COMPREHENSIVE ASSESSMENT OF DIFFERENT ENERGY SOURCES FOR ELECTRICITY GENERATION IN INDONESIA

ENERGY DEMAND AND SUPPLY ANALYSIS
(PHASE I)

REPORT PREPARED BY A TEAM OF EXPERTS FROM INDONESIA
WITH THE GUIDANCE OF THE INTERNATIONAL ATOMIC ENERGY AGENCY
UNDER THE TECHNICAL COOPERATION PROJECT INS/0/016

May 2002

FOREWORD

Assistance has been provided to Indonesia by the International Atomic Energy Agency (IAEA) under a technical co-operation project titled **"Comprehensive Assessment of Different Energy Sources for Electricity Generation in Indonesia"** (INS/0/016). The project's main objective is to support the national planning and decision-making process in Indonesia's energy and electricity sectors, taking into account key economic, social and environmental factors. This study is intended to comprehensively assess the potential contributions of various energy options to the optimal long-term development of Indonesia's energy supply and demand consistent with sustainable development.

An Indonesian Team was created, which includes representatives of the following institutions: the Agency of Assessment and Application of Technology (BPPT), the National Nuclear Energy Agency (BATAN), the Directorate General of Electricity and Energy Development (DJLPE), the Directorate General of Oil and Gas (DJMIGAS), the Environment Impact Control Agency (BAPEDAL), the National Centre for Statistics Agency (BPS), the State Electricity Company (PT. PLN Persero) and the Non Governmental Organization for Environment (NGO). The project was organized in co-operation with these institutions, with IAEA support in the form of expertise from Russian and German experts. BATAN and BPPT have been designated by the Indonesian Government as the lead organization and the national counterpart for the project.

The comprehensive assessment of different energy sources for electricity generation in Indonesia consists of two phases. The energy demand and supply analysis using the MAED and MARKAL models is Phase I of the study and was carried out in 2001. The assessment of environmental impacts and externalities of electric energy generation using the SimPacts model will be done in Phase II of the study in 2002.

The principal objective in Phase I was to allow the Indonesian Team to obtain a comprehensive understanding of the MAED (Model for Assessment of Energy Demand) and MARKAL (Market Allocation) packages through applications based on the integrated use of the two models. All the Indonesian organizations mentioned above took part.

Several missions by IAEA experts were organized to help prepare the data base, run the model and review the progress of the study, resolve problems experienced in the conduct of the study, and provide advice about any follow-up activities needed at each step of the analysis process. All these activities led to the successful conclusion of an overall energy planning study for the country.

This present Phase I report documents the work conducted and the principal results obtained. The conclusions and recommendations are put forward for further consideration by the responsible authorities of the country regarding expected decisions on energy and electricity supply options, including nuclear power.

EDITORIAL NOTE

1. SUMMARY

1.1. Background

Energy development is an essential part of sustainable development at the national level, and sustainable development is in turn an essential step towards Indonesia's overall national goals – including the achievement of a just, prosperous, balanced and equitable society. The energy sector is crucial for industrialization, for which it provides both raw materials and fuel commodities. Energy also contributes directly to increase people's welfare and standard of living.

Indonesia, like other South East Asian developing countries, currently has low living standards and low energy consumption. The reality, therefore, is that substantial increases in energy use in general, and in electricity use in particular, will be needed in order to reach national development goals. Careful planning for wise development and use of national resources, and cost-effective participation in international energy markets, is crucial for assuring the adequacy, resilience and independence of the country's energy system.

Rapid increases in domestic energy demand make it more difficult to depend on Indonesia's existing increasingly limited resources. Consideration must therefore be given to developing and deploying all available energy technologies including fossil fuels, renewables and nuclear energy.

1.2. National Energy Policy

National energy policies must integrate development objectives across all economic sectors with protection of the natural environment necessary for both economic productivity and each individual's quality of life. Integration helps to assure full utilization of natural and human resource potentials; it helps assure efficient resource use consistent with natural resources conservation principles; and it helps to optimize net overall benefits to the nation. It emphasizes the importance of using non-renewable energy resources as sparingly and wisely as possible, and for renewable energy sources it emphasizes the care that needs to be taken to maintain their productive capacity. In general energy resource management should seek to maximize the value added through optimising resource use in support of sustainable development.

