Surrey Energy Economics Centre

ENVIRONMENT, ENERGY EFFICIENCY AND THE THIRD WORLD

Edited by: P J G Pearson

With papers by:
M Bell, J Cochrane, G MacKerron,
J Malcolm, R Tomkins and A Wheeler

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The papers were discussed at a workshop on "Energy Efficiency and the Environment in the Third World", arranged by the Study Group on Third World Energy Policy, at Imperial College, London in May 1991.

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PREFACE

The papers reproduced here arose out of a workshop meeting of the Third World Energy Policy Study Group (TWEPS), held in May 1991 in the School of Management at Imperial College, London. The workshop was organised by Ray Tomkins (Environmental Resources Ltd/Imperial College), Clare Smith (Imperial College) and Peter Pearson and Paul Stevens (University of Surrey). The organisation of the Third World Energy Policy Study Group is based at Surrey Energy Economics Centre. The workshop was assisted by a grant from the Overseas Development Administration (ODA), and we are grateful for the interest shown by Toby Harrison, in particular. The ODA is, of course, not responsible for the views expressed in this discussion paper. The final word-processing of the text of this discussion paper was carried out by Isobel Hildyard.

As **Joanna Cochrane and Ray Tomkins** point out in the first paper, people have been trying for many years to develop robust, practical methods for incorporating environmental and other externalities into the process of national energy planning. Their paper examines a number of the currently proposed methods and then suggests a way of combining several of them into a complementary step-by-step, iterative approach. The methods include: the identification of energy strategies, environmental screening, cost-benefit analysis, energy-environment systems modelling, and multi-criteria analysis.

Gordon MacKerron's paper is concerned with investment policies and the environment in relation to the electric power sector. It focusses particularly on the World Bank and on the impacts of the changes in investment policies that have been advised by the Bank in recent years. He notes that these changes closely mirror what has been occurring in the power sectors of industrialised countries. After examining the ways in which the electrical power sector is involved in environmental issues, MacKerron looks at the complex and potentially ambiguous influence on environmental impacts of the changes in investment practice, including a higher (implicit or explicit) cost of capital.

MacKerron concludes that the new approach to power sector investment cannot be said in any *a priori* way to have either a net favourable or unfavourable environmental impact. A second conclusion is that the factors that influence lending decisions, in this case interest rates, can have a greater influence on environmental outcomes than any explicit environmental policies that a bank may pursue. MacKerron ends by warning of the danger of inconsistencies in the messages given to Third World countries by different parts of the international system. As an example, if global warming is seen as *the* major environmental threat, then a higher cost of capital may encourage the use of fossil fuels while at the same time countries may be exhorted to use less fossil fuels so as to limit the growth of greenhouse gas emissions.

Martin Bell's paper, a summary of a longer report, is concerned with the ways in which new arrangements for international technology transfer to Third World countries might contribute to alleviating the emerging problems of global climate change. It concentrates on the efficiency of energy use in industry and on the conversion of energy resources to supply electrical power. It addresses issues concerned with the nature of the 'technology' which should be transferred and with the mechanisms and approaches to management which might be used to transfer such 'technology' within individual projects and programmes.

Bell reviews the process of 'energy saving' technical change in industrialised countries, noting that recent technological developments may offer Third World countries attractive opportunities for continuing industrial growth with substantially lower per unit levels of both energy and capital inputs. However, the exploitation of these opportunities will require a significant change from past patterns of using industrial technology. This would involve a strengthening of the technological and managerial capacities of industrial enterprises, particularly of their human and organisational resources for generating and managing technical change in response to price signals and competitive environments.

Bell notes that the technology-related challenges facing the continued development of the power sector in particular are not just those posed by new and emerging technologies, since there exists pervasive inefficiency in the use of existing technology in the power sector in many countries. This means that not only is the productivity of already-committed scarce capital resources low but so also is the overall efficiency of converting fossil fuels, with consequently high levels of carbon dioxide (and other) emissions per unit of finally delivered output. In his view, continuing the existing patterns of technology use into the future, while simultaneously encouraging the introduction of new technologies, would do little to alleviate either the economic constraints on the development of the power sector or the growth of carbon dioxide emissions associated with its continuing expansion. Moreover, any new and strengthened mechanisms of international technology transfer must relate to the entire spectrum of technologies that can affect the carbon dioxide-intensity of industrial and power sector production - they should not be narrowly-focussed on specific 'energy technologies' or 'energy-efficiency systems'. He stresses the importance of paying much more attention in future to transferring technology in the form of skills and know-how for operating production facilities, and knowledge, expertise and experience needed for generating and managing change in the technologies used in production.

Tony Wheeler's paper considers a specific situation, the prospects for improved energy efficiency in the power sector in Pakistan. His paper is intended to illustrate the inter-relationships between the planning and operation of electric power systems in Third World countries and questions of energy efficiency and environmental protection. For Pakistan Wheeler reviews both supply and demand side issues and options. He also identifies a number of key institutional issues that affect the degree to which increased efficiency might be successfully pursued. They include: the need to resolve conflicts between the power and water sectors; the need to encourage the two vertically-integrated utilities, KESC and WAPDA, to cooperate; the need to handle current financial constraints; political pressures on the setting of tariffs; the need to resolve the role of the private sector in the development of the power supply industry; and the role that should be played by the lending agencies.

In the final paper in this collection, **John Malcolm** discusses a specific example of a project designed to encourage energy efficiency, the development of a programme of energy advisory services in India using 'energy buses', the EC-India Energy Bus Programme. Three buses and their teams of trained advisers are providing energy advisory services to Indian industrial and other energy users. The services include instrumented surveys, energy audits and feasibility studies and training. The objectives are to identify workable methods which will enable clients to cut energy consumption and costs. The paper outlines the project and the general approach, discusses the preliminary results obtained and examines some of the problems and opportunities that have arisen. Malcolm concludes that the programme will only have been successful if it results in significant energy savings and consequent reductions in environmental impacts. If the programme works as intended, it will have made a significant contribution to increasing the body of energy conservation expertise available.

Peter Pearson

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APPROACHES TO INCORPORATING ENVIRONMENTAL EXTERNALITIES INTO ENERGY PLANNING

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1. INTRODUCTION

Given the present concern with environmental issues, energy planning almost invariably involves consideration of a wide range of environmental factors, although the priority attached to those factors differs between industrialised and developing countries. Economists and environmentalists have been striving for many years to develop robust and practical methods for internalising environmental and other externalities into the planning process. No consensus has yet been achieved as to how this is to be done. This paper sets out to review some of the currently proposed methods and suggest a way of merging several of them into a complementary approach.

The linking of the terms *energy efficiency* and *environment* suggests a principal concern with carbon dioxide emissions. Many other environmental impacts can be mitigated by specific measures (eg FGD to reduce sulphur emissions) but reducing CO_2 emissions requires an overall reduction in fossil fuel combustion.

This paper addresses itself to the broader question of efficiency in the energy sector. The use of the term *Least Cost Planning* in electricity is well understood to mean the meeting of demand for energy services by the least cost mix of investments in both the demand and supply sides. Here we adapt the term to apply to the broader consideration of minimising the total cost of supply and externalities within the whole energy sector. The objective of least cost energy planning is therefore to arrive at the energy/environmental strategy which ensures that energy is supplied and consumed at the 'least cost' to the economy/consumer, where these costs include the true economic costs (or benefits) accruing from the externalities which would result from such a strategy.

Least Cost Energy Planning is a planning process which meets the need for energy services with the least cost mix of energy supplies (supply side options) and energy efficiency improvements in end use applications (demand side management) where 'cost' is defined from society's point of view and includes non-financial factors such as environmental impact.

If the costs of environmental externalities were fully internalised into energy costs, conventional planning decisions to minimise private costs would result in a (near) optimal allocation of resources. The means of doing this, and second best Government policy options, are discussed in section 3. Section 4 reviews the methods available for incorporating environmental externalities into energy planning decisions, and section 5 suggests a practical approach for integrating these various methods.

2. ENERGY EFFICIENCY AND THE ENVIRONMENT

Until recently environmental factors have ranked second to energy efficiency, particularly in developing countries. The reasons for this are not lack of concern with environmental problems, since there is ample evidence of the importance attached by the public to this, but the difficulties of quantifying the effects on a comparable basis to the easily observed costs of energy supply. The value of environmental goods affected by energy sector developments may be substantial in relation to the energy costs. The evidence is inconclusive since many conflicting estimates exist for the costs of protecting the environment or of mitigating the damage. For example, PACE [1] give many estimates for the costs of mitigating the CO_2 production from electricity supply with estimates as high as 25-50% of the fuel cost being not uncommon.

There are two particular problems concerning the valuing of environmental goods.

- Much of the environment is a public good; a common resource in which no one individual or organisation has property rights. This leaves open the question of who bears the cost of environmental damage, and who pays the price for alleviating the effects.

- Environmental goods in which no market exists are difficult to quantify in economic terms.

One solution advocated by economists is to grant private property rights in the good so that a market will develop (eg the conferring of property rights in endangered species such as the elephant [2] or enforcing liability for damage to the environment, thus creating an insurance market). If the market is reasonably competitive the market price will reflect both private supply costs and consumers preferences. However, this market based approach is only a partial solution to dealing with the vast range of environmental impacts, as illustrated in table 2.1.

Table 2.1 Potential Environmental and Socio-Cultural Externalities

- Air Pollution
  - human health
  - exposure of plants, animals and built environment to acidification
  - climate change
- Water Pollution
  - marine and freshwater quality
  - fisheries and marine resources
- Noise Pollution
  - mining
  - power generation
- Waste Management
  - mining waste disposal
  - hazardous waste disposal
  - ash disposal
- Land Use
  - conflicts with agriculture
  - recreation
- Socio-Economic Impacts
  - resettlement
  - employment
  - welfare provision
- Socio-Cultural Impacts
  - aesthetics
  - amenity
  - architecture and archaeology

3. POLICY INSTRUMENTS

Private sector (and commercially oriented public sector) decision makers will take decisions reflecting their own private costs. If these do not include the cost of damage to the environment they will be economically inefficient. Government policy measures may be used to internalise the cost of externalities by bringing about equality between marginal (social) costs and private costs. These measures are conveniently divided into regulatory and economic instruments.

