Notebook

Energy Efficiency and
Conservation in Thailand:
Analysis of the 1980-1992 Period

*Notebook provides data not easily found elsewhere,
background descriptions of important aspects of the
energy system and reports on new developments.
Contributions are invited.*

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1. Introduction

Energy conservation and improvements in
end-use energy efficiencies are recognized as
very important components of energy policies,
not only because they allow to reduce the bur-
den of the energy import bill and to avoid the
negative impacts of international energy
shocks, but also because they allow to con-
serve domestic energy resources and the envi-
ronment. This paper examines the energy de-
velopment and the evolution of energy effi-
ciency and conservation in Thailand during
the period 1980-1992. Energy efficiency per-
formance in Thailand is examined *vis-à-vis* the
analysis of the economic development and the
energy demand management policies of the
country during that period. A set of quantita-
tive indicators at the macroeconomic level, as
well as at sub-sectoral and end-use levels, is
used to support the analysis. This set of energy

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efficiency indicators includes the following:

- *Primary/final energy intensities,* defined as the ratio of total primary/final energy consumption to GDP at constant prices.
- *Sectoral energy intensities,* defined as the ratio of energy consumption to the corresponding sectoral value added (VA) at constant prices. This is applied to the industrial and commercial sectors. For the transport sector, energy intensity is defined as the ratio of energy consumption to GDP at constant prices.
- *Unit energy consumption,* defined as the ratio of energy consumption in the given subsector or end-use to outputs expressed in physical terms or number of devices (*e.g.,* ton of oil equivalent (toe) per ton of steel; or kilogram of oil equivalent (kgoe) of gasoline per car).
- An index is associated with each indicator, defined as the ratio of the value of this indicator in a given year over its value in the base year (*e.g.,* 1980). These indices are more convenient for examining the evolution of energy efficiency indicators over time.

For the calculation of these indicators, only commercial energies are taken into consideration and no attempt is made to account for traditional fuels, due to the unavailability of data.

2. Economic and Energy Development

During the period 1980-1992, the Thai economy changed remarkably. This can be seen by looking at the transformation of the volume and structure of the country's GDP. Over this period, real GDP more than doubled, going from Baht[1] 913.7 billion in 1980 to Baht 2270.5 billion in 1992 (expressed in constant 1988 prices), growing at an average annual rate of 7.9% (Office of the National Economic and Social Development Board 1990). Since 1987 Thailand has been enjoying the strongest economic boom in its history. The annual GDP growth rate averaged around 12% during the period 1987-1990. Even though the economy slowed down in subsequent years (1991-1992),

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1/ Baht is the unit of Thai currency (US$ 1 = 25 Baht, approximately).

growth remained as high as 7.5% annually.

Thailand is undergoing a rapid transformation from an agriculture-based to an industrialized economy. Between 1980 and 1992, the share of agriculture in GDP decreased from 22 to 14%, while the share of industry increased from to 31 to 41%. Table 1 depicts some key indicators showing the remarkable economic development of Thailand during that period.

2.1 Primary Energy Supply

In Thailand, the role of renewable energy sources such as fuelwood, charcoal, paddy husk, and bagasse remains significant. However, modern energy production has increased very rapidly, in line with the accelerated development of the Thai economy in the last decade. During the 1980-1992 period, the share of renewable energy has fallen substantially, being replaced by increasing domestic supplies of lignite, natural gas, and oil. This trend is expected to continue in the late 1990s.

The rapid expansion of lignite production (due mainly to the expansion of the Mae Moh power plant from 225 megawatt (MW) in 1980, to 2025 MW in 1992) and natural gas production has changed the energy supply structure considerably. In 1992 Thailand produced about 15.3 million tons of lignite and 305.3 billion standard cubic feet (scf) of natural gas. The share of natural gas and lignite in total primary energy supply in 1992 reached 20 and 12% respectively, as compared with only 8.2 and 4.3% in 1980 (Department of Energy Development and Promotion, various issues).

The total primary supply of oil and petroleum products in 1992 amounted to 23 million tons of oil equivalent (Mtoe) or 63% of total primary supply, of which 91% came from imports.

Domestic hydro power potential, excluding the Mekong and Salween rivers situated along the borders with neighboring Laos and Burma, is estimated at 10,586 MW. Of this, only 2,429 MW was exploited as of 1992, 516 MW was being developed, and an additional 1,056 MW was planned up to the year 2006. High investment costs and environmental concerns are the major constraints on the development

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Table 1: Key Indicators, Thailand

	Avg. Annual Value (1992)	Growth Rate (1980-1992)
Land area, (km^2)	513,115	-
Population (million)	57.79	1.79%
GDP, billion ($US)	110.3	7.9%
Per capita GDP ($US)	1909	6.0%
Per capita primary energy consumption (kgoe)[1]	625	7.2%
Per capita final energy consumption (kgoe)	448	7.1%
Per capita electricity consumption (kWh)	845	9.7%

1/ kilograms of oil equivalent

Source: Authors' calculations based on National Statistical Office, Office of the Prime Minister (1992); Office of the National Economic and Social Development Board (1990); Asian Development Bank (1992).

Table 2: Final Energy Consumption Growth Rate (% per annum)

	1980-85	1985-90	1990-92	1980-92
Transport	8.9	11.7	5.5	8.5
Industry	2.0	14.1	12.4	6.5
Agriculture	-5.7	16.5	2.6	4.0
Household and commerce	6.9	14.0	14.0	8.6
Total	5.2	13.0	8.2	7.5

Source: Authors' calculations based on Asian Development Bank (1992).

of the planned and remaining hydro power potential. In 1990, hydroelectricity supplied only 4.7% of the total primary energy supply in Thailand.

2.2 Final Energy Consumption

Final energy consumption increased rapidly in the period 1980-1992. Total final consumption of commercial energy in 1992 was 25.416 Mtoe, which was roughly three times the volume consumed in 1980 (Department of Energy Development and Promotion, various issues). As Table 2 indicates, energy consumption growth was especially high in the second half of the 1980s (1985-1990), when it reached 13% per year, as compared with 5.2% in the first half (1980-1985). In the early 1990s, this growth rate dropped to 8.2% per annum, which was still very high. For the period 1980-1992, the measured elasticity of energy demand with respect to GDP was equal to 1.16, indicating that the rate of increase in energy consumption exceeded the growth rate of GDP.

Even though the role of petroleum products in the final fuel mix has gradually fallen — clear evidence of the success of government policies aimed at reducing oil import dependency — petroleum products remained by far the most consumed fuels in Thailand. Thus in 1992, petroleum products accounted for 77% of the final consumption of modern energy, slightly lower than its 87% share in 1980. This reduction in the market share of petroleum products was compensated by an increased penetration of electricity and lignite, which saw their market share increase by 4 and 6 percentage points, respectively, during the 1980-1992 period (Figure 1).

As can be seen from Figure 2, energy consumption in all the economic sectors increased almost uniformly between 1980 and 1992, with the transport sector accounting for the largest share (52.2%) of total final energy consumption at the end of that period. Energy consumption for transport purposes grew at an average rate of 8% per year, resulting in a threefold increase over the period (from 4.28 Mtoe in 1980, to 12.65 Mtoe in 1992). A substantial increase in energy consumption was also recorded in the industrial and the residential/commercial sectors. Average household energy consumption growth was around 8.6%, and average industrial energy consumption growth was nearly 6.5%.

