

A Guide to AIM/Enduse Model

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1. AIM/Enduse: An Overview

1.1 Introduction

AIM/Enduse is a technology selection framework for analysis of country-level policies related to greenhouse gas emissions mitigation and local air pollution control. It can also assist in energy policy analysis. It simulates flows of energy and materials in an economy, from supply of primary energy and materials, through conversion and supply of secondary energy and materials, to satisfaction of enduse services. AIM/Enduse models these flows of energy and materials through detailed representation of technologies.

This guide is intended to enable the user to easily learn and work with AIM/Enduse model. This chapter provides an overview of the model. Theoretical formulation is explained in chapter 2. Methodology for data preparation, as explained in chapter 3, is written to guide the user in the process of collecting and estimating data required for the model. Chapters 4 and 5 illustrate application of the model to India and Japan. Thirteen appendices provide useful information like terms of reference, GAMS code, description of AIM/Enduse database system, list of international publications of relevant data, standard numbers for efficiency and cost of selected technologies, standard numbers for calorific value, price and emission coefficients of fuels, and classifications and data for AIM-India and AIM-Japan.

1.2 Concept of the Model

AIM/Enduse is a bottom-up model of technology selection within a country's energy-economy-environment system. Energy and material flows through technology systems in an economy, and consequent emissions, are modeled elaborately. Selection of technologies takes place in a linear optimization framework where system cost is minimized under several constraints like satisfaction of service demands, availability of energy and material supplies, and

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other system constraints. System cost includes fixed costs and operating costs of technologies, energy costs, and other costs like taxes or subsidies. The model can perform calculations simultaneously for multiple years. Various scenarios including policy countermeasures can be analyzed in AIM/Enduse. Key features of the model are described below (refer to Appendix A for definitions of concepts and terms used in the model and this manual).

1.2.1 Reference energy system

An integrated reference energy system is captured in the model. Energy and material flows through various technologies – from primary energy extraction, through energy conversion and supply, to energy-enduse or final service conversion and delivery – can be modeled in detail for a given year. Model's structure is flexible to permit modeling of energy and material flows and technology linkages to any degree of scope.

As an aggregated option, a user can model energy and material flows beginning from energy conversion technologies producing secondary energy from primary energy, and ending at energy enduse technologies producing final services. Alternatively, as a disaggregated option, a user can model these flows beginning from primary energy extraction technologies, passing through primary energy transportation technologies, energy conversion technologies, secondary energy transportation and distribution technologies, and ending at final service conversion and delivery technologies. In the disaggregated option, each technology can be further represented as a combination of multiple devices, as explained in section 1.2.2.

Energy, materials and services can be represented in two ways in the model. An energy or material that is supplied externally to the model is an external energy. Similarly, a service that is demanded externally to the model is an external or final service. Any energy or material that is produced and consumed within the model is an internal service or energy (as shown in Figs. 1.2). Flow of an internal service or energy is balanced within the model. This feature of AIM/Enduse allows extremely disaggregated modeling of reference energy system as described in previous paragraph.

Service demands are the main external drivers that trigger technology selection decisions based on information on costs. Energy-mix and material-mix are derived from the technology-mix. Finally, emissions of CO₂, SO₂, and NO_x are derived from the information on emission characteristics of energy, materials, and technologies.

1.2.2 Technology representation and selection

AIM/Enduse permits detailed representation of technologies where, on one hand, a device and a combination of emission removal processes can be coupled together (see Figs. 1.1 and 1.2), and on the other hand, multiple devices can be linked in a complex network of sequential and parallel relationships that are close to reality (see Fig. 1.3). Thus, in AIM/Enduse, concepts of device and removal process are

integral to the concept of technology, and need to be carefully understood by the user.

A device may be defined as a distinct equipment or machine that is used in real life. Alternatively, a device may be defined as an aggregate concept comprising more than one distinct equipment or machines of real life (see Appendix A for definition and Appendices J and L for examples in case of AIM-India and AIM-Japan). A device can have multiple energy or material inputs and multiple outputs. An example of device is smelting process in aluminum-making technology that produces molten aluminum (internal service) from alumina (internal energy produced as internal service from Bayer's process) by utilizing electricity (internal energy produced as internal service from power plants) and fuel oil (internal energy produced as internal service from oil refineries). All devices are linked by a complex network of flows of energy and materials within a reference energy system of an economy.

