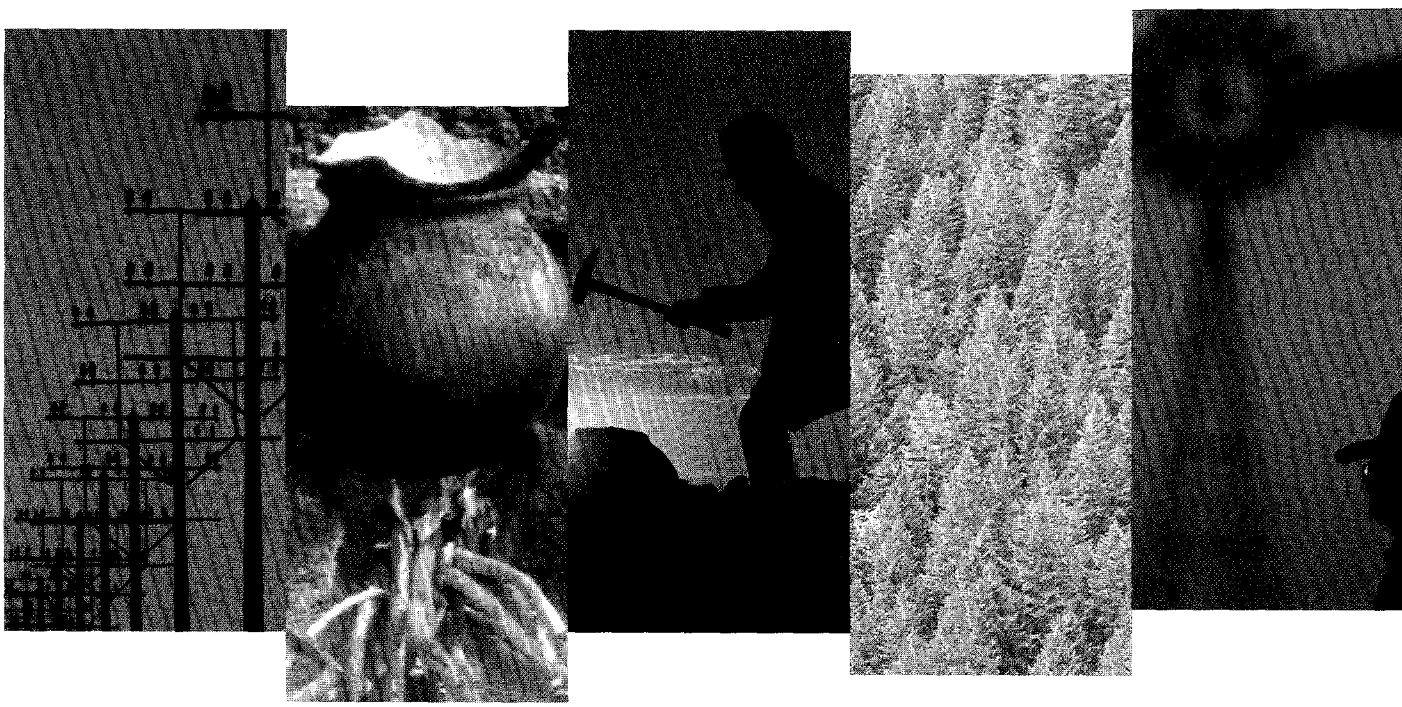
# *China*

# *Improving the Technical Efficiency of Decentralized Power Companies*

ESM222



Energy

Sector

Management

Assistance

Programme

ESMAP

Report 222/99

September 1999

JOINT UNDP / WORLD BANK

**ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)**

## PURPOSE

The Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) is a special global technical assistance program run as part of the World Bank's Energy, Mining and Telecommunications Department. ESMAP provides advice to governments on sustainable energy development. Established with the support of UNDP and bilateral official donors in 1983, it focuses on the role of energy in the development process with the objective of contributing to poverty alleviation, improving living conditions and preserving the environment in developing countries and transition economies. ESMAP centers its interventions on three priority areas: sector reform and restructuring; access to modern energy for the poorest; and promotion of sustainable energy practices.

## GOVERNANCE AND OPERATIONS

ESMAP is governed by a Consultative Group (ESMAP CG) composed of representatives of the UNDP and World Bank, other donors, and development experts from regions benefiting from ESMAP's assistance. The ESMAP CG is chaired by a World Bank Vice President, and advised by a Technical Advisory Group (TAG) of four independent energy experts that reviews the Programme's strategic agenda, its work plan, and its achievements. ESMAP relies on a cadre of engineers, energy planners, and economists from the World Bank to conduct its activities under the guidance of the Manager of ESMAP, responsible for administering the Programme.

## FUNDING

ESMAP is a cooperative effort supported over the years by the World Bank, the UNDP and other United Nations agencies, the European Union, the Organization of American States (OAS), the Latin American Energy Organization (OLADE), and public and private donors from countries including Australia, Belgium, Canada, Denmark, Germany, Finland, France, Iceland, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Sweden, Switzerland, the United Kingdom, and the United States of America.

## FURTHER INFORMATION

An up-to-date listing of completed ESMAP projects is appended to this report. For further information, a copy of the ESMAP Annual Report, or copies of project reports, contact:

**ESMAP**
c/o Energy, Mining and Telecommunications Department
The World Bank
1818 H Street, NW
Washington, DC 20433
U.S.A.

# China
# Improving the Technical Efficiency of Decentralized Power Companies

## September 1999

Joint UNDP/World Bank Energy Sector Management Assistance Programme

(ESMAP)

First printing July 1999

ESMAP Reports are published to communicate the results of the ESMAP's work to the development community with the least possible delay. The typescript of the paper therefore has not been prepared in accordance with the procedures appropriate to formal documents. Some sources cited in this paper may be informal documents that are not readily available.

The findings, interpretations, and conclusions expressed in this paper are entirely those of the author(s) and should not be attributed in any manner to the World Bank, or its affiliated organizations, or to members of its Board of Executive Directors or the countries they represent. The World Bank does not guarantee the accuracy of the data included in this publication and accepts no responsibility whatsoever for any consequence of their use. The Boundaries, colors, denominations, other information shown on any map in this volume do not imply on the part of the World Bank Group any judgement on the legal status of any territory or the endorsement or acceptance of such boundaries.

# Contents

# Abbreviations & Acronyms

| | |
|---|---|
| **DACPC** | Dong An County Power Company |
| **DPC** | Decentralized power company |
| **ESMAP** | Energy Sector Management Assistance Programme |
| **IHRC** | Hangzhou Regional Center for Small Hydropower |
| **ICN** | Implementation Completion Note |
| **IERR** | Internal economic rate of return |
| **LAN** | Local area network |
| **LV** | Low voltage |
| **MIS** | Management information system |
| **MV** | Medium voltage |
| **MWR** | Ministry of Water and Resources |
| **SHP** | Small hydro plant |

# Units of Measure

| | |
|---|---|
| **GW** | Gigawatt |
| **GWh** | Gigawatt-hour |
| **km** | Kilometer |
| **KWh** | Kilowatt-hour |
| **kVA** | Kilovolt-ampere |
| **m** | Meters |
| **MW** | Megawatt |
| **MWh** | Megawatt-hour |
| **MVA** | Medium voltage amperage |
| **t** | Metric ton |
| **tC** | Metric tons of carbon |
| **TWh** | Terawatt-hours |
| **V** | Volts |

# Currency Equivalency

8.5 yuan renminbi (RMB) = US$1.00 (1999)

8.3 yuan renminbi (RMB) = US$1.00 (1999)

100 fen = 1 yuan (Y)

# Preface

This Implementation Completion Note (ICN) summarizes assistance provided to the Ministry of Water and Resources (MWR) by ESMAP beginning in 1989. The MWR asked for assistance from ESMAP to improve the technical, institutional, and financial performance of decentralized power companies (DPCs). The following year, a joint team from the MWR and ESMAP completed preliminary analysis of the sector and identified areas for further study. Three studies were completed in their entirety, including the design improvements for small hydropower plants, power efficiency study, and the restructuring of the DPCs.

This ICN reviews the results of the power efficiency pilot study, which sought to improve the technical efficiency of the rural power generation and transmission system. Limitations of the reform process in the rural power sector were the impetus for this study as DPCs became forced to adapt their operations to a new environment of restricted central budgets and increased emphasis on company responsibility. Technical efficiency measures were seen as an important way not only to address the question of efficiency losses but to confront the restricted financial resources many DPCs faced. Last, although there are of course many institutional issues that must be addressed, this ICN focuses exclusively on technical responses in the energy sector.

Many individuals participated in the preparation of reports, which are summarized by this ICN. They include Noureddine Berrah, Winston Hay, Ranjit Lamech, Frederick Jouve, Chrisantha Ratnayake, and Mangesh Hoskote, as well as representatives from the MWR.

This ICN was prepared by Noureddine Berrah and Dean Girdis.

# Executive Summary

1. Decentralized power companies (DPCs) play an integral role in the delivery of power to rural areas in China. In large part the success of rural electrification and subsequent economic development relied heavily upon their initiatives. Today they continue to play an ever important role as the demand for power continues to grow while at the same time they face increased challenges in securing funding. This shortage of funding and the transformation of power markets toward a socialist market economy, away from state support, creates further challenges that need to be addressed.

2. Ultimately the success of DPCs lies in their ability to adapt to the changing market conditions. Transforming themselves into market driven entities—with a corporate oriented structure and commercially driven business principles—is essential. As the same time, they must recognize and invest in technical measures to reduce efficiency losses, a major area for energy and financial savings.

## The Need for Reform in the Rural Power Sector

3. About 800 DPCs in rural China generate more than 70 percent of their power needs through self-generation. These DPCs do not fall within the jurisdiction of the regional systems. Rather, they are administered by township, county, or prefecture. They own and operate distribution systems and some generation plants, usually hydroelectric, and have loose power pooling relationships.

4. DPCs have played an important part in the rural electrification of China, often by building their own infrastructure with assistance and funding from the central government. By 1990, despite rural electrification rates of over 80 percent, continued expansion of electrification coverage and increased consumption per consumer was questionable principally because of the elimination of central government funding support and subsidies.

5. The principal impetus for reform within the power sector includes the following:

- Reduced government funding.
- Lack of commercial management practices in DPCs in which revenues cover the cost of supply, and tariffs make provisions for financing expansion.
- Limited priority for administrative and technical efficiency in the planning and operation of DPC enterprises.

6. Where in the early 1980s government funded more than 90 percent of rural power investment in China, the percentage has steadily fallen and is now less than 30 percent. This, combined with a non-commercial tariff structure, has led to heavy reliance by some consumers on subsidies and a sector in need of pricing reform. Also, while considerable efforts went to developing the rural power sector, little attention was paid to

operational efficiency, which led to inefficient utilization of power sources, inappropriate site development, and above-average technical losses in the distribution systems.

## Technical Responses to Improved Efficiency

7. This ICN reviews a study on improving DPC power efficiency, specifically programs developed to reduce technical losses in two county distribution systems, with measurable results in improved system efficiency.

8. The efficiency studies reviewed many potential measures for loss reduction. In principal, these included capital investment strategies and program management changes. Capital investment strategies have proved to be the most successful and include the following:

- Installation of new 35 kV substations.
- Rehabilitation of transmission and low-voltage distribution lines and transformers.
- Replacement of equipment including conductors, distribution transformers.

9. Program management changes include the following:

- Better recording of seasonal load flows through feeders and transformers.
- Transformer load management to maximum utilization.
- Development and installation of management information systems (MISs) to track indicators of system performance.
- Reform of electricity tariff structure.

10. Total energy savings as a result of these two initiatives ranged between 6 and 8 percent in each county, with a payback period of between one and five years.

## Dissemination of Efficiency Measures

11. The benefits of improving energy efficiency of the DPCs, as assessed in pilot studies and as demonstrated in projects subsequently implemented, offer opportunities for substantial energy cost savings. Considering the nature of the individual companies, the differences in system sizes and operating conditions, it is difficult to quantify the potential benefits of similar activities in other DPCs. Nevertheless, it is obvious that loss reduction and other efficiency improvements can help to alleviate some of the difficulties facing the DPCs and assist them in approaching the requirements for operation as viable commercial enterprises.

12. Efficiency measures were disseminated in several ways, of which the two most important were preparation and use of a distribution planning handbook, and the establishment of a group within the MWR to train others in the techniques and methodologies applied in the two pilot counties. Both of these activities were actively supported and implemented by the MWR with considerable success.

# 1

# Project Implementation Assessment

## Project Background

1.1 China is the second largest producer of electricity in the world, and by the end of 1996 had a total installed capacity of more than 250 GW, about 77 percent thermal, 22 percent hydro, with nuclear power accounting for the remaining 1 percent. Over the past 15 years, the demand for electricity has grown at an average annual rate of 8 percent, but construction of new power stations has not kept pace with the demand, leading to widespread power shortages and inhibiting the rate of economic development. An estimated 10 percent of peak demand is suppressed in large systems as a result of inadequate generating and peaking capacity.

1.2 This situation—of decentralized power markets—characterizes the national power system, including the regional systems, the seven interconnected provincial grids, and the eight non-interconnected provincial grids. However, more than 1,600 rural counties that are not interconnected or are loosely interconnected with the regional or provincial systems are experiencing similar demand growth without access to the capital and experience of the larger systems.

## Decentralized Power Companies

1.3 In the rural areas and smaller townships that do fall outside the jurisdiction of the regional systems, electricity supplies are most often the responsibility of DPCs, which are administered by the prefecture or county. These DPCs own and operate sub-transmission (110 kV), medium and low-voltage (LV) distribution systems (35kV, 10 kV, and LV), and in most instances, small generating units as well. Most, however, are interconnected with an adjacent grid, and about 800 of them receive most of their supply from these grids. The remaining 800 generate at least 70 percent of their energy needs themselves, chiefly with small hydroelectric generating units, and rely on the grid to augment their supply in the dry season or to purchase their surplus energy in the wet season.

1.4 By the early 1990s, total installed capacity of the 800 DPCs was about 16,500 MW (of which 90 percent are small hydropower units), with more than 60,000 operating power plants. Total electricity generation was over 45 TWh, of which 40.5

TWh came from small hydro and the majority of the remainder of 4.5 TWh from small coal units.

1.5 Larger DPCs or prefecture power companies typically operate a loose pooling of township, county, and municipal systems, adding their own generating capacity and undertaking distribution in municipalities or other areas that do not have their own power enterprise. [1] DPCs in townships, counties, and municipalities are expected to be self-sufficient in generating capacity, although the prefecture company coordinates interchange between interconnected systems, including the national grid.

1.6 With central government assistance, the DPCs have played a major role in the rural electrification of China. Beginning in the 1950s, rural areas were encouraged to develop their own infrastructure, including electricity, to enhance economic development and improve the quality of life. Much of the equipment needed was supplied by the communities themselves. The result was a dramatic increase in the percentage of China's population with access to electricity. In 1970 less than 40 percent of the rural population had access to electricity, whereas this figure had increased to more than 80 percent by 1990 and to 85 percent by 1995.

## Project Objectives

1.7 Beginning in 1989, China's MWR requested ESMAP's assistance to improve the technical, institutional, and financial performance of the DPCs. A team comprising representatives of ESMAP and the MWR carried out a study and prepared an action plan to address these issues.

1.8 Initially, five areas were identified for further study:

- Design improvements for small hydropower plants.
- Power efficiency pilot study.
- Power planning pilot study.
- Restructuring of decentralized rural power systems.
- Financial and budgetary control.

1.9 Although several major steps were made in each of these areas, only three studies were completed in their entirety, including design improvement for small hydroplants, and the restructuring of the DPCs and power efficiency pilot study on which this ICN focuses.

1.10 As a result of the preparatory work, the following objectives for improved technical efficiency were established:

- Implementation of *Pilot Studies on Energy Efficiency*, which included a thorough technical analysis of reducing power losses and improving the overall efficiency and reliability of power system operations.

---

[1] A prefecture is a regional administrative entity below the provincial level that encompasses several counties. The counties are further divided into townships and the townships in turn into villages. Decentralized power companies operate essentially at the county and prefectural levels.

- Training MWR staff in the identification and implementation of measures to reduce power losses between the points of generation and sale
- Development of a handbook for efficient distribution system planning.

## Achievement of Project Objectives

1.11 The major objective completed was the *Pilot Studies on Energy Efficiency*, which included a thorough technical analysis with hands-on approach directed at reducing power losses and improving the overall efficiency and reliability of power system operations. The study was well received by the MWR and served as a basis for further discussions and work in energy efficiency. Based on the work completed in the pilot studies, a separate unit in the MWR was then established to pursue dissemination of energy efficiency measures, and a detailed handbook was developed in coordination with the MWR that was widely distributed to DPCs. The handbook was a particularly useful tool and was used in many training workshops and as a field guide, serving as an impetus for additional investment in technical energy efficiency measures by DPCs throughout China.

## Implementation Record and Factors Affecting the Project

### The Changing Structure of Rural Power Markets

1.12 The rural power sector has been undergoing structural reform for the past several years, including the elimination of central government support and subsidies, the growing role of performance-based technologies, and increased managerial responsibility to improve operating efficiencies.

1.13 Despite the early success, many of the DPCs are experiencing difficulties both in continuing to expand service to new consumers and in improving the quality of service to established consumers. These difficulties stem from a number of reasons, including the following:

- Reduced government funding.
- Lack of commercial management practices in DPCs, including cost recovery and sufficient financing for expansion.
- Limited priority for administrative and technical efficiency in the planning and operation of DPC enterprises.

1.14 In the early history of DPCs, the central government provided much of the required investment capital. As recently as 1980, the central government was the source of 91 percent of power sector investment in China. However, as a result of reforms introduced in the early 1980s, this percentage was reduced to less than 30 percent in 1994 and continues to fall. Prior to 1980, central government contributions to DPC investments were grants, and so had little or no effect on the charges to consumers. Second, tariffs were not structured on commercial bases, and DPCs effectively subsidized, and continue to subsidize, many areas of economic activity that are regarded as important to the common good, such as fertilizer plants and the processing of agricultural products.

1.15 When public electricity supplies first began to be developed in rural areas, little attention was paid to operational efficiency. In instances where equipment was manufactured locally, the workshops were unable to meet the standards of manufacturing tolerances that would be normal in specialized factories. The energy efficiency of such equipment was therefore well below internationally accepted standards. As well, hydroelectric resources appeared to be abundant, and planning for site development often did not maximize exploitation of the energy potential of the given location. Furthermore, since expansion of the infrastructure was relatively easy, operational efficiencies, such as maintaining losses in the distribution systems at economically low levels, were not given priority. These approaches became accepted and ingrained and are reflected in power system planning even today.

### Approach of Pilot Efficiency Studies

1.16 Prior to the first ESMAP pilot efficiency study mission, the MWR selected two county-run DPCs in which this study was to be undertaken. They were in the counties of Xin Chang in Zhejiang Province and Dong An in Hunan Province. ESMAP acquired instrumentation, computers, a digitizer and plotter for electronic mapping, and software for distribution system performance analysis, as well as for other applications for the computer and digitizer.