To support the national Future Long Term Development Program, and in light of recent changes in the global strategic environment, Indonesia has established an integrated energy policy comprising five principal policies and nine supporting policies. The five principal policies are: Energy Diversification, Intensification of Exploration for Energy Sources, Energy Conservation, Average Energy Price Adjustment, Environment for Sustainable Development. They, and the nine supporting policies, are summarized in Section 2, which describes the current energy situation in Indonesia as the starting point for the analysis to follow.

1.3. Objective of the Study

The study's objective is to support the national planning and decision making process in Indonesia's energy and electricity sectors, taking into account key economic, social and environmental factors. This study is intended to comprehensively assess the potential contributions of various energy sources to the optimal long-term development of Indonesia's energy supply and demand consistent with sustainable development.

1.4. Organization of the Study

The study team comprised members from the following Indonesian institutions: the Agency of Assessment and Application of Technology (BPPT), the National Nuclear Energy Agency (BATAN), the Directorate General of Electricity and Energy Development (DJLPE), the Directorate General of Oil and Gas (DJMIGAS), the Environment Impact Control Agency (BAPEDAL), the National Centre for Statistics Agency (BPS), the State Electricity Company (PT. PLN Persero) and the Non-Governmental Organization for Environment (NGO).

The International Atomic Energy Agency (IAEA) has developed computer tools to assist in the sort of comprehensive assessment undertaken in this study. The Agency has also accumulated substantial experience in working with other Member States that have gone through similar assessments. Therefore the Agency is well qualified to play a major role in assisting the Government of the Republic of Indonesia in conducting a comprehensive assessment and evaluation of different energy sources in the country.

1.5. Methodology

The comprehensive assessment of different energy sources for electricity generation in Indonesia consists of two phases. The energy demand and supply analysis using the MAED and MARKAL models is Phase I of the study and was carried out in 2001. The assessment of environmental impacts and externalities of electricity generation using the SimPacts model will be done in Phase II of the study in 2002.

To obtain a consistent comprehensive picture of the Indonesian energy economy, an integrated, computer-aided approach was used, which includes:

- estimating reasonable scenarios for future demographic and economic development;
- providing detailed sectoral and regional energy demand projections by applying the MAED simulation model to the scenarios for economic and population growth; and
- using the MARKAL model to optimize future energy and electricity supplies based on these scenarios, taking into consideration all known Indonesian energy sources and all relevant technologies.

Based on the projected future gross domestic product per capita in Indonesia (GDP/capita), the total Indonesian energy demand by sector is estimated for four regions: Java-Bali-Madura, Sumatra, Kalimantan and Other Islands. The sectoral and regional energy demands for Indonesia are estimated in terms of final energy. Electricity demand is estimated in terms of useful energy. The projected energy demand by sector from the MAED simulation model is then used as input data for the optimization using the MARKAL model.

An annual discount rate of 10 percent is used, which is generally applicable for the energy sector in Indonesia. To test the robustness of results, cases have also been assessed using discount rates between 2 percent and 8 percent per year. The cases analysed in the study, and the questions they were designed to answer are as follows:

Case:	Questions: **What could be the potential roles of fossil, nuclear and renewable energy if ...**
LOW1000	... energy market prices remain low (US$18 to US$21 per barrel of oil) and environmental policies remain unchanged?
IEA1000	... energy market prices rise to US$27 per barrel oil equivalent within the next two decades and environmental policies remain unchanged?
IEA1001 **IEA1002** **IEA1003**	... energy prices rise to US$27 per barrel oil equivalent within the next two decades but environmental policies to protect the atmosphere are introduced and progressively tightened?

1.6. Results

Final energy demand, broken down by fuel, is shown in Table 1.1. The largest component, for all but the final time period, is the demand for non-substitutable motor fuel. In the final time period (2025) this is surpassed slightly by the demand for substitutable fossil fuels. The greatest growth occurs in the case of electricity. Absolute electricity use is 4.5 times higher in 2025 than in the base year of 1997, and its share of commercial energy demand is 1.5 times higher. The contribution of non-commercial fuels to the total energy demand consistently declines. Table 1.2 shows the evolution of selected energy and socio-economic indicators.

