Integrated energy planning: Part II. Examples of DEFENDUS scenarios

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The first part of this paper presented an* ab initio *exposition of the development-focused end-use-oriented service-directed (DEFENDUS) approach to energy planning. In this approach, the future demand for any source of energy is estimated on the basis of the energy services required and the efficiency with which these are provided. To meet this demand, the costs per unit of the available energy-supply/saving technologies are estimated and a least-cost mix of options identified.
In this second part, some of the energy studies for which the DEFENDUS method has been used are described to demonstrate that its applicability is not confined to a particular region or source of energy. These studies include: electricity for five states of India, petroleum products for the country as a whole, biomass for the state of Karnataka, and a composite energy scenario for Karnataka involving integration of all the currently-used sources of energy.
In every case, the energy usage pattern in the commencement year of the plan, i.e., the total energy usage disaggregated between the existing categories of users according to their end-uses, is obtained. Then, depending on the goals selected and the strategies that could be adopted to achieve them, growth rates for each category of users are used to estimate the number of users in future years. Improvement in the efficiency of end-use devices and/or substitution of energy sources are considered, to determine the possible reduction in the category-wise unit energy usage, and the corresponding energy requirement is estimated.
The electricity plan for the state of Karnataka comprises future demand estimation as well as the comparative costs of various supply/saving options. For the other states, electricity demand has been estimated in various scenarios. In the oil scenarios for India, the focus is mainly on demand management through modal and carrier shifts, with emphasis on the middle distillates. The biomass strategy for Karnataka includes both demand- and supply-side measures.
All these studies show that the DEFENDUS planning procedure is easily amenable to modification according to the particular case under consideration. Further, the integration of worksheets for individual sources of energy demonstrates that this method, though simple, is capable of dealing with composite energy planning. Above all, with the popularity of personal computers and spreadsheet packages, the DEFENDUS method facilitates the democratization of energy planning.

1. Introduction

The first DEFENDUS demand and (least-cost) supply scenarios were for the electricity sector of Karnataka (referred to in Part I of the paper, [A.K.N. Reddy et al., 1995]). Since then, demand scenarios have been constructed for the electricity sectors of some other states in India, for biomass in Karnataka and for petroleum derivatives in the energy sector of India as a whole. The highlights of all these scenarios are presented below as examples of the potentialities of the DEFENDUS methodology.

2. Electricity demand and supply scenarios for Karnataka state (India) *(Figure 1)*

2.1. Scope of scenarios

The electricity demand and supply scenarios [Reddy et al., 1991] for Karnataka state[1] in South India consisted of the domestic, commercial, agricultural and industrial sectors. The domestic sector itself comprised two categories – domestic lighting and all-electric homes (AEH)[2] – and the industrial sector included low-tension (LT)[3] and high-tension (HT)[4] installations. Further, the following end-use devices have been considered for the various categories of electricity users:

- AEHs – bulbs, water-heaters, stoves, and ''others'' including refrigerators, fans, irons, television sets, mixers, music equipment, etc.;
- domestic lighting – bulbs and some small devices;
- agricultural sector – irrigation pumpsets;
- commercial sector – a variety of lighting devices and refrigeration and space-cooling equipment; and
- industrial sector – equipment for process-heating (elec-

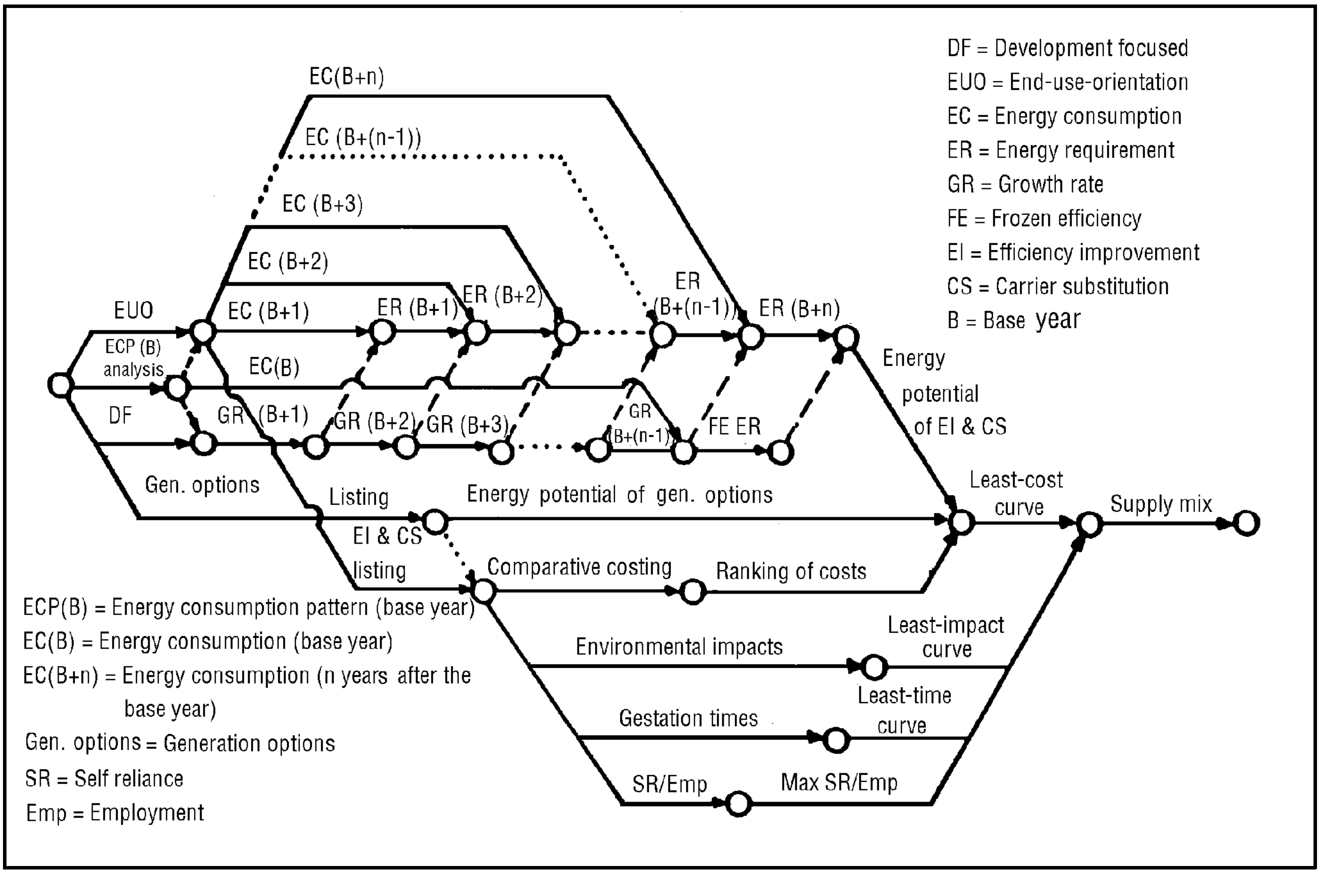

Fig. 1. Construction of DEFENDUS scenarios.

tric arc furnaces, etc.), motors for shaft power, compressing, pumping, blowing, material-handling, and other devices.

2.2. Base year consumption pattern

In the base year 1986-87, the pattern of usage of 7.554 TWh of electricity was as follows: HT 45%, AEH 17%, agriculture 17%, LT 11%, domestic lighting 8%, and commercial 3%; this usage was met primarily by hydroelectric power (85%).

2.3. Goal

The objective was to use electricity for the promotion of economic growth, along with the developmental objectives of employment generation and improvement in the quality of life.

2.4. Strategy

The DEFENDUS electricity strategy for Karnataka to achieve the goal of the electricity system has been based on a number of energy measures. The development-focused measures consist of the electrification of all homes and a structural shift towards less power-intensive and more employment-intensive industries through governmental policies.[5] The end-use-oriented measures consist of efficiency improvements, carrier substitution and peak-load management. The augmentation of electricity supplies is based on reduction of transmission and distribution (T&D) losses, cogeneration of surplus electricity in sugar factories, non-conventional electricity supplies (small hydroelectric, etc.) and biomass-based decentralized electricity generation for villages.

2.5. Demand scenario

The year 1986-87 was taken as the base year for the estimation of the Karnataka's category-wise electricity requirement till 1999-2000. Using the actual consumption and the information regarding demand and power cuts, the ‘‘true’’[6] electricity demand was estimated. Given the number of connections in each category, the average electricity consumption per consumer in each category was calculated for this base year.

The average compound annual rate of growth in the number of connections in each sector was computed for the preceding half decade. These growth rates were used to project the number of connections in the year 1990-91. For subsequent years, growth rates were assumed for each sector depending on this past trend as well as on an increase in electrification warranted by developmental considerations – for example, the growth rate of lighting connections in the domestic sector was enhanced to hasten complete household electrification, the growth of connections for small industrial units was raised to increase the employment potential, and so on.

