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INDUSTRIAL ENERGY UTILISATION IN KARNATAKA AND POTENTIAL SAVINGS

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Abstract—Energy is essential for industrial production. Because of the past abundance of low-cost energy, historically, the rate of social progress among industrial societies has not been limited by energy availability. Energy cost has not been significant when compared with no energy use. Mechanisation of agriculture, increased use of electrical appliances in the domestic sector and rapid industrialisation to meet the demand of exponentially growing population have resulted in an energy crisis. The raised fossil fuel prices and the environmental factors playing the dominant role in implementation of large scale projects, such as hydro, thermal and nuclear, have aggravated the problem further. In this context, an integrated energy plan for a country seems essential for ecologically sound development of a region. An integrated plan includes strategies to:

- improve the efficiencies of end use devices and/or conversion equipment in all sectors;
- optimise energy sources (end use matching);
- maximise the use of renewable resources;
- balance the exploitation of biomass energy resources; and
- discourage the use of depletable resources.

Conservation through improvement of the efficiencies of end use devices is one of the most effective ways to provide immediate relief for the energy problem. This helps to maintain economic growth and social progress of a region. Environmental problems, resource depletion and growing demand of energy in the state/region make it increasingly imperative that we use energy as efficiently as possible, and planners should take note of this untapped resource. The potential for improved energy efficiency is great, and a substantial part of that potential could be realised in the course of events.

The industrial sector constitutes a major consumer of commercial energy. Improvement of energy efficiency in the industrial sector would result in a slower rate of energy growth. A secure energy supply is the major concern of most industrialists. It is, thus, necessary to examine industrial energy use and the economy. The analyses of consumption patterns and the assessment of feasible energy conservation possibilities show that the potential for energy conservation in the industrial sector and in all sectors is substantial. The barriers identified to tap this potential are a lack of information on specific measures and options for achieving energy conservation, lack of capital for schemes involving technology upgrading and efficiency improvements, pricing policies which deviate from rational tariffs and the inadequacy of institutional arrangements for promoting energy conservation in different sectors of the economy. In this regard, research should be sponsored to develop system designs, cost and pricing policies, problems related to system interconnection with public utilities and an assessment of potential energy savings, and research into methods of matching energy resources to work requirements, rather than vice versa, for improved efficiency. It is essential for the planning machinery to foster the integrated approach in energy planning of a region.

This paper discusses an attempt made by us to illustrate the industrial energy scene in Karnataka and reveals the possibilities of energy conservation. Analysis of the energy consumption data of Karnataka and India shows that the per capita consumption of energy is low (compared with 56 countries in the world), while for the industrial sector, energy per state domestic product (SDP comparable to GDP) is at least 10–20 times higher than that of industrialised countries. This implies inefficiency in energy utilisation.

Detailed investigation of the industrial sector through analysis of the Specific Energy Consumption (SEC)—industry wise and yearly for a seven-year period—reveals that about 27.72% of energy could be saved in the industrial sector. This, when quantified, accounts for savings of 1541 million kWh per year in Karnataka, which is equivalent to the power output of 300 MW (Mega Watts) electric power generating station (hydro/thermal).

Per capita energy consumption (PCCE) Gross domestic product (GDP) Energy intensity Per capita GDP Energy elasticity Specific energy consumption (SEC) SEC ratios Energy planning

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INTRODUCTION

Energy utilisation in India and in Karnataka State differs radically from that of other, industrialised countries. Non-commercial sources of energy, such as firewood and agricultural residues, constitute the main source of energy in rural areas. There are enormous variations in the amount of energy used within India in different states and regions. There exists regional disparities both in terms of energy supply and demand. Linkages between various energy sub-sectors, such as coal, oil, electricity and non-commercial energy sources, are non-existent. Energy planning in our country is not an integrated activity. The plans for electricity, oil, coal and firewood are separate exercises. Secondly, the planning activity considers only the demand and projects the demand over a period of years. Efficiency in utilisation has not been investigated. The primary goal of planners is supply expansions based on the assumption of linkage between energy consumption and the economic growth of a region. With this approach, energy becomes an end in itself, and the focus shifts on meeting increased energy consumption through energy supply expansion alone. This supply and demand based planning for each individual energy form has resulted in problems like inefficiency, losses, more conversions and other environmental problems. This conflict between energy demand and environmental quality goals can be solved by an integrated approach to the problem of energy planning with emphasis to minimise the consumption of non-renewable sources of energy, such as coal, oil, etc. to maximise the efficiency of end use devices in all sectors and to organise an approach towards optimal use of renewable sources. This path would certainly help in boosting economic growth of a region, and equally important, it promotes structural changes which are conductive to overall development. In order to get an idea of Karnataka and India's level of energy consumption with other countries, we have carried out energy analyses and compared with energy consumption data from 56 countries.

The energy use per capita and GDP per capita data of 56 countries reveals that Karnataka State and India have very low per capita energy consumption. There are only small differences in per capita energy consumption between the developing countries. For high income countries, the difference is much larger. That is, energy use per capita increases with higher income, but cross country comparisons can be misleading and inappropriate due to large variations among countries in terms of economic structure, climate, geographic location, etc. Energy intensity (energy consumption per GDP) and GDP per capita data reveal that India and Karnataka State have high energy intensities compared to other developed industrialised countries, which clearly shows that Karnataka State and India have good potential in energy conservation.

A comparative study of energy use, mainly electrical, in industries in Karnataka and in those of some other industrialised countries reveals that Karnataka consumes 6.13 times the energy consumed in Switzerland, 5.28 times the energy consumed in Japan, 3.35 times the energy consumed in the U.K. and 1.98 times the energy consumed in the U.S.A. for the same GDP (Gross Domestic Product). Sectoral energy values also have been calculated.

A sectoral analysis of electricity users in Karnataka shows that the growth of connected load is mainly in two categories—AEH (All Electric Homes) and Small Scale (LT) Industries. The growth rate is 19.46% for the former and 27.33% for the latter. The growth increases in the past four years are 67.4% and 55%, respectively. If we look at the annual increases in the number of installations, again the LT industrial sector has a very high rate of 38.66% followed by AEH with a rate of 19.15%. More than 50% of our industries are clustered in and around Bangalore. Barring a few exceptions, there is only limited industrial activity in other parts of Karnataka. Energy consumption patterns show that Bangalore uses 26.67% of HT energy. A few industries like Indian Aluminum at Belgaum, VISL at Bhadravathi, etc. show higher energy consumption values for some divisions. Belgaum consumes 21.6% of total HT energy in the State. Sector wise commercial energy consumption data shows that the industrial sector, with 51.4% of total consumption, constitutes the major energy consumer in Karnataka. Hence, we have taken the industrial sector for further study.

Linkages between energy sources and the impacts of substitution of energy from one source by that from another can be understood only if there is an integrated picture of energy use. Since this type of information was not available, the energy analysis was confined to utilisation of energy from only one source, namely electricity. A survey was, therefore, conducted covering many industries in Karnataka. A questionnaire was prepared and sent to more than 250 industries. Replies received from about 60 industries were analysed for their energy consumptions for the period 1980–85. Recently, another round of surveys was carried out by sending questionnaires to 510 industries, and 78 replies were received pertaining to the data for the years 1990–91 and 1991–92. It was found that, in many industrial sectors, energy consumption/rupee of production was higher than the Indian norm. Further, energy consumption varied considerably within a group or sector, indicating a distinct possibility for a substantial reduction in energy use by many industries for the same level of production.

Similarly, a look at the specific energy consumption by an industry over a five year period shows an increase in some industries and, fortunately, a reduction in some others. The greatest possibilities for more efficient use of energy in industry lie in careful management of process heat, electricity, energy intensive materials and direct fuel consumption. Processes involving energy intensive operations or materials are to be reviewed to determine if new technology, recycling or substitution, or alternative forms of material or energy could be employed to increase efficiency.

This paper is organised as follows: Section 1 discusses energy utilisation patterns and energy intensity trends among 56 countries. In Sections 2 and 3, we discuss the energy scenarios of India and Karnataka. Section 4 discusses the primary survey carried out by us for compiling data, while Sections 5–9 deal with analyses, discussion and results of the energy analyses.

1. PATTERNS OF ENERGY CONSUMPTION AND ENERGY INTENSITY TRENDS AMONG COUNTRIES

The role of energy utilisation in economic growth has received much attention in the last two decades. Schurr and Eliasberg [1] investigated the long term relationship between energy consumption and real GNP. They conclude that, from 50 years time series data, there was a steady rise in energy requirement per unit of GNP initially. However, the use of energy per unit of GNP declined steadily in the next phase. Increased industrialisation initially might have resulted in the relative rise, while decline, according to Schurr and Eliasberg, is due to:

(1) increased efficiency of energy production, resulting in dramatic increases in the useful energy output obtained from raw energy input;
(2) significant technological improvements, resulting in greater efficiency; and
(3) changes in structural composition of GNP partially explain the decline in relative energy output.

1.1. Data

The basic gross domestic product and energy data used in this research are from the 1991 UN Energy Statistics Yearbook [2] and from the report "Current Energy Scene in India, 1993" published by the Centre for Monitoring Indian Economy Pvt. Ltd., Bombay [3]. The energy data are measured in tons of oil equivalent (toe), the GDP data are measured in local currencies but have been adjusted for price changes. The population of various countries is from the World Population Data Sheet 1994 [4].

1.2. Comparisons of energy use

Since energy consumption plays an important role in indicating the life style or quality, there are many indicators to compare life styles in various countries. Initially, energy consumption was compared with a country's gross domestic product (GDP). Later on, energy consumptions per capita for many countries were plotted against GDP/capita (Fig. 1a). It was found from 56 countries data that there is a strong correlation existing between national output per capita and energy per capita. Table 1 gives the energy-output relationships for the 56 countries and Karnataka State.

In order to make a quantitative estimate of the response of energy consumption per capita to GDP per capita, a regression analysis is carried out for a set of data pertaining to the 56 countries. Both linear and nonlinear regression analyses were carried out (about 25 types of equations were

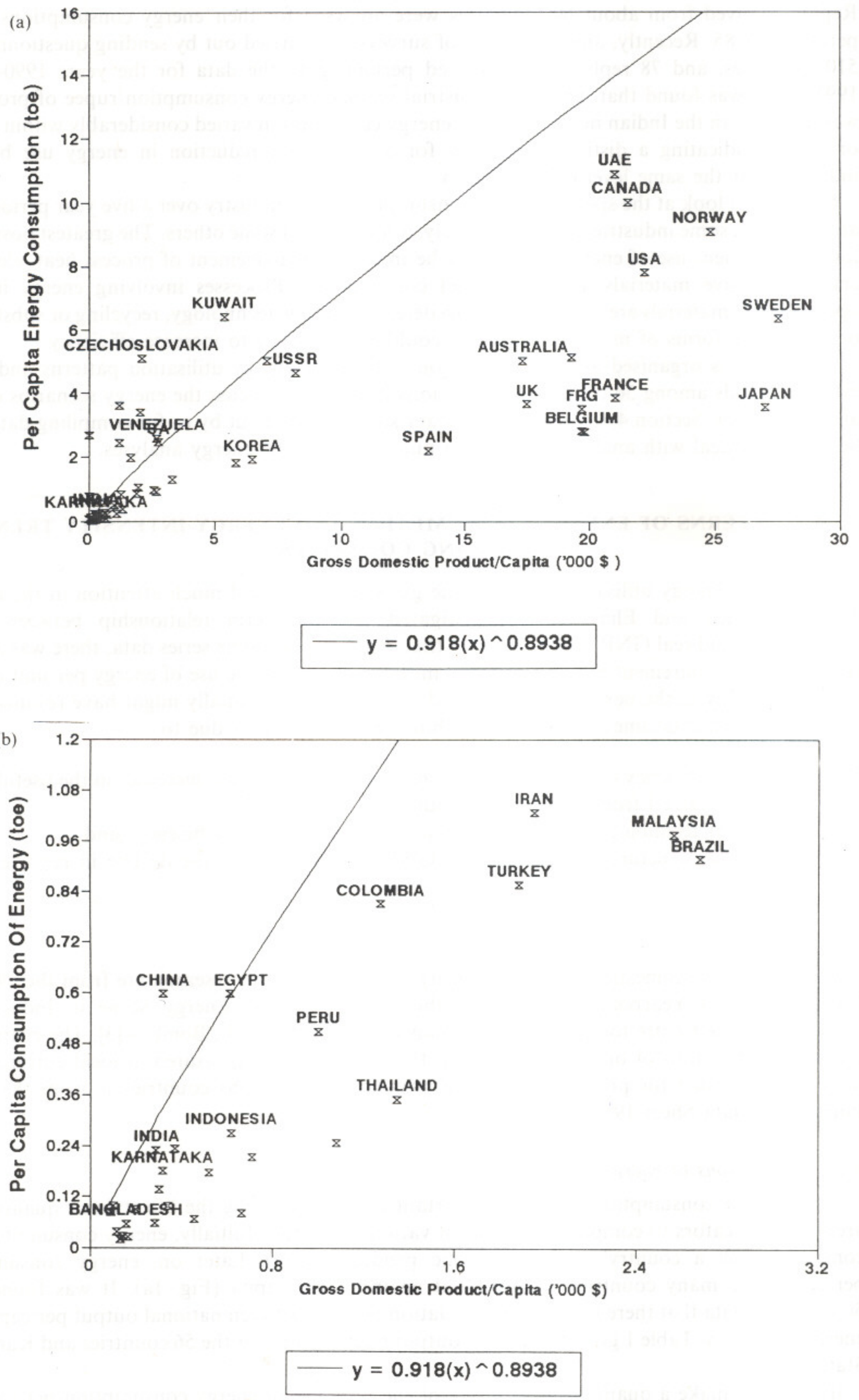


Fig. 1. (a) Per capita energy (toe) and GDP per capita ('000$); (b) for < 3200.

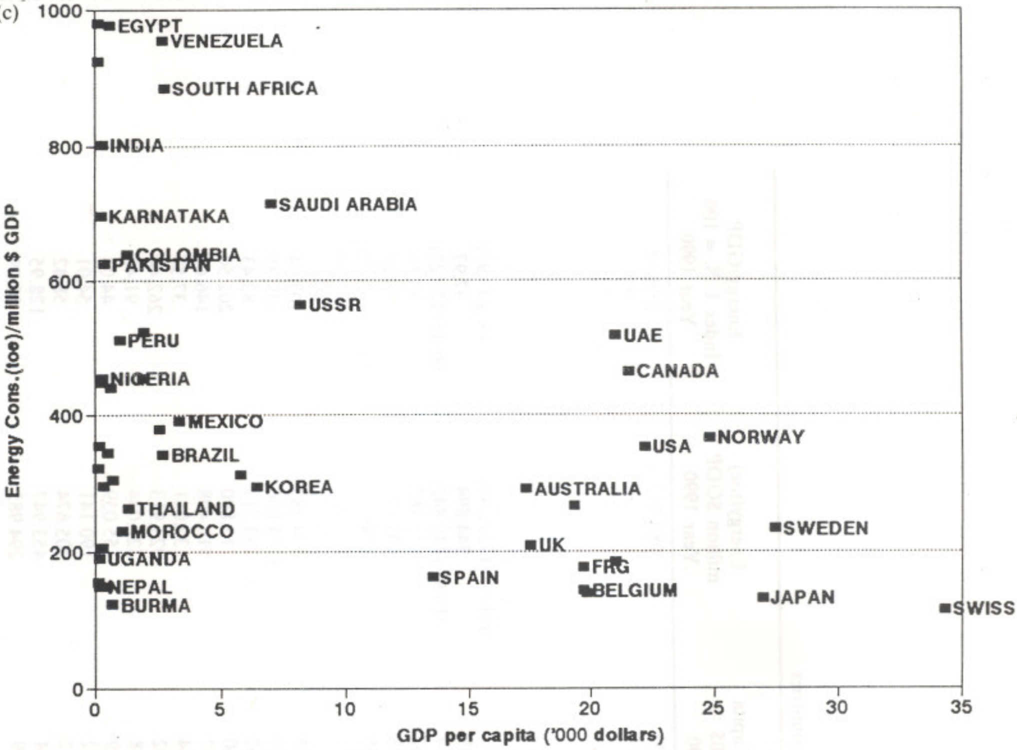
(c)


Fig. 1. (c) Energy consumption (toe) per million dollars of GDP.

tried). Based on the lowest percentage of error and best correlation coefficient, the best fit relationship for this set of data was found to be a power law of the form

$$En_{pc} = A*\text{GDP}_{pc}^{B} \quad (1)$$

where En_{pc} = energy consumption per capita in kg's oil equivalent, GDP_{pc} = gross domestic product per capita in US$.

$$En_{pc} = (0.9184)*\text{GDP}_{pc}^{0.8938},$$

with correlation coefficient $R = 0.90$, $R^2 = 0.8119$ and std error of Y est. = 0.05792.

