A METHODOLOGY FOR DECISION MAKING APPLIED TO NEW AND RENEWABLE ENERGY TECHNOLOGIES IN INDIA

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(ABSTRACT)

The increasing awareness of the need to look for new and renewable sources of energy to replace the depleting fossil-based resources has given rise to research in several prospective areas. While hydro power and bio energy has been with us long now, success and commercial viability is being achieved in solar energy applications. Similar trends are visible in wind energy. Long term potential for geothermal energy, sea power and fuel cells appear bright and they need to be vigorously looked into. This study looks at a decision making tool, Analytic Hierarchy Process -AHP- as a means of developing a methodology for exploring the feasibility of introducing new and renewable energy technologies in the Indian energy sector. AHP uses the hierarchical structure of a problem to elicit from a panel of experts, an opinion that is then used to derive composite opinions. The consistency of such opinions is monitored and those opinions that display a level of inconsistency above an acceptable threshold are rejected and modification requested. AHP has been tested and proved successful, in several other similar applications around the world and proves itself a good tool here too. A software package for its implementation had been developed earlier and is suitably modified to meet the objectives of this study.

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1.0 INTRODUCTION

Energy is a critical factor of production in addition to land, labor and capital. With rapid depletion of fosssil-fuels more and more countries are beginning to realize the need to explore energy options other than fossil-based ones. A vigorous informed effort is therefore needed to promote New and Renewable Sources of Energy (like Hydro, Solar, Wind, Bio etc), wherever feasible, especially in the energy futures of developing countries where every contribution is critical. Since the 1981 UN Conference in Nairobi on NARSE (New and Renewable Sources of Energy), and as a result of extensive studies and field trials, much useful experience has been gained and we are in a much better position today than 1981 to express well founded opinions about the viability of various NARSE technologies and to assess their prospects for the future.

Of significance is also the fact that energy planning, at the national level, is now receiving increasing attention in many developing countries. Energy models have proliferated. The optimal allocation of a set of resources to a given mix of demands in order to maximize certain economic or social objectives is a complex problem involving trade-offs between various impacts: political, environmental, economic, etc. In the case of India, political and social reasons can often dictate policies to extents that make them significant. Our goal is then to develop an appropriate methodology and tool, which can incorporate or capture as many of the policy variables as are necessary which impact significantly on the planning process.

1.1 Background Information

Several papers have addressed various aspects of energy planning in developing countries with emphasis on renewable sources of energy.

Ramakumar[1] examines the role of renewable energy sources in meeting energy demands in developing countries.

An approach proposed by Rahman[5] shows how to devise a hierarchical structure for energy system modelling into which task oriented models can be integrated. This paper also examines the use of AHP to decompose long range energy planning into various levels of hierarchy and quantify the impact of various components on the overall decision making process.

The India National Paper[4] at a conference in Nairobi reports on the new and renewable sources of energy in India, constraints on the utilization of such energy sources and national plans, and elements of action programs for their development. This paper clearly points to the fact that energy planning is a hierarchical multi-level process.

An IEEE(1980)[2] Committee report by Cronin and Watchorn talks about the assumptions built into electric utility planning techniques and models.

Rahman[3] discusses uncertainties associated with electric utility planning and analyses different methods that can be utilized for planning with poorly defined parameters. He also clearly demonstrates the applicability the Analytic Hierarchy Process (AHP) developed by T. Saaty[10], for decision making in problems involving multiple objectives that may be ill-defined & subject to uncertainty.

The present study develops a methodology that utilizes the hierarchical structure in Energy planning. Traditional energy planning problems have usually considered a single high priority objective such as minimizing cost, maximizing availability or ensuring reliability. Of late, a newer approach has gained importance. It entails elevating earlier low priority objectives like socio-economic side effects to a much greater importance. Of principal concern here will be the development of a method for relating the objectives of a number of policy making interests. This will be primarily concerned with large scale, long range energy planning problems facing India with specific reference to NARSE.

Planning in energy systems is a special case of the general planning problem. It is important that such planning efforts encompass a wide range of issues: technological, environmental, social etc. The revolutionary change in energy problems in recent years has centered around the impact that a particular technology has had on related economic, environmental and other earlier low priority factors. NARSE is a transformation in technology and adoption of any alternative is contingent upon satisfying a number of tests of feasibility which include scientific, environmental, technological, economic and societal.

Earlier very few energy planning models were equipped to tackle problems where secondary objectives were placed on par with the primary ones. The 1973 Oil crisis widened this chasm between energy planning problems and planning tools when the economic competitive position of oil was upset. As a result, since 1973 energy planning has emerged as multi-objective, ill-defined (parameter) problem where a variety of energy, economic and environmental trade-offs must be examined. Now, instead of an overall, all-consuming objective, we have a collection of individual actor objectives. The problem then is to structure this collection of actor interests to reveal all relationships, including subtle ones and create a framework, formulated from basic hierarchical concepts that will serve to interrelate the individual objectives of policy making interests as well as compose their collective objectives.

1.2 Why NARSE ?

The oil price hike in the 70's opened the eyes of the world to the grim realities of energy supply and provided the spark to seriously look into the various possible alternatives available to fossil-based fuels. The third world countries who were the worst hit need these alternatives more than the developed world. Amongst the developing countries India has been in the forefront of this search. Other factors that have contributed to India's search for renewable energy sources have been :

- Uncertainties in supplies of fossil-fuels, especially oil.
- Difficulty in producing and transporting increasing amounts of fossils fuels.
- Depletion of her reserves.
- Environmental degradation caused by conventional fuels.
- They contribute to self-sufficiency, which has been a corner stone of Indian development plans.

1.2.1 Alternative energy sources.

The major alternative and renewable energy sources that are of significance to India include:

1. Hydro Power
2. Solar Energy
3. Bio Energy
4. Wind Energy
5. Ocean Power (Tidal, Wave and OTEC[1])
6. Geothermal
7. Fuel Cells.

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[1] Ocean Thermal Energy Conversion

Some of these alternatives have certain features that make them more desirable than the others, and certain features that make them inferior to the other alternatives. For example, while hydro is perhaps the most economic of these it is capital intensive, has long gestation periods and causes major upheavals in local populations. Then there is wind energy which is based on simple ideas but is very site specific. Solar energy looks so promising in so many ways but the price needs to come down further if it is to be a serious rival to fossil based fuels.

So basically India cannot blindly grab any of these options nor all of them. What are the factors that her planners have to weigh in their minds when evaluating the options they face ? What approach should they adopt when tackling such a wide range of options with seemingly myriad uncertainties which, on the face of it, seem beyond being quanitified. In energy planning as in electric utility planning diverse factors need to be considered . Among these there are several which can be quantified but again several which cannot. Another significant fact is that in LDCs[2] the lack of data causes problems in quanitifying relationships. So we need to elicit expert opinions in place of hard and factual data. Efforts so far to quantify the latter kind have yielded different methodologies and a lack of unanimity. Perhaps the reason for this is the breadth and diversity of the uncertainties associated with these factors. Often these assumptions are unstated and the user may not be aware of these implied assumptions and hence be unaware of the need to quantify them.

1.3 Uncertainties

Among the uncertainties facing energy planning in India, the following are the most important:

1. Electricity Demand Uncertainty

    - Demand growth is a complex function of several variables.

[2] Lesser Developed Countries

- Price of electricity and prices of fuel substitutes for electricity.
- Success in conservation strategies.

2. Electricity Supply Uncertainty

- Future availability and price of oil.
- Environmental limitations on the use of coal.
- Public acceptance of nuclear energy and alternative energy sources.
- In alternative energy development uncertainties include -
  - When a technology will become commercial?
  - Research, developments and breakthroughs.
  - How much energy can be supplied and at what cost ?

3. Regulatory/Political Uncertainty -

- Possible changes in State and Central Government rates for electricity/fuels and environmental standards.
- Political uncertainties offer bizarre scenarios in India. Different ruling parties will have different energy policies and outlooks and they can be poles apart. Also political compulsions often result in unexpected decisions being taken (for example in certain constituencies[3] , or at certain times like an election year). Even the change of leadership from Mrs. Indira Gandhi to Mr. Rajiv Gandhi (though from the same political party) has ushered in sweeping changes in vital sectors.

4. Event Uncertainty -

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[3] Electoral district

Unpredictable events can occur, having significant impacts on an energy plan. There is the 1973 oil embargo and the dramatic oil price rise and the current Oil price crash followed by bickering among OPEC members. The 1979 Iranian oil crisis, the Iran-Iraq war, the nuclear accidents at Three-Mile and Chernobyl, the assassination of Mrs. Indira Gandhi are recent examples of such events.

At the other end of the scale are uncertainties which don't sound too major now, say for example the impact of active solar technology on human health and the environment.

1.4 Methodologies considered

Several techniques in decision theory present themselves to be applied to this problem. Of these the most popular ones are the Delphi technique and the Fuzzy Set theory.

The Delphi Method is one in which a panel in which opinions are solicited under controlled conditions. The group is controlled in such a away that bandwagon effects, personality influences, repression, social group pressures and specious persuasion are minimized. This is done by insulating the members of the panel, from each other, so that opinions and identities remain anonymous. The opinions and judgements are then polled through repeated rounds or solicitations. In most cases, if consensus does not occur within four or five rounds, then the method has failed. The Delphi is thus a method for the systematic solicitation of informed opinions. This method replaces direct debate with indirect anonymity. This controlled exchange of information stimulates the participants to consider opinions, reasons and information they might otherwise ignore. But, the Delphi method might fail where the participants need face-to-face contact or need to question each other in depth. The Delphi can also be faulted in that it does not allow group spontaneity and creative interaction. Also, it is the control group (that is managing the decision making process) and not the experts, who decide on the variables of interest and the context of presentation.

The Fuzzy set theory was introduced by Zadeh, in 1968 and has since proved useful for dealing with certain types of "fuzziness" or imprecision in decision analysis. For example the set of all green objects has a certain "fuzziness" associated with it. Rahman[3] notes that proponents of this theory claim that the fuzzy model maximizes the information about such processes and would consequently optimize one's ability to utilize such a technique as a decision making guide.

A technique has received wide attention in the field of energy planning and uncertainty evaluation over the last several years. This technique is called the Analytic Hierarchy Process or AHP and will be used in this study. It has proved very successful in planning problems involving multiple objectives that are characterized by poor definition and uncertainty. It operates using pairwise comparison judgements to consider factors not effectively quantified. Consultation with expert(s) is a key factor here. Their judgement guides the entire process. If the experts are consistent it is assumed that they are right. One can be wrong and consistent. But we do not expect several experts to be wrong **and** consistent. The process yields a calibrated ranking of various options and of the factors, actors, etc. that impinge on the decision making process. A detailed study of AHP follows in Chapter 3, with examples.

In Chapter two, a survey of the energy situation in India has been made. The sources of meeting energy demands now have been examined and the potential for the future with NARSE, explored. A look is also taken at the role of decision making interests and factors that govern them.

Chapter four outlines the application of AHP to this study. It also includes an analysis which sets up our base case which then forms the basis for the case studies in Chapter five.

A summary and conclusion of our study is presented in Chapter six.

2.0 THE ENERGY SCENE IN INDIA

Over-optimism about technological development appears to be a hallmark of energy conferences. While the first conference on NARSE[4], 20 years before the 1981 conference in Nairobi, presented a largely optimistic and conflict-free picture for solar and wind energy, that really did not materialize. However, after the oil crisis in 1973, industrialized countries have expanded their development efforts in renewable energy and substantial technical progress has been made. These efforts can well expand, as regards third world applications, as new markets for energy technologies become available there. For India, as in other third world countries the problem is to screen, select, adapt and manage emerging energy technologies.

A certain flexibility needs to be used to achieve progress with NARSE. Fuel and technologies need to be matched to the task; which means NARSE and conventional energy must be seen complementary to each other. Energy plans in India seem to recognize the fact that neither of them can solve the problems of rural energy development on their own. In all candor, it is important to see that NARSE is no panacea to India's energy crunch and will not make a spectacular contribution to the total energy requirements in a short term. NARSE can have a substantial strategic and catalytic impact on development where the right combination of supply and demand is present, say for e.g: agricultural residues as fuel for agricultural processing industries. In many cases therefore NARSE can accelerate economic growth and make possible many new ways to energize agricultural and industrial development.

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[4] New and Renewable sources of Energy

2.1 Conventional energy sources.

In India, conventional sources provide about 60%[7] of the national energy available for consumption. They comprise of:

1. Coal - It is the most abundant source of commercial energy in India today. It serves as the most important energy source in all sectors of the economy, except agriculture. Due the location of the coal mines, coal has to be transported over long distances. India's coal reserves are estimated at 85,000 million tonnes while her coal consumption has placed at 103 million tonnes per annum (in 1979) inclusive of coal used for power generation.

2. Lignite - Although inferior in calorific value, it is of particular importance to the southern region of India, due to geographical location the deposit and the scarcity of coal resources in this region. The production of lignite was placed at 124 million tonnes in 1981-82[7].

3. Oil - An important and versatile fuel used in all sectors of the economy for a host of purposes. Besides being a key energy source, oil also acts as an important raw material for the production of petrochemicals and fertilizers. Over 80%[5] of the total oil used as an energy source is consumed in two sectors - household and transport. Agricultural consumption of oil (running tractors and irrigation pumps) is also rising. By 1981-82 India was targeted to have been able to meet 50% of her oil requirements[6].

4. Nuclear Energy - Relatively a small contributor but growing, and has pretty good prospects especially due to India's ability to build nuclear plants, and availability of fuel (Uranium). A fast breeder reactor has already gone into operation at Kalpakkam near Madras India's indicated reserves of Uranium amount to about 67,000 tonnes, in addition 10,000 tonnes of U_3O_8 & 360,000 tonnes of Thorium Oxide.

Statistics of early 80s indicate that commercial fuels (coal, oil, electricity) fulfilled 56.5% of energy requirements[4].

2.2 Renewable energy sources

The main sources of renewable energy, of importance to India, are:

1. Hydro Power - It constitutes the cheapest source of power. It is the most important commercial renewable energy and its ancillary effect includes the conservation of fossil fuels due to its regenerative capacity. It is capable of meeting the large scale energy requirements of different sectors of the economy. In 1980, hydroelectricity accounted for 11,791 MW of the installed capacity of around 31,000 MW (38.03%)[5]. By 2001, it is still expected to account for 37%. The total hydroelectric potential in the country is presently estimated at 75,400 MW at 60% load factor and only 11% of this potential has been developed so far!! However, the capital intensive nature of hydroprojects and their long gestation periods are impediments in their efficient and rapid exploitation.

   The net social impact at the local level of such power plants may be significant especially if small-scale hydro power development serves as an economic and social catalyst for more extensive economic development. Presently there are 103 micro/small hydroelectric schemes under operation which accounts for an aggregate installed capacity of 150 MW[11].

Large scale hydro power necessitates the building of dams for a reservoir. It is a technology which visibly alters the face of a landscape. The human problems created are sometimes compounded by a number of environmental problems.

2. Solar Energy - India gets a significant level of solar radiation over wide areas for a major part of the year because of its favorable geographical location. Systematic efforts or research and development of solar energy have been initiated to tap this valuable renewable energy source which poses no problems for the environment. It has widespread applications many of which include replacement of conventional fuels. Solar energy is already a serious option with numerous applications at or near commercial feasibility. Prominent among these include cooking, water heating, water desalination, space heating, crop drying refrigeration etc. Most of these applications utilize photovoltaic cells (PV).

3. Bioenergy - This refers to energy obtained from various biological systems. This chiefly includes :

    a. Biogas - India has been playing a pioneering role in this field. Biogas is produced mainly from cow dung [5], night soil, poultry droppings, pig manure, etc. Biogas is used as a fuel in cooking, lighting, running diesel engines and for generation of electricity. It has several other physical and social positive side effects. Raw material for biogas- cow dung, poultry droppings, pig manure and night soil - are freely available. There are over 80,000 gobar gas (or cow dung) plants in India[5]. A by-product of biogas is valuable enriched fertilizer. A program is being implemented for spread of larg-size community biogas plants (CBP) each of which is targeted to meet the fuel needs of 25 families[11].

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[5] Animal waste

During 1976-83 more than 100,000 gobar gas plants had been targeted for set up and about 75,000 biogas units were identified in 1982-83. Between 1983 and 1986 the Khadi and Village Industries Commission (KVIC) proposed to set up 1000 community biogas plants while the target in the 6th Plan was 400,000.[7].

b. Bioconversion and biomass - The use of agricultural ,forestry and municipal wastes, growing plants for fuel and other methods of extracting solar energy from organic matter is bioconversion and is a potentially significant source. Biomass can be defined as all types of animal and plant material which can be converted into energy. It could involve the production of fuels and chemicals from agricultural residues, e.g: Ethanol. Firewood and agricultural wastes constitute important fuels particularly in rural areas. An idea is to use selected plant species on a short rotation system enabling harvest of biomass atleast once every 2 years for conversion into fuels.

Of the total energy requirements firewood supplied 22.5%, dung cakes 11.2% and agricultural wastes around 8.7% (1980 figures).

4. Wind Energy - can be used for pumping and power generation. The applications include units of the stand-alone variety e.g: water pumping mills, or on larger scale as in wind farms. In areas with high wind speeds (in excess of 6 m/sec) a possible application is for integrating into a larger electric power grid through a series of wind farms.

Research on wind mills is being carried out chiefly at the Central Power Research Institute, Indian Institute of Science, Indian Institute of Technology (Madras) and BHEL. In 1982-83 the Government of Madhya Pradesh[6] installed close to 30 wind mills[6]. Under a demonstration program, 575 windmills have been installed in the country for water water pumping purposes and several more of different types are being planned[11].

