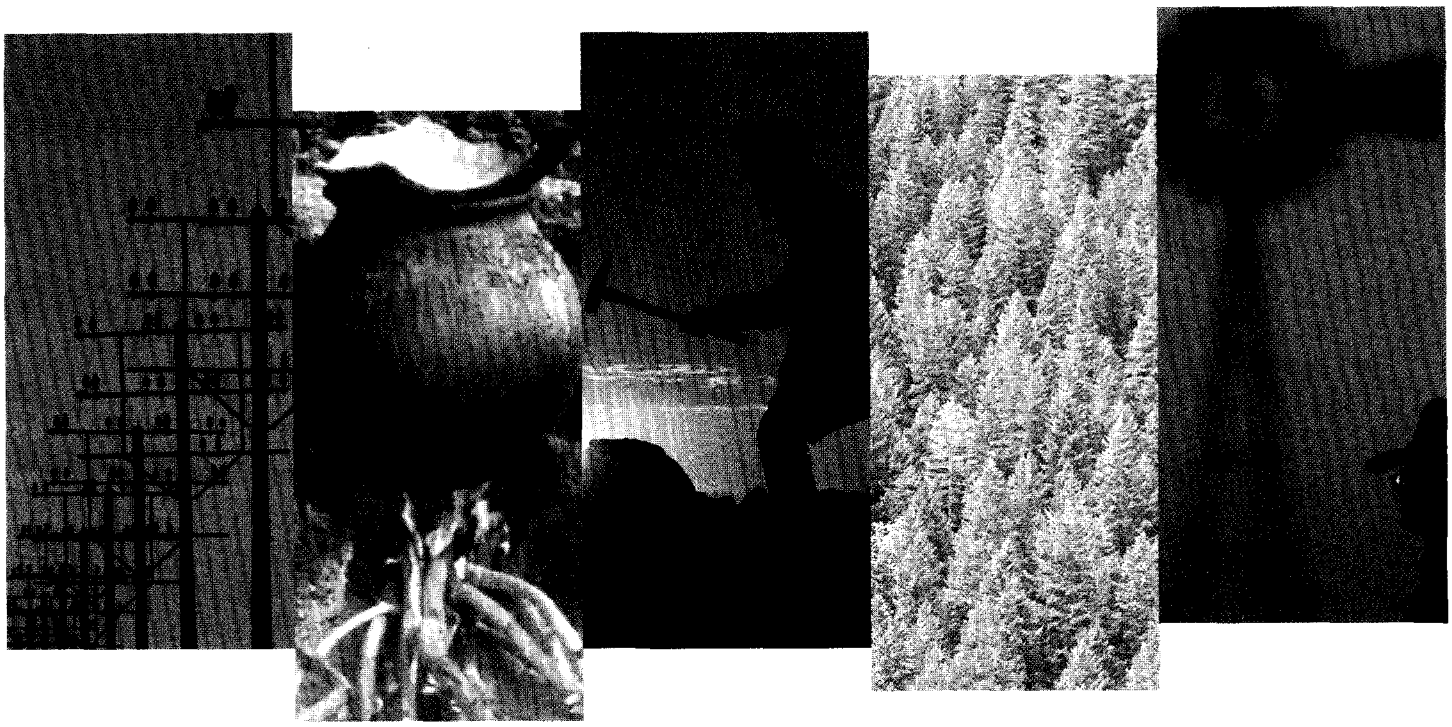
Reducing the Cost of Grid Extension for Rural Electrication

ESM227



Energy

Sector

Management

Assistance

Programme

ESMAP

Report 227/00

February 2000

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.

Reducing the Cost of Grid Extension for Rural Electrification

NRECA International, Ltd.

February 2000

Joint UNDP/World Bank Energy Sector Management Assistance Programme

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.

Contents

Contents iii
Acknowledgments iv
Acronyms and Definitions v
Glossary vi
Executive Summary 1
1. Overview 3
Rationale of the Proposed Study 4
Study Structure and Purpose 5
2. Case Studies 7
3. Factors Affecting Cost 15
Line Design 16
Poles 16
Underground Cabling 16
Shorter Poles 17
Longer Spans 18
Alternative Pole Materials and Designs 21
Conductors 27
Proper Sizing 27
Number of Conductors 29
Materials Used 1
Poletop Assembly 31
Line Configuration 31
Line Voltage 37
Distribution Transformer 38
Number of Phases 41
Transformer Size 42
Size of Service Area 45
Transformer Mounting 48
Non-Technical Losses 48
Approach to Design and Construction 50
Staking Methodology 50
Commodity Specifications 1
Labor Costs 54
4. Summary 57
Interventions to Reduce Cost 57
Benchmark Cost 58
Appendix A: Summary of Field Data 61
Appendix B: Making Rural Electrification More Affordable 69
Using Fuelwood: The Pros and Cons 69
Is Electrification the Solution? 69
An Integrated Solution 70
End Notes 77

Acknowledgments

A number of individuals must be acknowledged for their contributions to this effort. Myk Manon, NRECA's Team Leader for El Salvador, contributed costing data from El Salvador as well as many of the ideas and numerical examples used in this study. Mr. Manon has three decades of experience with rural electrification around the world in El Salvador as well as in Bangladesh, Bolivia, and Nicaragua and other Latin American countries. He has been actively involved in making rural electrification more accessible to rural populations through more appropriate designs and more efficient project implementation.

Ron Mettler, a distribution engineer with broad experience in the United States and Latin America, contributed costing information and furnished a critical review of this document.

An important part of this study was to assess existing experiences around the world that have often not been readily available and documented. A number of individuals helped track down or prepare breakdowns of line costs in the countries in which they were working. These include Ashok Ahuja from New Delhi, India; Stephen Anderson of the Benton Rural Electric Association in the state of Washington; Ricky Bywaters of the Rappahannock Electric Cooperative in the state of Virginia; Cheikhou Cisse of SENELEC of Senegal; Fernando Haderspock of Cooperativa Rural de Electrificación in Santa Cruz, Bolivia; Colin Jack of NRECA in Bangladesh; Mae Soriano of the National Electrification Administration (NEA) in Manila; and Eduardo Villagran from the NRECA office in Guatemala City.

James Taylor, a wood pole specialist from the state of Virginia with broad international experience in the wood pole business, contributed background into the issues on costs and quality of treated wood poles. James Carter of NRECA's Wood Quality Control program shared his knowledge of the workings of that program as an example of how the availability of specifications can help ensure the quality of the materials used for line construction. Pablo Pan III of NEA in the Philippines provided background information on their pole growing program and pole treatment activities.

From the World Bank, Willem Floor provided the resources to undertake this study and assisted in the tedious task of gathering field information. Robert van der Plas also aided in this task. Anthony Sparkes supplied numerous useful comments and suggestions.

And special thanks goes to Gil Medina, the NRECA representative in Manila, who was always prompt, reliable, and efficient in tracking down a range of other information from the field.

Finally, thanks to Mark Hayton, Dale Nafziger, Robert Gibson for providing the photographs in Figures 11, 13, and 31, respectively. All other photos were taken by the author.

Allen R. Inversin
Arlington, VA

Acronyms and Definitions

ACSR	aluminum-conductor, steel-reinforced; currently the most commonly used conductor for power lines
AAAC	all-aluminum alloy conductor
AAC	all-aluminum conductor
BAPA	Barangay Power Association (Philippines)
CCA	chromated copper arsenate
CIF	cost, insurance, and freight (the cost of the commodity, including interest and freight costs incurred in shipping)
GEF	Global Environment Facility
guys	stays
HV	high (transmission) voltage
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt hour
LV	low voltage (also called *secondary voltage*; generally based on 120- or 240-volt single-phase supply)
m	meter
mm	millimeter
MV	medium voltage (also called *primary voltage*; usually in the range of 1 to 35 kV)
NEA	National Electrification Administration (Philippines)
NESC	National Electric Safety Code (United States)
NRECA	National Rural Electric Cooperative Association
PV	photovoltaic (generating electricity through the conversion of light energy)
RE	rural electrification
REA	Rural Electrification Administration, the U.S. Government agency under the Department of Agriculture responsible for oversight of the American rural electrification program; now the Rural Utilities Service (RUS)
REB	Rural Electrification Board (Bangladesh)
RUS	Rural Utilities Service (see REA)
SWER	single-wire earth-return (pp. 20, 33)
SHS	solar home system (a PV-based system to provide basic lighting and entertainment needs to an individual home, with a capacity typically in the range of 10 to 100 peak watts)
W	watt(s)
WQC	NRECA's Wood Quality Control program (p. 53)

Glossary

European configuration	A medium-voltage (MV) distribution system characterized by the widespread use of a three-phase, three-wire configuration where consumers are generally served by relatively few transformers of a higher capacity. Single-phase distribution relies on supplying loads with two rather than all three (phase) conductors. Only recently has single-phase distribution been more widely used for supplying rural areas.
ground(ing)	Connecting to the earth, or ground.
North American configuration	A medium-voltage (MV) distribution system characterized by (1) the widespread use of a three-phase, four-wire configuration, with the fourth (neutral) wire solidly grounded at numerous points along the line and (2) the heavy use of smaller, single-phase transformers to serve most consumers. Single-phase distribution relies on supplying loads with the neutral conductor and only one of the three phase-conductors. Single-phase distribution is widely used for supplying rural areas. Vee-phase distribution is also used.
vee-phase	A North American distribution system configuration in which supply is provided by the neutral and only two of the three phase-conductors (p. 33), increasing line capacity when compared to single-phase distribution and permitting low-cost access to three-phase power.

Executive Summary

Meeting the broad development needs of rural areas in developing countries around the world places numerous competing demands on limited financial resources. Because rural electrification is just one of these demands, it is important to ensure that resources devoted to this sector are efficiently used. The focus of this study is to benchmark the cost of medium-voltage (MV) grid extension—of bringing power from a supply at point A to a load center at point B—and to then identify ways to reduce this cost and increase the attractiveness of grid extension as a means of bringing the benefits of electrification to rural populations.

Existing costs were gathered from a variety of countries, and findings are presented. Some of these can be summarized as follows:[1]

- The cost of labor and materials for three-phase line construction typically ranges from $8,000 to $10,000 per kilometer, with costs of materials alone averaging $7,000.
- The cost of poles accounts for roughly 40 percent of the cost of materials, and the use of low-quality poles can quickly double life-cycle pole costs.
- The cost of the conductor (i.e., wire and cable) is usually the second-most-costly component, but its contribution is case-specific because it depends on the load being served and the voltage used.
- Savings of 30 to 40 percent are possible through the increased use of single-phase construction, which can satisfactorily meet all foreseeable needs of most consumers.
- On an annual basis, the operating cost of transformers can be several times their capital cost.
- Because of the non-availability of smaller transformers, the use of oversized transformers can contribute significantly to the per-customer cost of electrifying small rural population centers.

The study presents a variety of options for reducing the cost of grid extension, including the following:

- Using higher voltage,
- Using higher quality poles to reduce life-cycle costs,
- Wider use of single-phase distribution,
- Considering the life-cycle costs of transformers rather than simply the initial capital cost ,
- Properly sizing and placing transformers,
- Considering alternative pole designs,
- Standardizing materials and designs,
- Implementing quality assurance programs,
- Developing manuals and specifications for staking and design, and
- Using small transformers to serve small load centers adjacent to MV lines.

By adopting practices such as these, the cost of three-phase construction (including both materials and labor) over normal terrain in developing countries could typically be $5,000 per kilometer (not including site-specific import duties and transportation costs). Use of single-phase distribution could reduce this cost to roughly $4,000 per kilometer. In countries where labor costs are high, these figures could typically increase by up to $2,000.

[1] All dollars are U.S. dollars.

1

Overview

Demand for electricity in rural areas worldwide has traditionally been met by extending the electricity distribution network out from the cities and towns that were the first areas to be electrified. As the years have passed, however, with the lower consumer density in the new rural areas being served, the cost of bringing power to each new consumer has increased. At the same time, these new consumers have less disposable income and purchase less electricity. In light of increasing construction costs per consumer, low revenues, and the logistical difficulties and associated costs encountered in managing rural systems, electric utilities around the world have found it increasingly difficult to meet demand for electricity in rural areas.

More recently, as the cost of photovoltaic (PV) modules has dropped, interest has focused on harnessing PV technology for rural electrification (RE). Although this can be done using centralized PV battery-charging stations or PV hybrid systems managed by an entrepreneur, the local community, or the government, individually-owned PV solar home systems (SHS) have proved more popular. A niche market exists for this technology, but drawbacks remain, including the following:

- Both capital and recurring costs are and will remain high for some time to come;
- Any subsidies to reduce cost tend to benefit the wealthier segment of the population that can more easily afford these systems; and
- Although the small quantity of electricity generated is welcomed, its use is limited to basic lighting and entertainment.[2]

For such a large per-household investment, it contributes little to the economic development of rural areas or to amenities and services for the general population.

Some see the need to rely on an electric utility—an organization external to the community being served—as another drawback to extending the grid to rural communities. However, reverting to PV generation, even through the use of isolated SHSs, does not preclude this need. Experiences worldwide are demonstrating that the equivalent of an electric utility is still necessary to provide acceptable financing

[2] Even if the PV module were free, the monthly recurring cost of a typical SHS is still significant for many rural households: at least $2-3 for the battery (irrespective of whether it is an automotive or deep-discharge battery), roughly $1 for eventual replacement of the controller, etc., and possibly $1 for periodic technical service calls.

and ongoing maintenance for SHSs, two key inputs required for affordable and sustainable SHS projects, respectively.

Other alternatives exist, each with advantages and disadvantages. Small hydropower plants can produce power at low cost but need a high capacity factor to be able to capitalize on their low cost. This is often difficult to achieve in rural areas where most of the load is residential and where no grid exists to absorb excess generating capacity. Furthermore, during the dry season, streamflows may be inadequate to generate sufficiently to meet demand.

Diesel plants are generally a low-cost option; however, in remoter areas access to fuel year-around may be difficult and costs high. Sufficient mechanical skills must also be available to maintain the equipment in proper operating condition.

Therefore, no single "best" option stands out for supplying affordable electricity to those beyond peri-urban areas. Rather, for each situation, the appropriateness of each RE option should be continuously assessed as technologies, costs, demand, and circumstances change. Electrification by grid extension, whether generated from fossil fuels or renewable energy sources, is one such option and is the focus of this study.

Rationale of the Proposed Study

In countries where the quantity and quality of power from the grid is insufficient, alternatives such as PV or diesel generation may be the only electricity-supply options in rural areas. These options may also be advantageous because those desiring electric service are then not subordinate to the whims of a national utility that may not be interested in extending lines into new service areas.

But where adequate capacity exists on the grid and the government is interested in extending service into rural areas, grid extension presents significant advantages over other options from the points of view of both cost-effectiveness and social equity. These advantages include the following:

- When power lines are extended to a village, all rural households—even those who do not have the financial resources to afford electricity in their own homes—can enjoy its benefits, such as pumped or irrigation water, street lighting, improved educational and health services, agro-processing, and employment.
- The grid provides enough electricity to permit broad economic development activities rather than simply lighting and entertainment.
- Extending the grid into often neglected rural areas is perceived by rural households as a permanent community investment and creates a national infrastructure on which to base future socioeconomic development.
- Economies of scale, which accompany the generation of electricity by large, centralized generation plants, result in low-cost electricity.
- For broad electrification programs, cross-subsidies between the generally wealthier urban consumers and the poorer rural population are straightforward to implement and can obviate the need for government subsidies.
- Where electricity is derived from generation based on fossil-fuel, centralized generation facilitates the implementation and monitoring of pollution mitigation measures.

Of course, although the advantages of grid extension are numerous, an important dissuading argument remains its cost. Those promoting other agendas may exaggerate this to their advantage by, for example, alluding to the "huge expense of expanding electric grids into rural areas, at an estimated cost of $20,000–$30,000 per kilometer" or the fact that the solar alternative is "a bargain compared to the $50,000 to $75,000 the local utility charges to extend power lines to a new home that is just one mile from the grid."[i] Nonetheless, cost does indeed remain an obstacle to broader electrification.

It is important to go beyond rhetoric, however, for two reasons: (1) the advantages of grid extension seem overwhelming in cases where sufficient generation capacity exists on the grid and (2) other approaches to RE are competing for the same limited financial resources. The situation calls for both a more accurate estimate of the true costs associated with grid extension and an assessment of the extent to which high costs are intrinsic to it. Only then will national policymakers have the information necessary to decide the best course of action to take to implement RE in each situation, whether by grid extension or by reliance on isolated PV, micro-hydropower, or diesel generation.

Indications already exist that grid extension can be much less costly than many currently assume and can be provided at a small fraction of the costs noted above. For example, at the lower end of the scale, efforts in Nepal have shown that total project cost for grid extension and distribution to rural households can cost less than $150 per connection, with minimal recurring costs.[ii] This can be compared to the capital cost of at least $600 per household for a typical (i.e., 50-peak-watt) PV SHS, in addition to a recurring cost of at least $4 per month. An initial review of costs even in rural areas of an industrialized nation such as the United States, moreover, reveals that the cost for materials used in line construction can be as low as $3,000 per kilometer, equivalent to the cost of only five typical SHSs.[iii]

From an historical perspective, finding ways to reduce the costs of RE is not a new idea. When a major effort at electrifying rural areas in the United States began in the 1930s—when only 11 percent of rural households had access to electricity—the problem of high costs was also at issue. The solution then was to reassess the approach that had been taken in implementing electrification projects. As a consequence, new technical designs (such as 4-wire multi-grounded neutral and single-phase taps) and new institutional approaches (rural electric cooperatives) were developed and adopted. This permitted most of rural America to be electrified over a period of roughly 20 years, in spite of the considerable diversion of resources to war efforts during a portion of this time. Studies of RE in Ireland and Thailand also illustrate approaches to reducing the cost and increasing the effectiveness of RE efforts.[iv]

These experiences suggest that, rather than dismissing grid extension as too expensive, efforts should focus on taking a fresh look at the needs of rural populations in developing countries and then to once more adopt and adapt, or develop if necessary, designs to more cost-effectively meet these specific needs.

Study Structure and Purpose

This study first reviews the cost of grid extension in a number of countries. It then identifies ways to reduce these costs by examining how they are affected by a variety of factors.

An electricity supply system may be divided into two discrete components:

Grid extension: the infrastructure required to transmit power at a medium voltage[3] from the source—the national grid or an isolated power plant—to demand centers where it makes it available at low voltage. This includes both the MV distribution line from the supply at point A to a load center at point B and the distribution transformers at this load center.

Low-voltage (LV) distribution system: the distribution system within a load center that serves individual consumers.

This study will focus on the first of these two components, the cost of grid extension. Three questions will be asked:

1. What factors give rise to the costs commonly associated with grid extension for RE?
2. Are high costs intrinsic to grid extension? If not, what has been learned from experiences around the world about technical design options that can reduce the capital cost incurred in line construction as well as the recurring costs incurred in operating the system?
3. How low can these costs typically be?

The second component—the LV distribution system within a village—is integral to an electricity supply system and basically can be the same whether the demand center is served by the national network, a village diesel plant, or a hydropower or other renewables-based power plant. Proposing designs to reduce the cost of this second component will be part of a separate effort.[4]

Although data on the capital cost of a line are the easiest to obtain and analyze, it must be kept in mind that, for those making an investment decision, the line's life-cycle cost should be of greater importance. An initially inexpensive line that needs frequent maintenance, overhauling, and upgrading can require considerably greater investment during its lifespan than a line that has been adequately designed from the outset. Consequently, where relevant, the following discussion will also consider the life-cycle cost implications of line design.

This study is not meant to be final or definitive and, for many readers, may include little that is new. Rather, it recognizes the need to reassess designs and construction practices in order to more cost-effectively introduce the benefits of electrification through high-quality, reliable service into rural areas, consistent with their needs. Its overall goal is to raise issues and propose options in order to initiate a discussion on this topic.

[3] Medium voltage, also referred to as a *primary voltage*, is used to transmit power relatively long distances from its source to the load centers. It usually ranges from 1 kV to about 35 kV, well above the consumer voltage of 120 or 240 volts. Use of these higher voltages reduces resistive losses in the line, losses that result in both voltage drop (adversely affecting the quality of the electricity) and energy losses (which add to the recurring cost of operation). It also permits the use of smaller, less-expensive conductors and less-expensive single-phase construction.

[4] NRECA has been contracted by Electricité du Laos, with the financial support of the Japanese Policy and Human Resources Development (PHRD) Fund, to prepare a village mini-grid design manual. The project idea and terms of reference were developed by ESMAP as part of its design of the GEF-financed decentralized rural electrification component of the IDA-financed Southern Provinces Grid Integration Project.

2

Case Studies

Data on the "typical" capital costs of grid extension were solicited from a number of countries and are briefly described and summarized in Appendix A. This chapter analyzes these data to draw lessons from these experiences. In reviewing these figures, several points must be kept in mind:

- Respondents were simply asked to present the complete cost breakdown for a "typical" kilometer of grid extension line into rural areas. This term was expressly not defined in order to permit respondents to propose what they felt was typical and not to discourage responses by over-specifying the scenario to be costed.
- Although the total cost for designing and constructing the lines was requested for each case presented, it is difficult to ensure that these figures are complete. More difficult costs to quantify, such as administrative, overhead, and maintenance, may have been omitted. Other costs, such as those for the transportation of poles to the field or for right-of-way clearing, are site-specific, difficult to generalize, or cannot accurately be included in a single cost-per-kilometer figure for line extension. Finally, although the quality of materials and construction affects the usable life of a line and therefore its life-cycle cost, this factor is often difficult to quantify.
- An attempt was made to gather costs from a variety of countries worldwide. However, in many cases, no responses were received after repeated requests by various parties. Of those countries for which data was obtained, many had not only adopted the North American configuration[5] but had implemented projects under the guidance of rural electrification engineers and planners associated with the U.S. rural electric cooperative movement. The data obtained can therefore be seen as somewhat biased, but this does not detract from the conclusion that can be drawn for this universe of experience presented. Other field data would, for the most part, only have reinforced the conclusions that were drawn.

