Economic, Security and Environmental Aspects of Energy Supply: A Conceptual Framework for Strategic Analysis of Fossil Fuels

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EXECUTIVE SUMMARY

This paper presents a methodology for analyzing long-term national energy strategy in relation to the issues of energy security and environmental impacts of energy supply and consumption. The proposed methodology concentrates on two policy decisions: 1) the appropriate mix of fossil fuels, and 2) the desirable level of petroleum inventories; and four exogenous factors: 1) growth in energy demand, 2) international price of crude oil, 3) possibilities of oil supply disruption, and 4) availability of natural gas.

The methodology is used to measure the impacts of the above decision and exogenous variables on two objective criteria (attributes), i.e., economic cost of energy supply, and environmental impact of energy use. The economic cost includes the cost of the entire supply chain, as well as the cost of possible disruptions in petroleum supplies. The environmental impacts include emissions of SO_2, NO_x, particulate matter, and CO_2, which are primary contributors to local, regional and global environmental damage.

The advantages of the proposed methodology relative to traditional models of energy planning are as follows:

- The proposed model is capable of handling multiple objectives, such as cost, security of supply, and environmental impacts. Traditional models are normally based on a single objective criterion, i.e., cost of energy supply.
- It is a convenient tool for dealing with uncertainty and risk associated with oil supply disruptions, international fuel prices, etc. Traditional models deal with the uncertainty only in a limited manner through sensitivity and scenario analysis.
- The proposed model is comprehensive but sufficiently practical to be developed with reasonable cost. The model is, however, suitable to long-term strategic analysis rather than medium-term energy planning practices.
- It utilizes the technique of Trade-off Analysis, which is itself an organized way of considering all possible plans and eliminating those which are inferior to others.

Trade-off Analysis involves the following steps:

1. identify the objective attributes, e.g., cost of energy in dollars, SO_2 emissions in tons, etc.
2. identify policy decisions, e.g., mix of fuels, strategic petroleum reserves, etc.
3. identify exogenous variables, e.g., energy demand, international price of oil, etc.
4. determine plausible values of each policy and exogenous variable. For example, one may choose ten fuel mix options, five various growth rates for energy demand, three oil price scenarios, etc.
5. form a database of all possible combinations of policy and exogenous variables. Each combination is referred to as a “plan”.
6. measure the impact of each plan on all objective attributes. For example, measure the economic cost and SO_2 emission of each plan.
7. consider the corresponding attributes, eliminate plans which are inferior to other plans.
8. prepare a short list of plans for presentation to policy makers.

The main drawback of this method is that the required computations become too voluminous if the number of attributes, the number of policy decisions, and the number of exogenous variables are large. Thus, it is not suitable for use in the medium-term energy planning practices where one deals with a large number of variables. But the method is suitable for the analysis of global impacts and choices relating to a few strategic questions. This happens to fit the requirements for strategic analysis of energy and environment. In such analysis, the policy maker is primarily concerned with global choices in the long-term fuel mix. The detailed specifications of the relationships do not yield much benefit. A relatively abstract model which concentrates on the strategic choices and the main sources of uncertainty would be sufficient.

The proposed methodology has been developed considering its possible application to a country like Japan which is exceptionally vulnerable to economic, security and environmental impacts of energy use. Within this framework, regional and global environmental concerns are addressed in relation to the national energy policy. However, for Japan in particular, regional and global environmental concerns can be also addressed within the framework of its relationship with other countries in and outside the region. Japan can pursue these matters within the context of its foreign aid program.

Japan is the world's largest donor of international assistance. It provides about $24 billion per year to developing countries and emerging economies. Some 25-30% of this aid is for energy related projects and activities. Japan's financial assistance to energy, and even some non-energy areas, provides an avenue for dialogue about local, regional and global environmental concerns. However, in order to establish a constructive dialogue, the Japanese government would need a clear strategy about the environmental concerns which can be pursued in each type of foreign assistance.