3.1 Regulatory Instruments

Regulations are actually required to implement all forms of instrument. The use of the above term is therefore taken to apply to instruments whose prime focus is on physical control of the pollutants themselves or the technologies used. Regulatory instruments may ensure pollution targets are achieved, but not necessarily at minimum cost. They may also involve an elaborate command and control administrative structure with consequent high compliance costs.

- ***Emissions Standards.*** More generally pollution standards. Set the maximum rate of discharge per unit of output or activity. Examples are power station emissions or vehicle emissions.

- ***Performance Standards.*** These regulations control pollutants indirectly by controlling the performance of the polluting activity. Examples are maximum temperatures in buildings, safety checks on nuclear power stations, maintenance requirements for vehicles, display of information.

- ***Pollution Permits.*** These set the absolute levels of permitted discharges, eg maximum chemical discharge into a river.

- ***Best Available Technology (BAT)*** (Or BATNEEC; Best Available Technology Not Entailing Excessive Cost). The producer is required to employ efficient, low-polluting technology.

3.2 Economic Instruments

Economic instruments attempt to directly internalise the environmental costs into the supply costs of polluting goods/processes. There are two main types of instrument.

- ***Pollution Charges.*** A charge is levied per unit of emission/discharge. The charge should be set equal to the external cost. A carbon tax is one example.

- ***Tradeable Permits.*** Quantitative permits are issued equal to the total emissions target. These may be traded among producers thereby creating a market.

Economic instruments have a number of well known advantages.

- They minimise the cost of achieving any given level of pollution reduction.

- They provide a continuing incentive to innovate in the development of less-polluting technologies.

- They can be a source of revenue.

4. PLANNING METHODS

Wherever environmental costs are not fully internalised, national energy planning procedures should be designed to take the remaining external costs fully into account. Many methods are available to do so but they should all ideally conform to the following requirements.

- Transparency
- Comprehensiveness
- Objectivity
- Consistency
- Flexibility
- Quantification

The methods discussed below differ in their scope of application (they are either applied at the individual project level or at the system level) and their principal units of measurement (physical units or monetary values).

4.1 Environmental Screening

Projects must be initially screened for their full range of environmental impacts (cf Table 2.1). While energy strategies are being refined, and before detailed and site specific project specifications have been prepared, generic data from existing sources will commonly be used.

Each impact will be measured in its own physical units. These may be compared to legal or desired physical standards. However, there is no trade-off between impacts and no attempt to aggregate the impacts into a single measure; therefore the screening results can only enter into the planning process as a set of discrete constraints or in a subjective way.

4.2 Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis provides an economic assessment of impacts, which allows for the incorporation of externalities into the analysis, provided some economic value can be attached to them. When used effectively, CBA provides a means of ensuring that all direct and indirect environmental impacts are taken into account at the strategic planning stage, including those that are difficult to quantify either in terms of their mitigation costs or physical or economic damage. Recent attempts to apply CBA as a comparative tool for energy technologies include Hohmeyer [3].

There are three main methods for valuing environmental goods which each aim to derive values by reference to surrogate markets, whether real or hypothetical (see, for example, Johansson [4] or Pearce et al [5]). Each method attempts, by different means, to evaluate the consumer's surplus by estimating the *willingness to pay* or *monetary compensation* required to forego the consumption.

- *Travel Cost Method.* This method, particularly suited to estimating the value of amenity sites, measures consumer's surplus as the difference between the maximum amount a person would be willing to pay to visit a site (perhaps derived from the marginal consumer), and the actual cost. Cost is the sum of travel cost plus the value of time spent travelling plus the entrance fee. Summing up over all consumers provides an estimate of total consumer's surplus.

- ***Hedonic Prices.*** This approach derives from the notion that property prices reflect the value of a bundle of attributes, including environmental variables. By collecting data on many houses and using econometric methods to estimate the independent effect of environmental factors on house prices, the value of environmental quality may be deduced. The approach may also be extended to wage rates and the attributes associated with different job environments.

- ***Contingent Valuation.*** These approaches collect expressed preference information by asking consumers how much they are willing to pay to receive some change in the provision of a public good, or the minimum compensation required (willingness to avoid) if the good is not provided. Although becoming more widely used, these methods may suffer from the *free rider* problem which introduces biases into the stated willingness.

The total value of a resource may also be analysed as comprising three components:

Total Value = Use Value + Option Value + Existence Value

Use value may be for consumptive or non-consumptive (eg viewing wildlife) purposes. Option value recognises the uncertainty in future use; there is a willingness to pay for a possible but uncertain future use (quasi-option value is the willingness to pay to avoid the irreversible loss of an environmental good). Existence value, which is a more contentious component, is based on altruistic motives to preserve an asset for other people.

4.3 Energy-Environment System Models

System models allow choices to be made by simultaneously selecting among alternative means of meeting energy services. For example, it may be more efficient to sequester CO_2 by planting trees than by reducing CO_2 emissions from fuel consumption. System models may be supply side models (examine alternative supply options, eg electricity system models), demand side models (examine alternative end-use technologies, eg alternative transport modes), or integrated supply-demand models. Solution methods may include simulation (alternative scenarios are examined and the user selects the preferred option) or optimisation (the model solves for the *best* solution, eg least cost).

Most system models which include both energy and environmental factors were originally developed as energy models and subsequently modified to add an environmental module (for a recent survey see Markandya [6]). Environmental costs are integrated into these models in four different ways.

- ***Impact Reports.*** This type of model produces a plan for the energy sector and then produces a report of the inventory of environmental impacts. The planner adjusts the energy sector plan in order to achieve a desired set of environmental impacts.

- ***Environmental Constraints.*** This type of approach, usually an optimisation model, solves for the (least cost) energy supply subject to one or more environmental constraints (eg maximum allowed emissions of CO_2 and SO_2) (see eg Amagai et al [7]). The constraints can be expressed in physical units.

- ***Energy-Environment Cost Minimisation.*** This type of model includes, in addition to energy supply technologies, control and mitigation technologies and alternative end-use technologies. The solution to the model simultaneously chooses the best set of supply, mitigation and end-use substitutions to minimise the combined cost of meeting energy services and environmental protection. A well-known example of this type is the European Community's EFOM-ENV model.

- ***Welfare Optimisation.*** As a further step to the previous type, this approach includes the cost of pollution and other environmental impacts not avoided (all expressed in monetary units) and the value of energy and environmental benefits received (consumer's surplus). The system is optimised to provide maximum benefit (welfare maximisation).

4.4 Multi-Criteria Analysis

Multi-criteria analysis recognises the *fuzzy* nature of many environmental impacts and attempts to provide a method of arriving at a non-monetary trade-off between different factors. The approach recognises the difficulty of providing precise measures of the impacts, the different (conflicting) objectives and the different values placed on environmental goods by different *actors*. There are many different methods; the best known is probably the analytic hierarchy process. The steps in the method are:

- Develop a hierarchy of factors. For example, the top level may be national objectives, the next may be different interest groups (actors), the next may be economic, energy and environmental objectives, the next may be specific targets, and so on. At each level in the hierarchy each factor is disaggregated into a number of meaningful lower level factors which influence the achievement of the higher level factor. An example is shown in figure 4.4 below.

- Apply a scoring scheme to each level of the hierarchy, which reflects the lower level's relative importance in attaining the higher level objective. Scoring is usually carried out using ranking methods or paired comparison.

- The scores are aggregated by multiplying down the tree to produce a final set of weights on the lowest level factors (which will usually be the environmental impacts, measured in physical or monetary units).

The final weights represent an indicator of relative importance of each factor; a pseudo-price. Multi-criteria methods suffer from problems of complexity and inconsistency. Their strength is the flexibility they offer in allowing the aggregation of factors measured in different units into a single overall assessment. The approach may be used on its own or as a complement to CBA or system models.

5. AN APPROACH TO ENERGY-ENVIRONMENT PLANNING

The methods outlined above may be used to complement each other in a progressive step-by-step approach to incorporating environmental externalities into national energy planning.

- ***Definition of Energy Strategies.*** A preliminary identification is made of supply technology choices, mitigation and abatement technologies, and alternative end-use technologies. A relevant data base is assembled including technical data and costs.

- ***Environmental Screening.*** Generic and existing data on environmental impacts, measured in physical units, are collected and added to the data base.