Additionally, attachments or retrofits of specific combinations of emission removal processes to regular devices can be represented in the model (see Figs. 1.1, 1.2 and 1.3). A combination of emission removal process, when attached to a device, removes a particular pollutant gas emission during the device's operation. AIM/Enduse permits attachment of SO₂ and NO_x emission removal processes at three possible stages in a device's operation – pre-combustion stage, in-situ combustion stage, and post-combustion stage. A combination of removal process is a coupling of removal processes at these three stages. Coupling such a combination with a device results in a combination of device and removal process, as shown in Fig. 1.2. Coupling of a device with combination of removal process is optional in AIM/Enduse. Ash-removal process introduced before a boiler, limestone addition process during combustion of coal, and desulfurization of discharged flue gas, are examples of pre-combustion, in-situ combustion, and post-combustion removal processes respectively in a coal-fired power plant. Selection of a combination of removal process (defined as exchange of one combination by another) for attachment to a device is decided based on its costs and emission removal performance. For instance, under strict SO₂ mitigation target, the model may select SO₂ removal processes as attachments to high SO₂ emitting devices like high-sulfur coal-fired power plants. Thus AIM/Enduse allows detailed technological assessment for both regular devices and emission removal processes.

Two sets of decisions are made every year for technology selection in AIM/Enduse – level of capacity recruitment and level of operation of each device in a given year. Service demands determine the level of operating capacities required in a given year. Decision regarding recruitment-mix of devices in a given year is made based on their annualized capital costs. Decision regarding operating-mix of devices in a given year is made based on their annual running cost which comprises both energy costs and non-energy costs of operating the devices.

1.2.3 Stock transfers and multiple-year simulations

The model can be run simultaneously for multiple years as it simulates retirement of devices and transfer of un-retired stock of devices across successive years. Installed capacity of a device in a given year is represented by its stock in the model (see definition in Appendix A). Total stock of a device available in a given year is the sum of un-retired stock transferred from previous year and new stock recruited in the given year. Un-retired stock transferred from previous year is the total stock available in previous year minus the stock that retired at the end of previous year. A stock of a device retires after its life elapses from the year of its recruitment.

1.2.4 Outputs

Outputs of the model include recruited stocks of devices, operating quantities of devices, use of energy-types, level of flow of internal energy or services, emission quantities of CO₂, SO₂ and NO_x, system cost including recruitment costs, operating costs of devices and costs of exchanging removal processes, in each year. These outputs enable evaluation of a particular policy intervention or countermeasure on multiple criteria.

1.2.5 Scenario analyses and countermeasures

AIM/Enduse model permits analysis of various countermeasures. These are categorized as follows:

- Enduse stage countermeasures like efficiency improvement or better use and management of devices.
- Emission tax on fuels for each of the following gases – CO₂, SO₂ and NO_x.
- Energy tax on a (polluting) fuel to discourage its use.
- Regulatory constraint on quantity of emission of a gas in selected group of sectors in an economy.
- Regulatory constraint on quantity of use of an energy-type in selected group of sectors in an economy.
- Subsidy on capital cost or operating cost of a device to promote its selection.
- Subsidy to promote attachment of an emission removal process to a device.
- Regulatory constraint on use of a clean or efficient device or its combination with an emission removal process.