3. Energy Demand Management Policies

As with other Asian developing countries, the main objectives of Thailand's national energy policies are ensuring reliable energy supplies to satisfy the growing demand that results from rapid economic growth, by diversifying energy supply sources and mobilizing domestic energy sources to alleviate the burden of the energy import bill. However, since the mid-1980s, rational use of energy, energy conservation and efficiency improvements, and active participation by the private sector in the
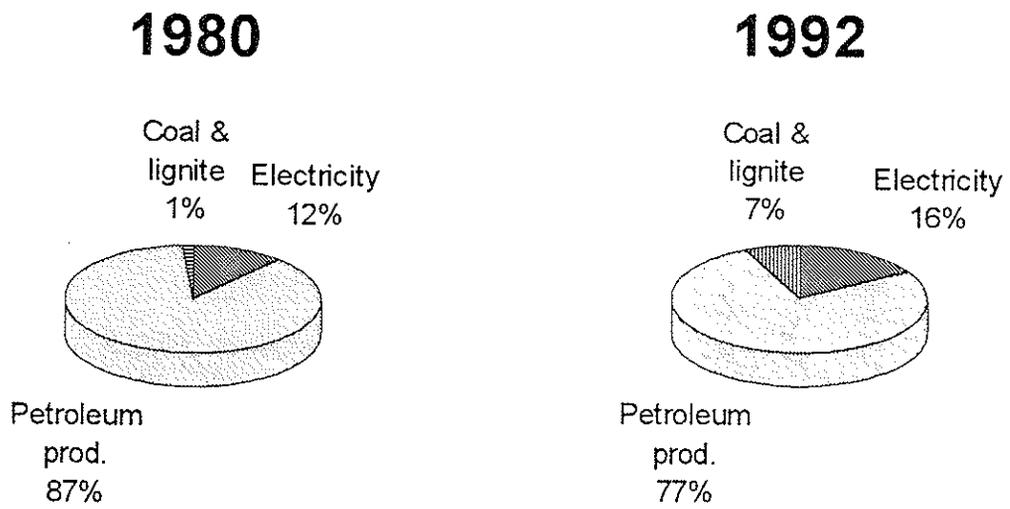
1980

Coal &
lignite   Electricity
1%   12%

Petroleum
prod.
87%

1992

Coal &
lignite   Electricity
7%   16%

Petroleum
prod.
77%

Figure 1: Final Energy Consumption Fuel Mix
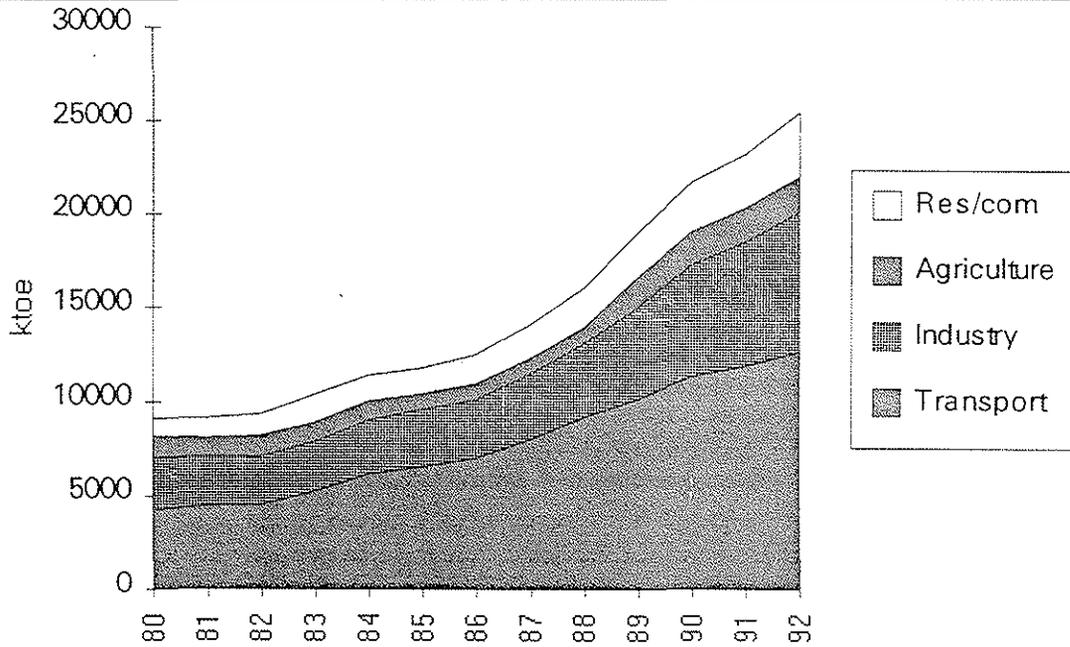Source: Department of Energy Development and Promotion

Figure 2: Final Energy Consumption by Sectors
Source: Department of Energy Development and Promotion

energy and electric power industries have gradually emerged as the main trends in the country's energy demand management policies.

At present, Thailand has a fairly comprehensive energy demand management framework. This framework is the result of a long development period, which started soon after

the first oil crisis, and continues to be strengthened today. Energy demand management measures in the early days (right after 1973, and until 1982) was mainly comprised of direct restrictive regulations by the government. Examples of such regulations are restrictions on the operating hours of gas stations, limits on street lighting intensity and time, bans on the use of lighting for advertising purposes, and tight controls of the distribution of final energy. These measures, though simplistic, were necessary interventions by the government to remedy the energy shortage that followed the oil crises.

Realizing that energy conservation management was a complex issue requiring a systematic approach, the Thai government turned towards more sophisticated and credible measures to develop energy demand management policies. The Fifth Five-Year Plan (1982-1986) marked the beginning of a new phase in the development of energy conservation strategies in Thailand. It was here that energy conservation objectives were explicitly stated as part of the energy plan. In subsequent Five-Year Plans, energy conservation strategies were reinforced by adding concrete programs, such as the Demand Side Management Program and the Energy Conservation Program, with its specified quantitative targets for energy conservation in every economic sector,[2] to become today's comprehensive framework.

Energy management measures initiated during the 1980s also included changes in energy pricing policies aimed at eliminating subsidies, the creation of centers and programs whose main functions were campaigning and providing services related to the rational use of energy and to efficiency improvements. In April 1985, the Energy Conservation Center of Thailand (ECCT) was established with the twin objectives of carrying out public education campaigns and providing energy management services to the industrial and commercial sectors. ECCT then launched several

programs to fulfill its mandate, e.g., the Energy Audit Program (EAP), the Energy Information Dissemination and Training Program (EIDTP), and the Energy Technology Demonstration Program (ETDP). Every year between 1986 and 1991, ECCT conducted energy audits on about 100 factories to collect data on key parameters, such as combustion efficiencies, power factors, and equipment efficiencies. As a result, energy audit reports aimed at providing, for individual factories, overviews of their energy situation and of their energy conservation potential, as well as at providing technical measures for energy use improvements have been prepared.

The establishment in 1986 of the National Energy Policy Council (NEPC) and the National Energy Policy Office (NEPO), strong and centralized institutions to oversee energy policy issues and to advise the government in this area, completed the institutional arrangements necessary for the further realization of the country's energy conservation strategies.

The beginning of the Seventh Five-Year Plan (1991-1996) is a milestone in the development history of the Energy Management Strategies of Thailand. In 1991, the first demand-side management (DSM) project in the electric power system was finalized – the first ever DSM project to be implemented in the entire Southeast Asia region. This DSM program called for electricity conservation through the implementation of a series of programs (e.g., a lighting program in the residential sector, lighting and air conditioning programs in the commercial sectors, an efficient motors program in the industrial sector). This five-year DSM program was launched with a budget of $(US)189 million and a target of reducing peak demand by 238 MW and saving 1,428 gigawatt-hour (GWh) of electricity by 1997 (Electricity Generating Authority of Thailand, 1995).

In 1992, the Energy Conservation Act of Thailand was promulgated. The Act has two key components, namely: (i) the definition of measures and targets for energy conservation in the industrial and commercial sectors; and (ii) the establishment of the Fund for Promoting Energy Conservation, and other promotion

2/ For example, in the Sixth Five-Year Plan (1987-1991), the energy conservation target was to save 2.45 million barrels of oil equivalent annually in the transport, industrial, and residential sectors.

and assistance measures. Regarding energy conservation in the industrial and the commercial sectors, the Act defines three target groups: "designated factories;"[3] "designated buildings;" and "producers and distributors of machinery, equipment with high efficiency, and material used in energy conservation." The Act also further defines the scope of activities to be applied to designated factories and buildings, duties and responsibilities of their owners, and also penalties against violators. All these conditions are detailed in a Royal Decree and a series of Ministerial Regulations issued under the Act (Department of Energy Development and Promotion 1995).