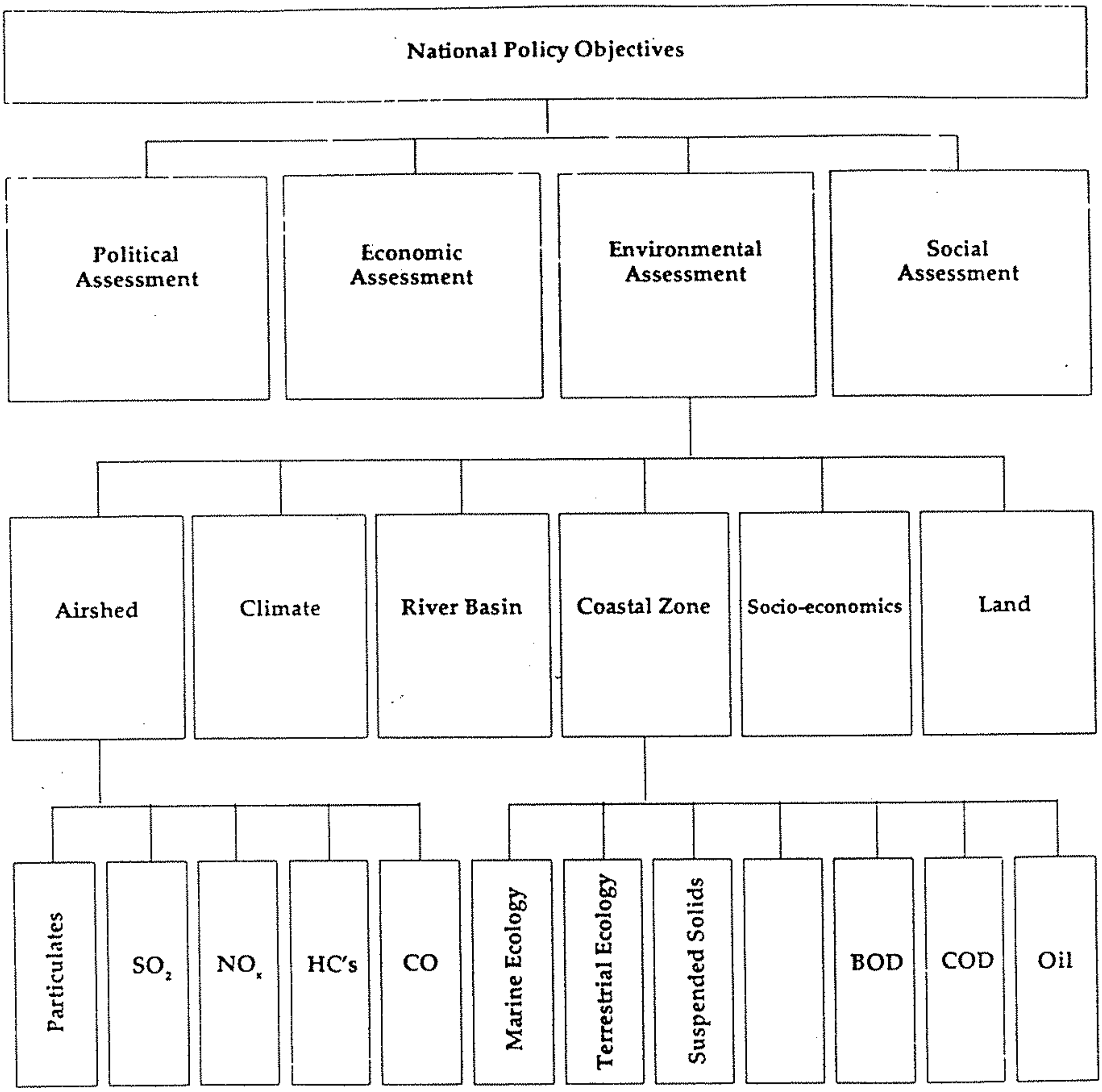
- ***Cost-Benefit Analysis.*** CBA is carried out at the project level. Environmental impacts are valued where possible, or targets (local or national constraints) are specified.

- ***Energy-Environment System Modelling.*** The data derived from the CBA and the environmental screening may then be included in a system model to examine the alternative strategies and find the least cost energy plan. The type of model used will depend on the quality and form of the data available.

- ***Multi-Criteria Analysis.*** The results of the previous steps may be included in a multi-criteria analysis to take account of further fuzzy factors (eg other social and political constraints).

The above steps lend themselves to an iterative procedure. As the choice of energy strategies is narrowed down, it will become cost-effective to improve the environmental data and CBA on the remaining choices. It is most unlikely that any study would follow all the steps outlined above. Nevertheless, the approach serves to show how environmental data, as and when it becomes available, may be incorporated into established planning procedures and so improve the quality of energy-environment planning decisions.

Figure 4.4


National Policy Objectives
Political Assessment
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Suspended Solids
BOD
COD
Oil

REFERENCES

1. PACE (1990), ***Environmental Costs of Electricity***, Pace University Centre for Environmental and Legal Studies, Oceana Publications.

2. Pearce D, Markandya A and Barbier EB (1989), ***Blueprint for a Green Economy***, Earthscan.

3. Hohmeyer O (1988), ***Social Cost of Energy Consumption***, Springer-Verlag.

4. Johansson P-O (1990), ***Valuing Environmental Damage***, Oxford Review of Economic Policy, vol 6, no 1.

5. Pearce D and Markandya A (1989), ***Environmental Policy Benefits: Monetary Evaluation***, OECD, Paris

6. Markandya A (1990), ***Environmental Costs and Power Systems Planning***, London Environmental Economics Centre, LEEC Paper 90-02, London.

7. Amagai H and Leung P (1989), ***Multiple Criteria Analysis for Japan's Electric Power Generation Mix***, Energy Systems and Policy, vol 13, pp 219-236.

ENVIRONMENTAL IMPACTS OF INVESTMENT POLICIES IN DEVELOPING COUNTRY POWER SYSTEMS

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INTRODUCTION

1. This paper is about investment policies and the environment in relation to the electric power sector of developing countries. It focusses particularly on the World Bank for two reasons: because it has an influence in the power sector that extends far beyond its share of lending in the sector, and because it provides extensive documentation about its own activities. In practice, the changes in policies advised by the World Bank in recent years closely mirror changes that have been occurring in the power systems of industrialised countries (IC).

2. The paper is organised in four main sections. The first simply establishes why the electric power sector is so important. The second asks what is meant by environmental issues, and how the power sector is implicated in them. A third section examines the changes in electric utility approaches to investment in the last few years, while the fourth uses the analysis of the previous two sections to look at the complex and potentially ambiguous impacts on the environment of changes in investment practice in the power sector. A final section draws some conclusions, particularly about the way in which serious inconsistencies may be emerging in the incentives and policies towards developing countries (DC) in the power sector.

WHY IS THE ELECTRIC POWER SECTOR IMPORTANT?

3. The electric power sector is the most capital-intensive of all civilian sectors (except perhaps for some areas of telecommunications). Because of its vital importance for economic activity it is inevitably the focus of substantial investment activity in all countries. Throughout the world electricity demand grows faster than demand for energy in general (electricity substitutes for direct fossil fuel uses, and is the necessary fuel for fast-growing activities like information technology).

4. This tendency is reinforced in developing countries by continuing urbanisation (electricity use even at the same income levels tends to be higher in towns than in rural areas) and the strong political drive towards rural electrification. Developing country investment in power ran at $90 bn. to $100 bn. annually in the 1975-80 period (1987 US $), and while this fell off to $66 bn. by 1987, the commitment of resources to this sector remains extremely high [Barnett, forthcoming]. Electricity features prominently in Third World debt: in Latin America, out of a total energy-related debt of $78 bn., electric power represents some $45 bn. [de Oliveira and MacKerron, forthcoming].

5. Secondly all the major options for electricity generation raise large - though thoroughly diverse - environmental issues. The three major approaches to power generation are through hydro-electricity, the combustion of fossil fuels (oil, coal and gas) and nuclear power. While discussion of specific environmental issues is postponed to the following section, it is easy to see that all three of these technologies are heavily implicated in contemporary environmental questions.

6. The reason for treating banking as important in the context of the power sector is that banks, especially private banks, have had a sharply increasing role in financing the sector. Traditionally electric utilities have tried to finance a high proportion of their investment needs by re-investing internally generated funds. This pattern remains intact for many IC utilities. However in the 1970s and 1980s cost pressures on developing country utilities often became acute. At the same time domestic political pressures severely restrained the growth in electric tariffs. The direct consequence was a sharp fall in self-financing ratios and recourse to a much expanded use of external finance. Little of this could be raised on domestic capital markets, and the volume of official aid was static. Co-incidentally, there was a large international supply of petro-dollars awaiting re-cycling, and so the greater part of the high levels of power investment in DC utilities in the 1970s and 1980s was financed by private foreign banks. Of the $78 bn. of energy debt outstanding in Latin America, as much as $54 bn. (70%) is owed to private banks.

WHAT ARE THE MAIN ENVIRONMENTAL ISSUES AND HOW DOES ELECTRICITY RELATE TO THEM?

7. It may seem pedestrian to ask basic question about environmental issues, but it is important in the present context. This is because the range of environmental issues connected to electricity is so extensive, and - even more important - the relative significance attached to different environmental issues varies widely between DCs and ICs.

8. There is no satisfactory single dimension along which to classify environmental problems. However for the power sector, a classification related to geographical reach is appropriate, largely because it is useful from a policy perspective. Thus we may see environmental problems in terms of:

- local impacts (ie within a few miles of an energy facility)
- national or regional issues, where the scope may be a few hundred or possibly a thousand miles
- global issues, particularly global warming.

These are discussed initially in the IC context from which they have mostly sprung.

9. Local impacts, which are generally site-related, are perhaps the longest established category (they can of course sometimes be interpreted as NIMBY - not in my backyard - questions rather than genuinely environmental questions). The form of environmental harm can range from the aesthetic (impact of windmills on hilltops or nuclear sites in remote countryside) to airborne pollution (particulate deposition from fossil fuel use) to ecological change (flooding in hydro schemes). Because most power schemes are large structures, often located away from existing areas of industrial activity, it is easy to see that any electric power investment may become embroiled in these kinds of local environmental issues.

10. While the site-related environmental issues have been of some importance in ICs since at least the 1920s, the national/regional category is mainly of post-war vintage. The UK had early experience in this area in the smogs of the 1950s and the Clean Air Act of 1956, which directly affected the power sector. In the ICs however this general type of issue began to be important from the 1970s onwards. Examples are the questions of the impacts of nuclear power facilities (especially nuclear waste), and more recently acid deposition. In the first case electricity alone is implicated: in the acid deposition case, the power sector is by far the major contributor. These problems have raised important cross-border questions and some are now dealt with routinely at international levels (eg recent and important result in Europe has been the Large Combustion Plant Directive on emissions).

