectors.”

The LEAP data structures for the hypothetical country, shown in Figures 3.1 and 3.2 for the LEAP Demand and Transformation programs, reflect this general principle. In Country X: (a) considerable GHG emissions result from electricity production, (b) several end-uses -- such as lighting, cooling, and industrial motors -- account for much of current and projected electricity use, and (c) the costs and potential of electric end-use efficiency improvements differs significantly among sectors. Therefore, the Demand data structure was designed with more disaggregation in these end-uses and sectors. In the commercial buildings (or services) sector, only lighting and cooling end-uses were specified separately, with no disaggregation among building types or commercial subsectors, due to their relatively similar characteristics and a lack of subsectoral data (which is typical). Similarly, the Transformation program structure emphasizes the specific characteristics of electricity production technologies. This detail will prove useful when specific mitigation options, such as efficiency standards for lighting or air conditioning or switching from coal to high-efficiency gas-fired electricity generation, are evaluated later in the analysis procedure.

Figure 3.1 Schematic of Demand Structure for Country X

```
  SECTOR         SUBSECTOR       END-USE          DEVICE/FUEL
  (level 1)      (level 2)       (level 3)         (level 4)

+-RESIDENTIAL----URBAN-----------LIGHTING---------ELECTRICITY
| (8 million   | (30%)         +-COOKING----------ELECTRIC STOVE
| households)  |               | (100%)        |  (30%, 1.44 GJ/hhhold)
|              |               |               +--CHARCOAL STOVE
|              |               |               +--LPG STOVE
|              |               |               +--WOOD STOVE
|              |               +-REFRIGERATION----ELECTRIC
|              |               +-OTH. END-USES----MISC. APPLIANCES
|              +-RURAL ELECT.----LIGHTING---------ELECTRICITY
|              | (%)           |               +--KEROSENE LANTERN
|              |               +-COOKING----------ELECTRIC STOVE
|              |               |               +--LPG STOVE
|              |               |               +--WOOD STOVE
|              |               +-REFRIGERATION----ELECTRIC
|              |               +-OTH. END-USES----MISC. APPLIANCES
|              +-RURAL NON-ELE---LIGHTING---------KEROSENE LANTERN
|                (%)           +-COOKING----------WOOD STOVE
|
+-COMMERCIAL-----ALL SUBSEC.-----LIGHTING---------ELECTRICITY
| ($ tot. COMM.                +-OTH. END-USES----ELECTRICITY
|  value added)                                +--DIESEL
|                                              +--WOOD
+-INDUSTRIAL-----IRON & STEEL----PROCESS HEAT-----COAL
|              | (tonnes)      |               +--GAS
|              |               +-MOTIVE POWER-----ELEC. MOTORS
|              +-PULP & PAPER----PROCESS HEAT-----WOOD-FIRED BOILERS
|              | (tonnes)      +-MOTIVE POWER-----ELEC. MOTORS
|              +-CEMENT----------PROCESS HEAT-----COAL
|              | (tonnes)      |               +--GAS
|              |               +-MOTIVE POWER-----ELEC. MOTORS
|              +-CHEMICALS-------PROCESS HEAT-----OIL
|              | ($ val. add.) |               +--GAS
|              |               +-MOTIVE POWER-----ELECT. MOTORS
|              +-OTHER INDUST.---PROCESS HEAT-----OIL
|              | ($ val. add.) |               +--GAS
|              |               |               +--COAL-FIRED BOILERS
|              |               +-MOTIVE POWER-----ELEC. MOTORS
|              +-OTH. END-USES---LIGHTING---------ELECTRICITY
|                ($ tot. IND.  +-OTH. END-USES----ELECTRICITY
|                 value added)                 +--DIESEL
|                                              +--WOOD
|                                              +--COAL
|                                              +--GAS
+-TRANSPORT------PASSENGER-------PRIVATE----------AUTOMOBILE (GASOLINE)
| (population) | (pass.-km     |               +--MOTORCYCLE (GASOLINE)
|              |  per capita)  +-PUBLIC-----------BUS (DIESEL)
|              |                               +--RAIL(DIESEL)
|              |                               +--RAIL(ELECTRICITY)
|              |                               +--TAXI(DIESEL)
|              |                               +--AIRPLANE (JET FUEL)
|              +-FREIGHT---------ROAD-------------SMALL TRUCKS (DIESEL)
|                (tonne-km     |               +--LARGE TRUCKS (DIESEL)
|                 per capita)  +-RAIL-------------DIESEL
|                              |               +--ELECTRIC
|                              +-WATER------------SHIPS (FUEL OIL)
|                              +-AIR--------------JETS (JET FUEL)
+-AGRIC & FISH---ALL SUBSEC.-----IRRIG. PUMPING---ELECTRICITY
  ($ tot. AGG.                 +-OTH. END-USES----DIESEL
   value added)                                +--GASOLINE
                                               +--ELECTRICITY
```

This figure created in the LEAP Demand program (with key driving variables added in parentheses). For complete data listing see Attachment B.

3.3.1 DESIGN ENERGY DEMAND STRUCTURE

To develop a demand analysis structure in the LEAP Demand program, such as the one shown in Figure 3.1, the analyst must:

(a) Design a branch structure. The analyst specifies the demand sectors (e.g., Residential, Industry, and Transport) to be modeled, then breaking down each sector, to the degree desired and appropriate, into subsectors (e.g., iron and steel production, chemicals, etc.), end-uses (e.g., motive power, process heat) and devices (e.g., electric motors, furnaces, boilers, etc.) as necessary. Each of the four levels may have as many, or as few, branches as are required. Greater disaggregation should be used to model those sectors, subsectors, end-uses and devices where the potential for GHG reduction is greatest. Often, the design of a demand structure is done on paper first, with frequent references to the available data as the design progresses.

(b) Specify the appropriate variables for each branch. Here the task is to pick the relevant variables that "drive" the demand for energy. Consider the simple representation of cooking in urban households in Country X shown in Figure 3.1. At the sector level, either population or the total number of households could be specified. Since cooking generally occurs at a household level, households are usually a better driving activity than population for projecting energy use for cooking and other household end-uses. Similar choices need to be made for other branches: should energy use in the iron and steel industry be a function of physical production (e.g., tonnes of an indicator commodities, such a steel, produced) or economic output (e.g. value added for the industrial subsector)? These choices will depend on local conditions, data availability, and robustness of the relationships. (see Schipper and Meyers, 1992)

The urban household cooking data in Figure 3.1 illustrates the full activity level and energy intensity specification for one demand "branch". The data shown are for base year, 1990. At the first level, the driving activity is households, of which there were 8 million in 1990. At level two, the fraction of these households in the "Urban" subsector is entered (30% in 1990). At the third and fourth levels, the saturation of cooking end-uses (100%, every household cooks) and fuel shares are entered respectively. In 1990, 30% of urban households used electric stoves at an annual energy intensity of 1.44 GJ per household. The LEAP demand calculations are, as shown in Box 3.2, are straight-forward. For each year, the values at each level (four activity levels and an energy intensity) are multiplied to yield the projected energy use for each branch. These individual branch projections are then summed across subsectors and sectors to yield total national energy demand projections, hence the term "bottom-up". For Country X, a LEAP "Demand Data Echo", which shows the data and projection values and methods, is presented as Attachment B of this appendix.

In some cases, branch data will be the value of a driving variable, such as the number of households in the base year, in others, it may be a fraction. Some data values can be taken directly from existing statistical compilations, while the analyst may have to derive or estimate other values based on existing statistics, survey data, or even representative data from nearby countries. In some cases only more aggregate statistics will be available; for example, the analyst may know the average electricity use per urban household, but have only suggestive data about the saturation and electricity use levels for specific end-uses (e.g. lighting, cooking, or other appliances). In such cases, the analyst will have to use judgment and refer to other studies.

(c) Specify model relationships and sources of projected data for each branch. A range of different forecasting methodologies can be used including those described in the Technical Report (Section 5.2.1): expert judgment, content analysis, trending, econometric forecasting, and end-use forecasting. LEAP allows for a variety of model relationships, and can accommodate variants of and/or data from each of these five forecasting methods. Methods can be combined in an *ad hoc* fashion in a LEAP demand analysis. For example, in the simple example of cooking in urban households shown in Figure 3.1, a growth rate (based on demographic studies) may be used to project the total number of households, while expert judgment may be used to estimate likely changes in other variables such as the energy intensity of different types of stoves.

The relationships used to estimate the future values of driving variables in LEAP will depend on local conditions and perceived behavioral and functional relationships within sectors. The assumed relationships for a given analysis can have a considerable impact on the outcome of the analysis. For example, if energy use in the residential sector is assumed to be a strict function of income, the projected energy use might differ substantially from the results of a purely end-use approach. The end-use approach might separately project energy demand for each major residential end-uses, based on saturation levels and energy intensities, which could, in turn depend on economic, cultural, and/or technological factors.

Box 3.2 Calculation of Energy Demands in the LEAP Demand Program.