The end-use orientation was incorporated in the scenario through efficiency improvement and carrier substitution measures. The efficiency improvements included were replacement of incandescent bulbs by compact fluorescent bulbs (resulting in a 62% reduction in the usage per household for lighting) and retrofitting irrigation pumpsets (resulting in a 30% reduction in electricity usage). The carrier substitution included solar energy and

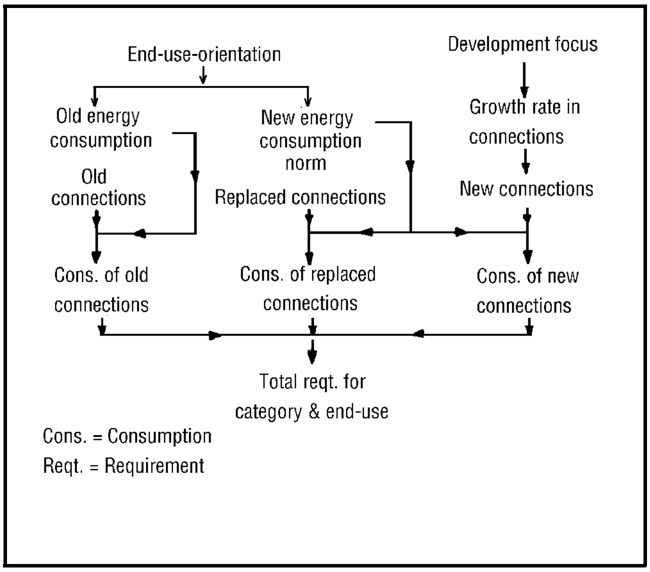

Fig. 2. Estimation of the total electricity requirement per category.

liquified petroleum gas (LPG) for domestic water-heating and cooking, respectively. In addition, a variety of efficiency improvements were considered, amounting to a reduction in energy usage to the extent of 25% in the HT industrial category, 15% in the LT industrial category, and 15% in the commercial sector (chiefly through improved lighting devices). The new average electricity usage for LT industry, HT industry and the commercial sectors reflected the cumulative efficiency improvements in these categories.

For the frozen-efficiency scenario (FE), the electricity usage per consumer was left unchanged; only the development focus was considered by altering the category-wise growth rates as mentioned above. Thus, for each successive year till the planning horizon, the category-wise electricity demand was computed as the product of the number of users (or connections) in each category (calculated using the given growth rate) and the unchanged electricity requirement per user in that category.

However, for the scenario which includes both a development focus and end-use efficiency improvements/carrier substitution, both the requirement per consumer and the growth of connections were treated as variables. A proportion of the consumers was assumed to shift to more efficient usage each year, while all the new consumers were expected to adopt the new (lower) usage norms associated with more efficient devices. This implies that, for each planning year, there would be three types of connections to be dealt with, namely, the old connections with the existing rate of usage, the retrofitted connections with the new (lower) average usage and the new connections – also with the new usage norm. The total demand would then be the sum of requirements of these three types of connections (Figure 2). Estimation of demand in this efficiency scenario leads to a *lower bound* for the energy requirement, which when compared with the FE scenario quantifies the maximum energy that could be saved through efficiency improvement and carrier substitution measures.

2.6. Supply scenario

A comparative costing exercise was then carried out for 16 electricity generation/conservation options [Reddy et al., 1990]. On the basis of these unit costs (Figures 3 and 4), electricity cost-supply curves were constructed to indicate how Karnataka's frozen-efficiency electricity demand (for energy and for power) in the year 1999-2000 could be met (Figures 5 and 6).

3. Electricity demand – other states

3.1. Scope of scenario

By suitably altering the Karnataka spreadsheet, electricity demand forecasts till the year 2004-05 (with provision for reduction in the average electricity usage and without) have been made for some other Indian states – Maharashtra [Sant and Dixit, 1993], Madhya Pradesh, Andhra Pradesh and Gujarat. As a first approximation, the Karnataka end-use proportions were used for similar sectors in other states whenever data were not obtained. Although the electricity-consuming categories in these other states differed from those of Karnataka, the procedure used for the demand estimation was similar. For instance, the states of Maharashtra, Andhra Pradesh and Gujarat had been using electricity for railway traction, so that this additional sector had to be included in these analyses[7]. The distinction between the two domestic categories also differed from state to state. In Andhra Pradesh and Gujarat, the domestic electricity usage was not disaggregated further. In Madhya Pradesh, the classification till 1982-83 consisted of ''lights and fans'' and ''power''; thereafter, only one category was maintained. (However, to facilitate disaggregation by end-use, the old distinction was retained for our analysis.)

3.2. Goal

As in the case of Karnataka, the main purpose was the use of electricity to promote growth along with the developmental objectives of employment generation and improvement in the quality of life.

3.3. Strategy

The energy measures that are the basis of the DEFENDUS electricity strategy for other states to achieve the goal of the electricity system are similar to those considered for Karnataka. Thus, the development-focused measures consist of the rapid electrification of all homes and a gradual structural shift to less power-intensive and higher employment-generating industries. The end-use-oriented measures consist of efficiency improvements, carrier substitution and peak-load management. The augmentation of electricity supplies is based on reduction of T&D losses, cogeneration of surplus electricity in sugar factories, non-conventional electricity supplies (small hydroelectric plants, etc.) and biomass-based decentralized electricity generation for villages.

3.3. Demand scenarios

For the demand scenarios, future sectoral growth rates were selected according to the shares of total electricity usage, past growth rates and specific objectives. Here, appropriate changes were made in the Karnataka scenarios

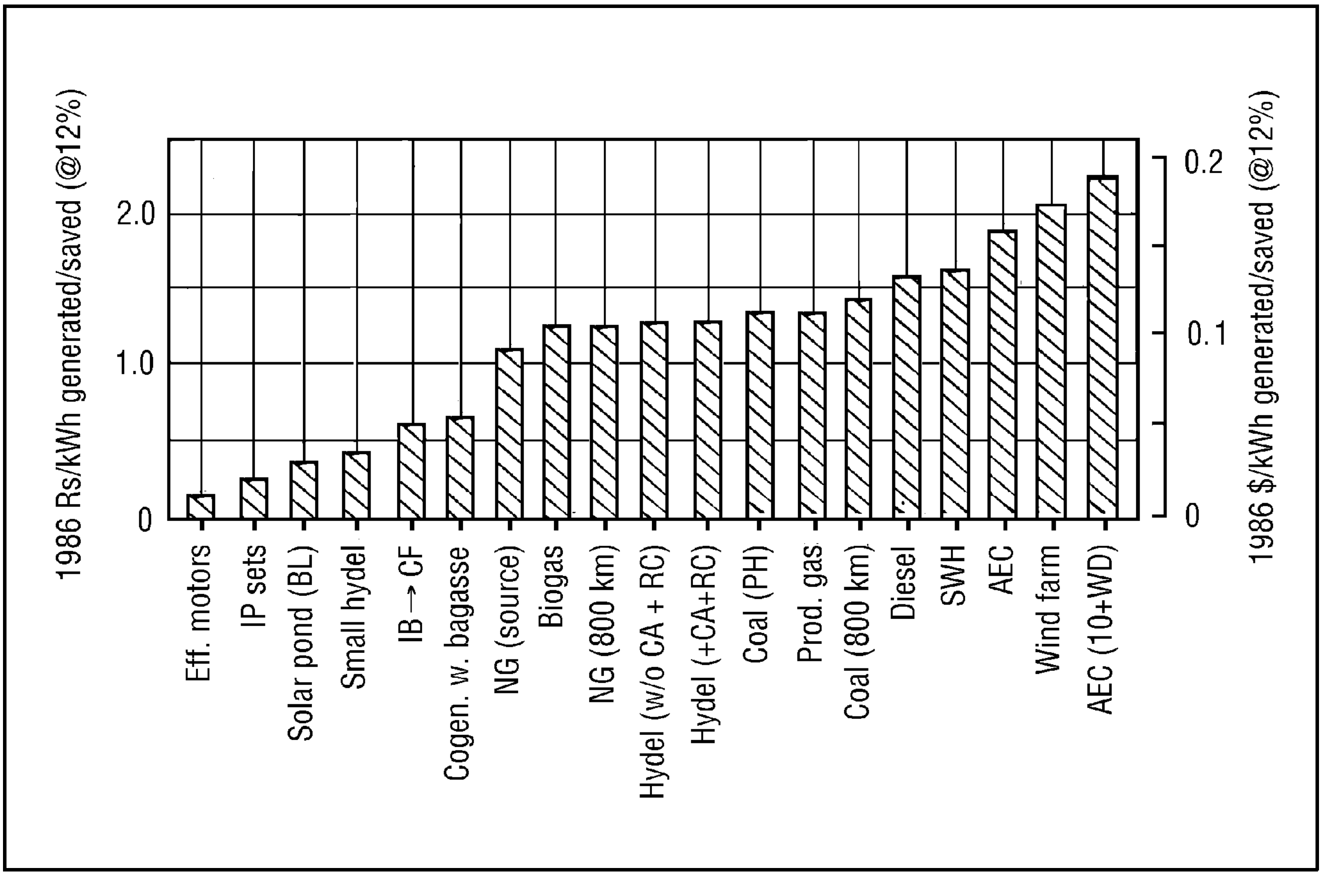

Fig.3. Unit costs of electricity in Karnataka *(including transmission and distribution for centralized sources)* @ 1986-87 prices.

Explanation of legends

Eff. motors: replacement of standard motors with efficient motors.

IP sets: improved irrigation pumpsets (with frictionless foot-valves and HDPE piping).

BL: base load.

IB → CF: replacement of incandescent bulbs with compact fluorescent lamps.

Cogen w. bagasse: cogeneration with bagasse in sugar factories

NG (source): natural-gas based thermal power plants (near the source of gas)

Biogas: biogas (+ diesel)-driven gensets.

NG (800 km): natural-gas based thermal power plants (800 km from the source of gas).

Hydel (+CA+RC): hydel power plants whose costs include compensatory afforestation and rehabilitation costs.

Coal (PH): coal-based thermal power plants (at the pit-head).

Prod. gas: producer-gas (+ diesel)-driven gensets.

SWH: solar water heaters replacing electric water heaters.

AEC: nuclear power plants (based on Atomic Energy Commission data, 8-year construction period).

AEC (10+WD): nuclear power plants whose costs include a 10-year construction period and waste disposal expenses (with Atomic Energy Commission data)

where the situation in the other states differed from that in Karnataka; otherwise, the Karnataka scenario was replicated as the default scenario. For instance, in the industrial sector, Gujarat had a disaggregation between LT and HT like Karnataka, so that growth rates could be planned in a similar manner. Madhya Pradesh had five main power-intensive industries through which substantial reduction in electricity usage could be considered. Andhra Pradesh showed a separate category for cottage industries; equity and employment considerations would warrant additional encouragement for this group.

