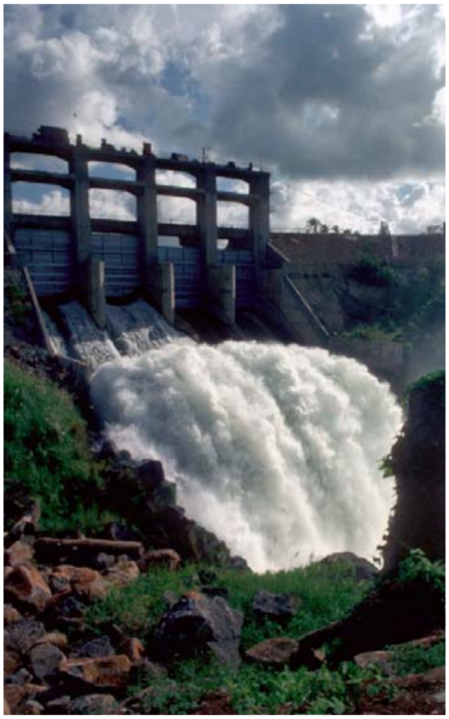
Developing the Greater Mekong Subregion
Energy Sector Strategy

Inception Report

June 2006



Discussion Draft

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June 2006

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for the
Asian Development Bank

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Discussion Draft

Abbreviations

ADB	Asian Development Bank
GJ	Gigajoule (10^9 joule)
GWh	Gigawatt Hour
GMS	Greater Mekong Subregion
IRM	Integriertes Resourcen Management
kW	Kilowatt
kWh	Kilowatt-hour
Lao PDR	Lao People's Democratic Republic
MW	Megawatt
MWh	Megawatt-hour
MESSAGE	Model of Energy Supply Systems Alternatives and their General Environmental Impacts
PRC	People's Republic of China
PJ	Petajoule (10^{15} joule)
RES	Reference Energy Systems
RPTCC	Regional Power Trade Coordination Committee
TA	Technical Assistance

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Developing the GMS Energy Sector Strategy

I. Introduction

In 1992, the Asian Development Bank (ADB) initiated a regional cooperation program among economies around the Mekong River. The Greater Mekong Subregion (GMS) program now covers five countries (Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, Viet Nam,) and two provinces of the People's Republic of China (PRC), (Guangxi Zhuang Autonomous Region and the Yunnan Province). Until recently, GMS cooperation on energy has centered around the power sector, cross-border electricity trading, and the interconnection of transmission networks. ADB has provided three investment loans and seven technical assistance (TA) projects to promote regional cooperation in the energy sector so far.

Recognizing that access to modern energy services is critical for economic development and for improving the quality of life of the poor, the GMS countries requested ADB to initiate a comprehensive study to define a regional strategy for all energy subsectors. A regional strategy for the energy sector is considered necessary for four reasons. First, the geography of energy supply options does not correspond to national boundaries. Often, there are opportunities to reduce overall energy costs by exploring supply options beyond borders. Second, individual markets are at times too small to justify large-scale investments needed to achieve scale efficiency. Third, cross-border energy supply provides diversification of sources and this is vital for energy security. Finally, the energy sector has environmental implications beyond national boundaries, which need to be integrated in energy planning to achieve sustainable development. ADB approved a TA in January 2006 entitled "Developing the GMS Energy Sector Strategy" to develop a regional strategy to expand cooperation among the GMS countries. This inception report is prepared by the TA consultant, Integriertes Resourcen Management (IRM), Vienna, Austria under the technical assistance TA 6301.

The TA aims to develop a regional strategy to expand cooperation among the member countries to meet the region's emerging energy challenges. Specifically, the TA expects to (i) help articulate the region's clear vision about GMS energy cooperation, (ii) prepare an action plan to meet the emerging energy challenges during 2006–2020, (iii) identify priority investment projects including private-sector financing to enhance energy trade and investment in the region, and (iv) prepare an outline of institutional and other arrangements to enhance regional energy security.

Ongoing Work on Energy and Environment

Developing a regional strategy for the GMS builds on a long series of ADB's efforts on poverty alleviation, infrastructure development, renewable energy, energy efficiency, and greenhouse gases abatement and environment. A recent strategy paper for the GMS Region (ADB, 2004d) lays out the fundamental goals of this collaboration. These are rooted in the Millennium Development Goals and focused on poverty alleviation.

Important and relevant country level information was developed under the ADB umbrella project Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement. GMS members of that project are Cambodia (ADB, 2003b), Lao PDR (ADB, 2005c), and Viet Nam (ADB, 2004e). Each of these reports provides information on country background, an energy sector review, estimates of technical potentials for Energy, Energy Efficiency and Greenhouse Gas Abatement technologies as well as information on institutions and existing policies. ADB's work on opportunities within the United Nations Framework Convention on Climate Change's Clean Development Mechanism is naturally related to this TA. In particular, the report on *Opportunities for Clean Development Mechanism in the Energy Sector: PRC* (ADB, 2004f) covers some work on the Guangxi Zhuang Autonomous Region. In addition to country-related information, ADB has also begun undertaking efforts to enhance the energy sector cooperation (ADB, 2004c), mainly in the power sector (ADB, 2003a and ADB, 2005a). The GMS energy strategy will use this and other information developed so far within the region. On the basis of the technical potentials, economic potentials until the year 2020 will be estimated.

Much of the regional work in the energy sector so far is part of the overall work plan for the development of regional power trade agreed in April 2005 by the member countries and development partners through the Regional Power Trade Coordination Committee (RPTCC). Physical infrastructure consisting of generation and transmission projects are being built, mostly with the assistance of ADB and other development partners, and in some cases, with the participation of the private sector.[1] Priority activities being carried out by the RPTCC also include the following: (i) formulation of GMS Power Master Plan, (ii) establishment of a regional power database and website, (iii) development of good practice guidelines for bilateral power trade agreements, (iv) formulation of power

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[1] These include the GMS Power Transmission Project which will install a transmission line from southwest Viet Nam to Phnom Penh and the Nam Theun 2 Hydropower Project which will export power from Lao PDR. Studies are being conducted to prepare future projects such as the GMS Transmission Project (PRC-Lao PDR-Thailand) and the GMS Power Interconnection Project Phase 1 (Lao PDR-Viet Nam).

system development plans for Lao PDR and Cambodia. The first two activities are financed by the Agence Française de Developpment and administered by ADB. The World Bank provides funding for the latter two activities. GMS countries help each other in the preparation of national plans as in the case of Thailand who is assisting Cambodia and Lao PDR as well as PRC who is assisting Myanmar.