In spite of these caveats, useful conclusions can still be drawn; these are presented in the following paragraphs. Note that in most of the accompanying graphs, costs have been grouped according to whether the design used adopted the European or North American configuration. These are the two principal approaches used for extending three-phase power lines. The first approach, which flourished in Europe, uses three phase-conductors and was designed to serve the more compact settlement patterns

[5] As opposed to the European configuration; see glossary.

found on that continent. The second approach uses four conductors—three phase-conductors and one multi-grounded, neutral conductor. This design evolved in North America to serve the more dispersed settlement pattern of the rural areas.

It should be noted that the grouping of data is only meant to permit a comparison of apples with apples and does *not* imply any advantages of apples over oranges or vice versa.

Figure 1 presents the total (i.e., material and labor) per-kilometer cost in several countries for three-phase MV lines used for extending the grid into rural areas. Cost typically ranges from $8,000 to $10,000 per kilometer, with the cost of materials averaging $7,000. As is clear from Figure 2, the low materials cost from India is primarily attributable to the use of a small conductor and to the extremely low costs for poles and hardware, which are presumably manufactured locally. Furthermore, the cost of labor typically seems to be a small part of construction cost, a fact attributable to the low labor rates in many countries. By contrast, labor in the United States accounts for at least one-half of construction cost. If clearing the right-of-way is also considered, this labor-intensive task adds considerably to line cost in industrialized countries. For example, for the Rappahannock Electric Cooperative in the United States, the cost of line construction nearly doubles when clearing is included (see Appendix A).

Figure 2 illustrates the important contribution of pole cost to the cost of three-phase line construction. Pole cost averages about 40 percent of the total cost of materials, with cost per pole generally varying between $120 and $300 for lengths in the 11- to 12-meter range. An exception ($30) seems to be for the pre-stressed concrete poles used in India, in part due to the short length (8 meters) of the poles quoted for a "typical" grid-extension line. It was not possible to verify either these costs or the quality of the poles. A range of different designs and materials are available for poles, and it is here that some cost savings may be possible in some countries.

Figure 2 also indicates the size (in mm^2) of the phase conductors. The cost of the conductor is much more project-specific than the cost of poles because it is primarily a function of the cross-sectional area of the conductor, and this depends on the actual load it is designed to serve. Figure 15 later in this study shows the variation of cost with size for several types of conductors in a number of countries.

Figure 3 illustrates the difference in total cost between single- and three-phase construction for those countries where both types of construction are found. The percentage cost savings in going to single-phase construction is noted above each set of costs and averages 30 to 40 percent. Typically, the cost of materials and labor for single-phase line construction averages about $6,000 per kilometer. Except for the case of Bangladesh—where the single- and three-phase lines quoted have conductor areas of 34 and 107 mm^2, respectively—the conductor size for both the single- and three-phase lines is roughly the same for each case presented.

In Figure 3, only the cost of single- and three-phase construction within each country should be compared. A cost comparison between different countries may not be valid because different factors may contribute to the cost. For example, the costs incurred by the Rappahannock Electric Co-op are more encompassing because they include the high cost for right-of-way clearance, a figure missing from the data from most other countries. If, on the other hand, only the cost of materials is considered, this electric utility has one of the lowest line-construction costs.

Although expenditures for poles and conductor usually account for most of the cost of grid extension, there are exceptions. In the cases shown in Figure 4, poletop hardware can account for as much as 40 percent of the material cost for a three-phase line. Although the use of pin-type insulators prevails in most cases, the higher cost in Laos stems from the use of more costly post insulators. From the data provided it is also clear that, in the cases of Bolivia and Senegal, increased cost is due to the use of both a higher distribution voltage (roughly 34 kV) and suspension insulators.

Figure 5 illustrates the considerably reduced cost of poletop hardware required for single-phase construction, especially with the North American configuration. This is attributable to the reduction in the number of poletop insulators (for the phase conductors) from three to one and to the elimination of the use of a crossarm. Cost savings for the European configuration are less significant because single-phase (phase-phase) construction still requires two-thirds of the poletop insulators and a crossarm.

In general, a review of costs for grid extension in even the limited selection of countries included within this study confirms that they span a considerable range. It also appears that this range is attributable to more than simple differences in site conditions and that, through a review of existing designs and alternative options, the potential exists for a reduction in the cost of RE in a number of countries.

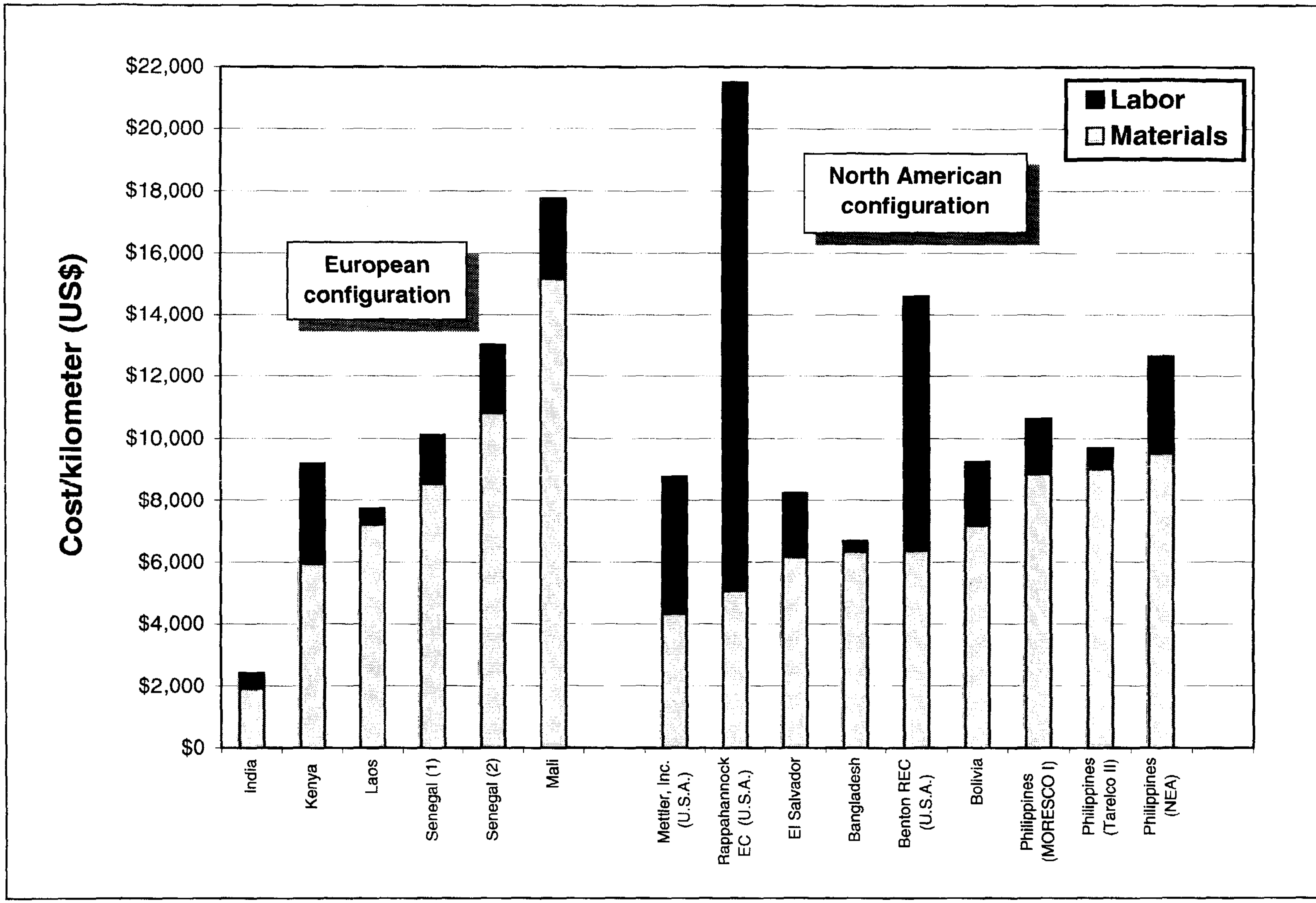


Figure 1. Total Cost (Labor and Materials) for Three-Phase Lines

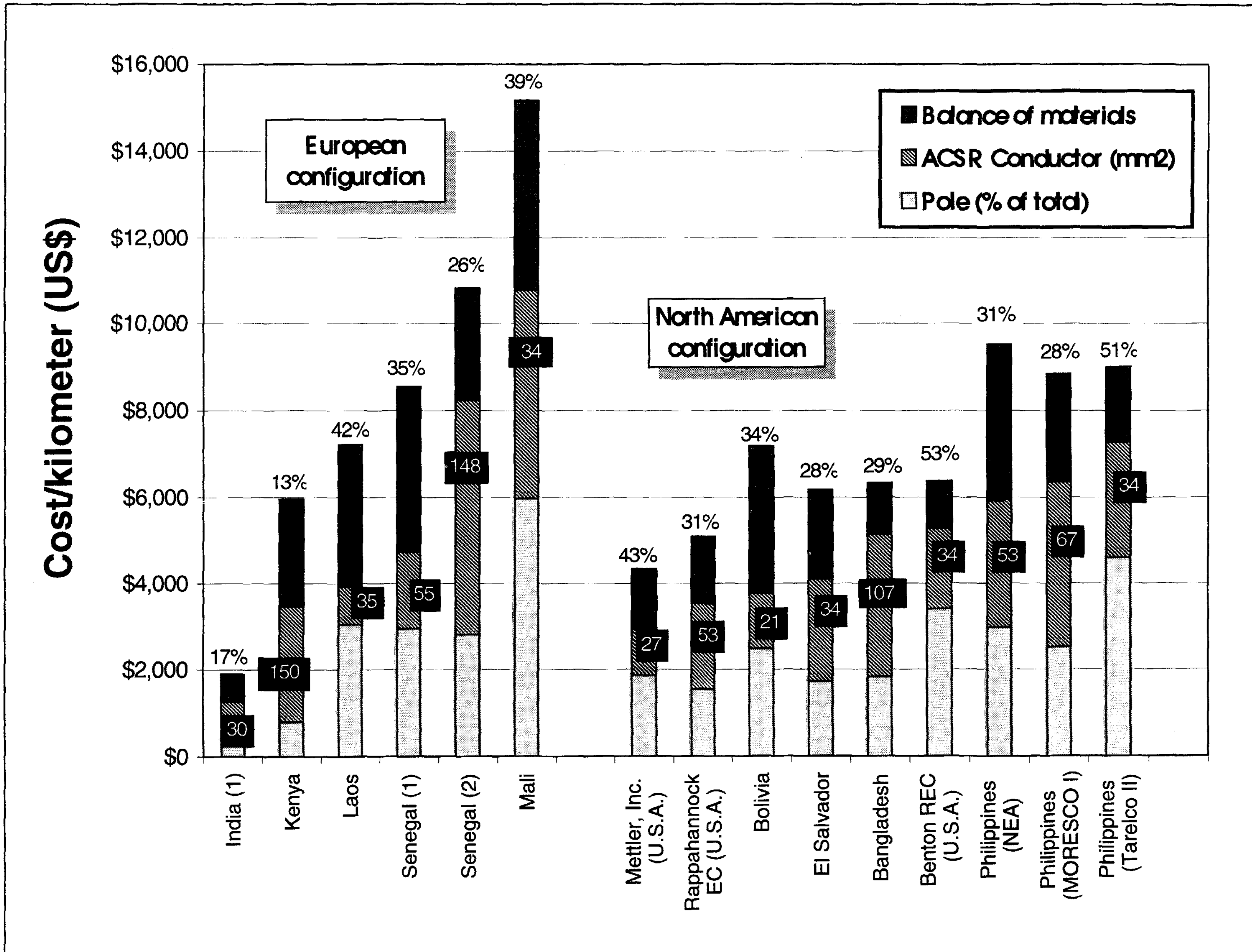


Figure 2. Cost of Pole and Conductor as a Portion of Total Materials Cost for A Three-Phase Line

Note: The size of the conductor used and the pole cost as a percentage of total materials' cost are noted on each bar.

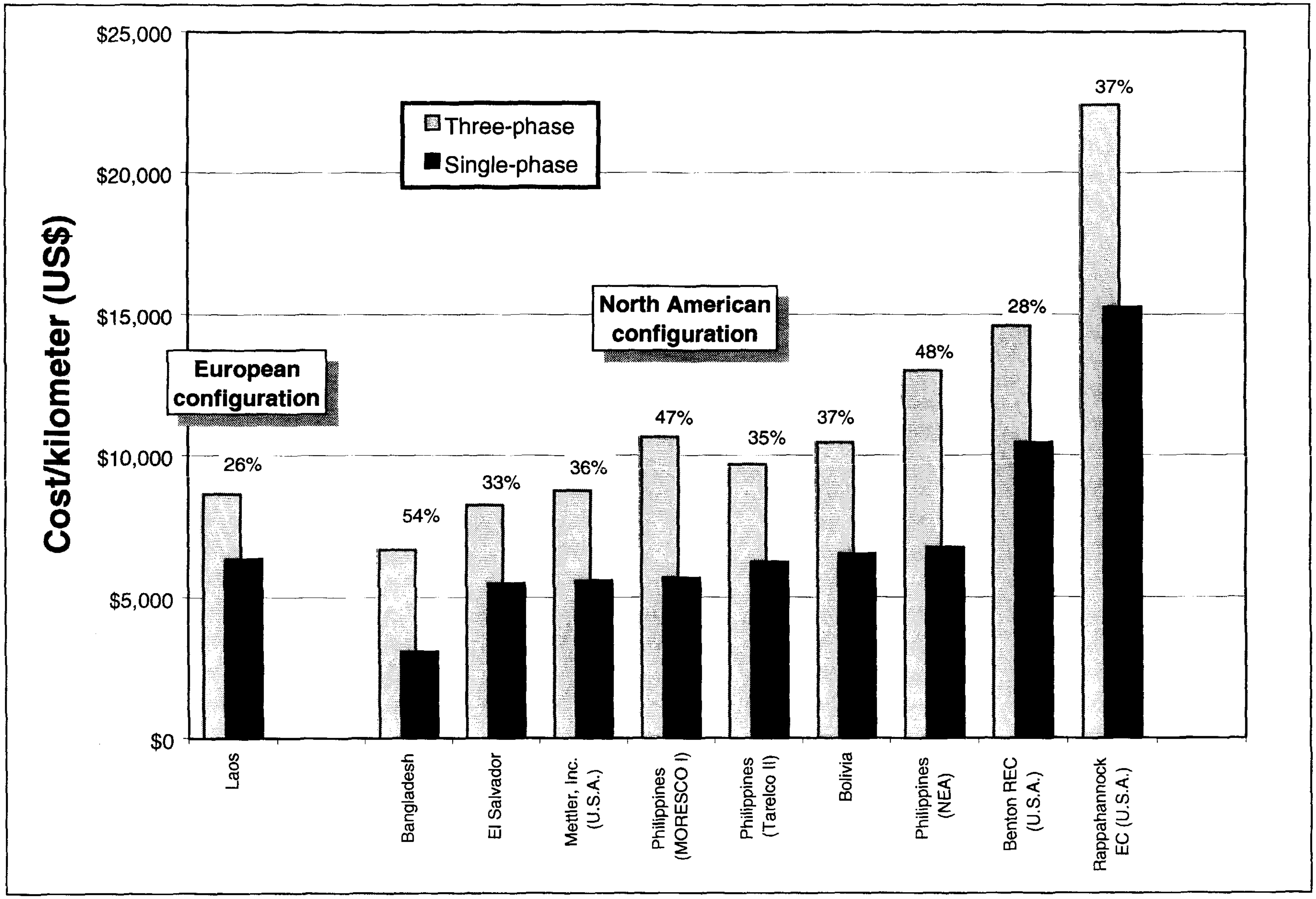


Figure 3. Total Line Costs (Materials and Labor) for Three-Phase and Single-Phase Configurations in Different Countries

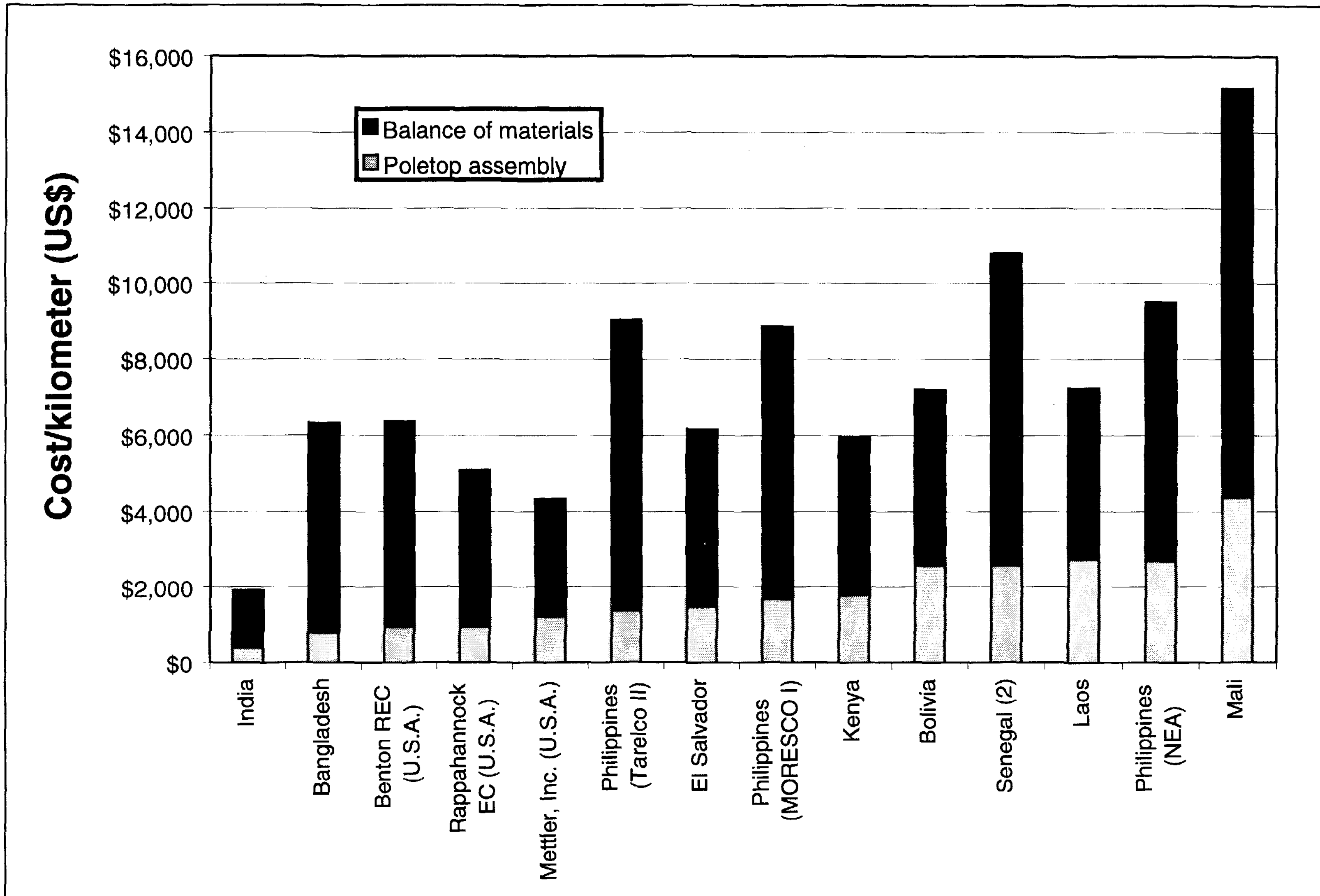


Figure 4. The Cost of the Poletop Assembly as a Portion of Total Materials Cost for Three-Phase Lines

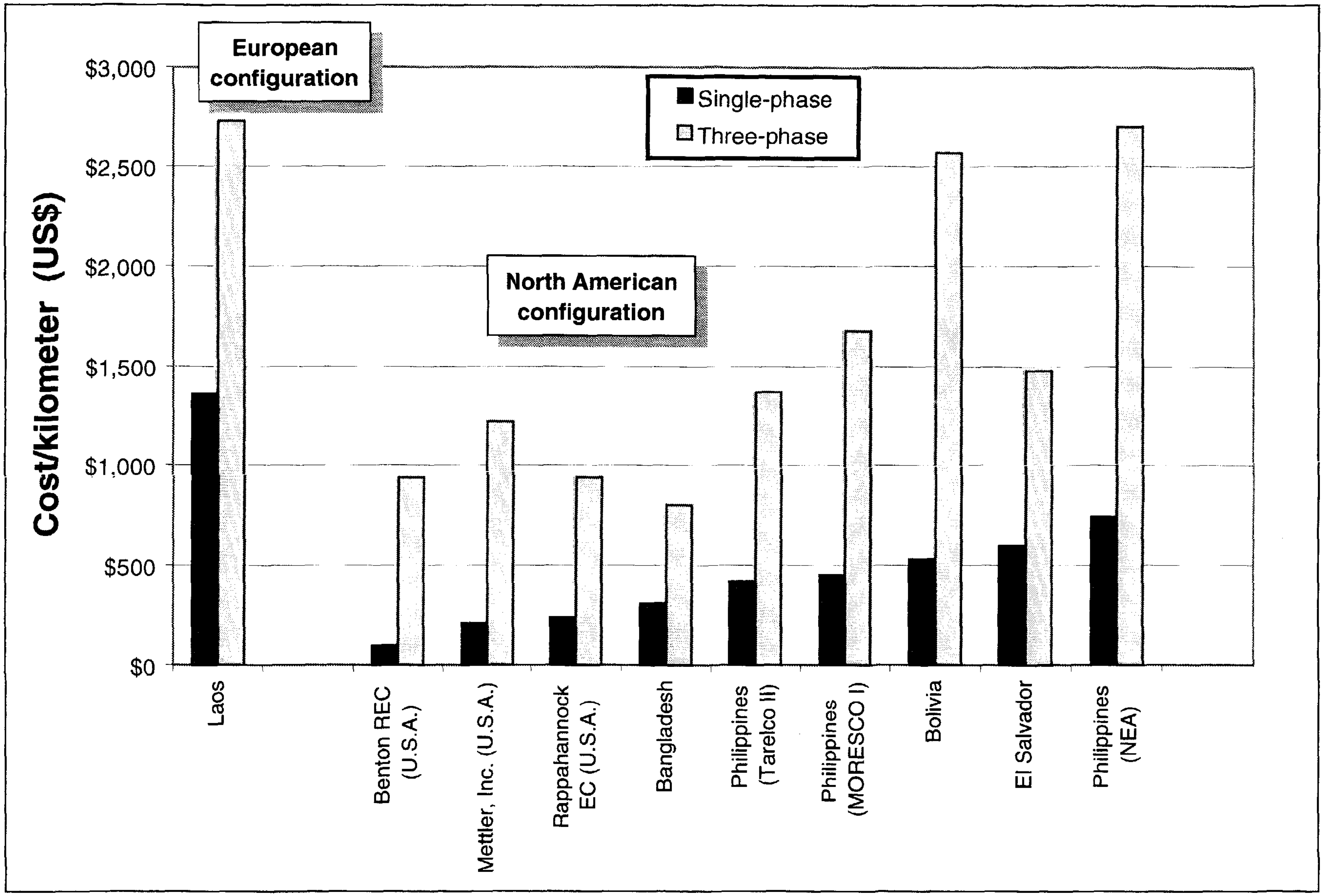


Figure 5. Comparative Poletop Assembly Costs for Single- and Three-Phase Lines

3

Factors Affecting Cost

Worldwide, the most common design for grid extension is a three-phase configuration. This study will begin with this commonly used configuration as the point of reference and illustrate options for reducing the cost of bringing power to rural areas.