The Energy Conservation Promotion Fund has been established by transferring the revenue generated by a small levy (0.07 Baht per liter) on refined petroleum products. The initial allocation to the fund was 1.5 billion Baht, or $(US)60 million, with an expected annual capital inflow of 1.5 to 2 billion Baht ($(US)60-80 million). The main purpose of the Fund is to encourage designated factories and designated buildings to carry out energy conservation, as required by the Act. In addition, the Fund is also used for providing financial incentives for renewable energy projects, energy research development, and the dissemination of energy efficiency technologies and personnel training.

With the promulgation of the Energy Conservation Act, the implementation of the DSM program, and more recently the initiation of power sector privatization, Thai national strategies on energy conservation and efficiency have gained strength, laying down the foundations for the future achievement of energy conservation and efficiency improvements in the actual socio-economic context.

3/ Designated factories are defined as those with installed electrical capacity above 1 MW or total energy consumption of more than 20 terajoules (TJ) per year.

4. Evolution of Energy Efficiency Indicators

4.1 Primary and Final Energy Intensities of GDP

Overall energy intensity, which is defined as the ratio of total annual energy consumption to GDP, shows the performance of the economy with respect to energy use at the most aggregated level. Throughout the 1980-1992 period, Thainland's overall energy intensity exhibited a general upward trend, with some fluctuations (Figure 3). In 1980, the final energy intensity of Thailand's GDP was 293 tonnes of oil equivalent per million US dollars (toe/M$US) at 1986 prices. In 1992, the corresponding value was 334 toe/M$US at 1986 prices. All in all, a 15% increase was recorded for the entire period. In the first years of this period (1980-1982), a drop of as much as 10% in final energy intensity was observed, but over the following years this trend was reversed and energy intensity increased continually.

A comparison of trends in the evolution of energy intensity and energy prices (Figure 4) shows a strong influence of the latter on energy intensity. Decreases in energy intensity in Thailand were recorded in the early 1980s - the years following the second oil shock, when the government removed subsidies from energy prices. As a result, the prices of all energy sources in 1982 were double their 1979 levels (Asian Development Bank, 1992). This sudden price surge obviously played a key role in the declining trend of energy intensity. From 1982 to 1984, as energy prices recovered from the oil shock, energy intensity rose up back to its 1980 level. In fact, a 15% drop in oil product prices was recorded during these years. The correlation of the two graphs given in Figures 3 and 4 indicates that, as energy prices stabilized and then went down starting in 1982, the country's overall energy intensity began an upward trend that lasted until the end of the period under consideration.

Energy price variations are not the sole factor behind changes in energy intensity. Thus, the steep increase in energy intensity between 1988 and 1992 occurred in line with the take-
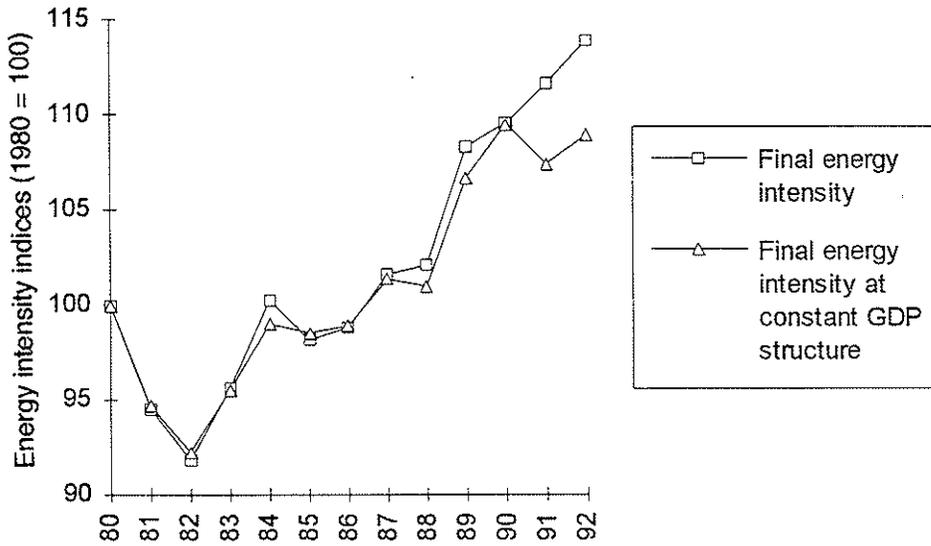
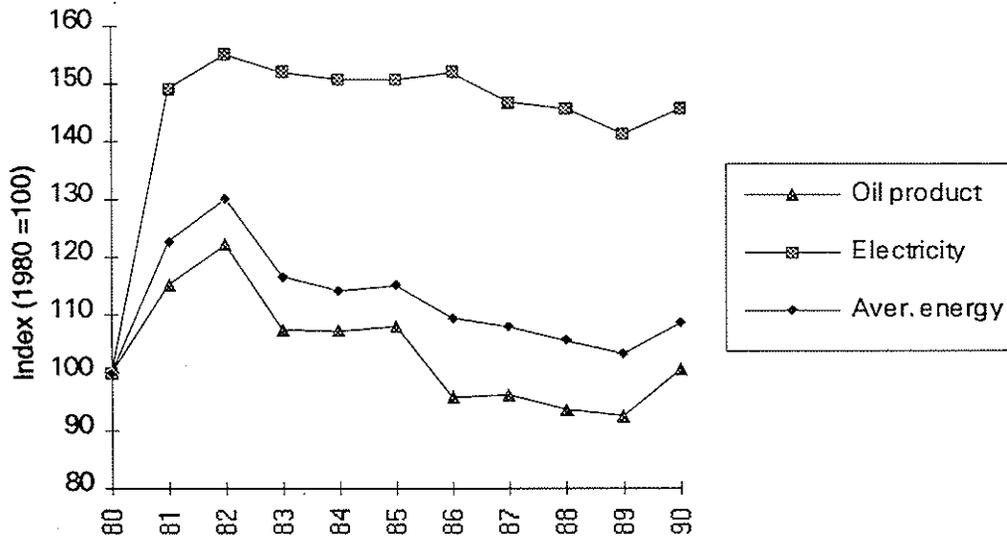**Figure 3:** Evolution of GDP Energy Intensities, 1980-1992

Figure 4: Energy Price Index in Thailand, 1980-1992

Source: Asian Development Bank, 1992

off of Thailand's economy, which achieved very high growth rates in this particular period. The increase in energy intensity, which in this case means a faster growth of energy consumption in comparison with an already high GDP growth, can be attributed to: i) the substitution of traditional fuels by commercial ones as the result of the on-going process of economic modernization; ii) a very fast increase in commercial energy consumption in some sec-

tors, such as transportation and residential/commercial; and iii) an increased share of energy intensive industries, which usually occurs in booming developing countries like Thailand.

Figure 3 also displays the variation in the final energy intensity calculated based on the GDP structure of the Thai economy in base year 1980. This indicator was derived by assuming that the shares of value added of the industrial, commercial, and agricultural sectors in total GDP had remained unchanged throughout the period. This allows us to isolate the effects of structural changes of the economy on the evolution of energy intensity. Final energy intensity, rather than primary energy intensity, was chosen for this purpose because it better reflects the evolution of end-use energy efficiencies. Figure 3 shows that, since 1987, the index of actual final energy intensity exceeded (especially during 1990-1992) the index of final energy intensity calculated with the structure prevailing in 1980, reflecting the increased share of the industrial sector and the reduction of the importance of agriculture in total GDP. The noticeably higher level of the actual energy intensity index compared to that of energy intensity at a constant 1980 GDP structure is evidence of an extensive penetration of more energy intensive activities.