The technically possible efficiency improvements determined future electricity usage per consumer.

The main difference between the DEFENDUS scenarios for the other states and that described in Section 2 is that the planned rate of implementation of efficiency improvements (and/or carrier substitution) is not assumed to be constant (a uniform 20% per annum for five years) but is expected to approximate a logistic (S-shaped) curve[8]. This implies that the proportion of connections that acquires the improved devices each year is determined by the parameters entered in the logistic equation.

Two DEFENDUS scenarios – frozen-efficiency and improved-efficiency – were constructed for each state and the electricity demand estimated for each year till 2004-05. In all cases, it was observed that the energy requirements in the DEFENDUS scenarios were much less than in the business-as-usual projections. Figures 7a, 7b and 7c illustrate the results obtained for Madhya Pradesh, Andhra Pradesh and Gujarat, respectively. (These analyses

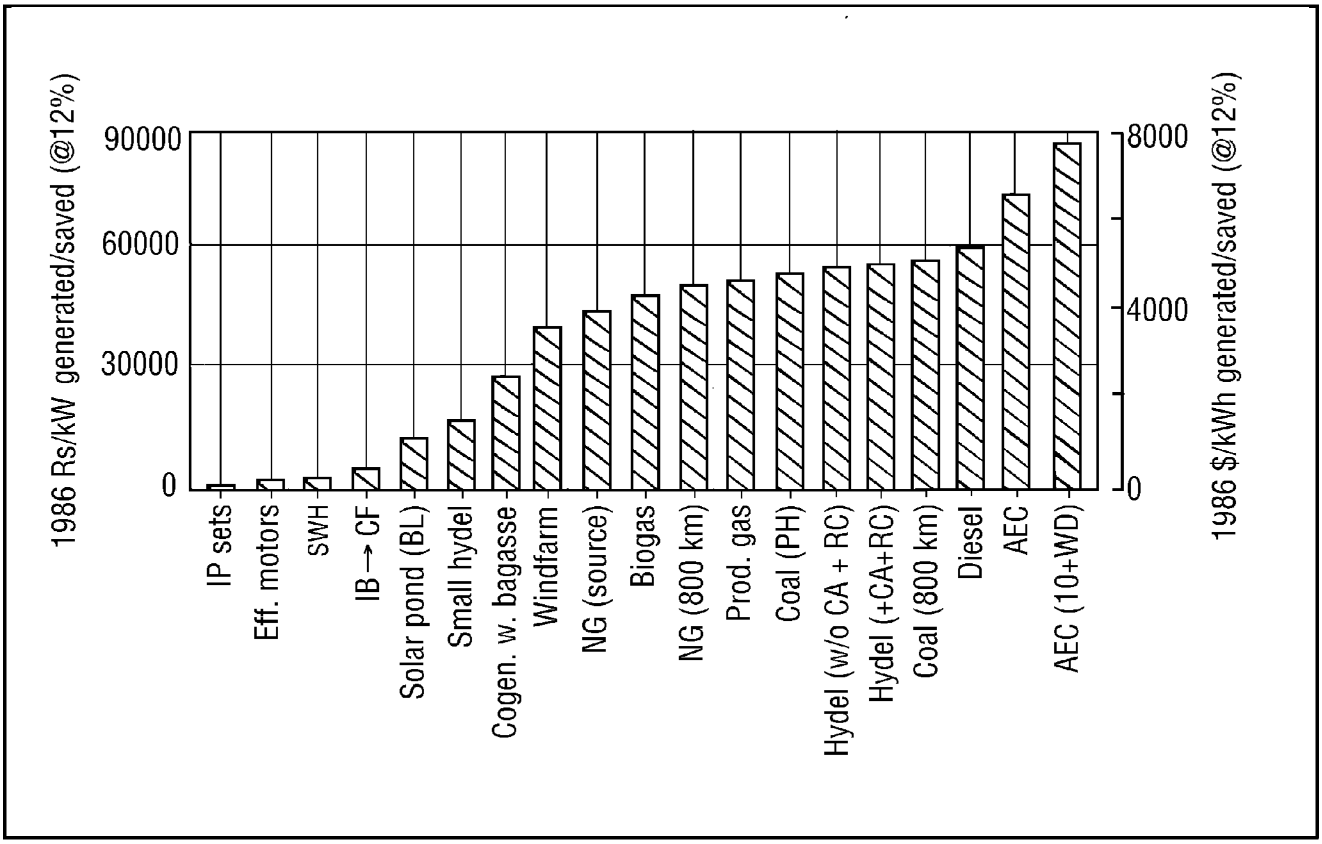

Fig. 4. Unit costs of power in Karnataka *(including transmission and distribution for centralized sources)* @ 1986-87 prices.

were completed in 1993 according to the data available at the time. A rigorous study is currently being conducted by some of the state electricity boards using the DEFENDUS method; the new estimates will differ from the figures shown here in accordance with the refined data and assumptions).

4. Petroleum products – all-India

4.1. Scope of scenario

The all-India requirement of various petroleum products – diesel (high speed diesel and light diesel oil), kerosene, liquefied petroleum gas (LPG), motor spirit (petrol), furnace oil (fuel oil) and aviation turbine fuel (ATF) – for energy purposes in the year 1986-87 was analysed [Reddy et al., 1992]. On the basis of existing and expected needs, scenarios for the sectoral demand for all these petroleum products in the year 1999-2000 were constructed.

The consumption of each distillate has been disaggregated between the main services provided. Diesel use has been for freight haulage by road (comprising trucks and light commercial vehicles), passenger transport by road (chiefly buses), freight haulage by rail, passenger transport by rail, water transport (ferry- and fishing-boats), agricultural equipment (tractors, tillers and irrigation pumpsets), and miscellaneous uses (gensets, etc.). Motor spirit (petrol) is used for road transport, that is, for cars, taxis and jeeps, three-wheelers, and two-wheelers. Furnace oil is used for industrial purposes (process heating, etc.) and shipping. Kerosene is disaggregated between domestic lighting and cooking and commercial cooking. LPG is used chiefly by the domestic and commercial (service) sectors for cooking.

4.2. Base year consumption pattern

In the base year 1986-87, the oil consumption was 43.66 million tonnes, distributed thus: 36% transport, 31% industry, 17% domestic, 11% agriculture and 5% power generation. The pattern of consumption of petroleum products was: 17% light distillates, 61% middle distillates and 22% heavy distillates. Within middle distillates, the distribution was 64% high speed diesel, 26% kerosene, 5% aviation turbine fuel and 5% light diesel oil.

4.3. Goal

The main objective was to reduce oil consumption and, thereby, the oil import bill. This in turn was necessitated by the country's persistently negative balance of trade, to which oil imports had contributed[9].

4.4. Strategy

Reduction of consumption would have to be achieved by using petroleum products more efficiently and prudently. This would require a large number of measures. However, as the middle distillates (chiefly diesel and kerosene) accounted for over 60% of the consumption of all petroleum products and 93% of the total imports of petroleum products (in quantitative terms), our near-term strategy was to focus on middle distillates. At this juncture, therefore, only the following measures applicable to diesel and kerosene were considered.

- *Diesel*
  - shifting long-distance freight from trucks to the railways[10]

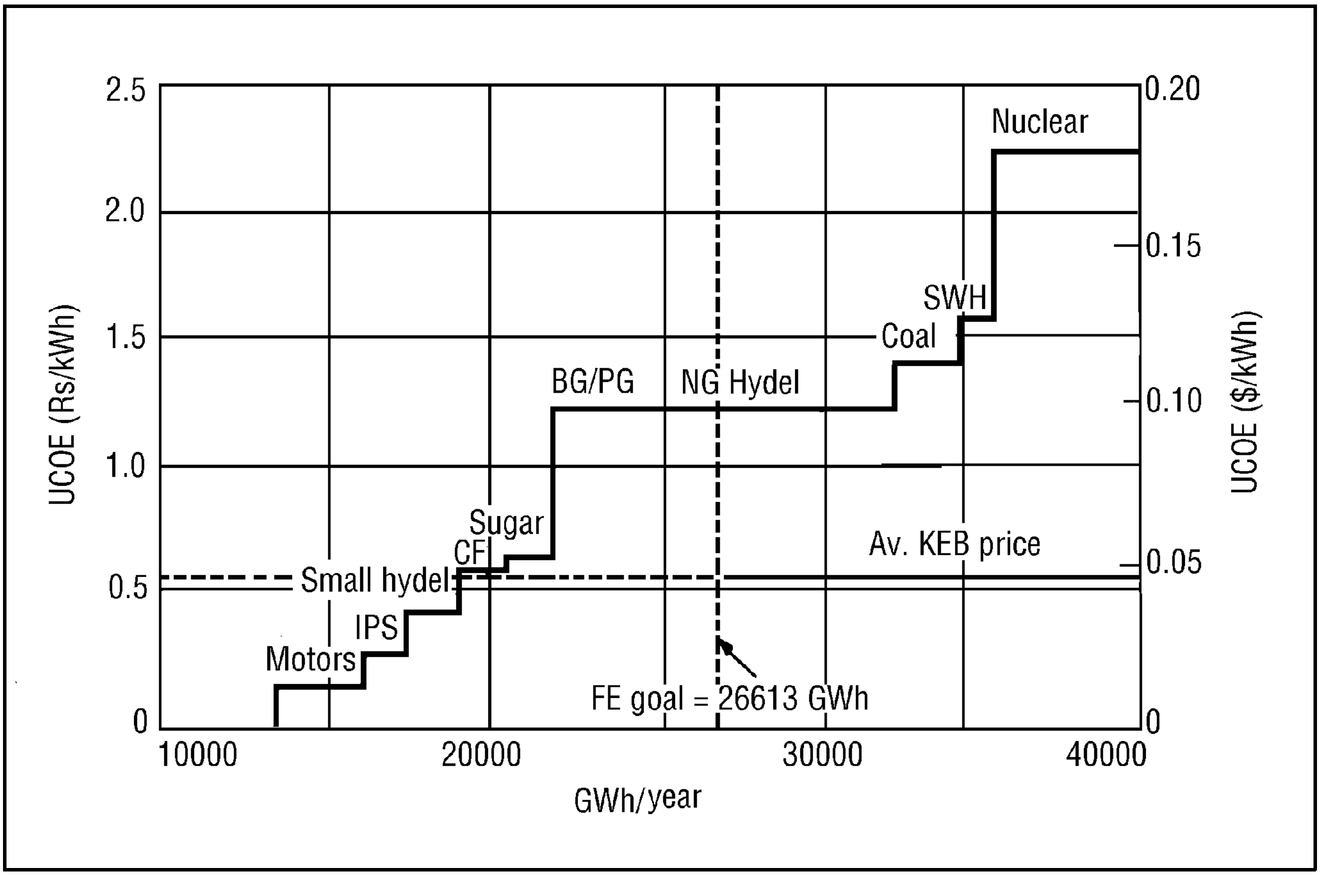

Fig. 5. Electricity cost-supply curve for Karnataka (@ 1986-87 prices).