We propose future research aimed at: (a) reviewing Japan's foreign aid policy to identify countries and sectors relevant to regional and global environmental concerns; (b) exploring the synergies between local, regional and global environmental preservations; (c) devising appropriate strategies for establishing a dialogue with the targeted countries, and encouraging actions which would result in "win-win" situations. The study can be further expanded to review Japan's potential role in the future of Joint Implementation. This is especially relevant after the Kyoto Conference of December 1997, where the international community is endorsed "operationalizing" Joint Implementation.

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1. Objective

The objective of this paper is to present a methodology for analysis of long-term national energy strategy in relation to (i) economic cost of energy supply; (ii) security of energy availability; and (iii) environmental impacts of energy production and consumption. The proposed methodology prescribes a model that is capable of handling multiple objectives, such as cost, security of supply and environmental impacts; convenient for dealing with uncertainty and risk associated with oil supply disruptions, international fuel prices, development of advanced technology, etc.; suitable to address local, regional and global environmental concerns; and comprehensive but still sufficiently practical to be developed with a reasonable effort and at a reasonable cost.

The underlying model can be implemented based on sophisticated simulation algorithms, or with simple spread-sheet computation techniques. The latter can be used in the event that analysis concentrate on long-term strategic questions rather than specific short and medium-term plans. The latter approach also enables the planners to preserve and present more effectively the intuitive aspects of the model to policy makers.

2. Introduction and Road-Map of the Paper

The traditional methods of energy planning aim at deriving policy decisions which result in meeting the country's energy demand at the lowest possible cost. These methods are often embedded in complex and large models representing detailed relationships in production, processing, transportation and consumption of various forms of energy. Most of these models are based on a single objective criterion, i.e., cost of energy supply, and cannot conveniently deal with other national objectives such as environmental preservation and security of supply. Also, the majority of these models have limited capacity to deal with uncertainty and risk associated with international energy markets.

The relatively recent awareness about environmental concerns have convinced the policy makers to extend their attention beyond the black-box least-cost models and consider other aspects of their policy decisions. As such, the policy makers have now moved ahead of analysts in taking a more comprehensive approach to energy strategy. In an attempt to catch up with the requirements of the policy environment, analysts are introducing, on a piecemeal basis, additional capabilities for dealing with recent developments. Most of these capabilities are at the early stages of implementation and still of limited use in strategic analysis.

This paper introduces a methodology for analyzing the national energy strategy of a country like Japan in relation to three most important concerns of policy makers -- economic cost of energy, security of energy supply, and environmental aspects of energy production and consumption. In doing so, the paper first presents the conceptual design of a model which relates the objective criteria to policy and non-policy variables. Second, it describes the analytical tools which are useful in investigating the impacts of uncertainty on policy decisions. Finally, it provides guidelines for specification and measurement of the objective attributes.

3. Conceptual Design of the Model

Conceptually, energy-environment models consist of three main components: (i) policy decisions; (ii) exogenous factors; and (iii) objective criteria. The model then provides a vehicle to examine the impacts of various policy and exogenous variables on the objective criteria and to arrive at policies which result in an optimum outcome, as measured by the objective criteria.

In the context of long-term strategic analysis, there are three policy decisions which are important. First, the mix of energy that should be selected, targeted or encouraged, to meet the country's long-term concerns regarding energy supply and consumption. Second, the level of fuel stocks, particularly strategic petroleum reserves, that should be maintained to respond optimally to possible supply disruptions. Third, the energy technologies that should be pursued, supported or promoted, to ensure efficient, sound and safe energy supply.

The energy policy analysis normally include a large number of exogenous factors which affect energy demand and supply. For the purposes of strategic analysis, we should concentrate on three groups of exogenous factors. First, we should consider variables such as economic growth which influence energy demand. Second, we should examine the impact of international prices of fossil fuels on economic and environmental attributes. Third, we should consider explicitly the possibility and consequences of oil-supply disruptions.

The impacts of the above policy and exogenous variables are measured in two general categories. First, economic costs of energy, which represent the cost to the country's economy of the energy sector. This cost includes cost of energy as well as cost of any energy-disruption . Second, environmental impacts of energy production, transportation, processing and consumption.