Figure 5 depicts the so-called "Economy-Energy Trajectory" of Thailand for the period 1980-1992. It vividly illustrates the country's significant economic development and the improvement in the living standards of the Thai people. It also clearly shows the evolution of energy intensity at a macroeconomic level. The 15% increase in final energy intensity from 293 to 334 toe/M$US at 1986 prices was accompanied by a much more impressive increase in GDP per capita (*i.e.*, from 650 to 1200 $US at 1986 prices) and by the doubling of per capita energy consumption (from almost 180 to 360 kgoe)[4] during the period under study.

4.2 Sectoral Energy Efficiency[5]

INDUSTRY[6]

Industry is the second largest energy consumer in Thailand, accounting for 29% of commercial final energy consumption in 1992 (7.17 Mtoe). Throughout the period under study, along with the rapid expansion of production capacity and outputs, the Thai industrial sector achieved a marked decrease in the energy intensity of industrial value added (Figure 6). A reduction of 20% was achieved by 1984, and industrial energy intensity has remained more or less unchanged ever since.

The improvement in the energy efficiency of the Thai industrial sector was largely due to the fact that a substantial portion of the production capacity was added during the last decade, utilising relatively up-to-date technologies. For example, two-thirds of the cement production capacity was installed after 1980, and thus utilises the energy-efficient dry process. The pulp and paper industry was also in a similar situation. It is estimated that the energy intensity of Thailand's paper industry is among the lowest in the developing world and comparable to those in industrialized countries. The textile and food industries are the two sub-sectors that recorded the highest

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4/ For a detailed comparison between Thailand and several other Asian developing countries, readers are referred to Lefevre, Thanh *et al.* (1995).

5/ An analysis of energy efficiency indicators for the agricultural sector was not carried out in this study due to the fact that energy consumption in this sector (99% of which is petroleum products) accounted for a minor share (between 6 and 7%) of total commercial final energy consumption in Thailand. The potential for energy conservation in the agricultural sector is likely the smallest in comparison to that of the other sectors.

6/ In this study, the industrial sector is further disaggregated into several sub-sectors: the metallic industry (*e.g.*, ferrous and non-ferrous metals); the non-metallic industry (*e.g.*, glass, ceramics, *etc.*); food and beverages; textile, leather, and clothing; the mechanical industry (also called the equipment-goods industry); the electric and electronics industry; the chemical industry; pulp and paper; and other industries. This disaggregation allows for a detailed look at sub-sectoral energy consumption patterns.
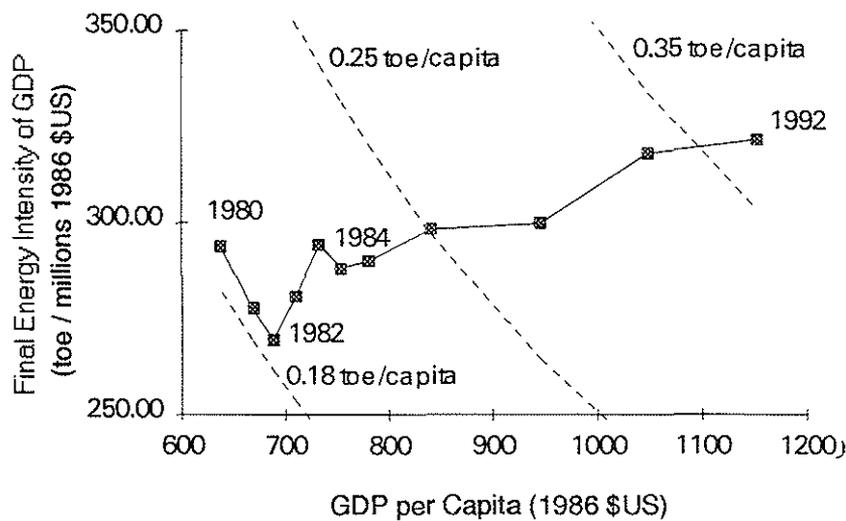
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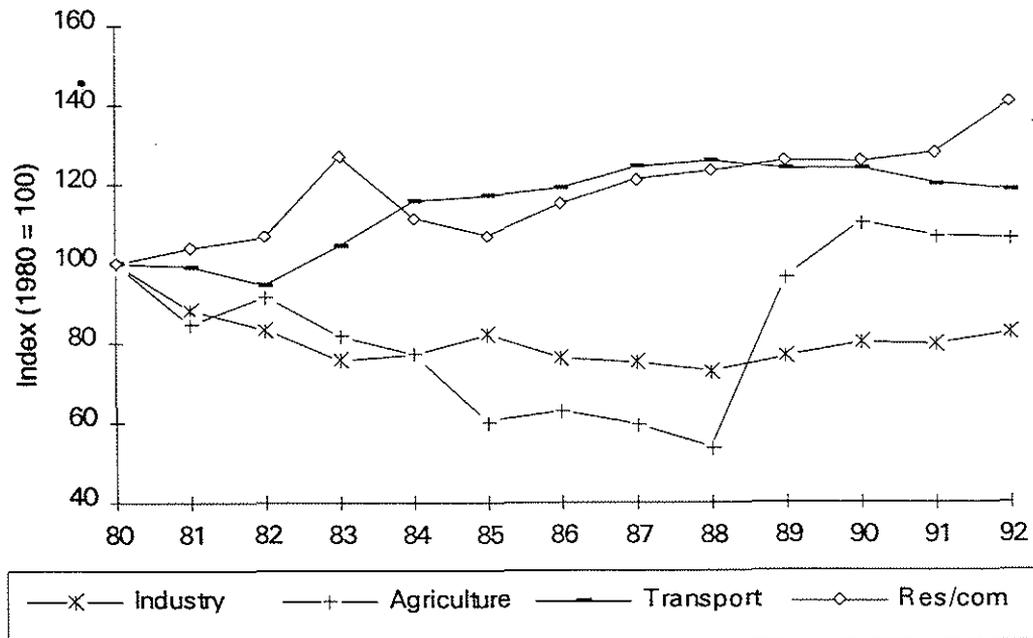**Figure 5:** The "Energy-Economy Trajectory" of Thailand, 1980-1992

Figure 6: Evolution of Sectoral Energy Intensity Indices

output growth and a large share of value added during the whole period. This is not surprising because the growth of Thailand's economy in the last decade has been export-oriented, with garment and food products being the major export products.

Analysis of sub-sectoral intensities revealed that, among sub-sectors and during the period under study, only basic metal industry recorded an increasing energy intensity; the food industry's intensity fluctuated within a range of 800 to 1200 toe/M$US at 1986 prices. Meanwhile, the textile, mechanical, electric and electronics industries substantially re-

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duced their energy intensity (Table 3). This substantial reduction coupled with the fact that these industries had big shares in industrial value added (in 1992, textiles, equipment goods, electric and electronics accounted for 20%, 10%, and 15% of industrial value added, respectively) partly explain the decreasing trend of energy intensity in the industrial sector as a whole.

TRANSPORT

The transport sector was the largest energy consumer in Thailand throughout the period under study, and consumed 12.65 Mtoe in 1992. Energy consumption in this sector accounted for about 50% of the country's total final energy consumption. In addition, road transport, in which only two fuels (*i.e.*, gasoline and diesel) were used, accounted for three-quarters of total transport energy consumption during the entire period. Therefore, the potential for energy conservation largely depended on this mode of transport.

The growth rate of energy consumption in the transport sector was also the highest among the major final energy consuming sectors. An average annual growth of 10.4% was recorded between 1980 and 1992. This growth was moderate during the first three years (1980-1982), and became uniformly high thereafter.

The evolution of the energy intensity of the transport sector, which is defined as the ratio of energy consumption in this sector to GDP, is depicted in Figure 6. As this figure shows, the energy intensity of this sector exhibited a generally increasing trend, which can be explained by the following factors.