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[6] A State in the Indian Union

5. Draught Animal Power - Animal energy is a significant source of energy in applications like agriculture and transportation. This is more important in rural areas. It is estimated that over 80 million work animals in India supply more than 40 million horse power[5].

6. Ocean Power (Tidal, wave and OTEC) - Tidal energy is extremely site specific, requiring mean tidal differences of greater than 4 m and also favorable topographic conditions, such as estuaries or certain types of bays, in order to be economically viable.

   Wave energy is still in the research stage and being developed. OTEC (Ocean Thermal Energy Conversion) is a method of using solar energy in the oceans, that is stored as temperature differences. However, in practice, the potential seems severely limited by the problem of finding suitable sites which are reasonably close to load centers. Other problems include the high capital costs of the large piping units required to pump cold deep water up to the warmer surface layers, and the low efficiency of the turbines due to small temperature differences.

   Ocean Thermal Energy Conversion (OTEC) exploits the temperature gradient between warm surface water and cold deep water to operate turbines which drive electric generators. Although, a very old concept it is still in an experimental stage. Full scale demonstrational plants will not be operable until 1988 and optimistic forecasts expect commercialization by 1995.

7. Fuel Cells - The fuel cell indigenously converts the chemical energy in the fuel (like Natural gas) directly into electricity. It has tremendous advantages in that it is a quiet, pollution-free, efficient source of power. It possesses an overall fuel utilization efficiency of between 70% and 80%. It's greater spread will help conservation of fossil fuels. Besides it offers fast and simple construction and can be run on almost any fuel-Naptha, Methanol and Natural Gas being most commonly used.

8. Geothermal Energy - The current technology for geothermal energy uses natural steam. While this is economically competitive, the resource base is limited since it requires the relatively rare geologic combination of hot rocks, an underground water system & an impermeable caprock for trapping the steam and providing pressure. Such energy has been found to be more concentrated in volcanic regions.

Analysts claim that it could be possible to replace the entire diesel oil required for water pumping and rural industry by renewable sources by 2000 A.D. Likewise 50% of the petroleum products required for household and transport sectors, 25% of the fuel oil and 20% of coal normally used for low and medium temperature heating can be replaced by NARSE alternatives[5].

2.3 Policy making interests

There are three key decision-influencing players that will govern the spread of NARSE technologies in India. They are :

1. The Government.

2. Research Organizations.

3. Overseas Donors.

Let's have a closer look at their relative positions on this

2.3.1 Government

Two major factors face government energy planners in India :

- It is clear that energy consumption must continue to grow if development is to proceed and if poverty and deprivation, especially in rural areas, are to be alleviated.
- It is also evident that traditional and conventional approaches to energy supply have a limited future and need to be re-evaluated to ensure short-term survival and establish long-term energy viability.

Policies for the development of effective energy technologies must take into account the wider economic, social and cultural context. For example, using the industrialized nations' solution to the energy demand in the 20th century - high grade energy and highly centralized systems - tend to create very few new job opportunities and require many years to complete. The immediate need is for access to cheap, more autonomous sources of energy supply maintained by skills and materials locally available, and limited dependence on costly imports and sophisticated technologies.

A major emphasis so far, has been on making conventional or traditional energy available rather than introducing schemes and equipment to harness renewable energies for rural areas. There are several reasons for this;

1. It is easier to attract and allocate investments for conventional fuels since the energy contribution of some of the renewable energy choices is often uncertain.
2. Renewable energy spells more expense in terms of newer equipment and trained technicians.

The current slackening of the oil market certainly makes oil more affordable and thus many renewable energy projects less interesting in the short term. NARSE presents factors for economic development, but this can also lead to a creation of a substantial diversity of end-use demands which will cause these alternatives to enjoy widespread diffusion. Indian planners have begun to take notice of NARSE. In the Sixth Plan (1980-85) they had allocated close to 116 million US Dollars for its development (1/45th of the outlay for petroleum exploration or 1/24th of the outlay for coal)[7].

About 31 million US Dollars had been allocated for research, development and demonstration programs in the 6th Plan period (1980-85), in addition to about 7.7 million US dollars for MHD.[7] A separate allocation of 38.5 million US Dollars has been made for schemes on fuel and farm forestry. The Plan also provides for 38.5 million US dollars to be spent on subsidies and supporting facilities for establishment of family biogas plants[7]. Two important steps taken by the Indian Government include the formation of the Commission for Additional Sources of Energy (CASE) in early 1981 and a National Bio-technology Board. CASE would be responsible for formulating policies and programs for the development of new and renewable sources of energy, coordinating and intensifying research and taking conscious steps for commercial exploitation of the technologies already developed or being developed and ensuring the implementation of the government's policies in this regard. The National Bio-Technology Board would concern itself with genetic engineering in relation to agriculture, medicine, energy and industry.

So, obviously the Government of India is interested in viable energy options. Their requirements are that this be cost-effective, show quick results and be part of an integrated plan with long-term potential.

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[7] Magnetohydrodynamic Power Generation

2.3.2 Research organizations

In all nearly 70 organizations, government or private, are involved in research design and development of NARSE related technology and equipment A number of institutions have contributed to the development of solar energy and its utilization in India. The key ones have been Indian Space Research Organization (ISRO), Bhabha Atomic Research Center (BARC), Solid State Physics Laboratory and Central Electronics Ltd. (CEL). Their major role has been in the development of photovoltaic technology. Among these, CEL has done pioneering work and their solar-panels are in wide use where PVs are used.

BHEL (Bharat Heavy Electricals Limited) is also an important performer here. It has begun manufacturing 'space grade' solar cells for ISRO and by 1990 would have supplied ISRO with 100,000 PV cells[7]. BHEL has also signed a contract with United Energy Corporation of California for the manufacture of PV cells. CEL has also produced 'space grade' solar cells for use in solar modules of Rohini.[8]

These organizations should be obviously very keen in such developments as those which provide them an opportunity to utilize scientific potential towards applications that are of immediate relevance to India. This field is one with immense prospects for third world researchers. Having missed out on several revolutions (Industrial, electronic, computer, etc.) this is one area where they could work at par with their counterparts in the industrialized countries, since neither sophisticated technology nor complex hardware is needed. In fact even in developed countries a lot of work in this field is being done by scientists from developing countries.

[8] An Indian satellite series name

2.3.3 Overseas donors

International aid agencies have a crucial role to play in screening, selecting, adapting and managing emerging technologies . Overseas aid programs traditionally give priority to the more prestigious large-scale constructions. Besides, aid donors find it difficult to to retain accountability when their funds and resources are deployed over wide sectors of the population in small amounts. Organizations like World Bank and UN agencies are themselves highly centralized institutions and this unconsciously reflects in the aid-administering bodies and schemes they set up. Also, they have their obligations to investors whose wealth is frequently derived from the export of high-technology and equipment to the growing markets in the third world. So their schemes will not always have the benefit of a third world country in mind.

This is not to underplay their role however. "Energy Aid" has certainly helped. Various international agencies are playing a vital role. Bilateral aid from industrialized countries is contributing to improving the energy situation in LDCs.[9]

The US Government provided 3.5 million US dollars to India for alternative energy resources development in four major areas[7].

- Biomass production and conversion.
- Coal conversion.
- Energy efficiency
- Information exchange in new and renewable energies.

[9] Lesser Developed Countries

UNDP[10] provided 1.68 million US dollars for tidal power development in the Gulf of Kutch, in Gujarat[11], with the aid of experts from France[7]. Key areas that foreign aid could help in are:

1. Survey of energy resources.
2. Demonstration projects, research and technology development.
3. Information exchange networks.
4. Manpower development, including training programs, exchange of technical personnel, seminars and workshops.

Overseas donors provide much needed capital for the implementation of plans which will bear fruit over a long period of time. These plans otherwise involve expenditure of a magnitude India could ill-afford. That is the crux of the problem in developing countries like India. They lack financial resources to implement plans that will stand them in good stead in the long run. But no country or organization is going to play the good samaritan. All aid will have strings attached and India should look for the middle ground which will help them, to satisfy the donors while retaining her independence. Foreign assistance is absolutely vital. In the age we live in neither the developed nor the developing countries can follow an isolationist course.

2.4 Other factors

Let us also have a quick glance at other subtle but important factors that certainly have a bearing here.

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[10] United Nations Development Program

[11] An Indian state

2.4.1 Incentives

In terms of incentives, the government grants an enhanced depreciation allowance at 30% on machinery or plant installed, exemption of excise duty and access to bank loans. The Union Government[12] proposes to set up one unit of renewable sources of energy in each district, with a pronounced preference for solar energy. Most of the state governments have already set up biogas cells to provide technical guidance, bank loans and cement[7]. There are also schemes for providing subsidies, and loans to prospective owners of biogas plants.

Incentives will play a very important role if the initial spread of these technologies is to be as widespread as is planned. An indication to this effect would however be needed at this stage so that owners of capital feel sufficiently confident to invest it.

2.4.2 Social changes

Changes in social patterns are certainly an important factor. The effect of renewable energy technologies on them are important.

Take solar cooking for example, there is the task of persuading potential users to adopt different habits such as eating the main meal at mid-day and cooking in open air to utilize solar radiation. These factors may represent a major obstacle for communities that work in the fields during the day or in areas where hospitality to beggars and strangers is a compulsory religious requirement.

In the Indian society caste systems and social conventions can also be a severe problem. For example even with small family biogas plants, there may be adverse side effects such as accentuating the gulf between those who own animals to provide the wastes and the very

[12] Indian Federal Government

poor. This could also lead to the monetization of cow dung which could then no longer be collected and used by landless peasants.

There are several positive effects too. For example biogas helps improve sanitary conditions, checks environmental pollution, improves health condition of rural women and reduced drudgery. Another very important side effect is that it can also help arresting the denudation of forests. Wind patterns in some areas may however, require changes in agricultural cropping patterns. So, basically problems like this that arise out of a mismatch of traditional practices with the availability of renewable resources need to be smoothened out.

Public participation in the energy debate is essential if discontent and violence are to be avoided. Investment in expensive energy options involving potential health and safety hazards to the community should be subject to public scrutiny at regional and/or national level to ascertain public acceptance.

2.4.3 Indeginization

This refers to the utilization of local material, labor etc. Much of the impetus for the development of indigenous resources stems from a societal desire to achieve self-sufficiency in energy production in order to avoid rising prices of imported energy.

It is not really economic to use international consultancy firms to carry out feasibility studies, design and contract supervision. It is always better for planning to be done local people who know specifics about local conditions and potential users. Also capital costs will be kept down by using designs that use local materials and labor as much as possible.

To minimize risk, a politically inspired energy policy should, as far as possible, support a diversification of energy sources so as not to place an undue reliance on any one supply source.

Energy autonomy is greatly strengthened by diversifying supply sources as far as is expedient, and relying to the least possible extent on imported fuels.

Renewable energy devices or pieces of equipment need to be matched to the requirements and opportunities of a particular situation or community in order to be effective. Wherever possible it would be better for them to be manufactured locally, not only for political and economic reasons, but also to increase acceptability and understanding of such applications at that level.

One way would be forming networks of local energy agencies with adequately trained personnel to cause dissemination of renewable energy equipment for local energy systems. They should be based on a diversification of indigenous energy supplies so as not to be dependent on any one. Education in energy use and conservation should be widespread. India needs to avoid the expensive mistakes made by the energy-squandering industrial countries during their evolution.

2.4.4 Energy and development

At times it is argued that building of large centralized energy-supply systems (e.g:- oil terminals, nuclear reactors) will provide significant employment opportunities and is therefore a persuasive reason for investing in such schemes. However, it must also be kept in mind that such employment opportunities are of a temporary nature and bring with them problems like social dislocation. Once the project is over this artificial community will collapse leading to further unemployment and and migration. There will also be unnecessary delays in completion of such projects and a rise in its cost.

In a setting like India's where energy is scarce and labor, cheap and plentiful, energy policy makers may find it more advantageous to shift to an emphasis on decentralization and smaller more-local energy systems until a more tenable balance is achieved.

2.4.5 Reducing dependence on imported oil

The use of oil in India is on an extremely essential basis, with most of it restricted to vital needs of development. Around 60% of the crude oil requirements are met through imports which have been absorbing about two-thirds of the country's earnings of foreign exchange[9]. The saving in foreign exchange can be tremendous, as the above facts reveal. A portion of this money thus freed could be ploughed back into NARSE research, development and commercial exploitation.

2.5 Other influences

- One of the most important constraints in the wider utilization of renewable energy systems is the high initial capital cost. The low level of production on account of this inhibits any cost reduction that may be achieved through a large volume of production.
- A vast infrastructure for manufacture, distribution, supplies, maintenance, servicing, etc. is needed. In India such a set up is just coming up. However, the inadequacy of institutional framework exists [13] and it needs to be taken care of.
- The spread of modern renewable technology may be also limited by high illiteracy and the religious, social and cultural barriers that divide a vast majority of people amongst themselves. But, if an economic necessity like this can help cause these kinds of barriers to crumble then renewable energies would have played a major social role themselves!!

[13] as was seen in the case of Biogas

3.0 THE APPROACH

In real-life situations, much of decision making has to take place in environments in which the goals, the constraints and consequences of possible actions are not known precisely. Decision analysis deals with the problem of uncertainty in a variety of forms. There is need for mathematical tools to represent uncertainty adequately without changing the problem or "corrupting" it in anyway.

The imprecision in decision analysis can manifest itself either as fuzziness or randomness. Fuzziness is a major source of imprecision in many decision processes. Fuzziness is distinct from randomness. Randomness is an arbitrariness among clear cut options whereas "Fuzziness" is "vagueness" - a central feature of human perception. It is a well known fact that it is virtually impossible to give an exact description of any real physical situation; needless to say this holds also for managerial problems. As systems increase in complexity, it becomes increasingly difficult to make mathematical statements about them which are both meaningful and precise. Probability theory has been a major tool so far. However, the fundamental inadequacy of conventional theories -functions, sets, probability measures- began to be felt. Whereas probability theory handles randomness, fuzzy set theory enables the handling of fuzziness. Thus, fuzzy set theory is a tool for handling uncertainty, imprecision and vagueness, without undue simplifications. It enables us to structure and describe activities and observations which differ from each other only vaguely, to formulate them into models and use it in decision making. Fuzzy sets are very simply defined as a class of elements in which there is no *sharp* transition from membership to non-membership. Before talking more about its application to decision analysis, let us take a look at what a Fuzzy set is.

3.1 Fuzzy sets

The Fuzzy Set theory was introduced by L. A. Zadeh in 1968. Classical set theory is governed by a two-valued logic. A proposition is either TRUE or FALSE. In real decision situations, we often deal with propositions that need not be simply true or false, but which can be true to any degree. Unlike the mathematical concept of a set, most classes in the real world do not have crisp boundaries that separate those that belong to the class from those that do not.

In Fuzzy set theory, an element has a degree of membership. This is usually taken to be in the interval [0,1]. Consider the fuzzy set "rich". The elements are the men and the degree depends on their wealth. A man with $1000 may have a degree 0, and one with $100,000 might have degree 1. So a possible representation of the set and the degree of membership could be:

WEALTH (Thousand dollars)	DEGREE OF MEMBERSHIP
1	0.0
10	0.12
25	0.25
50	0.60
90	0.85
100	1.00

We do not formally, deal with fuzzy sets, but fuzzy subsets of a given set. A fuzzy subset of S is a function from S into [0,1].

That is $f : U \rightarrow [0,1]$

On the set of all fuzzy subsets defined on the universe U, the following operations are defined:

UNION

(f OR g) (x) = max (f(x),g(x)), ie, the maximum of the two.

INTERSECTION

(f AND g)(x) = min (f(x),g(x)), ie,: minimum of the two.

Other properties that follow from these are: commutativity, associativity, distributivity, de Morgan's laws and identity. These definitions are extensions of the definitions for ordinary sets.

There needs to be made one more qualification that is characteristic of Fuzzy sets. Now, the term *big* defines a fuzzy set of objects not because the size of any one of them varies each time it is examined but because the there are cases that give rise to a doubt: Does a borderline case belong to the set or not? A significant part of the application of fuzzy set theory in decision analysis arises through the interpretation of some forms of "imprecise" statements as placing a *possibilistic* restriction on the class of events which satisfy that statement. This restriction is then represented through a set with graded membership such that any event has a *degree of membership* in the set defining the extent to which it is consistent with the possibilistic restriction.

3.2 Application to decision making

Decision making involves appraisal of alternatives. A systematic approach would require the beginning to be made with problem structuring. There is always a range of objectives, goals or options to choose from. Frequently, some can be seen as contributing to the others. For this purpose, the hierarchical organization of these sets of items so as to help the Decision Maker (DM) take the decision, has proved to be suitable . An item higher up in the hierarchy is simply an abstraction or generalization of those below it. The structural complexity of social, economic and other multi-purpose policies frequently involves selection between alternative proposed projects which are evaluated with respect to a hierarchical system of objectives. In addition, a proportion of the objectives may be axiological in nature so much of the information will be ill-defined and inexact. The problem then is to quantify this information. In the hierarchy, the higher level accrues value through the lower levels. Links between all stages of the hierarchy, can be represented as cross-interaction matrices, between adjacent levels. The hierarchy as a whole, functions as a filter through which various proposals may be evaluated in terms of different attributes like worth, cost, risk, etc.

3.3 An implementation

Saaty[10] has presented the Analytic Hierarchy Process (AHP) as a method for tackling decision problems involving uncertainty. AHP can be thought of as a method that imparts meaning and structure to problems that involve fuzziness. A multi-criteria and ill-defined problem is handled as a system of properties which are decomposed into levels. Fuzziness is handled by structuring a hierarchy so that one can determine a course of action.