Energy demand is calculated separately for each branch demand at the device or fourth level (*DEVICEDEMAND*). The annual energy demand for device *d* in year *t* is the product of the four activity levels and energy intensity of the device:

$$DEVICEDEMAND_{d,t} = ACTLEV_{d,t} \cdot ENINTENSITY_{d,t}$$

Where:

$$ACTLEV_{d,t} = ACTLEV_{sector,t} \cdot ACTLEV_{subsector,t} \cdot ACTLEV_{enduse,t} \cdot ACTLEV_{device,t}$$

Activity levels (*ACTLEV*) and energy intensities (*ENINTENSITY)* in year *t* are based on one of 3 methods selected for that branch:

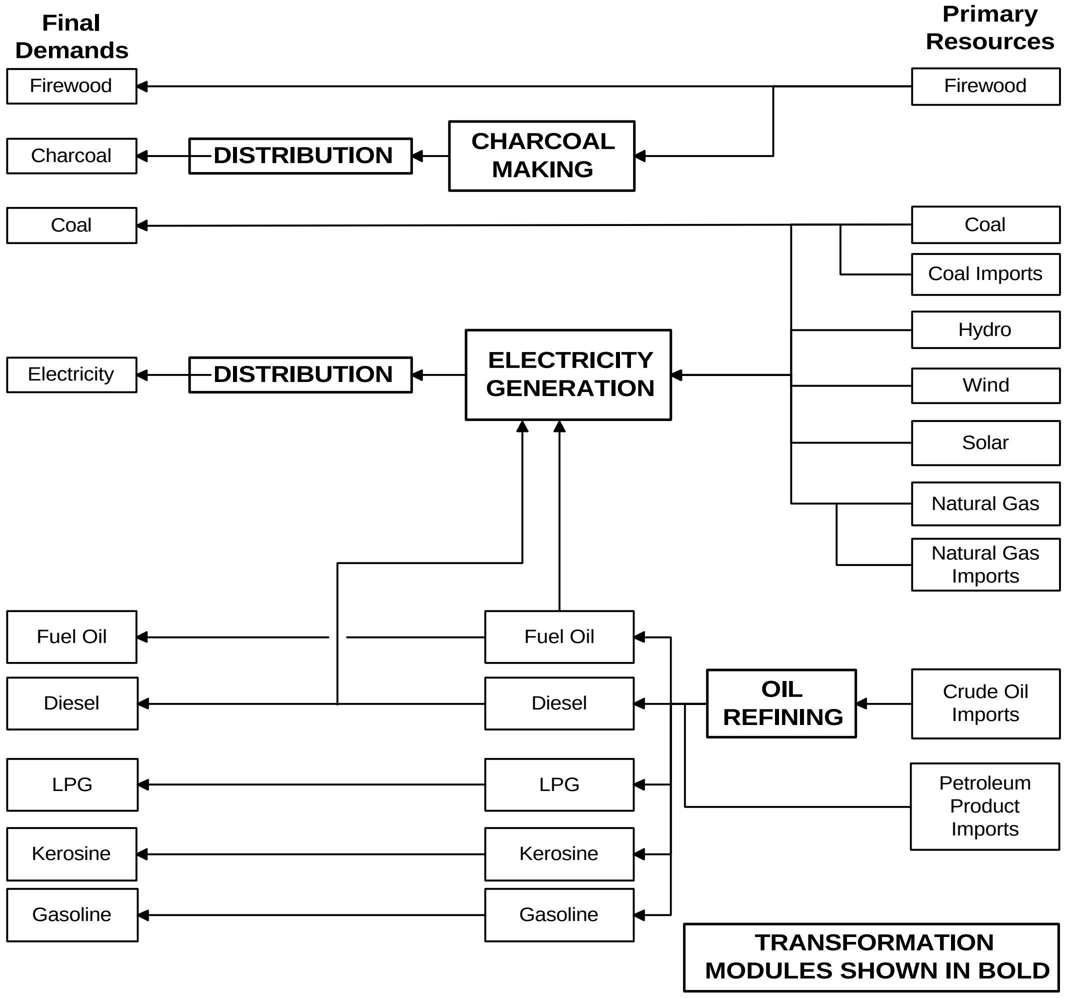
1. Interpolation:
   $FUTUREVAL_t$ = interpolated from previous non-blank value and next non-blank value.

2. Growth Rate:
   $FUTUREVAL_t = BASEYEARVAL \cdot (1 + GR)^t$

3. Drivers & Elasticities (Up to 3 drivers and elasticities):
   $FUTUREVAL_t = BASEYEARVAL \cdot (D1_t / D1_0)^{a1} \cdot \ldots \cdot (DN_t / DN_0)^{aN}.$
   Where:
   $FUTUREVAL_t$ = activity level or energy intensity in future year,
   $BASEYEARVAL$ = activity level or energy intensity in base year,
   GR = growth rate, t=0 in base year.
   DN_0 = Nth driver value in base year, DN_t = Nth driver value in future year t
   an = Nth elasticity value

LEAP provides various tools to assist the analyst in entering demand data. These include the ability to select any convenient energy or physical units for data entry, and the ability to customize a list of up to 65 fuels and resources.

Figure 3.2 Schematic of Transformation Structure in Country X



3.3.2 DESIGN ENERGY SUPPLY STRUCTURE

To develop a supply analysis in the LEAP Transformation program, such as the one shown in Figure 3.2, the analyst must:

(a) Create a list of modules. Modules represents the important energy conversion, extraction, and distribution activities in a given country. LEAP contains a default list of Transformation modules that can be changed to suit local conditions and mitigation options being considered. These include a module to represent transmission and distribution of electricity and other fuels, and others to model the production of electricity, charcoal, oil, natural gas, and coal.

(b) Specify process data. Within each module, the analyst specifies more detailed process level data describing individual facilities or types of facilities such as electricity generation plants. The degree of detail in which data are specified should reflect the importance of the module in the mitigation analysis. For example, in Country X, the electric sector is the most important GHG emissions source, and contains more detailed data on the cost and performance characteristics of individual generation technologies, such as gas-fired combined cycle units or coal steam technologies. For each process, the analyst specifies input fuels, capacity, efficiency, capacity factor and the capital and operating and maintenance costs, and if relevant the co-production of other energy outputs, such as cogenerated steam.

(c) Define the operating rules for each module. At the module level, the analyst indicates how the different processes in a module are used to meet the output requirements. A range of different simulation methods can be used. The analyst may want some modules to simply produce the amount of fuel required (up to specified resource limits), while other modules may have their output constrained by the amount of capacity available in any given year. For the electricity sector, specific plants can be dispatched by merit order to meet an annual system load curve, or simpler methods can be employed.

(d) Enter data on primary resource availability. The final outcome of calculating all Transformation modules is a set of requirements either for primary resources (fossil-fuel or renewable) or for imports of fuels in the area. By entering data on primary resources, these requirements can be compared to the projected availability of primary resources.

3.3.3 NORMALIZE TO BASE YEAR ENERGY BALANCE.

Once detailed data structures have been established, and data entered for the base year, the full data set should be calibrated to reflect official base year energy supply totals. When summed across end-uses, subsectors, and sectors, the total energy use and required supply determined from a set of disaggregate “bottom-up” data will often disagree with official supply totals. Disaggregated data must then be reviewed and adjusted, based upon the analyst’s judgment. Large differences generally indicate the need for closer analysis. Small differences can be allocated to the least accurately defined categories, such as “other industries”, or can be allocated to all energy use categories on a pro-rata basis.

For illustrative purposes, the base year energy balance for Country X, as produced by LEAP is shown in Table 3.2.

Table 3.2 Energy Balance for Country X: 1990

(MILLION GIGAJOULES)

	CRUDE OIL	PETRO PROD	COAL	NATURAL GAS	HYDRO	ELEC-TRICITY	WOOD FUEL	TOTAL
INDIGENOUS	0.00	0.00	168.54	0.00	19.18	0.00	64.90	252.62
EXPORTS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IMPORTS	83.29	133.54	0.00	0.00	0.00	0.00	0.00	216.83
PRIMARY SUPPLIES	83.29	133.54	168.54	0.00	19.18	0.00	64.90	469.45
COAL PRODUCTION	0.00	0.00	-33.71	0.00	0.00	0.00	0.00	-33.71
OIL REFINING	-83.29	79.13	0.00	0.00	0.00	0.00	0.00	-4.16
ELECTRICITY	0.00	-60.89	-112.82	0.00	-19.18	76.72	0.00	-116.18
CHARCOAL	0.00	0.00	0.00	0.00	0.00	0.00	-6.98	-6.98
DISTRIBUTION	0.00	0.00	0.00	0.00	0.00	-11.51	-0.02	-11.53
FINAL CONSUMPTION	0.00	151.77	22.01	0.00	0.00	65.21	57.90	296.89
RESIDENTIAL	0.00	10.67	0.00	0.00	0.00	11.47	40.74	62.87
COMMERCIAL	0.00	0.77	0.00	0.00	0.00	12.00	1.15	13.92
INDUSTRIAL	0.00	36.74	22.01	0.00	0.00	34.39	16.01	109.15
TRANSPORT	0.00	103.45	0.00	0.00	0.00	0.15	0.00	103.60
AGRIC & FISH	0.00	0.14	0.00	0.00	0.00	7.20	0.00	7.35
TOTAL DEMANDS	0.00	151.77	22.01	0.00	0.00	65.21	57.90	296.89

3.4 Set Up Emissions Data

Once the analytical structure for the demand and supply elements of the energy sector are complete, the next task is to set up the calculations by which fuel use estimates, and estimates of the magnitude of fuel conversion activities, are translated into estimates of the emissions of greenhouse gases from the energy sector. This task has three elements:

(a) Decide which gases to consider. Energy sector activities release a number of different types of pollutants in varying quantities. The analyst must reduce the large field of pollutants to a number that is manageable for the study. Among greenhouse gases, carbon dioxide (CO_2) is almost always the GHG released from energy sector activities in the largest quantities, and its emissions will usually have the largest impacts on climate. For the Country X example, we therefore focus on emissions of CO_2. Other greenhouse gases can also be of considerable importance, including methane and nitrous oxide. The analyst may also wish to reflect the impact of mitigation scenarios on other pollutant emissions, such as sulfur oxides (SOx) and nitrogen oxides (NOx).

(b) Specify emission factors for each energy activity. In LEAP, relevant emission factors should be specified for each appropriate energy conversion, transport, and production activity in the Transformation program, and each appropriate energy consuming activity in the Demand program.[11] GHG emission factors are available from the IPCC and other sources, as listed in Table 3.1. EDB contains data on emissions of GHGs and other pollutants, drawn from numerous international references. The analyst can choose sets of emission factors from EDB or enter their own data into EDB from other sources.

(c) Calibrate base year emissions. Once connections have been made between energy data and emission factors, the results national energy sector emission estimates (produced by the LEAP Environment program) should be compared and calibrated to official country base year emissions inventories, if they are available. Differences between the base year emissions estimates from the mitigation study and an official GHG inventory may be due to a number of factors, including differences in energy data, differences in emission factors, or off-line computational errors.