1.17 The strategy adopted by ESMAP for loss analysis and development of loss reduction programs relied heavily on modern technology. Because the distribution systems in rural networks are seldom adequately instrumented, portable instruments were purchased that could measure, and in many instances electronically record, the important system performance parameters (such as current, voltage, power factor, and active and reactive energy). The data electronically recorded could be downloaded to computers and processed in spreadsheet or graphic formats.

### Overview of Power Efficiency Process

1.18 Improving the operational efficiency of Chinese DPCs by reducing power and energy losses on the distribution systems of those companies is an important complement to management reform initiatives and together, they serve as a basis for overall sector improvement. The counties selected provided practical demonstrations of the techniques and methodologies applied in identifying and quantifying the sources of losses. The procedures employed were generally applicable to all DPCs in China. The loss reduction measures selected included investments in system hardware, as well as purely operational procedures. An important goal of the activity was to train MWR counterpart staff in the techniques and methodologies that had been developed by ESMAP through international experience in power system loss reduction.

1.19 Several principal conclusions can be drawn from the two studies undertaken in counties served by DPCs. They provide an indication of areas for future intervention and include the following:

- High-loss transformers account for the largest portion of technical losses, as high as 50 percent in some cases.

- Investment in replacement transformers, rehabilitation of existing transformers, and load management programs have the greatest opportunities for efficient and provide the highest returns.
- Rehabilitation of existing transformers provides the highest return for the lowest investment in the shortest payback period, as low as two years.
- Rehabilitation of LV distribution networks has the longest payback period, as high as ten years.
- Xin Chang County transformers were the focus of investment though non-technical and land management measures played a major role in reducing losses.
- Dong An County low system losses were related to low load factors while transformer losses were relatively high because of similar low utilization factors.

1.20 Operational procedures were revised to achieve greater overall effectiveness, and a cadre of MWR staff was trained in the methodologies employed for theses studies. This group was subsequently able to undertake the study in the second county (Dong An in Hunan Province) substantially on its own, with some assistance from ESMAP, and now continues to complete similar studies in other counties as well.

### Key Intervention Strategies

1.21 The efficiency studies reviewed many potential measures for loss reduction. In principal, they included both capital investment strategies and program management changes. The former proved to be more successful in efficiency gains. Capital investment strategies included the following:

- Installation of new 35 kV substations.
- Rehabilitation of transmission and LV distribution lines.
- Replacement of equipment including conductors, distribution transformers.

1.22 Program management changes included the following:

- Better recording of seasonal load flows through feeders and transformers.
- Transformer load management to maximum utilization.
- Development and installation of MISs to track indicators of system performance.
- Reform of electricity tariff structure.

### Distribution Planning Handbook

1.23 A handbook was reviewed by ESMAP and the MWR, after preparation by consultants, and then translated into Chinese. This handbook was presented to a dissemination workshop that took place in Hangzhou (Zhejiang Province) in April 1995, and is now being used in several counties.

1.24 The distribution planning handbook, while important, is not adequate for dissemination of the lessons presented in the two pilot counties. Practical demonstrations of the technologies to be applied (such as instrumentation and software), as well as the methods of application are also required. Consequently, in 1994 the MWR established a group to do, inter alia, the following:

- Organize workshops at which the lessons learned in the pilot studies would be disseminated to staff of the DPCs. The workshops would include formal training in the technologies and methodologies used by ESMAP to identify and quantify the sources of technical and non-technical power system losses and to evaluate options for reducing these losses to economic levels.
- Undertake loss reduction studies similar to those completed in Xin Chang and Dong An counties in a number of other counties. The staff of these counties would receive on-the-job training during the execution of these studies.
- Recommend revisions to relevant regulations and technical standards that would improve the operational efficiencies of the DPCs.
- A number of professionals from the Hangzhou Regional Center for Small Hydropower (HRC) were included in the group, but it will be referred to only as the MWR group in subsequent paragraphs.

1.25 In mid-1994 the MWR group began loss reduction studies with the power companies in Huai Hua (Sichuan Province) and Yichun (Jiangxi Province) counties. Applying the lessons learned during execution of the ESMAP study, a competent team was selected to work along with the MWR group in each county. Local counterpart teams have shown strong interest in the work and are receptive to the training being provided. Similar studies will be undertaken in other counties when those currently being carried out are completed.

### Training

1.26 In April 1995 the MWR organized the dissemination workshop in Hangzhou at which the distribution handbook was presented. The participants, mainly managers of their companies' operations, were drawn from 15 DPCs in southern China and from the Xinjiang Autonomous Region. The workshop gave participants not only theoretical instructions but also practical training in the use of the hardware, instrumentation, and relevant software. The MWR plans to organize two such workshops annually.

1.27 Some problems arose which impede the smooth implementation of the MWR's plans for dissemination. Perhaps the most important of these is that, because of limited staff resources, the MWR has been unable to provide the activity with the number of full-time staff required to maintain the schedule originally planned. Financial constraints also made it difficult (a) to purchase the instrumentation, hardware, and software required to execute the studies, or (b) to make the investments necessary to implement the recommendations.

### Xin Chang (Zheijang Province) Pilot Study

1.28 In Xin Chang County the pilot study identified a number of economically attractive loss-reduction measures which would reduce losses by 7–8 percent of the county's net generation in 1991. The payback period for most of these recommended investments ranged between 1 and 5 years, calculated on the basis of a 12 percent discount rate and with the average tariffs that prevailed in 1991. (See Annex A.)

1.29 In summary, the loss-reduction recommendations were as follows:

- Installation of two new 35 kV substations and replacement of conductors on the Saxi 1022 and Jinlin 1046 lines. For an investment of $670,000, a payback period of three to five years was calculated.
- Rehabilitation, including conductor replacement, of seven 10 kV lines. The investment required was estimated to be $230,000, and the payback period two to five years.
- Replacement of all high-loss distribution transformers (approximately 60 MVA) with energy-efficient S-7 transformers. The calculations indicated that for an investment of $1.2 million, a payback period of five to six years would be achieved.
- Rehabilitation of the LV distribution network to acceptable operational standards. The estimate of the investment required was $220,000, for which a payback period of ten years was calculated.

1.30 The study also identified a number of non-technical and load-management measures that would further contribute toward reduction of system losses. The economic attractiveness of such investments was not evaluated in the study because, although the implementation costs were known to be very low, there was uncertainty as to how those costs could be quantified. The loss-reduction recommendations for Xin Chang County, which did not require significant capital investment, were ways those costs could be quantified. The loss-reduction recommendations for Xin Chang County, which did not require significant capital investment, were the following:

- Better recording of seasonal load flows through feeders and transformers in the county's electricity network. Such a database would not only help to delineate the characteristics of electricity supply, but would also be of value to the macroeconomic analyses required for forecasting regional rates of load growth. Estimates of load growth rates are also required for appropriate selection of energy efficient transformers and feeders.
- Adopt transformer load management to ensure that existing transformers are most effectively utilized and that new transformers are appropriately sized. This will improve the utilization factor of transformers, which

currently ranges as high as 5, and result in transformer losses that are now as high as 10 percent of input energy.

- Develop and install an MIS to track indicators of system performance, and provide indications as to the areas in which management action is most urgently needed to improve the efficiency of company performance and maintain it at high levels.
- Reform the structure and level of electricity tariffs to provide a system that would be simpler to implement while better reflecting the cost of supplying electricity to the different consumer groups.

1.31 The Xin Chang County power company, Xin Dian, moved quickly to implement many of the recommendations of the study. Box 1 provides a summary of the actions taken by Xin Dian by the end of 1996. It was obvious that there was a new awareness of the benefits of reducing power system losses and a determination to continue the downward trend until economic loss levels were attained and then to keep them there.

***Box 1. Remarkable Progress by Xin Chang Electricity Supply Company***

Xin Chang County continued to experience rapid load growth after conclusion of ESMAP field work for the pilot study in 1993. In 1994 energy sales were 11.5 percent higher than in the previous year, and 1995 sales were expected to be 17.4 percent above the 1994 figures. In response to the surging demand, Xin Dian developed an expansion program for the period to 2010. The program projects a total investment of the equivalent of $13 million over this period, and includes many of the recommendations made by the MWR-ESMAP pilot study. The recommendations that were included, and on which work has already begun (end 1995) or is about to begin, are as follows:

- Replacement of high-loss transformers, with an aggregate rating of 46 MVA, by the more efficient S-7 models at an investment cost of 7.3 million Juan (about $1.3 million). Plans are proceeding for replacement of a further 60 MVA of older transformers.
- Replacement of two inefficient 110/10 kV, 10 MVA transformers with more efficient, modern transformers. The total investment was approximately Y 3 million ($450,000).
- Installation of a 3,150 kVA primary transformer on the Shaxi 1022 line. This transformer was commissioned in 1994. The investment of Y 1 million ($150,000) will reduce losses by more than 1 percent of the energy that passed through it in 1992.
- Reconductoring of three 10 kV lines has been completed. The total investment was about Y 300,000 ($90,000), and the value of the reduction in losses is expected be equivalent to Y 200,000 ($30,000) annually. Reconductoring of other 10 kV lines is proceeding.
- Selection of 50 villages for LV network rehabilitation to improve the performance of these networks to operationally acceptable standards. The total investment will be about Y 5 million ($750,000).
- Development and testing of a local area network (LAN) computer-based customer system and MIS are far advanced. The MIS is being developed and commissioned through the joint efforts of Xin Chang Electricity Supply Company and the Institute of Rural Electrification in Hangzhou, Zhejiang Province. The MIS has been approved by the Zhejiang Electric Power Bureau.

## Dong An County (Hunan Province) Pilot Study

1.32 The pilot study in Dong An County identified system losses amounting to approximately 8 percent of net generation in 1991. The study recommended investments totalling about $400,000 to reduce the level of losses to about 6 percent of net generation.

Each of the projects recommended would have payback periods of less than 2 years, except in one instance where the period was 4 years. (See Annex B.)

1.33 The relatively low level of overall system losses is attributable to the low load factors at which the Dong An County system operated in 1991. However, the contribution of transformer losses to aggregate losses was high, because of the low transformer utilization factors, resulting in part from installation of transformers which were oversized for the demands they served. As a result, 68 percent of transformer losses were attributable to no-load losses.

1.34 Losses in the LV network amounted to just over 1 percent of net generation. However, these losses represented more than 5 percent of the total electricity supplied through the LV network, both urban and rural. Given the rapid growth in electricity demand from consumers connected to the LV network, the study emphasized that Dong An County Power Company (DACPC) needed to place great importance on reducing these losses, drawing on the expertise available in the MWR where needed.

1.35 Following are the study's loss reduction recommendations:

- Develop and implement a transformer load management program by which transformer capacity ratings would be selected according to the demands they serve.
- Implementation of the closed loop operation of Feeder 3502A, reconductoring of this feeder, and reconductoring of Feeder 3502 as well. These measures were calculated to reduce losses by about 1 percent of net generation. The investment required was estimated to be $200,000, and the resulting payback period to be two years.
- Rehabilitation, including reconductoring, of the 10 kV feeders Numbers 1043, 1044, and 1045. The investment of about $18,000 was estimated to provide a payback period of two years.
- Balancing of phase currents on three-phase LV feeders. This is a minimum-cost measure that is highly effective in reducing losses.
- Converting overloaded single-phase LV lines into three-phase feeders and reconductoring selected high-loss three-phase feeders to reduce losses. This recommendation was estimated to require an investment of $180,000 and provide a payback period of between one and four years.
- Developing distribution planning standards that include consideration of the cost of losses.

1.36 Although initially DACPC appeared to move more slowly than Xin Dian to implement the study's recommendations, by the end of 1995 the list of actions taken to reduce losses was impressive. A summary of these actions is presented in Box 2.

***Box 2. Impressive Loss Reduction Activity in Dong An County***

By the end of 1995, the Dong An County Power Company (DACPC) had implemented or begun implementation of a number of significant measures toward reducing system losses. These included the following:

- Replacing high-loss transformers accounting for 50 percent of total grid capacity with lower loss units. Further, the decision was taken that only low-loss transformers would be installed on the system in the future, and that a transformer load management program would be introduced to ensure that, in each new installation, the economically appropriate transformer size would be chosen for the specified duty.
- Extending Feeder 3502A by about 300 meters and connecting it to the Bai Ya Si substation. This has allowed Feeder 3502 to distribute more power and considerably reduce the overloading of Feeder 3501.
- Reconductoring of 34 kilometers of 35 kV and 55 kilometers of 10 kV lines.
- Balancing the three-phase loads on the three LV feeders in the county. DACPC reported a net energy saving of 2 GWh per year. The benefit of this minimum-cost corrective measure was valued at Y 360,000 ($50,000).
- Installing capacitors in substations and on the premises of industrial customers to improve power factor, reduce reactive current flows, and thereby reduce losses.
- Improving the accuracy of power and energy metering in generating stations, substations, and industrial installations. A program of inspecting consumer installations for possible sources of nontechnical losses and checking the accuracy of meters in commercial premises and residences has also been instituted.
- The progress in loss-reduction in Dong An County has been achieved despite some significant obstacles. The guidance of the experienced staff in the MWR (in Beijing) was not easily obtainable, since there was no direct-dial telephone link between the two cities. The time required for travel between Beijing and the county prevented the MWR team from making frequent supervision visits. In some respects, the internal DACPC organization contributed to the initial difficulties. The company did not appoint a task force to deal specifically with the issues arising from the pilot study. Therefore, the MWR team did not have a strong counterpart team with which to interact on its visits, and there was no team leader to act as the liaison between the MWR and DACPC and to supervise execution of agreed programs in the absence of MWR personnel. In addition, supply overcapacity reduced the incentive for the DACPC to embark on any loss reduction activities.
- Overall, the experiences gained in Dong An County will provide useful lessons for successful dissemination of loss reduction techniques and economic evaluation to other Chinese DPCs.

## Project Sustainability and Assessment of Outcome

1.37 Investment in efficiency measures by the Chinese have been particularly successful due in large part to the success and lessons learned from the pilot studies and most importantly through the use of the handbook on energy efficiency. Local Chinese authorities continue to explore and invest in opportunities to improve energy efficiency with technical measures without any continued financial or technical assistance through this project or ESMAP. Thus, the project was quite successful in achieving initial objectives and was sustainable by means of promoting a continued investment in energy efficiency.

## Future Operation

### Dissemination of Efficiency Measures

1.38 The benefits of improving the energy efficiency of the DPCs, as calculated in the pilot studies and demonstrated in the projects subsequently implemented, offered opportunities for substantial savings if they could be realized by all 2,000 DPCs. In view of the varied nature of the individual companies, and the differences in system sizes and operating conditions, it will not be realistic to extrapolate the savings projected for the two pilot studies in an attempt to quantify the potential benefits of similar activities in all DPCs. Nevertheless, it is obvious that loss reduction and other efficiency improvements can help to alleviate some of the difficulties facing the DPCs and help them approach the requirements for operation as viable commercial enterprises. For these reasons it is important that the principles applied be disseminated as widely and as quickly as possible. The two most important methods of dissemination are (a) use of a distribution planning handbook, and (b) the actions of a group within the MWR to train others in the techniques and methodologies applied in the two pilot counties.

### Prospects for Efficiency Improvements

1.39 The Power Efficiency Pilot Study demonstrated approaches by which China's DPCs could reduce losses and thereby increase the efficiency of their operations. These approaches were successfully applied in the two counties in which the study was carried out, and are being disseminated to other counties by the national counterparts who worked with ESMAP staff during the study. The success of the ESMAP project has been due in large measure to the competence and dedication of Chinese counterpart staff and to the support provided by the MWR.

1.40 Despite the proven value of the lessons conveyed in the pilot studies, success in achieving operation of the DPCs as efficient, commercially viable enterprises cannot yet be claimed. The studies showed the need for institutional strengthening of the companies, not only in greater autonomy of operation, but also in the staffing and structure of the organizations. The tariffs need to reflect the costs of supply more closely so that the companies' revenues will cover their operating costs, provide an adequate return on investment, and make some provision for investment in system expansion. In addition, tariffs that reflect the costs of supply will provide an incentive to consumers to use electricity efficiently, and could conceivably reduce the rate of increase in demand and therefore the need for new investments. Attention to these issues will make the companies more responsive to market forces and contribute to realization of the national government's objective of a socialist market economy.

### Strategy for Introducing Power Loss Reduction Methodologies to MWR Counties

1.41 Given the significant potential for loss reduction in the DPCs at the county level, as agreed at the onset of this study, the MWR developed a strategy by which it was able to introduce power loss reduction to as many counties as possible. However, because of the large number of counties that are under MWR management, this implementation strategy was designed to bring to the forefront the DPCs that offer the best chances of making investments, based on the recommendations of the studies. A high rate of follow-up actions based on recommendations is viewed by the MWR as a primary critical success factor to a broader nationwide loss reduction strategy. Once such a positive track record was established, the MWR pursued the introduction of power loss reduction on a broader scale by relying more on the initiative of the DPCs for follow-up investments.

## Key Lessons Learned

1.42 Key lessons learned as a result of bank interventions include the following:

- Despite the changing market conditions, the rural power sector has the capability to take the necessary actions to adapt their organizations to the new market conditions and successfully flourish.
- Institution of performance-based incentives and improved efficiency are key steps in facilitating successful adaptation by the rural power sector to market-oriented conditions.
- Subsidies, low operating efficiency, and a lack of administrative controls need to be eliminated or addressed if the rural power sector is to succeed in the coming years.
- Local government needs to accept the changes promoted by central government and assist and support DPCs in implementing these changes.
- The processes of corporatization and commercialization are integral components in transforming DPCs into market-based entities.
- Management is sufficiently competent, if given the authority, to begin implementing the decisions that will transform commercial and technical performance of the companies.

1.43 Capital investment in energy efficiency measures proved to be the most successful in efficiency gains.

# Annex A

## Xin Chang County (Zhejiang Province): First Power Efficiency Study

1. This annex provides a short description of Xin Chang County and its power system as well as an outline of the activities undertaken to quantify sources of power losses and evaluation of various options to reduce them. The loss reduction work included all 35 and 10 kV feeders, four sample LV feeders (three representative village systems and one urban neighborhood), and all transformers on the county system.

### Xin Chang County

2. Xin Chang County, situated in the eastern part of Zhejiang Province, has an area of 1,200 square kilometers. At the end of 1992 its population was estimated to be 431,000, of which about 390,000 were farmers.

3. The per capita income in the county is about Y 4,200. Economic growth was very high during recent years because of dramatic development of township and village enterprises (and private enterprises. In 1991 the total industrial output was Y 1,506 million, more than five times the aggregate agricultural output, which totalled Y 291 million. Economic activity in 1991 was more than 30 percent higher than in 1990.

### The Power System

4. **Infrastructure**. At the end of 1991 the power network in Xin Chang County consisted of a medium-voltage (MV) system of 140 kilometers of 35 kV lines and 1,210 kilometers of 10 kV lines. The total transformer capacity was 194 MVA, of which 20 MVA (2 x 10 MVA) were installed in a 110/35 kV substation connecting the county system to the East China regional grid.