11. Finally and most recently there is the issue of global warming, which is now too familiar to warrant much comment. In this context the relevant point to make is that CO_2 is responsible for around 50% of the impact of the various greenhouse gases: The energy sector as a whole is responsible for the great bulk of this CO_2 and the power sector is in turn responsible for the majority of the energy sector's contribution.

12. It is therefore clear that at all levels the electric power sector is a major - indeed ***the*** major - contributor to environmental problems as currently perceived in the industrialised countries. However there are two important problems associated with this.

13. The first problem is that it is effectively impossible to compare the relative importance of environmental issues across the three levels, and often within them. How can the damage to a local eco-system because of a new dam be directly compared to the damage done to people's lungs because of sulphurous emissions from a local power station? Or how can the risks of death and land sterilisation from a major nuclear accident be compared to the risks of the earth's temperature rising by 1.5 degrees? Economists have ways of trying to measure damage of these kinds (re-affirmed recently in David Pearce et al. [1990]) but are hampered, among many things, by frequent lack of satisfactory ***physical*** damage data and by the well-known difficulty of persuading people that an event of very low probability but high damage (eg a nuclear accident) should not be regarded as more worrying than an event of high probability but low damage (eg respiratory problems from high sulphur concentration). In practice of course political systems do find more or less rough and ready ways to find priorities among these very different issues.

14. But this problem of comparison raises immediate difficulties in relation to rational decisions on how to invest in different technologies in the power sector. It will often be the case that eco-system damage (as well as severe if local population dislocation) from a hydro scheme will need to be compared to the more diffuse but potentially highly damaging long term impacts of an alternative fossil-fuel project on acid deposition or global warming.

15. This takes us to the second main problem, which is also about perceptions of damage. As a broad generalisation, environmental issues as understood in ICs have made little impact as yet in DCs. Where they have made an impact, this has nearly always been in the first category of local, site-related issues. Examples are recent concern in Brazil about the impact of hydro schemes on local populations, and continuing concerns in Chinese and Indian cities about very poor urban air quality resulting from energy use in local households, transport and electric power. National and regional issues are less important partly because they are genuinely fewer (eg DCs have few nuclear facilities and generally have lower acid deposition concentrations) and partly because political consciousness in these areas is not generally high in relation to other more pressing problems.

16. Global warming is even further off the political agenda in most developing countries (perhaps only in Brazil, India and China has serious consideration started to given to it). Global warming is seen as at best a very long term issue, predominantly created by ICs and therefore to be solved by rich countries. At worst it is often seen in the Third World as a ploy to retard their legitimate aspirations to higher standards of living.

17. Because the political prominence of these various issues is so different between ICs and DCs, it will often be the case that IC banks' potential interest in global warming as an environmental question will be met by bewilderment if not hostility in DCs - who, if they have environmental concerns at all, are much more likely to have them focussed on local and relatively tangible problems.

HOW HAVE ELECTRIC UTILITY APPROACHES TO INVESTMENT BEEN CHANGING?

18. Until the last decade it was almost universally true that electric utilities have been conservative businesses, involved in relatively long term, low risk and low return activities. Whether privately or publicly owned they provide a public ***supply*** of electricity and have generally at least partly adopted a public service as well as (or instead of) a profit-maximising ethic. Their investment strategies have therefore been informed by a very long term planning horizon, and the technologies favoured have generally been highly capital-intensive and front-end loaded: their scale has tended to get large and larger. Typical examples have been nuclear power, large hydro and increasingly large fossil-fired plant.

19. The 1980s have begun to see radical change to this picture. In a number of ICs (especially, but not exclusively, English speaking eg UK, New Zealand and the USA) utilities have been encouraged to behave in a much more short-term, market-oriented way, with a main drive towards high profitability. This has often been accompanied by privatisation, the injection of private capital and (though with limited success) the attempt to introduce competition.

20. The UK has been particularly prominent in this process and the Government here has made an unusually radical attempt simultaneously to privatise, to re-structure and to introduce competition as a central organising principle. The results in terms of investment strategy have been little short of spectacular. In early 1989 the old CEGB considered only large nuclear or (as second best) large and traditional coal-fired technologies as serious contenders for new investment. By late 1989 ***all*** plans for large coal-fired and nuclear plant had been cancelled, and a very large number of new projects had emerged (many of them financed on a purely project basis by banks) in the field of combined cycle gas-fired technology, which has the characteristics of small scale, flexibility, short construction periods and therefore potentially rapid paybacks.

21. The environmental impact of this kind of switch in investment strategy is considered later: what is important to notice here is simply that this radical change pivoted round one major single difference in the approach to investment appraisals: under the CEGB the cost of capital (discount rate) was effectively 5% (real); in the new privatised, market-oriented environment the cost of capital had risen to a minimum value of 10% real, and effectively somewhat higher for many projects.

22. The relevance of all this for developing countries and the World Bank is that the Wold Bank's policies in lending to the power sector (and so often setting the context for others' lending) mirror very closely the changes observed in the UK. Thus privatisation and/or the injection of new private capital; the abandonment of long term electricification goals and the concentration on managing current assets more effectively; and the need to earn high returns on any investments that are undertaken: these are all hallmarks of the way in which the DC power sector is now approached by the banking community. In terms of a single indicator of change, a higher (implicit or explicit) cost of capital is the driving force in terms of investment strategy. The question then is: what does a high cost of capital do to the level and type of investment in the DC power sector, and what kinds of environmental impact are likely to follow?

THE ENVIRONMENTAL EFFECTS OF THE NEW POLICIES

23. The first and relatively easy question is the kinds of effect that a high cost of capital will have on power investment in DCs. The first and most obvious impact is that at higher costs of capital fewer projects are likely to be undertaken, because the 'hurdle' that projects have to surmount has become higher. The second impact is a change in the capital-intensity of those projects that do go ahead towards lower capital intensity. This was illustrated above in the UK case above by the abandonment of nuclear and coal projects and their replacement by smaller gas-fired projects. At high costs of capital there is a premium on projects which are quick to construct and which therefore start to earn a return within a very few years. Concomitantly the longer term costs or revenues (eg long term fuel bills) will be of less concern. What does this all mean for the environment?

24. ***First*** and in the broadest opportunity cost terms, it is necessary to consider the possible economy-wide impacts. If power sector investment volumes fall, will investment elsewhere in DC economies correspondingly rise? The answer depends on whether the higher discount rate for power is part of a general capital scarcity of is rather the result of trying to restrict the 'inside track' that has often given electric utilities preferential and often economically inefficient access to capital ahead of other sectors. In this latter case, the net environmental impact depends on which kinds of new investment replace the reduced levels of power investment, and here it is impossible to say anything in *a priori* terms.

25. The ***second*** opportunity cost question is at one level of generality lower, and concerns the impact of lower public supply investment within the energy system in general. In other words what are the energy-related environmental consequences of reduced power investment? While there is no complete general answer, there is one clear tendency visible in many power-short developing economies. This is the practice of private industrial and service undertakings, increasingly experiencing interrupted and unreliable public supply, to buy their own small-scale generating facilities as back-up. These are generally fossil-fuel based (most commonly diesels). From a national resource viewpoint they are generally highly inefficient, because they add substantially to the capital stock without greatly increasing electricity supply. Their use of fossil fuel in a relatively fuel-inefficient way will usually constitute a negative if fairly minor environmental impact.

26. This brings us ***third*** to environmental impacts within the public supply system. Here we come to an ambiguity (also noted by the recent Pearce book). On the one hand, so far as the volume of investment is reduced (despite the possible effects outlined above) there will be a positive environmental effect because fewer natural resources will be used up in the investment and operation processes (eg less fossil fuel burned). If it were therefore true that all power investment used the same technology, with a standard impact on the environment, then there would be an unambiguously favourable impact compared to the previous status quo. But as this is manifestly not so, we come to the ambiguity: in the changing capital intensity of projects approved, those which get through pay little attention to long term impacts: and environmental impacts are of course frequently long term. Thus if fossil-fired projects come to be favoured over hydro projects (as may often happen in DC context), environmental impacts, at least in particulate, acid deposition and global warming terms, will get worse.

27. On the other hand a reduction in hydro projects will reduce other negative environmental impacts. In such cases the net effect on the environment cannot again be predicted without detailed empirical study. The probable reduction in impact caused by a fall in investment has to be weighed against the ambiguous environmental impacts of changing capital intensity. While new projects which ignore the long term might be expected to increase environmental damage, a reduction in hydro schemes (some of the environmental impacts of which are actually quite short term) may move the balance in the opposite direction. We are once again faced with the difficulties of comparing different kinds of environmental damage, and in a context where many developing countries are more concerned with tangible environmental issues (like hydro impacts) and less with the longer term and more intangible consequences of fossil fuel burning.

28. Because the net environmental impact of changing capital intensity depends on the technology replaced as well as the technology introduced, there are other cases where there is less ambiguity. There is a virtually world-wide move towards using gas as a fuel in new power facilities, often in the relatively thermally efficient form of the combined cycle gas turbine (efficiencies of 50% rather than 38%). In some countries (the UK among ICs and very probably India among DCs) gas-firing, encouraged by higher discount rates, will replace coal-fired power. Because gas scores better than coal on virtually every environmental indicator (as long as unburned methane levels are under control), changing capital intensities are here virtually certain to improve total environmental impact: less total investment will be added to lower environmental impact investment. But the replacement of hydro plans by fossil are perhaps a more likely DC result, and in such cases the net environmental impact will need detailed and case by case study.

CONCLUSIONS

29. An obvious conclusion to this discussion is that the new World Bank-type approach to power sector investment in developing countries cannot be said in any *a priori* way to have either a net favourable or unfavourable environmental impact: each case needs to be analysed on its merits. The simple idea that because new projects will be short term in conception they will therefore damage the environment is not necessarily justified: total investment volumes will probably fall (a favourable impact) but while the new forms of investment may be damaging they may or may not be more damaging than those they replace. The net balance

will vary according to local circumstances. It is rather the ***economic*** impacts of the new regime which are much more likely than the environmental to be unambiguously unfavourable: restricted electricity growth, and a long term electricity price path that may well be higher than before because of higher dependence on fossil fuels.