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[11] For instance, electricity consuming activities are not assigned emission factors on the Demand side in LEAP, since their associated emissions are accounted for in the simulation of the electricity production in the Transformation system

SECTION 4:
DEVELOPING THE BASELINE SCENARIO

This section describes the development of a baseline scenario using LEAP, with reference to the hypothetical country example. The development of a baseline scenario begins with the definition of scenario characteristics (e.g. business-as-usual or official government plans) and projection methods (e.g. expert judgment or econometric modeling). Changes in exogenous driving variables must then be specified and entered into the model, which is then run to simulate overall energy use and emissions over the time horizon selected. Finally, the baseline scenario must be evaluated for reasonableness and consistency, and revised accordingly. Uncertainty in the evolution of the baseline scenario can be reflected through sensitivity analysis of key future parameters and their effects on the baseline and mitigation scenarios.

4.1 DEFINE BASELINE SCENARIO

As noted in the Technical Report, defining a baseline scenario can be one of the most challenging aspects of a mitigation analysis. It must portray the expected economic, social, demographic, and technological development over a 20-40 year or longer time horizon. These assumptions are critical to the analysis, since they can affect the levels of projected future baseline emissions, the amount of reductions required if a specific mitigation scenario target is specified, and the relative impacts and desirability of specific mitigation options. For instance, the adoption of many low-cost energy efficiency improvements could be assumed to happen in the baseline scenario. This assumption would yield lower baseline emissions, as well as increasing the overall cost and lowering the savings of efficiency improvements in the mitigation scenario, possibly making them less attractive relative to fuel-switching mitigation options.

Along with assumed rates of technological change, the rate of economic growth and changes in domestic energy markets are among the most important baseline assumptions affecting projected baseline emissions and the impacts of mitigation options. Official government GDP projections may differ from other macroeconomic projections or past trends. In terms of domestic energy markets, the removal, or increase, of energy price subsidies could greatly affect fuel choice and energy efficiency, and thus baseline emissions and the impacts of mitigation options. These and other baseline scenario considerations are discussed in the Technical Report (Section 4.3) and in the UNEP/RISO Guidelines (UNEP, 1994b, Section 6.3.2.), and should be specified based on local circumstances. As a descriptive model, with energy prices and economic growth as inputs, LEAP can simulate either “efficient”, “business-as-usual”, or other baseline scenario definitions.

4.2 COMPILE BASELINE ASSUMPTIONS

Once the basic definition of the baseline scenario is made, the key baseline assumptions that drive the development of the energy sector under the baseline scenario are assembled. In bottom-up approaches like LEAP, most of these future values for most key driving parameters are exogenous. In other words, they are based on external estimates or projections rather than being estimated by the model itself. Future values can be drawn from a variety of sources, using the forecasting methods described in the Technical Report (Section 5.2.1) and Section 3 above: expert judgment, content analysis, trending methods, econometric forecasting, and end-use forecasting.

The first step toward compiling the baseline scenario is thus to assemble forecasts, projections, or plans for statistics or activities that will affect the energy scenario. These will include national economic development plans, demographic and economic projections, sector-specific plans (e.g. expansion plans for the iron and steel industry), studies of trends in energy use (economy wide, by sector, or by end-use), plans for investments in energy facilities (electric generation facilities, mines, gas pipelines, etc.), and studies of resource availability (for example, studies of wind power sites in the country) and projections of future resource prices. In short, all studies that attempt to look into the country's future -- or even the future of the region -- may be sources of useful information for the specification of a baseline scenario.

Once this information is collected and compiled, it must be synthesized into a form suitable for entry into LEAP or another modeling tool. This means converting the available data into future values for driving activities, e.g. population and household growth, growth in GDP, production of key commodities, and consumption of key goods and services. Other key parameters , such as domestic, import, and export fuel costs, future levels of reserves of key resources, and the rate of inflation must also be derived or otherwise decided upon by the analyst. Energy sector expansion plans must be converted to a form that can be incorporated into a model, such as the timing, cost, and performance characteristics of projected capacity additions. It is unlikely that every parameter needed to complete the baseline scenario will be found in national documents, or even that the documents obtained will provide a consistent picture of a country's future. As with much of the modeling process, the judgment of the analyst in making reasonable assumptions and choices is indispensable.

The characteristics of the hypothetical example country, Country X, were reported in Box 3.1 above. The key assumptions for the baseline scenario are as follows.

- population grows at 2.5 %/year through 2030. Due to an ongoing reduction in the size of households, the number of households grows at 3.0%/year. The share of households in urban areas increases from 30% in 1990 to 45% in 2030;
- national GDP grows at 3.5%/yr. through 2030, with faster growth in the commercial or services sector compared to the industrial sector;
- rural electrification increases the number of electrified rural households from 65% to 95% from 1990 to 2030;
- rising standards of living increase the saturation of electric end-uses (refrigeration, air conditioning, television, etc.), the level of lighting usage (up at 1.0% per year), and the rate of switching from traditional to modern cooking fuels. With the exception of slower improvements in traditional cook stove efficiency (0.3%/year), the energy efficiency of household devices improves at about 0.5% per year, reflecting the natural replacement of older with newer more efficient appliances;
- energy demand in the commercial, agricultural, and most industrial sectors grows with sectoral value added (GDP). The baseline energy intensity (energy use per unit value added) decreases by 0.5%/year;
- personal transport services, indicated by passenger-kilometers traveled per capita, increases at 2.5%/yr. until 2010 and 2.0%/yr. beyond that. There is a gradual shift from public transportation to private vehicles. Private passenger vehicles are assumed to have an average natural increase in energy efficiency of 0.75%/year, while the natural increase in efficiency of buses, trains, and planes is 0.5%/year;
- freight transport (tonne-km per capita) grows at 2.0%/year. Freight transport undergoes a slow shift from smaller trucks to larger trucks and from road and water-borne freight to air and rail freight. Road freight still maintains a dominant 78.5% share of freight transport by 2030, only a modest reduction from its 1990 level of 83%;
- about two-thirds of new electric capacity is coal-fired, the remaining one-third is oil-fired. Existing facilities are retired at the end of their planned lifetimes, with the exception of hydroelectric facilities which are maintained;
- domestic coal production capacity is expected to increase almost four-fold over 1990 levels by 2030;
- no new oil refining capacity is added;
- the real price of crude oil and refined petroleum products increase modestly, averaging 0.8%/year (real) through 2030. (Based on UNEP, 1994b); and,
- indigenous renewable resources (wind, solar, and biomass) remain untapped, except for continued use of traditional woodfuels and existing hydroelectric capacity.

4.3 ENTER DATA AND RUN BASELINE SCENARIO

Once the assumptions to be used in the baseline scenario have been mapped out, the next step is to enter the projected values for key parameters. When using LEAP, the analyst can enter one or more single future values or growth rates. The LEAP Demand program will calculate values for intermediate years by interpolation. In the Transformation program, it is only necessary to enter future data for modules that change over time, e.g., to describe the expansion of capacity in the electricity generation system.

When the data set is complete, the analyst calculates the results of the baseline scenario and checks results to ensure that they appear reasonable and logical. When reviewing initial Demand results, many questions should be raised, such as: Do the growth rates of fuel demand in each sector make sense, based on the input assumptions, past trends, and expected developments? Are there changes in demand patterns that seem unlikely? LEAP provides the analyst with a variety of tools to help "debug" and understand the behavior of Demand results, including graphical tools, the ability to focus on results for a single sector, subsector, end-use, or fuel type, and the ability to express results as percentages, growth rates, or values. These features can help to quickly track the source of major changes in future energy demands.

When reviewing Transformation results, the analyst should ensure that all fuel demands are being met, either through domestic production or by imports. In the electricity module, the analyst should check to see that an adequate reserve margin[12] is maintained throughout the planning period, and that there is a reasonable balance between baseload, intermediate, and peaking resources[13]. If supply resources are insufficient, demands should be curtailed, prices augmented, and/or new supply resources added. If excess capacity (e.g. unneeded power plants) and/or resources are present, expansion plans should be delayed or curtailed, if possible.

The final step in running the baseline scenario is to calculate the emissions consequences of the scenario. In LEAP, this means running the Environment program. Here again, the analyst should review results to see that they are not unreasonable. Are the emissions of expected order of magnitude? If not, and errors in the Demand or Transformation data sets have been eliminated as possible causes, some emission factors may be incorrect or missing.

Selected results of the baseline scenario for Country X are shown in Figures 4.1 to 4.3 and Tables 4.1 and 4.2 below. As shown in Figure 4.1, energy demand increases significantly across all sectors over the 1990-2030 period. The fastest growth occurs in the transport sector, which eclipses the industrial sector as the dominant source of energy demand by early in the 21st century. Table 4.1 shows the increase in terms of final fuel demands. Fuel switching and modernization increase the use of electricity from 22% of total final demand in 1990 to 26% in 2030, and decrease the role of firewood and charcoal from 20% of total fuel use in 1990 to 6% in 2030. The increasing dominance of the transport sector increases the share of petroleum products from 51% in 1990 to 63% in 2030. Given that future, marginal electricity resources will be largely coal based, electricity demands, along with petroleum product demands, should be important targets for GHG mitigation in Country X.

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[12] The reserve margin is the difference between total installed electric generation capacity and the annual peak demand, divided by the peak demand. In general, reserve margins of 15 to 25% are considered adequate for ensuring reliability of electric service. Larger reserve margins might indicate an electricity generation system that is over-built (and thus more expensive than necessary) or poorly maintained.

[13] Baseload resources are power plants that run most of the time to meet a constant level of demand day and night, even when demand for electricity is low. Peaking plants run less frequently to meet demand only at "peak" periods (e.g. in the morning or evening) when demand is highest. Intermediate plants are in-between generating resources, operating during periods of moderate to high demand.