Institutional infrastructure is likewise continuously being developed. Recently, the Focal Group and the Planning Working Group of the RPTCC were established in accordance with the Memorandum of Understanding on the Guidelines of Implementation of the Regional Power Trade Agreement Stage 1 signed by RPTCC members in July 2005.

A technical assistance proposal is now being developed in collaboration with the other RPTCC members, to support sustainable and environment-friendly regional power trading. Funding will be sourced from the Swedish International Development Agency. As initially conceived, the TA will involve, among others, regulatory development, capacity building for environment impact assessment of power projects, and promotion of energy efficiency and conservation.

There are broader environment-related initiatives that cover the whole region. Among these is ADB's Core Environment Program and Biodiversity Initiative which seeks to (i) assess the environmental sustainability of priority development strategies and investment plans for GMS economic sectors and corridors, (ii) implement biodiversity corridor activities, and (iii) institutionalize environmental performance assessment procedures and systems in GMS countries. The TA is administered by ADB and is supported by a host of development partners including the governments of Netherlands and Sweden, United States Agency for International Development, Global Environment Facility, United Nations Development Program, as well as non-government organizations including Conservation International, Fauna and Flora International, World Wide Fund for Nature, Wildlife Conservation Society, WWF for Lao PDR and Viet Nam, and World Conservation Union.

All these ongoing work will contribute to establishing a sound basis for this TA and to defining important information on existing policies concerning the energy sector in GMS countries.

II. The Context

The GMS is a very diverse region: the economies of the region are at different stages of development, Cambodia, Lao PDR and Viet Nam are undergoing transformation from a planned economy to market, but each one is at a different stage of transition. Thailand has been an established market economy and has to deal with different kinds of economic challenges. The physical and human resource base, the structure of economy, their integration with the global economy, income and poverty levels, infrastructure access and the pace of reforms vary across economies.

Though the region as a whole is well endowed with the necessary energy resources, these are distributed unevenly: Lao PDR, Myanmar, and the Yunnan Province have large hydro electrical potential whereas Thailand is the largest importer of energy in the region and has to import nearly 40% of its energy. Overall consumption levels vary dramatically too: per capita electricity consumption in Thailand is ten times that of Lao PDR or Cambodia and four times that of Viet Nam. Such variation in access reflects very different levels of development of the economy and also the infrastructure access. Table 1 provides basic indicators for the GMS economies and some idea about the energy indicators.

Table 1. Greater Mekong Subregion: Selected Indicators 2004

	Cambodia	Lao PDR	Myanmar	Thailand	Vietnam	Yunnan	Guangxi
Land Area (1000 sq km)	176.5	230.8	657.6	510.9	325.5	396.8	236.7
Population (million)	13.8	5.8	54.3	64.2	82.1	44.2	48.9
GDP per capita (current $)	360.7	420.1	n.a.	2518.6	550.7	813	869
GDP per capita (PPP current $)	2338	1935	2009	8179	2704	4061	4340
Trade Openness (% of GDP)	116.1	42.0	n.a.	116.8	125.3	10.4	12.0
FDI ($ million)	131	17	556	1,064	1,610	142	300
Electricity use per capita (kwh)	n.a.	173	101.1[a]	1751.8[a]	433.1[a]	837.8[a]	860.9[a]
Energy use per capita (kgoe)	n.a.	323.4	276.4[a]	1405.7[a]	544.3[a]	n.a.	n.a.

Source: ADB (2004, 2005), ADB Database

[a] Refers to 2003 data

GMS Economy

The economic performance of the GMS region since 1992 has been impressive: Since 1992, gross domestic product in the GMS economies (with the exception of Thailand) grew at an average annual rate of over 6% (Table 2). What is more, in spite of a number of adverse internal and external shocks such as the East Asian financial crisis, the slowdown in the global and regional economy in 2001, the onset of SARS in 2003 and Avian influenza more recently, and the persistent rise in oil prices in last few years, the average growth rate has been 4% or higher in all economies with the exception of Thailand.

Table 2. Growth of Real Gross Domestic Product
(annual percentage change)

GMS Economies	1992	1995	1997	2000	2001	2002	2003	2004	2005
Cambodia	7.0	6.5	5.7	8.4	5.5	5.2	7.0	7.7	8.4
Lao PDR	7.0	7.0	6.9	5.8	5.8	5.9	5.8	6.9	7.2
Myanmar	9.7	6.9	5.7	13.7	11.3	12.0	13.8	13.6	12.2
Thailand	8.1	9.2	-1.4	4.8	2.2	5.3	7.0	6.2	4.5
Viet Nam	8.7	9.5	8.2	6.1	6.9	7.1	7.3	7.8	8.4
Yunnan Province	10.9	11.2	9.4	7.1	6.5	8.2	8.6	11.5	9.0
Guangxi Zhuang AR	18.3	11.4	8.0	7.3	8.2	10.5	10.2	11.8	12.7
Average for GMS[a]	**9.5**	**9.5**	**3.2**	**6.4**	**5.2**	**7.2**	**8.3**	**8.8**	**7.9**

Source: ADB (2005). AR= Autonomous Region; PDR- People’s Democratic Republic

[a] Computed based on purchasing power parity Gross Domestic Product weights

Major Energy Challenges

High demand growth. Such rapid economic growth is fueling a significant rise in energy demand. A major challenge facing the GMS countries is keeping up with the expected demand growth due to rapid industrialization, and maintaining competitiveness through reasonable and reliable energy supplies. Most energy forecasts at national levels see the demand for energy to rise rapidly, and at rates much faster than that of economic activities in the next decade. Therefore, the medium-term regional energy strategy has to identify possible alternative strategies based on environmental feasibility so that this rapidly rising demand does not become a barrier to economic development.

Low energy access. Overall access to energy is also very uneven across the region. It is estimated that over 50 million people in the GMS lack access to electricity at present. These aggregate numbers, though large, do not fully reflect the rural energy challenges individual countries or local and isolated communities face. In Cambodia, for example, over 70% of the rural population do not have access to modern forms of energy and Cambodia's per capita electricity consumption is less than 10% of that in Thailand.

Quality of energy supplies. The quality of energy supplies remains low and unpredictable in large parts of the region. Poor quality of energy infrastructure imposes not only additional costs on the existing industrial production but also affects the business environment negatively. Improving access and overall quality of energy infrastructure and services is thus an important challenge facing the region.