Two factors inflating the cost for grid extension into rural areas are

1. The sub-optimal use of available materials and designs, such as the use of shorter spans than possible and the poor placement and sizing of transformers; and
2. The adoption of designs used to serve urban loads that do not take into consideration the unique design implications of serving rural populations, including the widespread use of three-phase lines and oversizing of transformers and conductors.

This chapter will review variables that affect these costs and illustrate how design modifications might reduce cost.

As noted in Chapter 2, variants of either of two basic configurations—the European and the North American—are used worldwide for electric power distribution. The suggestions for cost-reductions made in this report apply to both configurations.

However, the actual configuration selected can itself also affect cost. For example, by the early 1970s, Tunisia's electric utility had not yet extended its distribution systems far from the urban centers, and it took the occasion to assess the cost and other advantages of converting to the North American system. It concluded that, under circumstances found in that country, savings in the range of 18 to 24 percent would result, at which point it proceeded with the implementation of the North American configuration.[v]

Determining which configuration is the most cost-effective is a site-specific endeavor involving a comparative costing applied to the actual situation, as was done in the case of Tunisia. It should be noted that by now most countries already have well-established designs and trained staff, and conversion at this late date may no longer be cost-effective. Furthermore, it is not clear that cost is the predominant factor in selecting one option over the other. Of greater importance may be more-amorphous issues concerning safety, reliability, versatility, and flexibility.

However, one feature of the North American configuration that has resulted in cost savings is the widespread use of single-phase distribution. The fact that this feature is even being used increasingly by those who use the European configuration seems to confirm that there is some virtue to this feature. The impact of single-phase construction on cost savings is addressed later in this chapter.

Line Design

Before even considering any alternative technical designs to reduce the cost of MV lines, it is necessary to ensure that the poles, conductor, and line hardware incorporated in existing designs are used optimally and that the lines are efficiently designed and constructed. For example, spans should be maximized to take advantage of the strength of conductors while ensuring a generally acceptable degree of safety. Conductors should be optimized to handle realistic demands expected over the life of the system with acceptable losses; they should not be oversized. Pole lengths should not far exceed those necessary to meet established ground clearance requirements. Usable pole strengths should be established using realistic safety factors. Finally, designs should be standardized to minimize the use of specialized engineering expertise, which adds to the time and cost of line design.

Poles

As previously seen in Figure 2, poles are often the costliest single component required for grid extension and are the obvious area in which to focus in attempting to reduce cost. Several options are possible for reducing pole cost, including the use of

- Underground cabling to eliminate the needs for poles altogether,
- Shorter poles to reduce cost of materials,
- Longer spans to reduce the number of poles, and
- Alternative pole designs.

Underground Cabling

An obvious way to reduce pole costs is to do away with the poles altogether and rely on underground cables. In addition to economics, however, aesthetics is a driving force behind the growing use of this option, whether in a new housing development in suburban San Francisco or for the micro-hydropower mini-grid in Namche Bazaar, Nepal, the last village on the trekking route to the Mt. Everest base camp. Another advantage is reduced exposure to the elements—winds, ice, and tree branches—and decreased susceptibility to outages or life-threatening situations.

On the other hand, an overriding deterrent to the use of underground cables is its cost: underground construction costs at least twice as much as using overhead lines. Several other important disadvantages are associated with underground construction when used in areas where a potential future increase in demand or in the physical extent of the system is envisioned:

- Line capacity cannot easily be increased either by adding another phase conductor to a single-phase line or by upgrading the conductor size.
- Making joints along a line or tapping a line to serve new consumers is difficult and costly and requires specialized training.

- Underground lines must be carefully mapped and these maps readily available so that the location of these lines is precisely known when access is required for extensions, taps, or repairs in the future.
- Locating and repairing underground faults requires suitable equipment and training.

Consequently, although underground cabling may eliminate the need for costly poles and have several other positive attributes, these rarely outweigh the significantly higher costs associated with the conductor and its installation as well as with future expansion and repairs. If concern centers on cost, this would generally be an option of last resort.

There are exceptions to this rule, of course. For example, underground construction might be the least-cost approach in areas where overhead lines are susceptible to storms, such as typhoons or cyclones, because of the high cost of replacing poles that fail prematurely (p. 21). Under these conditions, the life-cycle cost of poles and their replacement might exceed the cost of underground construction.

On islands in the Pacific, another circumstance prompting the use of underground cabling is the presence of expansive coconut plantations: in addition to susceptibility to wind damage, overhead distribution lines require the removal of large numbers of trees along the right-of-way, representing lost income to their owners.

Shorter Poles

Countries around the world use poles that are considerably longer than necessary to achieve the required line-to-ground clearance. For example, in Laos, three-phase lines with 80-meter spans over level terrain are frequently constructed using 12-meter poles and aluminum-conductor, steel-reinforced (ACSR) conductor, while in India 8-meter poles are used under similar circumstances.

Smaller girths are possible with shorter poles, and reduced girth and length each lead to reduced cost. Reducing the length of a treated wooden pole 17 percent, from 12 to 10 meters, decreases the cost of a pole by 24 percent (assuming U.S. pole costs; see Figure 6).[6] A further reduction from 10 to 8 meters decreases the cost by another 28 percent, for a total cost reduction of 45 percent. With the pole being a major contributor to the cost of a line, this reduction should have a noticeable impact on the cost of grid extension.

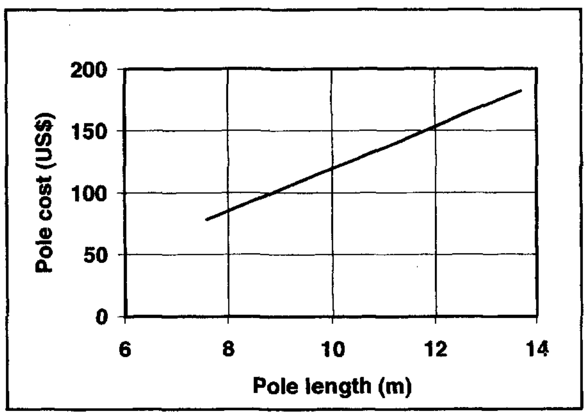


Figure 6. Approximate costs for Class 5, CCA-treated Southern Yellow Pine poles in the United States

Therefore, although 35-foot (10.6-meter) poles are commonly used in the United States and 12-meter poles are routinely used in a number of countries around the world, neither length need be the norm

[6] This assumes the need to withstand the same transverse poletop force.

when extending lines into rural areas. For example, in central Nepal, fabricated steel poles beginning at 8 meters are used in private RE projects. In India, both pre-stressed concrete poles and rectangular hollow steel poles in the range of 7.5 to 9 meters are used for 11-kV lines.

However, the extent by which poles can be shortened is clearly limited. This is established by the minimum acceptable clearance between the lowest conductor and the ground (or any structures found under the line). For example, according to the National Electric Safety Code (NESC) in the United States, the minimum clearance between open supply conductors (rated up to 22 kV) is 5.6 meters when located above roads subject to truck traffic and 4.4 meters above spaces accessible only to people.

In the more densely populated areas, joint use of utility poles by cable TV and telephone companies requires poles of additional height to permit adequate clearances between these various sets of cables and between these cables and the ground. However, in most rural areas in non-industrialized countries, this is not presently of concern. In fact, the evolution of more cost-effective technologies such as direct broadcast television and cellular telephones may mean that joint use of poles may not even be a future concern in rural areas.

Longer Spans

In addition to using shorter poles for a given span to reduce cost, the cost of poles can be further decreased by reducing their number per kilometer of line through the use of longer spans (see Figure 7). Allowable span is set by several factors: the need to maintain adequate line-to-ground clearance for safety purposes, adequate line-to-line clearance to prevent clashing of the conductors and ensuing faults, and strength of poletop insulators. To maintain adequate line-to-ground clearance, longer poles would be required because longer spans imply larger sag if conductor strength is not to be exceeded. So although fewer poles would be needed per kilometer, each pole would be costlier because of both its increased length and diameter.[7]

Figure 7. Lines in Bolivia (left) have significantly longer spans than in Laos (right) in similar types of terrain.

[7] Longer poles would require larger cross-sectional areas to counter the increased bending moments due to (1) the greater wind loading on the conductor and pole (because of the greater diameter presented to the wind by longer spans and larger poles) and (2) the fact that transverse forces (wind forces and conduction tension at deviations along the line) act higher on the pole.

Figure 8 illustrates how the length of poles varies with increasing span in order to maintain the necessary ground clearance—in this case, about 5.6 meters per the NESC—and the resulting effect on line cost, not including labor.

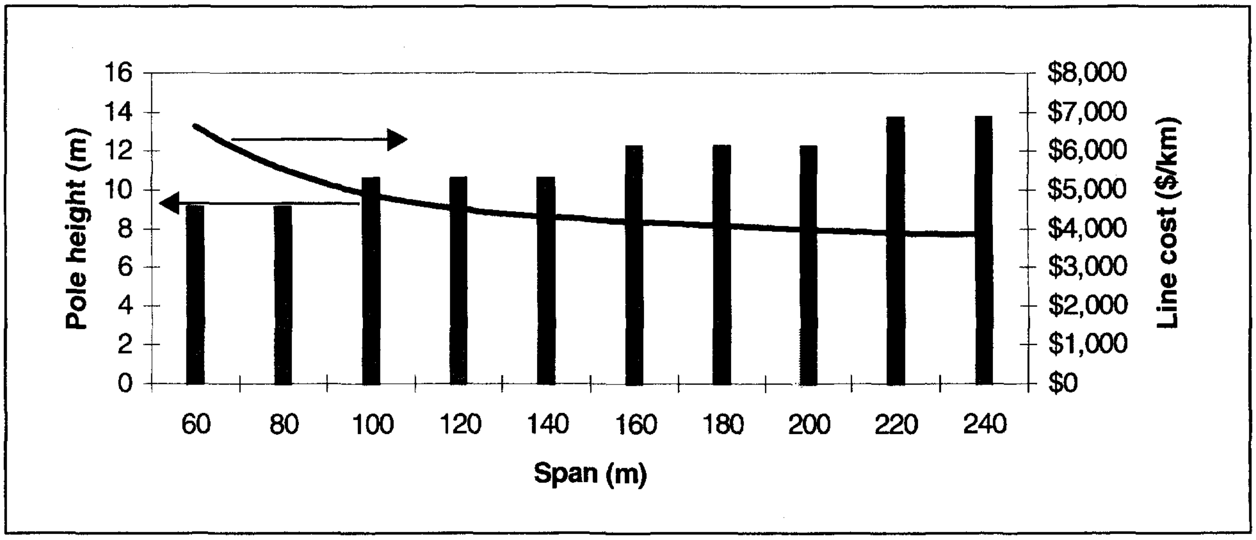


Figure 8. Relationship between span, pole length, and line cost

Note: The bars represent the heights of standardized poles needed to maintain the required ground clearance for different spans. The trend line decreasing to the right indicates the effect of span on the unit cost of construction. In this idealization, a straight #2 ACSR three-phase, three-wire line over level, unobstructed terrain is assumed—i.e., no guys, deviations in direction, or double crossarms. Costs for El Salvador are assumed.

Under these assumptions, line costs decrease with increasing span, but this decrease becomes insignificant for large spans. Actually, beyond a certain point, the difficulty of finding poles of sufficient length prevents a longer span or causes line cost to increase. Using shorter spans results in less sag, and shorter poles can be used to maintain the minimum ground clearance requirements. Shorter poles are less costly, but their increased number per kilometer results in a net increase in cost.

Although spans closer to 200 meters would have the lowest cost for the idealized line considered in this example, significantly shorter spans are commonly used for the following reasons:

- Longer spans may make it difficult to follow a winding road, accommodate the terrain, or clear structures;
- Longer poles are more difficult to find; and
- Minimum clearances considerably in excess of the 5.6 meters are used.

The use of long spans is limited by the paucity of adequately flat terrain. However, this example does illustrate that countries should consider considerably larger spans than are commonly used. In El Salvador, 10.6-meter poles with spans of 130-140 meters are commonly used. This stands in comparison to an average span of 90 meters with poles of similar lengths in the field data gathered (see Appendix A). Because the terrain forces deviations in the direction of the lines, six to seven guys per kilometers are typically used in El Salvador, at an additional cost of about $100 for each guyed pole.

A single-phase European design usually requires crossarms supporting a conductor at each end. The conductors for a single-phase North American design are usually installed in a vertical configuration to save on the cost of crossarms and associated hardware.[vi] A vertical configuration would initially seem to imply the need for longer poles to maintain similar ground clearances as with the horizontal, European configuration. However, less ground clearance is required for the lower, neutral conductor used with North American construction than for a phase conductor. For example, in the United States, although the NESC specifies a minimum vertical clearance of 14.5 feet (4.4 m) for a phase conductor in areas only accessible to pedestrians, only 9.5 feet (2.9 meters) is required for the lower, neutral conductor.

Caution should be exercised when considering increasing span by using a single-phase line: If a real possibility exists that the demand along the line will increase to a point that the line must be converted to a two- or three-phase line within its lifetime, span length should anticipate accommodating a larger number of conductors. But this is not as important an argument against the use of single-phase lines as may first appear. Single-phase lines have considerable capacity, and it may be a long time before such a line requires replacement with a line of higher capacity. Even in an industrialized nation like the United States, the widespread single-phase service first introduced about 60 years ago in rural areas continues to provide more than adequate service today. Use of single-phase distribution lines still predominates in many part of the United States, in spite of the large farms and commercial establishments found in these areas. (See page 35 and following for a further discussion of the suitability of single-phase construction.)

Reducing the cost of grid extension by increasing the span and reducing the number of poles can be pursued one step further. When maximum span is limited by the need to avoid clashing of adjacent conductors or by the wind loading on two conductors, restricting the line to the use of only a single conductor removes or reduces this constraint. This configuration, commonly referred to as the SWER (single-wire earth-return), uses a single phase-conductor and relies on the earth as the return path. For a given pole length, the only factors limiting span would then be the tensile strength of the conductor, the strength of poletop insulators, and the required ground clearances.

Nearly 200,000 kilometers of SWER line is used in Australia to serve its dispersed rural population. In the state of New South Wales, use of SWER permitted a saving of at least 10 percent when compared to a conventional single-phase system.[vii] If steel conductor is used, spans of 200 to 300 meters are possible, with typical sags of 2.5 meters. In the state of Victoria, the use of SWER is said to result in a saving of 30 percent in comparison to the capital cost for a conventional single-phase system. The distribution system requires only 50 percent of the components necessary to build a conventional single-phase system, but savings are less because more extensive grounding is required. The cost incurred for grounding is approximately 30 percent more than that associated with conventional single-phase systems, and the cost of losses is also greater; however, offsetting these is the reduction in maintenance costs because of the reduction in (1) the number of components used and (2) the width of the right-of-way requiring periodic clearing.[viii]

In Laos, the proposed use of a single-phase SWER configuration is expected to halve the number of poles from 12 to 6 per kilometer. Estimated cost of materials (not including labor and transportation) for SWER construction is expected to be $3,100 per kilometer, whereas single-phase (phase-phase) construction costs $4,600, or roughly 30 percent more.

Alternative Pole Materials and Designs

Poles can be made from a variety of materials, most frequently wood, concrete, and steel. None of these has a clear-cut advantage in all situations, and both cost and specific attributes associated with the various options are factors that should be considered in the selection process.

Before reviewing each of these options, however, it is important to note that the quality and strength of the poles selected should not be compromised in the process of reducing cost. Simply having to replace each pole once during the expected life of a system because of poor quality effectively doubles the cost of the pole for that line. The cost of labor adds further to the total because replacing a pole can cost considerably more than its initial installation.

For example, in El Salvador the installed cost for a simple pole structure (i.e., the cost for the pole and poletop assembly and for framing and setting the pole) for single-phase and three-phase lines is $400 and $570, respectively. However, the cost for replacing this structure—including a new pole but assuming a de-energized line and reuse of all the poletop hardware except for armor rod and wire ties—is about $500 and $700, respectively. Replacing the pole while the line is energized increases this cost by 50 percent. And if the pole includes other hardware—such as guys, transformers, or streetlights—that needs to be exchanged between the old to the new pole, costs further increase.

Consequently, rather than costing $570 per simple installed pole for a three-phase line, the total cost for that structure, including a replacement pole, would be about $1,300, effectively resulting in a total undiscounted life-cycle cost that is roughly twice the cost of the original structure. Replacing the pole while the line is energized pushes the total to $1600, about three times the original installation cost.[8] Because poles are the most costly item of a line, short-lived poles have a significant impact on the life-cycle costs of a line.

Experience in the United States confirms these costs. For example, according to the Benton Rural Electric Cooperative, the cost of replacing a three-phase pole installed in the state of Washington is about 150 percent of the installed cost of the original structure and 200 percent if the pole is replaced while the line is energized.

Consequently, although using less-durable poles can reduce cost, it can considerably increase the discounted life-cycle costs of a line. This is especially true in countries where the cost of labor is high. Even in countries with lower labor rates, however, the need to maintain a poorly designed line diverts resources that should rather be utilized in broadening the reach of RE rather than simply reinforcing what has previously been done.

The remainder of this section discusses the relative merits of wood, concrete, and steel in pole construction.

[8] This assumes the pole lasting half of its expected life. Use of inadequately treated wood poles has led to poles with even shorter lives, further increasing the life-cycle cost per pole.

Wood

Treated wood poles have been widely used for electrification worldwide because they exhibit a variety of advantages. These poles

- Can be a produced and treated locally,
- Are lighter than the equivalent cast concrete pole (the common alternative) and easier to handle in the field,
- Are easier to climb,
- Are not susceptible to breakage during transport and handling,
- Rely on a raw material that, unlike cement and steel, is not energy-intensive in production, and
- Permit greater flexibility in the placement of mounting bolts and facilitate later modification in the field.

Properly treated wood poles have been proven to last for decades, even in wet environments (see Figure 9). Any decay is likely to first occur at ground level, where conditions for decay—moisture and air—are most optimum. With a groundline treatment procedure incorporated into a wood pole line inspection and maintenance program, this can be increased considerably. Furthermore, wood poles are not adversely affected in coastal zones where airborne salt can cause corrosion of steel poles or the reinforcing steel in concrete poles.