Figure 4.1 Baseline Energy Demand by Sector in Country X
(Billion Gigajoules)

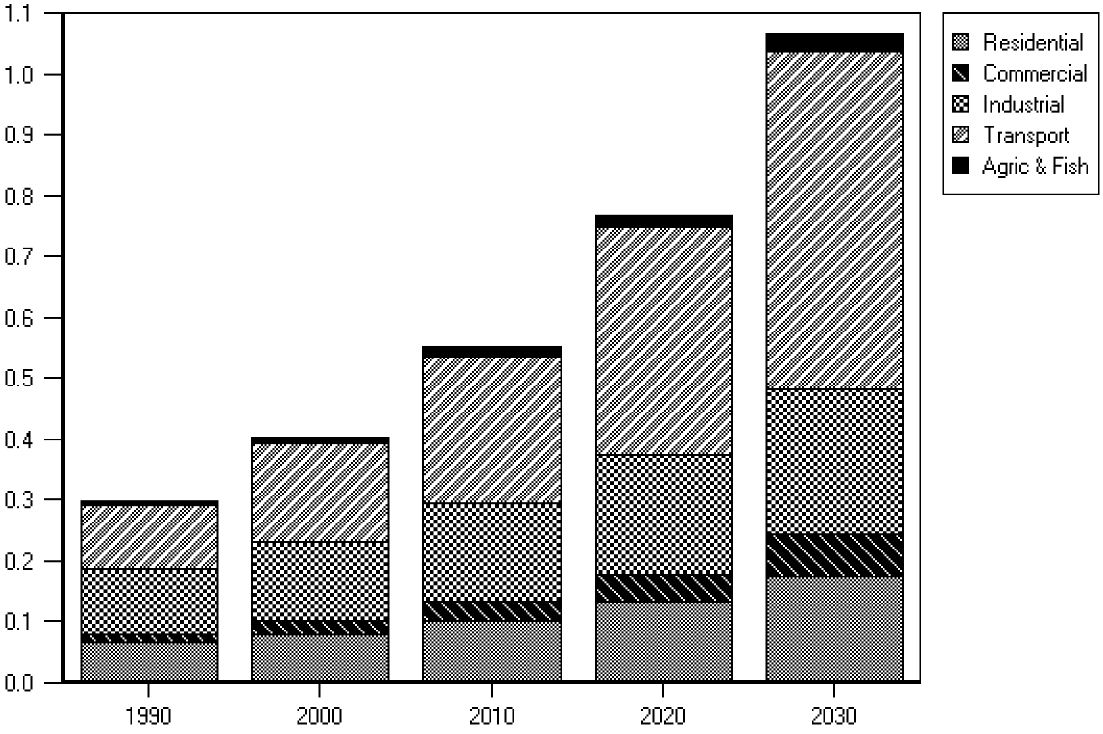

Figure 4.2 Baseline Primary Energy Supplies in Country X
(Billion Gigajoules)

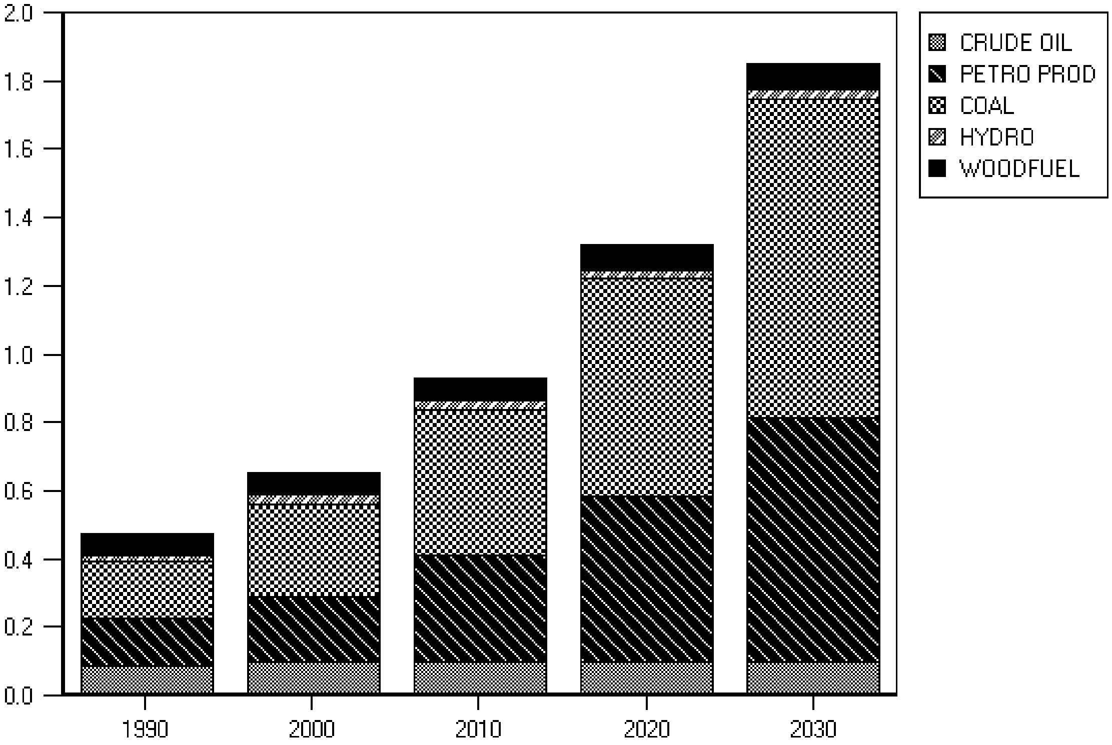

Table 4.1 Baseline Energy Demand by Fuel in Country X

(MILLION GIGAJOULES)

	1990	2000	2010	2020	2030
ELECTRICITY	65.21	93.98	137.35	195.62	281.69
GASOLINE	72.30	114.83	174.64	270.70	402.77
KEROSENE/JETFUEL	10.78	18.32	27.82	39.91	55.16
DIESEL	28.33	36.48	51.12	74.27	106.81
FUELOIL	36.84	44.88	54.66	66.59	81.13
LPG	3.53	6.33	10.16	14.72	21.21
COAL	22.01	26.79	32.62	39.72	48.36
FIREWOOD	55.59	55.92	57.70	62.28	64.44
CHARCOAL	2.30	2.50	2.38	2.83	3.23
TOTAL	296.89	400.03	548.45	766.66	1064.81

(PERCENT SHARE)

	1990	2000	2010	2020	2030
ELECTRICITY	21.97%	23.49%	25.04%	25.52%	26.45%
GASOLINE	24.35%	28.71%	31.84%	35.31%	37.83%
KEROSENE/JETFUEL	3.63%	4.58%	5.07%	5.21%	5.18%
DIESEL	9.54%	9.12%	9.32%	9.69%	10.03%
FUELOIL	12.41%	11.22%	9.97%	8.69%	7.62%
LPG	1.19%	1.58%	1.85%	1.92%	1.99%
COAL	7.41%	6.70%	5.95%	5.18%	4.54%
FIREWOOD	18.72%	13.98%	10.52%	8.12%	6.05%
CHARCOAL	0.78%	0.63%	0.43%	0.37%	0.30%
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%

Table 4.2 Selected Baseline Environmental Emissions in Country X

	1990	2010	2030	
CARBON DIOXIDE	26.75	57.67	124.11	(BILLION KG)
CARBON MONOXIDE	477.21	819.63	1623.00	(MILLION KG)
METHANE	84.12	214.52	419.85	(MILLION KG)
NITROGEN OXIDES	95.94	180.56	371.27	(MILLION KG)

CO_2 emissions are from fossil fuels. CO_2 emissions from biomass are not included here.

Figure 4.2 shows the total primary energy supplies required to meet projected demands. Most of the projected growth of 3.5% per year over the 1990-2030 period is accounted for by imports of petroleum products and coal production. Crude oil imports are relatively flat, since no new refinery capacity is added. Figure 4.3 reports key aspects of the future electric system. As new coal plants are added to meet growing baseload electricity demand, they come to dominate total electricity production, accounting for about half of all electricity production in 2010 and three-fourths by 2030. Oil and hydro facilities cover the remaining peaking and intermediate loads. The reserve margin is maintained at just over 18% throughout the planning period. (These and other reports should be to identify whether insufficient or excess supply capacity are projected, and adjustments are needed in terms of expansion planning, retirement schedules, or demand-side management.)

Table 4.2 shows the pattern of CO_2 and other air emissions from Country X from 1990 to 2030. CO_2 emissions are projected to increase 115% over 1990 levels by 2010 and 360% by 2030. These increases result from rapidly increasing energy demands, particularly in the oil-based transportation sector, and the reliance on coal to meet growth in electricity requirements. Other greenhouse gas and local air pollutant emissions also increased markedly by 2030: energy sector CH4 emissions are up roughly 400% over 1990 levels, while CO levels are up 340% and NOx levels are up 290%.

4.4 REVIEW REASONABLENESS OF BASELINE

Once the initial baseline scenario is prepared, it should be reviewed to assess whether it is a comprehensive and plausible future for the country in light of real-world constraints. Some specific questions might include:

- Can the indicated growth rates in energy demand reasonably be expected to be sustained over the study period? Is it a reasonable rate, given recent experience in the country and region?
- Is the level of capital investments needed to sustain the indicated levels of industrial growth likely to be forthcoming?
- Is the country likely to be able to afford the bill for fuel imports that is implied by the baseline scenario?
- Is the level of capital investments needed to build up the energy supply system (e.g. for growth in electricity generation capacity and for the rural electrification program) likely to be available, given intra- and inter-country competition for financial resources?
- What will the indicated increase in transportation use mean for urban traffic in the future? Does it imply a need for increased transportation infrastructure that could reasonably be met?
- Are the emission factors in use appropriate for the new technologies, both on the demand and supply sides[14]? Do new sets of emission factors need to be used for new technologies?