Similar analyses carried out earlier by Janosi and Leslie [5] have shown quantitatively for each of 31 countries that the relationship between *En* (Energy consumption) and GDP (gross domestic product) is

$$\text{Log}(En) = A + B*\ \text{Log(GDP)},$$

with R^2 in all cases being greater than 0.8. Even though the statistical reliability of the regression is uniformly high, the striking substantive result is that the relationship between the economic growth and energy consumption differs widely among various countries in terms of exponent *B*. Exponent *B* in equation (1) is also referred to as the income elasticity of energy consumption and is, in part, influenced by a country's stage in economic development. *B* is less than one for countries like Japan (0.9605), U.S.A. (0.9588), France (0.8788), U.K. (0.4780) and Germany (0.6612), while for countries like India (1.8925), Thailand (1.9341), Mexico (1.3328), Italy (1.7662) and Phillipines (2.0696), it is greater than one. This shows that the energy consumption is, in part, influenced by a country's stage of economic development. Apart from this, the structure of energy consumption exerts an important influence on the elasticities, depending on the efficiency, price of predominant energy sources, economic structure and climate.

Table 1a lists the countries in order of increasing GDP per capita. For each country, energy use per capita (PCCE), energy intensity or specific energy consumption (both excluding and including

Table 1a. GDP and energy data for 56 countries

Per capita commercial energy consumption (PCC)							
Country	Cont. code	PCCE (toe) 1965	Year	PCCE (toe) 1900	GDP/Capita 1000$ 1990	Energy(toe) million $GDP Year 1990	Energy/GDP Index U.S. = 100 Year 1990
Vietnam	A	0.097		0.100	0.102	980.392	278.49
Bangladesh	A			0.057	0.160	356.250	101.20
Nepal	A	0.006		0.025	0.166	150.602	42.78
Afghanistan	A	0.030		0.090	0.201	447.761	127.19
Karnataka	A**			0.180 (0.260)	0.258	696.729 (754.890)	197.91 (214.43)
India	A*	0.100		0.214 (0.286)	0.288	654.12 (802.083)	185.80 (227.83)
China	A	0.178		0.549 (0.597)	0.317	1644.43 (1886.435)	467.11 (535.85)
Pakistan	A	0.135		0.233 (0.262)	0.373	624.664 (732.140)	177.44 (207.97)
Sri Lanka	A	0.106		0.179	0.519	344.894	97.97
Indonesia	A	0.091		0.214 (0.406)	0.617	316.91 (440.842)	90.02 (125.22)
Burma (Myanmar)	A	0.039		0.082	0.662	123.867	35.19
Philippines	A	0.160		0.215	0.708	303.672	86.26
Thailand	A	0.082		0.352 (0.542)	1.346	261.515 (540.02)	74.28 (153.39)
Turkey	A	0.257		0.857	1.886	454.401	129.08
Iran	A	0.537		1.026	1.955	524.808	149.08
Malaysia	A	0.313		0.974	2.568	379.283	107.74
Kuwait	A	16.781		6.414	5.369	1194.636	339.35
Korea South	A	0.238		1.898 (1.898)	6.462	293.717	83.43
Saudi Arabia	A	1.759		5.033	7.060	712.890	202.50
UAE	A	0.126		10.874	21.057	516.408	146.69
Japan	A	1.474		3.563 (3.568)	26.984	132.041	37.51
Mozambique	AF	0.081		0.085	0.092	923.913	262.44
Tanzania	AF	0.037		0.038	0.118	322.034	91.48
Ehtiopia	AF	0.010		0.020	0.129	155.039	44.04
Uganda	AF	0.036		0.027	0.142	190.141	54.01
Sudan	AF	0.067		0.058	0.282	205.674	58.42
Nigeria	AF	0.034		0.138 (0.358)	0.304	453.947	128.95
Kenya	AF	0.110		0.100	0.339	294.985	83.79

Ghana	AF	0.076	0.068	0.452	150.442	42.73
Egypt	AF	0.313	0.477 (0.501)	0.611	820.88 (978.723)	233.17 (278.01)
Morocco	AF	0.124	0.247	1.077	229.341	65.15
Algeria	AF	0.226	1.956	1.674	1168.459	331.91
South Africa	AF	1.744	2.447	2.763	885.632	251.57
Mexico	CA	0.605	1.300 (1.385)	3.321	391.448 (502.12)	111.19 (142.63)
Romania	E	1.536	3.623	1.187	3052.233	867.01
Yugoslavia	E	0.898	2.409	1.187	2029.486	576.49
Poland	E	2.027	3.416 (3.453)	2.037	1655.2 (1676.97)	470.17 (476.35)
Czechoslovakia	E	3.374	5.081	2.114	2403.500	682.73
Spain	E	0.901	2.201 (2.201)	13.510	162.916	46.28
U.K.	E	3.481	3.646	17.538	207.891	59.05
Netherlands	E	3.134	5.123	19.319	539.792	153.33
Germany West	E	3.197	3.491	19.709	177.127	50.31
Belgium	E	3.402	2.807	19.717	142.364	40.44
Italy	E	1.568	2.754	19.830	138.880	39.45
France	E	2.468	3.845	21.053	182.634	51.88
Norway	E	4.650	8.134 (9.083)	24.824	365.896	103.94
Sweden	E	4.162	6.347 (6.857)	27.520	230.632	65.51
Switzerland	E	2.501	3.902	34.304	113.748	32.31
Canada	NA	6.007	10.009	21.561	464.218	131.86
Australia	O	3.287	5.206 (5.374)	17.348	290.581	82.54
Peru	SA	0.395	0.509	0.996	511.044	145.17
Colombia	SA	0.412	0.811	1.269	639.086	181.54
Brazil	SA	0.286	0.549 (0.915)	2.677	219.24 (341.800)	62.27 (97.09)
Venezuela	SA	2.319	2.582	2.705	954.529	271.14
Argentina	SA	0.975	1.313 (1.801)	5.800	310.517	88.20
U.S.A.	USA	6.535	7.722 (7.822)	22.219	352.041	100.00
USSR (Former)	USS	2.603	4.632 (4.705)	8.203	564.671	160.40
World		1.114	1.567			

A: Asia, AF: Africa, CA: Central America, E: Europe, NA: North America, SA: South America, O: Oceania

Figures in parentheses indicate commercial energy + non-commercial energy.

Table 1b. Sector wise consumption of commercial energy in Karnataka and energy intensity (Energy(toe)/SDP (Rs. crores)), during 1990–91

Sector	Comm. energy million toe	% share of comm. energy	SDP—Rs. Crores	Energy intensity (toe/crore Rs)
Household	0.91	11.22	—	—
Agriculture	0.28	3.50	7631.01	371.90
Industry	4.16	51.38	5212.22	7989.32
Transport	1.86	22.96	2041.68	9115.24
Others	0.89	10.93	5962.52	1485.12
Total	8.10	100.00	20847.43	3887.39

Table 1c. Comparison of industrial energy share and electrical energy share in total energy

Country	Industrial energy as a % of total	Electrical energy as % of energy in industry
U.S.A.	30.0	17.3
Canada	29.1	21.8
France	34.7	15.1
Italy	36.0	17.1
Netherlands	27.8	13.9
U.K.	35.6	14.8
Sweden	29.0	31.5
Japan	44.6	20.0
Karnataka	44.0	68.99
India	50.71	42.02

non-commercial (traditional) energy) computed are also listed in Table 1a. In developing countries, like India, Nigeria and Pakistan, the share of non-commercial energy is more than 50%. Figure 1a depicts pictorially the per capita consumption of energy vs gross domestic product per capita. Figure 1b is the plot of per capita consumption of energy vs gross domestic product per capita for low income countries. Figure 1c gives country wise energy consumption per GDP. It is noticed that the energy consumption per capita accelerates as GDP per capita gets beyond $500. In terms of per capita GDP, there is a wide spectrum ranging from $92 for Mozambique, $288 for India, $22,219 for U.S.A., $24,824 for Norway and $34,304 for Switzerland. Apart from this, they also differ in terms of economic characteristics, such as level of industrialisation, rate of economic growth, etc. From Fig. 1a, it appears that per capita energy use increases with higher incomes at a higher rate than the linear growth. There are only small differences in per capita energy between the developing countries. For most Asian countries, barring Japan, the per capita energy consumption is less than 1 toe (Fig. 1b). For high income countries, the differences in energy use per capita are larger. For example, the difference between the U.S.A. and France or Japan is a factor of two. Among industrialised countries, Spain and Italy have relatively low per capita energy consumption. Further disaggregation of source wise data shows that Japan, Sweden and Switzerland have a high share of primary electricity, in the order of 90–96%, which contributes to the high energy use per capita and per GDP. Other factors explaining the difference between countries include industrial composition, end use efficiencies and geography. It is essential to include these factors in accounting for per capita energy consumption, otherwise cross country comparisons of aggregate measures such as energy use per capita or energy intensities could be misleading. Karnataka has a figure of 0.180 (Per Capita Energy Consumption), while for India, it is 0.231 during the year 1990–91. This illustrates that Karnataka State has very low energy/capita and GDP/capita values, but these do not reveal the true state of energy use; one would like to know how the energy is used and what the level of efficiency is. Normally, it is said that, since our energy use/person is very low compared to that for advanced countries, we should increase our energy production so as to reach the level of "advanced" societies. It is wrongly assumed that energy/capita reflects a true state of development in a country. If this argument is accepted, then we should increase energy consumption rates in our country and our state.

The energy analysis is carried out by incorporating non-commercial energy sources in computing

Per Capita Energy Consumption, which constitutes the significant portion in total energy consumption in countries like India, Nigeria, etc. By incorporating non-commercial sources of energy in the total energy, the per capita energy consumption for Karnataka becomes 0.260, while for India it is 0.266. The Per Capita Energy Consumption computed by including non-commercial energy sources is given in parentheses in Table 1a.

Recently, there has been a shift in the thinking, even in the industrial nations. The index to be used is not energy/person, but energy/GDP, i.e. the amount of energy consumed for producing 1 unit of GDP. This index is given in column 7 of Table 1. This index also reflects the efficiency of energy use at a macro level. Column 6 gives the absolute values of energy/GDP in tons oil equivalent per million dollars. The values for Canada, 464.218, Norway, 365.896 and, the U.S.A., 352.041, are on the high side. Japan, France and Italy with values of 132.041, 182.634 and 138.880, respectively, are on the low side. Although per capita energy use increases with higher GDP, Fig. 1c does not suggest or reflect that the energy intensity (energy consumption/GDP) of low income countries needs to be increased much with economic growth and development. Energy intensity is listed in column 6 of Table 1, while column 7 presents a relative figure wherein energy/GDP is computed with the U.S.A. value equal to 100. India has an energy intensity value of 654.12 toe/million dollars and Karnataka State has a value of 696.729 toe/million dollars. With inclusion of the non-commercial energy share, India's energy intensity increases to 802.083, while for Karnataka, it is 754.89. Compared to the U.S.A., India consumes 2.25 times, compared to France, 4 times and Japan 6 times more energy for the same output. However, these calculations do not include animate energy share, such as human and animal energy. If these are quantified and included, then the energy/GDP for India would shoot up further.

During 1991, India's energy intensity was 838 toe/m$ compared to U.S.A.'s 344, Japan's 133 and Sweden's 172. This shows the increase in energy intensity for India while a decline for Japan, U.S.A. and Sweden. An explanation for the differences in energy intensities between these countries cannot be done based on this aggregate analysis. That would require each region/country's sectoral energy use, industrial composition, etc. This necessitates a detailed look at the energy scenario and energy auditing in energy intensive sectors to improve the efficiency of energy usage in order to bring down the energy intensity. Hence, the industry sector in Karnataka has been chosen for detailed analyses.

Karnataka is on the very low side as far as energy/capita is concerned. Let us look at the picture for energy/SDP (State Domestic Product). Karnataka State has an energy consumption/SDP value of 694.729 toe/million dollars for the year 1990–91. This means that we are consuming more energy for less output. For a relative picture, column 7 of Table 1 is computed. Here, the energy/GDP is calculated with the U.S. value equal to 100. Coupled with column 7, we see that Karnataka has an index of 197.91 for the year 1990–91. This means that we are consuming 1.98 times the energy consumed by the U.S. for the same output. When compared with Switzerland, Japan and Italy, we consume 6.13, 5.28 and 5.02, respectively, times the energy consumed by them for the same output. This energy consumption does not include human/animal energy. If these are also included, then the energy/SDP value will be higher (ours is more of an employment oriented society still).

The second factor seen is that the energy/SDP is increasing for Karnataka. One possible conclusion is that the energy efficiency (of use) is decreasing and not increasing. Post oil crisis situations saw considerable reductions in energy/GDP. For instance, West Germany showed a decrease from 1,080 to 1,010; similar decreases were evident for the U.K. and the Netherlands. The United States has shown a steady value for a period of nearly 20 years (1961–74), varying from 1,400 to 1,480 (a max. of 5% difference), whereas Karnataka has shown an increase of about 10% in 5 years. Hence, it is desirable to actively pursue the introduction of energy efficient methods. The reasons why the U.S. has a flat curve for the 15 years period may be: frequent updating of technology; efficient methods due to competition; stability in the system due to many years of energy use; and saturation (?).

In order to see which sector consumes more energy in Karnataka, sector wise GDP and energy have been calculated. These are presented in Table 1b and Fig. 2 for Karnataka. The index here is the energy consumption in tons of oil equivalent per crore rupees of the sector's contribution to SDP. The value for agriculture is very low—371.90, whereas the value for transport is very high—9115.24.

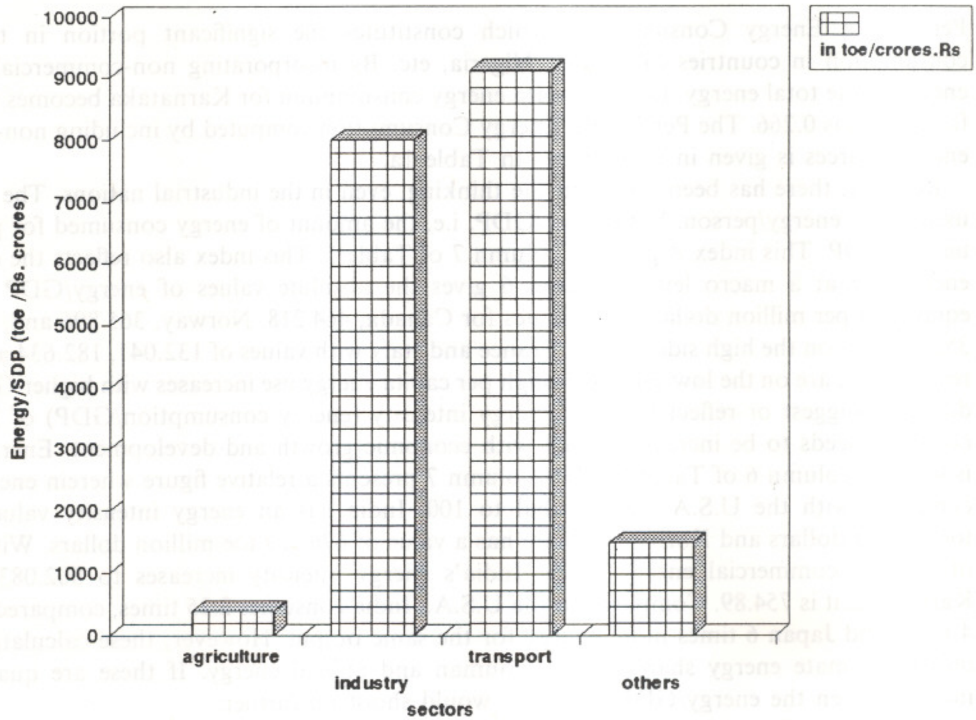


Fig. 2. Sector wise energy per state domestic product during 1990–91.

industrial sector has a mix of many sources and devices, and also has a higher index, it was chosen for further comparison.