30. A second conclusion is that while the cost of capital has no direct relation to explicit environmental policies it can and usually will have a profound environmental impact, whether favourable or unfavourable. This means that in considering the impact a bank may have on the environment in its lending policies, it is important to look not only at its explicit environmental policy, but also at the central banking issues involved in lending decisions. In this case the banking issue is interest rate, decisions on which may have a more fundamental and wide-ranging impact on environmental outcomes than any explicit environmental policy that the bank may pursue.

31. Thirdly if the (brave) decision is taken to rank environmental issues in terms of their importance, and (as is increasingly argued) global warming is seen as ***the*** major threat, then a high cost of capital may give precisely the wrong message to developing countries: it will in general encourage, through the emphasis on fast paybacks, the more intensive use of greenhouse gas-producing fossil fuels. Insofar as other parts of the international system will be precisely encouraging developing countries to use ***less*** fossil fuels for global warming reasons, the risk of a powerful inconsistency in the messages given to developing countries is increasingly real. Almost certainly some new and more encompassing institutional approach to questions of investment in developing countries, avoiding such damaging inconsistencies, will be needed if the global warming threat continues to be perceived as a serious one.

REFERENCES

Barnett, A. (forthcoming) 'The Financing of Electric Power Projects in Developing Countries' Energy Policy.

de Oliveira, A. and MacKerron, G. (forthcoming) 'Is the World Bank Approach to Structural Reform Supported by Experience of Electricity Privatisation in the UK?' Energy Policy.

Pearce, D. et al. (1990) Blueprint for a Green Economy, Earthscan.

CONTINUING INDUSTRIALISATION, CLIMATE CHANGE AND INTERNATIONAL TECHNOLOGY TRANSFER

(Summary of a Report prepared in Collaboration with the Resource Policy Group, Oslo, Norway)

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1. THE PURPOSE AND SCOPE OF THE STUDY

1.1 This study is concerned with the ways in which new and strengthened arrangements for international technology transfer to Developing Countries might contribute to alleviating the emerging problems of global climate change.[1]

1.2 It concentrates on two areas where technical change and international technology transfer may be especially significant in helping to reduce the rate of growth of CO_2 emissions associated with continuing industrialisation in Developing Countries:

- the efficiency of energy use in industry,
- the conversion of energy resources to supply electrical power.

1.3 In contrast to much of the debate in this area so far, the study takes a 'bottom-up' approach to the problem. It is concerned less with the overall framework of international organisation, negotiation and funding for new approaches to technology transfer. Instead, it addresses more detailed issues about:

- the nature of the 'technology' which should be transferred,
- the mechanisms and approaches to management which might be used to transfer such 'technology' within individual projects and programmes.

[1] The study was commissioned by the Resource Policy Group in Norway as an input to a broader report for the Norwegian government. The first section concerned with industrial energy efficiency draws extensively on work originally undertaken for the EC Cooperative Programme on Energy and Development (COPED).

2 TECHNOLOGY AND THE ENERGY-EFFICIENCY OF INDUSTRIAL PRODUCTION

2.1 Increases in the overall energy intensity of industrial production stem from two processes:

- changes in the composition of industrial output,
- changes in the energy efficiency of individual industrial sectors.

2.2 The effects of changes in the composition of output have been moving in opposite directions in the Developed and Developing Countries. In the former, the growing importance of less energy-intensive products within total industrial output has contributed substantially to falling long-term trends in average energy-intensity. In the latter, the growing significance of materials-intensive and energy-intensive products has contributed to rising trends in average energy-intensity. Those 'structural' trends are likely to continue in most of the Third World.

2.3 This report concentrates on role of technological change in the second process: increasing the 'energy-efficiency' of production in particular industrial sectors.

2.4 In the Developed Countries, rising efficiency in energy use in individual industries has occurred over long periods - not only when energy prices were rising but also when they were low or falling. The role of rising energy prices should therefore be seen not so much as primary 'causes' of increasing energy efficiency in industry, but as reinforcing a deeply rooted, 'autonomous' process of energy-saving technical change.

2.5 That process of 'energy-saving' technical change in Developed Countries has involved three important features:

- It has depended only partly on change in the 'energy-specific' elements of the technology used in industry (boilers, combustion systems, electric motors, etc). It has also depended heavily on changes in the whole spectrum of other elements of industry's process and product technology.

- It has depended only partly on investment in substantial new production facilities incorporating significant advances in technology. Continuous and incremental forms of technical and organisational change have also contributed substantially to rising energy efficiency.

- The process of change has therefore depended only partly on the availability of financial resources for investment in major new physical facilities. It has also depended heavily on the human and organisational resources committed by firms to generating continuous change across the whole spectrum of their technical and organisational systems.

2.6 Those paths of ***technical*** change have been associated with two different patterns of ***economic*** change in terms of the impact on ***per-unit*** costs of production:

- Paths of technical change in which falling unit energy costs have been achieved at the expense of ***increases*** in the unit costs of other inputs such as capital.

  This pattern characterised the experience of most of the energy-intensive industries in the period since the 1950s.

- Paths in which falling unit energy costs have been complemented by ***reductions*** in the unit costs of other inputs, including capital.

  This pattern was typical of large parts of industry in the early decades of this century. However, current and expected technological developments appear to be re-opening similar opportunities for the 1990s and beyond - new possibilities for simultaneously raising the efficiency with which energy and other inputs are used in industrial production.

2.7 These technological developments may open up particularly attractive opportunities for the Developing Countries. They may widen the possibilities for continuing industrial growth with substantially lower per-unit energy and capital inputs.

2.8 However, in large parts of the Developing World, exploiting those opportunities will require a substantial shift from past patterns of using industrial technology.

- In many Developing Countries, levels of industrial energy-efficiency typically lag far behind the levels in equivalent industries in the Developed Countries - even when similar scales and types of plant are involved in the comparison. But this is not just an 'energy problem'. The common pattern of low energy-efficiency seems to be associated with inefficiency in the use of other resources as well, including scarce capital resources.

- A common feature of this inefficiency in using existing technology is the weakness of continuing incremental improvement of existing production facilities. Indeed, in many situations even initial design-level standards of efficiency have not been attained.

- Those inefficiencies in using and improving technology after its introduction have many causes, including distorted prices and limited competitive pressures. However, a pervasive underlying cause is the weakness of the technological and managerial capacities of industrial enterprises - their limited human and organisational resources for generating and managing technical change in response to price signals and competitive environments.

3 TECHNOLOGY AND THE CO_2-INTENSITY OF POWER SUPPLY

3.1 Current plans for the growth of the power sector in Developing Countries envisage generating capacity almost doubling over the next ten years, with new coal-fired capacity more than doubling.[2] But these investment plans far exceed the probable scale of available financial resources; and power supply capacity is unlikely to be able to meet projected demand.

3.2 These financial constraints on the growth of the power sector highlight the importance of raising end-use electricity efficiency for reasons totally unconnected with concerns about CO_2 emissions and global climate change. But they also highlight the critical significance of two other issues:

- the need to attain the highest possible levels of efficiency in operating the installed capital stock - not only the facilities which currently exist, but also the successive 'vintages' of capacity that will be created by continuing investment in the future;

- the need to manage investment in new power supply capacity in ways which minimise capital costs per unit of output.

3.3 A wide range of technological, organisational and managerial advances at the international frontier are opening up new ways of dealing with both those issues, while ***also*** reducing CO_2 emissions per unit of finally delivered power output.

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[2] Obstacles to investment in nuclear and large scale hydro plant may be greater than currently expected, perhaps pushing higher the share of new capacity consisting of CO_2-intensive, fossil-fuelled (especially coal-fired) plant. Over at least the next decade, even allowing for forseeable technological developments, power supply based on other renewable resources is unlikely to ease the financial constraints on power sector growth. Nor will those technologies make a significant contribution to offsetting the growth of CO_2-intensive forms of power supply.

3.4 These developments pose three major challenges, as well as opening up new opportunities:

- The complexity of decision-making for power sector expansion will become substantially greater, presenting increased demands on the technological and managerial capabilities of utilities and related organisations.[3]

- Demands on the engineering, management and operating skills required for efficient use of many of the emerging technologies are also likely to be substantially increased.

- Power plant producers in the more industrialised Developing Countries like India, Korea, China and Brazil are likely to be faced with the need to make new step-jumps in the technology embodied in their equipment, and then to keep moving through rapid rates of incremental advance and adaptation.

3.5 However, the technology-related challenges facing the continuing development of the power sector are not just those posed by ***new and emerging technologies***. As in industry, there exists pervasive inefficiency in the use of ***existing*** technology already used in the power sector in many countries. This has two major consequences:

- the productivity of the scarce capital resources that have already been committed to generation, transmission and distribution facilities is often very low;

- the overall efficiency in converting fossil fuels into finally delivered power supplies is also often very low, resulting in high CO_2 emissions per unit of finally delivered output.

3.6 Continuing that pattern of technology use into the future, while seeking to accelerate the introduction of new and emerging technologies, would contribute little to alleviating either the economic constraints on the development of the power sector or the growth of CO_2 emissions associated with its continuing expansion.

3.7 Issues about technology and the CO_2-intensity of power supply cannot, therefore, be isolated from more pervasive issues about overall efficiency in using technology. And, in many countries, the particular problems that will arise about efficiency in using ***new and emerging*** technologies cannot be isolated from current problems about pervasive inefficiency in using ***existing*** power system technology.

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3 Those demands on utilities' technological and managerial capabilties are likely to be even greater where their least-cost investment options include co-generation, increased end-use efficiency and decentralised supply from small-scale 'renewable' sources.