5. Power is supplied from three sources:

- About 80 small hydroelectric stations with a total capacity of 40 MW. Three of these stations have small storage reservoirs, and they feed into 35 kV lines, but the others are all run-of-river stations that feed into the 10 kV system.

- A 5 MW coal power station that provides significant contribution to satisfy peak system demands, especially during the dry season (November to March).
- Imports from the East China grid, especially during the dry season.

6. **Organization.** The MV system (35 and 10 kV) and the LV system in urban areas (the county seat) are operated and maintained by a county-owned power company, referred to as Xin Dian. Xin Dian buys power from the generating stations connected to its system, at prices set by the county power bureau, and from the East China system, at prices set by the provincial power bureau. It then sells the power as follows:

- In bulk, at the 10 kV level, to state-owned enterprises, industrial customers, and townships.
- To LV customers (400 and 220V) in the urban area, limited to the county seat.

7. Xin Dian Power Company is supervised by the county hydropower bureau, to which the general manager reports. The division of responsibilities between the county hydropower bureau and the power company is not clearly delineated. The bureau makes major investment and operational decisions, sets the prices, and enforces rigid rules regulating the transactions between power stations and the power company. In practice, the company has little autonomy and does not operate as a commercially oriented enterprise.

8. The company is administered internally by a general manager appointed by the county power bureau. There are seven operating departments, namely (a) customer supply and management, (b) finance, (c) procurement (planning of equipment supply), (d) operations technology, (e) administration, (f) security and safety, and, (g) dispatching (including the distribution control center).

9. The townships are responsible for operation of the 10 kV lines, where applicable, and the LV lines in the villages, which constitute the township. The management, operation, and maintenance of the township systems are contracted to private electricians. The electricians' remuneration is provided by a mark-up (difference between the purchase price from the power company and selling price to the consumer) set by the township committee. In theory, the contractors have a direct incentive to keep operating costs low and increase the effectiveness of the billing and collection system, because they can then retain a larger percentage of the margin.

10. **Demand Forecasts**. From 1980 to 1991 the rate of electricity demand in the county grew at the very high average rate of about 15 percent per year. Since 1989 capacity shortages have been a severe constraint on the system's ability to meet peak consumer demand, as is shown in Table A-1. Demand curtailment was achieved through interruption of supplies to feeders, restrictions on the times at which consumers could operate various types of equipment, and limiting the supplies to a number of consumers. It is estimated that in 1991 the suppressed demand amounted to 20 percent of sales.

**Table A-1. Xin Chang County Electricity Balance**

| *Year* | | *1980* | *1985* | *1989* | *1990* | *1991* | *1992* |
|---|---|---|---|---|---|---|---|
| 1 | Power generation (GWh) | 20.3 | 55.3 | 87.2 | 107.6 | 100.0 | 122.0 |
| 2 | Imports (GWh) | 17.3 | 21.6 | 52.2 | 42.0 | 62.8 | 60.4 |
| 3 | Exports (GWh) | n.a. | 4.7 | 8.5 | 8.6 | 4.8 | 0.6 |
| 4 | Total supply (line 1 + line 2 - line 3) | 37.6 | 72.2 | 130.9 | 142.0 | 159.0 | 181.8 |
| 5 | Sales (GWh) | 31.2 | 64.6 | 118.7 | 129.2 | 147.1 | 170.7 |
| 6 | Losses | | | | | | |
| | GWh | 6.4 | 7.6 | 12.2 | 12.8 | 11.9 | 11.1 |
| | % of total supply | 17.0 | 10.5 | 9.3 | 9.0 | 7.5 | 6.1 |
| | % of total sales | 20.5 | 11.8 | 10.3 | 9.9 | 8.1 | 6.5 |
| 7 | Peak load (MW) | 11.0 | 20.0 | 25.5 | 25.7 | 28.4 | 32.5 |
| 8 | Load factor (%) | 39.0 | 41.2 | 58.6 | 62.1 | 62.9 | 62.9 |

n.a. Not applicable.
*Source:* Xin Dian and mission estimates.

11. The power company's forecasts show electricity consumption growing by an average of about 22 percent annually to more than 850 GWh in 2000. The ESMAP team considers these forecasts to be unduly optimistic, since the impact of higher electricity prices is not taken into account. However, even if the rate of growth is half the projected figure, electricity consumption will triple by the end of the century. It is doubtful whether the East China regional grid will be able to sustain such dramatic increases in demand, since Xin Dian is already experiencing considerable difficulties in negotiating additional purchases. The incremental cost of supply from local generation would be higher than purchases from the grid because of the higher production costs. This consideration provides an incentive to Xin Dian to give priority to efficiency improvements, which will make more effective use of existing capacity and reduce the need for new investments in generation.

12. **Statistics.** A noteworthy feature of Xin Dian's statistical system is that the data provided often varies with the source. For example, the energy sold in 1991 is reported by the customer management section as being 147.1 GWh, but as 151.9 GWh by the financial section in its annual operating statement. Some monthly recorded sales in 1992 were higher than the total available supplies. Such discrepancies and anomalies affect the confidence with which final conclusions on total system losses can be drawn. In addition, the company's statistics do not reflect losses in the LV systems or in transformers. This is so because, although villages are metered on the LV side of the transformer, average transformer losses are added to the metered energy. The largest consumers are metered at 10 kV. Therefore, the transformer losses are included in the energy consumption for which the bills are issued.

### Loss Calculations

13. **MV Network Analysis**. An important operational characteristic of the MV network in Xin Chang (indeed in most of the decentralized power systems) is the large number of dispersed small hydroelectric power plants connected to the 35 and 10 kV feeders. In Xin Chang County 40 percent of total supply is fed to the system from small hydro plants through the 10 kV feeders. As a result, the power flows through the affected MV lines vary widely with the seasonal and daily fluctuations of generation levels. Therefore, the loading patterns of the lines are not consistent, making it difficult to estimate the losses on the feeders with acceptable accuracy. It becomes necessary to select a number of "typical cases" that are representative of the complex operational practices and subject them to careful data collection and evaluation.

14. To account for the specific characteristics of such systems, the loading on the feeders was modelled to represent the conditions that would have existed without local generation. This was done by determining the total load distributed by the feeder and assuming that the load distributed by each transformer was in the ratio of the rated capacity of that transformer to the aggregate transformer capacity installed on the feeder. (This means that each kVA of transformer capacity was assumed to distribute the same power at times of peak demand on the feeder, regardless of the transformer location.) Subsequently the generation inputs were input into the model, which then adjusted power flows (and losses) to accommodate the power provided by the generators, allowing exports from the feeder where necessary. These "typical cases" were developed from a thorough study carried out by Chinese counterparts before the first ESMAP mission.

15. **35 kV Feeder Analyses.** Calculations of losses in all 35 kV feeders were carried out for two loading patterns corresponding to the peak demands on each feeder in the wet and dry seasons. The calculations show that in no instance does the maximum loading on 35 kV lines exceed the conventionally accepted current carrying capacity (ampacity) of the conductors. Energy losses total 1.8 GWh per year, which is about 1 percent of the total energy supply (net generation plus purchases from the grid).

16. **Loss Reduction Measures on the 35 kV Network.** No reconductoring or other hardware investments are recommended for the 35 kV system. However, the loss level could be reduced if certain reconstruction investments proposed for the 10 kV system were to be implemented, because some output of local generating plants currently transmitted through the 35 kV system would be diverted to the 10 kV system.

17. **10 kV Feeder Analyses.** It has already been mentioned that a characteristic of most DPCs in China is that generating plants are connected to the distribution feeders. In Xin Chang, from the standpoint of power-flow analyses, the situation is further complicated by the fact that the power plants are generally connected to feeders in the rural areas, but the urban areas constitute 70 percent of system demand. Precise analysis of such a system would require coincident records (that is, taken at the same time) of (a) feeder flows, (b) distribution transformer loading, and (c) the generating levels (kW) of each hydroelectric plant. Such detailed records were not available. It was therefore decided to monitor the flows of the feeders selected for analysis on a specific day in May 1992 (the wet season) and attempt to model the system by adjusting the

readings on the basis of such records as the following: (a) monthly generation of the hydro plants, (b) annual system peaks, (c) sales, and (d) feeder load factors.

18. Given the paucity of historical data, in order to properly reflect the complex operational characteristics of the 10 kV system, the peak demand supplied by each feeder was estimated using two different approaches, and the performance of each feeder was calculated for both estimates of peak demand:

- In one instance, each generating plant was assumed to be operating at its maximum capacity at the time of the 1992 system peak. The load allocation along the feeders as a whole was arrived at by assuming that each distribution transformer was loaded to the same percentage of its rated capacity. By this method, the total demand supplied by each feeder, as well as the power flows in the feeder, could be estimated. This approach assumes coincident maximum demand on each feeder and therefore probably overestimates peak current flows and power losses.
- In the second instance, it was assumed that there was a 50 percent coincidence factor between the peak demands of the system and the feeders, and that the loads supplied by the feeders at each transformer location corresponded to 60 percent of the rated transformer capacity. [2] Sixty percent of rated transformer capacity results from a 1992 system peak of about 32 MW, 100 MVA of distribution transformer capacity and the assumptions of a 50 percent feeder coincidence factor and equal loading of each transformer.

19. Since generating units are connected to the feeders, peak losses on the feeders may not occur at the same time as peak feeder demand. In other words, peak feeder losses may not be the same as feeder losses at system peak. It was determined that consumer demand on the feeders was not significantly affected by the time of year. However, current flows at different sections of the feeders will be influenced not only by consumer demand (resulting in power flows through the distribution transformers), but also by the amount of power supplied to the feeder from generating stations connected to it. Most of the generating plants are run-of-river and their outputs vary considerably between the wet and dry seasons. On the average, the seasonal output variation ranges between 100 percent and 15 percent of rated capacity. It was therefore decided that loss calculations should be done not only for the two approaches to load allocation, but also for wet and dry season generation levels for each method of load allocation. Therefore, maximum loss calculations were carried out for four different possibilities of loading conditions for each feeder.

20. The distribution analysis software calculated the power (kW) losses for each feeder under given loading conditions. The maximum power losses were used to

---

[2] A 50 percent feeder coincidence factor means that, on the relevant day, the aggregate of the maximum demand of all feeders on the system would correspond to twice the maximum demand experienced by the integrated system. This reflects the fact that maximum demands are not imposed on all feeders at the same time.

calculate annual energy losses by applying a loss factor of 0.43, derived from the empirical formula of loss factor being equal to:

$$c \times \text{Load Factor} + (1 - c) \times (\text{Load Factor})^2$$

where "c" is a constant with a value of 0.2. The annual energy losses were then calculated as the maximum power losses multiplied by 8,760 hours per year and by the loss factor. Annual losses were calculated on the basis of peak losses in the wet season, as well as in the dry season, and the weighted average was determined by application of the hydrological duration curve.

21. Forty-one 10 kV feeders were analyzed, which corresponds to 60 percent of the total number. The sample encompassed the longest 10 kV feeders on the system, supplying urban as well as rural consumers, and also included all 11 feeders to which generating stations were connected. The results of the loss calculations for all feeders are summarized in Table A-2. The table shows reasonable agreement between the results obtained from the different approaches to assumed feeder loading, showing a weighted average of between 2.2 percent and 2.7 percent for annual energy, and between 2.8 percent and 4.3 percent for power losses. The averages are calculated on the basis of net supplies in each instance. If these loss percentages are extrapolated to apply to the whole 10 kV system, it would mean that in 1992 energy losses in the 10 kV system exceeded 9 GWh and that at times of peak demand about 2 MW were lost in that system.

**Table A-2. Loss Calculations. 10.5 kV Feeders**

| *Assumed feeder loading* | *Power loss at feeder peak (% of peak demand)* | *Annual energy loss (% of annual energy supply)* | |
|---|---|---|---|
| Distribution transformers | 4.3 | Dry season | 2.6 |
| Loaded to equal percentage of rated capacity | | Wet season | 2.8 |
| | | Weighted average | 2.7 |
| Feeders operate with a Coincidence factor of 50 percent | 2.8 | Dry season | 2.8 |
| | | Wet season | 2.4 |
| | | Weighted average | 2.2 |

22. **Loss Reduction Measures on the 10 kV Network.** Because it was not possible to evaluate loss reduction options for all 41 feeders in the time available to the ESMAP mission, the 9 feeders with the highest loss levels were selected for loss reduction evaluation. The options evaluated included (a) reconductoring those sections of the feeders in which high loading levels resulted in above-average losses, (b) adding new feeders to reduce the demand on, and average length of, each feeder, and (c) increasing the number of distribution transformers to reduce average transformer loading levels. [3]

[3] Reconductoring involves replacing existing conductors with others of larger cross-section, or (less often) of different material.

The benefit-to-cost ratio of various options for each of the nine feeders was calculated at a discount rate of 12 percent, and the options with the highest net present value selected.

23. The proposed loss reduction measures are calculated to reduce annual energy losses by about 2.5 GWh, based on 1992 system data. These energy savings would correspond to 1.4 percent of the net energy supplies to the system in 1992. Implementation of the recommended system modifications would require a total investment estimated to be about $1 million, or Y 5.7 million.

24. The calculated annual energy savings (again based on 1992 system data) total $0.22 million or more than Y 1 million. The economic payback period is less than four years at an assumed discount rate of 12 percent.

25. **Complementary Observations.** In many instances, the 10 kV lines of adjoining county systems come in very close proximity to those of Xin Chang, but interconnections are not made for administrative reasons. The Xin Chang system could realize considerable benefits by coordinating its system planning with that of adjacent power companies for the following reasons:

- Interconnection of more small hydro stations is desirable from the viewpoint of system stability and effective resource utilization.
- Interconnecting the feeders of adjoining districts will probably result in lower losses and improved reliability.

26. **LV Feeder Analyses.** LV loss analyses were conducted in one urban residential estate and three rural villages. Although the number of systems surveyed is relatively small as a percentage of the total number (775) of LV systems, the results are nevertheless considered representative, since census data show that villages throughout the county are generally similar in size (about 1,000 inhabitants) and that the technical and institutional arrangements for electricity distribution are also virtually identical. In any case, wholesale rehabilitation of all LV systems will not be undertaken on the basis of the results of this pilot study alone, since the losses and economic investment program ought to be calculated individually for each LV system. Therefore, if the sample evaluated in this pilot study is not truly representative, it will primarily affect the estimate of global LV system losses, but should not result in uneconomic investments.

27. Transformer loadings were monitored and recorded over a period of several days for each of the LV systems. The number of consumers served by each transformer was ascertained. Power losses at times of peak demand were calculated for each feeder on the assumption that the demand of each consumer was identical and that the consumers were distributed at equal intervals along the feeder length. The results of the loss calculations are shown in Table A-3.

**Table A-3. Loss Calculations LV Feeders**

| *System* | *Peak demand (kW)* | *Peak losses (kW)* | *Peak losses (% of peak demand)* | *Energy supplied in 1992 (kWh)* | *Energy losses in 1992 (kWh)* | *Energy losses in 1992 (% of supply)* |
|---|---|---|---|---|---|---|
| Da Ta Keng | 39 | 4.8 | 12.3 | 8,830 | 4,625 | 5.2 |
| Shang Shan Xi | 97 | 1.5 | 1.5 | 220,930 | 1,445 | 0.7 |
| Quang Qing | 45 | 1.1 | 2.4 | 102,490 | 1,060 | 1.0 |
| Xin Chang Residential Estate | 216 | 14.4 | 6.7 | 491,960 | 13,880 | 2.8 |

Assumptions: Load factor = 0.26; loss factor = 0.11.

28. A number of assumptions were made in attempting to estimate the total losses in the Xin Chang County LV systems. The main assumptions were as follows:

- The energy supplied to the rural LV systems represented 30 percent of total energy supplies. This assumption is based on data acquired from the power company's billing records, but is not an exact figure.
- The load factor for all systems corresponds to 0.26. On that assumption, a loss factor of 0.11 was calculated by applying the empirical formula previously discussed.
- The urban residential estate for which data was gathered was taken to be representative of all LV systems in urban areas. On this basis, 16 percent of total system energy supplies is assumed to flow through the urban LV systems.

29. With the assumptions listed in the previous paragraph, it is estimated that (a) power losses at peak amounted to 1.9 MW or 5.7 percent of the peak total LV system demand, and (b) energy losses in the LV system were 1.85 GWh per year (1992), corresponding to 2.5 percent of the energy fed into the system.

30. If the villages only are considered, the annual losses amount to 2.3 percent of energy supply. This may appear to be on the low side, but is explained, in part by the relatively low household demand. Another contributory factor is the typical practice in rural China of running separate feeders for domestic and industrial loads. The intention is to be able, in the event of capacity shortages, to interrupt only residential supplies during working hours and only industrial loads at night. However the investment costs are much higher than would be the case with the single feeder design, which is standard practice in most other countries.

31. **Loss Reduction Measures on the LV System.** Despite the relatively low overall level of LV system losses, opportunities exist for a number of measures that can economically reduce losses to even lower levels. One of these measures, balancing the phase currents on multiphase circuits, involves minimal direct, cost but will bring

significant benefits. There was significant imbalance between feeder currents in all four LV feeders evaluated. This condition not only increases losses substantially, but can also lead to problems in voltage regulation. All further options for loss reduction on three-phase circuits were evaluated on the assumption that the phase currents had been balanced.

32. The additional approaches to loss reduction evaluated were (a) conversion of high-loss single-phase feeders to three-phase feeders, and (b) replacing the existing feeder conductors with other larger ones. For two of the villages the recommended measures involved no significant expenditures. One of these villages was Quan Qing village in which the feeder had been installed with conductors for three phases, but only one phase was in use. It was recommended that the feeder be converted to operate with all three phases. The second village with only minimal cost recommendations was Shang Shan Xi, in which phase current balancing only was recommended. As has been previously noted, balancing of phase current was recommended for all the LV systems analyzed, but Shang Shan Xi village was the only instance in which no further loss reduction measure was found to be economic. In summary, it was estimated that an investment of about $8,300 would reduce losses by almost 7 GWh per year (based on 1992 consumption levels) and produce annual savings of more than $6,000. (These savings estimates include those that result from the minimum investment measures.)

33. **Service Drops**. Experience in developing countries has shown that a major contributor to nontechnical losses is the widespread theft of power. Although no instances of theft were observed during the execution of the study, it was reported that on average 16 to 17 such cases were discovered each year in Xin Chang County.

34. Appropriate standards for the design and installation of service conductors, meters, and internal wiring are specified in the National Power Supply and Utilization Code. A stipulation in the code makes the power companies responsible for enforcing its provisions in initial installations and for reinspecting existing wiring. However, the condition of wiring in many locations indicates that the code is not being stringently observed.

## Evaluation and Reduction of Losses in Distribution Transformers

35. Iron (sometimes called "core" or "no-load") losses and copper (also known as "winding" or "load") losses of the distribution system were evaluated based on manufacturers' specifications and average loading levels for each category of transformers. There were three categories (a) 110/35 kV; (b) 35/10 kV; and (c) 10/0.4 kV (MV to LV). Calculations were carried out, using spreadsheets, to estimate losses in all the transformers and evaluate options to reduce them.