Energy security. In the medium term, the region has to grapple with multiple concerns surrounding energy security.[2] The region's rapid economic growth is fueling motorization and a vehicle boom in the region. As a result, the region's oil dependence is expected to increase dramatically in the next two decades. Poor production prospects, weak demand management, insignificant penetration rates for alternative energy sources, and high global oil prices make the region insecure and vulnerable. The region is heavily dependent on imported fossil fuels; for example, Thailand, one of the largest energy consumers in the region has to import 50% of domestic energy needs whereas Cambodia and Lao PDR import all commercial fuels. A program to diversify the oil resource base within and outside the region can help reduce vulnerability. In addition, there are no institutional mechanisms to deal with energy disruptions arising out of emergency or supply shocks.[3] In addition to physical energy supply security in terms of systems reliability, affordability is an important aspect of energy security. Given the low access rates and the importance of energy in promoting growth and poverty reduction, energy security is a regional public good and thus needs to be addressed comprehensively.

Energy efficiency. Greater private participation in the energy sector is needed not only for mobilizing resources to support energy projects, but also to enhance overall use efficiency. In particular, energy losses in the power systems are high in some parts of the region. Cost recovery and reform programs need to be examined to identify structural and other barriers to energy efficiency. Also at the consumer level, energy efficiency needs to be given adequate

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[2] The concept of energy security has been broadened to include external (geopolitical), internal (operation and maintenance), and temporal aspects of ensuring energy supplies at affordable prices.

[3] Except the commercial stock requirements.

attention. The overall policy environment for the energy sector needs to be aligned to achieve energy efficiency through a medium-term action plan that encourages an expanded role for the private sector. With the growing energy demand, environmental sustainability issues will need to be integrated in the design at the planning stage to reduce the environmental costs of energy projects. There is also a need to enhance efficiency in using traditional energy sources such as forests and biomass, given the high dependence on these resources in some parts of the region.

Environmental issues. The region is rich in hydropower potential and future development of this resource needs to integrate possible environmental costs in the plan itself. This is important because as the experience of the Nam Theun 2 project has shown, cross-border environmental externalities need to be integrated in the planning and design of large energy projects. There is also a need to enhance the institutional and policy framework to integrate environmental and social costs in energy projects at the regional level.

Role of Renewables

It is clear that renewable energy has the potential to successfully address some of the challenges discussed in the previous section. It can improve the access of the rural population to energy, for instance, by converting agricultural residues into high-quality final energy; it can increase energy security; it can decrease the overall fossil-fuel intensity of the economy; and it can reduce the environmental impact of energy use. Moreover, renewable energy projects are subject to the Clean Development Mechanism and thus generate income at the same time as contribute to the global reduction of greenhouse gases.

The important potential of renewable energy has been fully recognized by the ADB and it has been working with the Asian governments and other stakeholders to promote cleaner energy use in Asia. ADB brought several trust funds to form the REACH (Renewable Energy, Energy Efficiency and Climate Change) Program, which works at three levels: (i) identifying policy barriers, (ii) financing and risk mitigation, and (iii) developing capacity. It provides assistance to its Developing Member Countries for projects that promote investment in renewable energy and energy efficiency to mitigate the effects, and that help communities adapt to the impacts of climate change. One example of this recognition is the PREGA (Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement) project which helps 13 countries, including the GMS countries Cambodia, Lao PDR and Viet Nam as well as PRC, as a whole in carrying out studies that address problems related to diversification of renewable energy resources, supplying energy for the areas where the national power grid is impossible to reach due to topographical difficulties. PREGA is now in its Phase 2.

Projects and case studies developed within these projects will be of great value for this TA as a source of data on renewable energy. Also by analyzing financing and other barriers, the two projects will contribute a basis for the assessment of the feasibility of projects to be recommended.

III. Proposed Methodology

Strategic energy sector planning requires the use of formal methods that ensure transparency, comprehensiveness, consistency between subsectors and reproducibility. As least-cost strategies are to be identified for each scenario considered in this project, the required tool must be capable of optimization. Also, the tool must be equally suited for different sizes of the underlying energy system and it must lend itself to integration of country results to study all aspects of regional integration of energy subsystems into a bigger system of collaborating countries and regions.

The widely known model - MESSAGE (**M**odel of **E**nergy **S**upply **S**ystems **A**lternatives and their **G**eneral **E**nvironmental Impacts) meets the above requirements and therefore the Consultant will use this to develop an energy strategy for the region. The Consultant will prepare six model applications - one for each economy and for the integrated GMS region. The model will have least cost strategies built into each for given constraints. The possible constraints can be energy demand, availability of primary energy, energy conversion technologies, and the environmental impacts of energy production and use.

The proposed model analyses will use existing domestic and internationally available information and formulate alternative energy supply strategies, each of them optimized under different assumptions reflecting future uncertainties. These strategies will be assessed for robustness of policy options, and policy recommendations will be based on these analyses. In particular, the costs and benefits of expanded cooperation among the GMS countries will be discussed and quantified

We describe MESSAGE in appropriate detail in the remainder of this section. The most comprehensive description of MESSAGE is found in Messner and Strubegger (1995).

Background

MESSAGE is a system engineering optimization model used for medium to long-term energy planning, energy policy analysis, and scenario development. The roots of its development go back to the Energy Systems Program of the 1970s of the International Institute for Applied Systems Analysis. MESSAGE has been used for many applied projects and scientific studies. More recent examples of these include the report on Global Energy Perspectives (Nakicenovic et al., 1998), the Special Report on Emissions Scenarios (Nakicenovic et al., 2000), the Intergovernmental Pannel on Climate Change Third Assessment Report (Davidson et al., 2001), and the book *Sustainability in Global Energy: An Analysis of Long Term Energy-Economy-Environment Scenarios* (Schrattenholzer et al, 2004). An appendix of that book includes a more detailed description of MESSAGE.

The most recent version of the model is MESSAGE V. This version, with an MS-Windows user interface, is, among others, used by the International Atomic Energy Agency in their project Capacity Building in Energy Planning in Developing Countries. The project also features an extensive course about the model for East Asian countries in general and for Viet Nam specifically. In East Asia, the model is currently used in PRC, Republic of Korea, Viet Nam, Indonesia, Philippines and India. Other countries in Latin America and Africa likewise make use of this model for their energy systems planning.

Model Description

MESSAGE identifies the flow of energy from primary-energy resources to useful-energy demands that (1) is feasible in a mathematical and an engineering sense, and at the same time (2) represents the investment choices that lead to the least cost of all feasible energy supply mixes to meet the given energy demand.

Engineering feasibility is ensured by making energy flows consistent with model constraints on primary-energy availability and extraction, energy conversion and transportation as well as on end-use technologies and limits on the environmental impact of energy conversion. Energy flows are further determined by constraints on the rate of new capacity installation (new capacity can be installed only gradually), the substitutability among energy forms, renewable-energy potentials and others.