3.4 What is AHP?

The diverse factors that one encounters in electric energy planning are usually given a quantitative weight without sufficient justification. The Analytic Hierarchy Process (AHP) presents itself as a valuable tool that could help examine the mutual dependence of various factors that lead to a decision. AHP has been applied to the multi-criteria decision making process subject to uncertainty in several areas like energy planning and transportation studies. The applicability and potential of the Analytic Hierarchy Process for electric energy planning has been investigated by Rahman[3]. There, it has been demonstrated that the proper application of AHP can result in a methodology that energy planners may employ when faced with decision making on problems involving multiple objectives that may be ill-defined and subject to uncertainty. This technique allows for consideration of many parameters of concern, that do not lend themselves to quantification. Examples may be political, financial, social and environmental aspects of generation expansion planning expansion by a utility or the evaluation of NARSE [14] alternatives and their impact as our goal is here.

Basically the AHP is a systematic procedure for representing the elements of any problem, hierarchically. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and guides decision makers through a series of pairwise comparison judgements (which are documented and can be re-examined) to express the relative strength or intensity of impact of the elements of the hierarchy. These judgements are translated into numbers. The AHP includes procedures and principles used to synthesize the many judgements to derive priorities among criteria and subsequently for alternative solutions.

3.5 The principle of identity and decomposition

This calls for structuring problems, hierarchically which is the first step taken when using AHP. Of the various types of hierarchies the Dominance Hierarchy is the simplest.[15] and descends like an inverted tree.

3.5.1 How to structure the hierarchy

The hierarchical portrayal of a problem is best illustrated by a simple example. Consider a modification of the one used by Rahman[3].

---

[14] New and Renewable Sources of Energy

[15] This theory has been generalized for other hierarchical forms.

FOCUS

Future electric load growth in Bangladesh

FACTORS

Cost	Reliability	Environment	Conservation

ACTORS

Consumers	Donors	Research bodies	Govt.	Industry

CONTRAST SCENARIOS

A	B	C	D	E	F	G

As can be seen this hierarchy consists of typically:

1. The Objective or Focus.
2. Factors influencing the actors.
3. Actors.
4. Contrast Scenarios (or alternatives).

This particular hierarchy illustrates a study to construct seven weighted scenarios and derive a composite one. The factors that are seen affecting the future load growth in Bangladesh are cost, reliability, environment and conservation. These factors are seen to manifest themselves through the actions of the following actors: consumers, donors, research bodies, government and industry. The scenarios visualized are not outlined here; they are not the focus of our discussion, a hierarchical formulation of a verbal problem is. They have been named A, B,...,G. This should give an idea as to how a possible problem can be broken down into its logical constituents, naturally connected through a downward flow in the diagram.

As pointed by Rahman[3] there is no set procedure for generating the objectives, criteria and activities to be included in a hierarchy. These are essentially chosen by the way we choose to decompose the complexity of the system. This process is interactive and could involve brainstorming and group debating ! The Decision Maker(s) (DM) should be satisfied that the levels flow into each other, naturally. Hierarchic continuity requires that the elements at the bottom level of the hierarchy be comparable in a pairwise fashion according to elements in the next level and so on to the focus of the hierarchy. Meaningful answers are needed to such questions as: "With respect to the influence of donor support on the future of load growth in Bangladesh what is the importance of Govt. as compared to Industry.?". The object is to derive priorities on the elements in the last level that reflect as best as possible their relative impact on the focus of the hierarchy, the first level. It is important to note that AHP demands that the problem be structured by the participants in the decision making process; in this example the students, professors, etc.

3.6 The principle of discrimination and comparative judgements

Now that a hierarchic representation of the problem is created we need to establish priorities among the criteria, actors, etc. In AHP, elements of a problem are compared in pairs with respect to their comparative impacts. This comparison is reduced to a matrix form. An example is:

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & \cdots & a_{mm} \end{bmatrix}$$

This is a matrix of order (mxm). The matrix elements in this case will have reciprocal properties. That is,

$$a_{ij} = \frac{1}{a_{ji}}$$

where the subscripts i and j refer to the row and column, respectively.

Let $A_1, A_2, A_3, \ldots, A_n$ be any n elements and $w_1, w_2, \ldots, w_n$ be the corresponding weights. Now, using AHP we wish to compare the corresponding weights of each element with the weights of every other element with respect to an attribute they have in common. This comparison of weights can be represented as (for a 4x4 matrix, as an example):

$$
\begin{array}{ccccc}
 & A_1 & A_2 & A_3 & A_4 \\
A_1 & \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \frac{w_1}{w_4} \\
A_2 & \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \frac{w_2}{w_4} \\
A_3 & \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} & \frac{w_3}{w_4} \\
A_4 & \frac{w_4}{w_1} & \frac{w_4}{w_2} & \frac{w_4}{w_3} & \frac{w_4}{w_4}
\end{array}
$$

This is also called the judgement matrix and is of the above shown form. To illustrate this let use use the hierarchy desribed earlier for the load growth in Bangladesh. There will be one matrix at the second level with respect to the focus. There is one matrix of size 4 (ie, 4x4, since these are always square matrices). '4' because of the number of elements in the second level. While the $A_{1,}\, A_{2,}$... are the four factors an example of the matrix could be:

$$
\begin{bmatrix}
1.0 & 5.0 & 4.0 & 6.0 \\
1/5 & 1.0 & 1.0 & 3.0 \\
1/4 & 1.0 & 1.0 & 5.0 \\
1/4 & 1/3 & 1/5 & 1.0
\end{bmatrix}
$$

Note that the diagonal elements are all '1', since they represent the weight of an element with respect to itself. This reciprocal matrix has positive entries everywhere. Similarly, there will be 4 matrices at level 3, one with respect to each of the factors in level 2. Each of these 4 matrices will be of size 5 (ie.,5x5) since there are 5 elements in level 3. Following this train of logic will eventually provide 5 matrices at level 4, each of order 7.

3.6.1 The recommended scale of relative importance

There is a need for a scale for making subjective pairwise comparisons. The one illustrated in Table 1 on page 35 is suggested by Saaty.

When activity has one of the above numbers compared to a second activity (eg, 7), then the second activity has the reciprocal value when compared to the first (ie, 1/7). In the matrix one begins with an element to the left and compares it with an element listed at the top. When compared with another element, it is either more important or less important (is equal when compared to itself, ie, the diagonal elements). If more important then an integer value from the above scale is entered, and its reciprocal is entered in its transpose position in the matrix.

To start with, elements in the second level are arranged in a matrix form in order to elicit judgements from people who have the problem about the relative importance of the elements with respect to the overall goal.

Table 1. Scale for pairwise comparison

INTENSITY OF RELATIVE IMPORTANCE	DEFINITION	EXPLANATION
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8 1/2, 1/4 1/6, 1/8	Intermediate values between two adjacent judgements	When compromise is needed

Additional matrices are constructed for each successive level. We actually need elicit only $\frac{n(n-1)}{2}$ judgements, where n is the total number of elements being compared.

3.6.2 What questions to ask in making comparisons

In making pairwise comparisons between A & B the following questions are relevant -

- Which is more important or which has a greater impact? (Criteria)
- Which is more likely to happen? (Scenarios)
- Which is more preferred? (Alternatives)

3.6.3 Synthesis of priorities

At this point, we now have a hierarchy, arranged matrices and judgements offered in a pairwise comparison. Now, we need to interpret all these numbers and see how they can help guide us in a meaningful approach to multi-criteria planning problem.

3.7 Local priorities

We need to obtain a set of *local* priorities which assess the relative impact of a group of elements in a certain level on an element in the level immediately above. This can be done by finding eigenvectors for each matrix and then normalizing the result to unity to obtain the vector of priorities. To avoid time-consuming methods of determining eigenvectors, the following procedure has been suggested by Saaty[10]. This is the method of geometric means; multiply the elements of each row and take the nth root where n is the number of elements in the row. Then normalize to unity the column of numbers thus obtained by dividing each entry by the sum of all entries. This vector of priorities then expresses not only the priority rank of each item (Order of importance), but also the magnitude of this priority (How important?).

To obtain an estimate of the first component of the eigenvector $\frac{w_1}{w_1} \times \frac{w_1}{w_2} \times \frac{w_1}{w_3} \times \frac{w_1}{w_4}$ are multiplied out and the fourth root taken. Let that be a, ie, $\left[\frac{w_1}{w_1} x \frac{w_1}{w_2} x \frac{w_1}{w_3} x \frac{w_1}{w_4}\right]^{\frac{1}{4}} = a$.

Similarly b, c and d can be obtained.
eg, b $= \left[\frac{w_2}{w_1} x \frac{w_2}{w_2} x \frac{w_2}{w_3} x \frac{w_2}{w_4}\right]^{\frac{1}{4}}$ and so on.
Then this vector needs to be normalized. That can be done as follows.

Let T = a + b + c + d.

$\frac{a}{T} = x_1$, $\frac{b}{T} = x_2$

$\frac{c}{T} = x_3$, $\frac{d}{T} = x_4$

At this point, we must briefly return to the point where the weights $w_1, w_2, \ldots\ldots, w_n$ were defined. Now in reality we do not have these w's, just numbers (from the scale described in Table 1). that represent the ratios $\frac{w_i}{w_j}$ for all i =1 to n, j= 1 to n. The numbers $x_1, x_2, x_3\ x_4, \ldots\ldots, x_n$ then represent these ratios. To illustrate this, consider that matrix created before, for the second level. Using the above described method the eigen vector is obtained as seen in Table 2 on page 39.

3.7.1 Consistency of local priorities

We must however know what is the consistency reflected by these priorities. The index of consistency is needed which tells us what the extent of deviation from consistency is. If this is seen to exceed the limits specified, there is need for the people (the experts) who provided the judgements in the matrix, to re-examine their inputs into the matrix.

For that we first need to determine λ_{max}, the largest eigenvalue of the judgement matrix. Add each column of the judgement matrix. Then multiply the sum of the first column of the judgement matrix by the value of the first component of the normalized vector, the sum of the second column of the judgement matrix by that of the second component and so on. Adding the resulting numbers will give λ_{max}. For our example matrix, $\lambda_{max} = 4.17$. For the consistency index C.I, we have:

$$C.I = \frac{\lambda_{max} - n}{n - 1}$$

where n is the number of elements being compared.

We now compare this value with what it would be if our numerical judgements are taken at random from the scale $\frac{1}{9}, \frac{1}{8}, \frac{1}{7}$, ,........,.1, 2,...9(using a reciprocal matrix). Saaty[12] considered a sample size of 500 for matrices of order 1 to 10, and their eigenvalues were computed for matrices of each size. In Table 3 on page 39 are average consistencies for different order random matrices, as found by him.

Table 2. Eigen vector

0.596
0.151
0.190
0.060

Table 3. Average consistencies for different order matrices

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If we divide C.I by the consistency number (from the table above) for the same size matrix we obtain the consistency ratio, C.R. The value of C.R should be around 0.10 (10 percent) or less to be acceptable. In some cases, of matrices larger than 3, 20 percent may be tolerated but never more. If found to exceed this figure the experts might want to redo some of the matrices and this will help them attain greater consistency. If the experts are consistent, we assume they are right. The process of redoing the matrices helps place factors in proper perspective by pushing the important points to the foreground and letting minor facts pale into the background. The human mind attains greater clarity in thought by such a limited iterative process.

For our example matrix,

$$C.I = \frac{(4.17 - 4)}{(4 - 1)} = 0.0567$$

and

$$\text{C.R (Consistency Ratio)} = \frac{0.0567}{0.90} = 0.063$$

3.7.2 Principle of synthesis

The principle of synthesis is now applied. Priorities are synthesized from the second level down by multiplying local priorities by the priority of their corresponding criterion in the level above and adding them for each element in a level according to the criteria it affects. (The second level elements are each multiplied by unity, the weight of the single top level goal). This gives the composite priority of that element which is then used to weight the local priorities of elements in the level below compared by it as criterion and so on to the bottom level.

So, for carrying out all the steps outlined above would yield several sets of priority vectors and eigenvalues. If ultimately, the composite weights for the 7 scenarios are:

0.20 0.38 0.14 0.09 0.11 0.05 0.03

Then clearly, scenario B seems to be preferred over the others in this analysis. Scenarios A and C are closer compared to others. Therefore elements characteristic of them will have to be taken note of by the decision makers and the experts.

Thus, this technique developed by Saaty is used, presenting an interactive computer model, for analyzing diverse opinions put forward by experts from different backgrounds- politics, socio- economic conditions, etc.- in developing a consensus.

3.8 IAHP3

IAHP3 is a FORTRAN77 program, running on IBM PC. This program has been developed to carry out the AHP analysis on a given hierarchy, generating the requisite indices, eigenvalues and ratios that provide information about the consistency of the hierarchy and some details about the constituents of the hierarchy that will give insight into the elements of the hierarchy.

IAHP3 is an interactive program that can be used either to make a completely new run or modify the elements of a previous hierarchy.

1. **New run:** In this case the user will interactively enter the dominance matrices of the hierarchy and get the required results on the screen. These results will also be stored in a file called "AHP.DAT". The representation for a single matrix is depicted below.[16]

   $

   X Y Z

[16] Every new run creates a data file called "AHP.DAT" overwriting the previous one. So if you wish to save the results of a paricular run then give it a name different from "AHP.DAT" immediately after a new run.

$$\begin{matrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & \cdots & a_{mn} \end{matrix}$$

Explanation:

$: Acts as a separator between two matrix representations.

X: Level at which the matrix is being considered.

Y: The number of the matrix in that level.

Z: The order of the matrix [The matrix is square (ZxZ)].

The a_{ij}'s are the entries of the matrix.

2. **Old run:** If the user wishes to make a few modifications to a set of data for which the AHP program was run before, it can be easily done. Then, AHP is run for the new data. The program will go through almost the same sequence of steps as before. However, this time for each matrix, it will display the matrix (as existing in the old data set) and ask whether it is the one the user wishes to make changes to. If one wants to modify that particular matrix then one is required to interactively enter the new matrix (as before). This matrix will then replace the old matrix . If one does not wish to effect changes to a particular matrix and would like to have it considered in its earlier form then that matrix will be saved for the new data. Like in the case of "New run", the user will be provided with all necessary information like the various indices, eigenvalues and ratios. They will also be saved in a file whose name the user will provide. Note that both, the old data set and the new one are saved.

3.8.1 Program prompts

- "TYPE OF RUN ?? (N for NEW/ O for modifying an older run)"[17]

  If you enter "N" you will be running AHP for a set of data that you are required to enter interactively. The data and results will be stored in the file AHP.DAT.

  If you enter "O", the following questions are asked:

- "ENTER NAME OF FILE THAT CONTAINS THE OLD DATA"

  Here enter the name of the file that contains the data you wish to modify before running again. Could be "AHP.DAT" or anything else. The only requirement is that it should be a file that was created by this program. (This way you can store a whole lot of data sets, for your reference). The next prompt will be:

- "ENTER NAME OF FILE INTO WHICH NEW DATA IS TO BE STORED"

  Here you will enter the name you would like the file that will contain the old data set, now modified, to have.

The rest of the program runs smoothly with suitable prompts and questions. There is one caveat however. When modifying an old run, remember to enter the relations between matrices of one level with respect to those in another level in the same order as before, unless you deliberately want to change it. For example when asked,

ENTER ALL OF THE FACTORS IN LEVEL 3 RELATED TO ELEMENTS OF LEVEL 2, ON THE SAME LINE BY ASCENDING ORDER.

you might enter for example

1 2 3 4

if that is what you want it to be.

However, if only elements 1,2 and 4 of level 3 are related to an element in level 2, then you should enter the following:

---

[17] note the upper cases for both N and O

1 2 4 0

Note the absence of '3'. Also use as many '0's as are necessary to make up the deficit in the number of elements related to the level above. Here one zero was used to make up for the missing '3'.

The same holds for number of elements in a level, which should **not** change at all.

The format in which the results are produced by IAHP3 is that the results follow the matrix representation made above.

WEIGHTS= W1 W2 W3 W4 W5 W6 W7 W8

LAMBDA(MAX)= Y C.I.= C1 C.R.= C2

W1, W2, ,,etc are the weights of the items that comprise the matrix (with respect to an attribute).

LAMBDA(MAX) ,i.e: Y is the maximum eigenvalue of the matrix.

C.I.(the consistency index) is C1.

C.R.(the consistency ratio for the judgements expressed in the matrix) is C2.

At the end of the run, the Consistency Ratio of the Hierarchy (C.R.H) is provided.

3.9 In retrospect

The underlying theory behind AHP is introduced here. It's flow from the domain of uncertainty is identified. A number of questions can come to mind regarding the use and misuse of AHP. They may range from interaction of people, how to obtain consensus or take geometric averages over the judgements or different methods of obtaining the eigenvector. One might also ask, what happens to a decision if the judgement of an individual or group changes over a period of time? If the decision has already been taken, it may be revised or reimplemented, if possible, perhaps incurring cost. Or the AHP will have served as a learning tool in which case the last judgement is used, if it is thought to be the best; or all previous judgements are synthesised by taking their geometric mean or some more valid judgements are emphasized by weighting them before taking the geometric mean. In this manner, changes in judgement can be dealt with as part of the complexity being studied. Like other analytic procedures, AHP can be abused by forcing data and judgements to comply with preconceived notions and biases of the analyst instead of letting natural thought flow. Thus, it must be possible to defend the weights assigned to the judgements. The real power of AHP lies in the broad scope and varied types of problems to which it can be applied. In many ways it can be considered as an extension of our information-processing capacity and our thought processes.

Saaty[12] has successfully applied it in a wide diversity of areas ranging from private individual decisions, to setting priorities and allocating resources in some of the largest corporations, to assisting developing nations to deal effectively with their many problems and limited resources. [18]

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[18] The Sudan transport study is a point in case. It was a plan developed to improve the Sudanese economy. This study won an award from the Institute of Management Studies for being one of the best applied studies in 1977.

4.0 SET UP

In the analysis of the situation in the energy sector of India, we first need to set up a hierarchy that will, from top to bottom, reflect the focus and purpose of this study.