The evolution of the primary energy supply mix consistent with the demand projections in Table 1.1 is shown in Table 1.3.

Table 1.1. Total Final Energy Demand by Fuels (PJ)

Years	**1997**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Electricity	360	380	491	674	898	1,202	1,620
Fossil substitutable	706	741	919	1,198	1,518	1,946	2,540
Motor fuel	1,005	1,051	1,203	1,413	1,657	1,960	2,313
Feedstock (coke)	3	2	3	4	5	6	8
Feedstock (oil & gas)	171	205	260	310	360	430	500
Non-commercial forms of energy	1,784	1,690	1,688	1,673	1,611	1,463	1,165
Total Final Energy	**4,028**	**4,070**	**4,564**	**5,272**	**6,048**	**7,007**	**8,146**

Table 1.2. The Values of Some Energy Demand Indicators.

	1997	2000	2005	2010	2015	2020	2025
Total GDP (10^{12} Rp_{93})	433	395	504	691	924	1,237	1,655
GDP per capita (10^6 Rp_{93}/cap)	2.21	1.94	2.35	3.09	3.97	5.12	6.62
Electricity demand (PJ)	360	380	491	674	898	1,201	1,620
Total final commercial energy demand (PJ)	2,245	2,380	2,876	3,599	4,437	5,544	6,980
Total final energy demand (incl. Non-commercial) (PJ)	4,028	4,070	4,564	5,272	6,048	7,007	8,146
Electricity per capita (PJ/10^6 persons)	1.84	1.87	2.29	3.01	3.86	4.98	6.47
Final energy (commercial) per capita (PJ/10^6 persons)	11.47	11.70	13.41	16.08	19.07	22.96	27.90
Total final demand per capita (PJ/10^6 persons)	20.59	20.00	21.28	23.56	25.99	29.01	32.55
Electricity per GDP (PJ/10^{12} Rp_{93})	0.83	0.96	0.97	0.98	0.97	0.97	0.98
Energy (commercial) per GDP (PJ/10^{12} Rp_{93})	5.18	6.03	5.70	5.21	4.80	4.48	4.22
Energy (total) per GDP (PJ/10^{12} Rp_{93})	9.30	10.30	9.05	7.63	6.54	5.66	4.92
GDP elasticity of electricity			1.05	1.00	0.99	1.00	1.03
GDP elasticity of commercial energy			0.77	0.71	0.71	0.76	0.79

Table 1.3 Total Primary Energy Supply in Indonesia, Case IEA1001 (PJ/a)

	2000	2005	2010	2015	2020	2025
1. Mining Extraction of Fossil Fuels						
Coal	1,634	1,898	2,098	2,696	3,316	3,792
Oil	3,026	1,877	1,290	1,066	1,055	1,055
Gas	2,625	3,015	3,689	3,301	3,342	3,739
2.Net Imports of Fossil Fuel						
Coal	-1,324	-1,422	-1,549	-1,762	-1,926	-2,086
Oil	-394	581	1,598	2,570	3,435	4,816
Gas	-1,457	-1,528	-1,721	-1,426	-1,329	-1,329
3. Total Primary Energy Supply						
Coal	310	477	549	934	1,391	1,705
Oil	2,632	2,458	2,888	3,636	4,491	5,871
Gas	1,168	1,487	1,968	1,875	2,013	2,410
Renewables						
Traditional	1,649	1,655	1,648	1,594	1,456	1,174
Commercial	203	214	344	493	708	708
Nuclear	0	0	0	0	25	271
Total	5,962	6,290	7,397	8,531	10,082	12,221

The most prominent change facing the Indonesian energy sector over the study horizon is a shift from being a net energy exporter to becoming a net importer. Once a major oil exporter, Indonesia begins to import substantial amounts of crude oil during the first decade of the 21st century. Domestic demand for oil products greatly exceeds projected indigenous oil production capacity. Expanding coal production and fluctuating gas exports cannot prevent this change, which appears to be unaffected by the underlying oil market price scenario.

Natural gas and renewables take the lead in electricity generation while oil products remain an important source for decentralized electricity generation. In the absence of environmental constraints, nuclear power does not enter the cost-optimal solution. The imposition of small emission reduction requirements, however, immediately tilts the balance in favour of nuclear.