Explanations:

Motors: replacement of the existing motors with efficient motors.

IPs: improved irrigation pumpsets.

Small hydel: small hydroelectric power plants.

CF: replacement of incandescent bulbs with compact fluorescent lamps.

Sugar: cogeneration (with bagasse) in sugar factories.

BG/PG: small generation plants based on biogas and producer gas (& diesel gensets) in rural areas.

NG: natural-gas based thermal power plants.

Hydel: hydroelectric power plants.

Coal: coal-based thermal power plants.

SWH: solar water heaters replacing electric water heaters in the domestic sector.

AEC: nuclear power plants.

Av. KEB price: the weighted average of the electricity tariff charged by the Karnataka Electricity Board.

FE goal: electricity requirement (goal) in the frozen efficiency scenario.

UCOE: unit cost of electricity.

   - replacing diesel-run irrigation pumpsets with electric pumpsets[11]
- *Kerosene*
   - replacing kerosene lighting with electric lighting
   - replacing kerosene cooking stoves with LPG stoves[12]

Thus, for the near term, only inter-carrier and inter-modal shifts have been considered.

A medium-term strategy would include improvements in the efficiency of the end-use devices and equipment based on detailed technical analysis. There could also be inter-carrier shifts involving other distillates, such as shift from petrol-driven (mostly private) passenger vehicles (four-wheelers, three-wheelers, and two-wheelers) to diesel-run (mass transport) buses and from petrol to compressed natural gas. These were not considered at the time of the study because of the preponderance of middle distillates (diesel and kerosene) in India's petroleum consumption and imports and the resultant effects on the debt burden.

A long-term strategy would also have to include a shift to alternative non-petroleum-based fuels, preferably fuels from renewable sources.

4.4. Demand scenario

Three different scenarios were created for the future. First, a business-as-usual scenario was drawn up, in which the growth rates obtained during the eighties were assumed to apply till the end of the horizon year. This was a mere

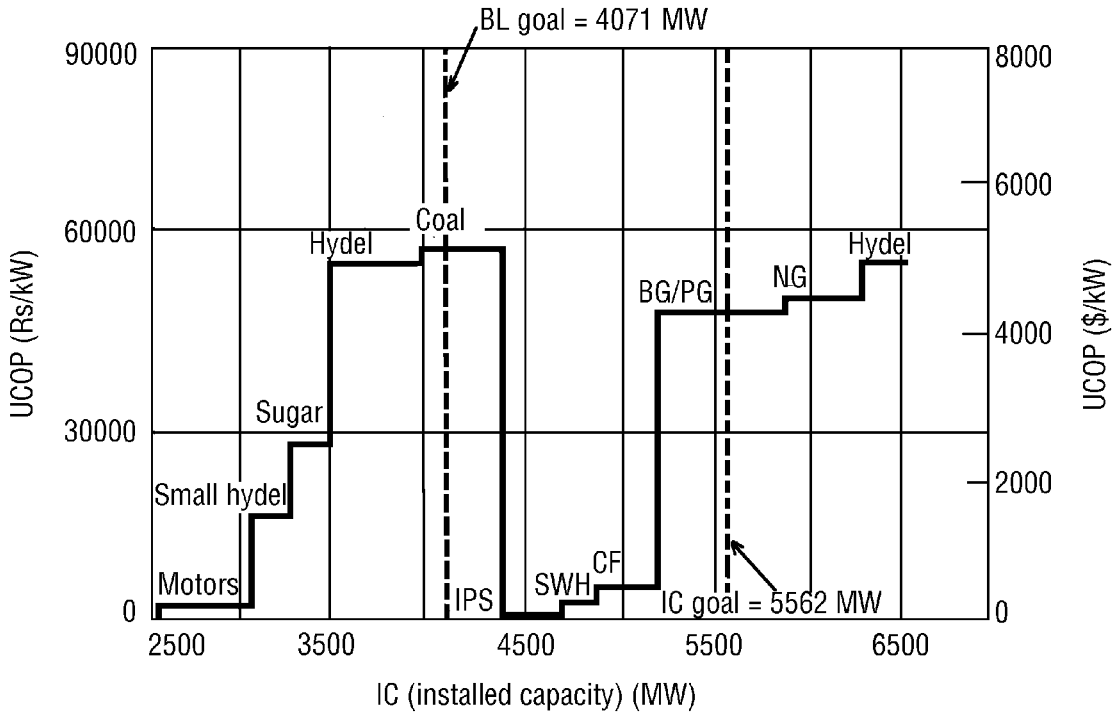

Fig. 6. Electricity cost-capacity curve for Karnataka (@ 1986-87 prices).

Note

This cost-capacity curve shows the potential for capacity increases through the relevant options, in increasing order of unit cost of power (UCOP). It does *not* indicate a chronological sequence; rather, all the options could commence simultaneously.

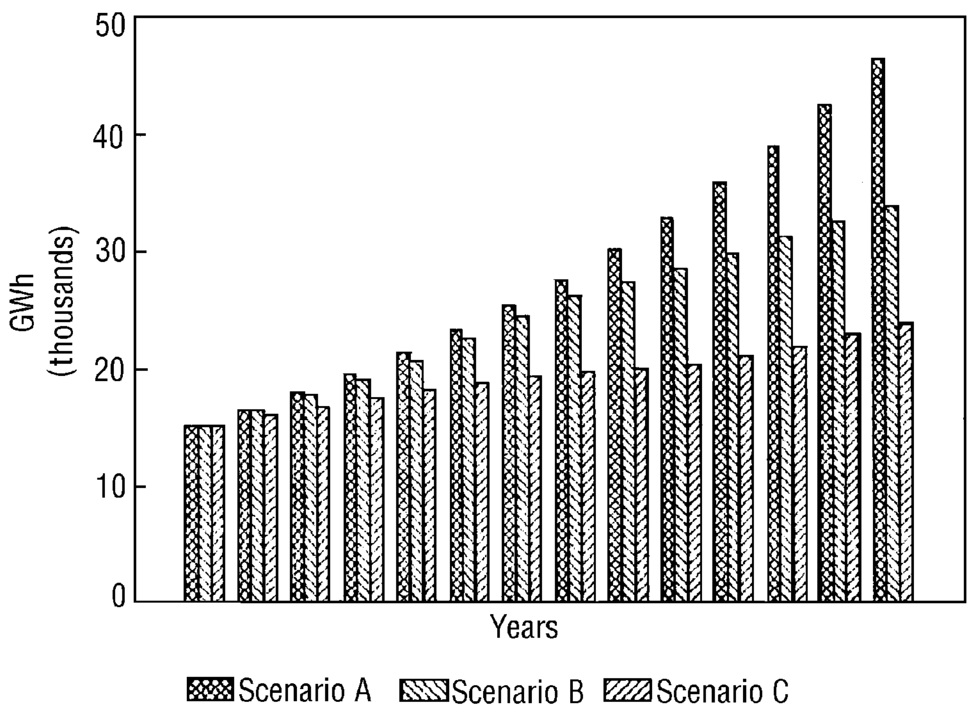

Fig. 7a. Estimated electricity requirement for the state of Madhya Pradesh (1991-92 to 2004-05).

Notes

Scenario A: Projected growth of demand @ 9% per year.

Scenario B: Frozen efficiency scenario (consisting of changed sectoral growth rates, but no efficiency improvements).

Scenario C: Improved scenario (consisting of changed sectoral growth rates, efficiency improvements and carrier substitution).