### Losses in 110/35 kV and 35/10 kV Transformers

36. In 1992 the Xin Chang power network was equipped with the following:

- Two 110/35 kV transformers (2 x 10 MVA).
- Eleven 35/10 kV primary distribution transformers (1 x 1.8 MVA, 1 x 2.4 MVA, 3 x 2.15 MVA, 1 x 2.2 MVA, 3 x 4 MVA, and 2 x 6.3 MVA).
- Three 10/35 kV step-up transformers installed in the mini hydropower stations (1 x 2.5 MVA, 1 x 4 MVA, 1 x 8 MVA).
- One 35/10 kV customer-owned 35/10 kV transformer (2.15 MVA).

37. Table A-4 presents the results of the calculations of the total losses in the transformers listed above for 1992 system loading data. Peak load losses total about 450 kW, about 1.4 percent of the system peak demand. The calculated energy losses totalled 2.48 GWh, corresponding to 1.4 percent of the total energy supply and about 1.5 percent of the sales in 1992.

**Table A-4. Losses in Primary Distribution Transformers**

| | *Energy losses (GWh)* | | | |
|---|---|---|---|---|
| *Type of transformers* | *Iron* | *Core* | *Total* | *Peak losses (kW)* |
| 110/35 kV | 0.50 | 0.38 | 0.88 | 218 |
| 35/10 kV | 0.55 | 0.60 | 1.15 | 178 |
| Step-up (35 kV) | 0.18 | 0.13 | 0.31 | 35 |
| Customer (35/10 kV) | 0.04 | 0.10 | 0.14 | 18 |
| Total | 1.27 | 1.21 | 2.48 | 449 |

38. **Replacing Transformers in the 35 kV Network.** Transformer losses in the 35 kV systems are high and could be reduced by replacing high-loss transformers and by improved operating procedures. However, the number of these transformers is relatively small (compared to those operating at 10/0.4 kV), and losses cannot be accurately evaluated on the basis of statistical sampling. Nevertheless, calculations based on limited sampling of a small number of 35 kV transformers were made, and if the results of these calculations are assumed to be typical and extrapolated to the entire group, then losses in the 35/10 kV transformers could be reduced by 982 MWh per year for an investment of Y 1.164 million. To determine the economics of replacing these transformers more exactly, a study needs to be undertaken in which the physical and operational characteristics of each of these transformers are individually evaluated. It is therefore proposed that Xin Dian carry out the following:

- A program to collect the relevant data for all transformers in the 35 kV network.
- Calculations of the losses being experienced in each transformer on the 35 kV system.

- Evaluation of options to achieve economic loss reduction by replacing the high-loss transformers or improving operational practices.

## Losses in the 10 kV/LV Transformers

39. Losses were estimated separately for the step-up transformers of the small hydropower stations feeding into the 10 kV network and the distribution (10 kV/LV) transformers. In 1992 the Xin Chang power system had the following:

- Step-up transformers (0.4/10 kV) totalling 5.17 MVA.
- 1,331 distribution transformers (10/0.4 kV) totalling 104.25 MVA.

40. The total energy losses calculated for these transformers are presented in Table A-5. Peak power losses were estimated to be about 891 kW, representing 2.7 percent of the maximum system load in 1992. Energy losses were calculated to be 7.62 GWh, equivalent to 4.2 percent of the energy supplied to the transformers and 4.5 percent of the 1992 sales.

**Table A-5. Losses in 10 kV Transformers**

| | *Energy losses (GWh)* | | | |
|---|---|---|---|---|
| *Type of transformers* | *Iron* | *Core* | *Total* | *Peak losses (kW)* |
| Step-up (0.4/10 kV) | 1.27 | 0.70 | 1.97 | 160 |
| Distribution (10 kV/LV) | 4.54 | 1.11 | 5.65 | 731 |
| Total | 5.81 | 1.81 | 7.62 | 891 |

## Total Transformer Losses

41. Energy losses in the transformers installed in Xin Chang County were calculated to be a total of 10 GWh, of which no-load losses comprised 70 percent. The total losses represent 5.6 percent of the energy supplied to the transformers and 5.9 percent of the sales in 1992.

42. Power losses at times of system peak are estimated to be 1,340 kW, accounting for about 4.1 percent of the peak system demand in 1992.

43. Overall, transformer losses, especially iron losses, are very high, accounting for 75.5 percent of system energy losses and 66.4 percent of the peak power losses in the county in 1992.

## Reduction of Transformer Losses

44. The transformers manufactured in China were very inefficient until about the mid-1970s when the first series of improved transformers, the Series 7 (S7), was introduced. It was followed by a more efficient design, the Series 9 (S9), in the early 1990s. Table A-6 compares the nameplate loss values of the earlier high-loss transformers with the S7 and S9 designs for a range of sizes.

**Table A-6. Losses in Chinese Transformers (kW)**

| *Size* | *High-loss transformers* | | *S7 transformers* | | *S9 transformers* | |
|---|---|---|---|---|---|---|
| *(kVA)* | *Iron* | *Copper* | *Iron* | *Copper* | *Iron* | *Copper* |
| 50 | 440 | 1,130 | 190 | 1,150 | 170 | 870 |
| 100 | 730 | 2,400 | 320 | 2,000 | 290 | 1,500 |
| 250 | 1,660 | 5,200 | 640 | 4,000 | 560 | 3,050 |
| 500 | 2,260 | 8,760 | 1,080 | 6,900 | 960 | 5,100 |
| 2,500 | 10,220 | 29,900 | 3,650 | 23,000 | n.a. | n.a. |

n.a. Not applicable.

45. The efficiency of the S7 transformers compares well with, or may even be somewhat higher than, the typical efficiency of Western transformers in 1980. The newer S9 transformers compare well with current Western state-of-the-art transformers. Chinese government regulations prohibit installation of new high-loss transformers. However, a large number are still operating, as evidenced in Xin Chang where 40–50 percent of the transformers currently on the system are high-loss transformers.

46. The transformer loss reduction analysis focused primarily on the 10 kV transformers because they account for more than 75 percent of the energy losses and 66 percent of the peak power losses. Primary transformers (those operating at 35 kV or above), however, also offer opportunities for economic loss reduction. Since the loading patterns on these transformers vary from location to location, and since the total number is relatively small, it was recommended that loss analyses be undertaken for each of these transformers individually. General recommendations for loss reduction also include improved operational practices and procedures to optimize the utilization of transformer capacity.

47. **Replacement of High-Loss Transformers in the 10 kV System.** The transformers in the 10 kV system were analyzed as a group to evaluate the economic benefits of replacing the high-loss transformers with S7 or S9 transformers. The results are summarized in Table A-7, and show that replacement of the high-loss transformers is economically justifiable, even under conservative assumptions of operating and economic conditions.

**Table A-7. Economic Benefits of Replacing High-Loss Transformers in the 10 kV Network**

| *Program* | *Benefit of replacing high-loss, step-up transformers* | | *Benefit of replacing high-loss distribution transformers* | |
|---|---|---|---|---|
| | *With S7 transformers* | *With S9 transformers* | *With S7 transformers* | *With S9 transformers* |
| Annual energy savings (GWh) | 0.70 | 0.84 | 1.82 | 2.01 |
| Annual benefits[a] (thousand yuan) | 350 | 418 | 905 | 103 |
| Investment costs (thousand yuan) | 1,409 | 1,813 | 4,578 | 5,662 |
| Economic payback[b] (years) | 5.0 | 5.5 | 6.9 | 8.2 |
| IERR (percent) | 33 | 29.8 | 24.2 | 21.0 |

IERR = internal rate of return.
a. At 50 fen per kWh.
b. Discount rate 12 percent.

48. **Step-up Transformers**. The economic benefits of replacing high-loss step-up transformers (for example, 0.4/10 kV) are greater than those that would be realized by replacing the step-down (10/0.4 kV) transformers. This is so because the loading on each step-up transformer is generally closer to its rated capacity, and therefore the winding losses are higher. Replacing step-up transformers with S7 and S9 types was evaluated with the following results:

- Replacement of high-loss, step-up transformers with S7 transformers would reduce losses by 0.7 GWh per year, and the discounted benefits of the energy saved would repay the total investment in the new transformers in five years.
- Replacement of the high-loss transformers with S9 transformers would reduce losses by 0.84 GWh per year. The discounted benefits of the saved energy would pay back the total investment of the new transformers in less than six years if calculated at the base value of power and energy.

49. **Step-down Transformers**. Although the average step-down distribution transformer is not loaded as closely to its rated capacity as the step-up units, calculations show that it is nevertheless economic to replace them with more efficient units. These calculations indicate the following:

- S7 transformers would reduce losses by 1.82 GWh per year and the discounted benefits from the saved energy would pay back the total investment of the new transformers in about 7 years at the base cost of electricity (50 fen per kWh). The payback period would be reduced to about three years if 100 fen per kWh is used as the cost of electricity.

- S9 transformers would reduce losses by 2 GWh per year, and the discounted benefits from the saved energy would pay back the total investments of the new transformers in about eight years at the base cost of electricity.

50. In summary, the calculations show that replacement of high-loss distribution transformers by S7 transformers would be highly economic in all cases considered. Replacement of the existing transformers with S9 units would be less economically attractive, but would still produce net benefits in most instances.

51. It is recommended that Xin Dian prepare an implementation program for replacing high-loss transformers with S7 transformers and concurrently introduce an improved system of transformer load management. The implementation program should focus initially on the company-owned transformers, with priority being given to the step-up units. Transformers owned by consumers would be targeted in a second phase, after introduction of appropriate incentives to make replacement of high-loss transformers financially attractive to the consumers.

52. **Improved Transformer Load Management.** The lower level of losses in the transformers (about 4 percent) which could be realized by replacing the existing transformers with S7 models, would still be high compared to international standards. This is primarily because the maximum loads experienced many transformers, especially those feeding villages, are well below their rated capacity. The no-load losses experienced for 8,760 hours per year are therefore higher than would be the case if the rated capacity were lower and closer to peak demand. Although the peak-load losses with the larger transformers are lower, the peak load period is a very small percentage of the total operating time and does not compensate for the higher no-load losses. The utilization factor (installed capacity peak load, both in kVA) of the 10 kV distribution transformers varies from 3 to 5, resulting in losses as high as 10 percent of input energy in many instances.

53. Transformer losses could be reduced considerably by a transformer load management program designed to ensure optimal use of the transformers by doing the following:

- Redistributing existing transformers among the substations, if the benefits from installing transformers more appropriately sized to the loads outweigh the cost of moving the transformers from one location to another.
- Selecting the most economic transformer size for the load in new installations.

## Customer Management

54. Non-technical losses could be reduced if the organization and operation of customer management systems in Xin Chang County were improved in a number of areas, particularly in technical standards for service entrances, wiring in consumers' premises, and computerization of customer billing and associated information systems.

## Technical and Non-technical Losses

55. An exact figure for non-technical losses at Xin Dian is difficult to compute, because the statistics are clouded by the practice of adding estimated transformer energy losses to meter readings to determine customer consumption for billing. Further, energy used internally at the generating stations is treated as energy sold, while energy used at other power company facilities is not metered and not included in the overall energy accounting. Yet another complication is that statistics for the same parameters vary with the source from which they are obtained. For example, the Financial Department reported sales in 1991 as having been 151.9 GWh, while the figures from the Customer Supply and Management Department indicated sales of 147.1 GWh. It is important for an MIS to be introduced to ensure consistent data collection and calculation, and generate confidence in the statistics presented.

56. Technical and non-technical losses downstream of the power company's meters do not affect its revenues. The cost of these losses is shared by the end consumers in the case of multi-unit residential blocks and villages. Appreciable losses in the service drop conductors and internal wiring are expected from using undersized conductors. These losses have not been calculated. Nevertheless, they represent real losses to the economy because of the costs involved in generating energy that is uselessly dissipated as heat to the atmosphere instead of being productively employed.

## Metering

57. The meter test facilities, consisting of both fixed test benches and portable standards, are of high quality. The records confirm that Xin Dian complies with the provincial requirements for regular checking of the calibration of the test benches and portable standards. The staff in the meter section is well trained and competent to undertake the work. Xin Dian also meets the national standards as set by the National Technology Supervision Bureau for metering accuracy, meter recalibration, and field testing of meters on the premises of large consumers.

58. Large consumers account for about 40 percent of Xin Dian's total sales. The meters recording the consumption of large consumers are recalibrated frequently (one to four times annually), which may be a major factor in deterring power theft by consumers in that category in Xin Chang County. (Some counties report power theft by large consumers as a problem.) The extensive meter calibration program carried out in the field by Xin Dian promotes a high level of confidence in the accuracy of the metering for large consumers.

59. To establish an overall accuracy level for the meters used for consumers who do not fall in the "large" category, and who account for 60 percent of total sales, a sampling of meters was given an "as found" test before they were cleaned and recalibrated. Five percent of these meters were found to under-record consumption (to "run slow") by an average of 2.5 percent. This level of accuracy is typical for the Chinese single-jewel–bearing meters used in Xin Chang.

60. There is no statutory requirement for recalibrating customer-owned meters and those installed to record village supplies. Meter inaccuracies at those levels mean that the bill from the power company is not always shared equitably among all users. The power company has started a program to take over the ownership and maintenance of meters in the villages, which should be completed in five years. This will result in greater consumer confidence in the apportionment of charges.

61. The meter data base is currently maintained manually. Meters are filed by customer numbers that are not cross referenced with the meter serial number. The Meter Section is responsible for asking the power supply bureaus to return meters as they become due for recalibration. The lack of a computerized data base, however, makes necessary a laborious search of the records to determine which meters are due for service.

62. Xin Dian administers an effective program to ensure metering accuracy. This program is considered well above the average for similar counties and can be used as an example for other counties to follow. The efficiency of the meter recalibration program could be improved by computerizing the meter data base that interfaces with the customer information system.

63. It is recommended the MWR initiate a pilot project in a county power company to develop and test a computerized, integrated customer management and information system, including the meter data base, that will be a prototype of computerized information systems for all the county power companies.

## Meter Reading, Billing, and Collection

64. Meters are read and accounts billed monthly. Meter reading routes are reasonably well organized, although the location of many meters makes reading very difficult. A field visit showed that many meters are located nearly three meters above floor level, making a ladder necessary for accurate reading. Some meters are not sealed, and although meter readers are equipped to reseal meters, this task had obviously not been done over several meter-reading cycles.

65. The untidy arrangement of service conductors and connections in many metering installations makes it very difficult to determine if illegal connections exist. There appears to be no pressure on the meter readers to inspect, correct, or report such situations.

66. Bills are prepared using a computerized billing program that is based on general purpose database software. This billing program is a big improvement over manual preparation of bills, which is a particularly onerous task because of the complex

tariff structure. However, the program is really only a bill calculator and does not generate statistical data as is normal with an integrated customer information and billing system.

67. All bills are prepared by the 20th of each month, allowing consumers time to settle their accounts by the due date of the 28th of the month. In each bureau, on completion of bill production, a summary is printed showing the total kilowatt-hours sold, the revenue from the basic charge as well as from each of the additional charges, and the total revenue billed by the bureau concerned. The number of bills issued is not recorded. The summary for each of the power supply bureaus is sent to Xin Dian's Financial Department. This billing summary is later used for comparison with the revenue collections reported by each bureau for the relevant month. Currently the monthly grand totals of kilowatt-hour sales and revenues billed for the entire Xin Dian customer base are not tallied, nor is the number of bills issued recorded.

68. Bills for small customers are sent to the Cash Office. Bills for large consumers are sent to the customer's bank, where the customer's account is debited by the amount of the bill. Bills for villages with bank accounts are also sent to the appropriate bank, while villages without bank accounts (usually the smaller villages) are dealt with in the same manner as other small customers, who must pay cash. In outlying power supply bureaus, all bills must be settled through the local banks, because the small number of customers does not justify establishment of a cash office.

69. Disconnection is carried out quickly when accounts are not paid. The Customer Supply and Management Department has set a target for each of the power supply bureaus to collect 98 percent of the billed revenue each month, and to collect 100 percent of the revenue by year end. Records indicate that the target is essentially being met. Write-off to bad debts is negligible.

70. Billing of villages and urban multi-unit residential blocks as block accounts significantly reduces Xin Dian's work load in meter reading, billing, and collecting, when compared with what would have been necessary if the power company had to deal with each consumer individually. Xin Dian issues about 4,330 bills per month compared to an estimated total of 143,000 end user installations.

71. Xin Dian's collection procedures are effective. Cash inflow is rapid, with only about 2 percent of billed revenue uncollected three weeks after billing. This creditable performance is due in large measure to the automatic payments received through direct debiting of the bank accounts of large consumers and of government agencies. Small consumers are subject to disconnection the day following the due date for payment.

72. The billing processes in about one-third of the county-run power systems in Zhejiang Province are not computerized. The level of penetration of computerized systems in counties in the more remote areas of the country is even lower. It is also unfortunate that there is no standardization of billing programs among the counties that are computerized, since each of the existing systems has reportedly been independently developed.

73. Common billing processes (including computerized programs) should be developed for the DPCs. This would result in programs that address the data requirements more completely and provide greater uniformity in the generation and presentation of such data. It would also simplify the incorporation of improvements to billing programs in all county systems. It is therefore recommended that, before any additional county power companies embark on individual development of billing systems, a pilot project should be carried out in one of the companies, under the sponsorship of the MWR, to develop, install, and test hardware and software for a completely integrated customer services MIS.

74. Customer services MISs for small utilities have been developed and proved in many countries, and are readily available commercially. It is recommended that the MWR investigate obtaining one of these established systems that can be adopted for use in China. Alternatively, the MWR could embark on grassroots development of a system tailored to the unique characteristics of the DPCs. In either case, once it has been successfully proved in use, the program could then become the standard for other decentralized companies to use in computerized billing and customer management systems.

## Service Entrance Equipment

75. The power company has the sole right to determine the location of the meter, but apparently does not exercise it. Many meter locations contribute to the following problems:

- They require the service conductors to pass directly in front of windows or doors.
- They are too high for easy reading.
- They create confusing tangles of wires that make it difficult to identify illegal

76. In general service entrance conductors for high-voltage and other large consumers are over-designed. On the other hand, service drop conductors and internal wiring in premises occupied by small consumers is under-designed and often sloppily installed. Service conductors that are undersized for the load supplied create losses and compromise safety. Untidy workmanship invites theft of power because it considerably reduces the risk of being detected. Under these circumstances, the instances of theft could increase rapidly, especially in the event of large tariff increases.

77. It is recommended that the county power companies enforce the National Power Supply and Utilization Code in accordance with their mandate to decrease losses, eliminate hazards and reduce the risk of power theft in both new and existing installations. In low-consumption service installations, the average size of the service drop conductor should be increased to reduce losses and accommodate future loads better. Conductors should not be routed close to windows and, when run on the sides of buildings, should be installed in metal pipe.

## Tariffs

78. The tariff structure employed in the DPCs conforms with nationally mandated standards and requires complex metering and bill processing. Special tariffs are applied to different types of end use without regard for the effects of the specific characteristics of the demand on the marginal cost of supply.

79. The multiplicity of tariff levels in the structure increases the costs to the consumers for extra meters and wiring, and to the power companies for higher operating costs, including increased meter maintenance, meter reading, and billing activities.