• During the late 1980s Thailand witnessed a very rapid motorization (Transport and Communications Economics Division 1985, 1993). From 1983 to 1992, the stock of private cars in Thailand doubled, and the stock of light road vehicles (pickups, vans, microbuses, *etc.*) increased threefold. As a result, fuel consumption in the transport sector grew so fast that it outpaced GDP growth, resulting in a 20% increase in the energy intensity of the transport sector between 1980

Table 3: Energy Intensity of Several Industrial Subsectors in 1980 and 1992 (toe/M$US at 1986 prices)

	1980	1990
Textile Industry	2,600	1,500
Mechanical Industry	1,750	700
Electric and Electronics Industry	352	141

Source: Authors' calculations

and 1992.

• Heavy traffic congestion in the Bangkok Metropolitan Region, where a predominant part of vehicle stock is concentrated, caused a big loss of fuels and therefore increased energy consumption in road transport. This could also contribute to the sector's higher energy intensity.

On the other hand, the index of fuel consumption per vehicle (Figure 7) shows a noticeable decreasing trend during the period under study. Average gasoline consumption per road vehicle (including private cars, motorcycles, light road vehicles) decreased by 30% (*i.e.*, from 0.53 to 0.35 toe per vehicle per year) and average gasoline consumption by private cars decreased by 35% (*i.e.*, from 0.73 to 0.51 toe per car per year) between 1983 and 1992. This decreasing trend in unit energy consumption in road transport can be explained by the fact that a substantial part of the motor vehicle fleet in Thailand has been added during recent years. Indeed, two-thirds of the present fleet consists of vehicles which were first registered in the late 1980s and the beginning of the 1990s, and have relatively high standards of unit fuel consumption (Transport and Communications Economics Division, 1985; 1993).

It must be emphasized that this discussion about energy consumption patterns in Thainland's transport sector is just an overview of this issue, and that more data are needed to examine efficiency indicators for the different transport modes. However, the main conclusion at this point is that even if a 30 to 35% decrease in the annual fuel consumption of individual vehicles is impressive, it has not been sufficient to offset the impact of a two to three times increase in the number of vehicles, which means that final energy intensity has
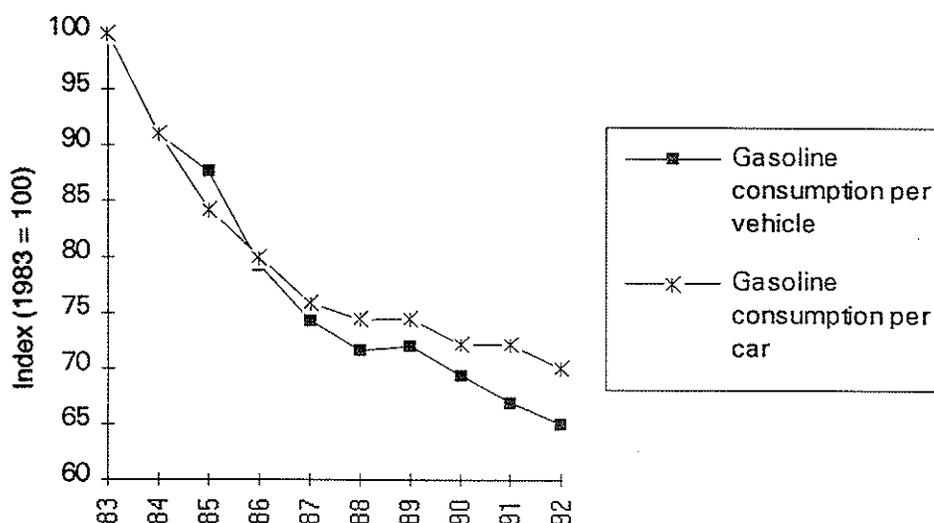
Figure 7: Evolution of Indices of Average Fuel Consumption per Vehicle

been escalating during the period under study.

RESIDENTIAL/COMMERCIAL

In 1992, energy consumption in the residential/commercial sector represented 3.46 Mtoe, or 13.6% of total final marketed energy consumption. However it should be noted that marketed (or commercial) energy accounted for only one-third of total energy consumption in this sector. About two-thirds of household energy needs in Thailand are still met by biomass, which was not taken into consideration in this study.

The evolution of residential/commercial energy intensity is shown in Figure 6. The energy intensity of this sector was calculated as the ratio of residential/commercial energy consumption to GDP. The figure shows a clear ascending trend of this sector's energy intensity during the entire period. In 1992, the residential/commercial energy intensity was 30% higher than in 1980. This could be the result of: (i) the rapid expansion – especially in the last three years – of the service sector, which in fact has a big potential for energy conservation that was not materialized during that period; (ii) higher penetration of modern energy in households to replace traditional energy, in

line with the improvement in living standards (National Statistical Office, Office of the Prime Minister 1992)

Between 1980 and 1990, average energy consumption per household rose from 470 to 760 kgoe per year. During the same period, average electricity consumption per household increased from 400 to 771 kWh per year. The fact that average electricity consumption per household increased at a faster rate than the total commercial energy consumption in this sector shows the result of the electrification process in Thailand, which gave access to electricity to more households in both urban and rural areas. In 1992, electricity accounted for more than 70% of total final commercial energy use in Thailand's residential/commercial sector.

5. Concluding Remarks

From the discussion presented so far, it can be seen that energy consumption in Thailand during the period 1980-1992 exhibited the typical pattern associated with a fast growing developing economy. In particular, the volume of energy use in all economic sectors rose rapidly, in parallel with high GDP growth. In the case of Thailand, the rate of increase in commercial

energy consumption exceeded the growth rate of GDP, resulting in an increase in overall energy intensity.

During the period under study, the two main factors that most markedly influenced energy consumption patterns in Thailand were: (i) the continuously growing level of economic activity, which tends to push up energy intensity for economies in transition like Thailand; and (ii) the policy measures gradually undertaken by the government to counter the excessively high growth of energy demand, such as ending the regulation of energy prices (*e.g.*, elimination of subsidies), the implementation of energy audit programs, of demonstration and training programs, and the introduction of lower taxes for energy-efficient equipment, *etc.* These measures have had a noticeable effect in the industrial sector, which was the prime target of energy conservation efforts. In addition, the recorded improvements in techno-economic energy efficiency indicators in the industry and the transport sectors can be attributed to the modernization of equipment, machinery, and the vehicle stock, due to Thailand's successful economic development, which has helped to maintain a favorable investment climate and to raise the standard of living of its people.

The evolution of energy intensities, which are the main indicators of energy efficiency, is largely determined by the combination of the structural changes in the economy and the effectiveness of the management policies being implemented. In fast growing developing countries, the observed trend of structural change corresponds to the expansion of the industrial and commercial sectors, and to the increasing urbanization rate resulting in a very high growth of energy demand (Lefevre, Thanh *et al.* 1995). Thus, a comprehensive demand management strategy has proven to be essential to sustain the socio-economic development of the country. In Thailand, energy management strategies including institutional arrangements have evolved in the right direction and gradually become a comprehensive framework that will benefit Thai society. Not only will it provide balanced energy supply-consumption patterns, but it will also create a

cleaner environment. To that end, a strong commitment on the part of policy makers, business people, and public alike is needed to implement actively measures to exploit the huge potential for energy conservation in all the socio-economic sectors of the country.

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Scope for Solar Energy Devices in Karnataka State, India

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Introduction

The primary renewable energy source on earth is solar radiation. The total flow of solar energy through the earth's natural system is some 10,000 times greater than the present flow of energy through man's machines. Even the 1% of the solar influx that generates the great atmospheric pressure systems which drive the winds, and which in turn generates the waves, is some 180 times as large as man's rate of energy use. And though, on average, the photosynthetic process accounts for less than 0.2% of the total flow, even photosynthetic production creates 10 times as much energy as man uses. The flow of solar and solar-derived energy forms is not independent from the activities of man. Radiation fluxes are modified by changing the reflectivity of the earth's surface through, for example, urbanisation, agricultural practices, and deforestation. Man's activities also change wind patterns and modify cloud coverage. Injection of pollution into the environment, removal of forest cover, and man-made structural changes influence radiation, heat, and water flows (Ramachandra 1993).