3.8 While numerous factors account for the inefficient use of power sector technology, a major constraint in many countries is the utilities' limited accumulation of human and organisational resources needed to plan and manage the initial acquisition of technology, to attain and maintain its initial, 'design-level' operational efficiency, and then to raise those initial levels through continuing, incremental forms of technical and organisational change.

4 INTERNATIONAL TECHNOLOGY TRANSFER

4.1 Both a problem and an opportunity are posed by the fact that the CO_2-intensity of production in the industrial and power sectors of Developing Countries is affected by the whole range of interrelated technologies they use.

- The problem is that any new and strengthened mechanisms of international technology transfer must relate to the whole spectrum of technologies which influence the CO_2-intensity of industrial and power sector production. It would be misplaced to seek to reduce the rate of growth of CO_2 emissions in these sectors by developing new technology transfer arrangements that were narrowly focused on specific 'energy technologies' or 'energy-efficiency' systems. Any new initiatives must be much more pervasive.

- The opportunity is that there exists substantial complementarity between global interests about limiting the rate of growth of CO_2 emissions on the one hand and the economic interests of the Developing Countries on the other. Effective new technology transfer initiatives could simultaneously contribute to (i) reducing the CO_2-intensity of industrial and power sector production, ***and*** (ii) increasing the productivity of scarce resources, especially capital.

4.2 However, in seeking to develop new technology transfer initiatives it is important to distinguish between several different forms in which industrial and power sector 'technology' may be transferred.

4.3 One form consists of the ***capital goods , engineering services and equipment designs*** needed to build new, more efficient production facilities. Large parts of the Developing World currently face major constraints on their ability to acquire these type of industrial and power sector technology. The most important of these constraints is the limited ability to finance the imports and investment involved - constraints which stem in large part from the position of those countries within the prevailing patterns of international finance and trade.

4.4 Concerted international measures to reduce those countries' debt and interest rate burdens, and to widen their access to markets in the industrialised countries, are therefore necessary conditions for enhancing their ability to invest in technology that will reduce the CO_2-intensity of their industrial and power sector output.

4.5 The pervasive effect of such measures on the ability of Developing Countries to import the whole spectrum of capital goods and services required for investment in industry and the power sector could have a much greater impact on the efficiency and CO_2-intensity of production than the creation of special funds or technology transfer mechanisms focused on narrowly defined categories of technology which appear to be concerned specifically with 'energy-efficiency'.

4.6 However, a greater ability to finance the acquisition of capital goods, engineering services and equipment designs does not ensure that the technology so obtained would be used any more efficiently than in the past. If past patterns of inefficiency are to be avoided, any increased financial capacity to import those forms of technology would need to be complemented by considerably strengthened technological and managerial capabilities for acquiring, using and changing technology.[4]

4.7 That highlights the importance of giving much greater attention than in the past to transferring technology in the form of (i) ***skills and know-how for operating production facilities*** ,and (ii) ***knowledge, expertise and experience needed for generating and managing change*** in the technologies used in production.

4.8 Transferring those forms of 'technology' involves significant costs over and beyond the costs of transferring any associated capital goods, engineering services and technical specifications. It also requires managerial strategies

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[4] One contribution to changing past patterns of inefficency in using technology would be made by reinforcing the shifts towards altered macro-economic conditions that have been made in several Developing Countries in recent years - shifts towards more competitive economic environments and more efficient price regimes, especially for energy. However, those changes need to be complemented by considerable strengthening of the human and organisational resources for responding efficiently to price stimuli and competitive pressures.

and organisational efforts which treat the acquisition/transfer of these forms of knowledge and expertise as an explicit objective in its own right - not just a marginal component that is 'tagged on' to projects which are primarily concerned with transferring goods and services to create new physical facilities.

4.9 However, financing explicit investment in these types of human and organisational capital presents considerable difficulties for most commercial financial institutions. The assets involved are 'intangible' and mobile; and the returns to their acquisition are long-term, often appearing to be uncertain as well. Moreover, a substantial proportion of those returns will often be 'externalities' to the enterprises and projects involved: they will accrue in large part to enterprises and projects other than those which incurred the costs of the initial investment in developing the human and organisational resources involved.

4.10 This is therefore an area where a greatly enhanced role needs to be played by a wide range of other institutions which are better able to finance investment in these types of resources: development banks, bilateral aid agencies, and multilateral agencies which are concerned directly and indirectly with industrial and power sector development.

4.11 By committing greatly increased efforts and resources to supporting investment in these intangible human and organisational assets, these types of institution can make a major contribution to changing the past patterns of technology transfer and technical change in the power sector and energy-intensive industries in Developing Countries. They should seek to do so in four main ways.

(i) 'Deepening' the technology transfer content of existing types of 'energy-efficiency' project

Numerous agencies are already involved in projects to raise the efficiency of power sector production and the energy-efficiency of industrial production. But these projects appear to concentrate on using imported equipment and expertise to achieve one-off steps of efficiency improvement. Consequently, they neither prevent reversion to the past patterns of inefficiency nor lay the basis for continuing and self-sustaining paths of rising efficiency in the future.

Greater attention should be given to developing through such projects the knowledge and organisational capacities needed to prevent the re-emergence of inefficiency and to generate continuing processes of efficiency-raising change in future.

(ii) 'Deepening' the technology transfer content of a much wider range of power sector and industrial investment projects

Many development banks, bilateral aid programmes and multilateral agencies are ***already*** involved directly and indirectly in a wide range of investment projects for expanding production capacity in the industrial and power sectors of Developing Countries. In many cases that involvement appears to be concerned primarily (and sometimes exclusively) with financing investment in the physical facilities for production - or with subsidising, underwriting and more generally stimulating the export of goods and services needed to create those facilities.

Across that wide spectrum of activities, much greater emphasis needs to be given to project components which are explicitly concerned with strengthening capacities for generating and managing change and improvement in the facilities initially created. That might involve project components concerned with, for example:

- investment in more substantial and 'deeper' engineering and management training than would otherwise occur;
- investment in strengthening and maintaining specific organisational units within industrial enterprises and power utilities which have responsibilities for generating and managing change in the technologies they use;
- the development of longer-term 'learning linkages' between those enterprises in Developing Countries and utilities and industrial enterprises in the Developed Countries.

Action along these lines could include not only direct financing of the costs of the 'sub-projects' involved. It could also include more pervasive efforts to stimulate the planning of those types of project component, and to facilitate their effective management and implementation.

A pre-requisite for those types of action is a fundamental change in the time-perspectives which are typically involved in project planning, appraisal, management and financing. Those perspectives need to stretch beyond what is usually considered to be the 'completion' of investment projects in these sectors.

(iii) Strengthening the technology transfer role played by transnational industrial corporations

Transnational corporations play a major role in the energy-intensive sectors of industry in many Developing Countries, and they usually contribute significantly to the development of managerial and engineering expertise in their subsidiaries and joint-ventures. However, they typically limit the intensity and 'depth' of those contributions in the light of the costs involved relative to their immediate needs and the availability of their existing central capacities to meet those needs. There appears to exist considerable potential for increasing those contributions without affecting those corporations' strategic control over their 'core' proprietary technologies.

Focusing on selected energy-intensive industries, therefore, bilateral and multilateral agencies and development banks might develop, in association with transnational companies, new financial mechanisms designed to enable Developing Countries to exploit more effectively the potential technology transfer role of those corporations. Such mechanisms would aim to offset the costs of programmes for developing human and organisational resources for generating and managing change in industrial technology which go beyond the limits set by those corporations' normal operational requirements.

(iv) Developing new forms of 'alliance' and network for technological and managerial learning

New and strengthened technology transfer mechanisms should be developed outside the framework of specific investment projects and intra-corporate channels. These mechanisms will be particularly important in the power sector since utilities and equipment producers in the Developing Countries currently play no role in the consortia and collaborative projects through which many of these new and emerging technologies are being developed. As a result, although these countries now account for nearly half of the global market for power plant, they have little influence over the directions of technological development being pursued. Possibly more important, they have little access to the various forms of detailed technological and managerial 'learning' which utilities in the Developed Countries are accumulating in order to incorporate consideration of those technologies in their investment planning and decision-making, and to ensure their efficient operation after they have been brought into use.

New institutional initiatives are already being taken to overcome those limitations - for example, initiatives within the framework of the Multi-Agency Working Group on Power Sector Innovation (MAGPI), or proposals to develop an International Electric Utility Network to sponsor collaborative research and technology dissemination. These emerging institutional initiatives merit substantial support and further diversification.

In relation to industry, similar international mechanisms could make a significant contribution to strengthening Developing Countries capacities for limiting the CO_2-intensity of production in the relatively small number of energy-intensive industries which account for a very large proportion of total industrial CO_2 emissions.

Bilateral and multilateral agencies and development banks could therefore explore the feasibility of establishing international mechanisms which, perhaps in ways similar to those envisaged for MAGPI, would enhance Developing Countries' access to the technology of the more energy-intensive industries. Such industry-specific institutional arrangements would concentrate on strengthening the human and organisational capacities which Developing Countries will require to exploit the full potential of existing and emerging industrial technology.

4.12 Despite their diversity, the initiatives outlined above have one feature in common: they would help to create a much stronger international market for the particular kinds of technology involved. There already exists a wide range of commercial and other channels through which Developing Countries can purchase capital goods, engineering services and design specifications - provided they have the financial resources. However, markets for the kinds of knowledge, expertise and experience which have been highlighted in this study are very much 'thinner' and unorganised. Bilateral and multilateral agencies and development banks can play a major role in changing that situation.