80. It is recommended that the MWR and the Ministry of Electric Power jointly undertake a comprehensive tariff reform to reduce, and eventually eliminate, special use tariffs and to move toward a simplified pricing system based on the economic cost of electricity supply.

# Annex B

## Dong An County in Hunan Province: Second Power Efficiency Pilot Study

1. This annex reports on the second of the two power efficiency pilot studies. This study was undertaken by a team of engineers from the MWR, the Hangzhou Regional Center for Small Hydropower (HRC), and Dong An County Power Company (DACPC), with some assistance from engineers of Xin Dian (the power company in Xin Chang County) in which the first power efficiency pilot study was carried out. ESMAP supervised the preparatory and final stages. In the course of the study, losses were calculated and the economics of loss reduction alternatives evaluated for all 35 kV lines, all 10 kV lines, five LV networks, and most of the transformers.

### Dong An County

2. Dong An County is situated in the south-west part of Hunan Province and has an area of 2,219 square kilometers. Its population was about 560,000 at the end of 1992, of which approximately 500,000 lived in rural areas. There are few industries in this county, unlike in Xin Chang. In 1992 the total industrial output was Y 280 million, while agricultural output amounted to Y 480 million.

### The Power System

3. Historically, Dong An County was supplied by the national grid via two 35 kV feeders that energized a 35/10 kV substation. In 1981, in accordance with the national policy of rural power decentralization, Dong An County Power Company (DACPC) was established and subsequently commissioned the Xiang Jiang hydropower station (21 MW), which supplied a new substation (Bai Ya Si) by a 35 kV feeder. The system was then isolated from the national grid system. However, the national grid still supplies four industrial consumers which are located in the vicinity of the older substation, using one of the two 35 kV feeders for incoming supplies, and a dedicated outgoing 10 kV feeder to each consumer. Recently, DACPC took over the second 35 kV feeder from the national grid, but was not able to connect it to the Bai Ya Si substation as it would have to cross over the four 10 kV feeders of the national grid, which could not be done while these

feeders were in service. At the time of the study, no agreement had been reached between the relevant parties to temporarily de-energize the 10 kV feeders and allow the line construction to take place.

4. DACPC's electricity is supplied entirely by 14 small run-of-river hydro plants (SHPs) with a total installed capacity of 27 MW. It is dominated by the Xiang Jiang plant (21 MW) which in 1992 supplied 96 percent (80.51 GWh) of the total energy transmitted over the 35 kV grid. Being dependent on run-of-river generating stations, the power supply is subjected to seasonal and daily fluctuations according to water availability. During the dry season (November to January), there are massive power and energy shortages, with total generating capacity falling as low as 3 MW. Consequently, there are prolonged power outages during the dry season. However, during the wet season (March to July), energy-intensive industries are placed in operation to take advantage of the surplus energy available.

5. The DACPC is actively investigating ways by which the shortages may be alleviated, either by developing local hydropower potential or by initiating exchange agreements with neighboring counties. Toward this end, DACPC is currently doing the following:

- Constructing a 10 MW seasonal regulation hydro plant (Gaoyan) with commissioning in 1995. Its average annual energy output will be 30 GWh for a year of normal hydrological conditions and 25 GWh for a dry year.
- Rehabilitating the Xian Jian power plant to increase its annual output by 8.7 GWh, which is about 10 percent of current output.
- Negotiating interconnection of the Dong An County system to the 60 MW hydropower plant currently operated and owned by the Quanzhou County in the adjacent Guangxi Autonomous Region.

6. At the beginning of 1993 the DACPC power network comprised (a) an MV (a system of 103 kilometers of 35 kV lines and 804 kilometers of 10 kV lines), and (b) an LV system of 1,360 kilometers of 380 V ( three-phase) and more than 6,000 kilometers of 220 V ( single-phase). The total transformer capacity was 130.15 MVA, comprising 68.75 MVA of 35/10 kV and 61.4 MVA of 10/0.4 kV.

7. **Organization**. The entire MV system (35 and 10 kV) and the LV system in urban areas (the county seat) are operated and maintained by DACPC. DACPC buys power from the 14 SHPs scattered throughout the county, at prices set by the Dong An County government. It then sells the power in bulk to two large industrial customers at the 35 kV level, to state-owned enterprises, industrial customers, and townships at the 10 kV level, and to LV customers (380 and 220 V) in urban areas.

8. DACPC has eight departments: (a) Large Customer Supply and Management, (b) Planning and Design, (c) Dispatch Center, (d) Central Power Bureau, (e) Finance, (f) Personnel, (g) Service and Maintenance, and (h) Rural Substations. Each

department is headed by an assistant manager. They all report to the company manager who is appointed by the county.

9. The 33 townships, each having jurisdiction over a collection of rural villages, are responsible for operating the LV lines in the villages in their own territory. The supply to each township is metered at the 35/10 kV transformer, and the township is billed by DACPC from the bulk meter. In turn, the MV/LV transformer supplying each village is metered, and the township bills the village on the basis of the consumption recorded by that meter. Administration of the village LV network is delegated to a resident electrician who derives his remuneration by adding a margin to the bill of each village consumer.

10. A certain degree of decentralization therefore takes place in the administration of the power sector from the central (Dong An County capital) to the local (village) levels. However, DACPC does not operate as an autonomous corporation and its decisions are often strongly influenced by the provincial and local governments, especially in the areas of (a) tariffs for purchase and sale of electricity, (b) investments, and (c) day-to-day operation of a capacity-constrained system.

11. **Demand Growth**. Between 1982 and 1992, the county's electricity consumption grew at an average annual rate of 9.5 percent. Table B-1 shows that the annual growth rate since 1990 has been dramatically reduced because of the acute shortages of power and energy experienced during this period, especially during prolonged dry periods.

12. Since most of DACPC's sales are metered in bulk at the transformers, energy losses downstream of these meters are reflected in the sales figures and are billed to the consumers. The result is that the true level of system losses is underestimated.

13. According to the power company's 1991 Power Planning Report, energy requirements grew at an average annual rate of 15 percent from 1989 to 1995, when they reached 168 GWh. This estimate seems reasonable considering (a) the current suppressed demand, (b) the expected increase in average individual consumption, and (c) the rural electrification target set by the government (to increase the electrification ratio from 82 percent to 95 percent in the next six years).

**Table B-1. DACPC Electricity Balance**

| | *1982* | *1985* | *1990* | *1991* | *1992* |
|---|---|---|---|---|---|
| Power generation (GWh)[a] | 38.3 | 58.9 | 90.4 | 93.0 | 95.5 |
| Total supply (GWh)[b] | 37.9 | 58.3 | 89.5 | 92.1 | 93.6 |
| Energy sales (GWh)[c] | 29.2 | 47.4 | 82.3 | 85.1 | 86.9 |
| Energy losses | | | | | |
| GWh | 8.7 | 10.8 | 7.1 | 7.0 | 6.7 |
| % total supply | 23.0 | 18.6 | 7.9 | 7.6 | 7.0 |
| % total sales | 30.0 | 22.8 | 8.6 | 8.2 | 7.7 |
| Peak load (MW)[d] | n.a. | n.a. | n.a. | n.a. | 23.0 |
| Load factor | n.a. | n.a. | n.a. | n.a. | 43.5 |

n.a. Not applicable.
a. 1982 to 1991 figures estimated by the study team.
b. Energy metered after step-up transformers.
c. Most sales are metered at 35/10 kV substations or at 10 kV/LV transformers.
d. Only 1992 data are available because of the lack of operational records.
*Source:* DACPC records.

## Feeder Loss Calculations and Loss Reduction Measures

14. **35 kV Network Analysis.** In 1992 the electricity transmitted through DACPC's 35 kV network amounted to 83.7 GWh. Two large industrial customers accounted for 44 percent of the total energy supplied from the 35 kV system. The largest hydropower station in the county, Xiang Jiang with an installed capacity of 21 MW (generated at 6.3 kV), is the major power and energy source. Like the rest of the county's run-of-river hydro plants, Xiang Jiang has virtually no regulation and suffers from seasonal and daily fluctuations in its output. Nevertheless, it supplies 96 percent of the total energy transmitted by the 35 kV network, while the remaining 4 percent comes from the other 13 SHPs.

15. Because of the predominant role the Xiang Jiang power station plays in determining power flows in the 35 kV system, its generation pattern has been used as the basis for analysis of 35 kV losses. Xiang Jiang's daily generation duration curves for 1992 were analyzed using spreadsheets, and the pertinent data are presented in Table B-2.

16. Operational records for several 35 kV feeders were not available, since no meter was installed at the feeder source. In such instances, the hourly power flows were estimated from the operational records of the associated substations.

**Table B-2. Summary of Xiang Jiang Energy Generation, 1992**

| *Maximum daily generation (June 11, 1992)* | *406.00* |
|---|---|
| Annual load factor[a] | 0.54 |
| Annual loss factor[b] | 0.38 |

a. Annual load factor = (actual energy generation in kWh) / (rated capacity in kW x 8,760).
b. Estimated.
*Source:* Study team estimates.

17. The 35 kV network energy losses were analyzed using two different methodologies. In one instance, the power loading records of each feeder was selected for the day on which the Xiang Jiang energy generation was at a maximum. Peak power and energy losses for that day were calculated. Annual energy losses of each feeder were then computed, assuming that the shape of the annual duration curve of the Xiang Jiang station was typical for all feeders. The 35 kV network energy losses were then calculated as the aggregate of the losses of all feeders. A summary of the results is presented in Table B-3.

**Table B-3. Annual Energy Losses on the 35 kV Network System**

| *Feeder name* | *Peak demand* | *Peak losses* | | *Maximum daily energy losses (kWh)* | *Annual energy losses (MWh)* |
|---|---|---|---|---|---|
| | *(kW)* | *(kW)* | *(%)* | | |
| 3501 | 12,000 | 769 | 6.4 | 15,030 | 2,079.4 |
| 3502 | 2,660 | 42 | 1.6 | 270 | 37.2 |
| 3503 | 3,300 | 9 | 0.3 | 150 | 20.8 |
| 3504 | 2,125 | 40 | 1.9 | 230 | 32 |
| 3505 | 665 | 4 | 0.7 | 30 | 4 |
| 3506 | 7,000 | 14 | 0.2 | 210 | 28.8 |
| 3507 | 400 | 1 | 0.2 | 10 | 0.6 |
| 3508 | 7,093 | 43 | 0.6 | 620 | 86.1 |
| Total annual energy losses | | | | | 2,288.9 |

*Source:* Study team calculations.

18. The annual energy losses of the 35 kV networks for Dong An County in 1992 are calculated to have been 2.29 GWh. The annual energy losses of the 35 kV networks were also calculated using an alternative methodology. Daily generation duration curves of Xiang Jiang power station for 1992 were analyzed and categorized into three generation periods: wet, normal, and dry. Each of these periods was adequately represented by the generation pattern of specific days in 1992, which were March 4, June

20, and November 17 for the wet, normal, and dry periods, respectively. The energy losses for each of the three generation periods were calculated and summed to arrive at total energy losses of 2.39 GWh for 1992, which is acceptably close to the value obtained when using the other methodology previously described.

19. **Economic Evaluation of 35 kV Reinforcement.** One of the options evaluated for reducing losses on the 35 kV network was to reduce the power flow on Feeder 3501. This feeder experiences very high losses at times of peak demand, as can be seen in Table B-3 There is a section of Feeder 3502, 7.8 kilometers in length, which extends from the tee-off point near the Jing Tou Xu substation to the Bai Ya Si substation. This section, referred to as Feeder 3502A, is currently not in service because connecting it to DACPC's Bai Ya Si substation would mean crossing over the national grid's 10 kV feeders, and the problem of de-energizing the 10 kV feeders had not been resolved at the time of the study. If the span over the 10 kV feeders (about 300 meters in length) could be installed and energized, it would enable part of the power flow in feeder 3501 to be redirected to 3502, thereby relieving the overloading on feeder 3501, as well as improving the reliability of the network.

20. The other group of options evaluated involved reconductoring of high-loss feeders. Of the alternatives investigated, only reconductoring of the heavily loaded Feeder 3502 met the economic criteria established for acceptance in the list of recommendations.

21. Economic evaluation of loss reduction measures were based on the following parameters:

- Material and construction costs were taken from countries similar to China in which procurement of goods and services was undertaken by international competitive bidding.
- The economic cost of energy was taken as Y 0.5 per kWh for base calculations, with sensitivity analyses carried out for Y 1.0 per kWh as well.
- A discount rate of 12 percent.
- A load growth rate of 15 percent per year, in accordance with company forecasts.
- Investments that resulted in economic payback periods greater than six years were rejected.

22. The calculations show that by closing the 300 meter gap across the 10 kV feeders with the same conductor size as used for the rest of Feeder 3502A, about 0.63 GWh of energy losses could be saved annually, with minimal investment and a very short economic payback period. At the same time, the losses at feeder peak would be reduced by about 240 kW, thereby helping to conserve system capacity.

23. The calculations also showed that it would be economic to reconductor the initial 12.7 kilometers of Feeder 3502 up to the tee-off point, and the 8.1 kilometers of

Feeder 3502A (including the new 300 meter section) with 120 square millimeter conductor instead of the 70 square millimeter conductor currently installed. The peak demand on the feeder would then be reduced by 370 kW and annual energy losses by about 0.98 GWh. The investment required is estimated to be Y 1.03 million, providing an economic payback period of two years.

24. Table B-4 shows the investments recommended for implementation, together with the potential reduction in the 35 kV network energy losses.

**Table B-4. Recommended 35 kV Investments**

| *Investment alternative* | *Investment (yuan)* | *Peak losses saving (kW)* | *Annual energy saving (MWh)* | *Annual financial saving (yuan)*[a] | *Economic payback (years)* |
|---|---|---|---|---|---|
| A1[b] | 9,900 | 240 | 630.5 | 315,250 | 0.03 |
| A2[c] | 1,030,000 | 370 | 976.5 | 488,250 | 2.0 |

a. Based on cost of energy of Y 0.5 per kWh.
b. 300 meters of 120 square millimeter three-phase conductor.
c. 12.7 kilometers for part of feeder 3502 and 8.1 kilometers for 3502A, including the new 300 meters reconductored with120 square millimeter three-phase conductor.
*Source:* Mission estimates.

25. **Evaluation of 10 kV Network Losses.** The Dong An County 10.5 kV network comprises 32 overhead feeders with a total length of about 800 kilometers. Thirteen small hydropower plants feed directly into the 10 kV network, supplying 23.4 percent of the energy transmitted through the 10 kV network. The remaining 75.6 percent of the transmitted energy comes from the 35/10 kV step-down substations.

26. Detailed simulations of the entire 10 kV distribution system for the reference year 1992 were carried out by the study team. Data on the system were obtained from the following:

- Hourly records of feeder loads collected at the 35/10 kV substations.
- Monthly kWh records on each feeder collected at the 35/10 kV substations.
- Monthly feeder operating hours collected at the 35/10 kV substations.
- Hourly output records collected at the small hydropower stations.
- Plant operating hours collected at the small hydropower stations.
- Field measurements.

27. In summary, the calculated peak power losses amount to *367 kW, that is, 1.8 percent of the 10 kV system power peak* (about 20.5 MW) and 1.5 percent of the DACPC system peak (about 24 MW). The annual energy losses amount to *619.4 MWh,*

*that is, 1.0 percent of the total energy transmitted through the 10 kV system* to the consumers and 0.66 percent of the sales.

28. The low levels of both power and energy losses on the 10 kV system are more indicative of the low values of peak and average loads than of network quality. Load factors of all 10 kV feeders were found to be below 0.50, even though the days when the feeders were de-energized, because of the load shedding, have not been taken into account. If the major supply problems of the county are solved in the near future, the level of losses will soon become a major constraint.

29. Although the average value of energy losses is low, some feeders show fairly high losses. Table B-5 presents the losses calculated for the feeders with the worst loss performance.

30. Losses in 10 kV feeders as presented in DACPC official statistics appear to be much higher (25 percent, including MV and LV transformation losses) than the study's estimates. The higher values do not seem to be realistic, considering the physical and technical characteristics of the lines, as well as their loading patterns and levels. The discrepancy could be explained by the poor quality of the meters the townships use in the villages. Accuracy of these meters and accuracy of the billing records should be carefully and periodically checked, since this discrepancy might indicate that financial losses are being sustained by DACPC and the townships.

31. At times of peak demand, the power factor on most feeders is generally good (above 0.93). From statistics on kWh recordings at the main substations, the average system power factor is calculated to be about 0.93. These figures seem to indicate that power factor is not currently a major issue, probably because of the low industrial demand. Nevertheless, appropriately targeted studies might identify localized opportunities for improvement in this area if additional measurements are conducted and analyzed.

**Table B-5. Losses on the Most Heavily Loaded 10 kV Feeders**

| *Feeder number* | *Energy transmitted annually (MWh)* | *Annual energy losses (MWh)* | *Losses (% of energy input)* |
|---|---|---|---|
| 1023 | 1,060 | 17 | 1.6 |
| 1026 | 710 | 10 | 1.4 |
| 1054 | 510 | 9 | 1.8 |
| 1063 | 1,110 | 45 | 3.1 |
| 1022 | 800 | 20 | 2.5 |
| 1052 | 3,110 | 74 | 2.4 |
| 1031 | 1,020 | 18 | 1.8 |
| 1062 | 1,000 | 34 | 3.4 |

*Source:* Study team calculations.

32. To confirm the first estimates of losses, a case study was undertaken with loads on the lines equal to 50 percent of the total installed transformer capacity for feeders not connected to small hydropower plants. (Fifty percent was selected because that is the approximate ratio between peak system demand and installed transformer capacity.) The power losses were found to be 2.7 percent of peak power on these feeders, while the energy losses were found to be 0.74 percent. These figures are in reasonably close agreement with the result (1.8 and 1.0 percent, respectively) obtained for the whole system, which gives some confidence in the results.

33. **Economic Evaluation of Reconductoring Proposals.** Feeders with high energy losses, as listed in Table B-5, were targeted for reconductoring. Proposed investments with economic payback periods of more than 6 years were rejected for implementation. The calculations were carried out on the basis of an annual load growth rate of 15 percent, the cost of energy being Y 0.5 per kWh with a discount rate of 12 percent. In the economic analyses for feeders without connected hydropower plants, annual operating hours were assumed to be the full 8,760 hours instead of the current annual operating hours, since the planning study must anticipate a stable supply as the normal operating situation. For feeders to which hydropower plants were connected, the 1992 duration curves were used in the economic analyses, because the seasonal variation in the output of these plants will continue.

34. The investments recommended for reducing losses on, and generally improving the performance of, the 10 kV networks are presented in Table B-6. *The calculations show that 89.9 MWh could be saved annually for a total investment of Y 99,100 with an average economic payback time of two years.* The reduction in losses represents about 0.2 percent of the total energy estimated to have been transmitted over the 10 kV lines in 1992.