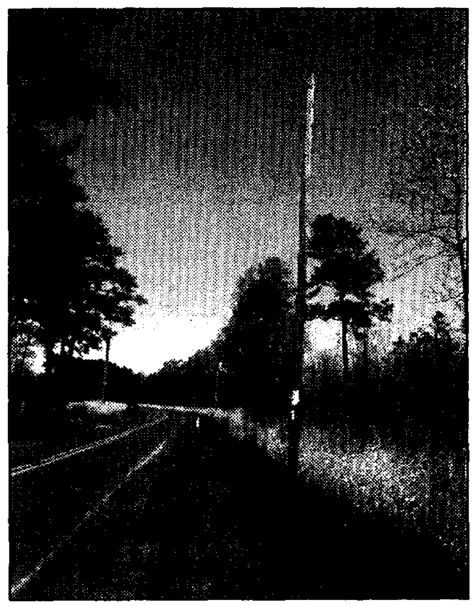


Figure 9. In some areas, properly treated poles, like the one above treated in 1947, spend most of their lives in water or water-logged soils. (Eastern shore of Maryland, United States)

Other benefits of using wood poles include the following:

- Local plantations permit self-sufficiency in the production of one of the costliest components of an RE program, thus creating employment, reducing the need for foreign exchange, and lowering the cost of RE.
- Properly managed, wood is a renewable resource with wood poles, requiring much less energy for their "manufacture" and contributing no net carbon dioxide or other greenhouse gases in the process, unlike the case with the production of concrete or steel for poles.
- Fuelwood from offcuts and from ongoing right-of-way clearing can serve as a low-cost, easily usable, efficient, and renewable fuel for cooking and space heating, thereby reducing electricity demand and associated construction costs (see Appendix B).
- Increasing forest cover for pole production in marginal areas can produce numerous environmental benefits, including reduced erosion of land and sedimentation that leads to the destruction of riverine habitats, improved ground water quality and quantity, more abundant and diverse wildlife, and opportunities for increased employment opportunities from processing a range of forest products. It also serves as a sink for carbon dioxide, a gas increasingly recognized as contributing to global warming and its adverse implications.

- In a number of countries, rural households have little disposable income, and the problem facing RE programs is the inability of these households to cover the cost of connection as well as the cost of energy. Growing trees for poles may be one option requiring few financial and labor inputs, thus reducing the cost of electrification. It can also provide a regular income to rural households that, in part, can be used to cover the cost of their electric service.

In a growing number of countries, the principal obstacle to the local production of wood poles is the lack of existing forest reserves with suitable trees. It is possible to plant trees specifically for pole production, but adequate lead time is required until newly planted trees can be harvested for this purpose. Tropical pines can produce a 9-meter pole in about 15 years but have limited strength. Faster-growing soft wood species exist, but these tend to be weaker. More commonly found hardwood species, such as eucalyptus, are another option, but these do not offer good preservative penetration and retention.

However, because poles will continue to be in demand for expanding RE as well as for replacing damaged existing poles, the need for poles will continue decades into the future, well after any tree plantation starts yielding trees of adequate dimensions. Furthermore, the advantages of using wood poles should be sufficient incentive for a national commitment to the creation of local tree plantations, possibly in collaboration with other government departments, nongovernmental organizations, or private entrepreneurs (see Box 1).

The quality of, and costs for, treated wood poles available from around the world can vary considerably. Table 1 illustrates the wide range of costs Bangladesh received in response to a single request for bids specifying CCA Type C treatment, kiln-dried 9- and 11-meter poles with no pre-treatment decay, and generally following the specification established by the Rural Electrification Board (REB) of Bangladesh. Incidentally, the effectiveness of these specs has been illustrated by the fact that none of the 1 million U.S. poles the REB has installed throughout that country has shown any signs of decay in spite of the wet tropical environment in which they are used.[ix]

Table 1. Average Bid Price from Several Suppliers of Treated Wood Poles

Pole description	Average cost per pole ($)
1. South Africa creosoted radiata pine	111
2. South Africa CCA radiata pine	112
3. Argentina CCA eucalyptus	151
4. South Africa CCA radiata pine	151
5. Norway CCA scotch pine	188
6. Finland creosoted scotch pine	213
7. Chile CCA radiata pine	216
8. Finland CCA scotch pine	228
9. United States CCA southern yellow pine	242

The desire to reduce the cost of RE should not drive pole selection at the expense of quality. A previous example already illustrated how the premature replacement of poles because of unexpected decay can significantly increase their life-cycle cost. Therefore, in selecting the most cost-effective wood pole for a project, the selection, pre-treatment handling, and treatment of poles should be carefully and knowledgeably evaluated.

Box 1. Example: The Philippines

In the Philippines, the National Electrification Administration (NEA) recognized the numerous advantages of using wood poles in rural areas. It also recognized the dwindling source of forest resources in their own country and the high cost in importing poles from overseas. Consequently, the Power Use Development Division of the Cooperative Services Department of the NEA initiated a tree-planting program in 1993. Nearly one-half of the 119 rural electric cooperatives in the country are now involved in this program.

These rural electric cooperatives raise seedlings that they donate to their consumers (either individuals or users groups) or sell under contract to large landowners. (The largest single area currently under cultivation is 400 hectares.) A condition for membership in some cooperatives is planting a couple of trees on the member's own land. Upon maturity, the co-ops agree to purchase the trees for their eventual chemical treatment and use as wood poles.

Specifically for the Philippines, the NEA recommends planting *Gmelina arborea*, *Eucalyptus deglupta*, and *Acacia mangium*, all of which can adapt to the varied climatic regimes in the country.* It is expected that a 35-foot (10.5-meter) pole with a diameter of 8 inches (0.20 meters) will be available after about 8 years following the planting of the seedling. The planting density is at least 500 trees per hectare. It is expected that the co-op will save roughly 50 percent over the current price of imported poles. At an estimated development cost of roughly $1,000 per hectare, NEA projects a 50-fold return on investment after 10 years.

To ensure a long life, poles have to be chemically treated. But the transportation of poles to centralized pole-treatment plants around the country is costly and would, at least in part, negate the advantages of growing trees in the areas served by the cooperatives themselves where they are to be used. For this reason, the Forest Products Research and Development Institute in Laguna has developed a device for the *in situ* treatment of wood poles through high-pressure sap displacement. A cylindrical pressure cap is fitted over the base of a newly felled tree (Figure 10). A water-borne preservative solution is then introduced into this cap and forced up through the bottom of the tree. This forces the sap out, leaving the preservative behind. Up to two poles can be treated simultaneously, with treatment times of up to several hours, depending on a range of variables. The treating equipment costs $5,500 with a 1/3-horsepower electric motor and $8,200 with a 2-horsepower diesel engine.**

Currently, about 28 rural electric cooperatives and entrepreneurs are using this treatment plant in the Philippines, with a production rate of about 10 poles daily. *Gmelina arborea*, a light, rapidly growing hardwood, is commonly used and harvested after seven years. By this time, poles have attained a height of about 10 meters and a diameter of 220 millimeters. Treatment is with chromated copper arsenate (CCA), with a retention of 12 to 17 kilograms per cubic meter and full penetration of the sapwood. To minimize environmental problems and ensure quality treatment, the operation should be carefully managed.

* *Primer on Woodpole Production Program* (brochure prepared by the Power Use Development Division, Cooperative Services Department, National Electrification Administration, Manila, Philippines).

** "Series 4, High Pressure Sap Displacement Treatment," second revision (Laguna, Philippines: Forest Products Research and Development Institute, December 1997).

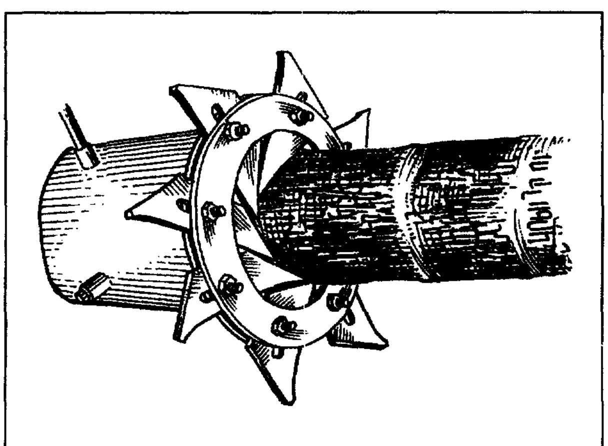


Fig. 10. Adjustable steel fingers mounted on the pressure cap restrain the rubber seal when the preservative within the cap is pressurized.

In the case of the bids in Table 1, some were found to be non-responsive because of the use of other preservatives (bids 1 and 6) or other specifications (bids 1-4). Some (1, 2, 4, and 7) were from plants operating under conditions that encouraged pre-treatment decay of poles (which quickly reduces pole bending strength and can prevent proper loading of preservative). Bid 5 was finally accepted, and although the initial cost may be high, this choice may well lead to lower life-cycle costs. In fact, the most expensive pole on this list also carried with it a 40-year "replacement or money-back" guarantee in writing, backed by a major U.S. bank. This essentially guarantees the life-cycle cost of the pole.

Concrete

Where wood poles are not an option because suitable poles are not grown locally or the cost of importing them is too high, steel-reinforced concrete is a common alternative. This permits local manufacture with relatively inexpensive, readily available materials: cement and reinforcing steel. Disadvantages can include the increased cost of transport and difficulty of handling due to their weight, increased breakage during transport and handling, and susceptibility to failure due to corrosion of the reinforcing steel because of either the environment or contamination within the concrete.

Because concrete has little strength in tension, steel is embedded in the concrete to provide this strength. Forces imposed by external loads are transferred from the concrete to the steel through a bond between the two. This bond is formed by the chemical adhesion that develops at the concrete-steel interface, by the natural roughness of the surface of hot-rolled reinforcing bars, and by the closely spaced, rib-shaped surface deformations on the bars, which provide a high degree of interlocking of the two materials.

The several pole designs that are commonly used include

- Cast reinforced concrete
- Cast pre-stressed concrete
- Spun concrete.

Although **cast reinforced concrete** is the easiest and least costly design, it yields the poorest strength characteristics. Reinforcing steel or "rebar" is simply placed in the forms prior to pouring the concrete (Figure 11). Reinforcing steel has no initial stresses; these stresses only develop as the structure is placed under load. As the structure begins to deflect, a portion of the concrete is placed under tension and can begin to develop hairline cracks *before* the steel begins to provide the necessary tension to counteract the imposed load. This design may also be subject to voids or variations in density, depending on the actual manufacturing process used.

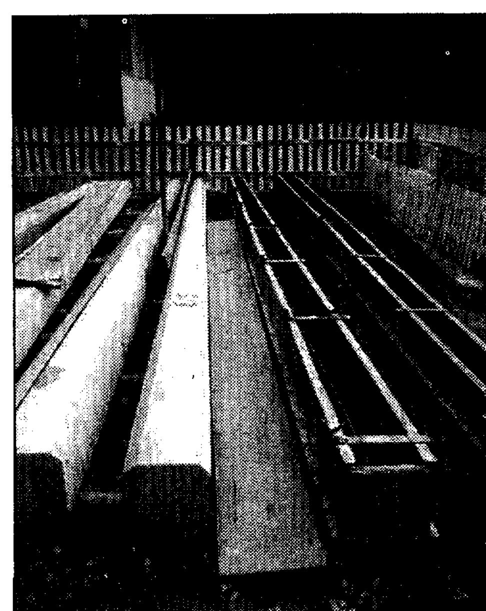


Fig. 11. Steel reinforcement placed in a mold ready for casting at an isolated site in Indonesia. Completed poles at the left are curing.

In **cast pre-stressed concrete**, the reinforcing steel is pre-stressed and is under tension even before the structure is placed in use. Furthermore, special pre-stressing steel with several times the tensile strength of reinforcing steel —in the form of either wires, cable, or bars—is used. Pre-tensioning and post-tensioning represent two alternatives for pre-stressing the steel. However, only pre-tensioning reinforcement is used in the production of poles. In this case, the pre-stressing strands are tensioned between massive abutments in the casting yard prior to placing concrete in the beam forms (Figure 12). The concrete is then poured around the tensioned strands. After the concrete has attained sufficient strength, the strands are cut. As they try to collapse back to their original length, the pre-stressing forces are transferred to the concrete through the bond and friction along the strands, chiefly at the outer ends.

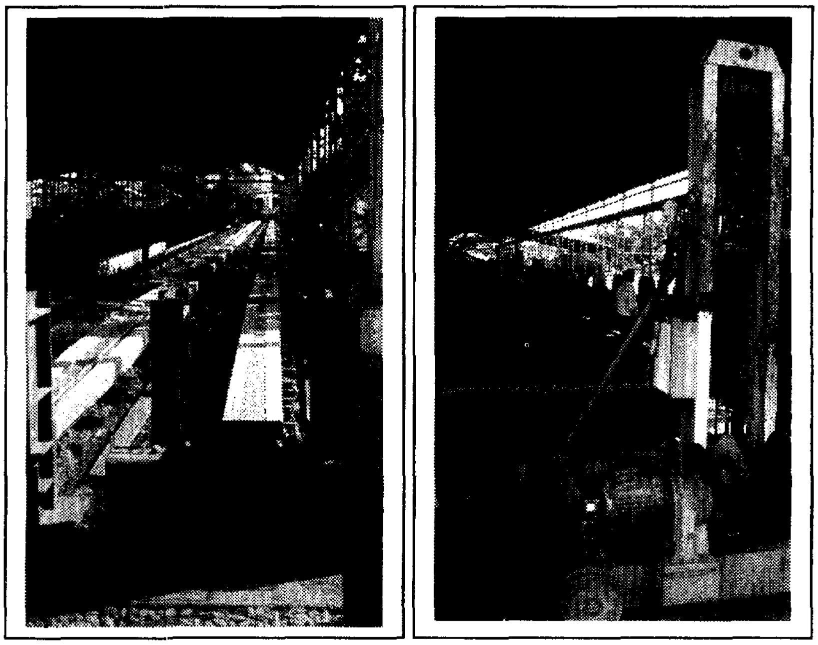


Figure 12. Reinforcing steel is stretched between two anchors by the winch (right, in the foreground) and secured in that position. On the left, poles poured nearly end to end for the length of the factory are left to cure (Thadeua, Laos).

Spun concrete begins with a "cage" of reinforcing rods placed into a mold into which concrete is added and rotated for up to half an hour. The pole is then steam-cured for several days before being removed from the mold and left to cure for a month. The centrifuging of the mold permits making the center of the pole hollow, reducing its weight without significantly reducing its strength, and leaving a shell of denser concrete. As with the ordinary cast concrete poles described above, spun poles can be made of unstressed or pre-stressed reinforcing steel.

Steel

Where a grid must be extended to areas without vehicular access, wood and concrete poles have the disadvantage of being too heavy and bulky if they have to be carried. Some efforts have been made for small, isolated projects to cast poles either on-site or even in-place. But these poles, which are made simply of reinforced rather than pre-stressed concrete, have limited strength.

An alternative has been to use steel poles. Their construction permits a pole to be fabricated of smaller sections that can be easily transported, by porter if necessary, and assembled on-site. The strength of steel is predictable and steel poles can be designed and manufactured to more exacting tolerance. Because steel is susceptible to corrosion (rusting), appropriate precautions must be taken, including galvanizing or painting.

One design for such poles originated from the work of Nepal Hydro & Electric Pvt. Ltd. of Butwal (Figure 13). Slightly tapered tubular poles comprise sections made of 1.5- and 2-millimeter plates, each with a length of 1.25 or 2.5 meters, and galvanized with a zinc coating at about 600 grams per square meter. For transport and storage, sections are placed inside each other. Each section weights from 4 to 60 kilograms, permitting one and sometimes more pole sections to be carried by a single individual. Assembled, these become poles with lengths of 5 to 17 meters. Cost is about $1.30 per kilogram. For example, a lighter-weight (i.e., 1.5-millimeter construction except for the base section) 10-meter pole costing $130 can handle a maximum transverse poletop load of 130 kilograms without guys. A heavier-weight and slightly longer 10.6-meter pole costing $310 can handle a maximum load of 540 kilograms.

Figure 13. Sections of a steel pole fabricated in Nepal easily can be carried by porters to isolated villages.

Another approach to design is utilized for 11-kV and LV lines in India.[x] Poles with a length of 7.5 or 8.0 meters are assembled from two rectangular steel sections of different diameter, one being inserted about 0.2 meter into the other. They are joined by bolts as shown in Figure 14. The larger section weighs no more than 60 kilograms. These poles are designed for a maximum working poletop load of up to 200 kilograms and are painted with red oxide primer to prevent rusting.

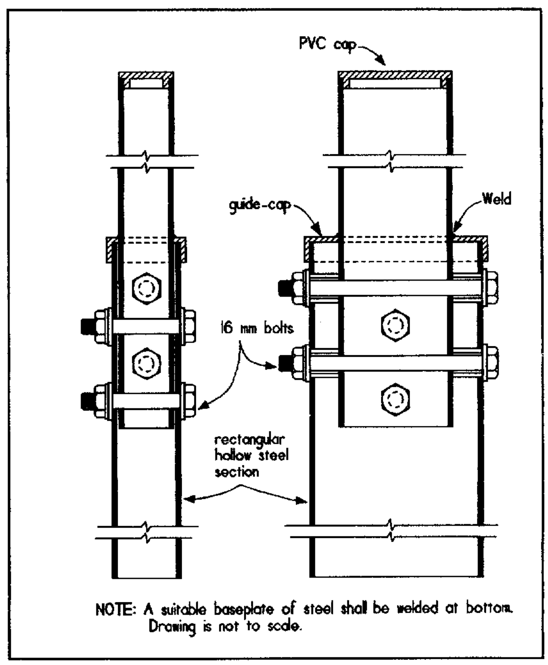


Figure 14. A steel pole design prepared by the Rural Electrification Corporation of India.

Conductors

In terms of cost per kilometer of line, the conductor generally represents the second costliest component. Materials used in the manufacture of conductors are usually limited to a combination of copper, aluminum, and, occasionally, steel. Figure 15 presents an idea of the cost for conductors made of these materials. Factors that affect the life-cycle cost of the conductor are the following:

- Size
- Required number of conductors
- Materials used in construction.

Proper Sizing

Higher costs than necessary can arise from oversizing the conductor. In addition to the increased cost of using heavier conductors, greater structural requirements for poletop hardware and poles and increased labor inputs also increase cost.

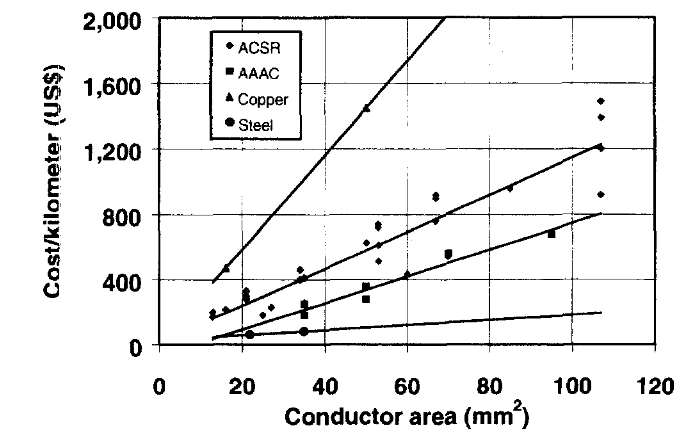


Figure 15. Some indicative conductor costs from around the world (Bangladesh, Bolivia, Indonesia, Laos, Nepal, Philippines, United States).

The first step toward minimizing life-cycle costs for the conductor is to realistically assess the loads to be met by the line during its life. Similar geographical regions that have already been electrified, with similar economic potential, should be surveyed to serve as a basis for assessing average initial loads as well as the growth of load in new regions. The already electrified regions surveyed should preferably have 24-hour, grid-connected service to ensure that the documented loads and load growth are not constrained by limited generation capacity. However, these regions could be supplied by a diesel or other isolated generation source as long as it is clear that the demands served by these isolated generators have not been suppressed because of either limited hours of operation or limited generation capacity. Projections of loads in areas to be electrified made on the basis of loads in areas with suppressed demand would tend to understate the actual demand to be met in the new areas. Consumers in the surveyed regions should also be paying tariffs similar to those projected in the new areas to be electrified.

In projecting existing electricity demand for a new area to be electrified, one must be alert to the impact on load and load growth in the area caused by such factors as the level of disposable income, the presence of raw materials or industry, the potential for tourism, and access to the market for goods that might be grown or produced locally.

In the interests of minimizing the cost of grid extension, although it is necessary not to underestimate the load over the foreseeable future, it could be equally important to consider making most effective use of line capacity. This would be achieved through demand-side management, i.e., managing electrical demand on the system in order to maintain as constant a load as possible. Examples include the following:

- In the villages around Aserdi in central Nepal, a MV line serves three types of loads: lighting (mostly in the evening), hulling of rice and milling of grain (during the day), and a water pump at the end of the line. If demand increases to the point that it affects the performance of the line, the pump at the end of the line could be operated whenever excess line capacity is available, because water is stored in a reservoir supplying a gravity-fed water-distribution system.

  Also, a capacity-based tariff is used for small domestic consumers in the area.[9] This is less costly

[9] With a capacity- or demand-based tariff, the consumer pays for using up to a pre-selected level of power (e.g., 25, 50, or 250 W) but can use this power for an indefinite period of time. Rather than paying a tariff based on the actual energy (in kWh) consumed—which is measured by an energy meter that periodically must be read and billed by the utility—the consumer pays a fixed monthly tariff. To ensure that the household's consumption does not exceed its pre-selected level of power, any of several types of current limiter is used to restrict demand.

to administer because no meter, meter reading, or billing is required. It also tends to increase the load factor (leveling the power demand) if the appropriate electrical end-use equipment is readily available. For example, to encourage people to cook using electricity rather than firewood—increasingly difficult to find—without the peaks usually associated with electric cooking, various designs for low-wattage heat-storage cookers have been developed and are being promoted. These are designed to be plugged in most of the day when excess capacity is available in the home, storing heat that can later be used for cooking or heating when needed. In the Aserdi region, the 250-W limit on consumption was specifically set with this use in mind; it permitted the simultaneous use of the cooker and one light.