4.1 Structuring the hierarchy

After looking through some hierarchies used by Saaty[10,12,17] in some of his successful studies, we decided to create a hierarchy with the following four levels:

1. Focus
2. Actors
3. Objectives
4. Alternatives

4.1.1 Focus

Clearly stating the focus of our study was a critical part, since there seemed to be so many ways of expressing it. Our basic aim was to analyze the prospects of dissipation of NARSE technologies in the Indian energy sector. We wished also to be able to identify such entities as are proving to be positive influences and those that would be beneficial to the rapid spread of NARSE. If impediments to the progress of NARSE in India were to reveal itself in preliminary studies, we wished to then detect trends and policies that would suitably limit these negative influences and also look for ways to remove them.

Keeping such a broad spectrum of objectives in mind, a suitable statement encompassing them was needed. We chose the following:

MARKET PENETRATION OF RENEWABLE ENERGY TECHNOLOGIES

4.1.2 Actors

Among the actors likely to exert an influence over such a focus, the consumers come to mind easily. In a planned economy, like India's, most key sectors, like energy, belong to what is called the "public sector". That is, they are wholly owned and run by the Government[19]. The Government is therefore another important actor.

NARSE represents new technology. While the consumers will benefit from it and the government will provide the infrastructure, funding and mandate, what is also needed is the technical ability to implement and spread NARSE, and also to provide continuous monitoring and servicing. There is also a need for continuous research to make NARSE more attractive and a simpler technology. All this is expected to be provided by what will be called the R&D organizational structure in India, which includes both, those in the public sector as well as in the private sector. To round off the list of actors, we also thought it important enough to include Donor agencies, like those sponsored by the UN or such similar organizations. This would also cover bilateral aid between countries.

To summarize, we have the following list of actors:

1. Government
2. Consumers
3. Donor Agencies

---

[19] Federal or State

4. R & D organizations

4.1.3 Objectives

These would consist of the objectives of the actors identified above, with respect to their ability to achieve the focus. In order to have a complete hierarchy[20], we decided to concentrate on the objectives that are common to all the actors. After a careful analysis of other similar studies and using Dr. Rahman's experience in third world countries and also some of my own understanding of the situation, the following list of objectives was formulated.

1. Low operating cost
2. Reliability - Traditionally, products and services in India have a low reliability. Things are changing now, with consumers demanding greater reliability and government insisting on higher standards. In the energy sector, this is translated as uninterrupted supply of the required amount of power, at least for the period it is guaranteed, if not all the time.
3. Indeginization - This refers to the ability to employ as much of national and local material, technical knowledge and ability in NARSE projects.
4. Improvements in life style - Here, we will be considering those positive effects on life style - rural and urban - that a certain technology brings in its wake. What is common to all technologies is the improvement in life style that they bring by the basic act of supplying power - that is not considered here. What is focussed on here is the ancillary benefits. For example, solar cookers causes changes in cooking and eating habits. Bio energy induces a certain cleanliness in the environment. Effects like these will be what we are looking for here.
5. Decentralization - The Indian economy is predominantly rural with a increasing industrial accent. So far it has been strongly centralized with little decision making freedom short

[20] A complete hierarchy is defined as one in which an item in a certain level is related to all the elements in the level below it.

distances away from the center. It is widely believed, and we share the belief, that it needs to be decentralized to avoid problems of red tapism, bureaucratic bottlenecks and slow flow of information and feedback, which at times can be utterly destroyed. Fortunately, NARSE technologies are so inclined as to promote a trend in decentralization which policy making interests, like the Government are now looking for.

6. Environmental impact- this covers conservation, the drive to conserve fuels like oil, coal, firewood etc and also looks into the possible environmental impacts of different NARSE technologies.
7. Import substitution - Foreign exchange is a scarce resource a third world economy can ill-afford to squander. In India, to tackle this problem the government has introduced the concept of "import substitution". Industry in encouraged to pick out items that India imports and try to produce it locally. This helps conserve foreign exchange.

4.1.4 Alternatives

We need to consider here a list of all NARSE technologies that will be of general interest to the Indian energy planners. They include those that may be already at or near commercial viability or be ones with excellent long-term potential. In chapter two we had made a broad survey of the Indian energy situation and the various NARSE options that the Indian planners are considering.

The following is the list of NARSE technologies that we believe should be considered in this study.

1. Hydro Power
2. Solar Energy
3. Wind Energy
4. Bio Energy

5. Sea Power

6. Geothermal Energy

7. Fuel Cells

4.2 Analysis of Run 1

The hierarchy considered for the first run is as seen in Fig. 1 behind. The total set of matrices with the associated indices and ratios are in the next section. From the results obtained it can be construed that of the seven NARSE[21] Bio Energy and Hydro power hold the greatest ability for market penetration. Thus the overall weighted priorities suggest that Bio should receive maximum emphasis followed by Hydro wind energy, solar energy, fuel cells, geothermal energy and sea power.

The composite priorities for level 4 are(in percent):

BIO	HYDRO	WIND	SOLAR	F.CELLS	GEOTH.	SEA
21.05	20.69	14.04	13.26	11.65	11.52	7.79

Bio energy gains on its relative abundance and ease of access. There is hardly any "technology" involved. It is an important resource especially for India because a majority of her populace is pretty much rural. The resource base is very large and capable of manyfold expansion from today's levels. More important is the fact mentioned before, that there appears to be no major "technical" obstacle to its expansions. An important motive to pursue this type of energy could be increased national independence in energy supply.

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[21] New and Renewable Sources of Energy

The high weight for Hydro is principally due to its massive generative capacity as also its multi-purpose attribute. Then there is also its ease of adaptability to rural economies. Hydro power has a key role to play in any oil-importing developing country.

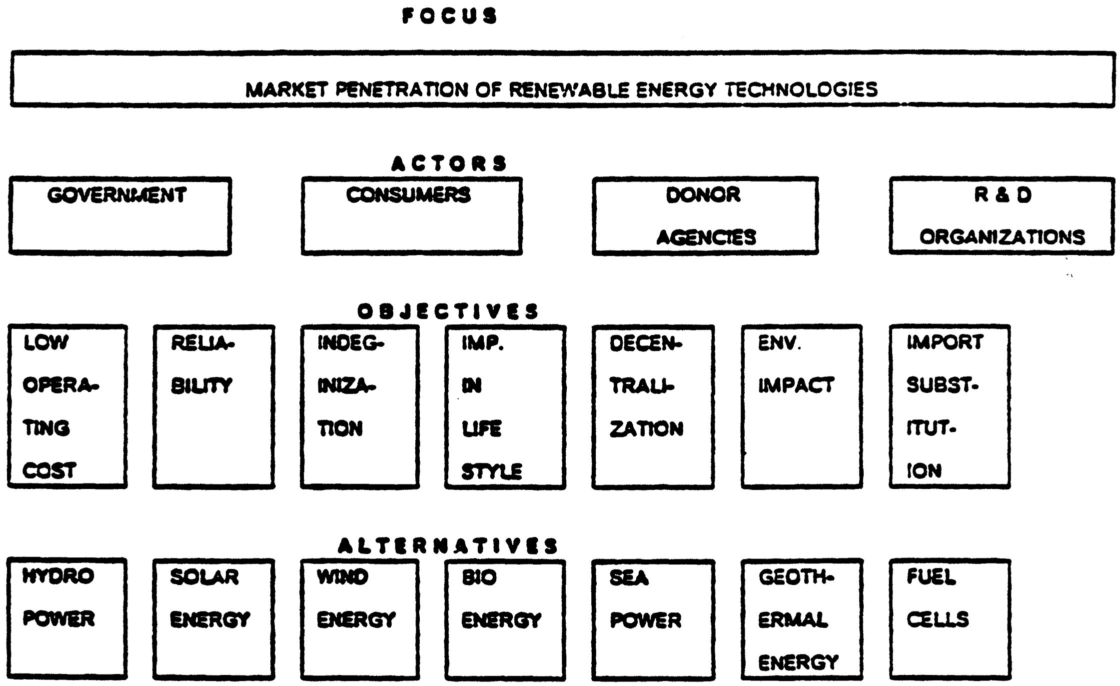

Figure 1. Hierarchy 1

Wind energy is highly location specific and climate dependent and is therefore where these factors are favorable, it certainly should be an attractive proposition.

Solar energy is indeed a versatile technology typically suited to decentralized, rural economies. But at the current point of time, technological and cost factors weigh against it as far as third world economies go. These appear to be improving though.

Despite the overwhelmingly positive factors in favor of Fuel Cells, its high cost and immature technology are perceived as a seriously negative factors to push it below.

Geothermal and sea power are again interesting but need to be further developed if they are to become serious rivals to the other options. They are highly site specific. Other factors that weigh against it are technology and cost.

Between levels 3 and 4 highest relative weights were seen for the objectives - low operating cost, improvements in life style, reliability and indeginization.

Table 4 on page 55 which contains composite priorities at level 3.

Between levels 1 & 2, the R & D organizations and the government have the greatest relative weights as regards their ability to effect the market penetration of the NARSE alternatives. The weights are(in percent):

GOVERNMENT	CONSUMERS	DONOR AGENCIES	R & D ORG.
28.29	16.36	10.59	44.76

Therefore Bio and holds the greatest promise for market penetration through its greater reliability, lower operating cost and its ability to provide major improvements in life styles and encourage a decentralized economy, through the roles played by the key policy influencing actors - the R & D organizations that will make it effective and the Government that will back it through the necessary infrastructure and funds.

Table 4. Composite priorities at Level 3

OBJECTIVE	WEIGHT
Indeginization	22.72
Reliability	20.78
Low Op. cost	17.60
Import Substitution	15.32
Env. Impact	11.91
Improvements in life style	6.13
Decentralization	5.54

4.3 Results of AHP run for hierarchy 1.

Pairwise comparison matrices, solutions and consistencies

$

2 1 4

1.0000 2.0000 3.0000 .5000

.5000 1.0000 2.0000 .3333

.3333 .5000 1.0000 .3333

2.0000 3.0000 3.0000 1.0000

WEIGHTS = .282903 .163619 .105920 .447558[22]

LAMDA(MAX) = 4.070932 C.I. = .023644 C.R. = .026271

$ 3 1 7

1.0000 3.0000 .2500 1.0000 3.0000 2.0000 .3333

.3333 1.0000 .3333 1.0000 1.0000 .5000 .2500

4.0000 3.0000 1.0000 3.0000 1.0000 3.0000 1.0000

1.0000 1.0000 .3333 1.0000 4.0000 2.0000 .3333

.3333 1.0000 1.0000 .2500 1.0000 1.0000 .2500

---

[22] these weights are expressed here in fractions; in the text of the thesis they are referred to in percentile

.5000 2.0000 .3333 .5000 1.0000 1.0000 .3333

3.0000 4.0000 1.0000 3.0000 4.0000 3.0000 1.0000

WEIGHTS= .129633 .065481 .249992 .125701 .079857 .076555 .27278

LAMDA(MAX)=7.697725 C.I.= .116287 C.R.= .088097

$

3 2 3

1.0000 3.0000 3.0000

.3333 1.0000 2.0000

.3333 .5000 1.0000

WEIGHTS= .593642 .249306 .157052

LAMDA(MAX)=3.053553 C.I.= .026777 C.R.= .046167

$

3 3 4

1.0000 2.0000 3.0000 4.0000

.5000 1.0000 2.0000 3.0000

.3333 .5000 1.0000 1.0000

.2500 .3333 1.0000 1.0000

WEIGHTS= .469938 .280147 .135606 .114309

LAMDA(MAX)= 4.030934 C.I.= .010311 C.R.= .011457

$

3 4 6

1.0000	.5000	.3333	2.0000	.5000	.5000
2.0000	1.0000	1.0000	3.0000	2.0000	1.0000
3.0000	1.0000	1.0000	2.0000	1.0000	5.0000
.5000	.3333	.5000	1.0000	.5000	.3333
2.0000	.5000	1.0000	2.0000	1.0000	2.0000
2.0000	1.0000	.2000	3.0000	.5000	1.0000

WEIGHTS= .094359 .220619 .283295 .073625 .185541 .142561

LAMDA(MAX)= 6.468838 C.I.= .093768 C.R.= .075619

WEIGHT: .282903 .163619 .105920 .447558

1	.129633	.593642	.000000	.094359
2	.065481	.249306	.469938	.220619
3	.249992	.000000	.280147	.283295
4	.125701	.157052	.000000	.000000
5	.079857	.000000	.000000	.073625
6	.076555	.000000	.135606	.185541
7	.272781	.000000	.114309	.142561

** COMPOSITE PRIORITIES FOR LEVEL 3

.176036 .207832 .227188 .061258 .055543 .119061 .153082

$

4 1 7

1.0000	.5000	.5000	2.0000	2.0000	1.0000	3.0000
2.0000	1.0000	1.0000	2.0000	3.0000	4.0000	7.0000
2.0000	1.0000	1.0000	2.0000	3.0000	5.0000	7.0000
.5000	.5000	.5000	1.0000	2.0000	3.0000	4.0000
.5000	.3333	.3333	.5000	1.0000	2.0000	4.0000
1.0000	.2500	.2000	.3333	.5000	1.0000	4.0000
.3333	.1429	.1429	.2500	.2500	.2500	1.0000

WEIGHTS = .140767 .256166 .266420 .137213 .093015 .075139 .031281

LAMDA(MAX) = 7.327711 C.I. = .054618 C.R. = .041378

$

4 2 7

1.0000	7.0000	7.0000	5.0000	3.0000	.5000	.3333
.1429	1.0000	1.0000	.3333	.2000	.1429	.1111
.1429	1.0000	1.0000	.2500	.2000	.1429	.1111
.2000	3.0000	4.0000	1.0000	2.0000	.5000	.3333
.3333	5.0000	5.0000	.5000	1.0000	.3333	.3333
2.0000	7.0000	7.0000	2.0000	3.0000	1.0000	.5000
3.0000	9.0000	9.0000	3.0000	3.0000	2.0000	1.0000

WEIGHTS = .210057 .027214 .026118 .097557 .088683 .221234 .329137

LAMDA(MAX) = 7.414777 C.I. = .069129 C.R. = .052371

$

4 3 7

1.0000	1.0000	1.0000	1.0000	3.0000	5.0000	7.0000
1.0000	1.0000	1.0000	.3333	3.0000	3.0000	5.0000
1.0000	1.0000	1.0000	.5000	3.0000	5.0000	7.0000
1.0000	3.0000	2.0000	1.0000	5.0000	7.0000	9.0000
.3333	.3333	.3333	.2000	1.0000	2.0000	4.0000
.2000	.3333	.2000	.1429	.5000	1.0000	5.0000
.1429	.2000	.1429	.1111	.2500	.2000	1.0000

WEIGHTS = .204308 .155062 .182928 .311887 .070181 .051971 .023663

LAMDA(MAX) = 7.294022 C.I. = .049004 C.R. = .037124

$

4 4 7

1.0000	.2500	.5000	.2000	4.0000	4.0000	5.0000
4.0000	1.0000	3.0000	.3333	4.0000	5.0000	5.0000
2.0000	.3333	1.0000	.3333	2.0000	3.0000	3.0000
5.0000	3.0000	3.0000	1.0000	5.0000	5.0000	5.0000
.2500	.2500	.5000	.2000	1.0000	1.0000	.5000
.2500	.2000	.3333	.2000	1.0000	1.0000	.5000
.2000	.2000	.3333	.2000	2.0000	2.0000	1.0000

WEIGHTS = .122314 .247479 .124389 .366547 .044680 .040331 .054260

LAMDA(MAX) = 7.611773 C.I. = .101962 C.R. = .077244

$

4 5 7

1.0000 .3333 .3333 .2000 1.0000 3.0000 .5000

3.0000 1.0000 1.0000 .5000 5.0000 7.0000 3.0000

3.0000 1.0000 1.0000 1.0000 3.0000 5.0000 3.0000

5.0000 2.0000 1.0000 1.0000 7.0000 9.0000 3.0000

1.0000 .2000 .3333 .1429 1.0000 2.0000 .3333

.3333 .1429 .2000 .1111 .5000 1.0000 .3333

2.0000 .3333 .3333 .3333 3.0000 3.0000 1.0000

WEIGHTS = .065405 .219069 .217686 .312739 .052169 .030980 .101953

LAMDA(MAX) = 7.179954 C.I. = .029992 C.R. = .022721

$

4 6 7

1.0000 5.0000 5.0000 7.0000 3.0000 2.0000 2.0000

.2000 1.0000 1.0000 3.0000 .5000 .2000 .2500

.2000 1.0000 1.0000 2.0000 .3333 .2000 .2000

.1429 .3333 .5000 1.0000 .1429 .1111 .1429

.3333 2.0000 3.0000 7.0000 1.0000 .3333 .2000

.5000 5.0000 5.0000 9.0000 3.0000 1.0000 3.0000

.5000 4.0000 5.0000 7.0000 5.0000 .3333 1.0000

WEIGHTS = .297258 .051773 .044893 .024289 .099347 .274802 .207638

LAMDA(MAX) = 7.446507 C.I. = .074418 C.R. = .056377

$

4 7 7

1.0000 6.0000 5.0000 .5000 3.0000 5.0000 7.0000

.1667 1.0000 .5000 .2000 2.0000 3.0000 5.0000

.2000 2.0000 1.0000 .3333 3.0000 5.0000 7.0000

2.0000 5.0000 3.0000 1.0000 5.0000 7.0000 8.0000

.3333 .5000 .3333 .2000 1.0000 2.0000 3.0000

.2000 .3333 .2000 .1429 .5000 1.0000 5.0000

.1429 .2000 .1429 .1250 .3333 .2000 1.0000

WEIGHTS = .297482 .086018 .140360 .342742 .063339 .047003 .023056

LAMDA(MAX) = 7.641439 C.I. = .106906 C.R. = .080990

WEIGHT: .176036 .207832 .227188 .061258 .055543 .119061 .153082

1 .140767 .210057 .204308 .122314 .065405 .297258 .297482

2 .256166 .027214 .155062 .247479 .219069 .051773 .086018

3 .266420 .026118 .182928 .124389 .217686 .044893 .140360

4	.137213	.097557	.311887	.366547	.312739	.024289	.342742
5	.093015	.088683	.070181	.044680	.052169	.099347	.063339
6	.075139	.221234	.051971	.040331	.030980	.274802	.047003
7	.031281	.329137	.023663	.054260	.101953	.207638	.023056

** COMPOSITE PRIORITIES FOR LEVEL 4

.206909	.132638	.140429	.210471	.077909	.115119	.116525

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.) = .0516

4.4 Formulation of second hierarchy

The previous hierarchy had 7 NARSE alternatives. They were seven different options that were clear cut and well-defined, ranging from Solar to Fuel cells. The AHP run on this hierarchy keeping the actors' priorities in mind gave an indication of the way different alternatives would be viewed by a set of Decision Makers (DMs). That provides us with material to proceed.