**Table B-6. Recommended Reconductoring Investments on the 10 kV System**

| *Feeder number* | *Investment* | *Annual savings* | | *Economic paybackperiod* |
|---|---|---|---|---|
| | *(yuan)* | *(MWh)* | *(yuan)*[a] | *(years)*[b] |
| 1043 | 17,600 | 12.2 | 6,100 | 2.5 |
| 1044 | 17,500 | 8.4 | 4,200 | 3.4 |
| 1045 | 64,000 | 69.3 | 34,650 | 1.7 |
| Total | 99,100 | 89.9 | 44,950 | 2.0 |

a. Economic cost of energy: Y 0.5 per kWh.
b. Discount rate of 12 percent and annual growth rate of 15 percent.
*Source:* Study team calculations.

## LV Network Analysis

35. There are 33 townships and 14 urban areas in Dong An County. Detailed studies of LV systems were carried out in three rural villages, a rural town and an urban residential area. These five samples were randomly selected, but are considered to be typical of the systems in the county, on the basis of annual electricity consumption and the daily loading patterns. The important characteristics of these systems are shown in Table B-7.

**Table B-7. Characteristics of Selected LV Samples**

| *Location* | *Transformer capacity (kVA)* | *Annual energy consumption (kWh)* | *Loading level* | *Number in category* | *Category total (annual energy) (GWh)* | *Percentage* |
|---|---|---|---|---|---|---|
| Da Niao Tang | 30 | 7,250 [a] | Light | 108 | 0.78 [b] | 3.2 |
| Shan Kou Tang | 30 | 10,590 [a] | Medium | 245 | 2.6 [b] | 14 |
| Shui Jing | 50 | 36,530 [a] | Heavy | 334 | 12.2 [b] | 65.7 |
| Dan Qiao Pu | 100 | 105,346 [a] | Heavy | 18 | 1.94 [c] | 10.4 |
| Railway station | 160 | 272,800 [b] | Heavy | 4 | 1.05 [c] | 5.7 |
| Total | n.a. | n.a. | n.a. | n.a. | 18.57 | 100 |

n.a. Not applicable.

a. Obtained from township billing records.

b. Study team estimates.

c. Obtained from power company billing records.

36. The power and energy losses calculated for the LV systems in these five townships are shown in Table B-8.

37. Total annual energy losses on the LV networks in Dong An County were estimated by matching each line in the county with one of the samples for which the calculations were made, and assuming that the loss percentages calculated for the proxy line would also be valid for all lines selected as being similar. Matching of the lines was done on the basis of similarity of the characteristics given in Table B-7. *On this basis, the annual energy losses for the entire LV network system in 1992 were estimated to be 928 MWh that is,* about *5.0 percent of the energy supplied to the LV systems.* These losses are estimated to be subdivided as 3.2 percent for rural villages, 11.2 percent for townships, and 5.5 percent for urban areas.

38. The low loss figures for rural villages are not an indication that the rural distribution networks are well designed and maintained, but rather a reflection of the very low demand of rural agricultural households, whose basic need is for lighting. If the annual growth in electricity consumption is in fact maintained at 15 percent as forecast

for the whole county up to 1995 (Dong An County Power Company "Power Planning Report—September 1991"), the losses will inevitably increase rapidly.

**Table B-8. Results of the LV Network Loss Study**

| *Township* | *Peak demand* | *Peak losses* | | *Annual energy supplied* | *Annual energy losses* | |
|---|---|---|---|---|---|---|
| | *(kW)* | *(kW)* | *(%)*[a] | *(kWh)* | *(kWh)* | *(%)*[b] |
| Da Niao Tang | 7.5 | 0.1 | 1.3 | 7,250 | 90 | 1.2 |
| Shan Kou Tang | 21.3 | 0.8 | 3.8 | 10,590[c] | 220 | 2.1 |
| Shui Jing | 23.5 | 2.2 | 9.4 | 36,530[c] | 1,750 | 3.8 |
| Dan Qiao Pu | 79.9 | 15.0 | 18.8 | 105,350[c] | 5,580 | 5.3 |
| Railway station | 73.6 | 12.0 | 16.3 | 272,800[d] | 15,000 | 5.5 |

a. Peak losses expressed as a percentage of peak demand.
b. Energy losses expressed as a percentage of annual energy supply.
c. Obtained from 1992 township billing records.
d. Based on study team measurements.

39. The effect of load growth on LV network losses and voltage profiles has been simulated in the case studies by assuming doubling of household demand. Unless corrective measures, such as those recommended below, are carried out to reinforce the LV networks, peak losses and voltage drops will exceed tolerable levels for most LV systems, the exceptions being rural villages with very low consumption levels, such as Da Niao Tang.

## Economic Evaluation of Reconductoring and Restructuring of the Sample LV Networks

40. Studies have been made of a number of options to reduce peak losses and improve voltage profiles for the sample LV systems, in order to maintain an acceptable quality of service. Cost-benefit evaluations of each option have also been carried out to compare the savings in energy losses with the investment costs needed. The economic evaluations were based on the benefits of loss reduction and of reduced voltage drop. Improvements were recommended whenever voltage levels fell below 85 percent of nominal, even if the investments could not be economically justified solely on the basis of reducing power and energy losses. Consumer demand cannot be considered to have been served under conditions of extreme low voltage.

41. Table B-9 summarizes the costs and benefits of recommended improvements for four sample case studies. Typically, balancing of phase loading in existing three-phase feeders is a minimum-cost option, and therefore a highly cost-effective approach to reducing network losses and improving voltage profiles. The other investments involve restructuring and reconductoring the lines, especially (a) conversion of overloaded single-phase feeders to three phases and (b) replacing existing conductors

with others of larger cross-section. System loading in Da Niao Tang village is so low that no corrective action, other than phase balancing, is proposed, and probably none will be needed until the demand increases about threefold.

**Table B-9. Recommended Investments for the LV Sample Networks**

| *Network* | *Investment (yuan)* | *Peak losses saving (kW)* | *Annual energy saving (kWh)* | *Annual gain (yuan)* | *Economic payback (years)* |
|---|---|---|---|---|---|
| Shan Kou Tang | 950 | 0.2 | 117 | 59 | 7.5 |
| Shui Jing | 2,100 | 0.6 | 546 | 273 | 3.7 |
| Dan Qiao Pu | 10,880 | 10.3 | 5,219 | 2,610 | 3.0 |
| Railway station | | | | | |
| Feeder 1 | 1,400 | 0.5 | 1,736 | 868 | 1.4 |
| Feeder 2 | 1,100 | 0.6 | 1,980 | 990 | 1.0 |

42. The results in Table B-9 were extrapolated for the entire DACPC LV system to obtain a rough estimate of (a) the potential for energy savings in the LV networks and (b) the investment needed to realize this potential:

- The potential for annual reduction of energy losses in the rural LV networks is about 0.32 GWh, equivalent to Y 158,400 savings per year, for an investment of Y 1.016 million, which corresponds to an economic payback period of 3.2 years.
- The potential for annual reduction of energy losses in the urban LV networks is about 0.03 GWh, equivalent to Y 15,500 savings per year, for an investment of Y 21,700, which corresponds to an economic payback period of 1.2 years.

## Evaluation of Transformer Losses and Loss Reduction Measures

43. Iron and copper losses of installed transformers were evaluated on the basis of the technical characteristics supplied by the manufacturers, recognizing the different average loading patterns for each category of transformer: 35/10 kV, 35/0.4 kV, and 10/0.4 kV. The losses were calculated using the same methodology as was employed in Xin Chang County during the first pilot study.

44. **35 kV Transformers.** At the end of 1992, the following transformers were connected to the Dong An County 35 kV system:

- Eleven 35/10 kV primary distribution transformers (1x0.75 MVA, 5x1 MVA, 3x1.6 MVA, 1x8 MVA and 1x10 MVA).

- Two 6.3/35 kV step-up transformers installed in small hydro stations (1x10 MVA and 1x16 MVA).
- Two 35/10 kV customer-owned transformers (1x5 MVA and 1x5.6 MVA).
- Two 35/0.4 kV customer transformers (2x1.8 MVA).

45. Table B-10 presents the results of loss calculations for the transformers listed above. The losses are calculated to be 1.68 GWh, corresponding to 1.8 percent of the total energy supply and 1.9 percent of the energy sales in 1992.

**Table B-10. Energy Losses in the 35 kV Transformers**

| *Transformer type* | *Annual energy losses (GWh)* | | | *Peak losses (kW)* |
|---|---|---|---|---|
| | No-load losses | Load losses | Total | |
| 35/10 kV | 0.40 | 0.23 | 0.63 | 208 |
| 6.3/35 kV | 0.25 | 0.37 | 0.62 | 192 |
| Industrial customers | 0.19 | 0.24 | 0.43 | 170 |
| Total | 0.84 | 0.84 | 1.68 | 570 |

46. **10 kV Distribution and Step-up Transformers.** Losses were estimated separately for (b) the distribution transformers (10/0.4 kV) interconnecting the MV and LV systems, and (b) the step-up transformers (0.4/10 kV) at the small hydropower stations feeding into the 10 kV network.

47. Seven hundred and sixty-four distribution transformers, with aggregate rated capacity of 50.2 MVA, were analyzed. The losses in these transformers were calculated to be 2.04 GWh, that is, 2.2 percent of system total energy supply, 2.3 percent of total energy sales, and 3.7 percent of the energy supplied to 10 kV network. Iron losses accounted for 80.4 percent of the losses. The total distribution transformer capacity installed on the system is 61.4 MVA. Therefore, by extrapolation, *the total energy lost in all the distribution transformers was 2.4 GWh* in 1992, that is, *2.5 percent of the total energy supplied to the system,* 2.8 percent of sales, and 3.3 percent of energy supply to the 10 kV networks.

48. The county power system has 21 0.4/10 kV step-up transformers installed in small hydro stations, representing an aggregate rated capacity of 7.4 MVA. The losses in these transformers were estimated to be *0.32 GWh* in 1992, corresponding to *0.3 percent of the total energy supplied to the system,* 0.4 percent of total sales, and 2.3 percent of the energy input to them. Table B-11 summarizes those results.

**Table B-11. Losses in the 10 kV Distribution and Step-up Transformers**

| *Transformers description* | *Annual energy losses (GWh)* | | | *Peak losses (kW)* |
|---|---|---|---|---|
| | *No-load losses* | *Load losses* | *Total* | |
| 0.4/10 kV transformers | 0.17 | 0.15 | 0.32 | 138 |
| 10/0.4 kV transformers | 2.00 | 0.4 | 2.4 | 659 |
| Total | 2.17 | 0.55 | 2.72 | 797 |

## Total Transformer Losses

49. Energy losses in the transformers installed in Dong An County amounted to 3.40 GWh, of which no-load losses comprise 68 percent. These losses accounted for 3.7 percent of the energy recorded as having been supplied to the system and 5.1 percent of the sales, all in 1992. Power losses in the transformers at times of system peak were estimated to be about 1.37 MW, corresponding to 5.7 percent of the peak demand (24 MW) in 1992. The no-load component contributed 29.2 percent of the power losses.

### Economic investments to reduce transformer losses

50. Most of the transformers installed on the Dong An County system (about 70 percent) are old, inefficient transformers, with much higher losses than the presently available S7 series (see Table B-6). Evaluation of the feasibility of replacing all 10 kV distribution and step-up transformers with new units of the S7 series was undertaken. Not all 35 kV transformers were considered for replacement by the S7 series. The more efficient but more expensive S9 series transformers were not considered as replacement alternatives, since the economic analysis made for Xin Chang County, where conditions are more favorable for such replacements, had shown that it was more economic to install the S7 units than the S9.

51. The economic analyses for step-up transformer replacements were carried out under the assumption that the current loading levels and patterns will remain unchanged, since these patterns are primarily determined by hydrology. For the other transformers, it was assumed that the interruptions of supply such as were experienced during the dry months of 1992 will not recur during the life of the replacement transformers. Average load factors for the new transformers were therefore estimated to be similar to those of Xin Chang. However, even these values are quite low, and could be increased by improving the diversity of demand. The results of calculations for the viability of transformer replacements are therefore considered conservative.

52. The results of the economic evaluation of transformer replacement are summarized in Table B-12. They indicate that if low-loss units were installed to replace the 315 transformers that have the highest losses, *energy losses would be reduced by 1.1 GWh per year, that is, 1.2 percent of total supply to the system in 1992.* The calculations

also show that the low load factors of the transformers currently installed make wholesale replacement of all transformers a marginally economic investment, if the value of the energy saved is set at 50 fen per kWh. This calculation must be treated with caution, since the load factors will improve if the supply problems are resolved and if the demand continues to grow rapidly. However, transformers are normally replaced on the basis of evaluation of individual units. Periodic measurements and records of the loading of each transformer should therefore be made to allow determination of the appropriate time for replacing old transformers. In the interim, transformers that become damaged and which have to be removed from service should be replaced with new lower-loss S7 models, as recommended in the national guidelines.

**Table B-12. Economic Evaluation of Transformer Replacements**

| *Transformer type* | *Replacement* | | *Investment* | *Annual energy saved* | *Annual savings* | *Economic payback* | *IERR (%)* |
|---|---|---|---|---|---|---|---|
| | *Number* | *kVA* | *(yuan)* | *(MWh)* | *(yuan)* | *(years)* | |
| 10 kV distribution | 297 | 24,080 | 3,185,000 | 747.9 | 374,000 | n.a. | 8 |
| 10 kV step-up | 11 | 3,500 | 295,300 | 63.8 | 31,900 | n.a. | 7 |
| 35 kV step-down | 4 | 3,800 | 275,000 | 79.8 | 39,000 | n.a. | 12 |
| 35 kV Iron alloy factory | 1 | 6,300 | 225,000 | 133.4 | 66,700 | 3.6 | 29 |
| 35 kV fertilizer factory | 2 | 3,600 | 220,000 | 69.8 | 34,900 | 12.5 | 14 |
| Total | 315 | 41,280 | 4,200,300 | 1,093.7 | n.a. | n.a. | |

n.a. Not applicable.
*Source:* Study team calculations.

53. Losses in the 10 kV distribution transformers could be greatly reduced if the capacities of the individual transformers were more appropriately matched to the demands they serve. The transformers in two of three randomly selected villages were oversized. The peak demand in one of these villages, Da Niao Tang, is 8 kVA, but the transformer installed is rated at 30 kVA. In the other village, Shui Jing, the peak demand is 25 kVA, but the capacity of the transformer is 50 kVA. Most of the villages are said to be supplied with 50 kVA transformers, which would be oversized in the majority of cases, considering the relatively low peak demand currently being experienced. A transformer load management program should be implemented to ensure better coordination between consumer demands and transformer capacities. In such a program,

the villages would be assessed individually, field measurements being undertaken periodically to determine the most economic transformer size in each instance.

## Customer Management

54. Responsibility for customer management is shared by three groups: (a) the Large Customer Supply and Management Department, (b) the Central Power Bureau; and (c) five rural substations. The head of each of these groups reports to the general manager. The Large Customer Supply and Management Department is responsible for administration of large industrial customers, inspection of supply installations, and calibration of meters. The Central Power Bureau, has jurisdiction over the remaining urban supplies, and the five rural substations are responsible for system operation and maintenance, meter reading, billing, and cash collection in the areas under their respective jurisdiction. Each of these groups employs about 11–16 staff, and together they comprise about half the total number of employees in the power company.

55. Electricity is delivered to large consumers at 35 kV or 10 kV. There are eight relatively large industrial factories, in each of which the installed transformer capacity is greater than 320 kVA. Some of these installations are supplied by dedicated 35 or 10 kV feeders, in which cases the energy meters are installed in the source substations. Some consumers own the transformers at the receiving end.

56. Power is supplied to the townships at the 10 kV level, and the townships' energy consumption is normally measured by a meter located at the 35/10 kV transformer. In the event of branches in a 10 kV feeder supplying a number of townships, a pole-mounted meter is installed to measure the consumption of each branch. The townships are then billed on the consumption recorded by the relevant meter. Each township may supply one or more villages. The village customers receive electricity through one or more 10/0.4 kV transformers that are owned by the village. A meter is installed on the secondary side of the transformer, and its readings provide the basis on which the township bills the village. The village resident electrician is responsible for reading household meters, issuing bills, and collecting payment. The system, as practiced, provides incentives at each administrative level to reduce technical and non-technical losses, but the staff are not always aware of the methodologies by which these efficiency goals may be achieved.

57. In the main city, the Dong An County Seat, metering is carried out in two ways: (a) each individual customer receiving electricity directly from the company's main service conductors has his own meter; and (b) state-owned enterprises and industrial consumers may sub-meter supplies to other consumers; for this purpose, secondary meters are installed downstream of the main meter. The owner of the primary meter is responsible to the power company for all energy consumed, but collects appropriate revenues from the downstream consumers by reading the secondary meters. All meters are owned by the consumers. DACPC does not adjust meter readings to compensate for transformer losses, as is done in Xin Chang County.

## Meter Calibration

58. The meter calibration laboratory is a section of the Large Customer Supply and Management Department, and is equipped with high-quality test benches. Its four employees are skilled and qualified to do testing and recalibration to the degree of accuracy required by the national standards. A meter database has been established, the files being kept manually. Company records for 1992 indicate that large industrial customers accounted for 71 percent of total energy sales. The company therefore places great emphasis on testing and recalibrating these meters twice each year.

59. The townships may send their meters to the power company for testing and recalibration. However, because the power company charges for its calibration services, the townships appear reluctant to avail themselves of these services. The Central Power Bureau is more assiduous in ensuring that its meters (recording the consumption of urban consumers) are periodically tested and recalibrated, if necessary.

## Meter Reading

60. Meters are read each month. Generally on the 24th–25th of each month, the meters at the six substations and eight large industrial factories are read by the Large Customer Supply and Management Department. At the same time, the village transformer meters are read by each township power bureau. In the urban area, the Central Power Bureau takes meter readings for large consumers, such as small factories, government agencies, and commercial consumers, on those days. The meters of urban residential consumers are read between the 1st and 7th of each month by nine meter readers (from the Central Power Bureau). If the meter disc is not turning when the meter is to be read, the power company requires its meter readers to check its condition by imposing a load (such as switching on one or more lights) to ensure that the meter is operating correctly before taking the reading. The route assigned to each meter reader is changed every two to three years to minimize the risk of collusion between the reader and consumers.

61. Meter reading in the county as a whole requires much physical effort and can be hazardous at times. Many meters are located on walls, 2 or 3 meters above floor level, and it is difficult to read them without a ladder. Meters on distribution transformers are located about 3 meters up the concrete poles near bare, live conductors. The study team visited one of the sample villages chosen for the LV study and found the distribution transformer simply placed on stone slabs at ground level, without any fencing whatsoever. The incoming and outgoing conductors were not insulated.

62. It is recommended that DACPC define and enforce acceptable technical standards for (a) meters, (b) metering installations, and (c) transformers and lines. Efforts should be made to ensure that the low incidence of theft and tampering that currently prevails is maintained. This will require special attention to training meter readers and monitoring their performance. The meter readers should be trained to recognize electrical hazards; detect unauthorized connections, meter tampering, and other instances of power theft; and report irregularities in these areas to the appropriate authorities.

## Billing and Collection

63. Table B-13 presents some of the more important performance data of customer management in the Dong An County Power Company.