Figure 1.1 shows the contribution of the two types of nuclear power plants considered in this study under different assumptions about environmental control policies regarding climate change. Using as a baseline the carbon dioxide (CO_2) emissions of case IEA1000 (high oil prices), Figure 1.1 shows the effect of introducing emission reduction requirements of 1%, 2% and 3%.

The sensitivity of nuclear power to even small (CO_2) emission reduction requirements indicates that the technology was at the margin given the overall scenario specification (resources, infrastructures and technology performance). Sensitivity tests around critical nuclear power performance parameters showed that near-term advanced reactors (rather than past or current designs) would enter the cost-optimal solution before 2020 even in the absence of an “environmental pull” or high energy market price scenario (see Figure 1.2).

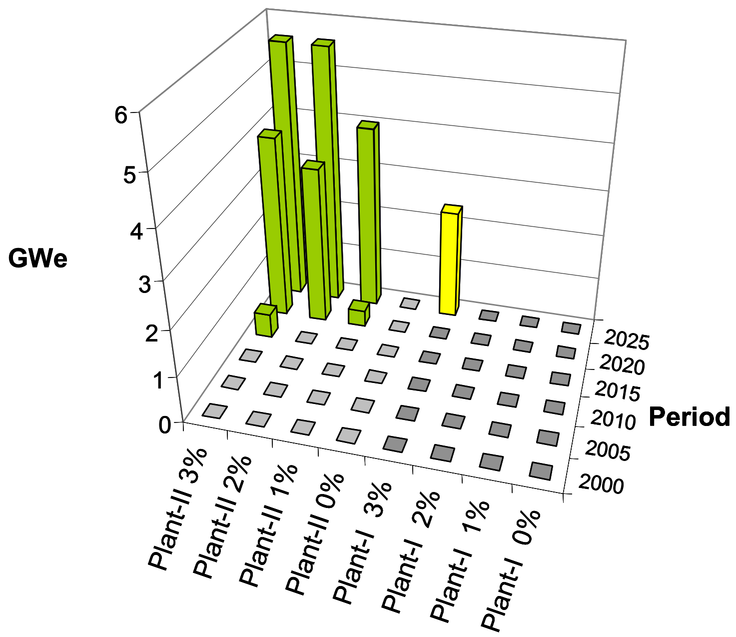

Figure 1.1. Capacity of Nuclear Power Plants (I and II) for Total CO_2 Reduction by 0% to 3%, High Price Path (IEA) - (GWe)

600 MWe Plant factor = 75%

GWe installed

$/kWe	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500	2,600	2,700
2010	1.2	1.2	1.2															
2012	2.4	2.4	2.4	1.2														
2014	3.6	3.6	3.6	2.4	1.2	1.2												
2016	4.8	4.8	4.8	3.6	2.4	2.4	1.2	1.2	1.2	1.2								
2018	4.8	4.8	4.8	4.8	3.6	3.6	2.4	2.4	2.4	2.4	1.2							
2020	4.8	4.8	4.8	4.8	4.8	4.8	3.6	3.6	3.6	3.6	2.4	1.2	1.2					
2022	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	2.4	2.4	2.4					
2024	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	3.6	2.4	2.4	0.6				

600 MWe Plant factor = 85%

GWe installed

$/kWe	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500	2,600	2,700
2010	1.2	1.2	1.2	1.2	0.6													
2012	2.4	2.4	2.4	2.4	1.8	1.2												
2014	3.6	3.6	3.6	3.6	3.0	2.4	1.2	1.2	0.6									
2016	4.8	4.8	4.8	4.8	4.2	3.6	2.4	2.4	1.8	1.2	1.2	1.2	1.2	0.6				
2018	4.8	4.8	4.8	4.8	4.8	4.8	3.6	3.6	3.0	2.4	2.4	2.4	2.4	1.8	0.6			
2020	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.2	3.6	3.6	3.6	3.6	3.0	1.8	1.2		
2022	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.2	1.8	1.2		
2024	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.2	3.0	2.4	0.6	

Note: Simulation done under everything else being equal conditions

Figure 1.2. Impact of varying capital costs and load factors on the time and rate of nuclear power introduction in Indonesia (600 MWe).