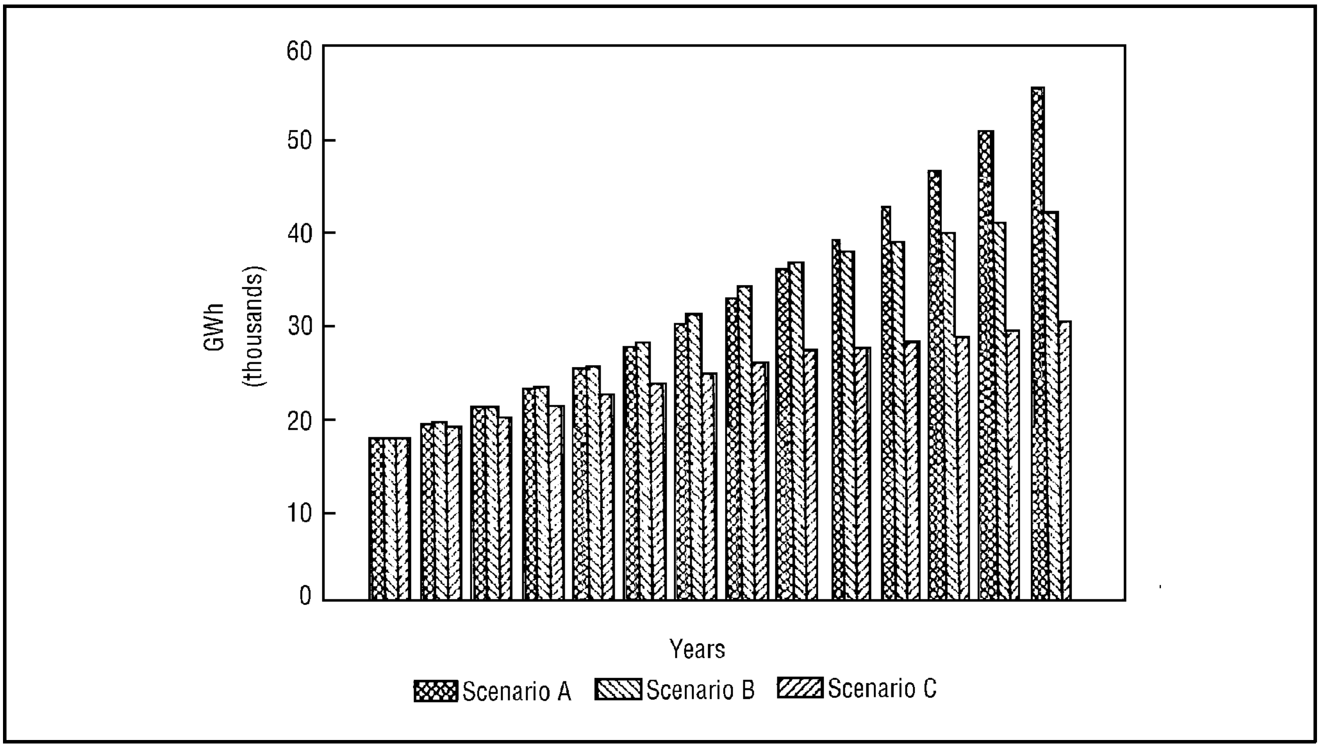

Fig. 7b. Estimated electricity requirement for the state of Andhra Pradesh (1991-92 to 2004-05).

Notes

Scenario A: Projected growth of demand @ 9% per year.

Scenario B: Frozen efficiency scenario (consisting of changed sectoral growth rates, but no efficiency improvements).

Scenario C: Improved scenario (consisting of changed sectoral growth rates, efficiency improvements and carrier substitution).

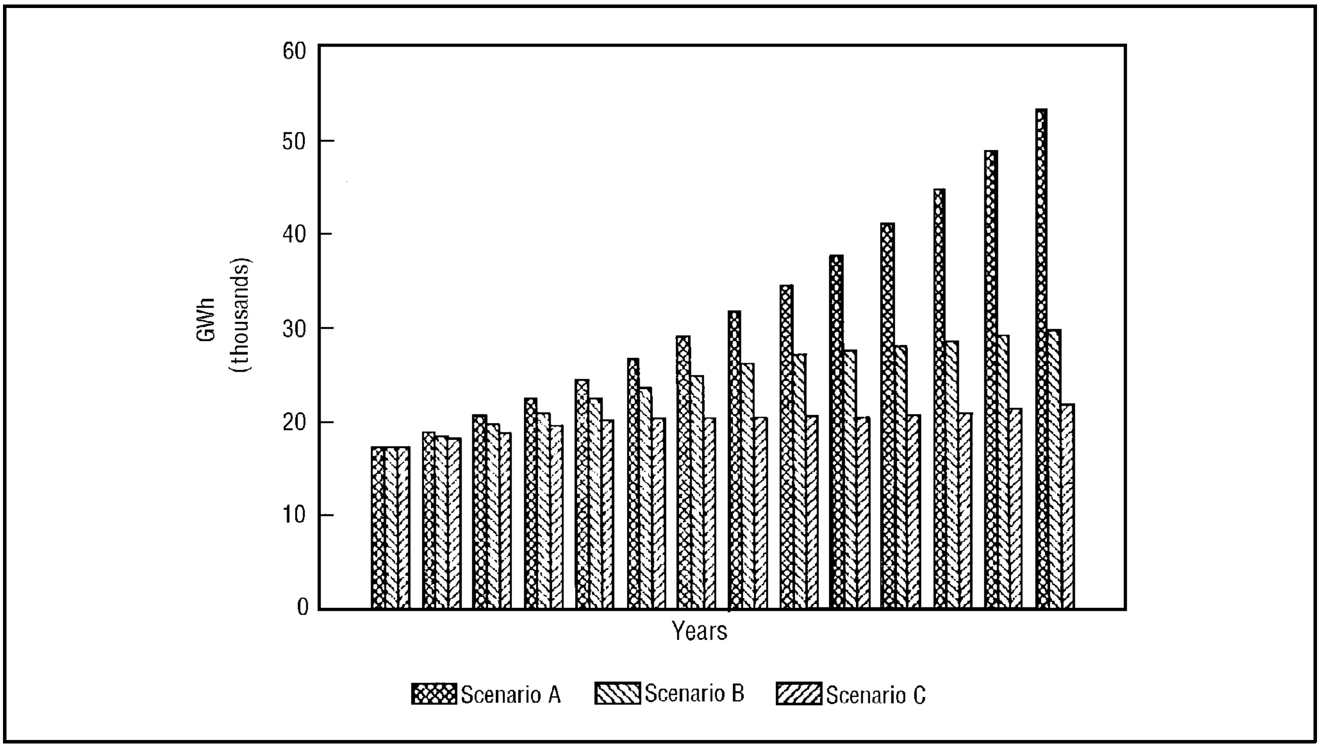

Fig. 7c. Estimated electricity requirement for the state of Gujarat (1991-92 to 2004-05).

Notes

Scenario A: Projected growth of demand @ 9% per year.

Scenario B: Frozen efficiency scenario (consisting of changed sectoral growth rates, but no efficiency improvements).

Scenario C: Improved scenario (consisting of changed sectoral growth rates, efficiency improvements and carrier substitution).

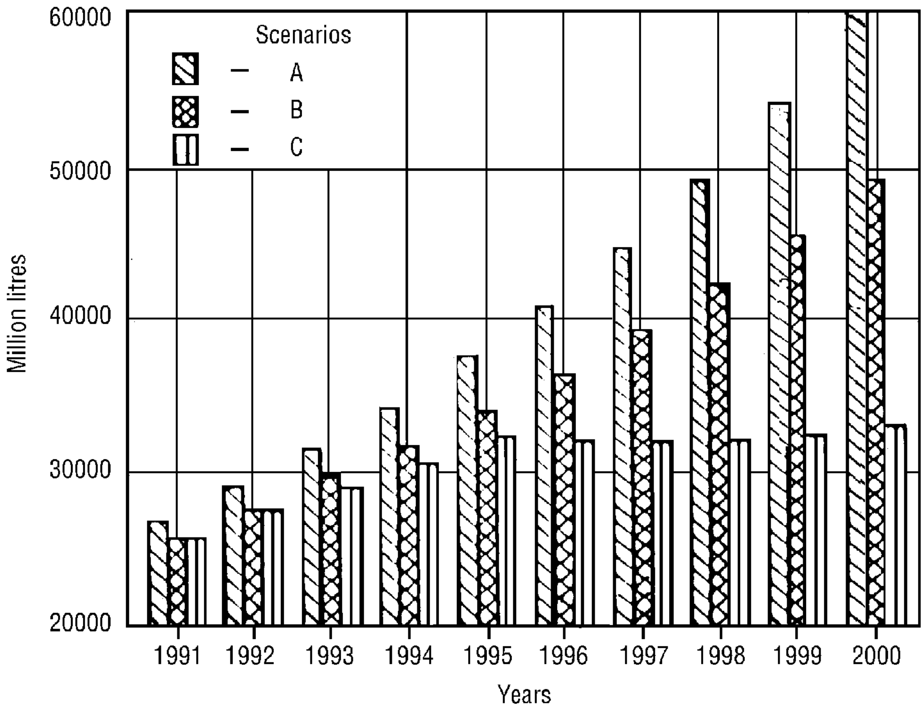

Fig. 8a. Estimated diesel consumption in India (based on three scenarios).

Notes

Scenario A: Extrapolation of past trends ("business-as-usual").

Scenario B: Expected requirement -- official estimates (including inter-modal and inter-fuel shifts).

Scenario C: Improved scenario estimates (enhanced inter-modal and inter-fuel shifts through policy intervention).

extrapolation of the trend in the previous decade, but it served the purpose of a base-case, unhindered by any policy interventions, with which comparisons could be made. The second scenario was an approximation of the one estimated in ''Sectoral energy demand in India'' [Regional Energy Development Programme, 1991], with their anticipated inter-fuel and inter-modal shifts. The third contained further improvements in the efficiency of usage – not through improved devices but by enhanced inter-modal and inter-fuel substitution. In all three scenarios, the average fuel usages (e.g., for vehicles) used in ''Sectoral energy demand in India'' were retained. The requirements of diesel and kerosene according to the three scenarios are depicted in Figures 8a and 8b.

Unlike the electricity exercises, the sectoral demand estimation for each distillate was based not merely on the number of users (which is easily obtained from the number of connections in reports of electricity distributors), but also on the ''load'' or service dealt with, such as the tonnage hauled or passengers carried in the transport sector, or the quantity of output manufactured in the industrial sector. An appropriate fuel usage per consumer was then calculated, according to the service referred to; for instance, litres of diesel per tonne-km of freight carried.