In the traditional least-cost analysis where there is only one attribute (cost of supply), the analysis is simplified into a single-objective optimization problem which can be solved with available optimization/simulation techniques. However, where we deal with more than one attribute, the analysis turns into a multi-objective problem which cannot be handled by conventional techniques. It is then no surprise that even after recognizing that energy strategy has other (than cost) dimensions, still analysts try to convert the multi-objective problems into a single-objective problem. They try to incorporate all the objective attributes into a single index and treat the composite index as the objective criterion. With this approach, environmental impacts are normally converted into monetary units, e.g., instead of tons of SO_2 emissions, one would take a measure of monetary damage of the SO_2 emissions. Thus, the composite index will be an all-encompassing "social cost" function which incorporates all types of costs which are of concern to the country's policy making body.

Although incorporating all attributes into a single measure simplifies the analysis, it is often argued that such integration is inappropriate and misleading. These are two basic problems with this approach. First, conversion of environmental impacts into monetary values is still inaccurate and controversial. Second, integration of objective criteria into a single index limits the possibilities of studying and demonstrating the trade-offs of various impacts of policy decisions.

The alternative is to keep the objective attributes separate, and to investigate the impact of variations in each policy decision on each attribute. This would represent a multi-objective optimization problem for which an analytical solution cannot be derived easily. A recent method for solving such a problem is trade-off analysis. Within this method, the analysis takes all the combinations of values of decision and exogenous variables, and calculates all objective attributes for all these combinations. The method then depicts the trade-offs among the objective attributes and eliminates plans which are inferior to others. At the final stage, the analysis concentrates on a short-list of preferred plans to arrive at decisions which are close to being optimum (see Box 1).

Box 1: Introduction to Trade-Off Analysis

Trade-off analysis is used to investigate the impacts of policy and exogenous factors on multiple, and often conflictive objectives. The multi-objectives approach is necessary when we need to ensure that we do not equate apples and oranges of various objectives. Instead each attribute is measured by an appropriate yardstick -- dollars, tons of SO_2, etc.

Trade-off analysis is an organized way of considering all possible plans and eliminating those which are inferior in to others. Trade-off analysis involves the following steps:

1) identify the objective attributes, e.g., cost of energy in dollars, SO_2 emissions in tons, etc.

2) identify policy decisions, e.g., mix of fuels, strategic petroleum reserves, and exogenous factors, e.g., energy demand, international price of oil, etc.

3) determine plausible values for each policy and exogenous variable. For example, one may choose ten fuel mix options, five various growth rates for energy demand, three oil price scenarios, etc.

4) form a database of all possible combinations of policy and exogenous variables. Each combination is referred to as a "plan". The number of these plans increases exponentially as we add to the number of variables or the optional magnitudes for each variable.

5) measure the impact of each plan on all attributes. For example, we may measure the economic cost, and SO_2 emissions of each plan.

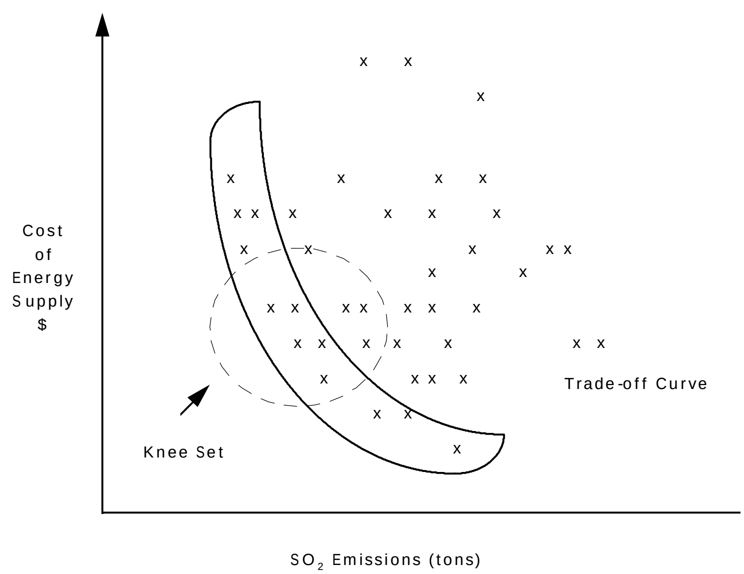
6) considering the corresponding attributes, eliminate many plans which are inferior to other plans. Prepare a short list of plans for presentation to policy makers.