1.7. Conclusions

(a) The results of this study provide a realistic projection of energy demand in Indonesia taking into account the economic crisis of 1998, projected population and economic growth and changes in lifestyles and technology. This projection is consistent with other projections and reflects current Government policies.

(b) Indonesia's need for energy is projected to double, from 4,028 PJ at the beginning of the study period to 8,146 PJ at the end of the study period. The contribution of commercial energy will increase very significantly from 2,245 PJ to 6,980 PJ. On the other hand the contribution of non-commercial energy to the total energy demand will decline from 1,784 PJ to 1,165 PJ.

(c) The net installed electricity generating capacity in Indonesia reaches 100 GWe at the end of the planning horizon (2027). Almost 59 percent of this capacity will be required in Java-Bali, corresponding to 59 GWe.

(d) For all cases, the Gas Base-load Plant is the top ranked technology for electricity generation in Java-Bali. For example in case IEA1000, gas is used up to the maximum volume set exogenously in the supply study (2023-2027), corresponding to a share of 45 percent or about 27 GWe.

(e) From solely an economic point of view, the Coal Base-load Plant is ranked second among electricity generation options in Java-Bali. In case IEA1000, for example, 22 GWe of electricity based on coal is used, corresponding to a share of 37 percent. This generation mix will emit 19.6 kt/a of particulate matter, 411.4 kt/a of NO_X and 171.7 kt/a of SO_2.

(f) The more the use of fossil fuels is constrained and environmental standards are enforced, the earlier nuclear power becomes part of the optimum generation mix. For example in case IEA1002 (reduction of CO_2 emissions by two percent), 3.5 GWe of nuclear energy is needed in Java-Bali in Period 5 (2018-2022).

(g) At the end of the study period, nuclear power is the third principal generation option. There are no real technical infrastructure constraints or limiting interdependencies with other sub-sectors of the energy system that would prevent its introduction. Nuclear power plants can be added to the system when increased demand requires new capacity or if reality unfolds differently from the scenarios underlying this study.

(h) The prospects for expanding natural gas exports (LNG and pipeline) are promising as the global dash for gas continues. The early introduction of nuclear power in Java-Bali could free up substantial amounts of natural gas for export revenue generation.

(i) However, the above conclusions are based on two nuclear options that both appear conservative for 2010 and beyond. Sensitivity analyses indicate the above results are indeed sensitive to variations in nuclear cost and performance parameters across a reasonable range for post-2010 technologies, with earlier nuclear introductions becoming optimal for a number of plausible cost and performance assumptions.

(j) The optimal upper limit on coal as a source of electricity generation remains to be determined in the next phase of the assessment. There is no doubt that a limit exists. Phase II will help quantify both the level and the point in time after which coal use should not grow further.

1.8. Recommendations

The key results of this study along with an explanation of the uncertainties and the study limitations should be presented to policy makers, ministries, and other institutions. Further sensitivity analyses on key technology performance parameters should be undertaken for all essential fossil and non-fossil technologies in order to delineate comprehensive cost-optimal solution areas.

Developments in the area of energy technology performance should be closely monitored. A database should be established on nuclear power plants and available alternatives. Advanced and innovative designs are under development, particularly in response to electricity sector deregulation and restructuring in many countries. Indonesia should take advantage of these developments, and the analysis reported here should therefore be periodically revised to incorporate, among other things, realistic updated estimates of post-2010 cost and performance parameters for nuclear power and other generation options.

Findings of the next phase of the assessment – the quantification of health and environmental impacts associated with the projected development of the energy system – should be incorporated in the energy demand and supply study and their impacts on the optimal supply mix assessed.

The next steps necessary for the introduction of nuclear power should be initiated. Foremost is a compilation of the tasks needed to establish the necessary legal and institutional framework. In parallel, the pool of qualified manpower should be expanded, including manpower capable of training personnel in all aspects of nuclear power operation and control with particular emphasis on operating safety and operation protection. Equally important is the enhancement of expertise and training in connection with safeguarding fissile material in full recognition of the international legal obligations that come with the adoption of nuclear power.