Answers to these questions might indicate the need to make adjustments to the baseline scenarios or to conduct sensitivity analyses of key parameters once the mitigation and baseline scenarios have been completed.

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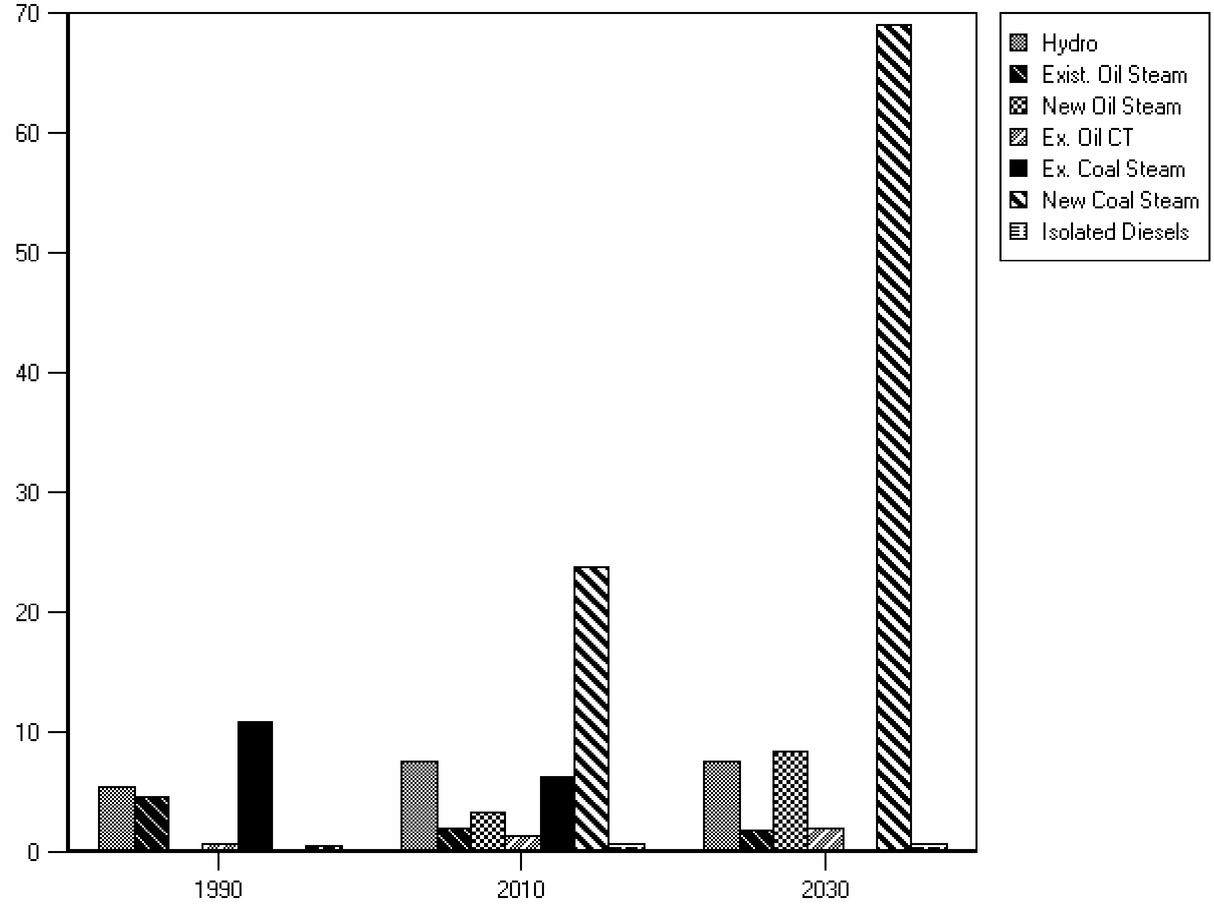
[14] CO2 emissions per unit of fuel use (or production) are unlikely to change much as new technologies are introduced. Emission factors for other gases are more likely to be affected by technological changes.

Figure 4.3 Baseline Electricity Generation in Country X
(THOUSAND GIGAWATT-HOURS)



ELECTRICITY SYSTEM STATISTICS

	1990	2010	2030
Load Factor	62.12%	62.12%	62.12%
Peak Output (THOUS. MW)	3.92	8.04	16.25
Reserve Margin	26.40%	18.74%	18.18%

SECTION 5:
CREATING AND EVALUATING MITIGATION SCENARIOS

This section describes the process of developing a mitigation scenario. The process involves three basic steps: (1) establishing a scenario objective; (2) identifying, screening, and selecting specific mitigation options; and (3) combining these options in an integrated scenario. These steps may be iterative, since running the integrated scenario (e.g. in LEAP) might reveal that the scenario objective is not met (for example, if a specific reduction level is targeted), requiring the further screening and selection of other mitigation options.

While the definition of a scenario objective is relatively straightforward, the following step -- identification, screening, and selection of mitigation options -- contains several, more challenging, elements. Section 5.2 below outlines the issues involved in: (a) defining screening criteria; (b) defining key parameters and considerations, such as discount rates and the definition of costs and benefits; (c) identifying mitigation options; (d) applying the screening criteria and selecting specific options for inclusion in a scenario; and (e) estimating reasonable and achievable penetration rates for the selected options. In general, these steps are performed outside of LEAP, based on local considerations and evaluation of relevant literature and studies, and might involve the use of spreadsheets or sectoral models.[15]

One attractive option for undertaking the identification, screening and selection of mitigation options is to employ individual experts with detailed knowledge of specific sectors. One LEAP-based mitigation scenario analysis took such an approach, involving teams of sector specialists who conducted separate analyses of technical and policy options for the buildings, transport, industrial, and energy supply sectors, using a common screening approach. (UCS et al., 1991) These sectoral analyses generated the cost and penetration rate estimates for selected options that were then entered into LEAP as data for the integrated scenario analysis.

Integrated scenario analysis, the third step discussed here, is essential in developing accurate and internally consistent estimates of overall cost and emissions impacts. Screening analyses typically calculate the relative cost-effectiveness of mitigation measures based on their levelized incremental cost per unit of CO_2 or GHG reduction. (See Box 5.1 below on the calculation of CSC, or the cost of saved carbon, and Sections 5.2 and 5.4 of the Technical Report.) The actual emissions reductions from employing a specific measure can, however, depend on the other measures included in a scenario. For instance, to screen a measure that saves electricity, the analyst must make an assumption about the electricity generation resources whose use would be avoided (e.g., coal, oil, hydro, or a mix) in order to estimate the level of reduction in GHG emissions that can be credited to the measure. In reality, the type of electricity generation that the efficiency measure would avoid will change over time, and, if lower GHG emitting electricity resources are also introduced in the scenario, the GHG savings of the efficiency measure may be reduced. Integrated scenario analyses, using LEAP or other tools, are intended to capture these and other interactive effects. This section concludes by illustrating the construction of the integrated mitigation scenario for the hypothetical example.

5.1 ESTABLISH OBJECTIVE FOR MITIGATION SCENARIOS

Several objectives are possible for designing a mitigation scenario. The objective will depend on political and practical considerations. Types of objectives include:

- **Emission reduction targets.** This is the type of objective considered in the hypothetical example: 12.5% reduction in CO2 emissions by 2010, and 25% reduction by 2030, from *baseline levels.* A common alternative is to specify reductions from *base year levels*, which

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[15] For examples, some industrial sector models include Long-Run Industrial Energy Forecasting (LIEF) model (Ross and Hwang, 1992) and Industrial Sector Technology Use Model ISTUM-2 (EEA, 1982).

avoids making the amount of reduction dependent on the specification of the baseline scenario. Using the procedure presented here, mitigation options are screened and ranked starting with the least costly per estimated amount of GHG reduction (see Box 5.1 below) or otherwise preferred options, based upon the screening criteria. Options are added to the scenario until the integrated scenario results (e.g. from LEAP) indicate that emission reduction objectives are met. Since the ranking procedure cannot capture interactive scenario effects and thus might not yield the lowest cost scenario for the given emission reduction objective, alternative scenario configurations may be tested.

- **Options up to a certain cost per ton of emissions reduction.** This type of scenario is the “bottom-up” equivalent to a “top-down” carbon tax scenario. In the bottom-up approach, all technology and policy options that are expected to cost over a given cost per tonne of emissions reduction would be excluded from the scenario. While it is suggestive of the measures that would become cost-effective were a carbon or GHG tax to be introduced, this type of bottom-up approach does not seek to capture the full range of macroeconomic and behavioral effects of a carbon tax, as the top-down approach would.
- **“No regrets” scenario.** This scenario is common variant of the previous type of objective, where the screening threshold is essentially zero cost per tonne of GHG reduced. In other words, such a scenario would include only those options that appear economic or otherwise desirable.
- **Specific options or packages of options.** Examples of this type of scenario might be a “natural gas” scenario, a “renewable energy” scenario, or a “nuclear” scenario.

Another important aspect of defining the scenario objective is to decide on whether CO_2 or all GHGs will targeted. Non-CO_2 GHGs, such as CH_4 (methane) or N_20 (nitrous oxide), can be separately targeted for reduction, or a combined reduction target can be specified using global warming potentials (GWPs). In the example presented here, we limit the focus to reductions in CO_2 emissions for the sake of simplicity.

Box 5.1 Comparing Options on the Basis of Costs of Saved Carbon (CSC)

A common metric for comparing mitigation options is the cost per tonne of CO_2 or CO_2-equivalent emissions reduction. This metric, as discussed in the Technical Report (Sections 4.5 and 5.2.2), is commonly referred to as either the CSC (costs of saved carbon), CCC (cost of conserved carbon), or, more simply, as the abatement cost. It can be measured on either a total, average, or marginal basis. The following equation describes the average CSC for a particular mitigation measure:

$$\mathrm{CSC} = (C_m - C_a)/(E_a - E_m)$$

where C_m = levelized cost of mitigation measure (usually per unit energy saved or produced)
C_a = levelized avoided cost, i.e. what would have occurred in baseline (per unit energy avoided)
E_a = emissions associated with avoided baseline activity (per unit energy avoided)
E_m = emissions associated with mitigation measure (per unit energy saved or produced)
(for the marginal cost version of this equation, see UNEP 1994a, p.25)

There are several important limitations to the use of this metric, which are described in the Technical Report and UNEP (1994a). Costs must be levelized, which requires specification of a discount rate. (see UNEP 1994a for levelization and discount rates) The CSC is a static representation, characterizing an option for a specific reference year. However, the costs and savings of an option can change over time depending on cost and fuel price escalation, baseline technological change, and the other mitigation options included in a scenario.