Obviously in real-life situations such clear cut options never exist. There is usually a merging together of different alternatives and a fusion of different scenarios that eventually produce a composite scenario. With this in mind we must now proceed to develop a set of realistic scenarios. This set should keep in mind the priorities for different alternatives, objectives and actors as presented by the previous run.

From analysis #1 it can be seen that the 7 alternatives are ranked in the following order of preference:

1. Bio
2. Hydro
3. Wind
4. Solar
5. Fuel cell
6. Geothermal
7. Sea

From the composite weights assigned to each of these it would be a good idea to derive a basket of alternatives grouping together such NARSE alternatives as would create a set of equally weighted baskets (using the AHP run on the first hierarchy as a guide). Then the planners have a choice of baskets and the one with the greatest weight will present itself as the group of NARSE alternatives which if backed would produce the best results with a given set of objectives in mind. Of course, the energy demand and the ability of any of these baskets to meet it should be kept in mind ie., each basket consists of a set of alternatives whose sum generating capacity is reasonably sufficient to meet demand. The following five scenarios seem to be a good and judicious combination.

1. Hydro-Solar-Wind-Geothermal
2. Hydro-Solar-Wind-Sea
3. Hydro-Sea-Fuel Cell-Bio
4. Bio-Wind-Geoth.-Fuel Cell
5. Bio-Solar-Fuel Cell-Geothermal

For example scenario #3 means that it is a situation where Hydro power, solar energy, fuel cell and bio energy would be preferred over the others and a cohesive strategy should be developed to encourage their rapid dissemination and development.

The hierarchy, for Run2, is as shown in Fig 2.

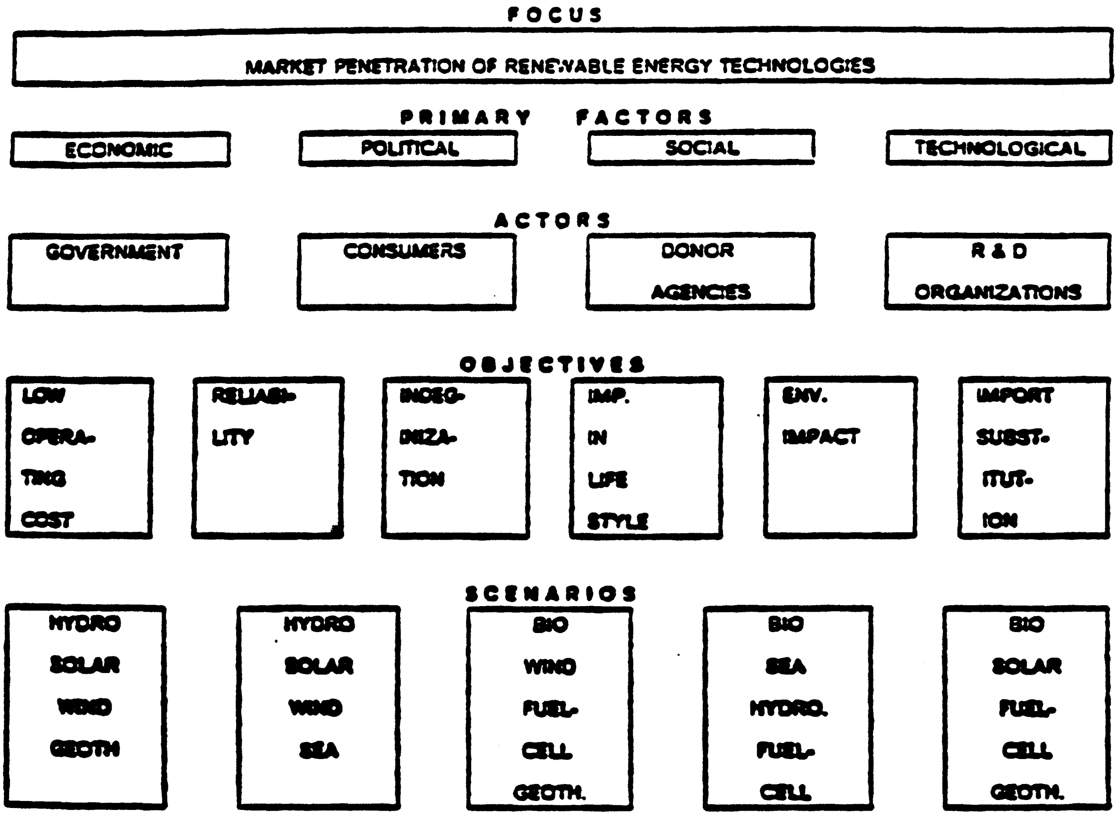

Figure 2. Hierarchy 2

4.5 Analysis of Run 2

The focus is again the market penetration of renewable energy technologies. This hierarchy has an added level-*Primary Factors*. The four factors considered are : Economic, Political, Social & Technological. The purpose of this level is to help clearly identify the primary factors that govern the actors' priorities in the decision making process. The third level has 4 actors as before. We consider the same set of objectives again in level 4 as before except that now one of them -decentralization- is dropped. The last level has the five scenarios derived above. The reason for not considering decentralization in our list of objectives is that the way the baskets of alternatives were considered, each of them equally promote decentralization. So it then ceases to be a motivating objective in our list of prioritized objectives. After going through the AHP algorithm composite priorities for the last level are obtained which helps identify the relative importance of each scenario to the Focus. As one familiar with the Indian power sector and the various constraints impinging on the decision making process in India, Dr. Saifur Rahman has functioned as the expert who has filled out the matrices.

The composite priorities for the final level are

SCENARIOS	1	2	3	4	5
WEIGHTS	22.34	25.28	14.41	19.15	18.82

Of the Five scenarios that were considered here, the second one - The Hydro-Solar-Wind-Sea combination seems to be the one most preferred over the others, narrowly in front of the first basket of NARSE alternatives.

For level 4, four matrices are created one with respect to each of actors. The composite priorities for this level are indicated in Table 5 on page 68.

Table 5. Composite priorities for level 4

OBJECTIVES	WEIGHTS
Low Op. Cost	13.78
Reliability	21.23
Indeginization	27.24
Imp. in Life Style	6.64
Env. Impact	11.22
Import Subst.	19.89

Therefore indeginization and reliability are seen to be more important objectives and should be the ones uppermost in the mind if the focus is to be successful. Import Substitution and low operating cost are also noted to have a certain level of influence in the spread of renewable technologies. This actually reflects a pragmatic thought process. A short term view would perhaps have placed low operating cost above all the others.

The composite priorities at level 3 indicate that the Government is the most influential actor and it seems to be quite predominant. Table 6 on page 70 indicates the weights.

From the 4 matrices generated for level 2, the composite priorities for level 2 are found to be as seen in Table 7 on page 70.

The Economic implications of the various options seems to be the major concern of all the actors and is heavily weighted. The technological influence is also found to be quite significant. This clearly points to the fact that the 2nd scenario is preferred over the other four because the Government which has the greatest influence in the decision making process is greatly influenced by economic factors like the operating cost and reliability(short term) and indegnization and import substitution(long term).

Between levels 4 & 5, the weights of the different objectives with respect to the various scenarios are seen in Table 8 on page 71. Thus the most significant objectives for scenario #2 are environmental impact, reliability, low operating cost, indeginization and import substitution.

Between level 3 & 4, the relative weights are for the actors with respect to the more important objectives are tabulated in Table 9 on page 71.

Table 6. Composite priorities at level 3

ACTOR	WEIGHT
GOVERNMENT	47.10
CONSUMER	9.96
DONOR AGENCY	22.05
R&D ORG.	20.89

Table 7. Composite priorities at level 2

PRIMARY FACTOR	WEIGHT
ECONOMIC	55.58
POLITICAL	13.64
SOCIAL	4.89
TECHNOLOGICAL	25.89

Table 8. Weights of different objectives with respect to the different scenarios.

	SCENARIOS 1	2	3	4	5
Low operating Cost	37.13	24.67	6.15	19.87	12.18
Reliability	4.04	33.21	25.16	9.9	27.69
Indeginization	27.74	20.15	12.89	30.32	8.9
Improvements in life style	28.81	14.40	25.46	16.92	14.41
Env. Impact	4.93	38.95	9.70	10.63	35.79
Import Substitution	31.9	20.17	9.71	18.75	19.47

Table 9. The relative weight of the actors with respect to the more important objectives.

	CONSER-VATION	RELIAB-ILITY	LOW OP. COST	INDEGIN-IZATION	IMP. SUBST.
Government	12.63	7.04	30.40	8.32	30.82
Consumers	59.36	24.93	0.00	0.00	0.00
Donor Agencies	0.00	46.99	28.01	13.56	11.44
R & D Organizations	9.19	24.24	32.27	20.66	13.64

In considering the five more important objectives a quick glance through the table above shows that the ones with the highest weights for the actors, are evenly distributed among the four actors with R & D organizations having two of five, thus giving us a a clear leader. A closer look for second-best weights for each of these five objectives clearly helps the following two emerge as the ones which exert the greatest influence on the focus with respect to the critical objectives - R & D organizations and the Government. Between levels 2 & 3, these actors showed that they were strongly influenced by economic, social and technological factors. The relative weights of all these primary factors with reference to these two important actors are as seen in Table 10 on page 73.

This trace through the hierarchy helps filter the more important points and cleanly identifies the primary factors, the actors they influence, the objectives the actors consider more important and the eventual choice as scenario #2 as the one with the ability to promote NARSE.

The preference of the Hydro-solar-wind-sea cluster , on close analysis, definitely appears to be well-founded.

Hydroelectric power generation is a well-established and widespread idea. Ongoing development in small-scale hydro power indicates a trend in further cost reductions through local adaptation and simplified designs. On both large- and small-scale, hydro power has tremendous potential, especially in the Indian context. The costs and benefits of hydropower plants are usually evaluated by an economic comparison with other technologies with similar generative capacities, like thermal or nuclear power stations. The main factors that must be kept in mind in addition to increased production costs, are changes in the cost of fossil fuels in in environmental protection regulations. In the last few decades, thermal and nuclear power station costs have risen at a greater rate than those of hydropower plants. This is mainly because the technology and management of hydro power plants has seen rapid strides.

Table 10. The relative weights of the primary factors with respect to the two important actors

	GOVT.	R & D ORG.
Economic	66.24	5.96
Political	19.58	4.97
Social	18.84	8.09
Technological	25.96	63.70

The spinoffs from hydro power use are as tremendous. For example, the creation of regulating reservoirs has been seen to make a substantial improvement in the water supply for domestic, industrial and agricultural purposes in many cases. The danger of catastrophic floods, which are a major problem in India, has often been minimized. Some largely unanticipated adverse reactions can be reduced or eliminated through careful resource planning.

Solar energy utilization is gathering momentum in India, especially the Photovoltaics (PV). With resources for its exploitation beginning to spread, it is slowly developing into a viable energy alternative. Current research is aimed at cost minimization and increase in durability and quality. Even now, the economics are often very attractive where electricity prices are very high. Energy impacts, mainly for replacing oil etc. will become significant, even though costs now may preclude access to larger sectors of the populace. But this, with a strong awareness and mobilization drive, should change.

India is among the very few developing countries that have production and assembly factories for photovoltaics. PV is cost-effective in special applications like remote communications, lighting, pumping, health stations etc. As costs come down to competitive level to fossil-based fuels, the potential market and impact on the energy mix may become significant.

There are several regions where wind electricity can play an important role in India, both in supplying electricity in remote areas and supplementing conventional generating plant in the main grid. Wind energy represents a technology which has been under development since 1890 and the recent years have seen rapid progress. A lot of the problems associated with its use today can be overcome by the use of the shallow waters around the Indian coastal line, especially because offshore wind velocities are considerably higher than many onshore sites. India's first wind farm is coming up in Kandla, Gujarat State. It is a joint project between the state-owned Gujarat Industrial Investment Corporation and Western India Erectors Ltd. Power will be sold to the state grid. Danish designed wind turbines are being used. The advantages of wind energy presupposes the existence of competent and efficient local manufacturers.

Such a segment is beginning to grow in India. There is Jyoti Ltd. of Baroda, India and the collaborative venture between Escorts Ltd. of Faridabad, India and MAN of West Germany. These are indeed encouraging signs pointing towards a fruitful expansion in India of the exploitation of an increasingly important technology.

Sea power includes tidal energy, wave energy and OTEC (Ocean thermal energy conversion). Tidal energy is a well-established technology for power production. It is very site specific and its contribution to energy demand could be small. Wave power should prove important in a situation where the conventional methods become more expensive. OTEC, like wave energy is in research and prototype stages. On-going development concerns research on cost-effective designs. India seems to be suitably poised, with its huge coastline, to exploit it it as and when it proves more economic

The overall weighted priorities thus suggest that a 4-pronged drive to promote the following four NARSE alternatives- Hydro, Solar, Wind and Sea power, would provide the best returns and have the relatively easiest path (among the five baskets of alternatives considered) to market penetration in the Indian energy sector.

5.0 CASE STUDIES

In order to appropriate an estimate of the robustness of our methodology it should be subjected to a series of perturbations. Considering the AHP analysis of the second hierarchy as the base case, a series of perturbations will be embarked upon, in which the robustness of this tool will be tested.

What questions or issues should such a procedure address?

It is quite possible, and in fact likely, that a different panel of experts than that which took decisions for the base case, will place different degrees of emphasis when presented with the same hierarchy and asked to express opinions. A total reversal of opinions can be ruled out since these types of trends are based on scientific facts and having been solidly established it would take a drastic failure in the practice of theoretical precepts to reverse an opinion. For example if solar energy is more economical than wind energy, it is an opinion based on resources available and technology that will spawn them. The same facts being available to both expert A and expert B (or any number of experts for that matter) solar energy will remain economical to wind energy unless a research breakthrough is achieved or some such fact, that will be available to all experts comes to light. Similarly as regards the role of the Government or consumers though a level of abstraction enters the picture knowing the vast differences between their roles and strength of influence a unanimity in the direction of emphasis is most likely to be achieved.

Then what is needed to be addressed is the difference in emphasis between two panels when faced with an array of alternatives.

For example, in our base case, the first matrix is the one at level one, which reflects the relative importance of the primary factors with respect to the focus. It is:

$$\begin{bmatrix} 1.0 & 5.0 & 7.0 & 3.0 \\ 1/5 & 1.0 & 5.0 & 1/3 \\ 1/7 & 1/5 & 1.0 & 1/5 \\ 1/3 & 3.0 & 5.0 & 1.0 \end{bmatrix}$$

Let the primary factors be PF1, PF2, PF3 and PF4 corresponding to the economic, political, social and technological factors. As seen, $\frac{PF1}{PF2} = 5$, $\frac{PF1}{PF3} = 7$, and $\frac{PF3}{PF4} = 1/5$.

For the given considerations, this matrix reflects an opinion A (of an expert or a group of experts). If an opinion B (of another expert or another group of them) is such that it places a higher emphasis it may find the following matrix more appropriate.

$$\begin{bmatrix} 1.0 & 6.0 & 8.0 & 5.0 \\ 1/6 & 1.0 & 6.0 & 1/4 \\ 1/8 & 1/6 & 1.0 & 1/5 \\ 1/5 & 4.0 & 5.0 & 1.0 \end{bmatrix}$$

where now, As seen, $\frac{PF1}{PF2} = 6$, $\frac{PF1}{PF3} = 8$, and $\frac{PF3}{PF4} = 1/5$.

The opinions have been highlighted in most cases, though not all. Possibly, all opinions could be tuned up.

Similarly another opinion C, may reflect a lowering in the degree of emphasis. The example matrix we have considered before may then take the form:

$$\begin{bmatrix} 1.0 & 3.0 & 6.0 & 2.0 \\ 1/3 & 1.0 & 4.0 & 1/2 \\ 1/6 & 1/4 & 1.0 & 1/3 \\ 1/2 & 2.0 & 3.0 & 1.0 \end{bmatrix}$$

This reveals a tuning down of the values of the matrix entries.

In order to test the robustness of the methodology a set of case studies were made which exposed the hierarchy and the AHP analysis to such a diverse range of opinions. The case studies are described in subsequent sections of this chapter. Four case runs were chosen for the tests.

5.1 Case 1 overview

The opinions expressed by the expert, in this case, were diluted from their values in the base case. This was done in 9 of the 15 matrices that we have. For example, a matrix entry '5' could have been replaced by a '3' or a '4'. A '1/5' could have been changed to a '1/3'. Basically this case tests an assortment of values wherein the opinions are either lowered in emphasis or status quo is maintained with respect to the base case.