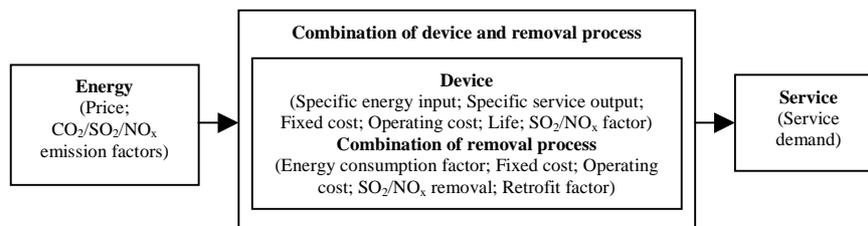


Fig. 1.1. Energy-Technology-Service linkage AIM/Enduse model

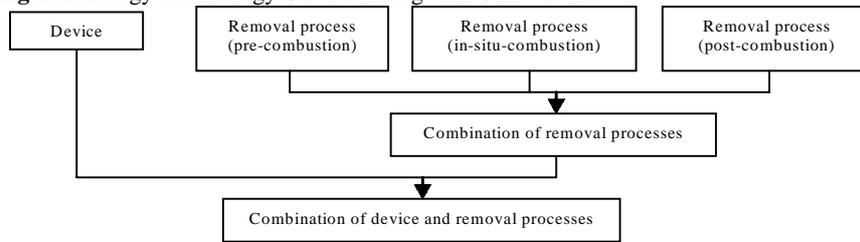


Fig. 1.2. Combination of device and removal processes in AIM/Enduse

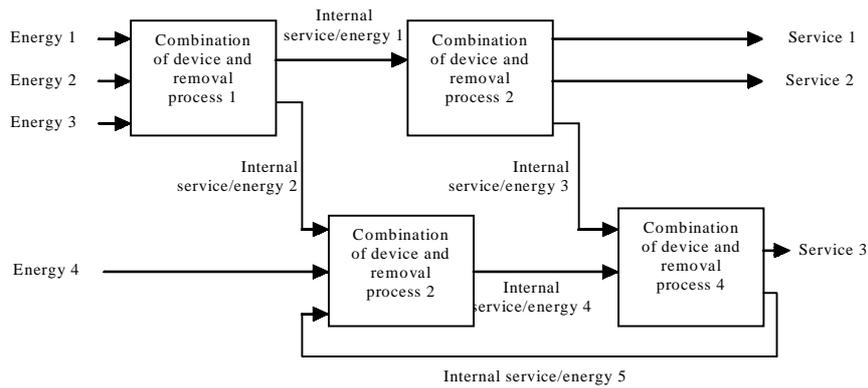


Fig. 1.3. Generalized technology representation in AIM/Enduse

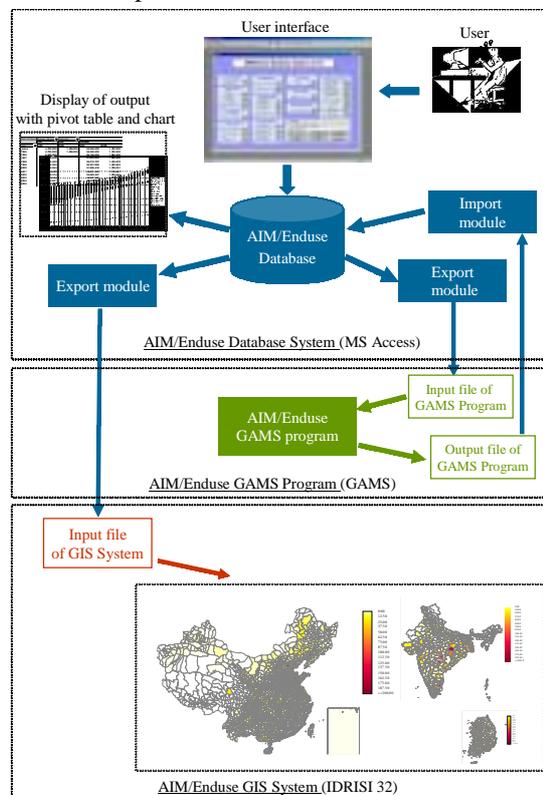
1.3 AIM/Enduse Software

AIM/Enduse software comprises an integration of Optimization system (GAMS), Database system (MS-Access), and Geographical information system (IDRISI) (see Fig. 1.4). The mathematical formulation (see Chapter 2) is written and solved in GAMS (see Appendix B). AIM/Enduse database system, developed using MS-Access, is the interface for GAMS program. It can supply input data for GAMS program file AIM-CMB.gms and display results of simulation. It also provides a user-friendly interface to the user for input of data, and design and analysis of scenarios or countermeasures (see Figs. 1.4 and 1.5). Interface with IDRISI (a GIS and image processing software) permits geographical disaggregation and spatial

representation of input data and output results. This manual does not include description of IDRISI data requirement and operation.