The CSC is nonetheless a useful tool for screening mitigation options, since it provides a consistent format for comparing and ranking alternatives. In the approach described here, this metric is used as a criterion for screening option cost-effectiveness.

5.2 SELECT MITIGATION OPTIONS TO INCLUDE IN MITIGATION SCENARIO

This step involves several major elements, as described below.

5.2.1 DEFINE SCREENING CRITERIA

As noted in the Technical Report (Section 3), GHG mitigation must be integrated with other key national objectives, such as improving the balance of payments or promoting rural development. The criteria for judging whether a specific GHG mitigation option should be included in a mitigation scenario must encompass social, political, and cultural factors in addition to standard economic concerns. Some of the potential criteria that could be used for evaluating mitigation options are:

- Potential for large impact on emissions of CO_2 and other GHGs
- Relative cost per unit of GHG reduction (e.g. CSC)
- Indirect economic impacts
    - Increase in domestic employment
- Increase in national self-reliance
    - Decrease in imports, improved balance of payments
- Consistency with national development goals
    - Improved equity, rural development, or physical infrastructure
- Consistency with national environmental goals
    - Reduced emissions of local air pollutants
    - Effectiveness in limiting other environmental impacts
- Potential effectiveness of implementation policies
- Sustainability of option
- Data availability for evaluation
- Technology characterization
- Costs of implementation programs
- Other sector-specific criteria

The final specification of screening criteria--and the weighting of the relative importance of those criteria--will depend on local conditions and priorities. For the hypothetical example below, we focus primarily on the application of the first two screening criteria in the list above.

5.2.2 DEFINE KEY PARAMETERS AND CONSIDERATIONS, SUCH AS DISCOUNT RATES AND RELEVANT COSTS AND BENEFITS.

Among the principal considerations are the choice of discount rates and the definition of which costs and benefits to include in the analysis. These issues are discussed in Sections 4.6 and 5.2.2 of the Technical Report. For the purposes of the hypothetical example, a real discount rate of 5% is used for screening and comparing options and for calculating of the net present value of the scenario.

In terms of costs, the analyst must decide whether less tangible social and environmental costs are included in the analysis. In the hypothetical example below, only direct economic costs are included for mitigation options and the resources that they would avoid. These include the direct costs for equipment, operations and maintenance, and energy resources. The administrative and program costs for implementing the energy efficiency improvements are also included, using a simplified 20% adder to the measure costs. Financing and other costs, including environmental externalities, can also be included in LEAP, but were not specified for the simplified example below.

5.2.3 IDENTIFY OPTIONS

Mitigation options can be identified from a variety of sources as described in Section 5.4.1 of the Technical Report: country case studies, literature review, expert judgment, and general opportunity studies. If derived from studies in other countries, the cost, performance, and emission characteristics of specific options that will be used for screening and (LEAP) scenario analysis should be reviewed for their relevance in the local situation.

The following ten mitigation options for the hypothetical Country X example were identified purely for the illustrative purpose of demonstrating the mitigation analysis procedure:

- Residential lighting efficiency improvements. A program would encourage the replacement of incandescent with much more efficient compact fluorescent light bulbs in both urban and rural households.
- Residential refrigerator efficiency improvement. A standards or import tariff program would improve the efficiency of new refrigerators on the market.
- Improved industrial and commercial lighting and motor drive efficiency. This could be achieved through standards, incentive programs, tariff and import policies, or other policy instruments.
- Switching from coal and oil to natural gas for industrial sector process heat applications. Natural gas furnaces and boilers produce less CO_2 per fuel consumed, and are often more efficient as well, requiring less fuel consumption.
- Improving vehicle efficiency for automobiles, light and heavy trucks, and buses. This could be achieved through standards, incentive programs, tariff and import policies, or other policy instruments.
- Replacement of new coal-fired electric plants with more efficient natural gas combined-cycle facilities that have lower CO_2 emissions per unit electricity output. Natural gas would be imported via pipeline from a neighboring country.
- Windfarms for electric generation. Most added capacity will occur between 2010 and 2030, by which time the technologies for power generation from wind are expected to be mature and cost-competitive in most applications.
- New nuclear power stations. These would be the first nuclear units in the country.
- Solar photovoltaic electric generation.

The levelized costs for these options, compared with the levelized costs of the equipment and fuels that they displace, are shown in Table 5.1 below. The associated emissions are also shown. These data are only illustrative.[16]

5.2.4 APPLY CRITERIA AND SELECT OPTIONS

Using a broad set of screening criteria to weed out unpromising, undesirable, or infeasible options requires considerable judgment. Many criteria will likely be qualitative and difficult to measure in an objective fashion. Other criteria may be easier to apply. An obvious reason for screening out an option might be the infeasibility of its wide-scale application. Location of options--e.g. fuel resource options or power plants--in environmentally or otherwise sensitive areas may rule them out. There might also be overriding concerns about political acceptability. In addition, there may be options, such as reducing traffic congestion, which may be difficult to analyze since quantifying the impact on GHG emissions may be difficult to do.

In Country X, for example, the nuclear option is screened out for non-economic reasons, due to political concerns and lack of infrastructure to support a nuclear program. The natural gas import option presents concerns about displacing a local resource, coal, with potential impacts on national employment and balance of payments, but nonetheless may be considered a feasible option, in part due to its other,

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[16] These options and data may be significantly revised in further revisions of this appendix.

local environmental benefits relative to coal. (This example, of course, is purely illustrative; actual countries might come to the opposite conclusions regarding these options.)

Assuming all of the other mitigation options identified for Country X pass other (e.g. qualitative) screening criteria, they can be compared according to their relative CSCs, as shown in Table 5.1.[17]

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[17] The steps involved in developing the levelized cost and emission per unit figures shown in Table 5.1., along with the input assumptions, may be described in a later attachment to this appendix.

Table 5.1 Mitigation Options for Country X: Costs, Emissions, and Estimated Costs of Saved Carbon (CSC)

Costs in 1990 US Dollars (a)

Sector	Mitigation Option	Levelized Costs of Mitigation Option (Cm) (Cost/ Unit)	Levelized Costs of Avoided Resource (Ca) (Cost/ Unit)	CO2 Emissions from Mitigation Option (Em) (Tonne C/Unit)	CO2 Emissions from Avoided Resource (Ea) (Tonne C/Unit)	Net Cost per Saved Carbon (CSC) $/Tonne C
Residential	Lighting Efficiency Improvement	$36 /MWh saved (b)	$44 /End-Use MWh(c)	0.000	0.301	-$26
	Refrigeration Eff. Imp.	$78 /MWh saved	$44 /End-Use MWh	0.000	0.301	$113
Commercial	Lighting Eff. Imp.	$18 /MWh saved	$44 /End-Use MWh	0.000	0.301	-$86
	Motor Drive Eff. Imp.	$18 /MWh saved	$44 /End-Use MWh	0.000	0.301	-$86
Industrial	Lighting Eff. Imp.	$18 /MWh saved	$44 /End-Use MWh	0.000	0.301	-$86
	Motor Drive Eff. Imp.	$18 /MWh saved	$44 /End-Use MWh	0.000	0.301	-$86
	Fuel Switch: Coal to Nat Gas	$5.0 /GJ Heat (NG)	$2.8 /GJ Heat (Coal)	0.018	0.039	$109
	Fuel Switch: Oil to Nat Gas	$5.0 /GJ Heat (NG)	$5.2 /GJ Heat (Oil)	0.018	0.031	-$16
Transportation	Automobile Eff. Imp.	$5.1 /GJ Gasoline saved	$6.6 /GJ Gasoline	0.000	0.020	-$78
	Light Truck Eff. Imp.	$4.5 /GJ Diesel saved	$5.3 /GJ Diesel	0.000	0.020	-$39
	Heavy Truck/Bus Eff. Imp.	$3.2 /GJ Diesel saved	$5.3 /GJ Diesel	0.000	0.020	-$104
Agricultural	Pumpset Eff. Imp.	$29 /MWh saved	$44 /End-Use MWh	0.000	0.301	-$50
Power Generation	Nat Gas Combined-Cycle	$40 /Busbar MWh	$39 /Busbar MWh	0.116	0.267	$9
	Wind Turbines	$42 /Busbar MWh	$39 /Busbar MWh	0.000	0.267	$10
	Solar Photovoltaic	$73 /Busbar MWh	$39 /Busbar MWh	0.000	0.267	$127

Notes:

(a) Calculated for scenario mid-year of 2010; discount rate = 5%, real.

(b) The incremental costs of more efficient equipment are expressed in terms of the levelized costs per unit of energy saved. (CSE)

(c) The assumed avoided electricity resource is new coal steam. Busbar costs are levelized costs, including capital, O&M, and fuel.
The avoided end-use costs and emissions for electricity are higher than at the busbar, because T&D and thus additional electricity generation are avoided.

The first column of data in Table 5.1, levelized costs of mitigation options, (referred to as C_m in Box 5.1) reflects the annualized cost of the measure, including energy efficiency program costs, divided by the annual energy it produces or saves. (For information on levelization procedures and costs of saved energy, see UNEP 1994b and U.S. DOE, 1994). The second data column provides the levelized costs of the avoided resource (C_a in Box 5.1). For example, residential lighting efficiency improvements cost $36 per MWh saved, while saving each MWh avoids the need to deliver a MWh of electricity. The delivery of a MWh of electricity would save $52 per MWh, assuming that generation from new coal plants would be avoided. In general, if C_a is greater than C_m, then a mitigation option can be justified on economic grounds, regardless of its GHG benefits.