5.1.1 Case 1 Results

The composite priorities at the lowest level indicate a stronger preference for the first two baskets of NARSE alternatives, with the second one coming on top. The figures are:

SCENARIOS	1	2	3	4	5
WEIGHTS	22.17	23.86	15.00	20.15	18.82

For level 4, four matrices are created one with respect to each of actors. The composite priorities for this level are as indicated in Table 11 on page 80.

Reliability, indeginization and import substitution have been assigned high weights. A look at the ratios for level 3, the one for the actors, is shown in the Table 12 on page 80. Government and R & D organizations dominate the weight distribution.

From the 4 matrices generated for level 2, the composite priorities for level 2 are found to be as seen in Table 13 on page 81. The economic and technological factors seem more important.

5.2 Case 2 overview

The method employed in Case 1 was now extended to all the 15 matrices (it covered 9 of 15 matrices in Case 1) ie.,all opinions are reduced in emphasis are tuned down. So as compared to the base case, this case represents a set of opinions all of which are milder in degree than those expressed in the base case.

5.2.1 Case 2 Results

Again, the composite priorities at the lowest level indicate a strong preference for the first two baskets of NARSE alternatives, with the second one being preferred over the first. The figures are:

SCENARIOS	1	2	3	4	5
WEIGHTS	21.30	24.29	15.37	19.57	19.47

Table 11. Composite priorities for level 4

OBJECTIVES	WEIGHTS
Low Op. Cost	15.17
Reliability	21.66
Indeginization	25.79
Imp. in Life Style	7.76
Env. Impact	10.78
Import Subst.	18.84

Table 12. Composite priorities at level 3

ACTOR	WEIGHT
GOVERNMENT	44.46
CONSUMER	15.15
DONOR AGENCY	17.71
R&D ORG.	22.68

Table 13. Composite priorities at level 2

PRIMARY FACTOR	WEIGHT
ECONOMIC	47.68
POLITICAL	17.40
SOCIAL	7.95
TECHNOLOGICAL	26.97

At level 4, there are four matrices one with respect to each of actors. The composite priorities for this level are as indicated Table 14 on page 83.

Reliability, indeginization and import substitution have been assigned high weights with low operating cost close behind as in the previous two cases. The ratios for level 3 are shown in Table 15 on page 83. This time, the factors that had higher weights in the base case - government and donor agencies - are favored.

The composite priorities for level 2 are determined to be the ones shown in Table 16 on page 84. No change in rankings is observed, vis-a-vis the base case.

5.3 Case 3 overview

In this case, the expert opinions have been tuned up, as compared to the base case. For example, a '4' will perhaps have been replaced by a '5' or a '6'. A '1/5' may have been replaced by a '1/7'. This technique was applied to 11 of the 15 matrices at hand. This case reflects opinions of the category 'B' described earlier in the chapter. It consists of of a mixture of higher positive bias opinions or status quo (relative to base case).

5.3.1 Case 3 Results

The composite priorities at the level 5 have greater preference for the first two baskets of NARSE alternatives, with the second having the higher weight. The figures are:

SCENARIOS	1	2	3	4	5
WEIGHTS	23.20	26.39	15.19	19.60	15.62

Table 14. Composite priorities for level 4

OBJECTIVES	WEIGHTS
Low Op. Cost	14.44
Reliability	24.26
Indeginization	27.72
Imp. in Life Style	7.85
Env. Impact	12.19
Import Subst.	18.54

Table 15. Composite priorities at level 3

ACTOR	WEIGHT
GOVERNMENT	43.01
CONSUMER	12.49
DONOR AGENCY	23.49
R&D ORG.	21.01

Table 16. Composite priorities at level 2

PRIMARY FACTOR	WEIGHT
ECONOMIC	47.68
POLITICAL	17.40
SOCIAL	7.95
TECHNOLOGICAL	26.97

The composite priorities for level 4 are displayed in Table 17 on page 86.

The same three objectives maintain their greater importance. A look at the ratios for level 3, the one for the actors is shown in Table 18 on page 86.

Composite priorities for level 2 are shown in Table 19 on page 87. The economic and technological factors continue to dominate the choice of alternatives.

5.4 Case 4 overview

The procedure adopted for case 3 is now extended to all the 15 matrices (it covered 11 of 15 matrices in Case 3). This case then consists of all "marked up" opinions.

5.4.1 Case 4 results

Again, the composite priorities at the lowest level indicate a stronger preference for the second basket of NARSE alternatives, with the second one being preferred over the first. The figures are:

SCENARIOS	1	2	3	4	5
WEIGHTS	24.95	26.33	14.30	19.54	14.86

At level 4 the four matrices, one with respect to each of actors yield composite priorities for this level are as indicated Table 20 on page 87

Similarly, the ratios for level 3, the one for the actors, is shown in Table 21 on page 88. and the composite priorities for level 2 are determined to be the ones shown in Table 22 on page 88.

Table 17. Composite priorities for level 4

OBJECTIVES	WEIGHTS
Low Op. Cost	12.21
Reliability	22.95
Indeginization	29.81
Imp. in Life Style	4.97
Env. Impact	10.22
Import Subst.	19.84

Table 18. Composite priorities at level 3

ACTOR	WEIGHT
GOVERNMENT	47.55
CONSUMER	7.28
DONOR AGENCY	22.51
R&D ORG.	22.66

Table 19. Composite priorities at level 2

PRIMARY FACTOR	WEIGHT
ECONOMIC	56.08
POLITICAL	11.99
SOCIAL	4.76
TECHNOLOGICAL	27.17

Table 20. Composite priorities for level 4

OBJECTIVES	WEIGHTS
Low Op. Cost	14.44
Reliability	24.26
Indeginization	27.72
Imp. in Life Style	7.85
Env. Impact	12.19
Import Subst.	18.54

Table 21. Composite priorities at level 3

ACTOR	WEIGHT
GOVERNMENT	43.01
CONSUMER	12.49
DONOR AGENCY	23.49
R&D ORG.	21.01

Table 22. Composite priorities at level 2

PRIMARY FACTOR	WEIGHT
ECONOMIC	47.68
POLITICAL	17.40
SOCIAL	7.95
TECHNOLOGICAL	26.97

5.5 Overall Results

Stepping back briefly, a careful study of the results obtained reveal the following salient features.

1. The choice among the five alternative NARSE baskets, as reflected by their ranking remained unchanged at level 4. The second grouping of NARSE technologies, came out on top for each case study. The ranking of these 5 alternatives, from top to bottom, in each case was 2-1-5-3-4, as in the base case.
2. At level 1 too, the rankings of the four options (here, the primary factors) are unaffected in each of the four cases, as compared to the base case.
3. At levels 2 and 3 however, a slight variation in the rankings of the options at those levels, were seen, as compared to the base case.
4. In these 4 cases, the exact weights assigned to the different options in the various levels, vary around those in the base case. The variations are of the order of single-digit percentile points; the extremes being +5.1912 and -7.89.

Table 23 on page 90 describes the options at each level, which are but the elements in each level of the hierarchy previously constructed.

Table 24 on page 91 indicates in each case the ranking of the various options at each level.

All the matrices generated in the case studies 1, 2, 3 and 4 are in the Appendices B, C, D and E, respectively.

Table 23. Option at various levels in the hierarchy.

	LEVEL TWO Primary factors
Option 1 Option 2 Option 3 Option 4	Economic Political Social Technological
	LEVEL THREE Actors
Option 1 Option 2 Option 3 Option 4	Government Consumers Donor Agencies R & D Organizations
	LEVEL FOUR Objectives
Option 1 Option 2 Option 3 Option 4 Option 5 Option 6	Low Operating Cost Reliability Indeginization Improvements in Life styles Env. Impact Import Substitution
	LEVEL FIVE NARSE Baskets
Option 1 Option 2 Option 3 Option 4 Option 5	Hydro-Solar-Wind-Geothermal Hydro-Solar-Wind-Sea Hydro-Sea-Fuel Cell-Bio Bio-Wind-Geothermal-Fuel Cell Bio-Solar-Fuel Cell-Geothermal

Table 24. Rankings of various options in each level: A comparison of all case studies.

Levels	Case 1	Case 2	Case 3	Case 4	Base Case
2	1-3-4-2	1-3-4-2	1-3-4-2	1-3-4-2	1-3-4-2
3	**1-4-3-2**	1-4-2-3	1-4-2-3	**1-4-3-2**	1-4-2-3
4	4-2-1-	**4-1-2-**	4-2-1-	4-2-1-	4-2-1-
	-6-5-3	**-6-5-3**	-6-5-3	-6-5-3	-6-5-3
5	2-1-5-3-4	2-1-5-3-4	2-1-5-3-4	2-1-5-3-4	2-1-5-3-4

Note: The highlighted rankings in the above table are meant to point out those rankings that have deviated from the base case.

From Table 24 on page 91 the variations in the rankings in levels 3 and 4, mentioned earlier, have been highlighted. The reason for this change in rankings is easy to understand. The changed values assigned to the the matrix entries in the matrices above the levels, where the change occurs, leads to a change in the values of the composite priorities for the level above. In evaluating the composite priorities in any level, those for the level above play an important role as explained in AHP technique description in chapter three. Therefore any change in them is bound to reflect on the composite priorities below. And in cases where the difference between two options is marginal, a small percentile change in the composite priorities at a level above can cause a switch in the rankings. This is precisely the case here. A look at the the results generated in the two runs and the case studies in the appendix will confirm that.

The validation procedure outlined at the beginning of this chapter for testing the robustness of the methodology developed here, in the face of differing shades of opinion expressed by different experts, was carried out here in the form of 4 different case studies. The results and the analysis of them do point to the fact that differing degrees of emphasis obviously do cause changes in the values of the composite priorities at different levels. Of course, the whole set of indices, ratios etc change too.

What does this say about the result?

The changes that occur reflect a general trend and opinion as best as possible. And though on 3 occasions, it was seen that the rankings of actors and objectives changed, the swing away from their values in the base case was marginal leaving the ultimate ranking of the 5 alternative NARSE baskets, unchanged. This means that AHP as a decision making tool is robust enough to express a decision consistently, in an environment where expert opinion is not consistent in its degree of emphasis. The relative weights assigned to different alternatives retain their positions relative to each other and provides for greater flexibility in the thought processes of the experts, which are based on accurate and updated information.

6.0 CONCLUSION

The focus of this study was to explore the prospects of the dissipation of NARSE[23] technologies in India and develop a methodology for this using a decision making tool.

A beginning can be made only by first understanding the energy situation in India. The energy scene in India, examined and presented in Chapter two, is a complex picture of various sources of energy meeting a variety of demands presenting a formidable problem in analysis. Energy consumed in India comes in a variety of forms ranging from nuclear fuels to heat obtained by burning agricultural wastes and animal dung. Other energy inputs also come from manual labor and draught animal power. The most important commercial energy sources are coal, lignite, oil and hydroelectricity; nuclear energy is a small though growing contributor to the total energy available. Firewood, agricultural wastes and animal dung are the important non-commercial sources.

Any assessment of the role and potential contribution of NARSE in meeting the overall energy requirements will have to take into account specific requirements for specific purposes. India has a large industrial infrastructure and a fairly extensive power network which services this infrastructure. Bulk power needs are very considerable and growing. These needs can be supplied in the foreseeable future only by increasing utilization of conventional and nuclear energy sources. Among NARSE types, hydro power has great potential and efforts are being made to step up its utilization.

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23 New and renewable sources of energy

The needs of India are a bit different from that of an industrially developed nation, especially in relation to rural areas. With the power transmission network covering around half of the villages and two-thirds of the rural populace, there are yet vast areas not yet served by centralized sources of energy and there are then a variety of options open for meeting the requirements. Hydroelectric sources may be the most advantageous form, and there is scope for renewable sources like solar energy, wind and biogas to meet the decentralized requirements of lighting, heating, pumping and low grade heat. The large size of the country also provides role for NARSE types of energy in isolated and remote locations. With India's long coast line and the sea around her, Sea power holds promise for the future. Developments in geothermal power and fuel cells hold potential for future applications. However research in these areas needs to be done in India so that these technologies are typically oriented and suited for that environment and conditions.

The actual contribution of renewable energy and its success in market penetration will depend on chiefly the following factors;

1. The availability of conventional sources.
2. The price of conventional fuels.
3. The desire among Indian planners to reduce dependence on external sources for meeting India's energy requirements.
4. The development of technology for effective and economic utilization of NARSE.
5. Infrastructure for the production, distribution, utilization and maintenance of systems based on new and renewable sources.
6. Awareness among sections of the population of the importance of NARSE and adjustment of life styles where required.

The constraints on oil supply are well-known, considering that most of India's oil comes from the volatile Middle east. It will also be difficult to raise the production of coal to levels required by demand projections. As regards the price of conventional fuels, it is important to realize that the conventional energy structure in India is subsidized. So, systems based on renewable energies are found to be less attractive. The current slackening in the oil price doesn't help. But, efforts to make NARSE systems economically competitive are making progress. The success of solar energy, especially in its PV cell form of application, is an example.

The hierarchy number 1 was so structured as to be able to address key issues here. An analysis of the results obtained from an AHP run on it showed that the development of appropriate technology is most important as evidenced by the highest weight accorded to R & D organizations. The government plays perhaps the most important role here in supporting all such research activity and also displaying the political will to pursue technologies which, though not completely attractive now, have tremendous long term potential. Such systems need to be thoroughly reliable and have low operating costs. Self sufficiency is a key idea in the Indian ethos. Objectives like indeginization and import substitution are therefore seen to be extremely important. Decentralization is another concept fast gathering in momentum in most third world countries and Indian planners need to see the tremendous potential NARSE systems have in this regard. These systems are so typically suited for remote applications, in areas where the electricity grid does not extend, bringing power and economic progress to vast tracts of the land that have yet to see an electric bulb.

The ultimate ranking of the various NARSE technologies helped in the creation of 5 groups of NARSE baskets as seen in hierarchy 2.

Why groups?

Well, it is hard to see a situation in India where a single NARSE system will fit the bill in every situation. With a natural setting in India extending from hilly areas and dizzy altitudes to valleys and from huge deserts to lengthy coastlines a basket of NARSE technologies is a suitable solution. From the 5 baskets created, AHP helped by expert decisions, zeroed down to the second and the first basket, the former having a greater composite priority value. As explained in chapter three, the combination -

Hydro - Solar - Wind - Sea

certainly is a good and judicious one keeping the resources available in India and the ability to exploit them now and over a long period.

This study also helped us get acquainted with a useful decision making tool - AHP, Analytic Hierarchy Process. It utilizes qualitative descriptions to define a problem and to represent interaction of its parts. It makes use of quantitative judgements to assess the strengths of these interactions.

6.1 Summary

We first need to have a clear idea of our overall objective in the study. With that clear, we should identify how many levels of policy making and influencing interests the hierarchy should have between the focus and the alternatives. This approach elicits and synthesizes information from decision makers and other knowledgeable participants to identify problems and agree on the structure. This process of building up the hierarchy could be particularly long and iterative. It may involve careful study of several aspects of the problem. Once the hierarchy is ready, AHP is used to weight the different options at different levels according to the priority of their importance to the decision maker(s). The different alternatives are evaluated in terms of the criteria chosen and a best one or best mix is chosen. These alternatives are then potential solutions to the problem.

6.2 Suggestions for future work

AHP could be applied to long range strategic planning. This envisages designing of plans or strategies , to cope with a future, that will survive and be effective. Most planning processes move in the forward direction, ie., beginning at the present time and considering the factors and players of the present state, which will generate some logical outcome. The other way - backward planning, begins with a desired outcome and works backward to evaluate the intermediate outcomes required to achieve the desired outcome. Iteration between these two processes narrows the gap and helps in the effort to get the logical outcome to merge with the desired outcome.

Considering an extension to this study, one can imagine a set of goals laid down by the Planning Commission [24]. These goals could be highly specific, as regards the type of NARSE technologies needed, regions where they will be deployed, the amount of power required to be generated etc. Then a set of hierarchies need be generated that can be linked to each other, keeping the various goals in mind. A series of iterative processes then follow, each of which consists of at least one AHP run and restructuring of the hierarchy and its links with other such hierarchies. Or there could be one Main hierarchy continuously interacting with a series of "sub-hierarchies". It could be a very creative exercise and could further extend the power of AHP and also give insight into energy planning.