A study was also made of the past consumption of the same petroleum products (from 1978 onwards), to compare the actual consumption with what it would have been if the improvement measures had been adopted in 1978 (Figures 9a and 9b).

4.5. Supply scenario

Least-cost supply curves for each petroleum product could be derived in a manner similar to that employed for electricity. In the case of electricity, the options included a variety of generation possibilities (from various sources and on varying scales of operation). Similarly, for production of any petroleum product several options can be considered. For example, diesel can be produced from crude oil from on-shore, off-shore and imported sources; it can also be directly imported. Also, diesel production can be altered by varying the proportion of different distillates in the refineries. The cost of each supply and conservation option would have to be computed. The selection would then be from among the options – production (by a particular process), imports, and implementation of one or more of the conservation measures (depending on the devices, automobiles, etc., in use).

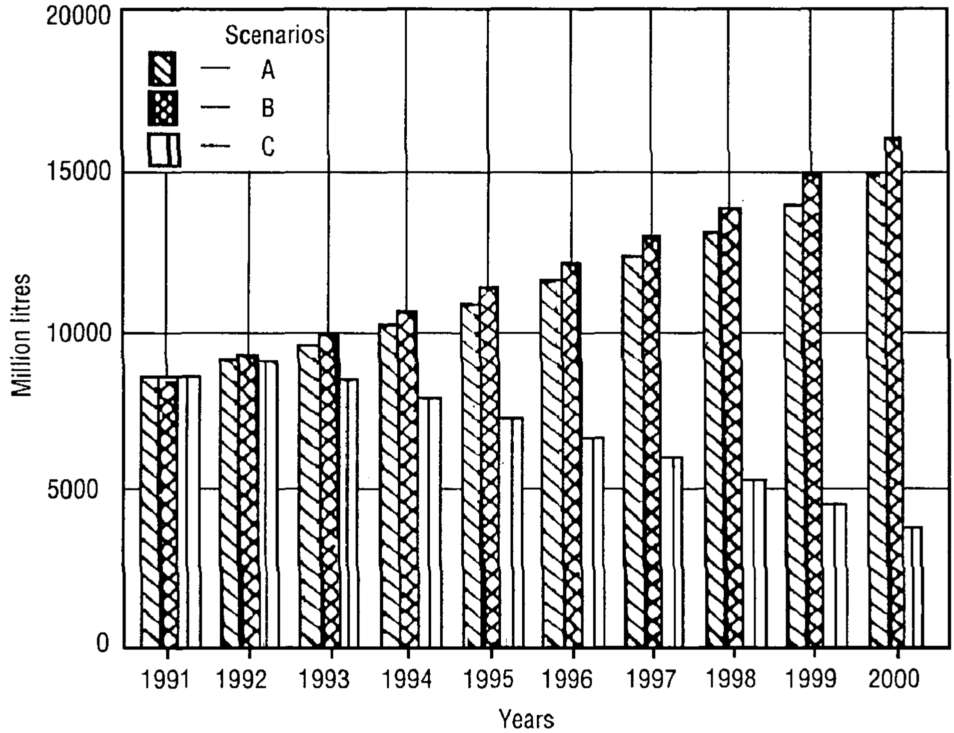

Fig. 8b. Estimated kerosene consumption in India (based on three scenarios).

Notes

Scenario A: Extrapolation of past trends ("business-as-usual")

Scenario B: Expected requirement – official estimates (including inter-modal and inter-fuel shifts).

Scenario C: Improved scenario estimates (enhanced inter-modal and inter-fuel shifts through policy intervention).

5. Biomass (fuelwood and crop-waste) scenario for Karnataka

5.1. Scope of scenario

A scenario for the demand for fuelwood (purchased and collected) and crop wastes in Karnataka (till the year 1999-2000) and for the supply of fuelwood has been constructed. Fuelwood is used chiefly by the domestic sector – for cooking and water-heating, and to a lesser extent by the commercial and industrial sectors for process heating; agricultural waste (from most crops other than sugarcane) is used by the domestic sector for cooking and water-heating. Waste from sugarcane (in the form of bagasse) is used by industry for process heating but it can also be used for cogeneration of electricity in sugar factories.

5.2. Consumption pattern

The base year for the calculation was taken to be 1984-85 (as data pertaining to this year's requirements were available). The estimated demand for fuelwood (purchased and collected) and crop waste was disaggregated according to the main users and the services provided. Fuelwood was used chiefly (97%) by the domestic sector – 74.3% for cooking and 22.3% for water-heating – and to a small extent by the commercial and industrial sectors for process heating [Department of Management Studies, 1991].

Sugarcane waste, comprising about 47% of the total agricultural waste collected for fuel, was used by industry for process heating. The remaining agricultural waste (from crops other than sugarcane) was used by the domestic sector for cooking and/or water-heating.

5.3. Goal

The goal was to improve rural self-reliance by decreasing the demand for fuelwood and crop waste and by increasing the sustainable supply of fuelwood, while maintaining (and if possible, improving) forest cover.

5.4. Strategy

The strategy involves both demand-side and supply-side measures. The demand-side measures include a reduction in the fuelwood usage per consumer in the domestic and commercial sectors through more efficient stoves and inter-fuel substitution. For cooking, firewood can be replaced by kerosene, or even biogas stoves, solar cookers, and LPG stoves. The available crop waste is also expected to be used both for cooking and water-heating in rural households. In addition, it is expected that there will be demand for electricity generated from bagasse. The emphasis here is on renewable energy sources and/or more efficient devices. However, an increase of fuelwood usage is envisaged because of the use of wood gasifiers to generate electricity in rural areas.

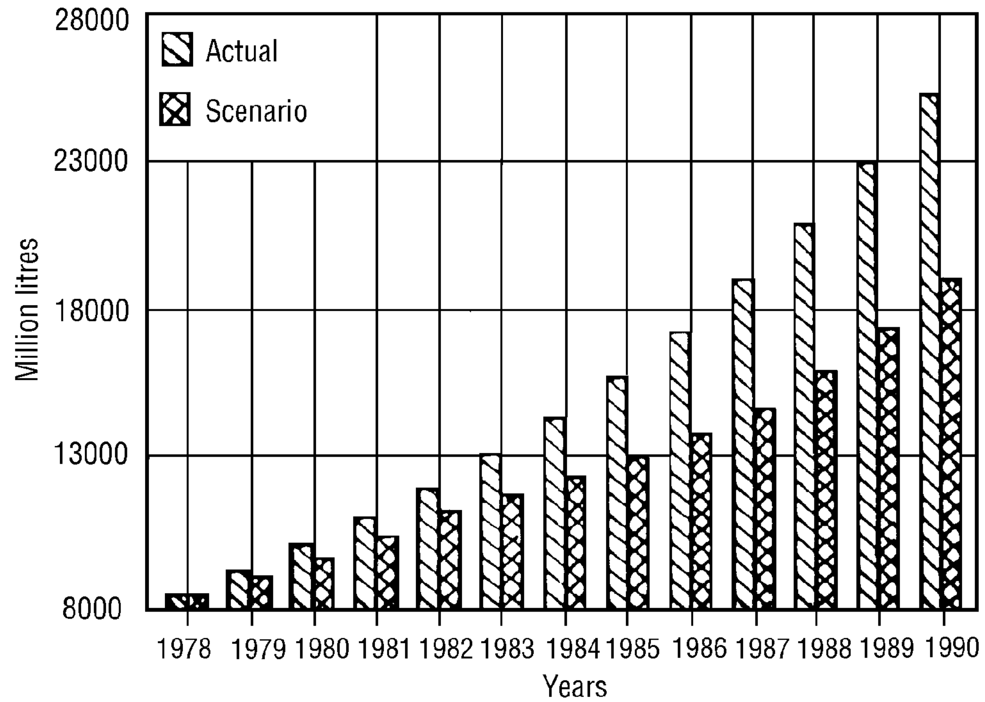

Fig. 9a. Diesel consumption in India (actual versus scenario).

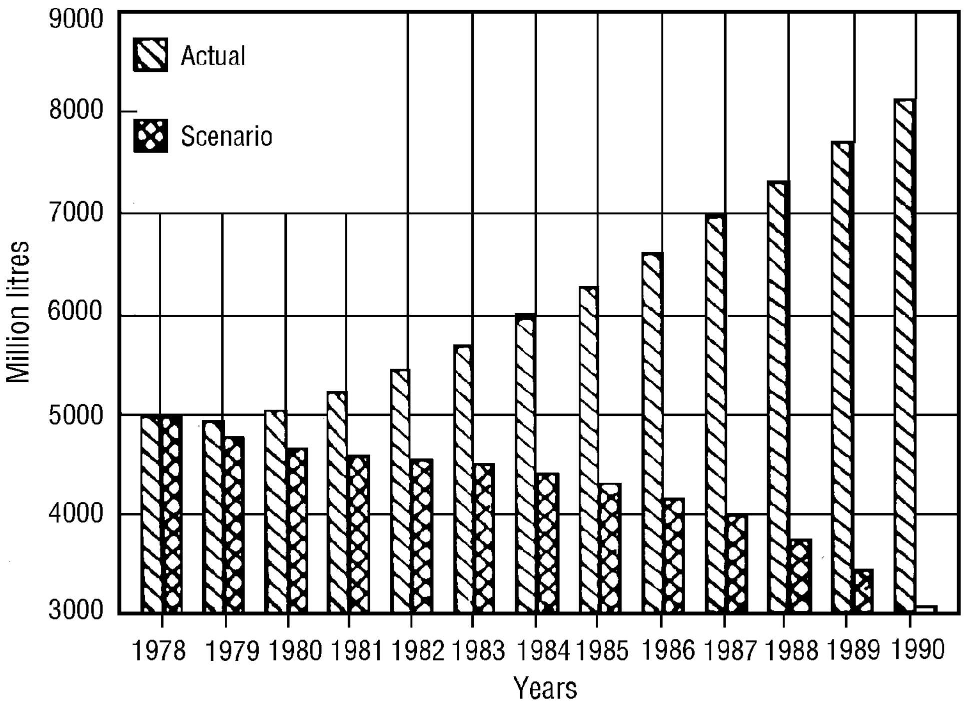

Fig. 9b. Kerosene consumption in India (actual versus scenario).