The third and fourth data columns in Table 5.1 provide estimates for E_m and E_a, the emissions of CO_2 per unit energy produced (or saved) for the mitigation and avoided, baseline options, respectively.[18] In some cases, a mitigation measure, such as efficiency improvements or wind power, has little or no CO_2 emissions. In other cases, including measures such as fuel switching from oil to gas, the mitigation measure simply has lower GHG emissions that the technology and fuel it avoids.

The final column in Table 5.1 presents the net cost per tonne of carbon (C) saved, or the CSC. The options with negative CSCs, are those with apparent net economic benefits. Other options present a positive cost of mitigation, ranging from $9 per tonne carbon saved for switching to gas combined-cycle plants for electricity generation to $127 per tonne C for implementing solar photovoltaic power.

While the assembly of a CSC table, or related “cost curves” as described in the Technical Report (Section 5.2.2), can be a useful exercise, it is not required step for a mitigation scenario analysis performed in LEAP. Alternatively, analysts can simply enter the options and their cost, emission, and performance characteristics directly in LEAP, and calculate the net effects of various combinations of options.

5.2.5 ESTIMATE PENETRATION RATES

The analyst’s next task is to determine reasonable *penetration rates* for the screened technology options. Penetration rates denote the speed at which an option can be implemented. For large investments, such as power plants or large industrial investments, the penetration rate will generally be expressed in terms of the timing and size of discrete changes or capacity additions. For instance, for technical and infrastructure reasons, there might be a limited amount of wind power that can be installed by a specific future date. Alternatively, the intermittent nature of wind power generation might limit its maximum achievable penetration to 20% of total electricity generation, if no storage capacity is available.

For smaller investments, such consumer appliances or smaller industrial investments (e.g. motors or lighting), penetration rates are typically expressed in terms of the percent penetration per year of improved technologies or practices. For instance, an achievable market penetration rate for high-efficiency refrigerators might be 50% of new purchases per year. If only 6% of all refrigerators are replaced (or purchased by households who previously had none) each year, the total penetration rate of energy-efficient refrigerators into the total stock of refrigerators would be only 3% per year. In addition to annual penetration rates, there might be a maximum achievable penetration level, akin to the limitation on wind power implementation described above, if a certain percentage of the market is unlikely to adopt a measure for technical or behavioral reasons.

In general, lower-GHG technologies can be introduced either (a) when existing equipment reaches the end of its economic life and needs replacement; (b) when new equipment is needed to meet growing demands; (c) as a *retrofit* measure which modifies existing equipment; or (d) by replacing existing equipment before the end of its economic lifetime, usually at greater net cost than (a) above.

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[18] Note that these emission factors are given in tonnes of carbon (C), not CO_2, per unit. Saving a tonne of carbon emissions is the equivalent of saving 44/12 or 3.67 tonnes of CO_2.

As a consequence, several factors can influence penetration rates including:

- equipment lifetime. For example, a coal plant may last for 30 years, refrigerator for 15 years, and incandescent light bulbs for 1 year or less. Stock models can be used to track the natural replacement of “vintages” of technologies and indicate the timing and opportunity for technological improvements. If desired, stock models can be represented in LEAP, and are most often used for vehicles.[19]
- technical, infrastructure or financing limitations. The local availability of products, technologies, skilled labor, and capital can influence how rapidly a mitigation option can be adopted.
- and the policy instrument used. For example, to accelerate the adoption of energy-efficient refrigerators, either efficiency standards or incentive programs could be used; the two options would likely achieve rather different penetration rates.

For Country X, several simplified penetration rate assumptions were made. The penetration of mitigation options was assumed to begin in 1994 or thereafter. For instance, for agricultural pumpsets, it was assumed that approximately one-quarter of all units would be replaced in 20 years, or an overall penetration rate of 1.25% per year. Since improved pumpsets could reduce electricity consumption by 40%, the overall energy intensity for agricultural pumpsets declines at 0.5% per year. As the result of similar sets of assumptions for efficiency improvement, energy intensities for other targeted end-uses decline at rates of 0.25% per year (commercial/industrial motors) to almost over 2% per year (residential lighting, first 20 years) relative to baseline scenario levels. For industrial fuel switching, it was assumed that about 1% per year of coal and oil use applications could be switched to natural gas, up to 20% by 2010 and 40% by 2030. For the power sector, it was assumed that combined cycle gas facilities could replace about 40% of planned coal additions, leading to 1000 MW of gas-fired capacity by 2010 and 3600 MW by 2030. The wind power potential was limited to 200 MW by 2010 and 1500 MW, or approximately 9% of total installed capacity, in 2030.

5.3 CONSTRUCT INTEGRATED SCENARIO

The final step is to develop an integrated scenario based on a combination of the screened mitigation options. Using LEAP, the general procedure for developing a mitigation scenario to meet the CO_2 emissions reduction target -- 12.5% below baseline levels in 2010, 25% below by 2030 -- for the hypothetical country is as follows:

(a) Create new Demand and Transformation scenarios.
(b) Select a set of mitigation options to include in the initial scenario. This initial list might include the most attractive options identified.
(c) Enter cost, performance, and penetration rate data on mitigation options. Only changes and additions to the baseline scenario data need to be entered. In the Demand program, costs can be entered in terms of costs of saved energy for efficiency improvements (as in Table 5.1) or costs of specific equipment. In the Transformation program, cost data can be entered in different formats depending on how modules are structured. These options include specifying combined costs per unit of energy produced (net of fuel inputs, e.g. cost per kWh) or specific capital, fixed and variable operating and maintenance (O&M) costs, and financing costs by plant type.
(d) Calculate and review results. The Evaluation program produces a variety of reports, including a summary of costs and savings and a summary of emissions reductions achieved and average cost per tonne emissions saved (see Tables 5.3 and 5.4). As in the baseline scenario, the energy supply capabilities should be checked to ensure that they are sufficient to meet projected demands, without significant excess capacity. Reduced electricity demand will delay the need for new capacity, and the results should be reviewed to ensure that a reasonable

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[19] See Venezuela mitigation study (UNEP 1994a) and US study (UCS et al., 1991).

reserve margin (approximately 18% for Country X) is maintained, but not substantially exceeded for many years.

(e) Iterate steps b-d to until the targeted GHG reductions are achieved. Add or remove mitigation options, either in order of the CSC cost measure shown in Table 5.1, or according to other criteria.

(f) Test variants of the mitigation scenario, if desired. Because the screening criteria such as CSC do not usually capture important interactive effects, different combinations of options might achieve a slightly lower scenario cost. Different combinations might also achieve an improvement in other criteria, such as balance of payments or local environmental well-being, at slightly higher calculated scenario cost. Since many other objectives are important to national policy, and modeling approaches cannot capture all costs and benefits, the absolute lowest cost scenario may not be the preferable one.

5.4 PRESENT AND EVALUATE RESULTS

Results of the illustrative mitigation scenario for Country X are illustrated in the form of edited LEAP results tables (Tables 5.3 to 5.5) and graph (Figures 5.1), and additional summary tables (Table 5.2, 5.6, and 5.7).[20] As shown in Tables 5.2 and 5.3, the scenario achieves a 17% reduction from baseline CO2 levels by 2010, and a 30% reduction by 2030, somewhat higher than the minimum target above. All options in Table 5.1 except solar PV were included in the scenario. If a closer matching of the target were desired, additional options could be removed or their penetration scaled back.

As a result of efficiency improvements, primary energy use in 2030 increases to only 4 times its 1990 level compared with a 5-fold increase in the baseline scenario. Electricity demand drops by about 20% from baseline levels by 2030. This decrease, combined with the introduction of gas-fired electric generation, leads to a decline in coal use of 55% by 2030. Coal remains the dominant source of electricity generation, but far less so than in the baseline scenario. Figure 5.1 shows the profile of electricity generation by plant type, for comparison with the baseline profile shown in Figure 4.3. By 2030, coal accounts for 41% of generation, while natural gas, oil, hydro, and wind account for 30%, 16%, 10%, and 4%, respectively.

Table 5.3, the summary cost report, shows the net effects of the mitigation scenario relative to the baseline scenario, by sector. The bottom line shows that net present value costs exceed benefits (defined here as cost savings) by about $850 million over 40 years, at a discount rate of 5%. When averaged over the total CO_2 emissions reduced, the average abatement cost is $3.5 per tonne of CO_2, or about $13 per tonne C. The rows of Table 5.3 indicate the major sectoral components of costs and benefits. For example, the cumulative cost of improvements in the efficiency of residential electricity use (lighting and refrigeration) is about $1100 million. The resulting savings in electricity costs contributes to: 1) the net benefits shown under “transformation non-fuel costs”, which represents avoided electricity capacity and O&M outlays ($3312 million); and 2) the benefits shown under “resource costs, indigenous”, which represents avoided coal costs ($1243 million).[21]

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[20] UNEP (1994a) provides several useful reporting formats (see in particular tables 4.4 and 4.5) for comparing results across countries. These comparisons include CSC curves that show both the per-unit costs and ultimate reductions provided by mitigation options (e.g. Figures 4.5 to 4.8 of UNEP 1994a).

[21] Some oil and other fuels may also be saved and would be included under the benefits for imports.