Another factor in the selection of the industrial sector is the fact that it is one of the major consumers of electricity—a high quality energy source. More than 44% of the total electrical energy is consumed by industries. Table 1c illustrates this phenomenon. The percentage of the total energy which is industrial energy is given in this table. As can be seen from this table, whereas many countries consume about 30% of their energy for industrial purposes, we consume 44% and Japan 44.6%. The quantity of electrical energy consumed by industries as a percentage of total industrial energy is also reflected in the table. Even countries like the U.S., U.K., West Germany, France, etc. resort to electrical energy for a smaller fraction of their requirements, about 15–17%, whereas the share of electrical energy in Karnataka's industrial energy needs is about 70%. This is despite power cuts for the past many years. Since electrical energy is a derived secondary energy source, it is inefficient for low quality work—like low temperature or medium temperature heating-applications. Electrical energy is efficient for lighting and static movement applications. As can be shown later, electrical energy finds a lot of use in heating applications in many industries in Karnataka, not because it is efficient, but because it is convenient and less expensive than other fuels.

Efficient use of energy implies proper pricing strategies. Subsidies to industries on the tariff or fuel charges or low tariffs result in larger waste of energy in addition to lower direct costs of production. The electricity tariff for Karnataka is the cheapest (second only to the U.S.). Many other countries, like West Germany, U.K. and France have tariffs which are more than twice our rate. One cannot say more on this, because it also depends on income levels. One point deserves mention here, with low costs of energy charges, labour and raw materials, many of our industrial products—engineering, chemical, etc.—should be highly competitive in international markets, but it is not so, one of the factors may be inefficient use of energy.

So far, we have seen comparisons of our energy usage with that of some industrialised countries. Let us look at the energy scene in India and Karnataka.

2. ENERGY SOURCES AND BALANCES

Various energy resources, considered in this paper, are generally classified into three broad categories as:

1. Commercial fuels: coal, oil, gas and electricity (including that generated in large scale hydro-electric schemes). These fuels have commercial value.
2. Non-commercial, traditional or biomass fuels: wood, charcoal and crop and animal residues. These fuels are non-commodified, may be gathered freely from the local environment, have been used extensively for many thousands of years and are the fuels closely associated with the crisis of energy for survival.
3. New and renewable sources of energy: wind, wave, solar, mini-hydro, ethanol, biogas, tidal and so on.

Conservation in one sense, could also be considered an energy 'resource' because using energy more efficiently produces the same work with less fuel.

2.1. India's energy scene

The supply of primary sources of commercial energy in the last two decades is tabulated in Table 2. As seen in Table 2, coal is the predominant energy source (58.39%), followed by oil (27.18%), natural gas (7.61%), lignite (3.71%), hydro power (2.84%) and nuclear power (0.27%). The growth in commercial energy consumption for the period 1980–81–1989–90 is shown in Fig. 3. Non-commercial sources, such as fuelwood, agricultural residues and animal wastes, account for more than 50% in the total energy consumption. Non-commercial energy consumption is estimated to be 143 million toe (69.55% in total energy scene) for 1972–73 and 161 million toe (59.47%) for 1982–83. A major portion of these non-commercial energy sources is used in rural areas for activities such as cooking, water heating and in industries.

Coal is a major commercial fuel source, constituting 58.39% of total consumption, of which 56.96% is available in the country and the balance of 1.43% is imported. Coal, historically, was available in all industrialised countries and probably used inefficiently. Thus, the greater the share of coal in total energy consumption, the less energy consumption is added per unit of increased GDP, as there is room for increased efficiency of energy utilisation. It is inversely related to the elasticities. Hydro-electricity, on the other hand, is usually inexpensive wherever it is available, and therefore the greater the share in energy consumption, the greater would be the income elasticity.

Table 2. Supply of primary sources of commercial energy (in million tonnes of oil equivalent—mtoe)

Year	Lignite	Coal	Oil	N gas	Hydro power	Nuclear	Total
70–71	1.66	35.75	18.51	1.24	2.10	0.20	59.46
71–72	1.81	35.49	20.25	1.32	2.34	0.10	61.30
72–73	1.52	37.84	19.41	1.34	2.27	0.09	62.468
73–74	1.62	38.31	21.04	1.47	2.41	0.20	65.05
74–75	1.47	43.36	21.70	1.75	2.32	0.18	70.79
75–76	1.48	48.84	22.07	2.03	2.78	0.22	77.42
76–77	1.97	49.51	22.95	2.08	2.90	0.27	79.68
77–78	1.75	49.43	25.27	2.43	3.17	0.19	82.24
78–79	1.62	49.96	26.29	2.41	3.93	0.23	84.44
79–80	1.42	50.94	27.89	2.37	3.79	0.24	86.64
80–81	2.50	55.97	26.76	2.02	3.88	0.25	91.38
81–82	3.09	61.06	30.65	3.30	4.13	0.25	102.48
82–83	3.40	64.44	33.46	4.23	4.03	0.17	109.72
83–84	3.58	67.90	36.47	5.11	4.16	0.30	117.51
84–85	3.82	72.55	36.15	6.20	4.48	0.34	123.56
85–86	3.94	76.76	44.78	6.97	4.24	0.42	137.12
86–87	4.62	82.42	45.95	8.44	4.48	0.42	146.33
87–88	5.47	89.63	48.09	9.82	3.95	0.42	157.38
88–89	6.16	97.73	49.85	11.32	4.82	0.49	170.37
89–90	6.19	100.73	53.58	14.55	5.17	0.39	180.61
90–91	6.91	106.63	53.72	15.42	5.96	0.32	189.16
91–92	7.80	115.29	54.33	15.98	6.05	0.46	199.91
92–93	7.60	119.66	55.70	15.59	5.81	0.56	204.92
% share	3.71	58.39	27.18	7.61	2.84	0.27	100.00

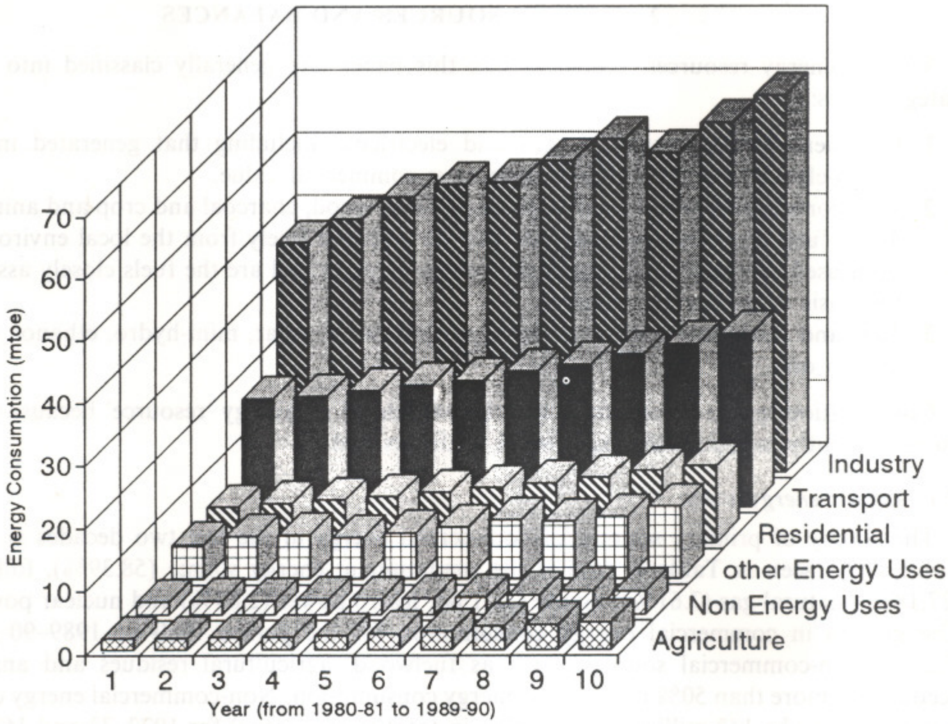


Fig. 3. Sectorial energy consumption (commercial) in India.

Table 3 shows the pattern of commercial energy consumption in India since 1980–81. The industry sector is one of the major consumers of commercial energy with a major share of 50.70% out of the total commercial energy (119.29 mtoe). Sector wise consumption of commercial energy in the last ten years is depicted in Fig. 3. The industrial share during 1991–92 is 66.65 mtoe (51%). This is followed by the transport sector with a share of 22.85%. The transport sector depends mainly on oil. It is seen that the use of petrol products increased from 12.62 mtoe (43%) in 1980–81 to 25 mtoe (48%) in 1991–92. The agricultural and residential sectors role in commercial energy consumption is very minimal. However, if non-commercial sources are also taken into account, there would be a dramatic change in the sectoral shares of total energy consumption.

The electricity consumption in India had a compound annual growth rate of 10% during the period 1950 to 1991–92, and the per capita consumption was about 253 kWh in 1990–91. The agriculture and domestic sectors have shown an increasing trend in the last four decades. Energisation of pumpsets in rural areas and subsidised electricity has led to the steep increase in electricity consumption in the agriculture sector from 7% in 1965–66 to 28.2% in 1991–92. Increased use of electric appliances and increasing urbanisation has shown a compound growth rate of about 10% a year in the domestic sector. The commercial sector, comprising of offices, hotels, etc., accounts for 5–6% of total electricity consumption. In the transport sector, the railways constitute the major consumer with consumption of 372 million kWh in 1970–71 and 4658 million kWh in 1991–92, showing a growth of 15% and accounting for 2.3% of the total electricity

Table 3. Sectoral consumption of commercial energy in India

Year	1980–81	1981–82	1982–83	1983–84	1984–85	1985–86	1986–87	1987–88	1988–89	1989–90
Total energy consumption	68.764	74.844	80.471	83.683	86.513	93.387	100.26	101.587	110.985	119.29
Agriculture	1.625	1.624	1.861	1.887	2.131	2.389	2.807	3.63	3.861	4.224
Industry	36.861	40.607	44.225	46.265	46.595	50.059	53.423	51.261	56.214	60.495
Transport	17.443	17.787	18.758	19.655	20.309	21.719	22.789	24.476	26.055	27.673
Residential	5.637	6.258	6.82	7.25	8.038	8.773	9.532	10.375	11.532	12.24
Other en use	1.901	2.042	2.127	2.214	2.341	2.488	2.677	2.953	3.684	3.44
Non en use	5.297	6.526	6.68	6.412	7.099	7.969	9.032	8.892	9.639	11.218

consumption. Power shortages and poor quality of supply has made the industrial sector dependent more on captive power generation.

During 1991–92, peak and energy shortages in India were 17.7% and 8.5%, respectively. With proper conservation measures and an integrated energy planning approach, these shortages could be reduced. Conservation measures include improvement of efficiencies of end use devices in all sectors, improvement of plant load factor in thermal power stations by improving the coal processing facilities and improvement of a properly trained work force. Paucity of funds in the power sector to implement conservation measures could be managed with proper restructuring the tariffs in line with the cost of power generation and supply.

2.2. *Energy planning*

Currently, energy planning in our country is not an integrated activity. Since there are many energy sources and end uses, there are many organisations and agencies that deal with different aspects of energy. The plans for electricity, coal, oil and fuelwood are made by respective organisations mainly based on the projection of energy demand. The primary goal of this approach is for energy supply expansions on the assumption that there is a correlation between energy use and gross domestic product. With this approach, energy becomes an end in itself, and the focus shifts on meeting increased energy consumption through energy supply expansion alone. This supply and demand based planning approach for each individual energy form has resulted in problems like more losses, more conversions and low efficiencies. This is evident from the disappearance of forests, village wood lots, roadside trees, construction of giant hydro electric dams, fossil fuel based power plants and controversial nuclear plants. This conflict between the energy demand and environmental quality goals can be solved by having an integrated approach to the problem of energy planning with a view to minimise consumption of non-renewable resources of energy, to maximise efficiency of energy usage and to harness renewable sources of energy in an ecologically sound way. Another aspect that has to be considered in the planning process is that of matching energy resources and end uses. Because of convenience, the current usage of high quality energy such as electricity for low quality activities like bath water heating, is to be discouraged. Hence, strategies for integrated energy planning should include (a) improvements in efficiencies of end use devices and/or conversion equipments, (b) optimising energy source—end use matching, (c) an organised approach towards optimal use of renewable resources, (d) proper exploitation of biomass energy resources and (e) discourage use of depletable resources (by penalising).

Our earlier studies give vast scope for energy conservation in the energy sectors. Highlights of these studies are: (1) domestic sector in rural areas shows that there is scope for savings of 42% in the quantity of fuelwood used by switching over from traditional stoves to improved stoves; (2) in electro metallurgical industry, efficiencies of 14% in welding sets, 10.4% in furnaces, 24% in cranes and 36.5% in diesel engines show vast possibility for improvement in end use efficiencies in all sectors; (3) energy analyses carried out for the food processing sector revealed that most of the industries are utilising less than 50% of installed production capacity. The low power factor when a motor is under loaded leads to inefficiency. It is estimated that 23–38% of the energy could be saved at improved efficiency due to full utilisation of installed production capacity; (4) usage of solar water heaters, especially for bathing water heating could bring down electricity consumption in urban areas and fuelwood consumption in rural areas; (5) harnessing hydro potential in ecologically sound way by means of mini/micro/small hydro potential in hilly districts. It is estimated that about 1250 million units per year could be generated in the Bedthi and Aghnashini river catchments alone in the Uttara Kannada District and (6) harnessing solar energy in coastal regions. Our estimate shows that, in coastal taluks like Kumta, Karwar, Honnavar and Bhatkal in the Uttara Kannada District of Karnataka State, there is potential of 5.5 kWh/m^2 (based on mean daily insolation).

3. KARNATAKA STATE: LOCATION AND DEMOGRAPHY DETAILS

Karnataka State extends over an area of 1.92 lakh sq. kms, it occupies about 5.84% of the total geographical area of the country. The state is situated in the West–Central part of the Deccan

Peninsula of the Indian union and is stretched between 13° 3′ and 18° 45′ north latitudes and 74° 12′ and 78° 40′ east longitudes. The major portion of Karnataka lies in the elevation range between 450 and 900 metres above mean sea level. With a population of 4,49,77,201, it accounts for 5.4% of the country's population. For administrative purpose, the state has been divided into divisions, districts and taluks. There are 27,024 villages spread over 175 taluks. 69.07% of the population resides in rural areas (31,069,413 people).

3.1. Karnataka's energy scene

Karnataka does not have any coal deposits. It gets its coal from outside. The electrical energy for Karnataka was purely hydro, and with the commissioning of Raichur thermal power station, it gets electrical energy from coal also. The other major source of commercial energy—oil—is also not available in Karnataka. Hence, the main source of commercial energy for the state comes from hydroelectric plants.

Karnataka State depends both on commercial and non-commercial forms of energy. Non-commercial energy constitutes 53.2%, met mainly by sources like firewood, agricultural residues, charcoal and cowdung, while commercial energy's share is 46.8%, met mainly by electricity, oil, coal, etc. Table 4 lists the source wise consumption of energy during the year 1990–91. This data is compiled from various agencies: Karnataka Electricity Board, Directorate of Economics and Statistics, Planning Department, Forest Department and Agriculture Department. As noticed in Table 4, commercial energy sources like coal, oil and electricity provide only a small part of the energy scene of Karnataka. The major energy share comes from firewood. Electricity represents 55.67% of commercial energy for 1990–91. There has been an increase in the per cent share for electricity in the last 10 years. Firewood consumption is around 7.44 million tons of oil equivalent. Agro wastes are also used for energy purposes. Figure 4a and b are pictorial presentations of source wise consumption. From Fig. 4b, it is seen that firewood constitutes 43.0%, while electricity is 26.1%, followed by oil (11.6%) and agricultural residues (8.7%). This demonstrates that we depend mainly on biomass to meet our energy needs. Figure 4c illustrates the sector wise consumption of commercial energy in Karnataka during 1990–91. This shows that the industrial sector, with 51.4% share, constitutes the major consumer of commercial energy, followed by the transport sector (23.0%), household (11.2%) and agriculture (3.5%). Hence, we focus our attention on the industrial sector to carry out a detailed investigation to see the extent of savings possible.

3.2. Industries in Karnataka

Industry is playing a pivotal role in the development of Karnataka State. The secondary sector in the state accounts for nearly a quarter of the state income in real terms of the total output in the economy. The average annual growth rate of industrial production over the period from 1981–82 to 1990–91 is about 6.4%, as against 7.9% in the country, as reflected in the index of industrial production. The sector wise indices for the years 1989–90 to 1990–91 are furnished in Table 5.