Solar energy is received entirely as radiation and is subsequently converted so that, at any time and place, an original quantum may appear in any one of several diverse forms. Thus, with respect to the energy encompassed in day-to-day climate at a given place and time, solar energy may appear as the latent heat of vapour, the advected heat of air masses, radiant energy from sky and terrestrial objects, and unconverted solar radiation arriving as direct beams. Unconverted solar radiation in the form of direct beams is a very important form of energy that is dominant in the hydrologic processes of evaporation, transpiration, snow ablation, as well as in the growth and succession of vegetation. The total flux of energy to a site at any given time is difficult to

measure and current techniques allow us only readily to measure the flux of radiant energy at a point. However, this flux varies so widely over most land surfaces as to render point measurements of limited value. The spatial heterogeneity in the radiant flux is due to the variation in solar-beam irradiation caused by variations in the inclination of the earth's surface with respect to beam direction. Within a geographic region, and subject to uniform atmospheric conditions, irradiation from the sky is fairly uniform regardless of surface inclination. However, the total of sun and sky irradiation would vary widely with surface orientation and slope. The variation of direct-beam radiation varies in time with atmospheric condition and path length, the combined effect of which can be estimated. All in all, these factors are of practical importance since solar energy can meet a large variety of the small-scale decentralised energy needs of a region.

A detailed study (Ramachandra and Subramanian, forthcoming) of five locations of the coastal belt of Uttara Kannada District (Karnataka State, India) in the Western Ghats region demonstrates that good solar energy potential is available in this region during most of the months in the year. The amount of solar energy that could be harnessed by utilising 5% of the present wasteland in coastal Taluks as a solar-collector area, is found to be in the order of 95.7 million kilowatt-hours (kWh) annually from the coastal belt of Uttara Kannada District alone. This means that solar energy could meet at least 32.5% of the District's present electricity needs. This study suggests that solar-conversion technologies have considerable potential for application, provided that questions of storage can be resolved and that electricity requirements during the monsoon season can be met through other means. The abundance of the solar resource can be illustrated by comparing the land requirements of solar (thermal or photovoltaic) with those of hydro or energy plantation projects. Except for run-of-river projects and for high head sites in deep gorges, the land requirements for such hydel projects average around 25 to 45 times those for solar energy, at today's conversion efficiencies. This means

that solar energy is capable to supply 5 to 10 times the electricity requirements of Karnataka State, while occupying smaller land areas than those currently used by hydel projects.

Rural communities depend on firewood and agricultural residues to meet the fuel requirement of domestic needs, such as cooking and water heating. Energy surveys in Karnataka State show that people are receptive to technologies which do not involve major attitudinal change and cultural barriers. In this regard, solar water heaters seem to be the most acceptable device in the domestic sector. Solar energy for water-heating purposes would reduce firewood consumption in the domestic sector.

Karnataka's Energy Scene

Karnataka State depends both on commercial and non-commercial forms of energy. Recent data (Subramanian and Ramachandra, forthcoming) suggest that 53.2% of total energy use is met by non-commercial sources such as firewood (43.6%), cow dung cake (1.4%), and agricultural wastes (8.2%). While commercial energy like coal (5.8%), oil (11.6%), kerosene (2.6%), liquid petroleum gases (0.7%), and electricity (26.1%) account for 46.8% of overall energy use. A significant part of these nonconventional energy sources cater to the heating (domestic) needs of the rural population (about 70-80% of the total) and, to a lesser degree, to that of village industries.

As far as electricity is concerned, the share of the industrial sector in total consumption is around 44.9%, followed by irrigation pump sets with a share of 28.6%, and domestic users which account for approximately 15.5%.

The Rural Energy Scene

A comparative analysis of village-level energy consumption patterns in the domestic sector of Uttara Kannada District has been carried out to assess the dependence of rural people on various energy sources. Our survey results (Ramachandra et al. 1995) are based on 18 months of field research in four Taluks of Uttara Kannada, covering 90 (of 119) villages and

all town divisions in Kumta Taluk. While in the Taluks of Sirsi, Mundgod, Siddapur, and Ankola our conclusions are based on randomly selected households of the order of 190 to 220 households in each Taluk.

Our sample of 1304 households from 90 villages in Kumta Taluk shows that most households still use traditional stoves for cooking (97.9%) and water heating (98.3%). Average consumption for cooking purposes ranges from 2.01 1.49 kilograms per person per day (kg/person/day) in the coastal region, to 2.32 2.09 kg/person/day in the hilly region. A seasonal pattern is also evident in both regions. Specifically, firewood requirements for coastal areas, in kg/person/day, vary from 1.98 during the summer, to 2.11 during the monsoon season. Similarly, for the hilly region the range is 2.22 to 2.51 kg/person/day during the summer and monsoon seasons, respectively.

Firewood requirements for water-heating purposes range from 1.17 0.02 (coast) to 1.63 0.05 (hilly) kg/person/day. Seasonal variation is also evident from the range for the coastal zone: from 1.12 to 1.22 kg/person/ day for the summer and monsoon seasons, respectively. For the hilly region, the range is from 1.53 (summer) to 1.73 (monsoon) kg/ person/day.

Analysis of other sources of energy used for domestic purposes shows that in the coastal zone kerosene is used for cooking and also for lighting. Kerosene consumption for cooking, in kg/person/day, ranges from 0.05 (hilly) to 0.34 (coast). The availability of bio-resources in the hilly region is the main reason for the lower consumption of kerosene. Kerosene for lighting purposes ranges from 0.74 litres per person per month (lit/person/ month) in the coastal areas, to 0.98 lit/person/ month in the hilly region. The latter region is more dependent on kerosene for lighting because of the non-availability of electricity for lighting purposes. In the hilly region, households are distributed over a large area and the electrification of all households has thus far not been carried out.

Based on the fuel consumption averages (by region, season, and end use) obtained from our detailed survey of households, we estimate that:

a) the firewood required in the domestic sector (for cooking, water heating, space heating, jaggery making, parboiling) of Uttara Kannada District works out to be 1.67 million tonnes per year;

b) the annual electricity consumption in the domestic sector (excluding irrigation) of the District is about 32.65 million kWh; and

c) kerosene demand of the District for cooking and water heating is about 15.9 megalitres per year.

The climate in coastal areas is favourable to setting up solar water-heating devices to meet the requirement of hot water for bathing purposes. If 30% of the population were to switch over to solar water-heating devices, the estimated quantity of firewood saved would be approximately 66.8 kilotonnes per year from the five coastal Taluks of Uttara Kannada District. The lack of information about the technology and the non-availability of proper service and maintenance backup in this region are the main reasons for energy-efficient devices and alternative technologies not finding a significant place in this rural energy scene.

Rural industries like cashew processing and others are major consumers of firewood in the rural coastal areas of Uttara Kannada District. Primary surveys conducted in some of the cashew-processing industries have revealed that some industries use 4 to 8 kilograms of firewood to process a kilogram of cashews. These industries are seasonal and operate at peak load during the pre-monsoon period (that is, in the months from February to June), so that it would be possible for them to switch over to solar energy for conditioning, mild roasting, and Broma drying operations since that form of energy is plentifully available during this period. In addition, drying is one of the most important processes in the post-harvest handling of agricultural products such as cardamom, peppers, chilies, copra, and area canuts. And the drying of agricultural products is an energy-intensive process: it is estimated that 2.5 megajoules of heat energy (mainly from firewood and other residues) are needed to remove a kilogram of water.