64. Bills are issued manually. Urban residential consumers receive the bills at the time that the meters are read (the 7th to 8th of each month). Payments are due by the 15th of the month. In rural areas, electricians from the township power bureaus visit the villages, read the meters on the transformers, and present the bills to the village electricians. These activities are generally finished before the 8th of each month. Recent company records show that the townships pay their bills promptly.

65. Bills for large industrial consumers are also issued when the meters are read (on the 24th or 25th of each month) and must be settled within two weeks of delivery. Although the large industrial enterprises consumed around 70 percent of total energy sales in 1992, the power company records show that 27 percent of the revenue billed to these consumers had not been paid by the end of that year. Accounts receivable amounted to 57.6 percent of billed revenue in 1992, as shown in Table B-13. This situation creates serious cash flow and long-term financial problems for the company, and has led to DACPC delaying payments for its purchases of energy from the small hydro power plants.

**Table B-13. DACPC Customer Management**

| | *1988* | *1989* | *1990* | *1991* | *1992* |
|---|---|---|---|---|---|
| Energy billed (million yuan) | 5.814 | 6.492 | 8.304 | 9.329 | 10.932 |
| Sales (GWh) | 72.1 | 71.5 | 82.3 | 85.1 | 86.9 |
| Money recovered (million yuan) | 5.233 | 3.951 | 7.167 | 8.396 | 8.827 |
| Arrears since 1988 (million yuan) | 0.581 | 2.122 | 3.259 | 3.192 | 6.297 |
| Arrears (months of Sales) | 1.2 | 3.9 | 3.7 | 5.4 | 6.9 |
| Percentage of revenues uncollected | 10 | 23.7 | 13.7 | 10 | 19.3 |
| DACPC debt (million yuan) | 1.328 | 2.255 | 5.432 | 7.910 | 7.094 |
| Average tariff (yuan) | 0.08 | 0.09 | 0.10 | 0.11 | 0.126 |

*Source:* DACPC and study team estimates.

66. Disconnection of supply to delinquent consumers is said not to be politically feasible. If this attitude cannot be changed, other remedies are urgently needed to facilitate the operation of DACPC as a viable commercial enterprise. An approach may be for the company to negotiate appropriate payment procedures with large industrial consumers and to set penalties for late payments. Since these consumer-companies are government-owned, arrangements based on budgeted payments over the course of the

year, with adjustments at the end of the year to reconcile payments made with actual consumption, appear to be a workable solution.

67. DACPC should develop plans to computerize preparation and printing of bills, and customer records, and meter inventory, and should acquire the hardware and software needed. This would greatly assist in management control by promptly identifying problem areas, and by providing reliable data for corporate and system planning. This recommendation is similar to that made for Xin Chang County,

## Service Connections

68. Much of the service wiring in the urban areas uses conductors that are too small and which are poorly installed. It is not uncommon to see connections to the overhead LV feeders, made by employees of the power company, which are very crude in appearance. Such connections encourage theft of power by making it difficult to distinguish between authorized and unauthorized connections. Although power theft by residential consumers is not considered a major contributor to non-technical losses, a number of instances have been recorded. Every effort needs to be made to prevent such instances from increasing as power tariffs rise.

69. The wiring in the rural villages visited by the study team was even worse. Service conductors appeared not only to be too small, but non-standard as well. Connections were made to overhead LV feeders with uninsulated wires and in several instances, stones were tied to these wires to increase the pressure at the contact points with the feeder and to prevent them from touching adjacent phases.

70. DACPC should develop and enforce standards for service drops, and insist that all services, whether supplied directly by the company or by the townships and villages, conform to these standards. Premises should not be connected (or should be disconnected if supplies have already been established) wherever the safety of the installation is questionable.

## Summary

71. In the entire Dong An County, the total energy losses in the power system, including transformers, were estimated to be 7.7 GWh, representing about 8.1 percent of the total energy generated. The mission has identified measures by which the annual energy losses in the power system could be economically reduced by an estimated 1.42 GWh per year for a total investment of Y 2.166 million. The investments required and their economic benefits are summarized in Table B-14.

**Table B-14. Summary of Recommended Investments by Voltage Level**

| *Voltage level* | *Investments (thousand yuan)* | *Annual energy savings (GWh)* | *Economic payback (years)* |
|---|---|---|---|
| 35 kV | 1,030.0 | 0.98 | 2.0 |
| 10 kV | 99.1 | 0.09 | 2.0 |
| Rural LV | 1,016.0 | 0.32 | 3.2 |
| Urban LV | 21.7 | 0.03 | 1.2 |
| Total | 2,166.8 | 1.42 | 2.6 |

Joint UNDP/World Bank

## ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

### LIST OF REPORTS ON COMPLETED ACTIVITIES

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| | **SUB-SAHARAN AFRICA (AFR)** | | |
| Africa Regional | Anglophone Africa Household Energy Workshop (English) | 07/88 | 085/88 |
| | Regional Power Seminar on Reducing Electric Power System Losses in Africa (English) | 08/88 | 087/88 |
| | Institutional Evaluation of EGL (English) | 02/89 | 098/89 |
| | Biomass Mapping Regional Workshops (English) | 05/89 | -- |
| | Francophone Household Energy Workshop (French) | 08/89 | -- |
| | Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development (English) | 03/90 | 112/90 |
| | Biomass Assessment and Mapping (English) | 03/90 | -- |
| | Symposium on Power Sector Reform and Efficiency Improvement in Sub-Saharan Africa (English) | 06/96 | 182/96 |
| | Commercialization of Marginal Gas Fields (English) | 12/97 | 201/97 |
| Angola | Energy Assessment (English and Portuguese) | 05/89 | 4708-ANG |
| | Power Rehabilitation and Technical Assistance (English) | 10/91 | 142/91 |
| Benin | Energy Assessment (English and French) | 06/85 | 5222-BEN |
| Botswana | Energy Assessment (English) | 09/84 | 4998-BT |
| | Pump Electrification Prefeasibility Study (English) | 01/86 | 047/86 |
| | Review of Electricity Service Connection Policy (English) | 07/87 | 071/87 |
| | Tuli Block Farms Electrification Study (English) | 07/87 | 072/87 |
| | Household Energy Issues Study (English) | 02/88 | -- |
| | Urban Household Energy Strategy Study (English) | 05/91 | 132/91 |
| Burkina Faso | Energy Assessment (English and French) | 01/86 | 5730-BUR |
| | Technical Assistance Program (English) | 03/86 | 052/86 |
| | Urban Household Energy Strategy Study (English and French) | 06/91 | 134/91 |
| Burundi | Energy Assessment (English) | 06/82 | 3778-BU |
| | Petroleum Supply Management (English) | 01/84 | 012/84 |
| | Status Report (English and French) | 02/84 | 011/84 |
| | Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) (English and French) | 05/85 | 036/85 |
| | Improved Charcoal Cookstove Strategy (English and French) | 09/85 | 042/85 |
| | Peat Utilization Project (English) | 11/85 | 046/85 |
| | Energy Assessment (English and French) | 01/92 | 9215-BU |
| Cape Verde | Energy Assessment (English and Portuguese) | 08/84 | 5073-CV |
| | Household Energy Strategy Study (English) | 02/90 | 110/90 |
| Central African Republic | Energy Assessement (French) | 08/92 | 9898-CAR |
| Chad | Elements of Strategy for Urban Household Energy The Case of N'djamena (French) | 12/93 | 160/94 |
| Comoros | Energy Assessment (English and French) | 01/88 | 7104-COM |
| Congo | Energy Assessment (English) | 01/88 | 6420-COB |
| | Power Development Plan (English and French) | 03/90 | 106/90 |
| Côte d'Ivoire | Energy Assessment (English and French) | 04/85 | 5250-IVC |
| | Improved Biomass Utilization (English and French) | 04/87 | 069/87 |
| | Power System Efficiency Study (English) | 12/87 | -- |
| | Power Sector Efficiency Study (French) | 02/92 | 140/91 |
| | Project of Energy Efficiency in Buildings (English) | 09/95 | 175/95 |
| Ethiopia | Energy Assessment (English) | 07/84 | 4741-ET |

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| Ethiopia | Power System Efficiency Study (English) | 10/85 | 045/85 |
| | Agricultural Residue Briquetting Pilot Project (English) | 12/86 | 062/86 |
| | Bagasse Study (English) | 12/86 | 063/86 |
| | Cooking Efficiency Project (English) | 12/87 | -- |
| | Energy Assessment (English) | 02/96 | 179/96 |
| Gabon | Energy Assessment (English) | 07/88 | 6915-GA |
| The Gambia | Energy Assessment (English) | 11/83 | 4743-GM |
| | Solar Water Heating Retrofit Project (English) | 02/85 | 030/85 |
| | Solar Photovoltaic Applications (English) | 03/85 | 032/85 |
| | Petroleum Supply Management Assistance (English) | 04/85 | 035/85 |
| Ghana | Energy Assessment (English) | 11/86 | 6234-GH |
| | Energy Rationalization in the Industrial Sector (English) | 06/88 | 084/88 |
| | Sawmill Residues Utilization Study (English) | 11/88 | 074/87 |
| | Industrial Energy Efficiency (English) | 11/92 | 148/92 |
| Guinea | Energy Assessment (English) | 11/86 | 6137-GUI |
| | Household Energy Strategy (English and French) | 01/94 | 163/94 |
| Guinea-Bissau | Energy Assessment (English and Portuguese) | 08/84 | 5083-GUB |
| | Recommended Technical Assistance Projects (English & Portuguese) | 04/85 | 033/85 |
| | Management Options for the Electric Power and Water Supply Subsectors (English) | 02/90 | 100/90 |
| | Power and Water Institutional Restructuring (French) | 04/91 | 118/91 |
| Kenya | Energy Assessment (English) | 05/82 | 3800-KE |
| | Power System Efficiency Study (English) | 03/84 | 014/84 |
| | Status Report (English) | 05/84 | 016/84 |
| | Coal Conversion Action Plan (English) | 02/87 | -- |
| | Solar Water Heating Study (English) | 02/87 | 066/87 |
| | Peri-Urban Woodfuel Development (English) | 10/87 | 076/87 |
| | Power Master Plan (English) | 11/87 | -- |
| | Power Loss Reduction Study (English) | 09/96 | 186/96 |
| Lesotho | Energy Assessment (English) | 01/84 | 4676-LSO |
| Liberia | Energy Assessment (English) | 12/84 | 5279-LBR |
| | Recommended Technical Assistance Projects (English) | 06/85 | 038/85 |
| | Power System Efficiency Study (English) | 12/87 | 081/87 |
| Madagascar | Energy Assessment (English) | 01/87 | 5700-MAG |
| | Power System Efficiency Study (English and French) | 12/87 | 075/87 |
| | Environmental Impact of Woodfuels (French) | 10/95 | 176/95 |
| Malawi | Energy Assessment (English) | 08/82 | 3903-MAL |
| | Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry (English) | 11/83 | 009/83 |
| | Status Report (English) | 01/84 | 013/84 |
| Mali | Energy Assessment (English and French) | 11/91 | 8423-MLI |
| | Household Energy Strategy (English and French) | 03/92 | 147/92 |
| Islamic Republic of Mauritania | Energy Assessment (English and French) | 04/85 | 5224-MAU |
| | Household Energy Strategy Study (English and French) | 07/90 | 123/90 |
| Mauritius | Energy Assessment (English) | 12/81 | 3510-MAS |
| | Status Report (English) | 10/83 | 008/83 |
| | Power System Efficiency Audit (English) | 05/87 | 070/87 |
| Mauritius | Bagasse Power Potential (English) | 10/87 | 077/87 |
| | Energy Sector Review (English) | 12/94 | 3643-MAS |
| Mozambique | Energy Assessment (English) | 01/87 | 6128-MOZ |

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| Mozambique | Household Electricity Utilization Study (English) | 03/90 | 113/90 |
| | Electricity Tariffs Study (English) | 06/96 | 181/96 |
| | Sample Survey of Low Voltage Electricity Customers | 06/97 | 195/97 |
| Namibia | Energy Assessment (English) | 03/93 | 11320-NAM |
| Niger | Energy Assessment (French) | 05/84 | 4642-NIR |
| | Status Report (English and French) | 02/86 | 051/86 |
| | Improved Stoves Project (English and French) | 12/87 | 080/87 |
| | Household Energy Conservation and Substitution (English and French) | 01/88 | 082/88 |
| Nigeria | Energy Assessment (English) | 08/83 | 4440-UNI |
| | Energy Assessment (English) | 07/93 | 11672-UNI |
| Rwanda | Energy Assessment (English) | 06/82 | 3779-RW |
| | Status Report (English and French) | 05/84 | 017/84 |
| | Improved Charcoal Cookstove Strategy (English and French) | 08/86 | 059/86 |
| | Improved Charcoal Production Techniques (English and French) | 02/87 | 065/87 |
| | Energy Assessment (English and French) | 07/91 | 8017-RW |
| | Commercialization of Improved Charcoal Stoves and Carbonization Techniques Mid-Term Progress Report (English and French) | 12/91 | 141/91 |
| SADC | SADC Regional Power Interconnection Study, Vols. I-IV (English) | 12/93 | -- |
| SADCC | SADCC Regional Sector: Regional Capacity-Building Program for Energy Surveys and Policy Analysis (English) | 11/91 | -- |
| Sao Tome and Principe | Energy Assessment (English) | 10/85 | 5803-STP |
| Senegal | Energy Assessment (English) | 07/83 | 4182-SE |
| | Status Report (English and French) | 10/84 | 025/84 |
| | Industrial Energy Conservation Study (English) | 05/85 | 037/85 |
| | Preparatory Assistance for Donor Meeting (English and French) | 04/86 | 056/86 |
| | Urban Household Energy Strategy (English) | 02/89 | 096/89 |
| | Industrial Energy Conservation Program (English) | 05/94 | 165/94 |
| Seychelles | Energy Assessment (English) | 01/84 | 4693-SEY |
| | Electric Power System Efficiency Study (English) | 08/84 | 021/84 |
| Sierra Leone | Energy Assessment (English) | 10/87 | 6597-SL |
| Somalia | Energy Assessment (English) | 12/85 | 5796-SO |
| South Africa Republic of | Options for the Structure and Regulation of Natural Gas Industry (English) | 05/95 | 172/95 |
| Sudan | Management Assistance to the Ministry of Energy and Mining | 05/83 | 003/83 |
| | Energy Assessment (English) | 07/83 | 4511-SU |
| | Power System Efficiency Study (English) | 06/84 | 018/84 |
| | Status Report (English) | 11/84 | 026/84 |
| | Wood Energy/Forestry Feasibility (English) | 07/87 | 073/87 |
| Swaziland | Energy Assessment (English) | 02/87 | 6262-SW |
| | Household Energy Strategy Study | 10/97 | 198/97 |
| Tanzania | Energy Assessment (English) | 11/84 | 4969-TA |
| | Peri-Urban Woodfuels Feasibility Study (English) | 08/88 | 086/88 |
| | Tobacco Curing Efficiency Study (English) | 05/89 | 102/89 |
| | Remote Sensing and Mapping of Woodlands (English) | 06/90 | -- |
| | Industrial Energy Efficiency Technical Assistance (English) | 08/90 | 122/90 |
| Tanzania | Power Loss Reduction Volume 1: Transmission and Distribution SystemTechnical Loss Reduction and Network Development (English) | 06/98 | 204A/98 |
| | Power Loss Reduction Volume 2: Reduction of Non-Technical Losses (English) | 06/98 | 204B/98 |

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| Togo | Energy Assessment (English) | 06/85 | 5221-TO |
| | Wood Recovery in the Nangbeto Lake (English and French) | 04/86 | 055/86 |
| | Power Efficiency Improvement (English and French) | 12/87 | 078/87 |
| Uganda | Energy Assessment (English) | 07/83 | 4453-UG |
| | Status Report (English) | 08/84 | 020/84 |
| | Institutional Review of the Energy Sector (English) | 01/85 | 029/85 |
| | Energy Efficiency in Tobacco Curing Industry (English) | 02/86 | 049/86 |
| | Fuelwood/Forestry Feasibility Study (English) | 03/86 | 053/86 |
| | Power System Efficiency Study (English) | 12/88 | 092/88 |
| | Energy Efficiency Improvement in the Brick and Tile Industry (English) | 02/89 | 097/89 |
| | Tobacco Curing Pilot Project (English) | 03/89 | UNDP Terminal Report |
| | Energy Assessment (English) | 12/96 | 193/96 |
| | Rural Electrification Strategy Study | 09/99 | 221/99 |
| Zaire | Energy Assessment (English) | 05/86 | 5837-ZR |
| Zambia | Energy Assessment (English) | 01/83 | 4110-ZA |
| | Status Report (English) | 08/85 | 039/85 |
| | Energy Sector Institutional Review (English) | 11/86 | 060/86 |
| | Power Subsector Efficiency Study (English) | 02/89 | 093/88 |
| | Energy Strategy Study (English) | 02/89 | 094/88 |
| | Urban Household Energy Strategy Study (English) | 08/90 | 121/90 |
| Zimbabwe | Energy Assessment (English) | 06/82 | 3765-ZIM |
| | Power System Efficiency Study (English) | 06/83 | 005/83 |
| | Status Report (English) | 08/84 | 019/84 |
| | Power Sector Management Assistance Project (English) | 04/85 | 034/85 |
| | Power Sector Management Institution Building (English) | 09/89 | -- |
| | Petroleum Management Assistance (English) | 12/89 | 109/89 |
| | Charcoal Utilization Prefeasibility Study (English) | 06/90 | 119/90 |
| | Integrated Energy Strategy Evaluation (English) | 01/92 | 8768-ZIM |
| | Energy Efficiency Technical Assistance Project: Strategic Framework for a National Energy Efficiency Improvement Program (English) | 04/94 | -- |
| | Capacity Building for the National Energy Efficiency Improvement Programme (NEEIP) (English) | 12/94 | -- |

## EAST ASIA AND PACIFIC (EAP)

| | | | |
|---|---|---|---|
| Asia Regional | Pacific Household and Rural Energy Seminar (English) | 11/90 | -- |
| China | County-Level Rural Energy Assessments (English) | 05/89 | 101/89 |
| | Fuelwood Forestry Preinvestment Study (English) | 12/89 | 105/89 |
| | Strategic Options for Power Sector Reform in China (English) | 07/93 | 156/93 |
| | Energy Efficiency and Pollution Control in Township and Village Enterprises (TVE) Industry (English) | 11/94 | 168/94 |
| | Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties (English) | 06/96 | 183/96 |
| | Improving the Technical Efficiency of Decentralized Power Companies | 09/99 | 222/999 |
| Fiji | Energy Assessment (English) | 06/83 | 4462-FIJ |
| Indonesia | Energy Assessment (English) | 11/81 | 3543-IND |
| | Status Report (English) | 09/84 | 022/84 |