Out of many possible energy flows, MESSAGE selects the one that supplies the exogenously given demand at least cost. The optimization process thus can be interpreted as modeling (private or public) agents who invest in energy technologies that are characterized by different performance, cost, and environmental impacts in such a way as to meet demands at least costs under given constraints.

Dynamic changes in the energy system are therefore endogenous, i.e., the pace for enhanced energy conservation or structural changes of energy supply and conversion are determined by shifts in the set of energy conversion technologies selected for a given scenario. Costs considered by the model include investment costs, (fixed and variable) operation and maintenance costs, fuel costs and any user-defined costs such as environmental costs of pollution. Calculating total cost, MESSAGE can use assumptions on specific costs of hundreds of individual technologies as they develop over time. The actual number of technologies is determined by the degree of detail included in the Reference Energy System (RES) and specified in the MESSAGE input files. The technical term of the function calculating the overall costs is objective function, which is to say that its value is minimized in the course of running the model. For determining cost optimality all costs are discounted using an annual discount rate, which is chosen by the user.

The result of these two steps (establishing feasibility and then calculating the optimal supply path) is an optimal energy supply mix by different energy supply technologies and different energy carriers, satisfying the given demands in the given sectors.

Other features of MESSAGE include a mixed-integer option (practically speaking, this means the ability of the model to consider fixed sizes of technologies), supply and demand elasticities (the price responsiveness of supply and demand), load regions (in particular for power demand), energy storage, and the capability of the model to perform multi-objective optimization. These features enhance the strength of the model in particular for its use on a country or regional level.

Model Implementation Strategy

It is important to be clear about the objective and purpose of the model. In addition to those points already made above, this includes the explicit consideration of the specific circumstances of the energy system(s) modeled and results in the determination of the level of detail (of demand sectors, energy carriers, technologies, etc.) to be included in the model. In this section, we describe the implementation strategy.

One important determinant of the implementation strategy is the given investment horizon. In our case, this is the year 2020. For the model implementation, this means that most options for energy technology projects to be implemented within this time horizon must be at least approximately known. Although this in particular means that a fundamental restructuring of a GMS energy system is infeasible during this 14-year time horizon, it will be important to keep in mind the possibility of the so-called “leap-frogging”, that is, the insight that development does not have to follow the same technological path as in other, further developed countries.

The degree of detail to be used for given model runs also depends to a large extent on the data available in each country. A first indicator of the degree of data availability is the completeness of the energy balances of a country. Ideally, a complete table with data describing the flows from the actual primary-energy production to the consumption of final energy would be available for the base year (2005) and reach sufficiently far into the past to allow for the identification of trends. If the statistics of a country include information about the uses of final energy, demands can be estimated with greater reliability.

At this initial stage of the project, it is too early to come to a definite conclusion about the degree of detail to be eventually included in the model runs. The actual choices will be made in close collaboration with all contributors to this project such as representatives of GMS Governments, Domestic Consultants and other stakeholders.

To facilitate data collection, the next section will describe the concepts underlying the model as well as different types of data needed to run the energy scenarios and formulate appropriate strategies.

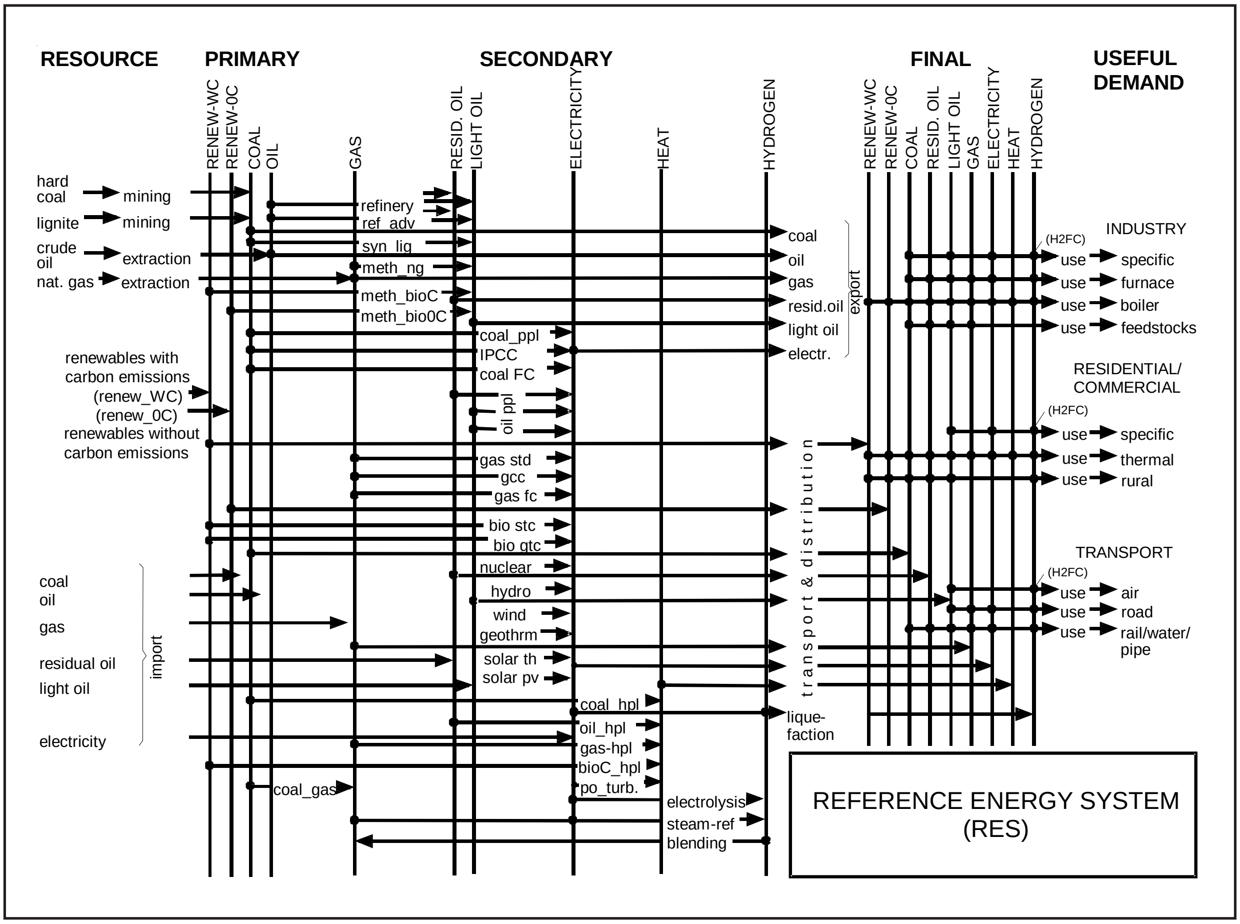
IV. Information Requirements

In this section, we first present the concept of Reference Energy System and discuss its relevance for the actual modeling. Based on this general discussion, we identify the specific data needs for this project.