Although daily load factors of 20 to 30 percent are commonly associated with isolated plants in Nepal and elsewhere, the 60 to 80 percent load factors at this site illustrate their success in making effective use of line capacity by smoothing the load profile.[xi]

- Large peaks caused by cooking with cheap, commonly available hotplates can easily more than quadruple the demand placed on a distribution system and increase construction and operations costs accordingly. Appendix B suggests that incorporating community woodlots as an integral part of an RE program could be an effective means of reducing these costs. Electricity would then be used to meet specialized needs where electricity is most efficient (especially for motors, lighting, and entertainment) and cheap, readily available fuelwood would meet heating requirements for domestic and industrial uses.

Once the nature of the loading has been determined, minimum cost can be assured by following the standard approach for properly sizing the conductor to meet the expected load and load growth. In this process, both the voltage drop at the end of the line as well as energy (kWh) losses along the line—both of which depend on conductor size—can be kept within acceptable bounds.

Number of Conductors

Probably the most significant approach to reducing conductor cost is to use less conductor, either by using higher distribution voltages or by using single-phase line extensions with adequate capacity to meet the projected load in the service area. As is described in the next section, use of single-phase lines requires only one or two conductors rather than three (European design) or four (North American system). Reduction in the length of the conductor can range between 33 percent (from three- to single-phase in the European configuration) to 75 percent (from three-phase with the North American configuration to SWER). Cost-savings due to a change in line configuration and in the number and size of conductors is covered later in this chapter (p. 31).

Materials Used

Materials used in conductor construction include copper, aluminum, and steel.

The argument can be made that a capacity-based tariff results in inefficient use of electricity, with villagers, for example, leaving lights on all day. Although this is possible, villagers quickly realize that leaving lights on all day results in the need to frequently replace lightbulbs, adding unnecessarily to their domestic expenses. Furthermore, a capacity-based tariff should not be used with larger consumers, as they can easily cover the cost of the meter and meter-reading.

Copper

Copper has the lowest resistivity of the three materials commonly used for distribution lines and is the costliest of the three. However, it is heavy relative to its strength. Consequently, forms of copper conductor have been developed to address this. One form is Copperweld, a conductor with a steel core (to impart strength) and covered with a thickness of copper (to reduce its resistance). Although it is a costly conductor, it may prove the most economical life-cycle solution in cases where the local environment could lead to corrosion of the line. For example, on a system on the east side of the island of San Andreas in the Caribbean, ACSR lasted only about four years and has since been converted to copper.

Aluminum

Because aluminum is a relatively good and inexpensive conductor, it is the most widely used. Its conductivity-to-weight ratio is twice that of copper and its strength-to-weight ratio is 30 percent greater. It comes in a variety of forms, including

- Aluminum-conductor, steel-reinforced (ACSR), the dominant conductor;
- All-aluminum alloy conductor (AAAC); and
- All-aluminum conductor (AAC).

The ACSR conductor is composed of a number of strands of aluminum wire wrapped around a core of one or more strands of galvanized steel to provide its strength. To avoid the use of galvanized steel, which tends to corrode when used in conjunction with aluminum, AAAC is sometimes used. It retains the strength and current-carrying capacity of ACSR but is lighter and resistant to corrosion. AAC is soft and is the least expensive of the aluminum conductors but has a lower tensile strength; it is more commonly used with LV spans.

It may be difficult to decrease the capital cost of the conductor beyond that obtained by (1) properly sizing the conductor over the design life of the installation or (2) using fewer conductors, as with single-phase distribution. However, because corrosion of the line reduces its service life, the improper choice of conductor can increase its life-cycle cost.

Therefore, the preferred option among the conductor options available is in part dictated by its compatibility with the environment in which the line is to be built. Because of its cost-effectiveness, ACSR conductor is one of the most commonly used. However, in an environment containing industrial pollution, the galvanizing that was applied to the steel strands acts as a sacrificial anode and is eventually consumed. The steel then deteriorates, diminishing in strength and lifespan.

However, industrial pollution is usually not a concern in rural areas. In a salt environment, a different corrosion mechanism occurs. The salt forms an electrolyte between the steel and aluminum conductors and the galvanizing corrodes, exposing small areas of steel. Then a galvanic reaction is set up between the steel and the aluminum, with the aluminum becoming the sacrificial anode. This results in the rapid loss of aluminum, followed by a steadily increasing resistance to current flow at the affected location. This failure mode leads to a shorter life than if only industrial pollution were present. In these circumstances, AAC or AAAC could be used–and the latter is generally preferred because of its higher strength. However, depending on the precise environment and extent of the pollution, this conductor may not be the best solution. For example, in Barranquilla on Colombia's Caribbean coast, AAAC lasts as little as 10 years because of industrial pollution and salt spray.

Steel

Low-cost steel conductor has considerable tensile strength for its weight. When used for line extension, it permits an increase in the permissible span, thereby reducing cost through the use of fewer poles per kilometer. Although the greater resistance of steel compared to that of either copper or aluminum often discourages its use, a higher voltage can partially make up for the increased resistance. Corrosion is also a problem, but this can usually be addressed by using galvanized conductor. Steel conductor has been used with SWER systems where spans are limited only by conductor strength and not by proximity to other conductors.

Poletop Assembly

Although the cost of poletop assemblies (including crossarms and braces, insulators, and associated bolts) is generally relatively small, Figure 4 does illustrate that it can occasionally be significant. Relying on pin insulators rather than on post or suspension insulators wherever possible can reduce insulator costs. Not only are suspension insulators, the required shoe support for the conductor, and the hardware required to attach this assembly to the crossarm more expensive than pin insulators, but it takes two and sometimes three suspension insulators to replace each pin insulator on a crossarm.

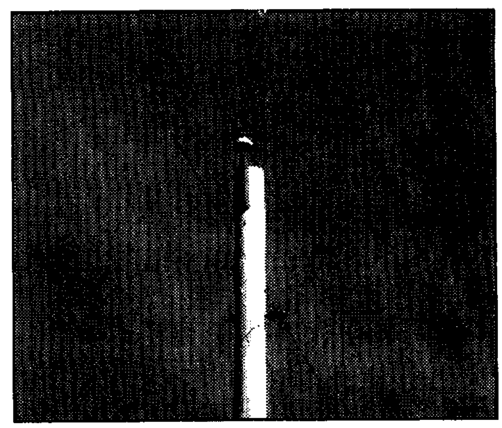


Figure 16. The simplicity of the poletop assembly associated with single-phase (phase-neutral) distribution is readily apparent.

For the North American configuration, costs for the crossarms is eliminated when a single-phase configuration is used (see Figure 16; also see Figure 30 on p. 52). For all three-phase configurations, crossarms can be eliminated if post insulators are mounted horizontally off the pole in a vertical configuration. However, in this case, the saving from not using the crossarm will be exceeded by the increased cost of the insulators (as well as possibly the increased pole length or reduced span required to maintain the required ground clearance).

Line Configuration

As noted earlier, MV lines into rural areas of non-industrialized countries have typically consisted of three-phase lines, an extension of the practice found in urban and peri-urban areas that were the first electrified. This is especially the case in countries influenced by the European colonizing powers, where the distribution systems are based primarily on a three-wire, three-phase configuration.

The driving forces behind the adoption of a three-phase line rather than a single-phase configuration is its increased efficiency for transmitting power. Although the conductor for a single-phase line of "European" design would cost 67 percent of the cost of the conductor required for a three-phase line, only 50 percent of the original power could be transmitted for the same conductor size, line voltage, and voltage regulation (i.e., voltage drop). For the North American configuration, the decreased efficiency is even greater: for a conductor savings of 50 percent (by going from four to two conductors), only about 17 percent of the power can be supplied (assuming the same phase-phase voltage as above).[10]

Although the rationale of using three-phase lines for increased transmission efficiency is valid, this applies more to high-voltage, alternating-current transmission lines as well as to MV lines serving larger load centers. In these cases, the larger current-carrying capacity associated with three-phase lines is essential.

However, for RE, lines are frequently needed to serve small load centers at some distance from the main line. In these cases, even with the smallest acceptable conductor, the capacity of a conventional three-phase line is still too great. For example, an 11-kV, single-phase line constructed with a very small, #6 (13-mm^2) ACSR conductor could be used to serve a load of 1,000 kW-km, with voltage regulation still within 4 percent. Such a line could serve two remote communities of 100 to 200 households each, located 20 kilometers from the main line, each with a coincident peak demand of 25 kW. (This reflects a typical demand for grid-connect rural consumers in countries around the world.) If single-phase capacity is adequate to serve the expected load, there is no use in going to more expensive, three-phase construction.

Even if more capacity were required than is possible using a single-phase line of given design, converting from single- to three-phase construction is not the only solution. Simply increasing conductor size can still be less expensive than reverting to three-phase construction.[xii] Using a higher operating voltage is another possibility (see p. 37).

In summary, a two-wire, single-phase configuration—either the European or North American variant—provides several ways of reducing the cost of grid extension to serve rural loads:

- A smaller length of conductor is required (even though a somewhat larger conductor or a higher voltage might be needed, depending on the projected demand).
- Fewer poletop assemblies are required (furthermore, a crossarm and braces or equivalent are not required if the North American configuration is used).
- In cases where crossarms are used, wider spacing of the poletop insulators permits longer spans and therefore fewer poles before being limited by clearances required between conductors (unless, as mentioned earlier, provision must be made to later convert to a three-phase line; in this case using mid-span line spacers is another option sometimes used for increasing span [Figure 17]).
- Fewer conductors would mean less transverse wind-loading (which must be counteracted by the pole) and may allow the use of smaller diameter poles. They also imply less transverse force due to conductor tension at poles where the line changes in direction, and this may permit the use of lighter guys and anchors, or both.
- The stringing of lines, installation of poletop hardware, and mounting of transformers are easier and do not require the use of any heavy equipment, and consequently involve reduced cost.

[10] In fact, because a portion of the return current loop in a North American system is through the ground, practice indicates that more power than this can be supplied when using small conductors. For example, with a 35-mm^2 ACSR conductor, the percentage of power that can be supplied for the same voltage drop increases from 17 to 28 percent because of the portion of the return current typically passing through the ground.

As shown previously in Figure 3, data from a number of countries that have some experience with both single- and three-phase construction confirm that substantial cost savings in line construction are possible by relying on single-phase lines.

If a single-phase line is constructed, and if an eventual increase in load beyond the capacity of that line is envisioned, adding another length or two of conductor to the existing line at some later time would increase its capacity. A single length of conductor can be added to a single-phase (phase-phase) line designed after the European configuration to convert it from single- to three-phase. In the case of the North American configuration, either a single length of conductor can be added to a single-phase (phase-neutral) line to convert it to "vee"-phase or two lengths of conductors can be added to convert it to a three-phase line. Not only does a vee-phase line have increased capacity over a single-phase line, but two transformers connected in an open-delta configuration can also be used to provide three-phase power (see Figure 18).

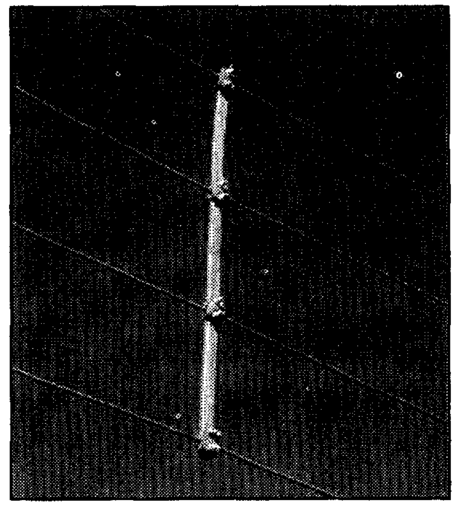


Figure 17. To reduce clashing of conductors for long spans, use of spacers of lightweight composite materials is becoming a popular option in some countries for both LV and MV lines.

However, in the case where future conversion is likely, the original line design should incorporate the more stringent design requirements of a three-phase line, such as shorter spans, with its somewhat higher cost. Although the argument might be made that nothing is gained by beginning with a single-phase line if the line will eventually revert to a three-phase design anyway, there are still at least two advantages to adopting this approach:

- Accurately predicting future load is frequently a difficult task that is subject to a variety of factors, and it is best to delay a commitment to three-phase distribution until it is clearly needed..
- Any delay in covering the cost of increasing line capacity reduces the life-cycle cost of the investment by decreasing its present value.

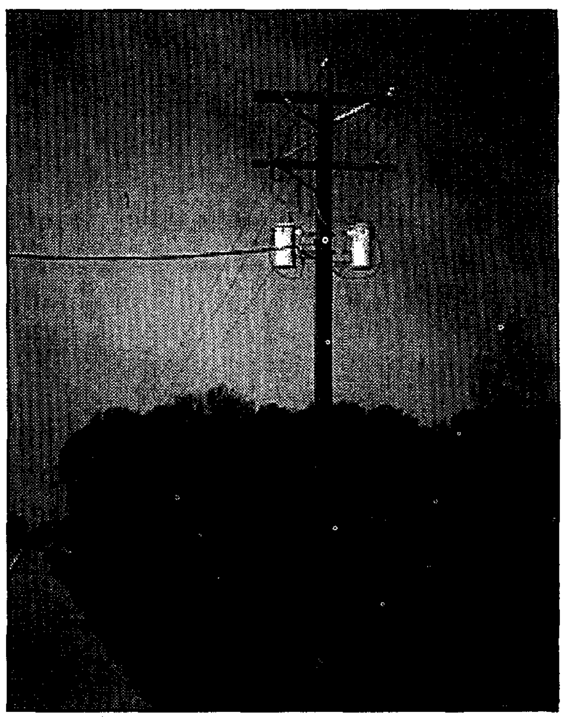


Figure 18. A two- or "vee"-phase line with two single-phase transformers providing three-phase power to workshop in eastern Maryland (United States).

Another variant of single-phase lines that can further reduce costs is the use of SWER, which is similar to the North American system but with the neutral conductor replaced by a return current loop entirely through the ground. This is widely used in portions of Australia and to a lesser extent in a number of other countries, including Brazil, Canada, New Zealand, and Tunisia. In this case, only a single conductor is used and, by using high-tensile-strength steel conductor, spans of considerable length are possible (p. 20).

Good grounding is an essential condition for the effective and safe application of this configuration. For example, SWER lines are usually restricted to lines handling no more than 100 kVA at 12.7 kV in order to that the voltage drop between the grounding lead and ground does not exceed 20 volts (requiring a ground resistance of no more than 2 to 3 ohms). For this reason, grounding at SWER distribution transformers is more complex, time-consuming, and costly than with conventional single-phase systems. Because of the increased safety risk with SWER systems, such systems are often left off the repertoire of options in a number of countries, especially in industrialized countries where the risk is not felt to be worth the cost savings. However, the widespread application of this configuration in the semi-arid areas of Australia seems to imply that safety concerns can be adequately addressed through proper design and construction.

With the application of this configuration, a redundant, extensive, and therefore more costly grounding system is commonly used at each transformer location. In areas such as Australia or Canada, where the population is dispersed and consumer loads can be significant (i.e., farms), a separate transformer with its own grounding system is necessary for each individual consumer, significantly adding to the cost of an installation. However, where consumers are not scattered but located in communities, a single, properly designed grounding system can be installed at a suitable point in the community. The ground conductor would be carried around the community, as is usually the case with secondary distribution systems. Additionally, this conductor can be grounded at guy locations, at service entrances, etc., as is already common practice with conventional LV lines in a number of countries, further decreasing risk.

In rural areas of less industrialized nations, it is not uncommon to see communities located in the vicinity of high-voltage transmission lines but lacking access to electricity because HV/LV substations are too costly to construct for such small loads. To address this problem and reduce the cost of rural electrification, a variant of SWER was first introduced in Ghana and, more recently, in Laos.[xiii] In this case, low-cost grid extension is achieved by using the shield wire above the transmission line as the conductor for a SWER line. This wire is insulated from the tower to sustain the medium distribution voltage that is imposed on it at the nearest major substation along the transmission line. The wire is tapped at the point on the transmission line nearest the village and brought to a distribution transformer in the village center (see Figure 19). A second conductor connected to a dedicated ground as well as to the transmission tower

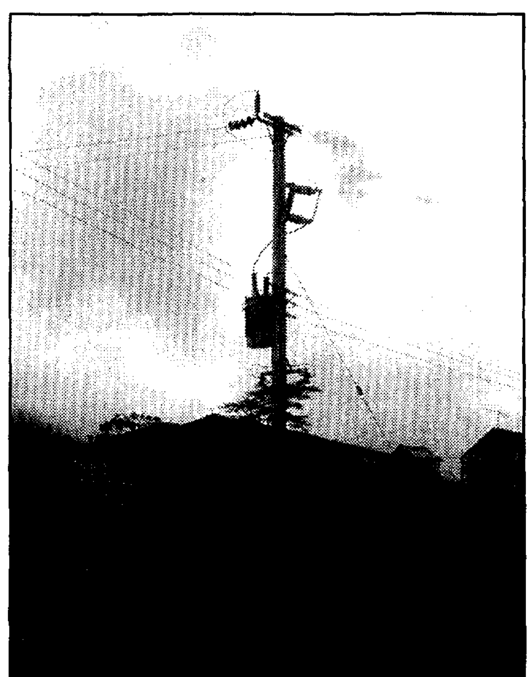


Figure 19. A distribution transformer (right) supplies electric power to one of the approximately 50 remote villages along the 115-kV Nam Ngeum-Luang Prabang (Laos) transmission line (above) by using its shield wire, which serves as a 25-kV SWER line.

ground is carried to the village. Some ancillary hardware is also used to ensure proper operation of the system. From the distribution transformer, a typical LV system supplies the villagers. Efforts are presently being undertaken in Laos to use the two shield wires in conjunction with the ground to supply three-phase power to load centers along their new transmission lines.

In storms during which lightning strikes the shield wire, the closest protective gaps mounted on the shield wire insulators will spark over and ground the wire through the arc. Because the shield wire is energized at the substation, this will initiate a short circuit to ground and the protection relay at the sending-end substation will trip the circuit breaker and have to be reset. To avoid repeatedly resetting the breaker, operators wait until the storm has passed.

If single-phase lines are clearly less costly under some circumstances, why is their use not more widespread? The reason is probably attributable to the fact that extending single-phase lines consisting of two phase-conductors may not have been a cost-effective approach to serving much of Europe, with its fairly concentrated populations centers and high demand. Similarly, when the European colonizing nations introduced electricity into what are now considered "developing countries," they continued with the practice of electrifying the more densely populated, urban areas where three-phase lines are more appropriate. Simply continuing with this same practice as lines are slowly being extended into rural areas is the path of least resistance.

More recently, the cost-advantage of using single-phase grid extension to serve smaller, more dispersed loads is being increasingly recognized, even in countries that had adopted the European design and its emphasis on three-phase distribution.

The European configuration was also initially used in the United States. However, as noted in the introduction, this configuration changed after the Rural Electrification Administration (REA) developed a new, cheaper approach to RE in the early 1930s to serve areas with low population density. This approach relied heavily on single-phase lines composed of one phase-conductor and one neutral-conductor to serve dispersed loads.

In the initial stages of development in the United States, commonly used substation sizes were 750, 1,000, and 1,500 kVA, providing three-phase power at 12.5 kV. These were located near the load center of the areas served and provided power within a radius of roughly 100 kilometers. Except for three-phase lines within several kilometers of the substation, single-phase construction was mostly used. When 24.0 kV was later adopted as a distribution voltage, distributed loads totaling 5,000 kVA were often served from one substation. In extreme instances, single-phase lines in excess of 200 kilometers in length were operated satisfactorily.

To this day, most rural electric utilities in the United States still average only 2 to 7 customers for every kilometer of line, and most residences and farms outside village agglomerations and towns continue to be served only with single-phase power. By permitting the electrification of rural America in a couple of decades and continuing to provide the power necessary to serve the very productive rural areas of the country, single-phase power has clearly proved its effectiveness.[11]

[11] It is interesting to note that the REA was placed not under the aegis of the government ministry or department associated with electricity, energy, industry, or mines but rather under the Department of Agriculture. This

Another perceived drawback of single-phase grid extension is that it does not provide the power requirements to drive larger motors. This idea is often reinforced by engineers more familiar with utilities that serve urban areas. For example, although recognizing the cost savings implicit in single-phase construction, a recent European publication on reducing the costs of electrification observed that "a MV, single-phase network is a deterrent to connection by commercial consumers because it is not adaptable for use with motors."[xiv]

As evidence to the contrary, it should be noted that after 60 years of electrification, much of rural America still has access only to single-phase power but that this fully meets the needs of even large farms and commercial establishments (see Figure 20). Single-phase motors of up to 10-horsepower capacity are readily available. If larger motors are required, three-phase motors up to 100-horsepower capacity can be run off a single-phase supply through the use of static or rotary phase converters. Newly developed written-pole motors are available up to 60 horsepower and electronic, single-phase, adjustable-speed drives are available to power three-phase motors in excess of 100 horsepower using a single-phase supply.[xv]

Figure 20. A 100-kVA single-phase pole-mounted transformer is adequate to serve the needs of this rural farm in the United States.

If larger motors are essential, a disadvantage of using single-phase motors is that they are somewhat costlier than their three-phase counterparts, especially above the fractional horsepower sizes. Using a phase converter to drive large motors of 10- to 100-horsepower capacity from a single-phase source may add a further $2,000–15,000 to the cost, respectively. However, it must be kept in mind that bringing three-phase power to rural areas simply to serve a few three-phase motors can itself be costly. The additional cost associated with the use of a few single-phase motors or the use of phase converters is usually small in comparison to the considerable cost of the alternative: stringing kilometers of three-phase lines in rural areas simply to serve a few three-phase motors, when the predominant loads are for lighting, entertainment, and small motors. Figure 3 illustrated that three-phase construction averages $3,000–4,000 more per kilometer than single-phase construction. It is not difficult to determine the number of large-motor loads necessary to justify the construction of a three-phase line.