As a simple example of trade-off analysis, we consider a case where there are only two objective attributes, e.g., cost of energy and SO_2 emissions, one policy variable, e.g., the mix of fossil fuels, and two exogenous factors, e.g., energy demand and international price of oil. We further simplify the example by assuming three plausible magnitudes for each policy and exogenous variable.

The combination of magnitudes of policy and exogenous factors results in --- plans. The cost and SO_2 emission of each plan is calculated and depicted on the following figure. Some plans are considered inferior and eliminated because they are worse than the others in both areas of concern (cost and SO_2 emission). What is left is a relatively small number of plans on the trade off curve of which the ones in the knee set are of particular interest.

Alternative Assumptions about Policy and Exogenous Variables

	Mix of Fossil Fuels (%) coal/oil/gas	Energy Demand Growth (%)	Price of oil in 2010 ($/bl)
1	30/60/10	1.5% p.a.	20 $/bl
2	35/55/10	3.0 % p.a.	25 $/bl
3	40/50/10	4.0% p.a.	30 $/bl



4. Incorporating Uncertainty and Risk

Uncertainty refers to lack of perfect knowledge about future events, and risk refers to the possible adverse consequences of this uncertainty on economic, social and environmental attributes.

Traditionally, energy planning did not take account of risk and uncertainty. Analysis were mostly carried out in a “deterministic” manner. The policy making body also often ignored uncertainty assuming that in the long-term uncertain issues will resolve themselves.

In the recent years, two important areas of uncertainty, i.e., the oil market, and the environmental impacts of the energy sector, have attracted the attention of the policy makers. However, even when explicitly recognized, the decision makers take different approaches to the problem. The most frequent ways of dealing with uncertainty are:

- defer the decision until additional information is available to reduce uncertainty;
- transfer risks to other parties (other countries) through long-term contractual agreements, like long-term oil and gas purchase contracts;
- plan for all reasonable contingencies; and
- adopt flexible strategies that allow for relatively easy and inexpensive changes.

All the above strategies do involve added costs. So the above approaches mean paying more money for reducing risk. However, they are better than basing decisions on the deterministic approach which does not take account of risks of failure to achieve desirable objectives.

The above policy approaches to uncertainty are often based on subjective judgments of the policy makers rather than objective analysis. This is mainly due to weaknesses of analytical tools in dealing with uncertainty and risks.

In recent years, some new methods have been introduced to support the analysis of risk and uncertainty in energy planning. The most frequently used methods are:

Scenario Analysis. Many plans are developed each corresponding to a certain set of assumptions about uncertain parameters. The objective is to arrive at policy decisions which remain valid under a large set of plausible scenarios.

Sensitivity Analysis. The emphasis is on one plan (or one scenario). But one studies the changes in the plan in response to variations of key uncertain parameters.

Probabilistic Analysis. Probabilities are assigned to different values of key uncertain variables, and outcomes are obtained through probabilistic simulations, e.g., Monte Carlo technique. The result will be an expected value and a probability distribution of the objective attribute.

Stochastic Optimization. A probability distribution, specified by a mean and variance, is assumed for each uncertain parameter while carrying out the optimization exercise.

Incorporating Uncertainty in the Discount Rate. This is an application of finance techniques and incorporates uncertainty by using different discount rates for different components of costs and benefits, to reflect the uncertainty in each component.

Search for a Robust Solution. It uses the technique of trade-off analysis to eliminate uncertainties which do not matter and to concentrate on the ranges of uncertainty which are most relevant to corresponding objective attributes.

Among the above approaches, two methods, i.e., scenario analysis and sensitivity analysis are most widely used because they are intuitively more appealing and their computational requirement is relatively simple. Probabilistic analysis and stochastic optimization involve complex computations. Incorporating uncertainty in the discount rate is simple but the choice of the risk-adjusted rate is a subjective exercise.

The last method, i.e., the search for robust solution, offers prospects for dealing with uncertainty and risk. This is indeed an extension of scenario analysis and thus remains an intuitively clear exercise. The method is based on the trade-off analysis technique (which was discussed in the previous section) and enables the analyst to consider in a systematic way a large number of possible scenarios, eliminate many scenarios which do not matter, and prepare a short list of scenarios which should be considered in policy making.