The Reference Energy System

The conceptual core of the MESSAGE model is the RES. In its most comprehensive form, it represents a given real-world energy system from resource extraction, imports and exports, conversion, transport, and distribution, to the demand for energy end-use services (i.e., useful-energy demand). Useful energy is the common term for the form of energy that provides consumers with energy services such as cooking, illumination, air conditioning, refrigerated storages, transportation, industrial production processes, and consumer goods. The purpose of the energy system is, therefore, to satisfy the demand for energy services. A schematic illustration of the RES is given in Figure 1.

Figure 1. Schematic illustration (example) of one particular Reference Energy System



Since it is the demand for useful energy that drives the entire RES, a good understanding of present and future useful-energy demand is the key to successful strategic planning in the energy sector. Alas, a thorough understanding of useful-energy demand requires a database that is available only in rare cases. It is therefore necessary to strike a compromise between the ideal case and reality as it is defined by the availability of data.

There are two principal ways of compromising. One is to reduce the precision of the description of useful-energy demand categories by aggregation and the other is to ignore the purpose of the last stage of energy conversion and use a RES that is driven by demands for final energy. Examples of final energy include electricity, heat, fuels, and others.

The actual choice to be made for the modeling of GMS energy systems will thus depend on the availability of data, not only energy balances of the past, but also the kind of energy demand projections available.

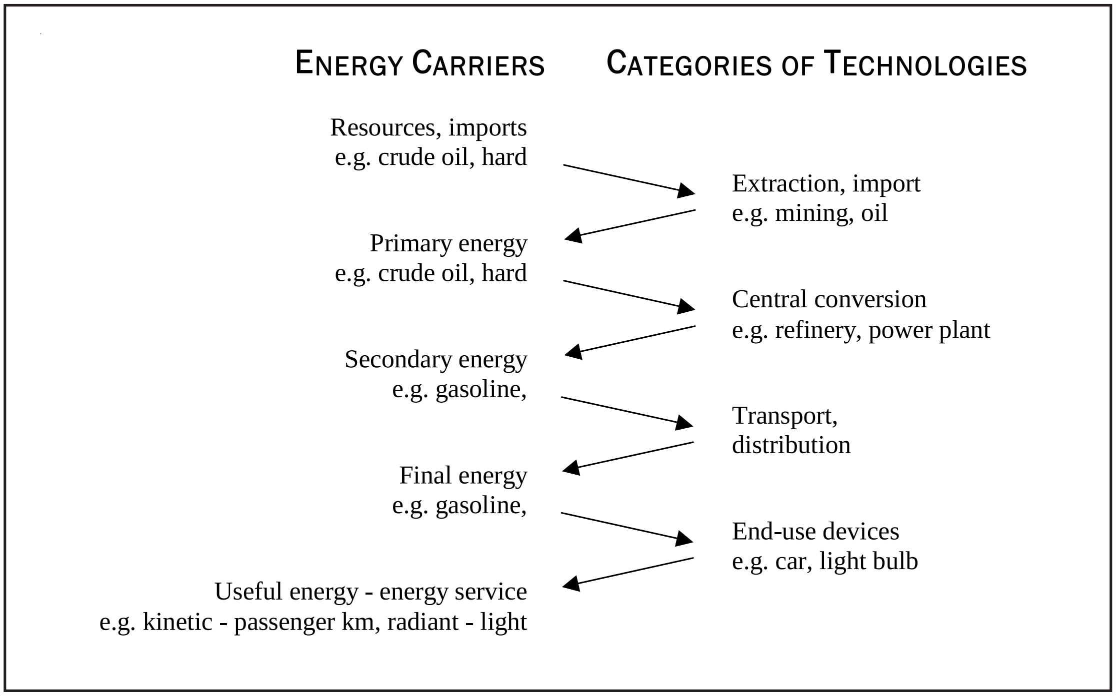
Another important classification in the area of energy demand is the distinction between commercial and non-commercial energy. According to this distinction, commercial energy is a form of energy that is bought and sold, whereas non-commercial energy is collected by consumers. The most important example of the latter is fuel wood. As to data availability, it is immediately obvious that data is more likely to exist for commercially traded fuels. Nonetheless, fuel wood consumption is an important aspect in GMS countries because the transition from the use of fuel wood to commercial forms of final energy is one major energy system-related component of development.

According to the RES, the last part of energy supply is represented by arrows that emanate from final-energy forms and point to useful-energy demand sectors. Each of these arrows thus corresponds to a concrete energy conversion technology. More generally, the horizontal arrows in Figure 1 refer to the entire set of energy technologies from resource extraction over transformation, transportation and distribution of energy carriers to end-use.

The front end of the RES is a vector of primary-energy carriers. These include fossil, nuclear resources and renewable energy sources. A distinction is made between domestic and imported energy carriers.

Energy carriers and technologies give rise to the definition of so-called energy chains: all possible (feasible) energy flows from resource extraction or imports to the useful-energy demand. The demands, which are inputs to the model, must be met by the energy supplied through one or more of the modeled energy chains. Figure 2 gives an example of a typical energy chain and of the energy levels together with the associated energy carriers and categories of conversion technologies.

Figure 2. Schematic illustration of an energy chain in MESSAGE



Since few energy conversion technologies convert primary energy directly into useful energy, intermediate energy levels (secondary, final) are defined in the scenarios. One important characteristic of energy conversion technologies included in the RES is therefore the specification of the two energy levels that this particular energy conversion technology links, that is, the specification of the energy levels from which they take their inputs and to which they deliver their outputs.

The mathematical formulation of MESSAGE ensures that the energy flows of the RES are consistent, i.e. that

- not more than the available quantity of resources is consumed,
- the inflowing amount of energy for each level and each energy carrier is at least equal to the out-flowing amount of energy and that
- energy demands are met.

These three conditions define balance constraints, which are generated by the MESSAGE matrix generator. In the following subsection, we summarize all important equations and the input parameters required for their complete definition.

Constraints and Data Requirements

Next to the objective function, the model's constraints are important for the understanding of the model's conversion of input data into outputs. The constraints can conveniently be grouped into three categories, describing resource extraction, conversion technologies and energy demand. We describe each of these three in turn, followed by a stylized input data sheet.