These analyses show that solar energy could be a viable alternative in meeting the energy needs associated with the drying of agricultural products, cooking (through solar cookers), hot water requirements for bathing and washing (solar water heaters), and lighting (through solar photovoltaic systems). In light of the above, we now turn to an examination of various aspects of solar water-heating devices, such as the underlying technology and their future prospects.

Solar Energy Conversion Modes

Solar energy is captured by being converted to other forms of energy by: (a) chemical reaction; (b) thermal excitation; and (c) photovoltaic effect. Solar energy is also chemically converted into energy through photosynthesis, which directly produces food and wood. Simple thermal-conversion devices, such as flat-plate collectors, are suitable mainly for providing low-energy, high-entropy heat to systems of the same nature. The flat-plate collector can deliver temperatures of up to approximately 100°C. The direct conversion of sunlight to electricity by means of solar cells is the photovoltaic effect. The solar cell use energetic photons of the incident solar radiation, converting solar energy into electricity (Wilbur 1985; Mortimer 1991).

Some advantages of photovoltaic devices are that they: a) have no inherent lifetime limit; b) have efficiencies that are independent of size; c) are modular; d) are compatible to all environments; e) provide fairly constant voltage, independent of sunlight intensity; f) are relatively low-maintenance; g) have low operating and maintenance costs; h) are simple; and i) do not require water cooling.

Potential areas of commercialisation of solar photovoltaics are: a) domestic lighting; b) community lighting (street lighting); c) health care; d) telecommunications; e) water pumping; and f) entertainment gadgets, like televisions and radios. Solar photovoltaics alone cannot successfully cater to energy requirements without a very high-efficiency balance of system design. Another major requirement is the storage of energy, wherein batteries of low-maintenance and high-recycling capacities are to be used. However, some disadvantages are: (a) the combination of theoretical efficiencies of about 25% combined with the low-energy intensity of sunlight means that relatively large collectors are needed; (b) the fact that these sources are not economically competitive with other, more traditional sources; and (c) the need for DC to AC inversion equipment to supply AC loads.

Solar Water Heating

Solar energy for daily use in households is already a popular concept. The current trend is such that these uses are virtually confined to water heating: more than 600 homes in Bangalore City are already using this system. Solar water-heating systems are simple devices, which work on the principle of black-body radiation and the greenhouse effect. These generally involve the use of flat-plate collectors, storage tanks, circulation systems, and appropriate controls and accessories. Solar water heaters can be broadly classified as either thermosyphon (natural circulation) or forced-circulation systems. Usually thermosyphon units are used for domestic applications (given a standard capacity of 300 litres), while forced circulation is used in the case of industrial and commercial applications.

Industrial and Commercial Systems

As noted above, forced-circulation systems are normally used for these purposes. A pump is used to circulate water through the collector system and a thermostat is used to control the temperature (Kishore and Bansal 1988). The fixed-temperature controller and differential-temperature controller are the two types of mechanisms used to control the flow of water in the system. In the case of the fixed controller, the system will deliver hot water at a constant temperature, but the quantity of hot water delivered depends upon the level of solar insolation and ambient conditions. As far as the differential-temperature controller is concerned, a fixed quantity of hot water is delivered at varying temperatures, depending

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upon the solar installations.

Domestic Water Heating

Thermosyphon systems are generally used because of their ease of operation and maintenance. For proper functioning, it is necessary to have as little resistance as possible in the thermosyphon path as well as an adequate supply of cold water. In some cases, an automatic electric backup system is incorporated to ensure hot water availability throughout the year, and storage tanks are usually double-walled, insulated constructions.

The collector is the heart of the system and consists of components such as absorbers, glazing, boxes, and insulation. A wide range of materials and design choices are available now. The basic absorber can be made of galvanized steel, aluminum or copper, and both flat black paint or selective coatings are available options. The glazing can be plain window glass, toughened glass, or acrylic. Sawdust and cork are occasionally used for insulation. However, the majority of commercially-available collectors use mineral wool, glass wool, or even polyurethane foam for bottom insulation. While wooden boxes are once again employed in some instances to contain the other components of the system, metals like steel and aluminum as well as reinforced plastic are more frequently employed.

Present Status in Karnataka

The total number of industrial and commercial systems installed in the State is approximately 150, with 35 systems of 1000 litres per day (LPD), 72 systems of 1000 to 5000 LPD, and 10 systems of 10,000 LPD. Assuming that the system is used effectively for 225 days a year, the amount of equivalent electrical energy saved annually is 6 million kWh. In Bangalore City alone, the amount of electrical energy that could be saved by installing solar water heaters in All Electric Houses (AEHs) is 1.8 million kWh per year. The generation capacity required to meet their demand is 250 MW, the cost of which is higher, by as much as 50%, than that of installing solar water heaters in AEHs.

The cost of a domestic water heater is between 8000 and 10,000 rupees (Rs.). The Government of India provides a subsidy of Rs.3000 to each person who decides to proceed with the installation of such a system. Solar heaters save about 50 to 75 kWh of energy per month per household. By educating people about solar energy through mass media, substantial savings in electrical energy and firewood could be achieved. It would appear that the main reasons for the low market penetration rate currently observed are: (a) the high capital cost of the system; (b) the inadequate availability of funds for the disbursement of subsidies; (c) the absence of attractive financial packages for buyers; and (d) a lack of awareness of the technology.

Technical Issues

The main technical snags encountered in solar heaters are:
(a) Corrosion of various forms has been a nagging problem. While the use of galvanization has produced reasonably satisfactory results in the case of steel absorbers, problems in certain localized areas still persist. The use of copper overcomes this problem, but increases the cost dramatically.
(b) Formation of scales in absorbers, due to the direct use of raw water, inhibits the flow and increases the resistance to heat transfer. This problem is more severe where thin and narrow passages are employed. A scale thickness of 1.22 millimetres (mm) in a 15 mm pipe would decrease the collector efficiency by about 1 to 2%.
(c) Failure and very poor reliability of the control hardware in the case of forced-flow systems, namely the fact that simple thermostats change calibration over time (capillary thermostats would provide better performance and reliable operation, but are quite expensive), and problems with solenoid valves and, at times, level controllers.

In addition, inadequate attention paid to controls and their maintenance, and compromises made with the selection and processing

of materials (to bring down initial costs) would severely hamper the commercialisation of solar water heaters.

Economic Issues

Without accounting for any available financial incentives, the normal payback period in commercially-installed solar water-heating systems works out to be about four to five years for domestic users (when compared with electrical systems). A number of factors such as climate, site location, type of application, conventional alternatives being substituted for also play a role in the economic evaluation of a solar system. As it turns out, the economics works out to be most favourable for applications that require very little storage or when the alternative conventional energy source is electricity. Revised economic analyses, which include various incentives (such as tax savings due to higher depreciation rates) and higher energy costs of conventional sources, show that the payback period for solar devices in commercial applications is about 1.5 to 2 years.

However, when solar systems are compared to firewood-based systems, where the price of firewood is highly subsidised, solar-system economics are rather poor. When the subsidy component is removed for firewood, the payback period for solar devices is five years. (In Kumta Taluk, for example, the cost of firewood supplied by government agencies is about Rs.25.6 per 100 kilograms (or quintal) of firewood, while the cost of firewood supplied by private agencies in certain areas can vary between as much as Rs.75 to Rs.100 per quintal.) These analyses show that with attractive payback periods, solar-heating technologies would automatically find acceptance among industries and domestic users, provided potential users are aware of the existence of these technologies. Appropriate policy measures and incentives are required for the accelerated commercialisation of solar devices.

Policy Issues

The energy crunch situation that prevails in Karnataka State is due to its large-scale de-pendence on conventional sources and a sectoral approach to energy planning. The conflict between energy demand and environmental-quality goals can be resolved by an integrated approach to the problem of energy planning, with an aim of maximising the efficiency of use, minimising the consumption of non-renewable sources, optimising energy source and end-use matching, and encouraging the use of renewable resources with proper policy and incentive measures. Incentive measures which would help both domestic and industrial sectors include exemptions from excise and sales taxes and the provision of enhanced depreciation. Apart from these, there is also a need to make people aware of the alternative technologies available.