Sector wise analysis for the period 1981–82 to 1990–91 shows that the highest growth rate of

Table 4. Source wise consumption of energy in Karnataka during 1990–91 (in million tons of oil equivalent)

Source	qty (mtoe)	% share
Coal	1.005	5.81
Kerosene	0.445	2.57
Oil (HSD, LDO, etc.)	2.014	11.64
LPG	0.130	0.75
Electricity	4.510	26.06
Commercial energy total	8.105	46.84
Agricultural residues	1.510	8.73
Firewood	7.440	43.99
Biogas, cowdung, etc.	0.250	1.44
Non commercial energy total	9.200	53.16
Total energy during 1990–91	17.055	100.00

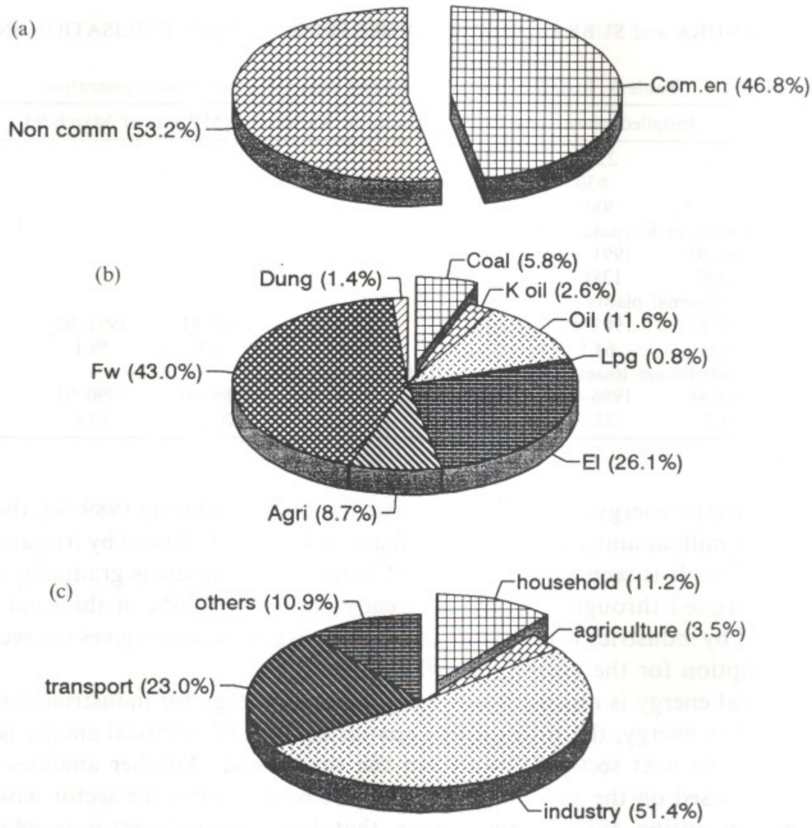


Fig. 4. (a) Commercial and non-commercial energy share; (b) source wise consumption; (c) user wise commercial energy consumption.

6.41% was recorded in the manufacturing sector, followed by the electrical sector (5.99%) and mining sector (4.90%). The total industrial performance is indicated by the general index of industrial production.

3.3. *Electrical energy use in Karnataka*

The share of industries in total electrical energy consumption is around 44%. The state generated 12,430 million units of electrical energy in 1990–91 and 12,887 million units during 1991–92. The share of industries in electricity consumption is 4,482 million units in 1990–91 and 4,316 million units in 1991–92. The installed power generating capacity, gross power generation and transmission and distribution losses are listed in Table 6. Transmission and distribution losses during 1991–92 are about 19.32%. Table 7 lists the electric energy requirement and available data compiled from the Karnataka Electricity Board. For the last six years, there is a deficit of electrical energy of the order of 26.88% during 1988–89, 23.57% during 1989–90, 22.90% during 1990–91, and 23.59% during 1991–92. Figure 5a gives a pictorial representation of the energy available and requirement in Karnataka, while Fig. 5b illustrates the surplus or deficit in availability of electrical energy. It is seen that, during 1988, the deficit is a maximum.

Table 5. Index of industrial production of Karnataka, Base year 1980–81 = 100

Sector	Weight	1988–89	1989–90	1990–91
Mining	1.41	135.29	136.23 (0.69)	149.03 (9.40)
Manufacturing	95.85	222.76	246.48 (10.74)	262.53 (6.43)
Electricity	2.74	145.00	173.94 (19.96)	188.46 (8.35)
General index	100.00	219.40	243.13 (10.82)	258.90 (6.49)

Table 6. Installed power generating capacity, gross power generation

Installed power generating capacity in Karnataka (MW) as of March 93									
Hydro		2375							
Thermal		630							
Total		3005							
Gross power generation in Karnataka (million units)									
	1990–91	1991–92	1992–93						
	12430	12867	12688						
Plant load factor of thermal plants (%)									
1985–86	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92		1992–93	
33.5	45.6	64.5	66.4	76.9	76.3	59.1		45.4	
Transmission and distribution losses (as % of electricity generation)									
1980–81	1985–86	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92	1992–93	
24.6	22.5	22.2	21	21.3	20.5	19.6	19.3	20.9	

Sector wise electric energy consumption is listed in Table 8. During 1989–90, the industrial sector consumed 4,780 million units, constituting a share of 44.86%, followed by irrigation pumpsets with a share of 28.63%. It is seen that the share of irrigation pumpsets is gradually increasing. 8.82% of pumpset energised through 1991–92 is already guzzling 36.26% of the total electrical energy. This is followed by industries with a share of 34.34%. Figure 6a and b gives the sector wise electrical energy consumption for the years 1989–90 and 1991–92.

Since electrical energy is an important component of energy for industrial consumption and as it is a high quality energy, the sectoral and spatial analysis of electrical energy is considered next. The analysis in the next section looks from the supply end. Another analysis follows from the consumer end, based on the sample surveys. Figure 6a illustrates the sector wise consumption of electrical energy during 1989–90. It is seen that the industrial sector is 44.9%, followed by agriculture (28.6%) and domestic households (15.5%). Figure 6b illustrates the rise in share of the agriculture sector in the electrical energy scene during 1991–92. The share has increased to 36.3% in 1991–92 from 28.6% (during 1989–90). The industrial share is 34.3%, followed by the domestic sector (15.3%).

3.4. *Electrical energy utilisation in industries in Karnataka*

Connected loads of the installations and energy consumption details in various sectors are the indices normally used to see the growth of electrical energy. A look at these indices indicates the primary users and not how they use energy. Table 9 illustrates the profile of connected load from 1969–70 to 1985–86 in various sectors. The annual increase for the year 1985–86, is greatest for agricultural pumpsets (11.9%), followed by AEH consumers (11.86%) and LT installations (10.5%). When we look at the increase for the three years from 1980–81 to 1985–86, the connected load AEH category grows faster (57.2%) than that of LT industries (46.5%). HT industries show a small growth rate. The overall annual growth rate is only 8.9%. AEH, LT and agricultural installations have growth rates greater than the overall growth rate. In the case of 1980–81 to 1985–86 growth rate, AEH and LT industries and the agricultural sector have greater increases than the overall values. This is shown pictorially in Fig. 7a. Category wise, the yearly percentage change in connected electrical load is illustrated in Fig. 7b.

Table 7. Power requirement, supply and deficit (million units)

	1986	1987	1988	1989	1990	1991	1992	1993
Requirement	12166	14163	15185	16290	18275	19590	20350	19260
Availability	9463	10350	10556	11911	13967	15104	15550	14390
Surplus(+)/ Deficit(−)	−2703	−3813	−4629	−4379	−4308	−4486	−4800	−4870
%	−22.22	−26.92	−30.48	−26.88	−23.57	−22.90	−23.59	−25.29
Villages electrified and pumpsets/tubewells energised as on 31/3/93								
Total no of villages		27028						
Villages electrified		26483						
% of total		97.98						
Pumpsets/tubewells energised		848985						
% Share		8.82						

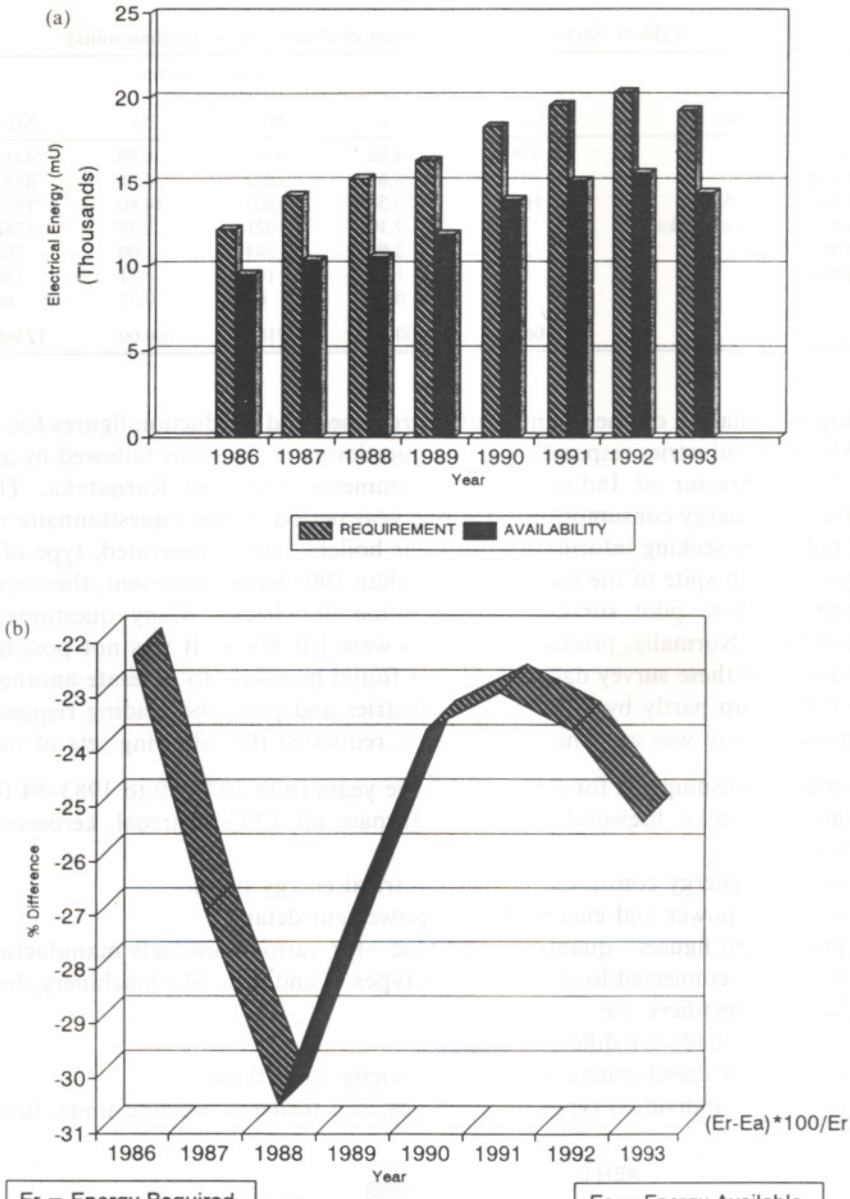


Fig. 5. (a) Electrical energy requirement and availability; (b) percentage difference in diamond and availability of electrical energy.

Table 10 gives the sector wise annual consumption of electrical energy in various sectors. During 1989–90, the industrial sector leads other sectors in electrical energy consumption with a share of 44.88%, followed by irrigation pumpsets (28.63%).

4. ENERGY SURVEY OF INDUSTRIES

Since the data available with various agencies dealt with only one aspect of energy use, it becomes necessary to collect data directly from the industries. This can be seen from the discussions in the last section. We concentrated on electricity and, that too, from the supplier's end. To understand the types of fuels used and production, we needed to conduct a survey, as this type of data was not available or accessible. Hence, we decided to conduct a survey of about 250 industries.

Since the survey was done for the first time, we went about it in many stages with help from many authorities like the Director of Industries and Commerce, Govt. of Karnataka, and the Chief Inspector of Factories and Boilers. The first questionnaire prepared by us was a simple one

Table 8. Sector wise consumption of electric energy (million units)

Category of consumers	Consumption 1989–90 MUs	%	1990–91 MUs	%	1991–92 MUs	%
Industries	4780	44.86	4482	36.79	4316	34.34
Irrigation pumpsets	3051	28.63	4422	36.30	4557	36.26
Domestic lighting & AEH	1653	15.51	1803	14.80	1929	15.35
LT industries & public works	757	7.10	1021	8.38	1244	9.90
Commercial lighting	217	2.04	244	2.00	280	2.23
Public lighting	146	1.37	148	1.21	156	1.24
Others	52	0.49	62	0.51	86	0.68
Total	10656	100.00	12182	100.00	12568	100.00

requesting information on the quantity of energy used and production figures for a period of two years. About 80 industries responded to this questionnaire. This was followed by another one sent by the Joint Director of Industries and Commerce, Govt. of Karnataka. This one sought information on energy consumption for a one year period. A third questionnaire was also sent to various industries seeking information on their boilers—steam generated, type of fuels used and quantity of use. In spite of the fact that more than 1000 letters were sent, the response was poor.

Analysis of these pilot surveys showed some drawbacks. Many questionnaires were not completed fully. Normally, production figures were left blank. It was not possible to draw any conclusions from these survey data. So, it was found necessary to generate another questionnaire and get it filled up partly by visiting the industries and partly be sending requests by post.

The questionnaire was an exhaustive one. It requested the following sets of information:

(i) energy consumption for a period of five years from 1979–80 to 1983–84 for each source, like coal, coke, firewood, electricity, furnace oil, LPG, charcoal, kerosene. etc. and their values;
(ii) monthly energy consumption (for electrical energy only);
(iii) electrical power and energy details, power cut details;
(iv) production figures—quantity and value—for various products manufactured;
(v) details on connected load for various types of end uses, like machinery, heating, welding, lighting, rectifiers, etc.;
(vi) details of loads for different sections;
(vii) capacity of diesel generating sets; electricity from them;
(viii) details for individual types of machines, like furnaces, welding units, lighting, etc.;

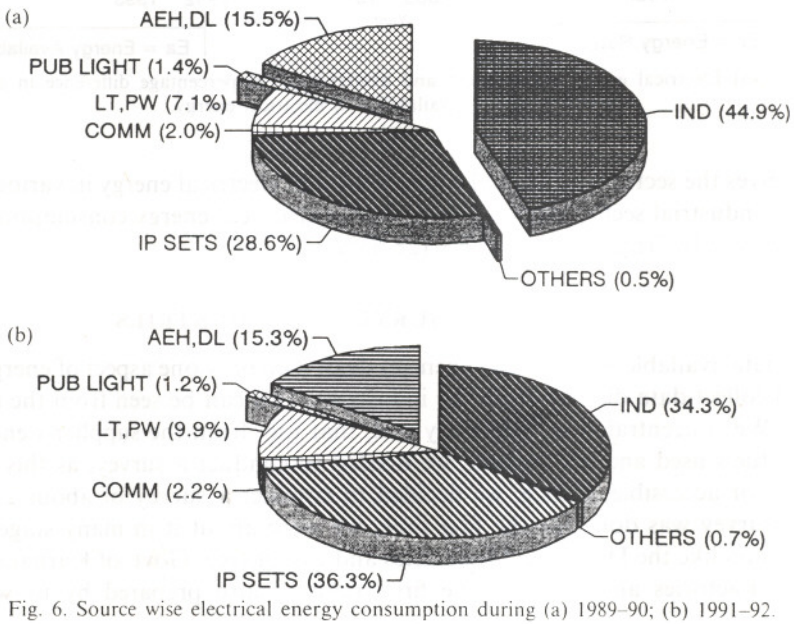


Fig. 6. Source wise electrical energy consumption during (a) 1989–90; (b) 1991–92.