Table 5.2 Selected Physical Indicators for Country X Scenarios

		Baseline Scenario		Mitigation Scenario	
	1990	**2010**	**2030**	**2010**	**2030**
Final Consumption (Million GJ)	296.9	548.5	1064.8	505.5	898.7
Petroleum Products	151.7	318.4	667.1	279.7	524.6
Electricity	65.2	137.4	281.7	125.7	235.5
Primary Energy (Million GJ)	469.5	926.2	1851.0	810.9	1429.5
Coal	168.5	430.4	936.7	284.4	429.3
Natural Gas	0.0	0.0	0.0	64.7	223.8
Petroleum Products	216.8	410.9	810.3	366.7	663.0
CO2 Emissions (Million Tonnes)	26.8	57.7	124.1	47.9	86.5

Table 5.3 CO_2 Emissions Reduction and Costs for Country X

(GHG Mitigation Scenario Compared to Baseline Scenario)

```
                             2010    2030
                             ----    ----
Emission Reduction           9.81   37.61  (BILLION KG)
Reduction (%)               17.01%  30.30% (from baseline level)

Average Levelized Cost per
Emission Reduction:          3.53 (REAL 1990 $/THOUSAND KG)

Levelization Notes
------------------
Study Period:             1990-2030
Real Discount Rate:       5.00%
NPV to 2030:            853.75 MILLION $
Levelized Ann. Cost:      47.01 MILLION $/YEAR
Avg. Emis. Reduction:     13.32 BILLION KG/YEAR
```

Table 5.4 Cost Summary for Country X: 1990-2030
(GHG Mitigation Scenario Compared to Baseline Scenario)

```
                          MILLION DISCOUNTED 1990 $
                (DISCOUNTED TO 1990 AT 5% REAL DISCOUNT RATE)

                        BENEFITS      COSTS         NPV
                            ----       ----        ----
 DEMAND NON-FUEL COSTS
  RESIDENTIAL               0.00    1119.70    -1119.70
  COMMERCIAL                6.11      90.88      -84.77
  INDUSTRIAL               19.33      66.71      -47.38
  TRANSPORT                 0.00    1781.85    -1781.85
  AGRIC & FISH              0.00     151.56     -151.56

 TRANSFORMATION NON-FUEL COSTS
  DISTRIBUTION              0.00       0.00        0.00
  CHARCOAL                  0.00       0.00        0.00
  ELECTRICITY            3312.28    1136.97     2175.31
  OIL REFINING              0.00       0.00        0.00
  COAL PRODUCTION           0.00       0.00        0.00

 RESOURCE COSTS
  INDIGENOUS             1243.04       0.00     1243.03
  IMPORTS                2705.34    3792.17    -1086.83
  EXPORTS                   0.00       0.00       -0.00
                            ----       ----        ----
 TOTAL ENERGY SYSTEM     7286.09    8139.84     -853.75
```

A “benefit” indicates where costs in the Baseline scenario exceed those in the GHG mitigation scenario. A “cost” indicates the reverse situation. Additional detailed Evaluation cost reports can help to track down the source of costs and benefits shown here. Reports can be displayed for annual nominal, or real costs or using other discount rates.

Table 5.5 Other Selected Emissions in Country X
(Mitigation Scenario)

```
                        1990       2010       2030
                        ----       ----       ----
CARBON MONOXIDE       477.21     740.24    1305.20 (MILLION KG)
METHANE                84.12     143.49     219.18 (MILLION KG)
NITROGEN OXIDES        95.94     159.70     287.90 (MILLION KG)
```

When considering the costs of mitigation measures, there is an important distinction between the average and marginal costs per unit emissions reduction. (See UNEP, 1994b, Section 7). The average abatement cost is the sum of costs for all of the measures implemented divided by the GHG reduction from implementing those options, while, to first order, the marginal cost is cost of the most expensive or last measure added to the scenario. In the case of the Country X scenario, the marginal measure was residential refrigerator efficiency improvement, costing approximately $110 per tonne C or about $30 per tonne of CO2.

Table 5.6. Key Indicators for Country X: Baseline and Mitigation Scenarios

Indicator	**1990**	**2030 (Baseline)**	**2030 (Mitigation)**
GDP per person ($1990/cap)	$600	$885	$885
Primary Energy/ person (GJ/cap)	11.7	17.2	13.3
Primary Energy/Unit GDP (MJ/$)	19.6	28.7	22.2
CO_2/Unit GDP (kg CO_2/$)	1.11	1.31	0.91
CO_2/Primary Energy (kg CO_2/GJ)	57	67	61
CO_2/Final Energy Demand (kg CO_2/GJ)	90	117	96
CO_2/per person (tonne CO_2/cap)	0.67	1.16	0.81

Table 5.7. Annual Growth Rates of Key Parameters:

	Annual Growth Rate (1990-2030)
Population	2.5%
GDP	3.5%
Primary Energy Use (Baseline)	3.5%
CO2 Emissions (Baseline)	2.8%
Primary Energy Use (Mitigation)	
CO2 Emissions (Mitigation)	

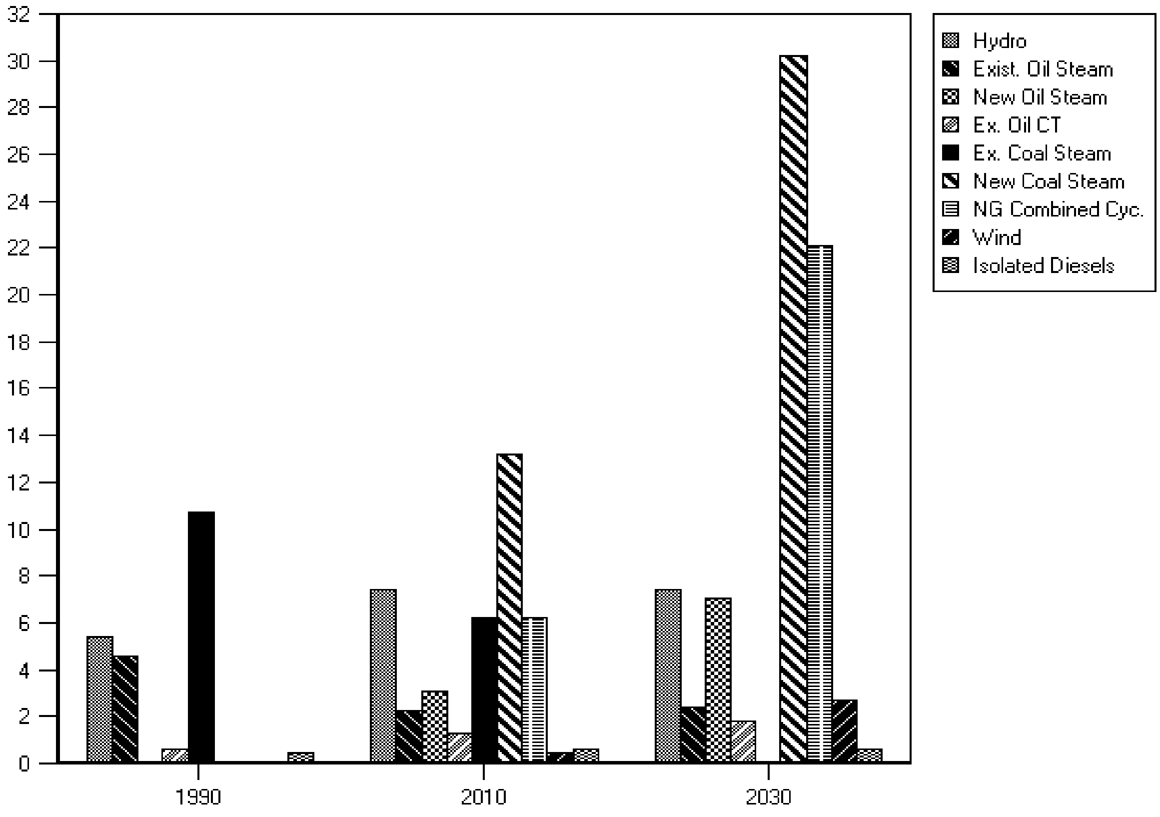
In addition to presenting scenario results, a mitigation study should present the key input assumptions and data used to formulate the baseline and mitigation scenarios. An appendix to UNEP 1994b provides several suggested tabular formats for reporting both results and assumptions. LEAP data echo reports provide a listing of entered data and assumptions, and are included as Attachment C.

5.5 ACCOUNT FOR UNCERTAINTY

Every analysis that looks into the future is affected by uncertainty to at least some degree. For mitigation analyses, many types of uncertainty are unavoidable, thus the analyst assemble a range of plausible assumptions for key input variables, and test the impacts of the range of assumptions through sensitivity analysis on those variables, as suggested in the Technical Report (Section 4.4).

In a LEAP analysis, new scenarios can be easily run to test variations in key inputs. For example, one could assume a “frozen efficiency” baseline scenario, by removing assumed future improvements in energy efficiency that are reflected in declining energy intensities. Such a change leads to an 18% increase in primary energy requirements, and a 20% increase in CO_2 emissions by 2030. Assuming that estimates of achievable efficiency improvements for the mitigation scenario are unaffected, the mitigation scenario now shows a net economic benefit of around $1 billion, rather than cost of almost $1 billion as before. The economic benefits that result from baseline efficiency improvements are now captured by the mitigation scenario. Such a sensitivity analysis underscores the importance of baseline scenario assumptions, and their effects on the estimated costs of a mitigation scenario.

Figure 5.1 Mitigation Scenario Electricity Generation in Country X
(THOUSAND GIGAWATT-HOURS)



5.6 REVIEW IMPACTS NOT CAPTURED BY LEAP ANALYSIS

As noted in Section 1 and Table 1.1, the “bottom-up”, end-use approach only captures the direct economic impacts of technologies, and if included, the costs of specific activities, such as energy efficiency programs. Various policy instruments -- efficiency programs, standards, import tariffs, taxes, and so on -- might be used to achieve the implementation of the specified mitigation technology options. Each policy instruments might have very different direct and indirect impacts on economic growth, employment, and other indicators.

One possibility for evaluating some of these economic impacts is to integrate LEAP results with macroeconomic analyses.[22] The integration of “bottom-up” analyses and “top-down” analyses is discussed in UNEP (1994b, Section 8), the Technical Report (Sections 4 and 5), and Grubb et al. (1993).

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[22] In one LEAP analysis (UCS et al., 1991), scenario outputs were coupled with an input-output model to estimate near-term (5-10 year) impacts on employment and GDP. (Geller et al., 1992.)