Energy Resource Extraction

The most important examples of primary-energy resources are coal, crude oil, natural gas and uranium. By convention, renewable primary energy carriers are referred to as sources (instead of resources). Their most important representatives are wind, geothermal, hydro, solar, and biomass.

To distinguish between different origins of primary energy resources, each resource can be divided in a user-defined number of (cost) categories. For each of these categories, resource recoverability is given in terms of total availability over the time horizon (as constraint on the sum of all annual extraction activities of a given resource) and in terms of annual extraction limits (one per time period) of primary energy.

In addition to total and annual resource extraction amounts, maximum and minimum rates of change can be specified. The most important group of constraints limiting the rate of change consists of so-called market-penetration constraints, limiting the speed of build-up of resources (and, in general, of all energy conversion technologies – see below) and thus speed in which energy system changes can occur. A simplified data sheet in this category is depicted in Table 3.

The build-up ("market penetration") constraints are conceptually simple but a bit complicated if they are formulated mathematically correctly. They are therefore just mentioned, but not included in the illustrative data sheet.

Table 3. Example for Resource Category Data Sheet (Crude Oil, Category 1)

Crude Oil	Units	Years		
		2005	...	2020
Total resource availability 2005 - 2020	PJ			
Annual extraction limit	PJ/yr			

Energy Conversion Technologies

Energy technologies are characterized by numerical model inputs describing their economic (e.g., cost), technical (e.g., conversion efficiencies) and ecological (e.g., pollutant emissions) aspects.

MESSAGE provides the option of treating technology data as dynamic quantities, that is, it allows the user to specify any technology descriptor as time series, specifying separate values for each time period. This makes it possible to include technological progress in the model, for example, by specifying technology cost decreases and performance improvements over time. Each energy conversion technology is characterized in MESSAGE by the following data.

- Specific energy inputs and outputs together with the respective efficiencies. Although the vast majority of energy conversion technologies is described by one input and one output, MESSAGE also foresees the possibility of defining multiple inputs and outputs. An example of the latter would be the combined production of heat end electric power.
- Specific investment costs (e. g., costs per kilowatt, kW). These can be defined as "turn-key" (that is, assumed to be incurred instantaneously in one point in time) or by specifying construction as well as distribution of capital costs over construction time.
- Fixed operating and maintenance costs (per unit of capacity, e.g., per kW).
- Variable operating costs (per unit of output, e.g. per kilowatt-hour, kWh, excluding fuel costs).
- Plant availability or maximum utilization time per year. This parameter also reflects maintenance.
- Technical lifetime of the conversion technology in years.
- Year of first availability (mainly for new and novel technologies).
- Pollutant emissions (e.g. emissions of kg of CO2 or SO2 per produced kWh).
- Constraints on the annual rate of growth of the newly installed capacity ("market penetration constraints" – see above).
- Technical application constraints, e.g., maximum possible shares of wind or solar power in an electricity network without storage capabilities.

A data sheet with the most relevant data is depicted in Table 4.

Table 4. Stylized Data Sheet for Technologies

Coal power plant(s)	Units	Years		
		2005	...	2020
Plant factor	Fraction			
Plant life	Years			
Specific investment cost	$/kW			
Fixed O&M cost	$/kW/year			
Variable O&M cost	$/kW/year			
Capacity, year 2005	MW			
Output, year 2005	GWh			
Coal input per unit of output	GJ			
Electricity	MWh(e)			

End-use Energy Demand

End-use energy demand is provided to MESSAGE as time series. In this case, a time series consists of 16 values (or equivalent information such as a base-year value and an annual growth rate), one for each demand sector and one for each of the years 2005 to 2020.

The following final-energy demand sectors are proposed: (i) Coal, (ii) Fuel oil, (iii) Light oil, (iv) Natural Gas, (v) Renewables (incl. fuel wood), (vi) Electricity, and (vii) Heat.

The final-energy demand sectors will be the target of optimization of energy supply. However, as much as data availability will permit, the correspondence between these final demands and useful energy demands in the following demand sectors will be maintained albeit outside the model. The following useful-energy demand sectors are proposed: (i) Electricity in industry, (ii) Other industrial energy use, (iii) Residential/commercial electricity, (iv) Other residential/commercial energy use, (v) Feedstocks, (vi) Transportation, and (vii) Non-commercial energy.

A demand data input sheet therefore looks like the one depicted in Table 5. In general, one set of demands will be specified for each scenario.

Table 5. Stylized Input Data Sheet, Energy Demand

Demand Category	Units	Years		
		2005	...	2020
Coal	PJ			
Fuel oil	PJ			
Light oil	PJ			
Natural gas	PJ			
Renewables	PJ			
Electricity	GWh			
Heat	PJ			

V. Work Plan

The work plan consists of five major parts, (1) information gathering, (2) generating scenarios with the MESSAGE model, (3) getting feedback on the scenario results, (4) formulating energy strategies for GMS on the basis of these results, and (5) dissemination. We will describe our plans for each of these parts in the following subsections.

Stage 1. Information Gathering

A comprehensive information base is an important prerequisite for a meaningful outcome of the project. A major data gathering effort, including experts from all GMS countries, has been planned to establish such a database.

In brief, the information base will describe the current status of each country's energy-economy-environment system. More precisely, a suitable RES will be identified and the overall economic as well as environmental situation will be assessed. Also, prevailing trends will be identified and an outlook into the foreseeable future will be included. All these will be based on the perspective of actual and planned cooperation within the energy sector of the GMS.

The formulation of a suitable RES will draw on existing energy demand-supply balances for each country and each energy subsector using the International Energy Agency categorization as a template if possible.

The energy supply part of the information base must include the total and annually available amounts of primary-energy sources and resources as well as the annually available amounts of import of primary (and other forms of) energy.

Energy technology data should include information on cost and performance (all technical characteristics including the environmental impact of energy conversion). For new technologies in particular, data on the maximum speed of introduction will be specified.

More detailed information requirements for all three categories of data (supply, technologies and demands) were earlier explained in Section 4.

Stage 2. Generating Scenarios with the MESSAGE Model

Data concerning future developments are naturally subject to varying degrees of uncertainty. The overall uncertainty surrounding the future of GMS's energy-economy-environment system will be reflected by choosing an appropriate number of scenarios, each of them resolving the uncertainties in one consistent way. One particular way of "grouping" uncertainties is sometimes called "storyline." The main descriptors of a storyline are usually qualitative (e. g., "favorable", "high", "low", "cooperative", "environmentally conscious", and the like). Together, the scenarios reflect different possible levels of energy demand and supply, global uncertainty with respect to oil prices, economic growth rates, macroeconomic and other constraints, etc.