5. Specification and Measurement of the Objective Attributes

Economic Cost of Energy Supply

Measurement of the economic cost of energy supply is the most straightforward part of the energy environment analysis. The economic cost includes the full cost of energy chain up to the point of consumption but excludes taxes and duties. Assessment of the economic cost of supply involves the following steps:

- estimation of energy demand by type of fuel based on certain assumptions about economic growth and price of energy products. It could be done based on aggregate relationships or detailed formulation of energy consumption in each sector or even sub-sectors of the economy. For the purpose of strategic analysis, an abstract approach is sufficient and even more appropriate.

- estimation of the cost of delivery of each energy product. Again, the estimation may be based on aggregate formulas which relate the delivered cost of each fuel to the international prices of crude oil, coal and natural gas. Alternatively, one may develop detailed models which assess the cost of processing (refining), and transportation, etc. For the purpose of strategic analysis, one may relate the price of petroleum products to the international price of crude oil based on simple mark-ups. Also, the delivered cost of coal and natural gas can be related to the import prices through simple formulas.

In summary we propose to: (i) project the electricity demand based on a simple relationship to the economic growth and the electricity price; (ii) estimate the fuel requirements of power generation based on the assumed mix of fossil fuels; (iii) estimate the petroleum, coal and natural gas demand in the non-power sectors based on simple and aggregate relationships with economic growth and energy prices; (iv) calculate the cost of petroleum needs of the power and non-power sectors based on simple ratios of product prices to the crude oil price; (v) calculate the cost of coal supply based on the price of imported coal and the cost of transportation, (vi) estimate the cost of natural gas based on the contract prices of LNG imports and the cost of transportation and regasification; and (vii) aggregate the cost figures to arrive at total cost of energy supply. This aggregate number would exclude the cost of nuclear and hydro power, which are assumed to remain independent of our strategic analysis of fossil fuels.

Cost of Supply Disruption

Cost of supply disruption is normally investigated in the context of a potential decline in GNP due to a disruption in the world-wide supply of crude oil. It is then assumed that the supply disruption causes a sudden increase in the price of oil while the increased oil price causes a reduction in the GNP. The amount of economic loss will be higher if a country is heavily dependent on petroleum imports, and lower if the country holds a significant inventory of crude oil or petroleum products.

Estimation of the economic cost of supply disruption involves the following steps:

- formulation of supply disruption scenarios. Each scenario relates to a probable political event and is reflected in reduction of the oil supply by a specific amount for a specific period of time.
- assessing the impact of each disruption on the oil price trajectory; and
- evaluating the impact of oil price increase on the GNP. This requires an estimate of the elasticity of GNP with respect to the price of crude oil. It is important to note that this economic loss is due to sudden (rather than gradual) price increase, and it is because the economy cannot adjust immediately to higher oil prices. Instead, the oil disruption causes higher unemployment and lower GNP than would have been the case in the absence of a disruption. Estimation of the economic impact requires extensive analysis of macro and micro economic reactions to increase in petroleum prices. In the case of the United States, which is dependent on imports for 40% of its oil consumption and holds close to 150 days of petroleum inventories, the elasticity of GNP to sudden increase in petroleum prices is estimated at -0.25. Thus, a 10% increase in the price of oil results in 2.5% decline in GNP. In the case of Japan, where import dependency is almost 100% and petroleum inventories amount to 150 days of consumption, the elasticity could be as high as -1.0.

The role of petroleum reserves[1] on the cost of supply disruption is two folds. First, petroleum reserves are held by all OECD countries and are supposed to be released in a coordinated manner during any supply disruption. This coordinated release would, to varying degrees, prevent a sharp increase in petroleum prices. Second, the petroleum inventory enables the country to avoid physical shortage of petroleum needs at least for some time period after a supply disruption. In an open and free-market environment, the two roles of petroleum inventories are intertwined.