Table 9. Category wise growth in connected load (MW)

Year	Domestic		Commercial			LT power				
	LG	AEH	LG	Heat	WW	OT	HT	AG	PL	Total
1969–70	206.1	77.4	52.1	(A)	19.04	195.6	330.35	368.6	14.9	1264.12
1970–71	221.2	95.8	60.2	(A)	21.87	215.8	344.84	436.66	16.27	1412.67
1971–72	237.8	118.1	68.65	(A)	22.52	236.5	420.6	496.49	18.66	1619.35
1972–73	255.2	134.9	76.07	(A)	23.58	251.1	448.5	556.75	20.349	1766.37
1973–74	280.1	160.7	85.99	(A)	24.32	269.2	473.7	609.74	21.233	1925.01
1974–75	296.6	201.8	43.69	52.69	57.64	298	466.25	668.38	21.932	2106.95
1975–76	313.7	247.3	47.87	58.07	64.36	324	745.36	725.14	22.508	2548.21
1976–77	326.4	293.8	52.76	65.55	65.09	348.7	770.35	784.55	23.068	2730.27
1977–78	340.5	341.3	57.81	72.63	65.94	371.7	783.8	853.52	23.693	2910.93
1978–79	356.4	371.5	63.56	81.71	66.48	393.1	796.1	920.89	24.347	3074.10
1979–80	379.5	429.8	71.08	86.39	67.77	428.4	810.29	962.11	25.002	3260.34
1980–81	404.8	507.9	78.72	88.73	69.08	471.9	822.42	1022.7	25.5	3491.79
1981–82	433.9	602.7	85.56	90.1	70.56	521.5	840.14	1099.7	26.045	3770.19
1982–83	462.9	720.3	94.17	(B)	71.91	664.4	871.6	1192.9	26.687	4104:92
1983–84	502.4	896.4	104.9	(B)	74.32	723.4	1057.6	1325.8	28.054	4712.82
1984–85	543.7	1062	114	(B)	77.28	799.2	1086.8	1482.9	29.554	5194.83
1985–86	587.6	1188	125.7	(B)	81.87	883.2	1103.7	1657.4	30.671	5658.25

LG: Domestic Lighting, AEH: All Electric Homes, LG: Commercial lighting, HEAT: Commercial Heating, LT WW: LT water works, LT OT: LT Industries, HT: HT Industries, AG: Agricultural Pumpsets, PL: Public Lighting.
(A) included under commercial lighting.
(B) included under LT Power (others).

(ix) conversions;
(x) future plans.

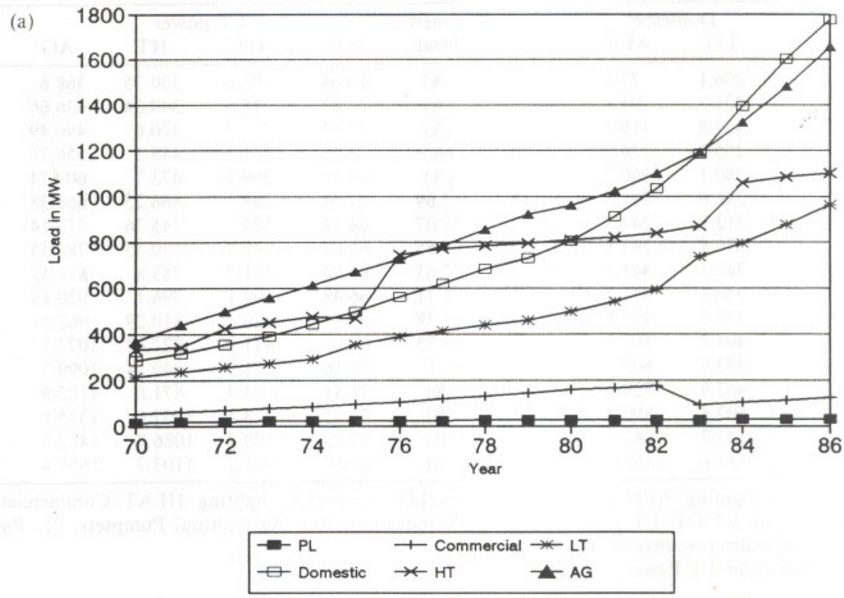
This questionnaire, numbering 16 pages, was sent to more than 250 industries. We received replies from 41 industries. These industries have understood the motive behind our studies and spent considerable amount of their time in filling in this questionnaire. They are of invaluable help to us in our analysis. Despite repeated reminders, the biggest energy guzzler INDAL, Belgaum (aluminium company) did not respond to any of our questionnaires—either to the earliest two simpler ones or to the detailed one. Recently, we conducted a fourth survey by sending questionnaires to 510 industries. About 82 industries promptly responded, out of these 78 industries filled in the questionnaire completely. This shows the growing awareness among industries in Karnataka.

Table 11 gives the details of the type of industries which responded to our questionnaire. Fortunately, we got a wide canvas of industry types in these responses. We have a number of industries for the groups of engineering, metallurgical, paper, textile and sugar industries. Except for the aluminium producer, all other major industrial types are to be found in the response. The types also include glass, batteries, watches, oxygen, fertilizers, steel, electronics, tools, tiles, cement, and heavy engineering units. Hence, the results will display information on a wide variety of industry types.

The questionnaire (third survey during 85–86) for nearly half the number of industries which responded were filled up by personally visiting the industries concerned and eliciting their answers to our queries. This involved a number of trips to each industry on timings convenient to them. This process entailed an effort of 4–5 months. Data pertaining to energy were analyzed, and the results are presented in a series of tables. Table 12 shows the energy consumption by these groups during 1983–84. The following points deserve mention. The energy unit used is million kilowatt hours equivalent.

(i) Total energy consumed by these industries works out to nearly 6.0 million tons of coal equivalent. This means that we have covered more than 80% of the energy consumed in industries.

(ii) The electrical energy component is only 1,198 million units. This is less than 50% of the total electrical energy consumed in the state. As already stated, the unavoidable exclusion due to the non-availability of one aluminium industry has a sizable effect on the total electrical energy. This is because this industry alone consumes about 20% of the total electrical energy for industries in Karnataka. Similarly, JINDAL (an aluminium company



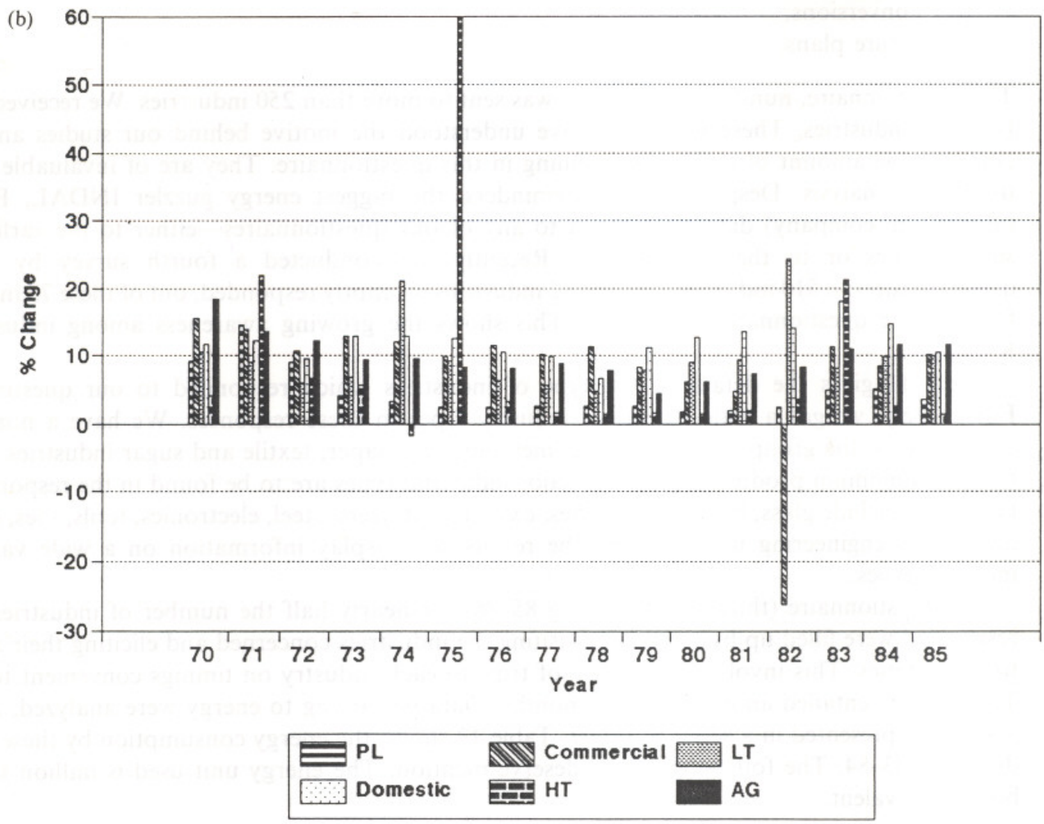


Fig. 7. (a) Category wise growth in electrical load; (b) category wise yearly % change in electrical load.

at Bangalore) also refused to give us information pertaining to their energy use and production, despite personal visits.

(iii) Fortunately, there is a balance in the industries consuming different types of fuels. For example, the paper, textile and cement industries use coal as their primary fuel; the sugar industries consume mainly bagasse; the metallurgical industries use coke and charcoal; the chemicals and metallurgical industries use furnace oil; electricity and diesel are used by most industries.

Table 10. Category wise growth in electrical energy consumption (million units)

Year	Domestic LG	Domestic AEH	Commercial LG	Commercial Heat	IND	LT Power WW	HT	AG	PL	Other	Total
1969–70	150.3	48.4	72.9	(B)	205.6	108.9	1519	149.3	47.24	37.02	2338.5
1970–71	163.8	52.64	88.54	(B)	239.5	115.4	2009	178.9	53.27	45.58	2946.6
1971–72	175.2	89.78	72.15	(B)	320.1	86	2347	202.1	60.14	53.50	3406
1972–73	152.1	122.2	67.1	(B)	305.1	106.3	2395	237.3	61	54.39	3500.7
1973–74	171.2	121.3	68.46	(B)	332.8	98.77	2462	256.6	76.15	56.79	3644
1974–75	185.6	170.8	79.87	(B)	409.2	151.4	2346	291.1	67.45	46.45	3747.9
1975–76	195.3	202.8	92.6	20.09	350.2	168.2	2973	307.5	59.28	26.48	4395.7
1976–77	202.6	221.8	89.17	4.47	326.5	97.64	3034	396.1	46.81	44.48	4464.1
1977–78	219.6	237.5	97.49	6.02	350.4	85.07	2524	356.6	48.41	36.17	3960.8
1978–79	237	267.7	99.57	(A)	425.3	(A)	3448	334.2	56.27	38.00	4906.3
1979–80	254.2	342.6	121.4	(A)	460.1	(A)	3211	360.9	69.48	38.07	4858.2
1980–81	278.5	417.8	132.7	(A)	489.4	(A)	3374	384.4	70.99	40.56	5188.7
1981–82	280.2	508.6	143.4	(A)	504.9	(A)	4050	425.5	77.02	41.76	6031.6
1982–83	331.3	649.6	161.2	(A)	620.7	(A)	3699	525.6	86.62	42.61	6116.3
1983–84	422	643	165	(A)	459	(A)	3499	936	99	28.00	6251
1984–85	567	910	196	(A)	698	(A)	4165	607	104	30.00	7277
1985–86	627	934	181	(A)	668	(A)	3413	1221	114	34.00	7192
1989–90	1653		217		757		4780	3051	148	52.00	10856
1990–91	1803		244		1021		4482	4422	148	62.00	12182
1991–92	1929		280		1244		4316	4557	158	86.00	12568

(iv) Electricity constitutes 19.4% of total energy; coal is the maximum with 40.4%, others—coke, bagasse, LPG and kerosene—form 24.9% of the total. Firewood use is quite small, mainly restricted to sugar, textiles, tiles and metallurgical industries.

Since absolute energy consumption patterns do not provide any indication, we used a standard unit and calculated the energy consumption in million units equivalent (million kWh). To understand the significance of the predominant type of fuels consumed, percentages were calculated

Table 11. Types and numbers of industries surveyed

Sector/Type	Produce range	1981–85 Number of ind. surveyed	1991–92 Number of ind. surveyed
Engineering	Pistons, valves, pumps	6	4
Heavy engg I	Looms, castings	1	1
Heavy engg II	Metallic products	1	1
Heavy engg III	Cylinders	1	2
Electrical I	Transforms	1	2
Electrical II	Switchgears	1	1
Electronics	—	1	2
Miscellaneous	—	1	12
Metallurgical I	Steel products	8	6
Metallurgical II	Ores processing	2	1
Metallurgical III	Ores extraction	2	2
Aluminium	Products	2	1
Insulators	—	1	1
Paper	—	4	2
Textiles	—	7	7
Sugar	—	8	5
Chemicals I	Fertilizers	2	1
Chemicals II	—	1	7
Tiles	—	2	0
Mines	Gold	2	1
Agromachines	—	2	1
Oxygen	—	2	
Tools	—		6
Glass	—	1	
Batteries	—	1	
Cement	—	1	7
Lamps	—	1	1
Refractory bricks	—	2	
Liquor			5
Total		65	78
No. of industries with 5 yrs data		41	

Table 12. Annual energy consumption in industries in 1983–84 Karnataka (million units)

Sector	Electricity	HSD	Furnace oil	LDO	Charcoal	Coal	Firewood	Others
Engineering	9.38	20.98	5.04	0.58	—	—	—	1.33
Heavy engg I	0.20	0.14	—	0.09	—	—	1.23	5.42*
Heavy engg II	6.30	8.07	—	—	—	—	—	—
Heavy engg III	0.24	0.20	—	—	—	—	—	—
Electrical I	0.48	0.01	—	—	—	—	—	—
Electrical II	0.63	0.34	—	—	—	—	—	—
Electronics	26.80	41.16	—	—	—	—	—	0.70
Miscellaneous	2.75	10.06	—	—	—	—	0.02	0.15
Metallurgical I	127.70	4.45	58.70	—	—	3.04	2.63	—
Metallurgical II	447.80	49.00	64.80	28.10	192.00	279.00	8.00	697*
Metallurgical III	28.70	—	—	0.33	—	20.30	—	—
Aluminium	0.18	—	—	—	—	—	—	—
Insulators	5.40	4.10	2.40	39.60	—	16.70	—	1.30
Paper	120.80	2.90	29.40	—	—	1205.00	—	—
Textiles	45.70	14.80	—	0.10	—	163.00	8.40	—
Sugar	4.10	20.20	—	—	—	3.40	13.20	809†
Chemicals I	154.00	0.65	194.00	—	—	—	—	3.02
Chemicals II	0.50	0.18	6.40	1.80	—	32.20	1.00	—
Tiles	0.50	0.12	—	—	—	—	19.30	—
Mines	109.50	17.50	1.80	0.95	—	0.40	—	—
Agromachines	0.87	0.16	—	—	—	—	0.43	—
Oxygen	8.31	—	—	—	—	—	—	—
Tools	0.29	—	—	0.01	—	—	—	—
Glass	16.90	3.80	23.50	2.40	—	—	—	—
Batteries	2.00	3.90	5.50	0.01	—	—	0.50	—
Cement	53.70	4.40	—	0.17	—	770.00	0.60	—
Lamps	1.80	0.42	16.30	—	—	—	—	16.30
Refractory bricks	0.08	—	4.20	—	—	—	—	—
Total	1175.60	207.54	412.04	74.14	192.00	2493.04	55.31	1534.22
Percent	19.13	3.38	6.71	1.21	3.13	40.58	0.90	24.97
Grand total	6143.88							

*Coke, †Bagasse (others include mainly LPG).

as in Table 13. The next stage of analysis is to calculate specific energy consumptions. It is our desire to know (a) how efficiently energy is used by a manufacturing unit, (b) how the efficiency changes with time and (c) how it compares among units manufacturing the same product. In order to look at these problems, energy consumption/unit of production should be calculated. We call this specific energy consumption. Two indices are possible—energy consumption per rupee of production or energy consumption per unit of production or ton of production. The next section looks at the specific energy consumptions for different industries, their variations with time for some industries and relative figures for total energy and electrical energy uses.

$$SEC = E_t/P_t$$

where E_t = total energy consumption in the period "t" (in this case "t" is one year) and P_t = production in the period "t". From a knowledge of SEC, the minimum energy required to operate the industries efficiently could be predicted.

5. SPECIFIC ENERGY CONSUMPTION IN DIFFERENT INDUSTRIES (1983–84)

The study of evaluating various industries on the basis of their energy consumption and production is being done for the first time in the country. One of our main aims in doing this study is to generate norms or existing levels of specific energy consumption. The other aims are (i) to compare similar units and (ii) to see the dynamics—change with time—SEC for an industry.