Each such storyline will be used to prepare a corresponding set of numerical inputs for MESSAGE.

MESSAGE results will be compiled for each country or region then the information will be aggregated to serve as a basis for defining model runs for GMS as a whole. Afterwards, the integrated strategies for the entire GMS will be compared with model runs for each country or region so as to quantify the benefits of optimal integration of the GMS.

For each scenario, MESSAGE results will consist of least-cost strategies of meeting the given energy demand. In addition to the financial cost, external aspects (for instance, its environmental impact) of each strategy will be assessed. The assessment of external aspect will permit, for instance, the analysis of trade-offs between internal and external costs by assuming different values for the levels of environmental constraints. As numerical values for many categories of environmental impact are known only within rather wide ranges, different policy attitudes with respect to precaution can be modeled by using high numbers for the external costs or using low ones.

Stage 3. Feedback on the Scenario Results

After the model runs are completed, a large amount of raw model outputs will have been produced, which will have to be discussed and analyzed. At this stage of the project work, IRM, the domestic experts, local policy makers and potential investors will assess the MESSAGE results from various socio-economic and environmental perspectives. These include social equity (e. g., poverty alleviation, job creation, relocation of populations), pollution (e. g., acid rain and greenhouse gases emissions), deforestation, desertification, and the probability of natural disasters. The distribution of costs and benefits of energy cooperation and particularly of cross-border interconnections will also be assessed.

Additional assessments will address the energy security implications of the scenarios and comment on the feasibility of GMS-regional integration. In particular, it will be analyzed how regional energy security is enhanced by the integration of the individual energy system into an integrated GMS system.

Stage 4. Formulating Energy Strategies for GMS

Another important perspective for the transformation of numerical MESSAGE results into policy recommendations will be to assess the political feasibility of the least-cost strategies as produced by the model. Only after this step, will the strategies be presented to policy makers. In cases where the political feasibility appears within reach but not assured, proposals for institution-building measures (e. g., regulatory mechanisms for regional energy markets) to sustain the regional energy strategic framework will be formulated.

Stage 5. Dissemination

A draft final report summarizing all project findings will be prepared and presented to the ADB as well as to officials of the GMS countries for review. Their comments and recommendations will be reflected in the final project report.

Other dissemination activities will include the preparation of one or more presentations summarizing the findings of the project for use at seminars, workshops and other similar activities.

VI. Expected Results

The purpose of formulating more than one scenario for the future development of the energy-economy-environment system in the GMS region is to identify robust investment strategies, that are good investments under most if not all scenarios considered. The quality of investments will be determined not only by their financial payback but also by their socio-economic and environmental impact.

As a result, after appropriate feedback from ADB and policy makers in the GMS region, a master plan for integrating the energy systems of the GMS region into one system will be formulated and a “road map” for the implementation of the proposed policy action will be prepared.

The recommendations will not only address public policy makers but also the private sector. The implementation options to be considered shall include public as well as private investments and public-private partnership in energy development for the benefit of the entire region.

It is expected that by the end of August 2006, IRM will come out with the Interim Report on the Energy Situation in the GMS Region, while the Interim Report on Alternative Least-Cost Scenarios based on MESSAGE will be ready by the end of October 2006. The final draft report will be prepared by end of February 2007 and submitted to ADB and the GMS governments for their comments.

Appendix A

Consultant's Profile

Based in Vienna, Austria, IRM specializes in energy systems analysis with a focus on developing software solutions for energy resource management and energy supply strategies. With a staff of over 70, the company serves more than 40 energy planning groups including top utilities, energy-intensive industries and transportation companies in 16 countries. Founded in 1998, IRM now ranks among the leading software providers of energy resource management software in Europe.

On a company level, IRM's solutions support companies working in the energy sector by streamlining complex business processes and thereby enabling them to minimize failure and operating costs.

IRM standard software packages iOPT and iPLAN (based on IIASA's MESSAGE model) have been tailored to meet the requirements of energy planning in deregulated markets, incorporating the experience of our customers and the expertise of our consultants into the products.

These tools aim at helping our customers to optimize the whole energy planning process starting at the investment policy all the way to the disposition of existing physical generation units and supporting the trading activities, based on effective risk management and taking into account any relevant conditions for very short time frames starting up to several years.

Maximum flexibility and economical use of resources are central to our projects. The result of our efforts is fast implementation and quick return on investment.

Target Groups -

- Ministries and Regulatory Bodies
- Technology providers
- Donors and lenders
- Investors
- Multi-commodity utilities
- Large utilities or producers
- Energy-intensive industries and transport
- Energy-traders

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Fields of Application -

- Integrated energy systems
- Energy investment and policy analysis
- Forecasting of prices, load, inflow, etc.
- Portfolio - risk management
- Energy scheduling or balancing
- Production or asset optimization

Commodities -

- Electric energy
- District heat
- Natural gas
- CO_2 certificates

Appendix B

Key Project Team Members

Leo Schrattenholzer, Team Leader, Energy Economist

In addition to his IRM affiliation, Dr. Leo Schrattenholzer is the part-time leader of the Environmentally Compatible Energy Strategies (ECS) Special Project at the International Institute for Applied Systems Analysis. He has been affiliated with IIASA since 1973, after graduating from the Technical University of Vienna, Austria. The focus of his present scientific work is energy systems analysis, in particular formulating policy-relevant conclusions from energy scenarios with an emphasis on energy technology assessment.

Since 1981 he has served as one of two co-directors of an international network of energy analysts, the International Energy Workshop (IEW). The IEW is an international network of energy analysts who aim to compare published energy projections and to investigate the reasons for diverging views on developments.

Dr. Schrattenholzer received his Master's degree in mathematics in 1973 and his Ph.D. in energy economics in 1979, both from the Technical University of Vienna. His Ph.D. thesis was on modeling long-term energy supply strategies for Austria. From 1972 to 1974, he was a research and lecture assistant with the Institute of Mathematics I of the Technical University of Vienna. He has worked as a consultant to the Energy Sector Management Assistance Program sponsored by the World Bank and UNDP, for which he conducted a major project assessing personal computer models for energy planning in developing countries. He has also been a consultant to governmental institutions on national strategies to reduce greenhouse gas emissions. He has represented IIASA-ECS in international teams working for three major projects co-sponsored by the European Commission and has lectured at universities and other educational centers. He is a Lead Author of the IPCC's Second Assessment Report.