Indeed, the latter role becomes part of the former, as the market reacts to shortages and a higher price clears the gap. However, in countries were the energy sector is somewhat managed and the government regulates the domestic prices of petroleum products, petroleum inventories are aimed directly at avoiding a potential supply shortage. In such a case, petroleum shortage affects the economy in a manner similar to that of power outage. In the case of power outage, planners determine the "reserve capacity" so that at the margin the cost of increasing the reliability of the power supply is equal to the economic benefit of avoiding a power outage. In a similar fashion, one can determine the desirable level of petroleum inventories so that at the margin the cost of maintaining the inventory is equal to the benefit of avoiding a sudden supply shortage.

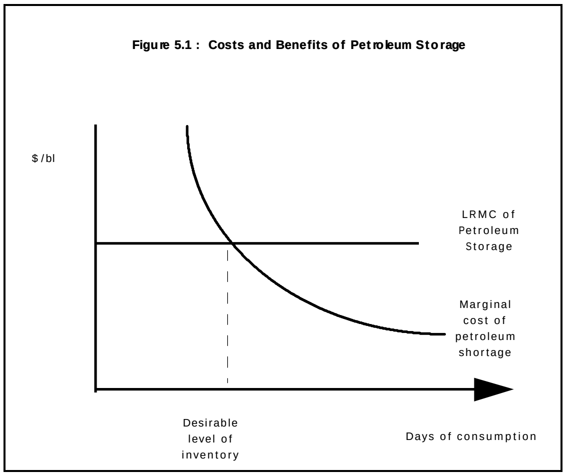
For countries like the United States, the costs and benefits of various levels of petroleum inventories can be assessed based on the open-market approach and by translating all the disruption costs into a higher oil price. For countries like Japan, where there is a much more serious degree of vulnerability, one should use both the open-market and the outage-cost approaches. Accordingly, we outline here guidelines for using each approach.

In the open-market approach, our proposed methodology for estimating the petroleum supply disruption cost is as follows:

We consider five scenarios of supply disruption. the first three scenarios assume that one of the major Middle Eastern producers will be interrupted for one month, six months, or for a long and undermined time. The fourth and fifth scenarios assume that the bulk of Middle East supply is interrupted for one month or six months, respectively. Each of these scenarios is then translated into a price increase and a price trajectory which would indicate the after-shock impacts on the price of oil. The petroleum price trajectories will be re-examined in relation to the level of petroleum inventories. The elasticity of price in relation to the level of inventories would depend on certain assumptions about the holding and release of inventories in other OECD countries. The economic cost of supply disruption will be assessed using a GNP elasticity of -1.0. Alternative elasticities should be tried to demonstrate the sensitivity of the results to this assumption.

For implementing the second approach, i.e., a "cost of outage" view of petroleum supply disruption, we propose the following methodology:

- assume the same five supply disruption scenarios but assess the impact on availability of oil imports to Japan;
- estimate the cost of petroleum shortage on a per barrel basis. The least complex, but perhaps too simplistic, method is to estimate the loss of production in the industrial sector due to unavailability of the required fuel. This loss would depend on the magnitude and the suddenness of the shortage. It will decline substantially if there is sufficient inventory to manage the shortage and to decline fuel consumption in a gradual manner.
- examine the cost of petroleum supply disruption in relation to various levels of inventory. The desirable level of petroleum inventory corresponds to a point at which long-run marginal cost of storage is equal to the marginal cost of petroleum shortage (Figure 5.1).



Environmental Impacts

Environmental impacts of energy production and consumption are well investigated and documented in the literature. A few observations relevant to our strategic analysis as follows:

- energy sector is a major source of damage to local, regional and global environment;
- within the energy sector, generation of electric power has the most significant impact on the local, regional and global environment;
- the main concern in regard to the local environmental impact is really the threat to human health caused by emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x) and small particulates (PM);
- the regional environmental impacts are also related to the emission of SO_2 and NO_x which are the primary contributors to acid rain;
- the global environmental impacts are related to the emissions of carbon dioxide (CO_2) and methane (CH_4), which are primary contributors to the enhanced greenhouse effect.
- there is normally a high degree of correlation among the emissions of SO_2, NO_x and CO_2. Thus, any attempt to reduce the global or regional environmental impacts will have some secondary benefits for the local environment. For example, a decision to switch from coal to natural gas normally reduces emissions of small particulates, SO_2, NO_x and CO_2, resulting in benefits to local, regional and global environments.