Consequently, although some observers may express concern that single-phase power constrains development, this notion has little substance. One drawback is that single-phase motors, beyond the fractional horsepower size, are difficult to find on the local market. But this is only because there is no

represents a *de facto* recognition that, in the United States, the desired impact of rural electrification was on developing agriculture in particular and rural areas in general rather than on simply increasing access to electricity. In this manner, the priority given to rural electrification is probably considerably greater than if it were lumped with some national utility or ministry of energy, whose primary obligations to urban areas would distract it from effectively dealing with the needs of rural electrification.

demand for single-phase motors in countries promoting the use of three-phase power. Create the market and motors will appear.

Contrary to accepted wisdom, moreover, three-phase distribution can result in increased motor costs. Although main three-phase feeders may be adequately built and maintained, experience in a number of countries has shown that this is often not the case with LV circuits. Subsequent occurrences of temporary fault conditions cause the opening of commonly used single-phase protection devices along three-phase lines. This results in single-phasing and eventual burning out of three-phase motors. It has been observed that one of the most prolific small industries on the Asian subcontinent is the rewinding of small three-phase motors.[xvi] So for small-motor customers, selecting single-phase over three-phase motors, even if a three-phase supply is available, may result in life-cycle financial benefits even if the initial cost per motor is higher.

Line Voltage

Another important option for reducing the cost of grid extension is to reduce the size of the conductor. However, reducing its size results in increased resistance. Reducing conductor size beyond the optimum limit has two adverse impacts: (1) it increases recurring costs for operating the line because of increased energy losses caused by resistive heating, and (2) it increases the voltage drop along the line, adversely affecting the quality of power for consumers, especially those toward the end of the line. Both of these impacts also depend on the magnitude of the current transmitted by the line.

However, increasing line voltage decreases the current required to meet the same power demand. Doubling line voltage halves line current, which reduces percentage voltage drop and energy losses to one-quarter their previous levels. The higher the line voltage, the lower the line current required to serve a given load. A smaller current means that a smaller, less costly conductor can be used to meet the same load under the same conditions.

As an example, Table 2 illustrates the impact on the cost of grid extension caused by increasing working voltage. In this example, the cost of constructing an illustrative three-phase, 11-kV line is first compared to that of a three-phase line operating at twice the voltage, i.e., 22 kV. As noted previously, a smaller conductor can be used because of the higher voltage and still result in the same voltage drop and power loss. In this example, construction costs per kilometer are reduced by about 20 percent (from $9,100 to $7,100). This saving from converting to a higher voltage of 22 kV is due to the possibility of now using smaller, less costly conductor and, also, lighter guying and poletop assemblies.

This example is then extended to illustrate the savings possible in using single-phase rather than three-phase construction. For this purpose, a single-phase (phase-phase) line operating at 22 kV is designed to replace the three-phase line operating at the same voltage. Because single-phase transmission is less efficient, a larger and costlier conductor is now necessary to maintain the same voltage loss and power drop. However, a total cost reduction of about 15 percent (from $7,100 to $6,000) still results from the conversion to single-phase construction. This saving is due to the need for two rather than three lengths of conductor, less poletop hardware, and somewhat lighter construction.

Table 2. Cost Savings Through Increased Working Voltage and Use of Single Phase

	Three-phase, 11 kV		Three-phase, 22 kV		Single-phase, 22 kV	
Component	**Description**	**Cost ($)**	**Description**	**Cost ($)**	**Description**	**Cost ($)**
Poles	10.6 and 12 m	70,900	10.6 and 12 m	69,800	10.6 and 12 m	62,100
Conductor	1/0 (53 mm^2) ACSR	76,900	#6 (13 mm^2) ACSR	32,900	#4 (21 mm^2) ACSR	24,100
Poletop assembly	Pin insulators, crossarms, etc.	50,000	Pin insulators, crossarms, etc.	49,000	Pin insulators, crossarms, etc.	40,500
Guys	cable, attachments	8,300	cable, attachments	7,800	cable, attachments	6,000
Labor		65,500		53,400		46,300
Total		271,600		212,900		179,000
Total/km		9,100		7,100		6,000

Note: In this example, the base case is a 1/0 (53-mm^2) ACSR three-wire, three-phase line operating at 11 kV and serving several remote villages with a total maximum load of the equivalent of 150 kW at the end of a 30-kilometer line. This would result in a voltage drop of nearly 3 percent and an energy loss of about 4 kW. Costs incurred in line construction in El Salvador are assumed here.

Although reverting to a higher distribution voltage reduces the size and cost of the conductor, the higher voltage may also require increased insulation value for the insulators, transformers, capacitors, lightning arrestors, and so on, as well as greater line-line and line-ground clearances. However, for the voltages noted in Table 2, this is not significant. Where there is a considerable jump in design, construction, and operating costs is from 22 to 33 kV. At this point the additional clearances, safety factors, and insulation have to be reviewed. Operating at a higher voltage also results in higher maintenance costs if the utility is involved in a program of insulator washing and cleaning. And in areas near the ocean, industrial estates, and volcanic areas, voltages above 6.6 kV usually require special design considerations.

Present worldwide practice limits distribution voltages to about 35 kV (1) to ensure the safety of the public and of utility workers and (2) to avoid increased costs of fault coordination. Above this voltage, the trend is to move toward large post insulators or suspension insulators similar to transmission line design. Small transformers at these higher voltages are also more expensive and not as readily available.

Distribution Transformer

Typically, the cost of distribution transformers is a small part of the construction cost of most lines serving rural areas. However, although the cost for constructing a line is generally borne by hundreds or thousands of consumers served by that line, the capital cost of each transformer is usually borne by the much smaller number of consumers it serves. Depending on design, its cost can be important.

Moreover, given that transformers consume power 24 hours per day independent of imposed load, recurring costs incurred in operating transformers can even be more significant. Therefore, in considering the cost of transformers, their life-cycle cost—in this case, the sum of both their initial capital cost and their operating cost—must be considered. The relative importance of various costs is illustrated in Box 2. Only after these components are understood can approaches to reducing cost be better designed.

Box 2. Life-Cycle Costs for Lines and Transformers

Let us consider only one of several transformers along the original 30-kilometer three-phase line described previously in Table 2 and assume that this line serves 600 households. This example will compare the cost that a household served by this line must pay each year to cover its portion of the amortized cost of (1) line, plus the recurring cost of energy losses along the line, and (2) the transformer serving it, plus the cost of losses incurred in the operation of that transformer.

In this case, we will look at one of these transformers, which serves 200 consumers and has a peak load of 50 kVA. Under actual operating conditions, it is assumed to operate under a load factor of 34 percent and a corresponding loss factor of 20 percent.* The cost of demand and energy are assumed to be $10/kW/month and $0.10/kWh, respectively. These are all typical values.

Line: At the time that the line provides peak power to consumers, it experiences resistive losses that can be calculated to be 4 kW over its length. In operating this line, two recurring costs are incurred.

(1) The cost of lost energy:

(4 kW)(0.20)(8760 hours/year)($0.10) = $700/year

(2) The cost of the additional installed capacity needed to generate the extra power to make up for this 4 kW loss in the line:

(4 kW)($10/month/kW)(12 months/year) = $480/year

If one assumes that the investment of $272,000 to construct the line is paid back over 20 years at an interest rate of 10 percent, this would be equivalent to about $32,000/year. The additional cost due to energy losses in the line calculated above—about $1,200 per year—adds about 4 percent to the annual cost of the line. Total cost for line construction and losses, which should be covered by the consumer, is equivalent to $55 annually per household served.

Transformer: A pole-mounted, 50-kVA three-phase transformer costs $2,000. As with the line, costs are also incurred in operating the transformer. This is due to core losses (heating losses caused by circulating currents in its core), which are always present, and wire losses (losses caused by current-induced heating of the wires), which are present only when current is demanded of the transformer. The magnitude of the latter loss is proportional to the square of the current. For this transformer, the core loss specified by the manufacturer is 200 W and the winding loss at full load is 600 W.

The following cost for **core losses** are incurred:

(1) The cost of lost energy:

(0.2 kW)(8760 hours/year)($0.10/kWh) = $180/year

(2) The cost of additional capacity to make up for this lost power is determined as follows:

(0.2 kW)($10/kW/month)(12 months/year) = $24/year

Regardless of how much electricity the households served by this transformer consume, $200 is incurred annually in serving them and they must cover this cost. *(Continued)*

* Load factor = (average power demand over a period, kW)/(peak power demand over that same period, kW). Loss factor = (losses over a period, kWh)/(losses if maximum power were demanded over that same period, kWh).

Box 2 (continued)

Because individual households also demand current, **winding losses** are also incurred. To calculate these, it is assumed here that the peak load served by the transformer equals its nameplate rating. These losses are as follows:

(1) The cost of energy is determined as follows:

$$(0.6\ \text{kW})(.20)(8760\ \text{hours/year})(\$0.10/\text{kWh}) = \$110/\text{year}$$

(2) The cost of additional capacity to make up for this lost power is determined as follows:

$$(0.6\ \text{kW})(\$10/\text{kW/month})(12\ \text{months/year}) = \$72/\text{year}$$

In summary, assuming a transformer life also of 20 years, the annual payment to cover the capital cost of the one transformer considered in this example would be \$230/year. The additional cost due to energy losses in the transformer during its typical operation—calculated above at about \$380 per year—results in more than a 150 percent increase in the annual cost of the transformer (whereas losses in the line calculated earlier contributed only 4 percent to the annual cost of the line).

Although the cost of losses can be significantly greater than the capital cost of the transformer, it is true that these may not contribute much to the cost of the entire system, adding only about \$610 for each transformer to the annual line cost (with line losses) of about \$33,000.

However, by the time all transformers served by the line are included, especially if oversized transformers are used (as they commonly are), the effective cost of the line could increase by a more significant percentage.

For example, as noted earlier, each of the 600 households served by the line would have to pay \$33,000/600 or **\$55 annually** to cover the cost of the investment for the line and power lost. However, if the cost of the transformer and its losses are added to the cost that the customer must cover, then below are two possible scenarios:

- If it is assumed that the average household has a coincident peak of 250 W, the 50 kVA transformer would then serve a full complement of 200 rural households.* In this case, each consumer would be responsible for its share of the amortized cost of the transformer (\$180) and cost of transformer losses (\$380) that would add \$610/200 households or about \$3 per year (for a total of **\$58 annually**).
- On the other hand, it is not unusual that in an RE program in developing countries, some of the load centers to be served are small. But because small transformers are not readily available, larger standardized three-phase transformer sizes continue to be used. If we assume that at one site, ten households are to be served by the smallest readily available 50-kVA transformer, core losses would again amount to \$200 but winding losses would be negligible as the transformer would be very lightly loaded. In this case, each consumer would be responsible for its share of the amortized cost (\$230) and cost of transformer losses (\$200); this would add \$430/10 households or about \$43 per year (for a total of **\$100 annually** for the distribution line and transformer). Using an improperly sized transformer can therefore significantly increase the cost of RE for those customers; in this case, it would nearly *double* their cost of electrification.

Transformer Efficiency

As illustrated in Box 2, the annual cost of transformer losses can exceed the amortized cost of the transformer and its installation. One way of reducing this cost is through the use of low-loss or amorphous-core transformers. Table 3 presents the costs associated with losses for transformers with two different types of core, illustrating how a more expensive transformer can result in a reduced life-cycle cost because of significantly reduced core losses.

Table 3. Cost of Losses Associated with Different Core Types

Core type	Capital cost/year ($)	Core loss (W)	Winding loss (W)	Cost of losses/year ($)	Total cost/year ($)
Standard	140	180	575	350	490
Amorphous	220	30	490	180	400

Note: Data are for a 50-kVA, three-phase transformer.
Assumptions: interest = 10 percent, term of transformer loan = 20 years, loss factor = 20 percent, cost of energy = $0.10/kWh, and cost of demand = $10/kW/month.

Number of Phases

The adequacy of single-phase power for meeting electricity needs in rural areas of even industrialized countries has already been well established. And although three-phase transformers currently serve many areas elsewhere around the world, most of the loads at the end of those lines remain single-phase loads. Because a single-phase transformer is both less costly and more efficient than a three-phase transformer of equivalent capacity and constructed with the same materials, further cost savings are possible through the increased use of single-phase transformers (see Figure 21). This is illustrated in Table 4 for transformers manufactured by the same manufacturer with about a 50-kVA capacity. In this case, the annualized costs (comprising both capital cost as well as the recurring cost of losses) for the single-phase transformer is about 20 percent lower than that for the three-phase transformer. Single-phase transformers are not only cheaper and more efficient but also somewhat lighter.

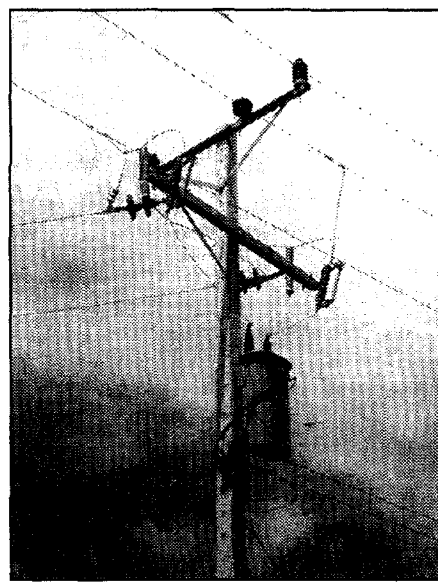


Figure 21. A single-phase (phase-phase) transformer.

Table 4. Cost of Losses Associated with Single- and Three-Phase Transformers

Type	Capital cost/year ($)	Core loss (W)	Winding loss (W)	Cost of losses/year ($)	Total cost/year ($)
Single-phase	94	138	495	283	380
Three-phase	140	180	575	350	490

Note: Data are for typically loaded single- and three-phase transformers of about 50-kVA capacity with the same basic construction and from the same manufacturer.
Assumptions: interest = 10 percent, term of transformer loan = 20 years, loss factor = 20 percent, cost of energy = $0.10/kWh, and cost of demand = $10/kW/month.

If an occasional three-phase power supply is required because of the nature and size of the load, a bank of three smaller single-phase transformers can be used rather than a single, larger, three-phase transformer. Although the annualized cost of a bank of three single-phase transformers and associated losses might be slightly higher than that of a single three-phase transformer and losses (see example in Table 5), this can be offset by several advantages associated with the use of single-phase transformers:

- Because only single-phase transformers are required to serve the needs for both single- and three-phase loads, cost is reduced by minimizing the number of different types of units that need to be warehoused to serve the range of loads that the utility must meet.
- The larger number of a reduced selection of transformers required permits economies of scale in purchasing.
- If a three-phase transformer fails, all consumers are deprived of power. However, if one transformer in a bank of three single-phase transformer fails, the other two will continue to serve the consumers. Replacement of a single-phase rather than a three-phase transformer is considerably easier and less costly.

Table 5. Cost of Losses Associated with Fully Loaded Three-Phase Transformers

Type	Capital cost/year ($)	Core loss (W)	Winding loss (W)	Cost of losses/year ($)	Total cost/year ($)
Three single-phase transformers	190	186	546	350	**540**
Single three-phase transformer	140	180	575	350	**490**

Note: In one case, a single three-phase, 45-kVA unit is considered; in the other, a bank of three single-phase, 15-kVA transformers is considered.

Assumptions: interest = 10 percent, term of transformer loan = 20 years, loss factor = 20 percent, cost of energy = $0.10/kWh, and cost of demand = $10/kW/month.

Transformer Size

As was illustrated in Box 2, improperly matching transformer size to demand can increase the cost of electrification because of the high cost of both the transformers and, more important, their losses. Using an oversized transformer can significantly reduce winding losses because these vary as the square of the current. For example, using a transformer at one-half its rated capacity means winding losses of one-quarter its rated losses. However, core losses are usually more significant because these losses occur continuously, as long as the transformer is energized. Core losses are the same regardless of the demand placed on the transformer.

In many countries, the smallest three-phase transformer typically available has a capacity of 25 or 50 kVA, even though these are often oversized in comparison to the load they serve. For example, in Tanzania, the national utility installed two 100-kVA and three 50-kVA transformers to serve the isolated town of Urambo. These were supplied by diesel generators that typically operated for four hours every evening. Transformer loading during this period was fairly constant and averaged only 22, 6.2, 2.6, 1.8, and 0.3 kW, respectively.[xvii] Although the sizes of some of these transformers were selected at a time when loads were about twice these values, they were still well oversized. If not for the fact that the transformers were de-energized most of the day, a considerable cost would have resulted from covering core losses attributable to serving those few consumers supplied with the lightly loaded transformer.

Because of the small loads commonly encountered in rural areas, the use of transformers with much smaller capacities should be evaluated. For example, in projects implemented by the Butwal Power Company in Nepal, 1- and 2-kVA dry transformers are assembled locally. In these largely subsistence areas, very limited disposable income means that loads are, and will continue to be, very low. A 2-kVA transformer supplies up to 18 homes. Under such circumstances, conventionally-sized transformers could considerably exceed the load to be served, unnecessarily increasing the cost of the transformer and its losses. Increasing the service area (to increase the number of consumers, thereby making better use of transformer capacity) would increase cost because of the heavier conductor that would be required to keep losses and voltage drop within acceptable limits over the extended service area. Figure 22 illustrates two different layouts for supplying the same service area: (1) the conventional approach, which uses a single, large, usually three-phase transformer to supply an extensive service area; and (2) the approach in the Nepali project, which uses a number of small, single-phase transformers, each serving a grouping of neighboring homes.

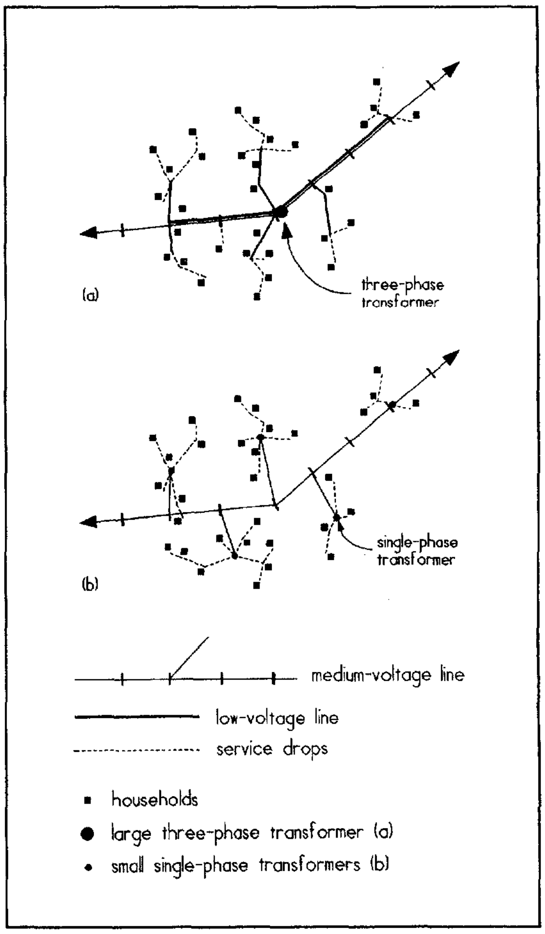


Fig. 22. Comparison of (1) a typical LV distribution system layout (European configuration) and (2) that used in the project in Nepal (North American configuration).

Even in the United States, the advantage of using very small transformers is recognized. For example, distribution transformers are available starting from 0.5-kVA capacity and increasing in 0.5-kVA increments; these are used to supply small, isolated electricity needs, such as for lighting at highway intersections and advertising billboards.[xviii] Use of these small, oil-cooled transformers reduces the cost of losses both in the transformer as well as in the LV lines from the nearest transformer to the isolated load being served.

Another way of effectively reducing the cost of RE per consumer is to increase the number of households served. But the high cost of larger, readily available transformers often prevents small populations from being electrified in spite of the fact the MV line may pass overhead (see Figure 23). The use of considerably smaller transformers would permit these households to be served at negligible additional cost, thereby expanding the consumer base.

Figure 23. Even though the MV line passes by a number of households, insufficient load prevents them from receiving electricity service.

In El Salvador, multiplex (a form of aerial bundled cable) is used for the LV line and the messenger (neutral) is dead-ended at each pole. A small, single-phase transformer feeds the center of that line. If and when load exceeds transformer capacity, the LV phase conductors can be sectionalized by simply cutting the loop between the two deadends at the pole at the required location, thereby isolating a section of line that is then served by a new transformers (see Figure 24). This approach permits transformers to be conveniently added as load grows, with no decrease in service efficiency.