Since energy consumption by an industry is an absolute quantity, it cannot be used as an index for comparison. Hence, the specific energy consumption is used as an index. In India, there is no integrated study conducted on the SEC for various industrial sectors. Ours is one of the first studies involving all forms of energy sources. There are no norms available for the consumption of electric energy/unit of production. Hence, one of our intentions is to obtain SECs for some industrial

Table 13. Energy consumption (in %) in Karnataka in 1983–84

Sector	Elect	HSD	FO	LDO	Charcoal	Coal	Firewood	Others
Engineering	25.20	56.20	13.50	1.50				3.60
Heavy engg I	2.90	1.90					17.60	77.60
Heavy engg II	43.80	56.20						
Heavy engg III	54.50	45.50						
Electrical I	98.60	1.40						
Electrical II	64.60	35.40						
Electronics	39.10	60.10						0.80
Miscellaneous	21.20	77.50					0.20	1.10
Metallurgical I	64.90	2.30	29.90			1.90	1.00	
Metallurgical II	25.40	2.80	3.70	1.60	10.90	14.10	0.50	41.00
Metallurgical III	58.10			0.70		41.20		
Aluminium	100.00							
Insulators	7.80	5.90	3.50	56.90		24.00		1.90
Paper	8.90	0.20	2.20			88.70		
Textiles	19.70	6.40				70.30	3.60	
Sugar	0.50	2.40				0.40	1.60	95.10
Chemicals I	43.90	0.20	55.00					0.90
Chemicals II	7.80	0.40	14.30	4.10		72.00	1.40	
Tiles	2.50	0.60					96.90	
Mines	84.00	13.40	1.40	0.70		0.50		
Agri. machines	80.90	15.00					4.10	
Oxygen	100.00							
Tools	98.00			2.00				
Glass	36.20	8.20	50.40	5.20				
Batteries	16.80	32.80	46.20				4.20	
Cement	5.80	0.50		0.10		93.50	0.10	
Lamps	5.20	1.20	56.80					36.80
Ref. bricks	1.80		98.20					

groups. This can be a reference for future use and can also be used for comparison with international norms.

As already stated, SEC is defined as energy per unit of production or energy per rupee of production. It has been calculated for all the industries who responded to us, but the values are given only for a sample of this group in Table 14. For some groups, energy per rupee is available, and for others, energy/unit of production is available. The second category is shown by (*) in the table.

The energy consumed/rupee varies from 0.011 to 1.78. Table 14 lists for each sector 4 entries for SEC. The first value gives the average, the second one the maximum value calculated for an industry in that group, the third one the minimum value obtained for an industry in that group and the fourth the standard deviation. The average values vary from 0.22 to 1.73. The standard deviation gives an indication of the variations in SEC.

One way of interpreting SEC is to assume that lower SEC's imply better efficiency because we consume less energy for the same amount of production. Looking at SECs for each industrial group can help us in classifying industries as energy intensive or non-intensive. This will be useful in the selection of industries to be nurtured in the future in the state. Instead of concentrating on higher

Table 14. Specific energy consumption for some sectors

Sector	Total energy (million units)	Energy in units/Rs. of production				SEC-El only (avg)
		Avg	Max	Min	Std	
Engineering	37.30	0.22	1.48	0.11	0.65	0.08
Metallurgical I	203.60	0.26	0.36	0.05	0.10	0.16
Metallurgical II	1766.00	1.73	1.78	1.59	—	0.45
Metallurgical III*	49.40	19.40	25.00	14.40	—	7.98
Paper*	1358.40	16467.00	17245.00	12510.00	5511.00	2220.00
Textiles*	232.10	5567.00	8102.00	5345.00	1865.00	1450.00
Sugar*	844.20	9657.00	11162.00	5264.00	3514.00	44.50
Chemicals I*	351.70	2689.00	7013.00	2511.00	—	1172.00
Tiles*	19.90	5.05	7.65	4.55	—	0.07
Oxygen	8.31	0.41	0.46	0.27	—	0.41

*The SEC values are energy in units/units of production.

intensity industries, one can look for and select lower intensity industries, or at least try to obtain an optimal mix. In this connection, it may be recalled that Karnataka has an overall energy intensity of 1.96 which is higher than the national level. In the case of energy/unit of production, we can see that it varies from 4.55 to 17245—a very wide variation (but the lower value is energy/tile).

Since norms are available for electrical energy, we also calculated the electrical energy consumed/unit of production. This is given in the last column of the table. Some industries, like tiles, use the least amount of electrical energy and some have a higher intensity for electricity. The SEC for electrical energy per rupee of production varies from 0.08 to 0.45. From the point of view of electricity, an industry, like oxygen, has become energy intensive, whereas from its overall SEC, it is not a highly intensive industry. So, when we have acute shortages in electricity, we can use the SEC for electricity to characterise the intensity of industries and use this for selection of future industries.

The SEC is very useful to look at individual members in an industrial group, and this may reveal interesting information. Some examples are cited below:

(i) In the case of paper, the minimum SEC is 12510 and the maximum is 17245 (38% higher). This shows that possibly one industry can reduce its energy consumption by improving efficiency to the scale of the minimum valued industry.
(ii) In the case of sugar also, the minimum SEC is 5264 units/ton and the maximum is 11162 (112% higher). There is a large possibility here also to improve efficiencies of use.
(iii) For tiles, the minimum value is 4.55 and the maximum is 7.65 (68% higher).
(iv) For textiles, the difference (in percentage) is 52%.
(v) Oxygen units have a difference (in percentage) of 70%.

The above illustrations show that there is a high probability of efficiency enhancements. It is also possible that, in some situations, the difference in SEC is due to the quality of the product and not due to energy efficiencies, but wherever large differences occur for similar products, it is desirable to look deeper for the maladies.

The inter-group variations in SEC may only show a probability of improvement. Actual improvements can be pin pointed only by a detailed study by the industry concerned. Since energy plays an important role in our life, it is desirable to do energy audits and energy budgeting. Many industries do not even have measurement facilities, but it is a very redeeming feature that many industries of Karnataka are aware of the energy shortages and energy–environment linkages. Some industries are already initiating steps for increasing the efficiencies of energy use. This can be seen from the study of variations in SEC for five years. Table 15 lists SECs for some typical industries

Table 15. Variation in SEC in five years in some industries

Sector	SEC for 1979–80	SEC for 1983–84	Percent increase
Engineering	0.006	0.011	83.333
Engineering	0.045	0.074	64.444
Engineering	0.020	0.040	100.000
Heavy engg*	51.450	131.300	155.199
Electricals	0.019	0.010	– 47.368
Metallurgical I	0.190	0.230	21.053
Metallurgical II	3.100	1.600	– 48.387
Metallurgical III*	126.900	148.000	16.627
Paper*	1.020	0.930	– 8.824
Textiles*	0.570	0.380	– 33.333
Textiles*	0.510	0.650	27.451
Textiles*	1.300	0.900	– 30.769
Sugar*	14883.000	11162.000	– 25.002
Agromachines	0.027	0.034	25.926
Oxygen	0.330	0.460	39.394
Oxygen	0.440	0.270	– 38.636
Glass	2.140	0.920	– 57.009

*The SEC values are energy in units/units of production.

Table 16. Comparison of percent electrical energy to SEC to total

Sector	Ratio of electric energy to total	% ratio of SEC for electric to total
Engineering	25.20	36.80
Metallurgical I	64.90	63.10
Metallurgical II	25.40	26.00
Metallurgical III*	58.10	41.10
Paper*	8.90	13.50
Sugar*	0.50	0.50
Chemicals	43.90	43.60
Tiles	2.50	0.36
Oxygen	100.00	100.00

which show a change in their SECs. It does not show industrial groups, but an industry in a group, the group identified by column 1. From this table, we can see that:

(i) The maximum increase is 155% between 1979 and 1984. The heavy engineering industry should look at this degradation in its efficiency of energy use. The increase is gradual and not sudden.
(ii) An engineering industry has also shown an increase of 100% in 5 years in SEC. This increase is also gradual.
(iii) Surprisingly, many of these large increases have occurred in engineering industries. Another reason for this increase may be substitution of fuels (like diesel for electricity generation instead of KEB electricity).
(iv) There are some units (8 in number) which have shown a decrease in their SEC values. This might mean (a) increases cost of the product due to demand or (b) better efficiency of use.

A look at the total energy consumed by each sector—shown in Table 14 col. 2.—reveals that the metallurgical iron and steel industries consume the maximum energy, followed by paper (1358.4 million units) and sugar (844.2 million units). Engineering units consume less energy.

We can see from the above that, even though general conclusions regarding energy efficiency and SEC can be drawn, we have to conduct deeper studies at the level of individual industries to confirm and pinpoint the lacunae.

Table 16 tries to compare the difference between the ratio of electrical energy to total energy and the ratio of SEC for electrical energy to SEC for total energy. These two ratios should be the same if the industries in the group have similar consumption patterns and efficiencies. A difference (like in the case of paper or tiles or engineering groups) indicates uneven patterns.

The effect of power cuts is seen from Table 17. The energy generated by captive diesel sets was very small in 1979–80. The per cent ratio between self generation and purchased energy from the KEB was only 0.22; but this ratio has gone up to 17.28 in 1983–84. Since the cost of electricity from diesel generators is very expensive, of the order of 2 rupees, compared to electrical energy purchased from the KEB, this shows that the cost of energy is not an important criterion. In fact, lower costs result in wastage. Hence, planners should consider proper costing of energy, including replacement costs for generating stations, thereby doing away completely with subsidies. Subsidised energy may not result in lower manufacturing costs. It results definitely in decreased efficiencies and unnecessary use of energy. The same is the case with capacity. The self generation capacity

Table 17. Electricity consumption ratios for some industries

	Year 1979–80	Year 1983–84
Energy from KEB (m. units)	1575.20	892.60
Self generation (m. units)	3.49	152.46
% self generation to KEB supply	0.22	17.28
Max demand (KVA)	18579.00	114451.00
Capacity of self generation	7563.50	79312.00
% of self gen. capacity to M.D.	40.70	69.30

Table 18. Percentage distribution of connected electric load in KW in some industries

Type of load	Percent
Heating	46.55
Machinery	47.25
Welding	1.10
Lighting	1.33
Others	3.77
Total	100.00

is equal to 69% of the maximum demand. Proper costing of energy will have benefits such as (a) energy conservation will increase, leading to greater energy conservation; and (b) the anomalous situation that exists now, like people installing diesel/kerosene/petrol generators and thereby paying higher costs for energy, will be alleviated, especially because capital can be generated for additional power plants.

Electrical energy need not be used for heating activities. To a large extent, substitution of lower quality energy is desirable in all these cases. Such a substitution will not only match sources with end uses, but also increase the efficiency of use. This is true in other sectors also. Table 18 gives the energy consumption values as percentages. It shows that 46.55% of the electrical load is in the heating category. This reinforces the points mentioned above.

Table 19 gives the SECs for total energy and electricity for some industries [6], such as coffee curing, tiles, bricks manufacture, etc. In the case of coffee curing, the SEC varies from 0.002 to 0.0044, a variation of more than 100%. For tiles, the SEC is 6.771. This is between the minimum and the maximum values for SEC calculated in Table 14.

Detailed analyses carried out industry wise for various sectors for five years are listed in Table 20. The SEC ratios computed for two consecutive years reveal an increase in SEC in most industries. Ratios of SECs for the years 1982 and 1981 are abbreviated as SEC82/81. This ratio being greater than one reveals the increase in inefficiency, while the ratio <1 indicates (for cement, chemicals, food products, glass, tiles industries) improvement in energy usage per unit of production. The last two columns in this table give average values and standard deviation for these ratios. In most of the industries, the average of SEC ratios for five years is greater than one, meaning that the SEC of the industry is increasing.

6. SPECIFIC ENERGY CONSUMPTIONS IN DIFFERENT INDUSTRIES (1991/92 AND 1992/93)

In order to see the change in the energy usage scene in the last 10 years, a survey was undertaken in the industrial sector by sending questionnaires to 510 industries spread all over the state. About 40 industries responded initially, followed later by 38 more industries in response to a second letter. The specific energy consumptions computed for the years 1991 and 1992 for various industries are listed in Table 21. The SEC ratios computed for 1992 and 1993 show marginal improvement in energy consumption in some industries, while for 35 industries, the SEC ratio is >1.

Table 19. Specific energy consumptions for some industries

	Unit	SEC	SEC elect
Tile industry	tiles	6.7710	0.2200
Mosaic industry	tiles	0.0060	0.0060
Coffee curing 1.	kg	0.0044	0.0044
Coffee curing 2.	kg	0.0040	0.0040
Coffee curing 3.	kg	0.0020	0.0020
Boards	sq.m	0.3800	0.1580
Steels	tons	42.2600	38.5800
Silk fabrics	mtrs	0.8600	0.0590
Sandal oil	kgs	68.2200	0.7000

7. ENERGY ELASTICITY

The relationship between *En* (energy consumption) and *Pr* (production) for the industrial sector, through regression analysis, is found to be $En = A(Pr)^C$, the coefficient C is commonly known as energy elasticity. By differentiating both sides, we get $C = (dE/E)/(dP/P)$ or

$$C = \frac{(E_2/E_1) - 1}{(P_2/P_1) - 1}$$

The energy elasticities computed for various industries for the years 1991/92 and 1992/93 are listed in the last column of Table 21. The value of $C > 1$ indicates an exponential growth in energy consumption, while $C < 1$ indicates a decline in energy consumption in the subsequent year for the same unit of production.

Yearly computation of the energy elasticities for the period 1980–85 and for the 10-year period (i.e. 1991/82 and 1992/83) have been calculated and are listed in Table 22. The SEC ratios computed for a ten year period are also listed in the 7th and 8th columns of Table 22. These values substantiate earlier findings, that is most of the industries in sectors, like chemicals (SEC91/82 = 1.997, SEC92/83 = 2.73), iron ore (SEC91/82 = 1.371, SEC92/83 = 1.676), accessories (SEC91/82 = 2.113, SEC 92/83 = 2.110), lamps (SEC92/83 = 2.47), steels (SEC1991/82 = 1.397, SEC1992/83 = 1.038) and textiles (SEC1991/82 = 3.983), are energy inefficient. There is a lot of scope to cut down unnecessary energy consumption.

8. ENERGY SAVING POSSIBILITIES IN INDUSTRIAL SECTOR IN KARNATAKA

Table 23 lists specific energy consumptions for seven years. Statistical parameters, such as average, standard deviation and maximum and minimum SECs for each industry, based on 7-year data are listed in columns 10–13 in the table. The yearly variation in SEC gives an idea about the extent of energy saving possible in each industry. The percentage saving possible per industry, listed in the 14th column of the table, is given by

$$\%\ \text{Savings Possible} = \frac{[(\text{SEC})_{avg} - \text{SEC}_{(min)}]*100}{(\text{SEC})_{avg}},$$

where $(\text{SEC})_{avg}$ = average SEC computed based on 7 years data and $\text{SEC}_{(min)}$ = minimum SEC among 7 years.

The last column gives the savings possible in each sector. It is seen that, in the iron and steel industries, a 28.83% saving is possible, while there is vast scope for savings in sugar (34.07%), engineering (40.83%), textiles (36.36%), fertiliser (44.09%), insulators (33.40%), iron ore (32.40%), chemicals (33.42%) and cement (21.82%).

It is seen that about 27.72% of the energy could be saved in the industrial sector, which means that about 1541 million units of electricity could be saved (as per electricity statistics, the industrial sector in Karnataka has consumed about 5560 million units during 1991–92). This saved electricity is equivalent to the electricity output of 300 MW installed capacity of generating stations. Environmental problems associated with mega-projects, the increasing demand of states/country and resource depletion make it increasingly imperative that our planners divert their attention towards improving efficiency in all sectors. This research illustrates that there is ample scope to conserve energy in the industrial sector.

Our earlier studies in the food grain sector [7] among small scale industries has shown that about 55 million kWh could be saved by just optimal utilisation of installed production capacity.

A study of energy efficiencies of end use devices in electro-metallurgical industries [8] has shown that the efficiency of welding sets is about 14%, furnaces 10.4%, diesel generators 36.5% and electro-plating process 36.5%. This shows possible savings in the industrial sector by switching over to transformer-rectifier welding sets with microprocessor based numeric controller from conventional motor generator welding sets. Motors and drives consume a large percentage of the electrical energy used in the industrial sector. High efficiency motors (85.5–95% efficiency) currently available in the market are now competitive with conventional types of motors, considering the cost of motor losses.