Kee-Yung Nam, Economist

Dr. Kee-Yung Nam is currently Senior Research Scholar in the Environmentally Compatible Energy Strategies (ECS) Special Project, International Institute for Applied Systems Analysis (IIASA). His scientific research focuses on developing long-term global energy-economic-environment (E3) scenarios from a policy perspective, including maintaining and expanding the up-to-date, extensive database on technologies and resources and conducting E3 analyses as well as development and applications of energy-economic-environment models in response to long-term patterns of energy and economic development as well as climate change.

Prior to working at IIASA, he worked as an Industrial Development Officer in the Studies and Research Branch, Information and Research Division in United Nations for Industrial Development (UNIDO) from 1988 to 1998, conducting quantitative analysis and policy analysis in the field of energy, economics and environment from the industrial development perspectives. From 1998 to 2005, he worked as an Energy Economist/Energy Data Analyst in the Planning and Economic Studies Section, Department of Nuclear Energy in the International Atomic Energy Agency (IAEA). His duties and responsibilities included the development, updating and maintenance of energy, economic and technology databases; analyzing the status and trends of energy, electricity and nuclear power economics; conducting E3 analyses; participating in the development and updating the software for comparative assessment and energy systems analysis; contributing to analyses of GHG mitigation options; organizing technical meetings; arranging and conducting country missions; and providing technical support for Technical Cooperation projects.

Dr. Nam holds a master's degree in economics from the University of Vienna, Austria, where he also completed his Ph.D. in economics.

Albrecht Reuter, Energy Economist

Dr.-Ing. Albrecht Leopold Reuter is the Managing Director of IRM Consulting und Services. He has been appointed as Managing Director of IRM Consulting and Services, a subsidiary company of IRM AG, Austria, since January 2005.

From 1995 to 2003 he was working for the Austrian Verbundplan as energy economist. In his position as Division Director he has set up the working field of energy management and created the product family with the synonym BIT@Energy.

Before coming to Austria, he was employed by the University of Stuttgart from 1993 to 1995 as an energy systems scientist. He was Department Manager at the Institute of Energy Economics and the Rational Use of Energy (IER), directed by Prof. Dr. Alfred Voss, who also supervised Dr. Reuter's Ph.-D. thesis.

Albrecht Reuter began his career in the power plant business, first with Brown, Boverie & Cie AG in Mannheim and then with Lahmeyer International GmbH in Frankfurt.

Dr. Reuter is well known through his publications. He is teaching at the universities of Stuttgart, Germany and St. Gallen, Switzerland. He is a Member of the Board of the Global Forum for Sustainable Energy (GFSE) and Member of the Advisory Committee of the Ludwig Bölkow Foundation.

Albrecht Reuter initiated the annual Energy Talks in Ossiach, Austria.

Manfred Strubegger, Energy Planner

Dipl.-Ing. Manfred Strubegger joined IIASA's Energy Systems Program in May 1979 as a Research Assistant, and in June 1983 became a Research Scholar with the Energy Program's Gas Study. Presently he is working as a part-time Senior Research Scholar with IIASA's Energy Program.

Manfred Strubegger graduated from the Technical University of Vienna. At IIASA, he worked initially on the environmental consequences of pollutant releases from energy production and conversion plants. This interest in environmental protection led also to the involvement in the design of a Zero Emission Energy Supply System based on chemical decomposition of hydrocarbons. During the last years he has worked mainly on global and regional energy modeling, specifically on the design and build-up of a European natural gas model, focusing on the demand/supply options of different regions in East and West Europe.

Since 1982 Mr. Strubegger has been working as an Energy Consultant for private companies and government organizations. His work focuses on the interaction of the energy system with the other economic sectors and the optimization of energy supply systems with respect to multiple objectives. Recently he has also been involved in the development of power plant scheduling programs.

During his work, Mr. Strubegger has gained knowledge in setting up and operating small UNIX-based multi-user computer systems, as well as in the design and realization of data bank and optimization programs.

Sawad Hemkamon, Economist

Sawad Hemkamon was former Deputy Director General of the Department of Energy Development and Efficiency at the Ministry of Energy (MOE) in Bangkok, Thailand where he was responsible for the general inspection and control working performance in accordance with Thailand's energy planning. He now works as a self-employed Consulting Engineer. He received a B.Sc. degree in Mechanical

Engineering from the Chulalongkorn University in Patumwan, Bangkok, Thailand and a M.Sc. degree in Mechanical Engineering from the University of Illinois, Urbana-Champaign, Ill., USA.

Phung Bui Huy, Energy Planner

Dr. Phung BUI HUY is a Senior Researcher and Head of the Energy Conservation Department at the Research Center of Energy and Environment in Hanoi, Viet Nam. He works in the field of forecasting energy demand and planning energy supply where he is specializing in energy data analysis, energy conservation, and CDM. He studied Power Plant Engineering at the Hanoi Polytechnic University and he received a Doctor of Energetics degree from the Bucharest Polytechnic University, Romania.

Sithirith Mak, Economist

Sithirith MAK is a National Consultant on Environmental Issues in Phnom Penh, Cambodia. He has contributed to the National Environment Performance Assessment for the GMS for UNEP and the ADB. He holds a Bachelor of Veterinary Science (BSc) degree from the Royal University of Agriculture Phnom Penh and a Master of Science (MSc) degree in Regional and Rural Development Planning from the School of Environment Resource and Development, Asian Institute of Technology (AIT), Bangkok, Thailand. He is also a PhD Candidate of the Geography Department, National University of Singapore (NUS), Singapore.

Linhsamouth Vilayvong, Economist

Linhsamouth VILAYVONG works for the National Consulting Company (NCC) and for the Department of Electrical Engineering, Faculty of Engineering of the National University of Laos (NUOL), Vientiane, Lao PDR. His professional activities include energy audits for renewable energy, an analysis of energy conservation potentials and energy saving for Lao PDR. He received a Master of Science (M.Sc) degree in Electric Power from the Polytechnic Institute of Tashkent, (Uzbekistan) and a Master of Engineering (M. Eng) degree in Energy Management from the School of Environment, Resource and Development at the Asian Institute of Technology (AIT).

Yuming Wu, Economist

Prof. Yuming WU is Professor of Regional Economics at Guangxi Normal University where he teaches regional economics, statistics and econometrics, developmental economics. He is also a consultant of the Guilin City Government and responsible for several national science foundations and provincial natural science and social science foundations. He holds a B. Sc degree from the Northwest Normal University in Lanzhou (School of Geography and) Environment Science, a M.Sc. from the same university, and a Ph.D. from the East China Normal University in Shanghai (School of Resources & Environment Science).

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