The first step in quantifying the emissions of SO_2, NO_x, PM and CO_2 involves an estimation of the amounts of these emissions which can be done relatively easily based on the contents of each fuel and the characteristics of the combustion process[2]. Thus it is possible to calculate the amount of each emission in tons/year for each mix of fossil fuels.

The second stage of assessing environmental impacts involves assignment of cost figures to each type of emission. There are two distinct approaches to arriving at such cost numbers. The first approach is based on the cost of incremental damages and the second is based on the marginal abatement cost. The cost of damage takes account of health and non-health effects. Both of these effects are measured in terms of loss of economic productivity. This approach is inherently inaccurate and controversial especially because it eventually depends on assigning some arbitrary value to human life.

The second approach, i.e., estimation of the marginal abatement cost, is more objective and is based on physical characteristics of fuels and energy conversion processes. However, the results can vary widely depending on the prevailing circumstances in a particular location. Furthermore, there is a synergy in abatement of various emissions, which complicates the use of the estimated abatement cost. For example, abatement of CO_2 often results in the abatement of SO_2, NO_x and particulates. This synergy is of great value in arriving at "win-win" solutions for energy-environment cooperation. However, the correlation is location and case specific and cannot be meaningfully translated into abatement costs of environmental impact at national regional and global levels.

Because of the above difficulties in assigning dollar values to various emissions, it is more useful to consider the emissions in terms of their original physical measures. Thus, the proposed methodology is based on:

- measurement of SO_2, NO_x, particulates, and CO_2 in tons/year;
- carrying out the trade off analysis based on a composite index of SO_2, NO_x and particulates;
- a re-examination of the analysis based on a composite index of SO_2, NO_x, particulates, and CO_2; and
- presentation of the short list of all the plans along with separate indications of the magnitude of each emission.

6. The Proposed Methodology

From the discussion of the previous sections, we arrive at the following conclusions:

Analysis of energy strategy should be carried out in a multi-objective framework so that the policy maker can explicitly consider the impact of his decision on each of the objective attributes such as cost of energy and environmental impact of energy consumption. As a case study, the analyst may integrate these attributes into one composite index to simplify the computation. But it is important to preserve the capability to analyze and demonstrate the impact of policies on each of the objective attributes separately.

Consideration of uncertainty and risk is essential in designing a country's energy strategy. The most important uncertainties relate to the international energy markets and environmental impacts of energy. Those uncertainties and their corresponding risks should be incorporated in the analysis of energy strategy.

Conventional methods of energy planning are very weak in handling both of the above considerations. These methods are often complex and capable of formulating detailed relationships involving energy demand and supply. But they are limited to a single-objective and deterministic framework.

A promising approach to dealing with both multi-objective and uncertain characteristics of energy strategy is the method of trade-off analysis. This method provides an organized and, systematic way to consider all possible outcomes, of policy decisions, exogenous factors, and uncertainty; then to eliminate the outcomes which do not matter, and finally to prepare a short-list of possibilities which should be considered by policy makers. The main drawback of this method is that the analysis may become difficult to manage if the number of attributes, the number of policy decisions, and the number of exogenous variables are large. The computational requirements will increase fast also with the number of optional magnitudes for each policy and exogenous variable. Thus, this method is not appropriate for conventional energy planning practices where one needs to deal with a large number of variables. But the method is suitable for the analysis of the global impacts and choices relating to a few strategic questions. This happens to fit the requirements for strategic analysis of energy and environment. In such analysis, the policy maker is primarily concerned with some global choices in the long-term fuel-mix. The detailed specification of the relationships does not yield much benefit. A relatively abstract model which concentrates on the strategic choices and the main sources of uncertainty would be sufficient.

We propose to use the trade-off analysis as our basic analytical tool to investigate the economic and environmental aspects of energy supply and consumption. In order to make the analysis manageable, we suggest the following model:

The objective attributes should include the cost of energy supply, the cost of supply-disruption, emissions of SO_2, NO_x, particulates and CO_2. These attributes should be then integrated into two indexes. An economic cost index measuring the sum of cost of energy supply and cost of supply disruption. This index is expressed in monetary units. The second index will be a measure of environmental damage representing the weighted average of all emissions.