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[24] The planning arm of the Government of India

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Appendix A. RESULTS FOR RUN 2

Pairwise comparison matrices, solutions and consistencies

$

2 1 4

1.0000	5.0000	7.0000	3.0000
.2000	1.0000	5.0000	.3333
.1429	.2000	1.0000	.2000
.3333	3.0000	5.0000	1.0000

WEIGHTS = .555794 .136396 .048907 .258903

LAMDA(MAX) = 4.240478 C.I. = .080159 C.R. = .089066

$

3 1 4

1.0000	7.0000	5.0000	9.0000
.1429	1.0000	.3333	1.0000
.2000	3.0000	1.0000	5.0000
.1111	1.0000	.2000	1.0000

WEIGHTS = .662434 .071431 .206488 .059648

LAMDA(MAX) = 4.123755 C.I. = .041252 C.R. = .045835

$

3 2 4

1.0000 1.0000 .3333 5.0000

1.0000 1.0000 .2000 5.0000

3.0000 5.0000 1.0000 7.0000

.2000 .2000 .1429 1.0000

WEIGHTS = .195832 .177331 .577089 .049748

LAMDA(MAX) = 4.157887 C.I. = .052629 C.R. = .058477

$

3 3 3

1.0000 .2000 3.0000

5.0000 1.0000 7.0000

.3333 .1429 1.0000

WEIGHTS = .188395 .730636 .080969

LAMDA(MAX) = 3.064991 C.I. = .032495 C.R. = .056027

$

3 4 3

1.0000 3.0000 .3333

.3333 1.0000 .2000

3.0000 5.0000 1.0000

WEIGHTS = .258280 .104728 .636992

LAMDA(MAX) = 3.038456 C.I. = .019228 C.R. = .033152

WEIGHT: .555794 .136396 .048907 .258903

1	.662434	.195832	.188395	.258280
2	.071431	.177331	.730636	.000000
3	.206488	.577089	.000000	.104728
4	.059648	.049748	.080969	.636992

** COMPOSITE PRIORITIES FOR LEVEL 3

.470971 .099621 .220592 .208816

$

4 1 6

1.0000 3.0000 .2500 1.0000 2.0000 .3333

.3333	1.0000	.3333	1.0000	.5000	.2500
4.0000	3.0000	1.0000	3.0000	3.0000	1.0000
1.0000	1.0000	.3333	1.0000	2.0000	.3333
.5000	2.0000	.3333	.5000	1.0000	.2500
3.0000	4.0000	1.0000	3.0000	4.0000	1.0000

WEIGHTS = .126337 .070394 .304017 .107877 .083028 .308347

LAMDA(MAX) = 6.254942 C.I. = .050988 C.R. = .041120

$

4 2 3

1.0000	3.0000	3.0000
.3333	1.0000	2.0000
.3333	.5000	1.0000

WEIGHTS = .593642 .249306 .157052

LAMDA(MAX) = 3.053553 C.I. = .026777 C.R. = .046167

$

4 3 4

1.0000	2.0000	3.0000	4.0000
.5000	1.0000	2.0000	3.0000
.3333	.5000	1.0000	1.0000
.2500	.3333	1.0000	1.0000

WEIGHTS = .469938 .280147 .135606 .114309

LAMDA(MAX) = 4.030934 C.I. = .010311 C.R. = .011457

$

4 4 5

1.0000 .5000 .3333 .5000 .5000

2.0000 1.0000 1.0000 2.0000 1.0000

3.0000 1.0000 1.0000 1.0000 5.0000

2.0000 .5000 1.0000 1.0000 2.0000

2.0000 1.0000 .2000 .5000 1.0000

WEIGHTS = .091866 .242394 .322764 .206645 .136332

LAMDA(MAX) = 5.357029 C.I. = .089257 C.R. = .079694

WEIGHT: .470971 .099621 .220592 .208816

1	.126337	.593642	.000000	.091866
2	.070394	.249306	.469938	.242394
3	.304017	.000000	.280147	.322764
4	.107877	.157052	.000000	.000000
5	.083028	.000000	.135606	.206645
6	.308347	.000000	.114309	.136332

** COMPOSITE PRIORITIES FOR LEVEL 4

.137823 .212270 .272380 .066453 .112168 .198906

$

5 1 5

1.0000 3.0000 5.0000 1.0000 3.0000

.3333 1.0000 3.0000 2.0000 3.0000

.2000 .3333 1.0000 .2500 .5000

1.0000 .5000 4.0000 1.0000 1.0000

.3333 .3333 2.0000 1.0000 1.0000

WEIGHTS = .371351 .246741 .061531 .198745 .121632

LAMDA(MAX) = 5.339614 C.I. = .084904 C.R. = .075807

$

5 2 5

1.0000 .1429 .1667 .3333 .1667

7.0000 1.0000 1.0000 3.0000 2.0000

6.0000 1.0000 1.0000 2.0000 1.0000

3.0000 .3333 .5000 1.0000 .2000

6.0000 .5000 1.0000 5.0000 1.0000

WEIGHTS = .040401 .332085 .251578 .099023 .276914

LAMDA(MAX) = 5.171463 C.I. = .042866 C.R. = .038273

$

5 3 5

1.0000 2.0000 3.0000 .5000 3.0000

.5000 1.0000 2.0000 1.0000 2.0000

.3333 .5000 1.0000 .3333 3.0000

2.0000 1.0000 3.0000 1.0000 2.0000

.3333 .5000 .3333 .5000 1.0000

WEIGHTS = .277381 .201493 .128868 .303236 .089022

LAMDA(MAX) = 5.356015 C.I. = .089004 C.R. = .079468

$

5 4 5

1.0000 2.0000 1.0000 2.0000 2.0000

.5000 1.0000 .5000 1.0000 1.0000

1.0000 2.0000 1.0000 1.0000 2.0000

.5000 1.0000 1.0000 1.0000 1.0000

.5000 1.0000 .5000 1.0000 1.0000

WEIGHTS = .288080 .144040 .254631 .169208 .144040

LAMDA(MAX) = 5.058618 C.I. = .014654 C.R. = .013084

$

5 5 5

1.0000 .2000 .3333 .3333 .1667

5.0000 1.0000 5.0000 5.0000 1.0000

3.0000 .2000 1.0000 1.0000 .2000

3.0000 .2000 1.0000 1.0000 .3333

6.0000 1.0000 5.0000 3.0000 1.0000

WEIGHTS = .049335 .389502 .097017 .106259 .357887

LAMDA(MAX) = 5.161578 C.I. = .040394 C.R. = .036066

$

5 6 5

1.0000 3.0000 2.0000 1.0000 2.0000

.3333 1.0000 2.0000 2.0000 1.0000

.5000 .5000 1.0000 .5000 .3333

1.0000 .5000 2.0000 1.0000 1.0000

.5000 1.0000 3.0000 1.0000 1.0000

WEIGHTS = .318998 .201706 .097117 .187470 .194709

LAMDA(MAX) = 5.314268 C.I. = .078567 C.R. = .070149

WEIGHT: .137823 .212270 .272380 .066453 .112168 .198906

1	.371351	.040401	.277381	.288080	.049335	.318998
2	.246741	.332085	.201493	.144040	.389502	.201706
3	.061531	.251578	.128868	.254631	.097017	.097117
4	.198745	.099023	.303236	.169208	.106259	.187470
5	.121632	.276914	.089022	.144040	.357887	.194709
6	.000000	.000000	.000000	.000000	.000000	.000000

** COMPOSITE PRIORITIES FOR LEVEL 5

.223438 .252763 .144104 .191459 .188236 .000000

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.) = .0592

Appendix B. RESULTS FOR CASE 1

Pairwise comparison matrices, solutions and consistencies.

$

2 1 4

1.0000 3.0000 5.0000 2.0000

.3333 1.0000 3.0000 .5000

.2000 .3333 1.0000 .3333

.5000 2.0000 3.0000 1.0000

WEIGHTS= .476847 .173994 .079511 .269648

LAMDA(MAX)= 4.059333 C.I.= .019778 C.R.= .021975

$

3 1 4

1.0000 7.0000 5.0000 9.0000

.1429 1.0000 .3333 1.0000

.2000 3.0000 1.0000 5.0000

.1111 1.0000 .2000 1.0000

WEIGHTS= .662434 .071431 .206488 .059648

LAMDA(MAX) = 4.123755 C.I. = .041252 C.R. = .045835

$

3 2 4

1.0000 1.0000 .5000 3.0000

1.0000 1.0000 .3333 3.0000

2.0000 3.0000 1.0000 3.0000

.3333 .3333 .3333 1.0000

WEIGHTS = .234870 .216577 .451971 .096583

LAMDA(MAX) = 4.117942 C.I. = .039314 C.R. = .043682

$

3 3 3

1.0000 .3333 2.0000

3.0000 1.0000 5.0000

.5000 .2000 1.0000

WEIGHTS = .229651 .648329 .122020

LAMDA(MAX) = 3.003695 C.I. = .001847 C.R. = .003185

$

3 4 3

1.0000 3.0000 .3333

.3333 1.0000 .2000

3.0000 5.0000 1.0000

WEIGHTS = .258280 .104728 .636992

LAMDA(MAX) = 3.038456 C.I. = .019228 C.R. = .033152

WEIGHT: .476847 .173994 .079511 .269648

1	.662434	.234870	.229651	.258280
2	.071431	.216577	.648329	.104728
3	.206488	.451971	.000000	.000000
4	.059648	.096583	.122020	.636992

** COMPOSITE PRIORITIES FOR LEVEL 3

.444650 .151533 .177103 .226713

$

4 1 6

1.0000 3.0000 .2500 1.0000 2.0000 .3333

.3333 1.0000 .3333 1.0000 .5000 .2500

```
4.0000 3.0000 1.0000 3.0000 3.0000 1.0000
1.0000 1.0000  .3333 1.0000 2.0000  .3333
 .5000 2.0000  .3333  .5000 1.0000  .2500
3.0000 4.0000 1.0000 3.0000 4.0000 1.0000

 WEIGHTS =   .126337   .070394   .304017   .107877   .083028   .308347
 LAMDA(MAX) =   6.254942     C.I. =    .050988     C.R. =    .041120


$
 4 2 3

 1.0000 2.0000 2.0000

  .5000 1.0000 2.0000

  .5000  .5000 1.0000

 WEIGHTS =   .493386   .310814   .195800

 LAMDA(MAX) =   3.053622     C.I. =    .026811     C.R. =    .046225


$
 4 3 4

 1.0000 2.0000 3.0000 4.0000
```

.5000 1.0000 2.0000 3.0000

.3333 .5000 1.0000 1.0000

.2500 .3333 1.0000 1.0000

WEIGHTS = .469938 .280147 .135606 .114309

LAMDA(MAX) = 4.030934 C.I. = .010311 C.R. = .011457

$

4 4 5

1.0000 .5000 .3333 .5000 .5000

2.0000 1.0000 1.0000 2.0000 1.0000

3.0000 1.0000 1.0000 1.0000 5.0000

2.0000 .5000 1.0000 1.0000 2.0000

2.0000 1.0000 .2000 .5000 1.0000

WEIGHTS = .091866 .242394 .322764 .206645 .136332

LAMDA(MAX) = 5.357029 C.I. = .089257 C.R. = .079694

WEIGHT: .444650 .151533 .177103 .226713

1	.126337	.493386	.000000	.091866
2	.070394	.310814	.469938	.242394
3	.304017	.000000	.280147	.322764

4	.107877	.195800	.000000	.000000
5	.083028	.000000	.135606	.206645
6	.308347	.000000	.114309	.136332

** COMPOSITE PRIORITIES FOR LEVEL 4

.151767 .216581 .257971 .077638 .107784 .188259

$

5 1 5

1.0000	2.0000	4.0000	1.0000	2.0000
.5000	1.0000	2.0000	2.0000	2.0000
.2500	.5000	1.0000	.3333	.5000
1.0000	.5000	3.0000	1.0000	1.0000
.5000	.5000	2.0000	1.0000	1.0000

WEIGHTS = .316975 .245993 .082458 .200466 .154108

LAMDA(MAX) = 5.197486 C.I. = .049372 C.R. = .044082

$

5 2 5

1.0000	.2000	.2500	.5000	.2500
5.0000	1.0000	1.0000	2.0000	2.0000

4.0000 1.0000 1.0000 2.0000 1.0000

2.0000 .5000 .5000 1.0000 .3333

4.0000 .5000 1.0000 3.0000 1.0000

WEIGHTS = .060776 .316100 .255509 .119644 .247972

LAMDA(MAX) = 5.095597 C.I. = .023899 C.R. = .021339

$

5 3 5

1.0000 2.0000 3.0000 .5000 2.0000

.5000 1.0000 2.0000 1.0000 2.0000

.3333 .5000 1.0000 .5000 2.0000

2.0000 1.0000 2.0000 1.0000 2.0000

.5000 .5000 .5000 .5000 1.0000

WEIGHTS = .271466 .208726 .128632 .286138 .105038

LAMDA(MAX) = 5.260181 C.I. = .065045 C.R. = .058076

$

5 4 5

1.0000 2.0000 1.0000 2.0000 2.0000

.5000 1.0000 .5000 1.0000 1.0000

1.0000 2.0000 1.0000 1.0000 1.0000

.5000 1.0000 1.0000 1.0000 1.0000

.5000 1.0000 1.0000 1.0000 1.0000

WEIGHTS = .291943 .145972 .225693 .168196 .168196

LAMDA(MAX) = 5.077574 C.I. = .019394 C.R. = .017316

$

5 5 5

1.0000 .3333 .5000 .5000 .2500

3.0000 1.0000 3.0000 3.0000 1.0000

2.0000 .3333 1.0000 1.0000 .2500

2.0000 .3333 1.0000 1.0000 .5000

4.0000 1.0000 4.0000 2.0000 1.0000

WEIGHTS = .078544 .327333 .118982 .135654 .339487

LAMDA(MAX) = 5.090724 C.I. = .022681 C.R. = .020251

$

5 6 5

1.0000 3.0000 2.0000 1.0000 2.0000

.3333 1.0000 2.0000 1.0000 1.0000

.5000 .5000 1.0000 .3333 .5000

1.0000 1.0000 3.0000 1.0000 1.0000

.5000 1.0000 2.0000 1.0000 1.0000

WEIGHTS= .314731 .172145 .098901 .231921 .182302

LAMDA(MAX)= 5.164711 C.I.= .041178 C.R.= .036766

WEIGHT: .151767 .216581 .257971 .077638 .107784 .188259

1	.316975	.060776	.271466	.291943	.078544	.314731
2	.245993	.316100	.208726	.145972	.327333	.172145
3	.082458	.255509	.128632	.225693	.118982	.098901
4	.200466	.119644	.286138	.168196	.135654	.231921
5	.154108	.247972	.105038	.168196	.339487	.182302

** COMPOSITE PRIORITIES FOR LEVEL 5

.221682 .238662 .150002 .201493 .188161

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.)= .0367

Appendix C. RESULTS FOR CASE 2

Pairwise comparison matrices, solutions and consistencies

$

2 1 4

```
1.0000 3.0000 5.0000 2.0000
 .3333 1.0000 3.0000  .5000
 .2000  .3333 1.0000  .3333
 .5000 2.0000 3.0000 1.0000
```

WEIGHTS = .476851 .173991 .079508 .269650

LAMDA(MAX) = 4.059263 C.I. = .019754 C.R. = .021949

$

3 1 4

```
1.0000 5.0000 3.0000 7.0000
 .2000 1.0000  .5000 1.0000
 .3333 2.0000 1.0000 3.0000
 .1429 1.0000  .3333 1.0000
```

WEIGHTS = .589988 .103943 .219602 .086467

LAMDA(MAX) = 4.023434 C.I. = .007811 C.R. = .008679

$

3 2 4

1.0000 1.0000 .5000 3.0000

1.0000 1.0000 .3333 3.0000

2.0000 3.0000 1.0000 3.0000

.3333 .3333 .3333 1.0000

WEIGHTS = .234872 .216574 .451977 .096577

LAMDA(MAX) = 4.117846 C.I. = .039282 C.R. = .043646

$

3 3 3

1.0000 .3333 2.0000

3.0000 1.0000 5.0000

.5000 .2000 1.0000

WEIGHTS = .229645 .648333 .122021

LAMDA(MAX) = 3.003663 C.I. = .001832 C.R. = .003158

$

3 4 3

1.0000 3.0000 .5000

.3333 1.0000 .3333

2.0000 3.0000 1.0000

WEIGHTS = .332516 .139648 .527836

LAMDA(MAX) = 3.053622 C.I. = .026811 C.R. = .046225

WEIGHT: .476851 .173991 .079508 .269650

1	.589988	.234872	.229645	.332516
2	.103943	.216574	.000000	.139648
3	.219602	.451977	.648333	.000000
4	.086467	.096577	.122021	.527836

** COMPOSITE PRIORITIES FOR LEVEL 3

.430124 .124903 .234905 .210068

$

4 1 6

1.0000 2.0000 .3333 1.0000 2.0000 .5000

.5000 1.0000 .5000 1.0000 .5000 .3333

3.0000 2.0000 1.0000 2.0000 2.0000 1.0000

1.0000 1.0000 .5000 1.0000 2.0000 .3333

.5000 2.0000 .5000 .5000 1.0000 .3333

2.0000 3.0000 1.0000 3.0000 3.0000 1.0000

WEIGHTS = .140878 .089820 .256431 .125721 .102344 .284806

LAMDA(MAX) = 6.238089 C.I. = .047618 C.R. = .038401

$

4 2 3

1.0000 2.0000 2.0000

.5000 1.0000 2.0000

.5000 .5000 1.0000

WEIGHTS = .493386 .310814 .195800

LAMDA(MAX) = 3.053622 C.I. = .026811 C.R. = .046225

$

4 3 4

1.0000 2.0000 3.0000 4.0000

.5000 1.0000 2.0000 2.0000

.3333 .5000 1.0000 1.0000

.2500 .5000 1.0000 1.0000

WEIGHTS = .477831 .256120 .137989 .128060

LAMDA(MAX) = 4.010363 C.I. = .003454 C.R. = .003838

$

4 4 5

1.0000 .5000 .5000 .5000 .5000

2.0000 1.0000 1.0000 2.0000 1.0000

2.0000 1.0000 1.0000 1.0000 3.0000

2.0000 .5000 1.0000 1.0000 2.0000

2.0000 1.0000 .3333 .5000 1.0000

WEIGHTS = .105401 .252086 .270228 .216479 .155806

LAMDA(MAX) = 5.243769 C.I. = .060942 C.R. = .054413

WEIGHT: .430124 .124903 .234905 .210068

1	.140878	.493386	.000000	.105401
2	.089820	.310814	.477831	.252086
3	.256431	.000000	.256120	.270228
4	.125721	.195800	.000000	.000000
5	.102344	.000000	.137989	.216479
6	.284806	.000000	.128060	.155806