Table 20. Specific energy consumption, industrywise for the period 1981–1985

Code	Place	SEC81 1	SEC82 2	SEC83 3	SEC84 4	SEC85 5	SEC82/81	SEC83/82	SEC84/83	SEC85/84	SEC ratios average	Std deviation
Accessories												
AC0013	BANGALORE	0.019	0.016	0.016	0.023	0.029	0.832	0.998	1.473	1.258	1.14	0.24
AC008	BANGALORE				0.374	0.556				1.485	1.48	0.00
AC0086*	BANGALORE	0.085	0.142	0.172	0.142	0.044	1.672	1.209	0.829	0.312	1.01	0.50
AC0088*	HUBLI	0.003	0.004	0.004	0.004	0.005	1.359	0.995	0.998	1.245	1.15	0.16
AC0089*	BANGALORE	0.440	0.370	0.531	0.954	0.564	0.841	1.435	1.797	0.592	1.17	0.48
Aluminium conductors												
AL0080*	BANGALORE	0.002	0.002	0.002	0.002	0.003	1.175	1.116	0.988	1.251	1.13	0.10
AL0081*	BANGALORE	0.001	0.001	0.002	0.002	0.003	0.754	2.432	0.757	1.430	1.34	0.69
Cement												
CE0056					0.854	0.505				0.591	0.59	0.00
CE0112	RAICHUR				0.294	0.279				0.949	0.95	0.00
Chemicals												
CH0014	MANDYA				0.633	0.687						
CH0017	BIJAPUR											
CH0025	BANGALORE	0.026	0.024	0.018	0.051	0.044	0.923	0.740	2.862	0.855	1.34	0.88
CH0027	MANGALORE	0.814	0.202	0.241	0.276	0.273	0.248	1.195	1.144	0.989	0.89	0.38
Cigarettes												
CIG0070	BANGALORE				0.005	0.003				0.652	0.65	0.00
Copper conductors												
COPP001	CHITRADURG					0.783						
Electrical												
EL0070*	BANGALORE	0.004	0.003	0.007	0.006	0.005	0.901	1.989	0.920	0.890	1.18	0.47
EL0085*	BANGALORE	0.002	0.002	0.003	0.003	0.005	0.976	1.413	0.966	1.639	1.25	0.29
Engineering												
ENG00110	BANGALORE				0.019	0.023				1.243	1.24	0.00
ENG0060	BANGALORE	0.037	0.058	0.047	0.039	0.063	1.543	0.825	0.818	1.627	1.20	0.38
ENG0064	BANGALORE				0.018	0.026				1.474	1.47	0.00
ENG0069*	BANGALORE	0.022	0.009	0.012	0.011	0.015	0.428	1.252	0.904	1.423	1.00	0.38
ENG0076*	BANGALORE	0.001	0.002	0.002	0.002	0.004	1.319	1.104	1.054	2.008	1.37	0.38
ENG084*	BANGALORE	0.004	0.005	0.012	0.013	0.024	1.282	2.312	1.028	1.912	1.63	0.51
Fertiliser												
FER0090*	MANGALORE	0.814	0.202	0.241	0.276	0.273	0.248	1.195	1.144	0.989	0.89	0.38
Food products												
FO00128					0.173	0.156				0.900	0.90	0.00
Glass												
GL0075*	BANGALORE	0.388	0.311	0.332	0.337	0.335	0.802	1.067	1.014	0.995	0.97	0.10

Gold extraction												
GO0079*	RAICHUR	0.077	0.106	0.105	0.102	0.114	1.377	0.991	0.976	1.117	1.12	0.16
GO00124					0.195	0.178				0.916	0.92	0.00
Diamond												
DIO0125	MYSORE					0.004						
Insulators												
INS006	BANGALORE	0.175	0.152	0.092	0.135	0.161	0.870	0.604	1.465	1.196	1.03	0.33
Iron ores												
IO0040	HOSPET	0.237	0.335	0.373	0.569	0.418	1.413	1.116	1.524	0.735	1.20	0.31
IO0091*	BELLARY				0.368	1.163				3.160	3.16	0.00
Lamps												
LA0071*	BANGALORE	0.041	0.068	0.056	0.075	0.062	1.655	0.818	1.352	0.830	1.16	0.36
Leather												
LE0072*	BANGALORE	0.015	0.066	0.021	0.020	0.020	4.482	0.322	0.956	0.967	1.68	1.64
Oxygen												
OX0073*	BANGALORE	0.064	0.060	0.073	0.085	0.192	0.935	1.216	1.168	2.259	1.39	0.51
OX0074*	BANGALORE	0.084	0.089	0.081	0.086	0.116	1.052	0.918	1.060	1.339	1.09	0.15
Paper												
PA0092*	MYSORE	0.276	0.244	0.242	0.250	0.427	0.885	0.992	1.032	1.711	1.15	0.33
Steel												
ST00100*	MANGALORE	0.210	0.062	0.078	0.062		0.295	1.259	0.798		0.78	0.39
ST00101*	BELLARY	0.145	0.145	0.139	0.167	0.150	0.994	0.962	1.204	0.896	1.01	0.12
ST0026	BHADRAVATI	0.152	0.226	0.265	0.201	0.303	1.505	1.164	0.757	1.510	1.23	0.31
ST0082*	BANGALORE	0.098	0.067	0.104	0.113	0.127	0.679	1.556	1.085	1.128	1.11	0.31
ST0083*	BANGALORE	0.043	0.072	0.090	0.072	0.086	1.663	1.247	0.799	1.187	1.22	0.31
ST0096*	BANGALORE	0.018	0.021	0.029	0.032	0.229	1.165	1.403	1.105	7.148	2.71	2.57
ST0097*	BANGALORE	0.106	0.110	0.145	0.110	0.095	1.041	1.311	0.759	0.869	1.00	0.21
ST0098*	BANGALORE	0.089	0.091	0.083	0.137	1.395	1.022	0.913	1.650	10.200	3.45	3.91
ST0099*	BANGALORE	0.111	0.105	0.160	0.296	0.273	0.942	1.523	1.856	0.921	1.31	0.40
ST00123	SHIMOGA				0.280	0.250				0.893	0.89	0.00
Soaps & detergents												
S&D0077*	BANGALORE	0.025	0.038	0.031	0.031	0.037	1.515	0.804	0.999	1.192	1.13	0.26
Tiles												
TI00120					0.028	0.025				0.914	0.91	0.00
TI00121					0.020	0.016				0.817	0.82	0.00
Textiles												
TX0037	HUBLI	0.053	0.204	0.120	0.059	0.096	3.845	0.586	0.493	1.627	1.64	1.35
TX0093*	BANGALORE	0.419	2.230	0.285	0.314	0.683	5.318	0.128	1.102	2.178	2.18	1.95
TX0094*		0.220	0.404	0.236	0.261	0.272	1.837	0.584	1.106	1.042	1.14	0.45
TX0095*	BANGALORE	0.152	0.302	0.170	0.138	0.351	1.986	0.563	0.813	2.543	1.48	0.82
TX00110	MYSORE				0.404	0.445				1.101	1.10	0.00
Tyres												
TY0043	MYSORE					0.529						
Watch												
WA0052	TUMKUR				0.005	0.007				1.462	1.46	0.00

Table 21. SEC for the period 1991–92

Code		Place	SEC91	SEC92	SEC92/91	C 92/91
Accessories	AC0013	BANGALORE	0.033	0.033	0.997	0.982
	AC0020	BANGALORE	0.016	0.019	1.189	2.810
	AC004	MYSORE	0.332	0.771	2.324	0.285
	AC008	BANGALORE	0.654	0.635	0.971	3.223
Aluminium Ext	AL0067	BELGAUM	0.265	0.197	0.743	−0.913
Blades	BLA0046	MYSORE	0.020	0.025	1.239	−1.119
Cement	CE0021	GULBARGA	0.460	0.244	0.531	−0.239
	CE0028	TUMKUR	0.500	0.532	1.063	0.224
	CE0039	GULBARGA	0.277	0.283	1.024	1.197
	CE0041	BELLARY	0.596	0.498	0.836	0.246
	CE0048	CHITRADURGA	0.258	0.250	0.966	1.110
	CE0051	GULBARGA	0.924	0.843	0.912	0.568
	CE0056		0.744	0.622	0.835	0.470
Chemicals	CH0014	MANDYA	0.122	0.117	0.958	0.599
	CH0025	BANGALORE	0.048	0.049	1.011	1.066
	CH0027	MANGALORE	0.209	0.134	0.640	0.096
	CH0044	HEBBAL BL	0.045	0.063	1.384	2.257
	CH0053	SOUTH CANARA	0.468	0.556	1.189	0.894
	CH0055	RAICHUR	0.140	0.247	1.766	8.806
	CH0074	MYSORE	0.025	0.022	0.874	0.681
Cigarettes	CIG0070	BANGALORE	0.009	0.007	0.824	0.245
Cylinders	CYL0054	BELGAUM	0.021	0.051	2.405	0.354
	CYL007	BANGALORE	0.057	0.076	1.339	1.679
Electricals	EL0023	BANGALORE	0.244	0.144	0.593	−1.265
	EL0057	HUBLI	0.012	0.009	0.755	0.171
	EL0061	MYSORE	0.002	0.002	1.019	1.100
Engineering	ENG0036	BANGALORE	0.001	0.001	1.891	3.898
	ENG0031	HEBBAL BL	0.006	0.015	2.277	2.030
	ENG0060	BANGALORE	0.013	0.025	1.929	0.482
	ENG0063	BANGALORE	0.008	0.005	0.601	0.287
	ENG0064	BANGALORE	0.016	0.016	0.958	0.811
	ENG0066	BANGALORE	0.022	0.024	1.137	1.886
	ENG0068		0.022	0.020	0.934	0.329
Food Products	FOO0034	BANGALORE	0.014	0.016	1.149	1.743
	FOO0072	BANGALORE	0.014	0.014	0.979	0.896
Gold extraction	GO0079*	RAICHUR	0.082	0.071	0.865	0.393
Graphite	GR0011	BANGALORE	0.142	0.184	1.292	2.977
Hotels	HO0075		0.117	0.126	1.074	1.345
Insulators	INS006	BANGALORE	0.121	0.130	1.076	1.985
Iron ore	IO0018	KUDREMUKH	0.113	0.169	1.492	0.873
	IO0040	HOSPET	0.459	0.626	1.364	2.309
	IO0091*	BELLARY	0.073	0.068	0.938	0.768
Lamps	LA0071*	BANGALORE	0.115	0.137	1.199	3.731
Liquor	LIQ0065	BANGALORE	0.036	0.053	1.449	3.650
	LIQ0069	BANGALORE	0.028	0.025	0.899	0.467
	LIQ0071	BANGALORE	0.001	0.001	1.677	4.296
	LIQ0073	BANGALORE	0.060	0.041	0.679	−0.247
Minerals	MI0022	HASSAN	0.039	0.039	1.020	1.100
Paper	PA0019	BELAGULA	0.515	0.456	0.886	4.560
	PA0029	BHADRAVATI	0.272	0.263	0.968	0.174
Plywood	PL0042	UTTARA KANNADA	0.139	0.127	0.913	3.828
Rubber	RU0030	BANGALORE	0.068	0.065	0.961	0.714
Tools	SA002	TUMKUR	0.013	0.012	0.920	0.347
	SO0012	BANGALORE	0.026	0.031	1.178	1.410
Steel	ST001	MANGALORE	0.127	0.119	0.943	0.772
	ST0016	MANGALORE	0.062	0.124	2.015	−0.561
	ST0026	BHADRAVATI	0.319	0.276	0.865	−0.431
	ST0049	BELGAUM	0.161	0.182	1.134	1.496
	ST0050	SHIMOGA	0.262	0.238	0.907	0.692
	ST009	TUNGABHADRA	0.010	0.009	0.970	0.854
Sugar	SU0015	K R NAGAR	0.106	0.095	0.896	0.781
	SU0024	DAVANGERE	0.003	0.003	0.796	0.000
	SU0047	RAICHUR	0.336	0.078	0.231	−0.517
	SU0059	BELLARY	0.011	0.012	1.077	2.078
	SU0062	BELGAUM	0.057	0.032	0.557	−1.677
Textiles	TX0010	BANGALORE	0.064	0.079	1.240	0.278
	TX0033	DHARWAD	0.086	0.104	1.212	2.823
	TX0035	DAVANGERE	0.033	0.022	0.668	−2.200
	TX0037	HUBLI	0.813	2.395	2.946	−0.993

Continued opposite

Table 21. (*Continued*)

Code		Place	SEC91	SEC92	SEC92/91	C 92/91
	TX0038	BELGAUM	0.046	0.046	0.984	1.958
	TX0045	DAVANGERE	0.106	0.113	1.071	1.421
	TX005	MADRAS	0.087	0.153	1.754	0.372
Tyres	TY0043	MYSORE	3.922	3.700	0.943	0.680
Watches	WA0052	TUMKUR	0.018	0.017	0.963	0.799

The advanced technologies discussed below promise significant reductions in energy use, and implementing these may be less costly compared to generating electricity through supply expansions, taking into consideration the environmental costs associated with new installations.

(i) Proper maintenance of electric motors in textile industries brings down energy consumption considerably; about 3% of power consumption can be saved by improved maintenance. This also reduced repairs as shown by the fact that burnout of motors varies in frequency from one in three months/10,000 spindles to 8–20 in three months/10,000 spindles. The increase is 8–20 fold in the second case. Similarly, burnout frequency varies from 1–7 to 60 for six months for 25,000 spindles.

(ii) Waste heat recovery in boilers can reduce energy use by about 10%. It is shown that the payback period is a few months.

(iii) Use of polyester cotton tapes, etc. in textile mills will reduce consumption by about 10%.

(iv) Replacement of old boilers with high efficiency boilers and introduction of turbines and generators can reduce total energy requirements by more than 20–30%.

(v) Spindle speed is an important factor in energy consumption in textile industries. Proper speed can reduce energy use. In the survey, energy consumption varies from 60 to 165% (with the base of 100 chosen for one mill). This shows that proper speeds can reduce consumption.

(vi) Advanced processes in the steel industry are mostly major process changes that could revolutionalise the iron and steel sector. The plassmelt method [9] involves smelting partially reduced iron powder with pulverised coal by using heat supplied by a plasma system. Ore to powder steel making could reduce the energy consumed by 40%. Direct steel making could double or triple production rates compared to the blast furnace and offer a 30% reduction in energy use. The energy required to produce steel from scrap is less than one-half that required to produce steel from raw materials. However, scrap contains residual elements that have adverse effects on the properties of the steel. The electric arc furnace is a well established technology, and because of its increasing market share, improvements such as scrap preheating, DC arc furnace, induction melting, heat and dust recovery and ladle refining are to be researched.

(vii) Conventional chemical pulping in the paper industry is dominated by the very energy intensive kraft process. The energy required to recycle paper is about one-half that required by the kraft process. Desired improvements in the recycling process concentrate on improving the process to remove colour and filler. Improvements in the paper making process focus on improved process control, process physics and improved materials. These improvements would have a substantial effect on decreasing energy consumption. Bio-pulping, chemical pulping with fermentation, and ethanol organosol pulping are the most recent promising advanced processes involving integration of at least one fermentation process with a conventional pulping process.

(viii) Carbothermic reduction of aluminium ore or alumina has the potential for substantial energy savings. Aluminium trichloride electrolysis allows for more production per unit cell volume. The permanent anode design would decrease the frequency of anode replacements and the wetted cathode might enable a reduction in the distance between the electrodes associated with a high voltage loss without a loss in current efficiency.