On the supply-side, the production of fuelwood is expected to be increased through afforestation of degraded land with fast-growing species of trees.

5.5. Demand scenario

In the domestic sector, a 50% reduction in the fuelwood *usage per household* can be effected with the use of several types of new efficient stoves. In addition, there could be a reduction in the *number of homes* dependent on fuelwood through inter-fuel substitution (shifts to kerosene stoves, biogas stoves, solar cookers, and LPG stoves). On the other hand, there will be an increased demand for biomass for the purpose of gasification.

In recent years, it has been observed that there has been a slackening in the growth of demand for fuelwood, due to improved stoves as well as the use of other fuels wherever available. Hence, estimates of fuelwood requirement cannot be made by simply extrapolating the growth rates of the 1980s (which would yield a requirement of 17.76 million tonnes for the year 1999-2000). With greater emphasis on usage efficiency and on alternative fuels, the demand for fuelwood in the year 1999-2000 will be 7.6 million tonnes – domestic cooking (68.6%), domestic water-heating (24.4%), industrial (3.9%) and commercial (1.6%) purposes, and wood gasification (1.5%).

The available crop waste will continue to be used for cooking and water-heating in rural households, but with an efficiency improvement of 10%. The industrial demand for crop waste will be not merely for process heating but for cogeneration of electricity.

Since bagasse is expected to be used for the generation of electricity (in excess of captive needs) in sugar factories, this will augment the supply of electricity for regional use.

5.6. Supply scenario

In order to meet the demand for fuelwood, the scenario envisages an increase in the area devoted to forests (from the present degraded lands) as well as enhanced wood productivity through rejuvenation of partially degraded lands and improved species planted during afforestation. Obviously, there will be a gestation period (7-10 years) for new saplings to mature and for the currently denuded land to be rejuvenated. This scenario does not involve encroachment upon land that is now being used (or is likely to be used, as in the case of fallow lands) productively for cultivation. Further, the use of over-exploited areas (i.e., those with less than 40% canopy cover) is being curtailed. Therefore, there will still be a shortage of fuelwood (to the extent of nearly 1 million tonnes) even at the turn of the century. However, if the growth rates suggested in the scenarios are maintained for a further period, supply will be adequate to meet the demand.

6. Integration of source/carrier scenarios

Thus far, the methodology of constructing scenarios for single energy sources/carriers has been discussed and illustrated with examples. It is now necessary to address the issue of proceeding from single source/carrier scenarios to multi-source/carrier scenarios; that is, from source/carrier scenarios to energy scenarios. The procedure is based on energy measures involving the substitution of one source/carrier Y for another, X; for example, electricity instead of diesel for pumpsets. A special case of such source/carrier substitutions would be fuel-substitution measures; for example, LPG for kerosene as cooking fuel.

Once a source/carrier substitution measure is identified, the two spreadsheets for the sources/carriers X and Y must be linked. For instance, in the case of a shift from diesel to electric pumpsets, the linkage must be such that a reduction in the number of diesel pumpsets results in an equivalent increase in the number of electric pumpsets. This connection is achieved by linking appropriate cells in the two spreadsheets so that a cell in the ‘‘target’’ spreadsheet has to derive its contents from the contents of a particular cell in the ‘‘source’’ spreadsheet. (So, for the shift from diesel-run to electric pumpsets, the cell in the electricity spreadsheet indicating the number of electric pumpsets (that have been shifted from diesel) has to call for the contents of the cell for the number of diesel pumpsets being shifted in the diesel spreadsheet. Only inter-modal shifts (e.g., from truck to rail haulage of freight, or from less to more fuel-efficient cars) with the same fuel source are visible on the same spreadsheets *provided the scenarios for the different distillates are on the same spreadsheet.*

For linkages between spreadsheets to be meaningful, all the scenarios must pertain to the same spatial domain or region; for example, province or country. This was not the case with the examples of DEFENDUS scenarios described above – one electricity scenario was for Karnataka while the others were for various other states, the oil scenario was for India as a whole, and the biomass scenario was for Karnataka. Since the aim here is to demonstrate the possibility of using the DEFENDUS methodology for multi-source/carrier energy planning and since the validity of the methodology is independent of whether the spatial domain is a province or a country, it was decided to focus on Karnataka. This decision was motivated by the need to reduce the new information required. A system of spreadsheets was therefore created to estimate the demand for all the energy carriers[13] being used in the state of Karnataka.

Energy demand in Karnataka comprises demand for electricity, coal, fuelwood and crop waste, and various petroleum products. As a result of the successful linking of spreadsheets, the impacts of all the source/carrier substitutions (listed in Table 1) on the associated sources/carriers can be tracked. As an illustration, consider the case of home electrification, i.e., the replacement of kerosene lamps with electric lights in the domestic sector. Then the results – in terms of number of homes dependent on a particular source of fuel for lighting and the corresponding demand for kerosene and electricity – can be estimated through the links between spreadsheets (Figures 10a and 10b).

7. Demonstration and use of the methodology

The DEFENDUS method is being used increasingly to construct energy scenarios in India and abroad.

At a workshop held in Kuala Lumpur (May 3-5, 1994) consisting of presentations of DEFENDUS and other methodologies of energy planning, participants from eight (out of fourteen) countries – Bangladesh, India, Indonesia, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam – indicated their interest in using the DEFENDUS methodology for energy planning. IEI therefore conducted a

Table 1. A list of the (service-wise) inter-carrier shifts occurring in the DEFENDUS energy scenario for Karnataka.

Service (by sector)	Present carrier (reduced requirement)	Target carrier (increased requirement)
Domestic lighting	Kerosene	Electricity
Water-pumping for irrigation	Diesel	Electricity
Rail traction for freight haulage & passenger transport	Coal	Diesel
Rail traction for freight haulage & passenger transport	Diesel	Electricity
Passenger road transport (from private vehicles to public buses)	Motor spirit	Diesel
Domestic water-heating	Firewood	Kerosene
Domestic water-heating	Kerosene	Solar
Domestic water-heating	Electricity	Solar
Domestic cooking	Firewood	Kerosene
Domestic cooking	Firewood	Biogas
Domestic cooking	Kerosene	LPG
Domestic cooking	Kerosene	Solar
Domestic cooking	Electricity	LPG

hands-on computer-based training workshop for participants from each of these countries. This workshop (November 14-22, 1994, in Bangalore) dealt with the actual construction of demand scenarios for various energy carriers, computation of the life-cycle costs of electricity-generation and -saving options to arrive at a least-cost mix of electricity options, and integration of files to capture the implications of fuel substitution. While some of the participants constructed energy scenarios for their countries during the workshop itself, others progressed as far as their data permitted.

Another computer-based workshop on integrated resource planning was held at the Institute for Techno-Economic and Energy System Analysis, Tsinghua University, in Beijing (May 30-June 8, 1994). With a paper on the DEFENDUS methodology translated into Chinese, about 24 participants were trained in the construction of demand and supply scenarios, the comparative costing of technologies and the formulation of least-cost plans.

Within India too, least-cost plans are now being worked upon by the planners of electric utilities in West Bengal, Kerala, Andhra Pradesh, Karnataka and Tamil Nadu, for their respective states. The exercises in progress have three broad components – construction of ''business as usual'', ''frozen efficiency'' and ''DEFENDUS'' demand scenarios,[14] calculation of life-cycle costs of various generating and saving options; and construction of a cost-supply staircase to arrive at the least-cost solution.

8. Conclusions

The *ab initio* exposition of the DEFENDUS methodology presented in this paper with several examples of its ap-

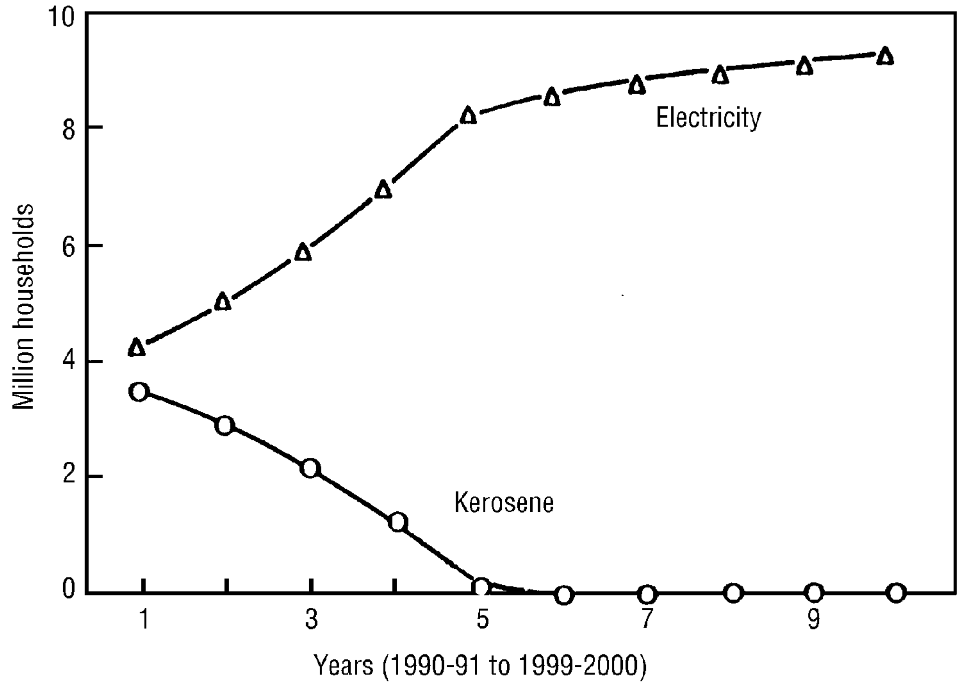

Fig. 10a. Home electrification: as homes are electrified, the number dependent on kerosene for lighting declines correspondingly.