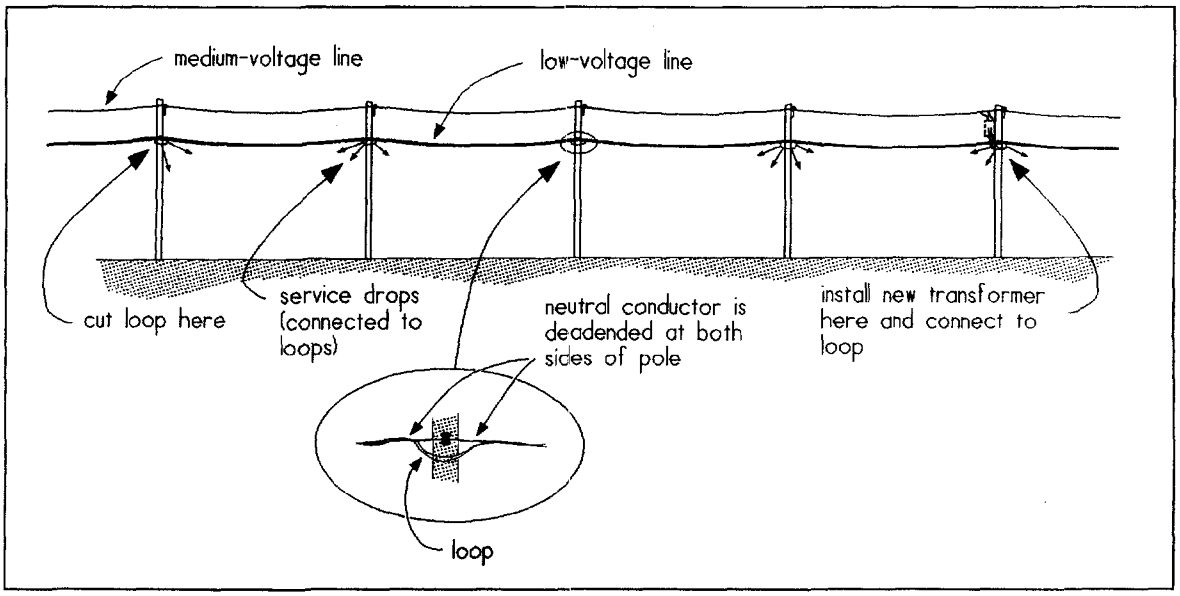


Figure 24. Sectionalizing LV lines facilitates the addition of transformers when consumers' load increases sufficiently.

Use of small transformers is even more important in isolated load centers without road access. In this case, transformers have to be carried by porters to the site. This poses a problem for even the smallest transformer typically used (i.e., a three-phase, 25-kVA transformer weighing about 200 kilograms). In the previously mentioned project in Nepal, where the medium voltage of 1 kV is used, 1- and 2-kVA dry-type epoxy-dipped transformers weighing only 18 and 25 kilograms, respectively, are used. Even though the small specialty transformers also noted previously are heavier, oil-cooled units, they still are more manageable at less than 40 kilograms each (see Figure 25).

Figure 25. Use of single-phase transformers in Bangladesh facilitates their transportation and obviates the need for cranes for hoisting them to their poletop position.

Another circumstance in which small transformers might be considered is to meet off-season loads. In Nepal, for example, numerous 100-kVA transformers are used to power irrigation pumps for a couple of months each year. Typically, core losses for such a transformer are about 350 W, implying a loss of roughly 2,500 kWh annually while the transformer is not being used for irrigation. At

$0.07 per kWh, this amounts to a loss of $180 annually. If the large transformer could be switched off at the end of the irrigation season and replaced by a small transformer to meet the small residential load for the remaining portion of the year, the annual savings of $180 would represent a payback period for the small transformer of only two years.

Size of Service Area

Although the focus of this study is reducing the cost of MV grid extension, one should not lose sight of the fact that the overriding objective is to reduce the overall life-cycle cost of rural electrification. One important component of this cost is that of LV lines and associated losses. In a number of countries, the typical practice has been to use one or more large distribution transformers to serve a load center and extensive LV networks to distribute power to consumers over a broad area. This is costly because large LV conductors are needed to keep losses and voltage drop to within acceptable limits. Otherwise, using undersized conductors results in (1) excessive losses, leading to larger costs that must be borne by the utility on a continuing basis, and (2) large voltage drops, adversely affecting quality of service to the customers.

Consequently, because LV distribution can be an expensive component of rural electrification, reducing the length of the LV lines served by each distribution transformer (by extending the MV lines as close to the load center as possible) can further decrease life-cycle costs of rural electrification. This also permits the use of less-costly single-phase distribution. This decrease in total cost for getting closer to the load may require a marginal increase in the extent and cost of the MV grid extension network, but there is still a net reduction in cost. This is illustrated in Box 3 and Figure 26.[xix]

A comparison of various parameters describing these systems is presented in Table 6 (see Box 3). The cost of the conductor and transformers for the single-phase option (C) is reduced because, although the cost of three single-phase transformers in this case is more than one three-phase transformer, this is more than offset by the reduced cost of the conductor. This effect is even more pronounced with larger villages.

This conclusion has been substantiated by numerous site-specific studies, such as the one undertaken in Tunisia (see p. 15) and another undertaken in Yemen. As part of a broader study in the latter country, costs were compared for two different approaches for electrifying the mountain village of an-Nadirah, which contains approximately 500 houses. This village was selected because it was densely populated, a factor that generally favors three-phase, LV distribution. Costs for the electrification of this village are summarized in Table 7.[xx] This study again illustrates that, although considerable costs savings can result from the use of single-phase at the LV distribution level, these costs savings extend to the single-phase MV grid extension line as well, even with the existence of a three-phase MV line fairly close to the village.[12]

[12] For the single-phase option, a three-wire LV configuration of 230/460 volts was assumed. Using two 230-volt transformer windings in series with a common neutral increases single-phase LV circuit-loading capability by four times that of the standard two-wire, 230-volt LV circuit. The 460 volts is not intended as a customer service voltage.

Box 3. Decreasing the Overall Cost of Rural Electrification by Bringing it Closer to the Load Center

In this example, it is assumed that the community to be served has 170 households. To simplify the analysis, the community is assumed to be served by ACSR distribution lines along the main paths through the village, and that each spur of 250 meters serves 17 consumers, each with a largely resistive, coincident demand of 260 W (4.4 kW per spur). The conductor has been selected to keep maximum voltage drops at the end of each line to no more than about 5 percent. Electrification is accomplished by using each of the three layouts shown in Figure 26:

A. This base case, which is commonly encountered, includes a single 50-kVA three-phase transformer located on the road at the entrance to the community and a LV network serving all the households.

B. The operating efficiency of the previous distribution layout is improved by placing the same transformer at the center of the community, reducing the current carried by the main LV lines. This permits the use of smaller, less costly conductor.

C. To further improve efficiency, the single three-phase transformer is replaced with three small single-phase transformers spread over the service area. This brings MV lines closer to the consumers, further reducing LV line currents and cost.

Table 6. Costing Comparison of the Three LV System Configurations

Item	A	B	C
Annualized hardware cost (conductor and transformers) ($)	740	400	330
Annualized cost of losses ($)	760	670	610
Total annual cost (conductor, transformers, and losses) ($)	1,500	1,070	940
Maximum voltage drop in LV network (%)	5.1	4.7	4.2
Weight of conductor (kg)	1780	700	350

Assumptions: interest = 10 percent, term of transformer loan = 20 years, loss factor = 20 percent, cost of energy = $0.10/kWh, and cost of demand = $10/kW/month.

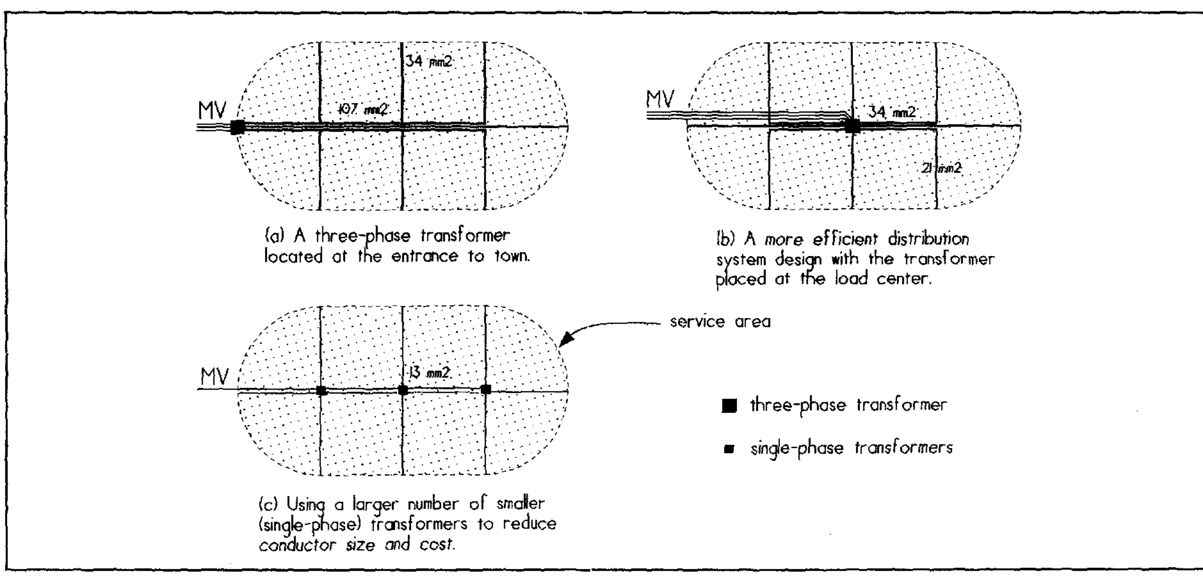


Figure 26. Schematic depiction of a service area being supplied using three different approaches: (a) a conventional approach, with the transformer placed at the entrance to the service area; (b) selecting a more efficient transformer location at the center of a service area; and (c) using small single-phase transformers scattered throughout the service area. Dimensions within each figure identify the required conductor sizes (mm^2).

Table 7. Cost Comparison for Supplying an-Nadirah (Yemen) Using Distribution Systems that Are (1) Entirely Three-Phase and (2) Entirely Single-Phase

Component	Total three-phase system ($)	Total single-phase system ($)	Difference (%)
MV circuits	39,700	32,700	21
Transformers	18,000	13,400	31
LV circuits	95,100	74,600	27
Total	152,800	120,700	27

Note: Costs are in 1979 U.S. dollars.

The cost advantages of using single-phase distribution—with smaller, single-phase distribution transformers—are considerably greater than shown in the examples above. The considerably reduced weight of the conductor and transformers facilitates their transportation and installation and also somewhat reduces cost. Increased system reliability and voltage regulation ensures increased consumer satisfaction and more secure financial returns to the utility. Using a single-phase MV line to bring power to small isolated communities can be considerably less expensive than using a three-phase line.[13]

An additional factor contributing to the increased life-cycle cost of RE is theft of electricity by customers illegally tapping LV lines. Unexpected overloading of transformers that results from such actions can lead to transformer failure and the need for their replacement. The importance of this factor is illustrated in a quote from a World Bank visit to the Rajasthan State Electricity Board (RSEB):

> ". . . RSEB's approach, in the rural areas, [is] to reduce losses by eliminating as much as possible the long LV lines, which over many years have evolved without much planning, due to pressure to connect rural areas and villages. Besides causing huge technical losses, these long lines provide easy access for users to "connect" themselves. This leads to the transformers being heavily overloaded and also results in improper protection against overloads, problems which RSEB has been experiencing for several years. In 1995/6 for instance, the failure rate for distribution transformers on RSEB's 11 kV system was a shocking 16 percent. Of the 114,000 transformers installed, 19,800 failed, and these failures were mainly caused by overloading...."

Therefore, a further advantage of using a more extensive MV network and reducing the extent of the LV network is the reduced opportunity for theft through tapping and the costs that ensue. Medium-voltage lines are rarely tapped because the higher voltage is of little use to most consumers.

Multimetering, an approach used to supply electricity to densely populated "slum" areas in Manila, illustrates an example of technical inefficiency in distribution system design. In this case, single-phase, MV lines only skirt the area. Each transformer along these lines supplies scores of households through individual meters mounted on a wall immediately under each transformer (see Figure 27). From each meter, an individual pair of LV lines winds its way through this neighborhood to supply each customer.

Although this can result in high losses, this system is not designed to be cost-effective for the customer. It is designed to meet the demand for electricity in these "temporary" communities, to facilitate meter reading, and to eliminate the cost of technical and non-technical losses incurred by the utility on the LV distribution system. All losses along the LV lines are recorded by individual customer meters and thereby automatically included in their monthly billings. Although this may be an interesting approach for a

[13] If the single-phase, North American configuration is used, additional savings are possible through the use of a common neutral conductor for both the MV and LV lines where these are located on the same pole.

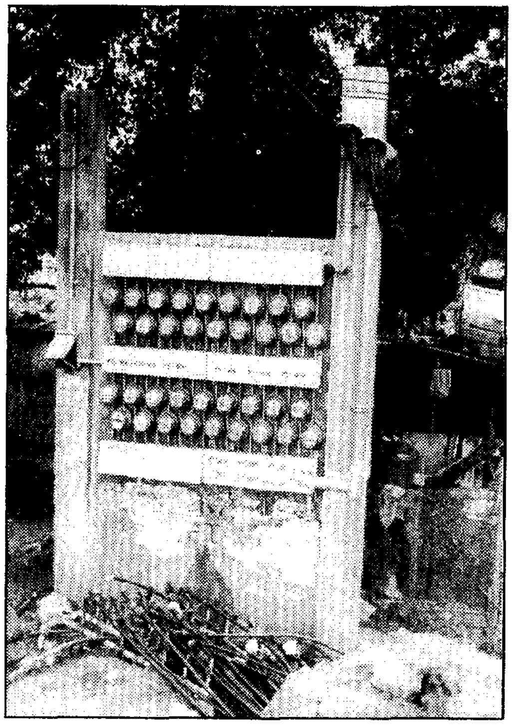


Figure 27. Meters are located on a wall just below the MV transformer. The LV line enters from the upper left and the bundle of service drops can be seen emerging at the upper right. At the base of the wall can be seen a similar approach taken for water supply.

utility to use to provide electricity without being saddled with the high cost of losses, the inefficiencies incurred do increase the cost of electrification borne by the customer.

Transformer Mounting

In some cases, transformers may be platform-mounted because the poles used lack the strength to support them (see Figure 28). In other cases, it has been done simply because it was standard practice. Where there is a choice, the additional costs of a platform-mounted transformer over a pole-mounted transformer should be considered. In El Salvador, for example, mounting a 50-kVA three-phase transformer costing $1,500 CIF directly on the pole would add about $500 in labor and incidental costs. Installing a platform mounted transformer would required an additional $1,500 for the pole, platform, and labor.

Non-Technical Losses

Losses on distribution lines involve both technical and non-technical losses. Technical losses are generally restricted to electric energy lost through resistive heating of the conductor and are reduced to acceptable levels through the proper selection of conductor size, the balancing of phases, and aiming for a unity power factor.

Non-technical losses arise primarily from such actions as illegal tapping of lines, meter tampering, and collusion of the meter reader with the customers. These losses are generally found on LV networks and can be significant. They not only represent losses to the utility at the LV level but also result in increased technical losses because this additional power is carried along the MV lines. Therefore, reducing non-technical losses also reduces the life-cycle cost of the grid extension lines bringing power to rural areas.

Technical approaches, such as the use of aerial bundled cable or effective meter seals, may reduce some of these non-technical losses. However, these are not completely effective and, perhaps more important, these fixes all come at an additional cost, further increasing the cost of RE.

However, one approach to reducing all non-technical losses at the LV level from the utility perspective is to assign the responsibility for covering these losses to the customers themselves. There are several versions of this approach but, generally speaking, all share characteristics common to those found in the Philippines. There, the population is divided into *barangays*, the smallest political unit in the Philippines and the equivalent of a neighborhood. If households in a *barangay* are interested in obtaining access to electricity, meetings are held with the electric utility responsible for serving the area to inform them that they can be served, provided they organize themselves into a Barangay Power Association (BAPA). These associations are similar to electricity users groups found in some other countries.

The specific objectives of a BAPA include the reduction of non-technical system losses, the improvement of collection efficiency, and the strengthening of broad popular participation in the electrification of the barangay. The utility agrees to provide bulk power to the BAPA that is metered just below each distribution transformer and to install and maintain the distribution infrastructure. In return, the BAPA agrees to be responsible for reading individual consumer meters and collecting the amount due from each consumer on dates specified by the utility.

The electric utility then calculates its expected revenue from the BAPA by taking readings from the one or several main meters mounted on the transformer pole(s) serving the barangay area. The BAPA is charged a discounted rate (a 10–15 percent reduction) for the energy it consumes and must promptly pay the bill from the utility. The latter reserves the right to cut off the power supply to the BAPA if it fails to settle its financial obligations within the agreed period. In this manner, the BAPA is motivated to minimize theft in order to ensure adequate revenues to pay the utility.

If the households in a barangay are interested in pursuing this approach and are in agreement with the terms under which electricity is to be supplied, they then form a BAPA, which operates under a constitution and bylaws, and sign a memorandum of agreement with the utility.

Through this mechanism, the burden for covering the cost of all losses falls on the barangay themselves and not on the utility. And because the consumers themselves must bear the cost of losses, they are encouraged to enforce all anti-electricity pilferage regulations themselves.

As an additional benefit, this approach reduces the utility's cost for administering more remote portions of its service area. All costs and problems encountered in meter reading, billing, and collecting are borne by the BAPA members themselves, removing a major burden that rural electrification often imposes on the electric utility. In the Philippines and other cases where meters are used, all meter-reading information, as well as a portion of the

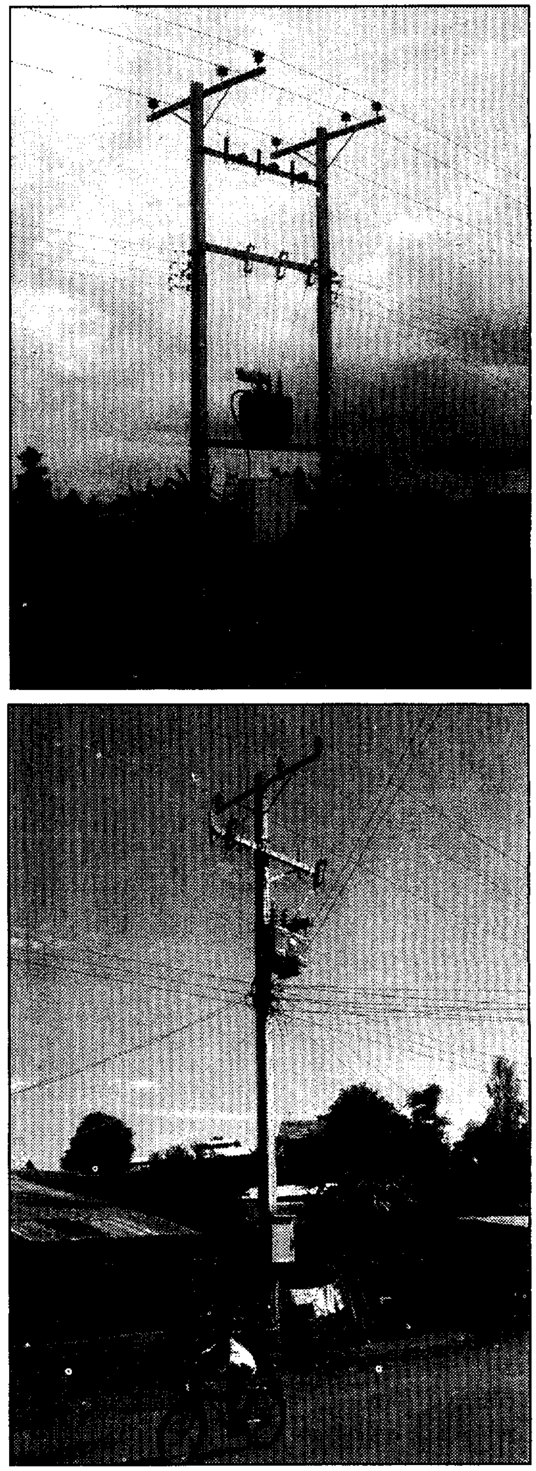


Figure 28. Three-phase, pole- and platform-mounted transformers serving rural areas in Laos.

collections, are passed on to the utility. In Nepal, where the Andhi Khola and Jimruk hydropower plants serve user groups, a maximum-demand tariff is used.[14] An individual identified by each users group maintains records and posts monthly remittances to the utility's account through the local bank. Therefore, rather than bearing the costly burden of looking after numerous small consumers scattered around the countryside as would normally be the case, the utility treats each user group as a single, large consumer whose monthly bill is automatically deposited at virtually no effort, or cost, on its part.

Approach to Design and Construction

Line design, staking, and materials management should be carefully planned and executed to ensure reliable, cost-effective line construction, operation, and maintenance. To facilitate this, a staking methodology and standardized distribution line design and commodity specifications should be prepared. Although additional costs will be incurred in this effort, these should be easily recouped through project implementation that is both less time-consuming and more cost-effective, from design through to procurement, construction, administration, and project closeout.

Staking Methodology

Developing a staking methodology and documenting it in the form of an accurate yet easy-to-use manual is recommended if line designs are to be optimized, reliability increased, cost reduced, operation facilitated, and maintenance requirements minimized. Such a manual would be a tool for optimizing the use of the various line construction units and materials through maximum span designs and optimum placement of structures. It should incorporate the desired design concepts and criteria that have been developed to meet the specific needs of those served by the local utility and, at the same time, satisfy the requirements imposed on the utility by other authorities in such areas as joint use of poles and safety. It would then be used to increase the efficiency with which staking crews design new lines while in the field.

The manual would first review the engineering functions and project planning that should take place in preparation for staking a line. The staking engineers would then complete the detailed structure-by-structure design of a distribution line in the field while staking the line. (It is while in the field that the engineers can best understand the numerous factors affecting line design—including the locations of homes, roadways, rivers, trees, terrain, new homes, and future line extensions.) They would use the manual, associated tables, and other data to help in staking the lines—maximum span limits based on clearance requirements and pole height, tension limits on insulators and crossarms, placement of guys, etc. With this design information and the standardized structure designs drawings, staking engineers can concentrate on field design of a safe, economical line, determining required clearances, pole class and heights for each span, adequate guys, required poletop assemblies, etc.