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| Indonesia | Power Generation Efficiency Study (English) | 02/86 | 050/86 |
| | Energy Efficiency in the Brick, Tile and Lime Industries (English) | 04/87 | 067/87 |
| | Diesel Generating Plant Efficiency Study (English) | 12/88 | 095/88 |
| | Urban Household Energy Strategy Study (English) | 02/90 | 107/90 |
| | Biomass Gasifier Preinvestment Study Vols. I & II (English) | 12/90 | 124/90 |
| | Prospects for Biomass Power Generation with Emphasis on Palm Oil, Sugar, Rubberwood and Plywood Residues (English) | 11/94 | 167/94 |
| Lao PDR | Urban Electricity Demand Assessment Study (English) | 03/93 | 154/93 |
| | Institutional Development for Off-Grid Electrification | 06/99 | 215/99 |
| Malaysia | Sabah Power System Efficiency Study (English) | 03/87 | 068/87 |
| | Gas Utilization Study (English) | 09/91 | 9645-MA |
| Myanmar | Energy Assessment (English) | 06/85 | 5416-BA |
| Papua New Guinea | Energy Assessment (English) | 06/82 | 3882-PNG |
| | Status Report (English) | 07/83 | 006/83 |
| | Energy Strategy Paper (English) | -- | -- |
| | Institutional Review in the Energy Sector (English) | 10/84 | 023/84 |
| | Power Tariff Study (English) | 10/84 | 024/84 |
| Philippines | Commercial Potential for Power Production from Agricultural Residues (English) | 12/93 | 157/93 |
| | Energy Conservation Study (English) | 08/94 | -- |
| Solomon Islands | Energy Assessment (English) | 06/83 | 4404-SOL |
| | Energy Assessment (English) | 01/92 | 979-SOL |
| South Pacific | Petroleum Transport in the South Pacific (English) | 05/86 | -- |
| Thailand | Energy Assessment (English) | 09/85 | 5793-TH |
| | Rural Energy Issues and Options (English) | 09/85 | 044/85 |
| | Accelerated Dissemination of Improved Stoves and Charcoal Kilns (English) | 09/87 | 079/87 |
| | Northeast Region Village Forestry and Woodfuels Preinvestment Study (English) | 02/88 | 083/88 |
| | Impact of Lower Oil Prices (English) | 08/88 | -- |
| | Coal Development and Utilization Study (English) | 10/89 | -- |
| Tonga | Energy Assessment (English) | 06/85 | 5498-TON |
| Vanuatu | Energy Assessment (English) | 06/85 | 5577-VA |
| Vietnam | Rural and Household Energy-Issues and Options (English) | 01/94 | 161/94 |
| | Power Sector Reform and Restructuring in Vietnam: Final Report to the Steering Committee (English and Vietnamese) | 09/95 | 174/95 |
| | Household Energy Technical Assistance: Improved Coal Briquetting and Commercialized Dissemination of Higher Efficiency Biomass and Coal Stoves (English) | 01/96 | 178/96 |
| Western Samoa | Energy Assessment (English) | 06/85 | 5497-WSO |

## SOUTH ASIA (SAS)

| | | | |
|---|---|---|---|
| Bangladesh | Energy Assessment (English) | 10/82 | 3873-BD |
| | Priority Investment Program (English) | 05/83 | 002/83 |
| | Status Report (English) | 04/84 | 015/84 |
| | Power System Efficiency Study (English) | 02/85 | 031/85 |
| | Small Scale Uses of Gas Prefeasibility Study (English) | 12/88 | -- |

| Region/Country | Activity/Report Title | Date | Number |
|---|---|---|---|
| India | Opportunities for Commercialization of Nonconventional Energy Systems (English) | 11/88 | 091/88 |
| | Maharashtra Bagasse Energy Efficiency Project (English) | 07/90 | 120/90 |
| | Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III (English) | 07/91 | 139/91 |
| | WindFarm Pre-Investment Study (English) | 12/92 | 150/92 |
| | Power Sector Reform Seminar (English) | 04/94 | 166/94 |
| | Environmental Issues in the Power Sector (English) | 06/98 | 205/98 |
| | Environmental Issues in the Power Sector: Manual for Environmental Decision Making (English) | 06/99 | 213/99 |
| | Household Energy Strategies for Urban India: The Case of Hyderabad | 06/99 | 214/99 |
| Nepal | Energy Assessment (English) | 08/83 | 4474-NEP |
| | Status Report (English) | 01/85 | 028/84 |
| | Energy Efficiency & Fuel Substitution in Industries (English) | 06/93 | 158/93 |
| Pakistan | Household Energy Assessment (English) | 05/88 | -- |
| | Assessment of Photovoltaic Programs, Applications, and Markets (English) | 10/89 | 103/89 |
| | National Household Energy Survey and Strategy Formulation Study: Project Terminal Report (English) | 03/94 | -- |
| | Managing the Energy Transition (English) | 10/94 | -- |
| | Lighting Efficiency Improvement Program Phase 1: Commercial Buildings Five Year Plan (English) | 10/94 | -- |
| Sri Lanka | Energy Assessment (English) | 05/82 | 3792-CE |
| | Power System Loss Reduction Study (English) | 07/83 | 007/83 |
| | Status Report (English) | 01/84 | 010/84 |
| | Industrial Energy Conservation Study (English) | 03/86 | 054/86 |

**EUROPE AND CENTRAL ASIA (ECA)**

| Region/Country | Activity/Report Title | Date | Number |
|---|---|---|---|
| Bulgaria | Natural Gas Policies and Issues (English) | 10/96 | 188/96 |
| Central and Eastern Europe | Power Sector Reform in Selected Countries | 07/97 | 196/97 |
| Eastern Europe | The Future of Natural Gas in Eastern Europe (English) | 08/92 | 149/92 |
| Kazakhstan | Natural Gas Investment Study, Volumes 1, 2 & 3 | 12/97 | 199/97 |
| Kazakhstan & Kyrgyzstan | Opportunities for Renewable Energy Development | 11/97 | 16855-KAZ |
| Poland | Energy Sector Restructuring Program Vols. I-V (English) | 01/93 | 153/93 |
| | Natural Gas Upstream Policy (English and Polish) | 08/98 | 206/98 |
| | Energy Sector Restructuring Program: Establishing the Energy Regulation Authority | 10/98 | 208/98 |
| Portugal | Energy Assessment (English) | 04/84 | 4824-PO |
| Romania | Natural Gas Development Strategy (English) | 12/96 | 192/96 |
| Slovenia | Workshop on Private Participation in the Power Sector (English) | 02/99 | 211/99 |
| Turkey | Energy Assessment (English) | 03/83 | 3877-TU |

**MIDDLE EAST AND NORTH AFRICA (MNA)**

| Region/Country | Activity/Report Title | Date | Number |
|---|---|---|---|
| Arab Republic of Egypt | Energy Assessment (English) | 10/96 | 189/96 |

| *Region/Country* | *Activity/Report Title* | *Date* | *Number* |
|---|---|---|---|
| Arab Republic of Egypt | Energy Assessment (English and French) | 03/84 | 4157-MOR |
| | Status Report (English and French) | 01/86 | 048/86 |
| Morocco | Energy Sector Institutional Development Study (English and French) | 07/95 | 173/95 |
| | Natural Gas Pricing Study (French) | 10/98 | 209/98 |
| | Gas Development Plan Phase II (French) | 02/99 | 210/99 |
| Syria | Energy Assessment (English) | 05/86 | 5822-SYR |
| | Electric Power Efficiency Study (English) | 09/88 | 089/88 |
| | Energy Efficiency Improvement in the Cement Sector (English) | 04/89 | 099/89 |
| Syria | Energy Efficiency Improvement in the Fertilizer Sector (English) | 06/90 | 115/90 |
| Tunisia | Fuel Substitution (English and French) | 03/90 | -- |
| | Power Efficiency Study (English and French) | 02/92 | 136/91 |
| | Energy Management Strategy in the Residential and Tertiary Sectors (English) | 04/92 | 146/92 |
| | Renewable Energy Strategy Study, Volume I (French) | 11/96 | 190A/96 |
| | Renewable Energy Strategy Study, Volume II (French) | 11/96 | 190B/96 |
| Yemen | Energy Assessment (English) | 12/84 | 4892-YAR |
| | Energy Investment Priorities (English) | 02/87 | 6376-YAR |
| | Household Energy Strategy Study Phase I (English) | 03/91 | 126/91 |

## LATIN AMERICA AND THE CARIBBEAN (LAC)

| | | | |
|---|---|---|---|
| LAC Regional | Regional Seminar on Electric Power System Loss Reduction in the Caribbean (English) | 07/89 | -- |
| | Elimination of Lead in Gasoline in Latin America and the Caribbean (English and Spanish) | 04/97 | 194/97 |
| | Elimination of Lead in Gasoline in Latin America and the Caribbean - Status Report (English and Spanish) | 12/97 | 200/97 |
| | Harmonization of Fuels Specifications in Latin America and the Caribbean (English and Spanish) | 06/98 | 203/98 |
| Bolivia | Energy Assessment (English) | 04/83 | 4213-BO |
| | National Energy Plan (English) | 12/87 | -- |
| | La Paz Private Power Technical Assistance (English) | 11/90 | 111/90 |
| | Prefeasibility Evaluation Rural Electrification and Demand Assessment (English and Spanish) | 04/91 | 129/91 |
| | National Energy Plan (Spanish) | 08/91 | 131/91 |
| | Private Power Generation and Transmission (English) | 01/92 | 137/91 |
| | Natural Gas Distribution: Economics and Regulation (English) | 03/92 | 125/92 |
| | Natural Gas Sector Policies and Issues (English and Spanish) | 12/93 | 164/93 |
| | Household Rural Energy Strategy (English and Spanish) | 01/94 | 162/94 |
| | Preparation of Capitalization of the Hydrocarbon Sector | 12/96 | 191/96 |
| Brazil | Energy Efficiency & Conservation: Strategic Partnership for Energy Efficiency in Brazil (English) | 01/95 | 170/95 |
| | Hydro and Thermal Power Sector Study | 09/97 | 197/97 |
| Chile | Energy Sector Review (English) | 08/88 | 7129-CH |
| Colombia | Energy Strategy Paper (English) | 12/86 | -- |
| | Power Sector Restructuring (English) | 11/94 | 169/94 |
| | Energy Efficiency Report for the Commercial and Public Sector (English) | 06/96 | 184/96 |
| Costa Rica | Energy Assessment (English and Spanish) | 01/84 | 4655-CR |
| | Recommended Technical Assistance Projects (English) | 11/84 | 027/84 |

| ***Region/Country*** | ***Activity/Report Title*** | ***Date*** | ***Number*** |
|---|---|---|---|
| Costa Rica | Forest Residues Utilization Study (English and Spanish) | 02/90 | 108/90 |
| Dominican Republic | Energy Assessment (English) | 05/91 | 8234-DO |
| Ecuador | Energy Assessment (Spanish) | 12/85 | 5865-EC |
| | Energy Strategy Phase I (Spanish) | 07/88 | -- |
| | Energy Strategy (English) | 04/91 | -- |
| | Private Minihydropower Development Study (English) | 11/92 | -- |
| | Energy Pricing Subsidies and Interfuel Substitution (English) | 08/94 | 11798-EC |
| | Energy Pricing, Poverty and Social Mitigation (English) | 08/94 | 12831-EC |
| Guatemala | Issues and Options in the Energy Sector (English) | 09/93 | 12160-GU |
| Haiti | Energy Assessment (English and French) | 06/82 | 3672-HA |
| | Status Report (English and French) | 08/85 | 041/85 |
| | Household Energy Strategy (English and French) | 12/91 | 143/91 |
| Honduras | Energy Assessment (English) | 08/87 | 6476-HO |
| | Petroleum Supply Management (English) | 03/91 | 128/91 |
| Jamaica | Energy Assessment (English) | 04/85 | 5466-JM |
| | Petroleum Procurement, Refining, and Distribution Study (English) | 11/86 | 061/86 |
| | Energy Efficiency Building Code Phase I (English) | 03/88 | -- |
| | Energy Efficiency Standards and Labels Phase I (English ) | 03/88 | -- |
| | Management Information System Phase I (English) | 03/88 | -- |
| | Charcoal Production Project (English) | 09/88 | 090/88 |
| | FIDCO Sawmill Residues Utilization Study (English) | 09/88 | 088/88 |
| | Energy Sector Strategy and Investment Planning Study (English) | 07/92 | 135/92 |
| Mexico | Improved Charcoal Production Within Forest Management for the State of Veracruz (English and Spanish) | 08/91 | 138/91 |
| | Energy Efficiency Management Technical Assistance to the Comision Nacional para el Ahorro de Energia (CONAE) (English) | 04/96 | 180/96 |
| Panama | Power System Efficiency Study (English) | 06/83 | 004/83 |
| Paraguay | Energy Assessment (English) | 10/84 | 5145-PA |
| | Recommended Technical Assistance Projects (English) | 09/85 | -- |
| | Status Report (English and Spanish) | 09/85 | 043/85 |
| Peru | Energy Assessment (English) | 01/84 | 4677-PE |
| | Status Report (English) | 08/85 | 040/85 |
| | Proposal for a Stove Dissemination Program in the Sierra (English and Spanish) | 02/87 | 064/87 |
| | Energy Strategy (English and Spanish) | 12/90 | -- |
| | Study of Energy Taxation and Liberalization of the Hydrocarbons Sector (English and Spanish) | 120/93 | 159/93 |
| | Reform and Privatization in the Hydrocarbon Sector (English and Spanish) | 07/99 | 216/99 |
| Saint Lucia | Energy Assessment (English) | 09/84 | 5111-SLU |
| St. Vincent and the Grenadines | Energy Assessment (English) | 09/84 | 5103-STV |
| Sub Andean | Environmental and Social Regulation of Oil and Gas Operations in Sensitive Areas of the Sub-Andean Basin (English and Spanish) | 07/99 | 217/99 |
| Trinidad and Tobago | Energy Assessment (English) | 12/85 | 5930-TR |

| Region/Country | Activity/Report Title | Date | Number |
|---|---|---|---|
| **GLOBAL** | | | |
| | Energy End Use Efficiency: Research and Strategy (English) | 11/89 | -- |
| | Women and Energy--A Resource Guide The International Network: Policies and Experience (English) | 04/90 | -- |
| | Guidelines for Utility Customer Management and Metering (English and Spanish) | 07/91 | -- |
| | Assessment of Personal Computer Models for Energy Planning in Developing Countries (English) | 10/91 | -- |
| | Long-Term Gas Contracts Principles and Applications (English) | 02/93 | 152/93 |
| | Comparative Behavior of Firms Under Public and Private Ownership (English) | 05/93 | 155/93 |
| | Development of Regional Electric Power Networks (English) | 10/94 | -- |
| | Roundtable on Energy Efficiency (English) | 02/95 | 171/95 |
| | Assessing Pollution Abatement Policies with a Case Study of Ankara (English) | 11/95 | 177/95 |
| | A Synopsis of the Third Annual Roundtable on Independent Power Projects: Rhetoric and Reality (English) | 08/96 | 187/96 |
| | Rural Energy and Development Roundtable (English) | 05/98 | 202/98 |
| | A Synopsis of the Second Roundtable on Energy Efficiency: Institutional and Financial Delivery Mechanisms (English) | 09/98 | 207/98 |
| | The Effect of a Shadow Price on Carbon Emission in the Energy Portfolio of the World Bank: A Carbon Backcasting Exercise (English) | 02/99 | 212/99 |
| | Increasing the Efficiency of Gas Distribution Phase 1: Case Studies and Thematic Data Sheets | 07/99 | 218/99 |
| | Global Energy Sector Reform in Developing Countries: A Scorecard | 07/99 | 219/99 |
| | Global Lighting Services for the Poor Phase II: Text Marketing of Small "Solar" Batteries for Rural Electrification Purposes | 08/99 | 220/99 |

ESMAP

The World Bank

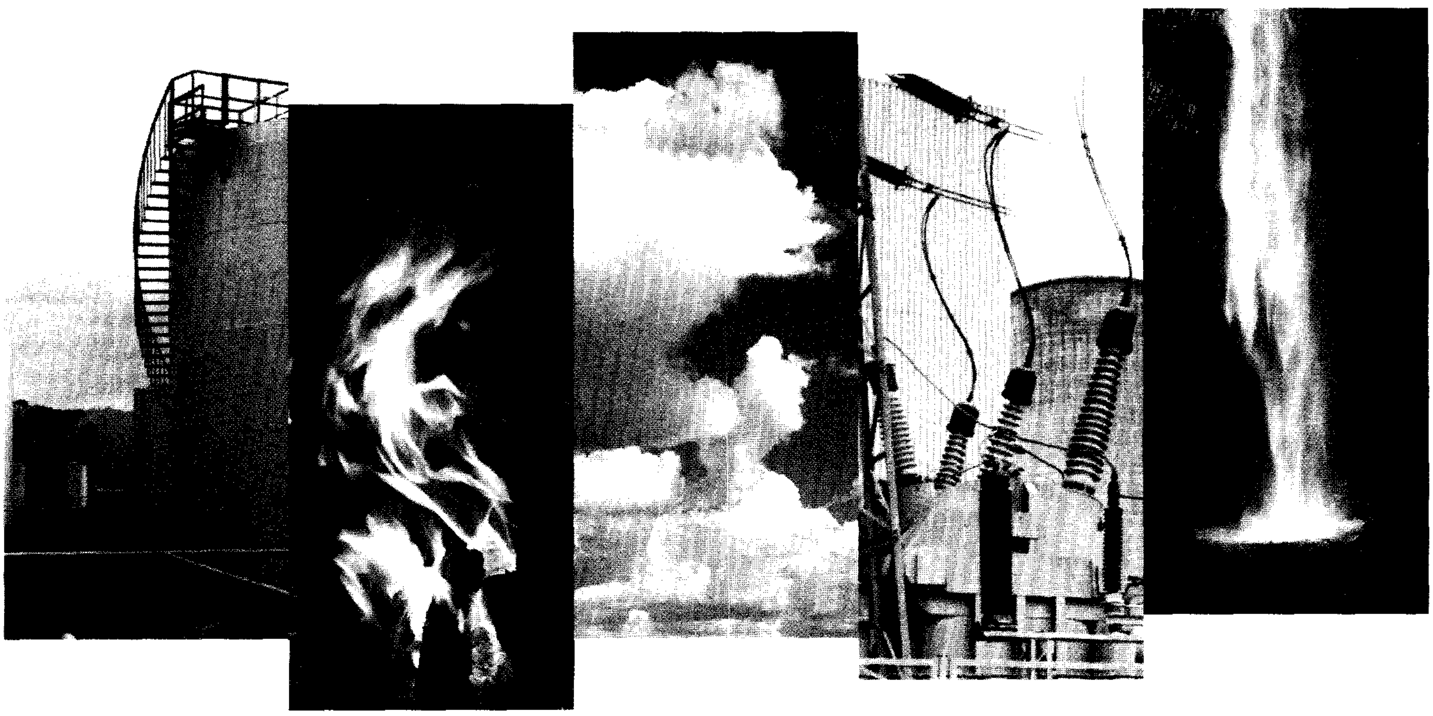
1818 H Street, NW

Washington, DC 20433 USA

Tel.: 1.202.458.2321 Fax.: 1.202.522.3018

Internet: www.worldbank.org/esmap

Email: esmap@worldbank.org



A joint UNDP/World Bank Programme