All in all, we would argue that appropriate policy initiatives in this area should ensure: a) the availability of capital for solar installations; b) provisions for the installation and capital-cost recovery of devices along with monthly electricity charges or in monthly instalments; and c) making the installation of solar devices in AEHs mandatory (at least in new installations) in places where the climate is favourable.

Conclusions

It is clear that to encourage sustainable development it is necessary to increase energy supplies from renewable sources like solar. Compared to the enormous theoretical and technical potential of solar energy conversion, little use has thus far been made of developed and demonstrated technologies, such as solar water-heaters, and dryers. A more intensive use of such technologies would reduce the pressure on supplies of electrical energy in urban areas and of firewood in rural areas.

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1996 Carbon Dioxide Fact Sheet

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The 1996 issue of the 'Carbon Dioxide Fact Sheet' follows the same format as in the previous year (*Energy Studies Review*, 7:3, 273-75, 1995). Energy consumption data for the world and its principal regions and nations is taken from the *BP Statistical Review of World Energy* and converted to emissions of carbon dioxide using standard factors. This well-accepted source of energy statistics is now posted on the World Wide Web at http://www.bp.com/bpstats. The *Review* is normally published in June following the year under review and so provides a means of estimating emissions of carbon dioxide from the fossil fuels on a consistent basis throughout the world as early as six months after the subject year.

The conversion of one million tonnes of oil equivalent (MTOE), the basic energy unit employed in the *Review*, was taken here as 41.868 petajoules and the specific factors applied to the three fossil fuels were those employed by the International Energy Agency: for oil – 19.9 million tonnes of carbon (not the dioxide) per exajoule (MTC/EJ); for natural gas – 13.8 MTC/EJ; and for coal – 24.1 MTC/EJ, calculated on the basis of the higher heating value. Should it be desired to express emissions in terms of carbon dioxide rather than the carbon convention used in this note, the factor is 3.67. The limitations on the use of energy consumption data for the estimation of carbon dioxide emissions have been noted previously. (Walsh, J.H. (1993) '1992 Carbon Dioxide Sheet,' *ESR*, 5:2:131-35).

In 1996, world emissions of carbon dioxide increased by 2.8% while the corresponding primary energy consumption (excluding biomass and non-commercial forms of energy as is the practice in the *Review*) grew 3.0%, a marked increase over the 1.4% increase in emissions and 1.8% in primary energy consumption reported for 1995. The fossil fuels continued to account for 90.0% of the world's energy consumption in 1996.

As listed in Table 1, Canadian emissions

Table 1: Carbon Dioxide Emissions from Selected Countries and Regions

Country/ Region	1995				1996				% Change and C Per Capita		
	Oil MTC/%	Nat.Gas MTC/%	Coal MTC/%	Total MTC/%	Oil MTC/%	Nat.Gas MTC/%	Coal MTC/%	Total MTC/%	% In-crease	% of World	Tonnes C/Person
World	2695 44.9%	1088 18.1%	2225 37.0%	6008 100%	2760 44.7%	1139 18.4%	2277 36.9%	6176 100%	+2.8%	100%	1.07
Canada	63.6 50.5%	36.9 29.3%	25.4 20.2%	125.9 100%	66.2 51.8%	38.4 30.0%	23.3 18.2%	127.9 100%	+1.6%	2.1%	4.27
U.S.A.	673.0 45.0%	322.7 21.6%	498.7 33.4%	1494.4 100%	694.1 45.0%	328.9 21.3%	520.6 33.7%	1543.6 100%	+3.3%	25.0%	5.79
E.U. (15)	504.4 56.2%	158.3 17.7%	234.2 26.1%	896.9 100%	514.9 56.2%	174.4 19.0%	227.6 24.8%	916.9 100%	+2.2%	14.8%	2.45
E.Eur. + FSU	237.2 27.3%	305.2 35.1%	327.4 37.6%	869.8 100%	221.9 26.1%	310.8 36.6%	316.6 37.3%	849.3 100%	-2.4%	13.8%	2.10
Austra-lia	29.4 36.3%	10.2 12.5%	41.6 51.2%	81.2 100%	29.8 35.8%	9.9 12.0%	43.3 52.2%	83.0 100%	+2.3%	1.3%	4.54
Brazil	57.7 81.3%	2.6 3.7%	10.6 15.0%	70.9 100%	61.8 82.1%	2.7 3.6%	10.8 14.3%	75.3 100%	+6.3%	1.2%	0.46
China	133.8 17.0%	9.2 1.2%	645.0 81.8%	788.0 100%	143.7 17.4%	9.2 1.1%	672.0 81.5%	824.9 100%	+4.7%	13.4%	0.68
France	74.2 70.1%	17.1 16.2%	14.5 13.7%	105.8 100%	75.8 70.6%	16.8 15.6%	14.8 13.8%	107.4 100%	+1.5%	1.7%	1.84
India	60.8 30.0%	10.2 5.0%	132.2 65.0%	203.2 100%	65.6 30.0%	11.3 5.2%	141.6 64.8%	218.5 100%	+7.5%	3.5%	0.23
Japan	223.8 65.3%	31.8 9.3%	87.0 25.4%	342.6 100%	224.9 64.6%	34.4 9.9%	89.1 25.5%	348.4 100%	+1.7%	5.6%	2.78
Rest-of -World	711.3 62.6%	201.5 17.7%	223.2 19.7%	1136.0 100%	737.4 62.0%	219.3 18.5%	232.4 19.5%	1189.1 100%	+4.7%	19.3%	0.53

increased 1.6% and accounted for 2.1% of the world's total. Canada's per capita emissions of 4.27 tonnes C/person/year were narrowly exceeded by Australia (4.54) but both countries' per capita emissions were less than the US value at 5.79. Emissions continued to decline in Eastern Europe (a category here that includes all the former members of the Soviet Union), but at -2.4% the rate was significantly less than the - 5.0% experienced the previous year. The 15 nations of the European Union also experienced an increase of 2.2% in emissions in 1996 in comparison with a small increase of 1.1% the previous year. France, though a member of the EU, was listed separately because of the importance of nuclear power in that country, which typically accounts for about 78% of its electrical generation: the increase in emissions was 1.5% in 1996.

In both Canada and France, natural gas was a larger source of carbon dioxide emissions than coal. The United States remains the largest contributor to emissions accounting for 25.0% of the world's total. The increase in carbon dioxide emissions for that country in 1996 is listed in Table 1 at 3.3%, which may be compared with the official value for the increase in total greenhouse gas emissions of 3.4% announced on October 20, 1997.

The growth in emissions in the large developing countries of Brazil, China, and India is noteworthy at 6.3%, 4.7%, and 7.5% respectively, although their per capita levels remain low. In the rather heterogeneous category of the Rest-of-World (calculated by deducting all the countries or regions specifically listed in Table 1 from the world total), emissions rose 4.7% but per capita emissions were low at 0.53 tonnes C/person/year.

Primary energy consumption increased in some nations in Eastern Europe in 1996 (Belarus, Czech Republic, Hungary, Poland, Romania and some other successor states of the old Soviet Union), although consumption continued to fall some 3.0% in the Russian Federation. It is clear that if economic conditions improve more generally throughout this region, world emissions of carbon dioxide will increase more rapidly.

International negotiations aimed at the mitigation of greenhouse gas emissions continue under the Framework Convention on Climate Change with a Third Conference of the Parties scheduled for December 1-10, 1997, in Kyoto.

The Department of Natural Resources issued its update of *Canada's Energy Outlook 1996-2020* dated April 1997, which provides a reference outlook for Canadian energy demand and supply and for greenhouse gas emissions over the next 25 years.

On present trends, greenhouse gas emissions are expected to increase 8.2% in 2000 over the base year of 1990.