THE PAKISTAN POWER SECTOR: PROSPECTS FOR IMPROVED ENERGY EFFICIENCY

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INTRODUCTION

This paper has been prepared to illustrate the inter-relationship between the planning and operation of electric power systems in the third world, and the questions of energy efficiency and environmental protection. The Islamic Republic of Pakistan is a particularly interesting model as it is faced with many of the technological, resource and institutional issues which are typical of less developed countries. This paper examines the Pakistan power and energy sectors to indicate the extent to which energy efficiency is an issue, and indicates the scope for efficiency improvements.

Ewbank Preece has been involved with analysing the operation and development of the power sector in Pakistan for a number of years, and this presentation draws heavily upon the experience gained in this process.

The paper considers the following issues with particular reference to Pakistan:

- the overall energy situation,
- the overall electricity supply and demand position,
- particular supply side issues and options,
- particular demand side issues and options,
- the scope for energy savings,
- the institutional situation.

The overall objective of the presentation is to indicate those aspects of the development of the power system where energy savings may be achieved, the scale of these, and local issues which may have an impact on the successful development of an energy efficient system.

ENERGY RESOURCES

Energy consumption in Pakistan is dominated by the use of natural gas and oil. These are consumed in almost equal quantity and represent some two thirds of the primary energy utilised at present. The remaining third is split between coal and hydro resources.

The total primary energy consumption for 1988/89 was 27 million tonnes of oil equivalent. This equates to a per capita consumption of about 254kg of oil equivalent. The supply mix was:

FUEL	% OF SUPPLY MIX
Oil	36.2
Gas	35.3
Coal	10.4
Hydro	18.1

About 28% of the commercial energy was imported, primarily in the form of oil, but with a limited amount of coal as well.

Pakistan possesses indigenous coal, oil and gas resources which are continually being developed, and a number of policy moves have been made to further reduce the Country's dependence on imports. Reserves were estimated in late 1990 as:

Coal	288 million tonnes
Gas	20.5 trillion cubic feet
Oil	28 million tonnes
Hydro	30,000 MW

Energy consumption is dominated by the industrial and transport sectors. The present split is:

SECTOR	% SPLIT
Industrial	36.8
Transport	24.7
Residential/Commercial	19.0
Agriculture	3.7
Others	2.8
Non-energy use	13.0

ELECTRICITY SUPPLY AND DEMAND

Power is presently supplied by two vertically integrated utilities. KESC (the Karachi Electric Supply Company) supplies the Karachi area, whilst WAPDA (the Water and Power Development Authority) which is based at Lahore in the Punjab, supplies the rest of the country.

The two utilities are interconnected at 220 kV, and although some trading occurs to reduce load shedding, the two systems are presently planned and operated as separate systems.

The KESC system is all thermal based on oil and gas. Their maximum demand in 1989/90 was 1,060 MW and their installed capacity was 1,093 MW supplemented by some nuclear and gas turbine capacity located in the Karachi area. The WAPDA system is a mixed hydro and thermal system with about 45% of the capacity being hydro, Peak demand in 1989/90 was 5,680 MW and the installed capacity was 6,411 MW. Annual load factor is in the order of 63%.

The split between consumption by different consumer categories as shown below, indicates that industrial and domestic use dominate, followed by agricultural.

CONSUMER CATEGORY	% SHARE
Industrial	34.5
Domestic	31.1
Agricultural	20.8
Traction etc	8.5
Commercial	4.5
Public lighting	0.6

Total demand is expected to show solid growth over the next few years of about 9% per annum. This implies an increase in system maximum demand from about 7,000 MW at present to over 35,000 MW by year 2010. For this demand to met it would require a massive investment programme, and there must be doubts about whether this will be achieved. Demand is suppressed at present, and it is likely in practice that this will continue to be the case.

Demand shows some seasonality with the peak occurring in June. The daily load curve shows a regular evening peak with demand dropping to 60% of peak during the early morning hours.

The operation of the generating system is dominated by the seasonality and variability of the hydro power and energy. The hydro stations are located on the Indus river and its tributaries.

Major reservoirs have been built at Tarbela and Mangla and these are operated to give priority to irrigation release requirements.

The Indus River is characterised by high flows in the period May to September due to the snow melt in the mountains and the annual monsoon rains. The reservoirs are drawn down to their minimum level at the start of the summer, and therefore the critical, period for hydro MW is during the summer before the reservoirs are refilled. This unfortunately coincides with the period of peak load, and therefore power sector planners must ensure that sufficient thermal plant is installed to meet the summer peak.

The critical period for energy is during the late winter when limited volumes of water are released for irrigation, and therefore thermal plant must run to ensure that energy demand is satisfied as far as practical. At present there is insufficient thermal capacity available in 'dry' years, and load shedding occurs regularly in this late winter period.

SUPPLY SIDE ISSUES AND OPTIONS

On the supply side, planners are faced with two key issues:

- selecting suitable new plants which make best use of existing energy resources and are environmentally acceptable,
- making better use of existing plants.

Hydro

Of the potential 30,000 MW of hydro capacity, only 2,900 MW is presently developed. A number of major projects have been identified and some are under detailed study. These include Ghazi Gariala, Kalabagh, Basha, Dasu, Banji and Thakot. Between them, these have a potential installed capacity of about 14,600 MW. The investment cost is likely to be nearly US$ 20 billion, or US$1,400/kW, which is relatively attractive compared to thermal plants.

However the practicalities of financing such a programme are severe, particularly at the present given Pakistan's shortage of foreign currency and constraints on borrowing imposed by the IMF. It is likely that only one major hydro project will be given the go ahead in the next five years.

Two other difficulties are holding back the development of the hydro resources. These are environmental pressures and the issue of water allocation between the provinces.

Plant Rehabilitation

A major programme of rehabilitating some of WAPDA's older thermal plant is nearing completion. 275 MW of capacity will have been recovered at a cost of US$233/kW. This is less than one third of the cost of new plant, although the remaining life of the plant will be less than for new sets. The work has centred on efficiency improvement, introduction of modern control systems, and improvements in O&M practices.

Combined Cycle Conversions

Some existing open cycle gas turbine plant are being converted to combined cycle operation through retrofitting of steam cycle equipment. An additional 88 MW of capacity is being commissioned under this programme. Further, the improvements in cycle efficiency are worth at least another 75MW if the extra energy were to have been generated on less efficient sets. The overall cost of these additions are about US$515/kW, which is just over half the cost of new base load thermal plant.

New Thermal Plant

New thermal plant will undoubtedly be required in Pakistan. Several issues have to be considered when planning such investments. These include fuel sourcing, fuel handling and infrastructure, selection of sites and technologies, and the environmental constraints, particularly on air emissions. Other factors which cannot be disregarded are the nuclear question and the financeability of the projects. These are all key issues in Pakistan.

The private sector is being encouraged to invest in new thermal projects as a means of overcoming the financing constraints, although negotiations have proved difficult and no private sector owned plants are yet under construction.

Despatch Efficiency

It is very much in Pakistan's interests to ensure that the existing plant is run in the most efficient manner. Three issues have been identified over recent years which warrant further consideration. These are:

- improved hydro/thermal co-ordination,

- fully integrated planning and operation of the WAPDA and KESC systems,
- introducing more flexibility into the operation of the thermal plant, particularly those which are designed for two shift operation.

Although not all these issues have been fully quantified, it is clear that savings of at least US$50-100 millions per year can be achieved through better utilisation of the existing plant.

DEMAND SIDE ISSUES AND OPTIONS

On the demand side, the issues of concern relate to ensuring that the electricity which has been generated is used efficiently. This has implications not only in terms of the end-user, but also in bringing power to the customer with acceptable levels of losses.

Transmission and Distribution Losses

Transmission and distribution losses at present exceed 21% of generated energy. That is to say that less than four fifths of the electricity generated is used by customers.

Studies carried out by the World bank suggest that the economic level of losses on most systems is in the order of 10-15%. Consequently there is major scope for loss reduction in Pakistan.

There are a number of programmes already under way, although there is plenty of room for further activities. These programmes are addressing:

- reduction of transmission losses through improved reactive power compensation,
- analysis of distribution feeders and re-conductoring as necessary,
- uprating distribution transformers to reduce overloading,
- improving customers' load factors.

Tariffs

At present tariffs are being raised to levels which more closely reflect the true cost of electricity. This compares to a historical situation where tariffs were too low and sent incorrect pricing signals to consumers.

Now that this situation is being corrected, it will be interesting to see how much consumer demand is affected, pa'rticularly those using air conditioning who are likely to be most affected.

Tariffs are a powerful tool to encourage energy efficiency, and it may prove necessary to further raise them to constrain profligate use of electricity. As well as encouraging efficiency, tariffs can also be used to shift demand and reduce system peak demand. This requires that time of day tariffs are introduced. These do not exist at present, and consideration is being given to their future introduction.

This could encourage consumers to think more carefully about their energy use, and to introduce load management techniques in response. No detailed analysis has been carried out on the degree to which demand may be shifted in this manner.

Other new tariffications under consideration include:

- buy back tariffs,
- bulk power purchase arrangements,
- interruptible tariffs.

Load Management Options

In addition to the introduction of new tariffs, load management may be achieved through direct control of customers' appliances such as water heaters and refrigerators. Signals may either be transmitted by radio or over the LV connection into the customer's premises as required by the utility to limit peak demand at critical times and with minimum inconvenience to the customer. This form of load management is not being generally planned at present.

Heat or coolth storage is also a useful way of shifting demand, but customers will only be persuaded of the value of this if time of day tariffs make it worthwhile.

Industry is a major user of electricity and there is likely to be great potential to introduce electronically controlled drives both for speed control and power factor improvement. At present, few customers in Pakistan are alert to the opportunities for achieving energy savings, and it is likely that this will remain the case until a more concentrated effort is made to educate the customer. This situation is typical of that experienced when a power system is evolving and a degree of user sophistication has yet to develop or be encouraged.

Some General Points

Pakistan is at present used to annual load shedding on a rota basis, and this is symptomatic of under investment in the sector against demand. However it is worth noting that load shedding does not produce the reduction in demand which might be expected, as customers shift the timing of their consumption to when power will be available. This is particularly true of small and medium sized industries.