Policy decisions should concentrate on two important strategic questions, i.e., the mix of fossil fuels, and the strategic petroleum reserves (SPR). The mix of fossil fuels can be studied within a limited number, say 10 to 15 alternative mixes of oil, gas and coal. The strategic petroleum reserves can be studied based on some 5 to 10 levels of SPR (SPR as percentage of annual petroleum consumption).

Exogenous factors should include growth in energy demand, international price of crude oil, availability of natural gas, and possibilities of oil supply disruption. The uncertainty regarding these factors would be expressed in the form of five scenarios for each factor.

Within the above framework, the analyst should construct a table of model input as depicted in Table 6.1. The model would then generate all the combinations. The corresponding values of each composite indexes (economic cost and environmental impact) are calculated for all combinations. Any combination which is inferior to others will be eliminated, to arrive at a short-list of plans which merit policy consideration. The process of preparing the short list is based on the two composite indexes. However, the short-list table should indicate the values of the components of each index as demonstrated in Table 6.2.

Table 6.1: Options Relating to Decision and Exogenous Variables

Mix of fossil fuels (oil/gas/coal) in 2010	Strategic petroleum reserves (% of annual consumption)	Growth in energy demand	International price of crude oil	Possibilities of oil supply disruption	Availability of natural gas in 2010
60/15/25 55/20/25 50/25/25 60/20/20 60/25/15 55/30/15	25% 30% 35% 40% 50% 60%	1% p.a. 2% p.a. 4% p.a.	15 $/bl 20 $/bl 25 $/bl 30 $/bl	case 0 case 1 case 2 case 3 case 4 case 5	Case 1 case 2 case 3

1/ Cases assumed here are (0) no disruption; (1) disruption from one Middle Eastern (ME) country for one month; (2) disruption from one ME country for six months; (3) disruption from one ME country for an unknown period of time; (4) disruption from the entire ME for one month; and (5) disruption from the entire ME for six months.

2/ Cases assumed here are: (1) up 100 bcm/year; (2) up to 150 bcm/year; and (3) up to 200 bcm/year.

Table 6.2: The Short-List of Plans for Presentation to Policy Makers

Plan	Decisions Fuel Mix SPR	Economic Cost Co Supply Disruption	Emission (Million tons/year) $S0_2$ NO_X PM CO_2

ENDNOTES

[1] Traditionally, the petroleum industry has carried inventories of crude oil and petroleum products to maintain the smooth functioning of its production and distribution systems. However, since 1970s petroleum stock building has taken two new forms -- speculative and pre-cautionary. Speculative stockpiling is a response to price fluctuations in the international oil market. Pre-cautionary stocks, more commonly called strategic reserves, are maintained to reduce the impact of disruptions in petroleum supplies. These stocks are under direct or indirect control of the governments. The implementation modality varies from country to country. But, generally, governments control this type of petroleum stocks by: (i) establishing strategic petroleum reserves (SPR) under government ownership and management; (ii) imposition of minimum mandatory stock levels that must be held by the private oil companies; and (iii) formation of public corporations that finance and manage the emergency reserve program.

The International Energy Program agreement, signed in 1974 by the OECD countries sets guidelines for member countries' level of petroleum stocks. The program currently requires the member countries to maintain stock levels, comprising strategic stocks and privately held inventories, equivalent to at least 90 days of the previous year's net imports.

OECD countries have taken different approaches to petroleum stockpiling. The United States has implemented only one program, the strategic reserve, which is owned and controlled by the US government. Japan holds two types of stocks: government stockpiling maintained by Japan National Oil Company (JNOC), and private sector mandatory stocks held by petroleum companies. The government stocks are equivalent to about 80 days and private stocks about 70 days of petroleum consumption.

[2] Methane emission has a significant impact, on a per unit basis, on the global environment. It is normally due to venting and leakage of natural gas and coal mining. However, the corresponding remedies are of medium-term nature and addressed in the context of efficiency improvement policies rather than long-term strategic decisions.