(ix) Catalysts are used in many industries to produce chemical reactions at a lower pressure and temperature, thereby using the less energy. Better understanding of the basic mechanisms of catalysts may lead to new classes of catalysts. These could be beneficial in

Table 22. Yearly elasticity for the period 1981–85, 1991–92, and SEC ratio for 1991/82 and 1992/83

Code	Place	C 81–82	C 82–83	C 83–84	C 84–85	SEC ratio 10 year period 1991/82	SEC ratio 10 year period 1992/83	Elasticity 10 year period C 91/82	Elasticity 10 year period C 92/83
Accessories									
AC0013	BANGALORE	3.35	0.99	−1.14	5.61	2.113	2.110	1.871	1.846
AC004	MYSORE								
AC008	BANGALORE				8.89				
AC0086*	BANGALORE	5.64	0.36	0.48	−0.53				
AC0088*	HUBLI	5.71	0.98	0.97	3.63				
AC0089*	BANGALORE	0.42	−1.26	−0.11	0.16				
Aluminium conductors									
AL0080*	BANGALORE	1.59	1.32	1.01	−1.32				
AL0081*	BANGALORE	0.34	−1.66	3.58	−0.58				
Cement									
CE0056					−0.03				
CE0112	RAICHUR				0.62				
Chemicals									
CH0014	MANDYA				1.41				
CH0017	BIJAPUR								
CH0025	BANGALORE	0.62	−3.74	−5.33	1.34	1.997	2.730	5.075	4.493
CH0027	MANGALORE	−0.18	1.57	0.10	1.08	1.036	0.555	1.027	0.592
Cigarettes									
CIG0070	BANGALORE				−0.52				
Electricals									
EL0070*	BANGALORE	0.80	−2.57	1.65	0.48				
EL0085*	BANGALORE	0.94	3.82	0.61	−2.20				
Engineering									
ENG00110	BANGALORE				−0.39				
ENG0060	BANGALORE	3.80	1.47	−0.06	3.35	0.221	0.517	0.263	0.638
ENG0064	BANGALORE				5.11				
ENG0069*	BANGALORE	−1.73	1.35	2.59	−4.18				
ENG0076*	BANGALORE	2.39	2.53	2.27	−3.49				
ENG0084*	BANGALORE	19.19	8.15	1.12	−0.21				
Fertiliser									
FER0090*	MANGALORE	−0.18	1.57	0.10	1.08				

Food products									
FO00128					0.55				
Glass									
GL0075*	BANGALORE	−0.11	1.28	1.06	1.03				
Gold extraction									
GO0079*	RAICHUR	2.61	0.97	0.82	2.32	0.776	0.677	0.841	0.746
GO00124					0.57				
Insulator									
INS006	BANGALORE	0.53	−0.81	−11.54	−0.41	0.796	1.418	0.753	1.467
Iron ore									
IO0040	HOSPET	1.89	1.42	0.61	0.36	1.371	1.676	1.206	1.447
IO0091*	BELLARY				−7.48				
Lamps									
LA0071*	BANGALORE	−1.88	−10.67	1.54	0.18	14.126	2.470	3.214	1.533
Oxygen									
OX0073*	BANGALORE	0.73	2.10	1.66	10.47				
OX0074*	BANGALORE	1.34	0.75	2.19	−1.67				
Paper									
PA0092*	MYSORE	0.41	0.86	0.58	1.25				
Steel									
ST00100*	MANGALORE	4.53	2.16	−1.33	1.00				
ST00101*	BELLARY	0.97	0.90	−3.87	0.68				
ST0016	MANGALORE								
ST0026	BHADRAVATI	6.20	5.09	1.97	−1.66	1.397	1.038	1.357	1.037
ST0082*	BANGALORE	0.31	2.17	0.79	1.88				
ST0083*	BANGALORE	3.75	2.70	−0.56	1.87				
ST0096*	BANGALORE	1.57	−1.78	2.77	7.69				
ST0097*	BANGALORE	1.27	3.86	−0.54	0.63				
ST0098*	BANGALORE	1.15	−1.93	−0.18	1.76				
ST0099*	BANGALORE	0.85	−3.22	0.04	0.83				
ST00123	SHIMOGA				0.78				
Soaps & detergents									
S&D0077*	BANGALORE	2.71	−0.86	1.56	0.46				
Tiles									
TI00120					0.43				
TI00121					0.29				
Textiles									
TX0037	HUBLI	8.86	−0.40	−2.21	−4.84	3.983	20.041	5.359	−3.920
TX0094*		5.87	−5.28	4.24	−2.35				
TX0095*	BANGALORE	7.65	−1.23	−0.35	2.35				
TX00110	MYSORE				2.04				
Watch									
WA0052	TUMKUR				2.29				

Table 23. Industry wise, sector wise percentage possible energy saving

Code	Place	SEC81	SEC82	SEC83	SEC84	SEC85	SEC91	SEC92	Avg	Std	Max	Min	% saving	% saving
AC0013	BANGALORE	0.019	0.016	0.016	0.023	0.029	0.033	0.033	0.024	0.007	0.033	0.016	34.939	34.402
AC004	MYSORE						0.332	0.771	0.551	0.220	0.771	0.332	39.840	
AC008	BANGALORE				0.374	0.556	0.654	0.635	0.555	0.111	0.654	0.374	32.545	
AC0086*	BANGALORE	0.085	0.142	0.172	0.142	0.144			0.137	0.028	0.033	0.085	38.020	
AC0088*	HUBLI	0.003	0.004	0.004	0.004	0.005			0.004	0.001	0.005	0.003	25.775	
AC0089*	BANGALORE	0.440	0.370	0.531	0.954	0.564			0.572	0.203	0.954	0.370	35.291	
AL0067	BELGAUM						0.265	0.197	0.231	0.034	0.265	0.197	14.775	27.499
AL0080*	BANGALORE	0.002	0.002	0.002	0.002	0.003			0.002	0.000	0.003	0.002	21.901	
AL0081*	BANGALORE	0.001	0.001	0.002	0.002	0.003			0.002	0.001	0.003	0.001	45.819	
CE0021	GULBARGA						0.460	0.244	0.352	0.108	0.460	0.244	30.602	21.825
CE0041	BELLARY						0.596	0.498	0.547	0.049	0.596	0.498	8.943	
CE0056					0.854	0.505	0.744	0.622	0.681	0.131	0.854	0.505	25.931	
CH0014	MANDYA				0.633	0.687	0.422	0.427	0.542	0.119	0.033	0.422	22.149	33.417
CH0017	BIJAPUR						0.238	0.139	0.189	0.050	0.033	0.139	26.278	
CH0025	BANGALORE	0.026	0.024	0.018	0.051	0.044	0.048	0.049	0.037	0.013	0.051	0.018	51.907	
CH0027	MANGALORE	0.814	0.202	0.241	0.276	0.273	0.209	0.134	0.307	0.212	0.814	0.134	56.362	
CH0044	HEBBAL BL						0.045	0.063	0.054	0.009	0.063	0.045	16.107	
CH0055	RAICHUR						0.140	0.247	0.194	0.054	0.247	0.140	27.698	
CYL007	BANGALORE						0.057	0.076	0.067	0.010	0.076	0.057	14.508	14.508
EL0023	BANGALORE						0.244	0.144	0.194	0.050	0.244	0.144	25.585	29.459
EL0070*	BANGALORE	0.004	0.003	0.007	0.006	0.005			0.005	0.001	0.007	0.003	33.831	
EL0085*	BANGALORE	0.002	0.002	0.003	0.003	0.005			0.003	0.001	0.005	0.002	28.962	
ENG0036	BANGALORE						0.001	0.001	0.001	0.001	0.000	0.001	30.822	18.008
ENG0058						0.001	0.001	0.001	0.001	0.001	0.001	0.001	12.369	
ENG00110	BANGALORE				0.019	0.023			0.021	0.002	0.023	0.019	10.833	
ENG0031	HEBBAL BL						0.006	0.015	0.011	0.004	0.015	0.006	38.967	40.834
ENG0060	BANGALORE	0.037	0.058	0.047	0.039	0.063	0.013	0.025	0.040	0.016	0.063	0.013	68.354	
ENG0063	BANGALORE						0.008	0.005	0.006	0.002	0.008	0.005	24.938	
ENG0064	BANGALORE				0.018	0.026	0.016	0.016	0.019	0.004	0.026	0.016	16.803	
ENG0069*	BANGALORE	0.022	0.009	0.012	0.011	0.015			0.014	0.005	0.022	0.009	31.760	
ENG0076*	BANGALORE	0.001	0.002	0.002	0.002	0.004			0.002	0.001	0.004	0.001	40.435	
ENG0084*	BANGALORE	0.004	0.005	0.012	0.013	0.024			0.012	0.007	0.024	0.004	64.581	
FER0090*	MANGALORE	0.814	0.202	0.241	0.276	0.273			0.361	0.228	0.814	0.202	44.095	44.095
FO00034	BANGALORE						0.014	0.016	0.015	0.001	0.016	0.014	6.912	6.093
FO00128				0.173	0.156				0.165	0.009	0.173	0.156	5.274	

GL0075*	BANGALORE	0.388	0.311	0.332	0.337	0.335			0.340	0.025	0.388	0.311	8.645	8.645
GO0079*	RAICHUR	0.077	0.106	0.105	0.102	0.114	0.082	0.071	0.094	0.016	0.114	0.071	24.398	14.395
GO00124				0.195	0.178			0.187	0.008	0.195	0.178	4.392		
GR0011	BANGALORE						0.142	0.184	0.163	0.021	0.184	0.142	12.754	12.754
INS006	BANGALORE	0.175	0.152	0.092	0.135	0.161	0.121	0.130	0.138	0.026	0.175	0.092	33.403	33.403
IO0018	KUDREMUK						0.113	0.169	0.141	0.028	0.169	0.113	19.749	32.400
IO0040	HOSPET	0.237	0.335	0.373	0.569	0.418	0.459	0.626	0.431	0.124	0.626	0.237	45.052	
LA0071*	BANGALORE	0.041	0.068	0.056	0.075	0.062	0.115	0.137	0.079	0.032	0.033	0.041	48.134	48.134
LE0072*	BANGALORE	0.015	0.066	0.021	0.020	0.020			0.028	0.019	0.033	0.015	48.159	48.159
LIQ0065	BANGALORE						0.036	0.053	0.044	0.008	0.053	0.036	18.334	14.255
LIQ0069	BANGALORE						0.028	0.025	0.027	0.001	0.028	0.025	5.306	
LIQ0073	BANGALORE						0.060	0.041	0.050	0.010	0.060	0.041	19.124	
OX0073*	BANGALORE	0.064	0.060	0.073	0.085	0.192			0.095	0.049	0.192	0.060	36.820	23.812
OX0074*	BANGALORE	0.084	0.089	0.081	0.086	0.116			0.091	0.012	0.116	0.081	10.804	
PA0019	BELAGULA						0.515	0.456	0.485	0.029	0.515	0.456	6.073	6.073
PA0092*	MYSORE	0.276	0.244	0.242	0.250	0.427			0.288	0.071	0.427	0.242	15.907	15.907
PL0042	UTTARA KAN						0.139	0.127	0.133	0.006	0.139	0.127	4.570	4.570
ST00100*	MANGALORE	0.210	0.062	0.078	0.062				0.103	0.062	0.210	0.062	39.880	28.830
ST0016	MANGALORE						0.062	0.124	0.093	0.031	0.124	0.062	33.655	
ST0026	BHADRAVATI	0.152	0.228	0.265	0.201	0.303	0.319	0.276	0.249	0.055	0.319	0.152	39.147	
ST0049	BELGAUM						0.161	0.182	0.172	0.011	0.182	0.161	6.282	
ST0082*	BANGALORE	0.098	0.067	0.104	0.113	0.127			0.102	0.020	0.127	0.067	34.394	
ST0083*	BANGALORE	0.043	0.072	0.090	0.072	0.086			0.073	0.016	0.090	0.043	40.209	
ST0097*	BANGALORE	0.106	0.110	0.145	0.110	0.095			0.113	0.017	0.145	0.095	15.707	
ST0099*	BANGALORE	0.111	0.105	0.160	0.296	0.273			0.189	0.081	0.296	0.105	44.539	
ST00123	SHIMOGA				0.280	0.250			0.265	0.015	0.280	0.250	5.660	
SU0024	DAVANGERE						0.003	0.003	0.003	0.000	0.003	0.003	11.439	34.067
SU0047	RAICHUR						0.336	0.078	0.207	0.129	0.336	0.078	62.423	
SU0062	BELGAUM						0.057	0.032	0.044	0.013	0.057	0.032	28.428	
S&D0077*	BANGALORE	0.025	0.038	0.031	0.031	0.037			0.032	0.005	0.038	0.025	21.850	21.850
TI00121				0.020	0.016			0.018	0.002	0.020	0.016	10.046	10.046	
TX0010	BANGALORE						0.064	0.079	0.072	0.008	0.079	0.064	10.714	36.356
TX0037	HUBLI	0.153	0.204	0.120	0.159	0.196	0.813	0.995	0.377	0.338	0.033	0.120	68.306	
TX0093*	BANGALORE	0.419	0.830	0.285	0.314	0.683			0.506	0.214	0.033	0.285	43.745	
TX0094*		0.220	0.404	0.236	0.261	0.272			0.279	0.065	0.033	0.220	21.032	
TX0095*	BANGALORE	0.152	0.302	0.170	0.138	0.351			0.223	0.087	0.033	0.138	37.984	
TY0043	MYSORE					3.529	3.922	3.700	3.717	0.161	3.922	3.529	5.061	5.061

the areas of one-step conversion of methane to methanol, photocatalytic reduction of water, combustion enhancement, and pollution control [10].

(x) Recovery and reuse of water heat offers significant opportunities for energy conservation. The development of cost effective heat exchanger and thermal storage units is needed for the recovery of high temperature reject heat. The development of high lift heat pumps could greatly enhance the utility of low grade waste heat.

(xi) Cogeneration is the simultaneous production of process heat and electric power. Providing moderate or low temperature heat as a by product of the work from a heat engine is much more efficient than providing heat directly by burning fuel. Most typical cogeneration industries convert only 10–15% of the energy into electricity [11]. The intercooled steam injected gas turbine[12], a new technology, is being developed which incorporates a modern aircraft engine and can accommodate variable amounts of steam returned to the turbine combustor and, therefore, has a flexible electricity–heat ratio. Steam not returned to the turbine is used for process heat. With full steam injection, 40% of the energy can be converted into electricity.

(xii) Variable speed controls for motors are currently available for application on existing and new equipment to adjust the speed control so that the motor and driven equipment can match the requirement of the process. Motors account for about 55% of the electric energy consumed in Karnataka State. The potential for conserving energy by applying high temperature superconductors [13] in place of conventional conductors in industrial motors is very large. The advantages include reduced volume and mass, higher power density, enhanced performance and improved operating efficiency.

(xiii) Industrial separation processes involving separation of the components in a mixture are highly energy intensive. Advancement of alternative processes, such as membrane separation, solvent extraction, critical fluid extraction and advanced drying concepts, promise less energy intensity. This could be beneficial to applications like black liquor concentration in the paper and pulp industry, hot food processing waste water concentration, dilute soluble food process stream concentration and drying of products, such as textiles and paper [14].

9. CONCLUSIONS

1. Even though energy consumption/capita is low, energy/SDP for Karnataka is quite high. This is true specially for the industrial sector. The energy/SDP for the industrial sector in Karnataka is 10–20 times higher than that for some of the industrialised countries. This shows that there is great room for improvement of the efficiencies in energy consumptions in our industries.
2. Electrical energy forms a major component in industrial energy use. The per cent ratio of electrical energy to total energy is also higher for Karnataka when compared with the index for industrialised countries. Electrical energy, being a high quality energy involving more energy conversions, should be used in high quality work.
3. Energy consumption per rupee of production for various industrial groups has been calculated. These will serve as indicators for industries in the same group. Some of these, when compared with international norms, look quite high.
4. Electrical energy consumption per rupee of production for various industrial groups has also been evaluated. This can again be used as an indicator.
5. The specific energy consumption within a group varies very widely—in some cases, a variation of about 100% or more exists. This shows that we can definitely reduce energy use through conservation measures.
6. Specific energy consumptions have been calculated for a period of five years. These variations show an increase in SEC in many industries. In some cases, there is a decrease, a welcome measure.
7. Electricity production is shifting towards diesel captive plants because of power cuts in the grid electricity. This increases the cost and decreases the efficiency of energy use. This has not induced industries to reduce energy consumption.

8. A study of electric load patterns indicates that about 40% of the load is for heating. Hence, these can be easily converted to use other forms of energy, thereby increasing efficiency of use and relieving the demand on electrical energy.
9. A study of electrical energy and power distribution throughout the state reveals a large spatial disparity in energy use with most of the use being concentrated in Bangalore and one or two singular points.
10. This study only reveals the possibilities of energy conservation. Actual measures depend on studies in individual industrial units. Hence, energy budgeting and auditing measures in many major industries should be initiated. The research and development must be undertaken now in order to make major contributions in the decades following the year 2000.

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