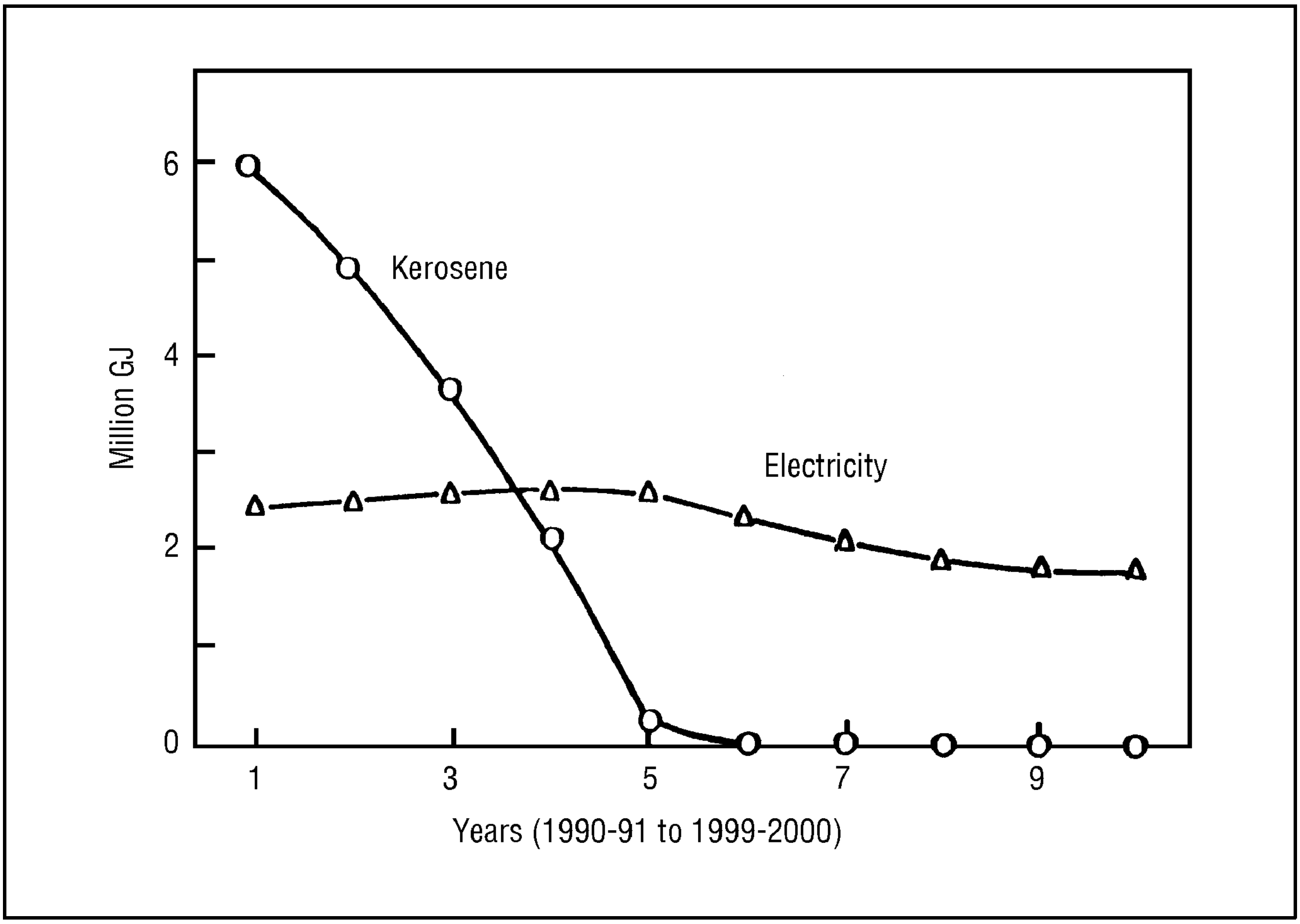

Fig. 10b. Home electrification: in energy terms, the increased requirement of electricity for lighting is more than offset by the reduction in the kerosene requirement.

plication has brought out its power and versatility. The DEFENDUS methodology provides a simple method of estimating energy demand and designing energy supply so that the planner has complete control over the entire computation and can evolve the most appropriate method for the particular case under consideration. The use of spreadsheet packages enhances the power of the planners because they can make alterations without being dependent on the source-codes of programmers. Auditing of the computation is easy because the progress of the calculation can be checked with a calculator. Also, the steps followed are ''transparent'' enough to be easily understood and amenable to easy modification by another planner. And those who wish to replicate computations can use the first computation as a model and/or ''default case'' and therefore avoid ''re-inventing the wheel''.

Though the methodology was initially developed for electricity, it has been shown to be amenable for use for other energy sources/carriers. It is also possible to go from scenarios for a single source/carrier to scenarios for a number of sources/carriers, i.e., from source/carrier planning to energy planning. The methodology also permits an estimate of the environmental impacts and the macroeconomic implications of the DEFENDUS scenarios.

Above all, with the widespread availability of PCs and the familiarity with spreadsheet packages, the DEFENDUS methodology facilitates the democratization of energy planning. ■

Notes

1. Karnataka has an area of 191,791 km^2 and a population of 44.977 million (as per the 1991 Census).
2. The AEH category involves a 15-amp connection that permits both lighting and heating loads while the domestic lighting (or non-AEH) category has an upper limit of 5 amp that corresponds mainly to lighting loads. The AEH category has a higher tariff (both fixed charge and per unit used), so that the more affluent homes have such connections.
3. This is applicable to 400V 3-phase and 230V single-phase connections.
4. HT refers to bulk power supply of voltages of 11 kV (including 2.3/4.6 kV) and above, at standard high voltage or extra high voltage when the contract demand is 100 kVA and above.
5. Less power-intensive and more employment-generating industries can be encouraged in several ways such as provision of better access to credit, tax breaks linked to employment generation, etc. This does not imply that the other power-intensive and/or low-employment-generating industries would be eliminated, but that the growth of these would be restricted to the extent that they are essential for the economy.
6. The "true" demand was computed by inflating the actual consumption figures to the extent of the restrictions that had been imposed and then reducing this by the restrictions that could be endured without affecting productivity.
7. Karnataka has begun using electricity for railway traction in 1992 and our demand estimation now takes this requirement into consideration.
8. The S-shaped logistic curve is appropriate for representing the graph of the number of efficiency-improved devices as a function of time as it indicates a gradual introduction, followed by increasingly rapid acceptance and finally a tapering off as saturation is approached: $p_t = K / [1 + \{K\text{-}N(0)/N(0)\} \times e^{-rt}]$, where K is the saturation level, N(0) is the initial acceptance level and r determines the slope.

9. Imports of crude oil and petroleum products constituted 23% of the value of all imports and were equivalent to 30% of the value of exports in the year preceding our study (1990-91). The corresponding figures were as high as 42% of the value of all imports and 78% of all exports in 1980-81.
10. This shift is desirable because of the improved efficiency (less diesel per tonne-km of freight hauled); although a long-term strategy would necessitate additional rail capacity, this is expected to be compensated for by the increased efficiency of operation.
11. The shift from diesel to electric pumpsets is recommended assuming that electricity will be generated at small hydroelectric, biogas, producer-gas plants, etc., thereby reducing the diesel requirement and without adverse environmental impact. Generating the required electricity from fossil-based fuels is not envisaged.
12. Here, the incremental cost of new stoves is expected to be more than offset by the increased efficiency of cooking with LPG, in addition to avoiding further imports of kerosene.
13. From the demand point of view, energy carriers such as electricity and diesel, rather than sources like natural gas (from which electricity may be generated) and crude oil, are being considered.
14. Sample surveys are being conducted to estimate the service-based electricity usage in various sectors, for greater accuracy of the demand scenarios.

References

Department of Management Studies, Indian Institute of Science, Bangalore, 1988. ''Karnataka regional sub-model and agricultural sector sub-model'', Final report submitted to the Advisory Board on Energy, Government of India. The basis for the estimation of firewood usage in various sectors was the ''Draft Seventh Five Plan 1985-90'' prepared in the Planning Department of the Government of Karnataka.

Government of India, in co-operation with the Economic and Social Commission for Asia and the Pacific, the United Nations Development Programme and the Government of France, 1991. Sectoral Energy Demand in India, Regional Energy Development Programme (RAS/86/136).

Reddy, A.K.N., Sumithra, G.D., Balachandra, P., and D'Sa, A., 1990. ''Comparative costs of electricity conservation, centralized and decentralized generation'', Special Article in *Economic and Political Weekly,* Vol. XXV, No. 22, June 2, pp. 1201-1216.

Reddy, A.K.N., Sumithra, G.D., Balachandra, P., and D'Sa, A., 1991. ''A development-focused end-use-oriented scenario for Karnataka'', Special Article in *Economic and Political Weekly,* Vol. XXVI, Nos. 14 & 15, April 6 & April 13, pp. 891-910 & 983-1001.

Reddy, C.R., D'Sa, A., and Reddy, A.K.N., 1992. ''The debt-energy nexus: a case study of India'', *Economic and Political Weekly,* Vol. XXVII, No. 27, July 4, pp. 1401-1415.

Sant, G., and Dixit, S., 1993. ''Least cost power planning: case study of Maharashtra state'', Least cost energy analysis project of the International Energy Initiative and TIDES Foundation, presented at the Workshop on Integrated Electricity Planning, Bangalore, India, March 8-13, and at several other workshops.

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