On the domestic front there is a great increase in the use of air conditioners. Within the domestic sector in particular, their use is often irrational and in some cases, profligate. Unfortunately it is having a significant effect on the extent of the summer shortage of electricity. Power shortages are also acting as a deterrent to new industrial investors to the disadvantage of the country as a whole. Some industrialists resort to buying their own generating plant, and the level of captive generation is very high, although reliable estimates are hard to come by.

REVIEW OF SAVINGS

The savings which have or could be achieved are summarised below:

ACTIVITY	MW GAINS	GWH GAINS	COST
Rehabilitation	275	-	$233/kW
c/c conversion	163	-	$515/kW
Integrated planning	684	-	$100mill +
Integrated operations	-	-	$50-100mill p.a.
T&D losses	-	2500/year	less than gen.
Load management		no estimates available	
Hydro-thermal co-ordination		no estimates available	

This table clearly shows that although there has been a significant achievement through the rehabilitation programme and combined cycle conversion, there is immense scope for further improvements throughout all aspects of the utilities' operations. A loss reduction programme is under way and this represents a major area for improvement among with the improved despatch function. Other areas not mentioned here may well be identified in the future, but the short term need is to mobilise resources to assist Pakistan in maximising the efficiency of its own operations.

INSTITUTIONAL ISSUES

No programme is going to succeed without the support inside Pakistan. A number of issues maybe identified which impinge one way or another on the degree to which efficiency might be encouraged. These include:

- the need to resolve conflicts between the power and water sectors,
- the need to encourage WAPDA and KESC to co-operate,
- the need to handle the present financial constraints,
- the political pressures on the setting of tariffs,
- the need to resolve the role of the private sector in the development of the power supply industry,
- the role which the lending agencies should play.

The scope for improved efficiency exists; the problem now is to effect it.

DEVELOPING ENERGY ADVISORY SERVICES IN INDIA USING ENERGY BUSES

John Malcolm : International Manager
NIFES Consulting Group

INTRODUCTION

The Indian Government has instituted a programme of energy conservation promotion measures, including the development of two energy bus programmes, one of which is sponsored by the European Commission and in which NIFES Consulting Group are acting as consultants. *

In this programme three energy buses have been procured, their operating teams have been recruited and trained and they are now providing energy advisory services to Indian industry and other energy users. The advisory services include instrumented surveys, energy audits and feasibility studies and training. The objectives are to identify viable methods whereby the client can cut their energy consumption and energy costs.

This talk outlines the project and approach and discusses the preliminary results so far obtained and some of the problems and opportunities that have arisen.

* There is another UN sponsored programme of 4 buses. In addition, in 1989 NIFES implemented a single energy bus specifically for the Indian Cement industry.

WHAT IS AN ENERGY BUS ? : ADVANTAGES AND DISADVANTAGES

This is a vehicle usually a van or similar, equipped with portable instruments to enable surveys and audits to be carried out. The vehicle has storage facilities and work spaces and is air-conditioned. A mini computer should be available to enable data reduction and analysis to be carried out on-site and at least a preliminary report to be produced for discussion with the plant management before leaving site. (A list of typical instruments is appended).

The idea for energy buses was developed in Canada in the 1970's. It has since been applied in Europe and elsewhere with varying results. There are many arguments over the worth of using energy buses. Some of the chief criticisms are :

- Inflexibility
- High capital cost
- Higher operating costs

Some of the advantages include :

- High visibility
- Promotional impact
- Acts as a focus
- All the instruments are available on site
- Safe means of transport in difficult circumstances

WHAT IS AN ENERGY BUS ? : ADVANTAGES AND DISADVANTAGES Continued

The applicability of using an energy bus depends very much on the circumstances. In developed economies where energy conservation awareness is at a high level, roads are good and nearly everybody has a car, then the benefits are not obvious compared with the standard methods of operating energy advisory services.

Where the economy is developing and energy conservation efforts are at an early stage and where roads are poor and transport a problem, then the benefits of having the buses are more obvious.

In any case, the energy bus itself is not the objective. Energy conservation is – and where the circumstances are favourable and where it is well structured and managed, then an energy bus programme can be a worthwhile means to accelerate energy conservation efforts.

INDIA -EC ENERGY BUS PROGRAMME

The EC–India Energy Bus Programmes.

Three vehicles were constructed in India to a NIFES' specification and delivered at the start of 1991. Portable instruments were procured mainly from Europe, computers from India. Each of the team leaders received preliminary training in the UK. The full teams have each received to date, six weeks training in India, with further training to come.

Each team was formed by a lead agency appointed by the Energy Management Centre in Delhi, which is a government body (Sponsored by the EC) and which is the executing agency for many of the current Indian energy conservation programmes. The three lead agencies are very different in structure and nature. One is a government advisory service with already a number of years activity in providing energy conservation advice. The second is a private energy research institute and the third a chamber of commerce.

Each team has been given a budget to operate. For the non–commercial stage, just ended, all of this budget was subsidised; for the semi commercial, 50% will be subsidised. In the fully commercial stage, each team is expected to fund their operations from revenue obtained from their customers.

The teams have broad objectives set by the EMC but the key objective is to keep the bus teams active. Their target is 200 chargeable bus days per annum. Within this, each team is free to operate and develop its business to suit the nature of the energy users in their area. They are expected to act as a small independent business with business development plans, information systems, cost control, remaining profitable. The team manager should have a high level of control and responsibility.

TRAINING

A list of technical training topics is appended.

Originally NIFES were charged with providing technical training only, but we have since included management and marketing skills in our training. We have helped each team to draw up a plan of the year in much the same way that we do ourselves :

ENERGY BUS TEAM STRUCTURE

GOVERNMENT OF INDIA

↓

EMC

↓

LEAD AGENCY

↓

TEAM MANAGER
SENIOR ENGINEER
3-4 ENGINEERS
SECRETARY/DRIVERS/OTHER

ADVISORY SERVICES

All of the teams are providing a mixture of short surveys – typically 20 consultant days, plus some longer extended surveys if required. One of the teams is in a position to provide full engineering and training as a follow-up service; the others have yet to develop these or develop the contacts with outside consultants and contractors, so that the clients can obtain these if required.

In the now well established patterns, the survey reports make recommendations to save energy classified by capital cost required :

- No capital cost, eg., housekeeping
- Medium, eg., insulation, lighting replacement
- High, eg., co-generation

RESULTS

It is early days yet. Each team has completed a programme of 10 audits as part of the first phase – the non–commercial stage. They are now beginning the second – non–commercial stage.

In general, response from energy users in their regions has been good and they do not seem to be having trouble obtaining willing customers.

The localised, diversified approach is very helpful in this.

The main difficulties are carrying out the work efficiently and to a high standard. Although energy costs are high in India compared to consultancy costs, Indian industries are still looking for value for money. The team managers have also to keep the teams busy to ensure they cover their operating costs.

The main positive results to date are :

- market response : very good
- energy savings identified have been high. This reflects the inefficient use of energy in many Indian industries.

Problems to date have been :

- inexperience with energy audits, instruments and use of computers
- lack of data on costs and equipment
- quality control of reports
- importing the instruments for the energy bus (now largely resolved)
- recruitment of experienced senior personnel
- conflicting objectives

OUTLOOK

- If the marketing objectives are achieved, then each team will have surveyed between 30 and 50 industries in the year.

- Between 4 and 8 engineers in each team will have gained valuable practical experience.

- In the long term, the experienced gained will enable the more ambitious engineers to set up their own consultancies or advisory services or to take jobs as energy managers in industry. All this adds to the availability of expertise.

- The establishment of well equipped teams of energy experts will be established providing sound practical advice to local industries.

In the end, the programme will only have been successful if it leads to significant energy savings and consequent environmental emissions reduction. There are a number of other obstacles to this such as availability to industry of finance, equipment, expertise, instruments, management systems and management/owner commitment. The condition of the Indian energy supply with inconsistant and poor quality supplies of electricity and fuels leads to its own inefficiences. But, if it works out as intended, the energy bus programme will have made a significant addition in at least increasing the body of energy conservation expertise available. The Indian Government are proposing implementing a further 15 of the energy bus teams based on the model provided by the EC–India programme.

EC INDIA ENERGY BUS

TRAINING PROGRAMME

- Energy Audits
- Combustion
- Boilers/Furnaces
- Heat Transfer/Recovery
- Drying
- Power Factor/Load Management
- Compression/Refrigeration
- Motor and Drives
- Energy Management
- Maintenance Implication
- Energy Audits Techniques
- Report Writing
- Instruments – Use/Care/Maintenance
- Cost Estimating
- Economic and Financial Analysis
- Co–generation

- Computer Techniques
- Spreadsheet
- Word Processing
- Database
- Application Programmes

- Marketing/Selling
- Team Management
- Planning
- Presentation Skills

- Practical Training On–site

INSTRUMENTS AND SOFTWARE

- Power Analyser
- Infra-red Non-contact Digital Thermometer
- Digital Thermometer
- Temperature Calibrator
- Thermograph
- Micromanometer
- Inclined Manometer
- Pitot Static Rubes
- Whirling Hygrometer
- Draeger Gas Detection
- Light Meter
- Ultrasonic Leak Detector
- Humidity Meter
- Steam Trap Tester
- Pressure Recorder
- Data Logger
- Temperature Probes
- Flexible Manometer
- Pressure Gauges
- Manometer Balancing Valve
- Thermocouples
- Compensating Cables
- Calibrated Thermometer
- Maximum Demand Indicator
- Anemometer
- Chart Recorder
- Oxygen Meter
- Combustion Gas Analyser

<u>Computer Software</u> – Lotus 123 Version 2.2
Wordstar Version 6
dBase III PLUS
NIFES Application Program
NIFES Database