** COMPOSITE PRIORITIES FOR LEVEL 4

.144362 .242655 .227227 .078532 .121910 .185314

$

5 1 5

1.0000 2.0000 4.0000 1.0000 2.0000

.5000 1.0000 2.0000 2.0000 2.0000

.2500 .5000 1.0000 .3333 .5000

1.0000 .5000 3.0000 1.0000 1.0000

.5000 .5000 2.0000 1.0000 1.0000

WEIGHTS = .316976 .245993 .082457 .200466 .154108

LAMDA(MAX) = 5.197471 C.I. = .049368 C.R. = .044078

$

5 2 5

1.0000 .2000 .2500 .5000 .2500

5.0000 1.0000 1.0000 2.0000 2.0000

4.0000 1.0000 1.0000 2.0000 1.0000

2.0000 .5000 .5000 1.0000 .3333

4.0000 .5000 1.0000 3.0000 1.0000

WEIGHTS = .060776 .316101 .255509 .119642 .247972

LAMDA(MAX) = 5.095582 C.I. = .023896 C.R. = .021335

$

5 3 5

```
1.0000 2.0000 3.0000  .5000 2.0000
 .5000 1.0000 2.0000 1.0000 2.0000
 .3333  .5000 1.0000  .5000 2.0000
2.0000 1.0000 2.0000 1.0000 2.0000
 .5000  .5000  .5000  .5000 1.0000
```

WEIGHTS = .271466 .208726 .128631 .286138 .105038

LAMDA(MAX) = 5.260167 C.I. = .065042 C.R. = .058073

$

5 4 5

```
1.0000 2.0000 1.0000 2.0000 2.0000
 .5000 1.0000  .5000 1.0000 1.0000
1.0000 2.0000 1.0000 1.0000 1.0000
 .5000 1.0000 1.0000 1.0000 1.0000
 .5000 1.0000 1.0000 1.0000 1.0000
```

WEIGHTS = .291943 .145972 .225693 .168196 .168196

LAMDA(MAX) = 5.077574 C.I. = .019394 C.R. = .017316

$

5 5 5

1.0000	.3333	.5000	.5000	.2500
3.0000	1.0000	3.0000	3.0000	1.0000
2.0000	.3333	1.0000	1.0000	.2500
2.0000	.3333	1.0000	1.0000	.5000
4.0000	1.0000	4.0000	2.0000	1.0000

WEIGHTS = .078542 .327335 .118981 .135653 .339489

LAMDA(MAX) = 5.090662 C.I. = .022666 C.R. = .020237

$

5 6 5

1.0000	3.0000	2.0000	1.0000	2.0000
.3333	1.0000	2.0000	1.0000	1.0000
.5000	.5000	1.0000	.3333	.5000
1.0000	1.0000	3.0000	1.0000	1.0000
.5000	1.0000	2.0000	1.0000	1.0000

WEIGHTS = .314732 .172144 .098900 .231921 .182302

LAMDA(MAX) = 5.164683 C.I. = .041171 C.R. = .036760

WEIGHT: .144362 .242655 .227227 .078532 .121910 .185314

1	.316976	.060776	.271466	.291943	.078542	.314732
2	.245993	.316101	.208726	.145972	.327335	.172144
3	.082457	.255509	.128631	.225693	.118981	.098900
4	.200466	.119642	.286138	.168196	.135653	.231921
5	.154108	.247972	.105038	.168196	.339489	.182302

** COMPOSITE PRIORITIES FOR LEVEL 5

.213017 .242913 .153689 .195714 .194666

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.) = .0297

Appendix D. RESULTS FOR CASE 3

Pairwise comparison matrices, solutions and consistencies

$

2 1 4

```
1.0000 5.0000 7.0000 3.0000
 .2000 1.0000 5.0000  .3333
 .1429  .2000 1.0000  .2000

 .3333 3.0000 5.0000 1.0000
```

```
WEIGHTS=   .555794   .136396   .048907   .258903
LAMDA(MAX)=   4.240478     C.I.=    .080159     C.R.=    .089066
```

$

3 1 4

```
1.0000 8.0000 6.0000 9.0000
 .1250 1.0000  .2500 1.0000
 .1667 4.0000 1.0000 6.0000

 .1111 1.0000  .1667 1.0000
```

WEIGHTS = .681200 .059006 .207130 .052664

LAMDA(MAX) = 4.213156 C.I. = .071052 C.R. = .078947

$

3 2 4

1.0000 1.0000 .2500 7.0000

1.0000 1.0000 .1667 6.0000

4.0000 6.0000 1.0000 8.0000

.1429 .1667 .1250 1.0000

WEIGHTS = .182201 .160775 .617164 .039860

LAMDA(MAX) = 4.260620 C.I. = .086873 C.R. = .096526

$

3 3 3

1.0000 .2000 3.0000

5.0000 1.0000 7.0000

.3333 .1429 1.0000

WEIGHTS = .188395 .730636 .080969

LAMDA(MAX) = 3.064991 C.I. = .032495 C.R. = .056027

$

3 4 3

1.0000 4.0000 .2500

.2500 1.0000 .1429

4.0000 7.0000 1.0000

WEIGHTS = .229047 .075429 .695523

LAMDA(MAX) = 3.076415 C.I. = .038207 C.R. = .065875

WEIGHT: .555794 .136396 .048907 .258903

1	.681200	.182201	.188395	.229047
2	.059006	.160775	.000000	.075429
3	.207130	.617164	.730636	.000000
4	.052664	.039860	.080969	.695523

** COMPOSITE PRIORITIES FOR LEVEL 3

.471973 .074253 .235033 .218740

$

4 1 6

1.0000 4.0000 .2000 1.0000 3.0000 .2500

.2500 1.0000 .2500 1.0000 .3333 .2000

5.0000 4.0000 1.0000 4.0000 4.0000 1.0000

1.0000 1.0000 .2500 1.0000 2.0000 .2500

.3333 3.0000 .2500 .5000 1.0000 .2000

4.0000 5.0000 1.0000 4.0000 5.0000 1.0000

WEIGHTS = .122723 .053654 .330764 .089153 .072422 .331283

LAMDA(MAX) = 6.459522 C.I. = .091904 C.R. = .074116

$

4 2 3

1.0000 4.0000 5.0000

.2500 1.0000 3.0000

.2000 .3333 1.0000

WEIGHTS = .673811 .225535 .100654

LAMDA(MAX) = 3.085767 C.I. = .042883 C.R. = .073937

$

4 3 4

1.0000 3.0000 4.0000 5.0000

.3333 1.0000 3.0000 4.0000

.2500 .3333 1.0000 2.0000

.2000 .2500 .5000 1.0000

WEIGHTS = .534911 .269663 .120142 .075283

LAMDA(MAX) = 4.114491 C.I. = .038164 C.R. = .042404

$

4 4 5

1.0000	.3333	.2500	.3333	.3333
3.0000	1.0000	1.0000	3.0000	2.0000
4.0000	1.0000	1.0000	2.0000	6.0000
3.0000	.3333	.5000	1.0000	3.0000
3.0000	.5000	.1667	.3333	1.0000

WEIGHTS = .064568 .296660 .353706 .179668 .105398

LAMDA(MAX) = 5.372706 C.I. = .093177 C.R. = .083193

WEIGHT: .471973 .074253 .235033 .218740

1	.122723	.673811	.000000	.064568
2	.053654	.225535	.534911	.296660
3	.330764	.000000	.269663	.353706
4	.089153	.100654	.000000	.000000
5	.072422	.000000	.120142	.179668

6 .331283 .000000 .075283 .105398

** COMPOSITE PRIORITIES FOR LEVEL 4

.122078 .232683 .296862 .049552 .101720 .197106

$

5 1 5

1.0000	3.0000	5.0000	1.0000	3.0000
.3333	1.0000	3.0000	2.0000	3.0000
.2000	.3333	1.0000	.2500	.5000
1.0000	.5000	4.0000	1.0000	1.0000
.3333	.3333	2.0000	1.0000	1.0000

WEIGHTS= .371353 .246741 .061530 .198747 .121629

LAMDA(MAX)= 5.339548 C.I.= .084887 C.R.= .075792

$

5 2 5

1.0000	.1250	.1250	.2000	.1250
8.0000	1.0000	1.0000	4.0000	3.0000
8.0000	1.0000	1.0000	3.0000	2.0000
5.0000	.2500	.3333	1.0000	.1667

8.0000 .3333 .5000 6.0000 1.0000

WEIGHTS = .029145 .356839 .298160 .085058 .230798

LAMDA(MAX) = 5.382771 C.I. = .095693 C.R. = .085440

$

5 3 5

1.0000 2.0000 3.0000 .5000 3.0000

.5000 1.0000 2.0000 1.0000 2.0000

.3333 .5000 1.0000 .3333 3.0000

2.0000 1.0000 3.0000 1.0000 2.0000

.3333 .5000 .3333 .5000 1.0000

WEIGHTS = .277381 .201493 .128868 .303236 .089022

LAMDA(MAX) = 5.356015 C.I. = .089004 C.R. = .079468

$

5 4 5

1.0000 4.0000 1.0000 4.0000 4.0000

.2500 1.0000 .3333 1.0000 1.0000

1.0000 3.0000 1.0000 1.0000 3.0000

.2500 1.0000 1.0000 1.0000 1.0000

.2500 1.0000 .3333 1.0000 1.0000

WEIGHTS = .389161 .101644 .271079 .136472 .101644

LAMDA(MAX) = 5.188805 C.I. = .047201 C.R. = .042144

$

5 5 5

1.0000 .1667 .2500 .2500 .1429

6.0000 1.0000 6.0000 6.0000 2.0000

4.0000 .1667 1.0000 .3333 .2500

4.0000 .1667 3.0000 1.0000 1.0000

7.0000 .5000 4.0000 1.0000 1.0000

WEIGHTS = .039798 .489275 .080149 .161754 .229024

LAMDA(MAX) = 5.390685 C.I. = .097671 C.R. = .087206

$

5 6 5

1.0000 4.0000 3.0000 1.0000 3.0000

.2500 1.0000 2.0000 2.0000 1.0000

.3333 .5000 1.0000 .3333 .3333

1.0000 .5000 3.0000 1.0000 1.0000

.3333 1.0000 3.0000 1.0000 1.0000

WEIGHTS = .376732 .183213 .076762 .196401 .166892

LAMDA(MAX) = 5.406892 C.I. = .101723 C.R. = .090824

WEIGHT: .122078 .232683 .296862 .049552 .101720 .197106

1	.371353	.029145	.277381	.389161	.039798	.376732
2	.246741	.356839	.201493	.101644	.489275	.183213
3	.061530	.298160	.128868	.271079	.080149	.076762
4	.198747	.085058	.303236	.136472	.161754	.196401
5	.121629	.230798	.089022	.101644	.229024	.166892

** COMPOSITE PRIORITIES FOR LEVEL 5

.232047 .263886 .151860 .196001 .156207

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.) = .0794

Appendix E. RESULTS FOR CASE 4

Pairwise comparison matrices, solutions and consistencies

$

2 1 4

1.0000	6.0000	7.0000	3.0000
.1667	1.0000	5.0000	.2500
.1429	.2000	1.0000	.2000
.3333	4.0000	5.0000	1.0000

WEIGHTS = .560854 .119917 .047581 .271648

LAMDA(MAX) = 4.329768 C.I. = .109923 C.R. = .122136

$

3 1 4

1.0000	8.0000	6.0000	9.0000
.1250	1.0000	.2500	1.0000
.1667	4.0000	1.0000	6.0000
.1111	1.0000	.1667	1.0000

WEIGHTS = .681198 .059006 .207133 .052663

LAMDA(MAX) = 4.213181 C.I. = .071061 C.R. = .078956

$
3 2 4

1.0000 1.0000 .2500 7.0000
1.0000 1.0000 .1667 6.0000
4.0000 6.0000 1.0000 8.0000
.1429 .1667 .1250 1.0000

WEIGHTS = .182201 .160779 .617157 .039863
LAMDA(MAX) = 4.260738 C.I. = .086913 C.R. = .096570

$
3 3 3

1.0000 .2000 4.0000
5.0000 1.0000 8.0000
.2500 .1250 1.0000

WEIGHTS = .199071 .733384 .067545
LAMDA(MAX) = 3.094015 C.I. = .047008 C.R. = .081048

$
3 4 3

1.0000	4.0000	.2500
.2500	1.0000	.1429
4.0000	7.0000	1.0000

WEIGHTS= .229049 .075438 .695513

LAMDA(MAX)= 3.076547 C.I.= .038273 C.R.= .065989

WEIGHT: .560854 .119917 .047581 .271648

1	.681198	.182201	.199071	.229049
2	.059006	.160779	.000000	.075438
3	.207133	.617157	.733384	.000000
4	.052663	.039863	.067545	.695513

** COMPOSITE PRIORITIES FOR LEVEL 3

.475594 .072866 .225074 .226465

$

4 1 6

1.0000	4.0000	.2000	1.0000	3.0000	.2500
.2500	1.0000	.2500	1.0000	.3333	.2000

5.0000 4.0000 1.0000 4.0000 4.0000 1.0000

1.0000 1.0000 .2500 1.0000 2.0000 .2500

.3333 3.0000 .2500 .5000 1.0000 .2000

4.0000 5.0000 1.0000 4.0000 5.0000 1.0000

WEIGHTS = .122723 .053653 .330765 .089153 .072422 .331284

LAMDA(MAX) = 6.459503 C.I. = .091901 C.R. = .074113

$

4 2 3

1.0000 4.0000 5.0000

.2500 1.0000 3.0000

.2000 .3333 1.0000

WEIGHTS = .673813 .225535 .100652

LAMDA(MAX) = 3.085742 C.I. = .042871 C.R. = .073916

$

4 3 4

1.0000 3.0000 4.0000 5.0000

.3333 1.0000 3.0000 4.0000

.2500 .3333 1.0000 2.0000

.2000 .2500 .5000 1.0000

WEIGHTS = .534914 .269661 .120141 .075284

LAMDA(MAX) = 4.114456 C.I. = .038152 C.R. = .042391

$

4 4 5

1.0000	.3333	.2500	.3333	.3333
3.0000	1.0000	1.0000	3.0000	2.0000
4.0000	1.0000	1.0000	2.0000	6.0000
3.0000	.3333	.5000	1.0000	3.0000
3.0000	.5000	.1667	.3333	1.0000

WEIGHTS = .064564 .296662 .353709 .179667 .105398

LAMDA(MAX) = 5.372648 C.I. = .093162 C.R. = .083180

WEIGHT: .475594 .072866 .225074 .226465

1	.122723	.673813	.000000	.064564
2	.053653	.225535	.534914	.296662
3	.330765	.000000	.269661	.353709
4	.089153	.100652	.000000	.000000
5	.072422	.000000	.120141	.179667
6	.331284	.000000	.075284	.105398

** COMPOSITE PRIORITIES FOR LEVEL 4

.122086 .229530 .298106 .049735 .102172 .198370

$

5 1 5

1.0000	4.0000	6.0000	1.0000	4.0000
.2500	1.0000	4.0000	2.0000	4.0000
.1667	.2500	1.0000	.2000	.3333
1.0000	.5000	5.0000	1.0000	1.0000
.2500	.2500	3.0000	1.0000	1.0000

WEIGHTS = .412259 .242863 .045025 .191535 .108319

LAMDA(MAX) = 5.527277 C.I. = .131819 C.R. = .117696

$

5 2 5

1.0000	.1250	.1250	.2000	.1250
8.0000	1.0000	1.0000	4.0000	3.0000
8.0000	1.0000	1.0000	3.0000	2.0000
5.0000	.2500	.3333	1.0000	.1667
8.0000	.3333	.5000	6.0000	1.0000

WEIGHTS = .029145 .356840 .298161 .085058 .230796

LAMDA(MAX) = 5.382754 C.I. = .095688 C.R. = .085436

$

5 3 5

1.0000	3.0000	4.0000	.5000	4.0000
.3333	1.0000	3.0000	1.0000	3.0000
.2500	.3333	1.0000	.2500	4.0000
2.0000	1.0000	4.0000	1.0000	2.0000
.2500	.3333	.2500	.5000	1.0000

WEIGHTS = .316518 .202692 .108024 .302827 .069939

LAMDA(MAX) = 5.648537 C.I. = .162134 C.R. = .144763

$

5 4 5

1.0000	4.0000	1.0000	4.0000	4.0000
.2500	1.0000	.3333	1.0000	1.0000
1.0000	3.0000	1.0000	1.0000	3.0000
.2500	1.0000	1.0000	1.0000	1.0000
.2500	1.0000	.3333	1.0000	1.0000

WEIGHTS = .389162 .101642 .271079 .136473 .101642

LAMDA(MAX) = 5.188771 C.I. = .047193 C.R. = .042136

$
5 5 5

1.0000	.1667	.2500	.2500	.1429
6.0000	1.0000	6.0000	6.0000	2.0000
4.0000	.1667	1.0000	.3333	.2500
4.0000	.1667	3.0000	1.0000	1.0000
7.0000	.5000	4.0000	1.0000	1.0000

WEIGHTS = .039802 .489267 .080152 .161756 .229023

LAMDA(MAX) = 5.390869 C.I. = .097717 C.R. = .087248

$
5 6 5

1.0000	4.0000	3.0000	1.0000	3.0000
.2500	1.0000	2.0000	2.0000	1.0000
.3333	.5000	1.0000	.3333	.3333
1.0000	.5000	3.0000	1.0000	1.0000
.3333	1.0000	3.0000	1.0000	1.0000

WEIGHTS = .376735 .183215 .076758 .196402 .166890

LAMDA(MAX) = 5.406820 C.I. = .101705 C.R. = .090808

WEIGHT: .122086 .229530 .298106 .049735 .102172 .198370

1	.412259	.029145	.316518	.389162	.039802	.376735
2	.242863	.356840	.202692	.101642	.489267	.183215
3	.045025	.298161	.108024	.271079	.080152	.076758
4	.191535	.085058	.302827	.136473	.161756	.196402
5	.108319	.230796	.069939	.101642	.229023	.166890

** COMPOSITE PRIORITIES FOR LEVEL 5

.249531 .263369 .143035 .195456 .148609

CONSISTENCY RATIO OF THE HIERARCHY (C.R.H.) = .0943

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