Users input data in AIM/Enduse through MS-Access tables or forms that correspond to numbered databases in Fig. 1.5. The figure shows flow of information in the database system. Combinations of indices indicated inside boxes for input data and output of GAMS program highlight both extensive input data requirement and flexibility of output results in the model. For example, combination (L, J, K, M, Y) in box ‘Device Specification’ means that required data for devices need to be specified for every valid combination of device, service-type, energy-kind, gas, and year. Similarly, combination (I, K, L, P, Y) in box ‘Energy Consumption’ means that energy use output can be specified for every valid combination of sector, energy-kind, combination of device and removal process, and year.

Appendix C describes the input data tables and each data item in detail. It also describes the procedure for export of input data to GAMS file, running GAMS program, import of output data from GAMS, and display of simulation results. Simulation results can be viewed through a flexible interface that allows both tabular and graphical views of any combination of output variables. For instance, year-wise results for energy use can be viewed by region, sector, or device; year-wise emission quantity of each gas can be viewed by region, sector, energy-type, or device; recruitment costs, operating costs, costs of exchanging removal processes, taxes, and total system costs can be viewed by region, sector, or device; etc. Users are advised to read Appendix C carefully to gain familiarity with the model interface and its implementation.



MS Access: Database management software designed by Microsoft Corporation
 GAMS: General algebraic modeling system designed by GAMS Development Corporation
 IDRISI 32: Geographical information system and image processing software designed by Clark Labs, Clark University

Fig. 1.4. AIM/Enduse database system, Optimization system and GIS

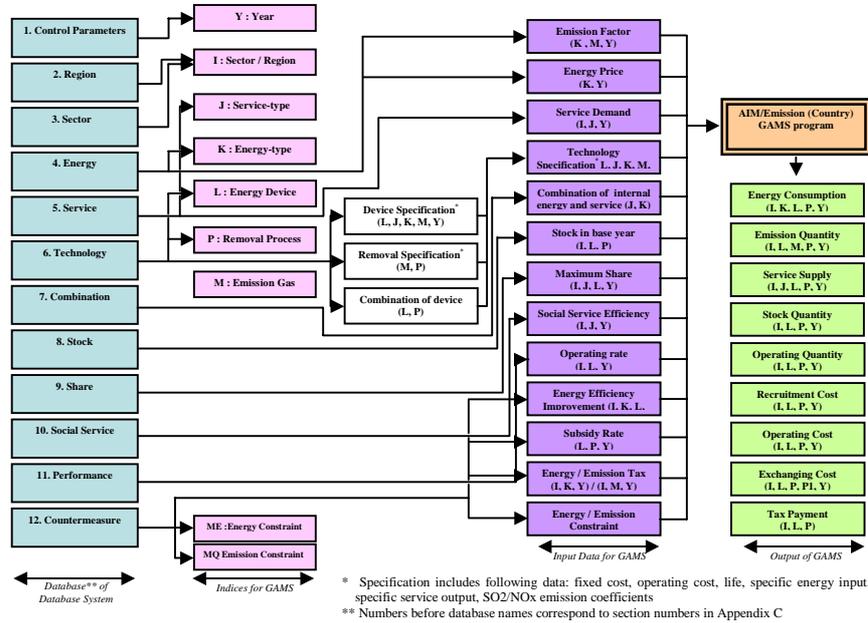


Fig. 1.5. Information flow in AIM/Enduse database system

To summarize, salient features of AIM/Enduse are as follows:

- Technology selection using linear programming framework
- Representation of technologies as
 - complex network of energy and material flows through multiple devices, and
 - emission removal processes as options for retrofit attachments to devices
- Service demands as external drivers
- Technology selection based on annualized capital cost and running cost of technologies including energy costs in a given year
- Retirement of technological stock at the end of its life, and transfer of non-retired stock across successive years
- Estimation of energy use for combustion and non-combustion operations of technologies
- Estimation of quantity of CO₂, SO₂ and NO_x emissions from fuel combustion as well as non-combustion operations of technologies
- Integrated software comprising GAMS, MS-Access, and IDRISI
- User-friendly database system and interface to facilitate easy input of data, design of scenarios or countermeasures, and analysis of results.