In the field, information for the entire line section would then be tabulated on a staking sheet (see Figure 29). This sheet would contain both a sketch of the required construction and a complete summary of the hardware required. This would be used to prepare a detailed list of required materials, to include with invitations to bid issued to prospective construction contractors, and to serve as a guide for construction crews. The staking sheet can then be updated during construction to record any changes that are required. Finally, it would then be used to tabulate the construction work that has been completed and to prepare final contract closeout documents.

[14] Each consumer subscribes to a specific maximum-demand level—e.g., 25 W—and has access to that amount of power as long as the plant is operating. The consumer's tariff is then based on this maximum demand.

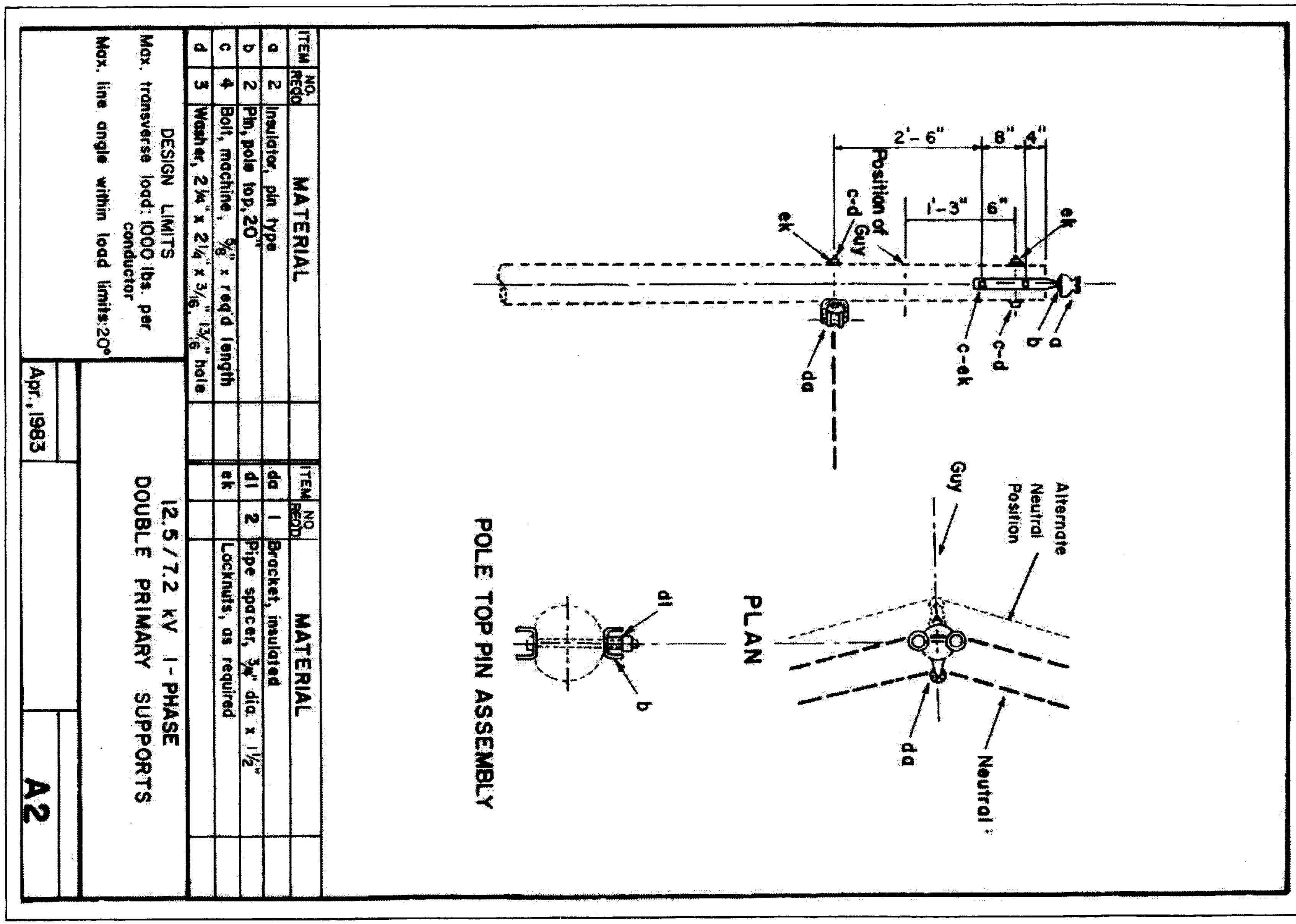


Figure 29. A staking sheet is one means of ensuring the ordered collection of data in the field. In this version of the form, a different set of columns is used for each assembly unit, with the numbers in the leftmost column referring to a pole number on the accompanying map. The list of all materials by assembly unit code is included along the bottom of this sheet. (El Salvador)

Investing sufficient time and financial and staffing resources in developing such a methodology and preparing a manual at the outset

- Can have a major impact on the efficiency with which the task of RE is addressed,
- Facilitates training of utility staff,
- Will quicken the pace at which distribution lines are extended into the rural areas, and
- Will yield considerable financial returns to the utility over time.

Commodity Specifications

Along with the development of basic line designs and staking methodology, the preparation of materials specifications will help reduce costs associated with construction and materials management and will assure a high level of quality control. Although most countries have adopted standardized designs, this has not always been done on an optimum basis that recognizes the specific needs of rural economies and the differences between urban and rural load characteristics.

In the United States, the use of standardized assemblies, called *construction units*, has facilitated the mass construction of lines at reduced cost. These units are the building blocks for complete line construction. For example, a single-phase poletop assembly for a maximum line angle of 20°, including the labor required to install it, is one unit (see Figure 30).[xxi] A single-phase transformer on a three-phase circuit is another. A single-down guy wire, with connectors and clamps and other hardware, along with labor, is a third.

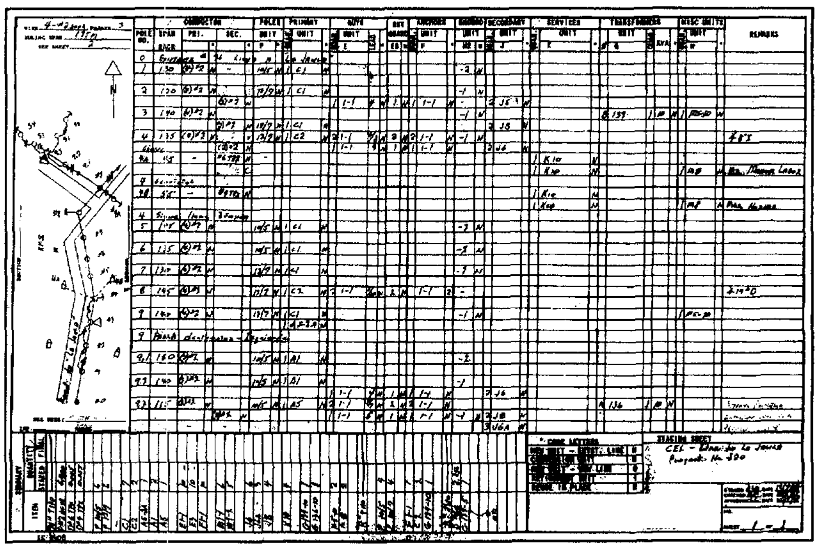


Figure 30. The design for a standardized, single-phase poletop assembly for a maximum line angle of 20° includes a basic drawing accompanied by a complete list of materials.

Use of standards ensures high-quality construction that is consistent, independent of whether design and construction are carried out by the utility itself, a contractor, or a consultant. It facilitates the training of utility personnel, minimizes ongoing maintenance requirements, streamlines inventory control and procurement, and contributes to increased cost-effectiveness in all these areas. After natural disasters such as typhoons or hurricanes, floods, or earthquakes have taken their toll, the use of standard designs and material specifications throughout a country facilitates the exchange of trained utility staff from one part to another help make repairs.

In developing such specifications, material items common to various line components—such as bolts, clamps, and transformers used for both single- and three-phase construction—should be used to minimize the variety of components that must be held in stock. Tooling requirements and skill levels required for assembly should be evaluated before finalizing specific designs. The availability of locally produced materials should be investigated and evaluated; certain components such as poles, wood products, porcelain insulator products, conductor products and connectors, bolts, and anchors might be produced by local industry. The quality of both locally and internationally produced materials—including retention of wood preservative, strength of connectors and clamps, and quality of insulators—should be investigated to determine their impact on their life-cycle cost.

Specifications for the final materials selected must also be prepared. In the United States, the Rural Utilities Service (RUS, formerly the Rural Electrification Administration or REA) maintains a "List of Materials Acceptable for Use on Systems of REA Electrification Borrowers" (REA Bulletin 43-5), which is updated about twice yearly and can be downloaded from the Internet at www.usda.gov/rus/electric/listof.htm. The RUS either directly tests the materials for suitability or requires that the manufacturers provide certified test results and that a history of use of the products be shown. Materials information in this bulletin includes specific manufacturer's catalog numbers required for each material item for installation on RUS lines. By specifying that the material items must comply with RUS requirements and be listed in the bulletin, users of the bulletin are assured the quality of the material items they are purchasing. They are also ensured that each item (1) is available from a number of suppliers—thus encouraging competition and reducing cost—and (2) is used by other utilities around the country.

The availability of specifications provides objective standards by which to gauge the quality of the materials used. For example, wood poles represent a major portion of an investment in RE. When purchasing treated utility poles, as when purchasing other line materials, most utilities rely on established standards. Manufacturers successfully bidding on pole orders are then expected to closely follow such specifications during all phases of production. By accepting an order, the manufacturer takes responsibility for providing a product that conforms to the customer's expectations provided in the specifications.

Key to a manufacturer's ability to produce a quality product is maintaining an effective internal quality control system. With a set of objective standards, third-party inspection programs can operate on behalf of the ultimate consumer, functioning as an independent, objective audit of the plant's quality-control system.

Traditional programs of independent inspection rely on attempting to catch non-conforming material via a single end-of-the-line inspection. In the United States, an example of another approach to pole quality assurance is that pursued by the Wood Quality Control (WQC) program.[15] This program is designed to help the manufacturer provide a high-quality finished product by insuring that the producer maintains a functional internal quality-control system. Manufacturers pay for this service by submitting fees to WQC based on their monthly WQC linear footage production. As with most other inspection programs, these WQC inspection fees are built into the price that the customer pays for the final product.

Under the WQC program, plant performance and product quality are assessed in two ways. First, an ongoing series of in-plant inspections is made. This phase of the program also includes an ongoing assessment of yard equipment, personnel experience, and storage yard conditions. It also includes

[15] This program is a wholly-owned subsidiary of the National Rural Electric Cooperative Association. Further information is available from jac1@nreca.org ("1" = "one").

checking poles for proper physical and treatment parameters. This product sampling, carried out only after the manufacturer has completed all of its required tests, is done on a statistical basis to insure that the product complies with the standards. Poles meeting standards are branded or tagged with the "WQC" logo on the face and also marked with a WQC quality mark hammered into the tip and the butt.[16] Purchasers see these WQC marks as an assurance that they are getting poles that consistently meet or exceed established industry standards.

In addition to this in-plant quality assurance work, once WQC poles have been shipped from the production facility, quality checks are periodically made on WQC poles that have been delivered to a utility's storage yards, prior to their installation. These are known as "destination" checks. In the case of WQC poles that have been purchased and shipped to destinations outside of the country, such as Bangladesh, Central America, or American Samoa, destination checks normally occur where the poles are accumulated at a dock facility prior to loading onto a ship.

If the WQC inspection determines that any manufacturer involved in the program develops significant problems with their internal quality control system, they are immediately suspended and lose possession of their WQC quality-mark hammer. The offending plant is then allowed a maximum of 30 working days to resolve the problem. Failure to do so results in their disqualification as a WQC producer.

Labor Costs

A final factor affecting line cost is the cost of labor. In less economically developed countries, this compensation may not even contribute 10 percent to the overall cost of the line and may therefore have almost no impact on cost, in spite of the number of people who may be employed. One reason it is misleading to quote line construction costs in industrialized countries as applicable elsewhere is that the high costs of labor found in some of these countries cannot be applied directly to non-industrialized countries. In the United States, a lineman can receive an hourly compensation of $40, which can easily double the cost of line construction and lead to high estimates when projected to other countries.

Construction costs can be reduced somewhat through the use of single-phase construction. Such construction results in 25 to 45 percent lower labor costs than three-phase construction. If one simplifies construction further by adopting the SWER configuration, Australian experience indicates that construction times are 40 percent less than those required for conventional single-phase construction.

It may be possible to further reduce construction costs somewhat by using local village labor. Much of the more costly work on MV lines is technical in nature and, in the interests of completing a job properly and punctually, may best be done by trained technicians. However, under proper supervision (which would represent an additional cost), villagers could help with some tasks such as moving and guarding materials, digging holes for poles, helping to set poles (see Figure 31), and providing local accom-

[16] Brands are burned into the face of the pole while tags are inserted a small distance into the pole (to prevent their being rubbed off during handling) and nailed. The WQC quality mark includes "WQC" at the top, the treatment plant's approved number at the center, and the initials of the monitoring agency at the bottom. Incorporated on the head of a special hammer, the WQC quality mark is hammered into the tip of each pole after it has been inspected *before* treatment and found to conform to the physical specifications. The mark is hammered into the butt of the pole *after* treatment once the plant's prescribed tests have been completed and show the pole conforms with regard to preservative penetration and retention.

modations for utility staff during the construction. Given the already low labor rates in many countries, any reductions in the capital cost per kilometer of line obtained by relying on local villagers will generally be small. On the other hand, involving them in such ongoing tasks as metering, collection, right-of-way maintenance, and enforcement of regulations against theft of electricity could significantly reduce the utility's cost of operating rural systems.

Figure 31. Villagers at a new cooperative in El Salvador assisting with raising a pole.

4

Summary

A review of existing costs for extending MV lines into rural areas in even a limited selection of countries around the world leads one to conclude that these costs can vary widely. This variation is in part due to such factors as import duties and cost of labor, which are country-specific and may not be within the ability of the electric utility to alter. However, the cost variation also reflects the approaches electric utilities have used in design, equipment and hardware procurement, and line construction, as well as the actual designs themselves.

Interventions to Reduce Cost

Some of the factors in this latter category that affect cost, and recommendations concerning these, include the following:

- Because the cost of the conductor contributes greatly to the overall cost of grid extension, utilities should investigate the use of higher voltages to reduce the cost of conductor. Up through at least 25 kV, the decrease in the price of the conductor more than offsets the higher cost due to increased insulation and clearance requirements (p. 37). A higher voltage also implies the need for fewer substations to serve a given area and leads to a further reduction in cost.
- The premature replacement of poles adds significantly to the life-cycle cost of line construction. The use of more-expensive, high-quality poles should be carefully considered as a means of reducing this cost (p. 21), as should a program of pole maintenance.
- Because of the nature of rural loads, increased use of single-phase lines can significantly reduce cost without significantly restricting the uses to which electricity can be put (p. 31). Single-phase transformers are more efficient and less costly than three-phase transformers of the same capacity (p. 42).
- The cost of transformer losses during normal operation can be significant and can easily exceed the amortized capital cost of the transformer (p. 38). When selecting transformers, utilities should consider the life-cycle cost of transformers, rather than simply their capital cost; they should also consider using transformers with low core-losses (p. 41).

- Using transformers with excessive capacity raises the cost of supplying electricity to those served. To minimize costs incurred, each transformer should be properly sized for the service area and for the load to be met (p. 42). Care should be exercised to ensure that realistic projections of the type, size, and growth of this load are used.
- Because of the significant cost of LV distribution systems, increasing the length (and cost) of the MV line to bring it closer to the end-users can reduce overall costs of electrification (p. 45).
- Using a larger number of smaller distribution transformers in areas to be electrified reduces the overall size and cost of conductors while maintaining low losses and good voltage regulation in the LV system (p. 45)
- Because the cost of poles represents an important part of the cost of grid extension, designs must optimize the span/pole-length combination for the conductor used (pp. 17-20).
- A variety of pole designs are available, encompassing a wide range of costs. Given the important contribution to grid extension costs due to poles, all design options should be reconsidered to determine whether one or more options exist that are more cost-effective than the one presently used. In this activity, the broad range of long-term advantages of local wood pole production should also be considered (p. 21).
- Standardization of materials, quality assurance, development of cost-effective staking methodologies, and preparation of manuals and guides are among those efforts requiring a commitment of time and effort that can, in the long run, reduce cost, facilitate electrification, increase reliability and quicken the pace of line construction (p. 50).
- The effective cost of electrification can be reduced by increasing the number of consumers served. One way of achieving this is to use small single-phase transformers along MV lines to serve small clusters of consumers. This can increase the revenue base at minimum cost (p. 43).

Benchmark Cost

In the interests of maximizing the impact of financial resources available for RE, the utility should strive for the lowest possible life-cycle cost for lines it constructs. If a reference or benchmark cost were available for line construction, along with a simple breakdown, the utility could then evaluate its costs in comparison to this target cost. It could then proceed with interventions in those areas where its costs seem unnecessarily high.

Much of this benchmark cost is simply the capital cost of the line, which for estimation purposes may be divided in two components: materials and labor. Aside from the cost of transportation and import duties, the cost of materials should be roughly the same around the world and be independent of the country in which the line is to be built. If a kilometer of ACSR conductor is available at $800 in the United States, it should be available at that price to anyone, whether manufactured in-country or imported from the United States (if that is less expensive). On the other hand, the cost of labor should be considered separately because this varies widely between industrialized and non-industrialized countries (see p. 54).

In considering the cost of a typical three-phase, MV grid extension, field data from the countries surveyed indicate an average materials cost for such a line of roughly $7,000 per kilometer. However, because any one country can utilize some components or designs that are low-cost and others that are high-cost, this figure does not necessarily represent the low cost that is attainable for such a line.

Table 8. Estimated Target Cost of Materials for an Average Kilometer for a Three-Phase Line

Item	Cost ($/km)
10.5-meter wood poles, 11 @ $170	1,900
Conductor, 3 km of 35 mm^2 ACSR	1,200
Poletop accessories	800
Guy assemblies	500
TOTAL	4,400

Note: Excludes the cost of labor and local transportation of materials. Import duties or construction in difficult terrain would add to this cost.
Source: NRECA/Dhaka field office.

If one were to derive a "reasonable" low cost for a three-phase, three-wire (European configuration) line over normal terrain that one might aim for, this cost per unit length might have a cost breakdown roughly as shown in Table 8. For this table, landed costs of imported poles and conductor in Bangladesh were used because this country seems to be typical of those that might be interested in rural electrification.[xxii]

It is interesting to note that, according to data presented in Appendix A, this low target cost ($4,400 per kilometer) happens to parallel costs incurred in the United States. Costs in the United States are expected to be a little higher only because designs there adhere to the North American configuration. This requires the use of four rather than three conductors, along with more extensive grounding along the line. (Although this increases cost slightly, it permits the use of very simple, reliable, and low-cost single-phase construction in rural areas.)

Labor costs must also be added to the above, however, to obtain the total capital cost for three-phase line construction. Because the focus of this study is rural electrification in non-industrialized countries, typical costs for such countries from the survey will be used to come up with an average cost. Appendix A and Figure 1 show that a low value for the cost of labor averages roughly $500 per kilometer for a range of non-industrialized countries, whereas it can reach $2,000 to $3,000 per kilometer in others. Because of high labor rates and the extensive benefits available to the average U.S. utility employee, costs in the United States can exceed these high figures by a further several thousand dollars.

Therefore, a lower target limit on capital cost (materials and labor) for the construction of a three-phase line in non-industrialized countries may be roughly $4,900 per kilometer under normal conditions (roughly $5,300 for the North American configuration). In regions where labor costs are high, this lower limit would be closer to $7,000 per kilometer for a line built according to the European configuration.

These costs can be reduced somewhat through the use of single-phase construction. For systems adhering to the North American configuration, costs can be reduced by a third (see Figure 3), to perhaps $3,500 per kilometer because of the simplification in the design that is possible, in addition to reducing conductor length to a half. For those adhering to the European configuration, savings may be somewhat less because conductor length would only be reduced by a third and significant poletop hardware, including a crossarm, would still be required. But although the cost reduction may be less, starting with a lower three-phase line cost implies that a target low cost for the single-phase European configuration would be about the same as that for the North American single-phase configuration above. Where circumstances are suitable, capital costs for line construction can be reduced further through the use of single-phase SWER construction.

Although capital costs are a principal contributor to the life-cycle cost of line construction, other factors must also be considered. As mentioned previously, keeping initial costs low—by, for example, using short-lived low-quality poles, inappropriate conductor material, and inefficient design and construction—can increase life-cycle cost. Moreover, the life-cycle cost of rural electrification is more than the life-cycle cost of the line; one must also take into account the cost of operating and maintaining the line, resistive losses and theft, the energy consumed, and distribution and housewiring.

Because it is a major contributor to the cost of RE, the life-cycle cost for line construction is one area that electric utilities interested in more cost-effectively serving rural populations should assess. If the capital cost of three-phase line construction in a certain country is higher than the figure derived in Table 8, the utility in that country should assess the cost of each component to determine what factors contribute to this increased cost and to what extent these are necessary. (In addition to the factors discussed in this report, these might also include high import duties and excessive mark-up of prices.) The utility should then determine what options are available to it to reduce its costs. And finally, in cases where new designs and approaches are found to be effective in reducing the cost of RE, these should be properly researched and then incorporated into the utility's standard construction practices.

In designing programs for rural electrification, utilities should continually keep in mind the nature of the needs of rural populations and the realities facing electrification in these areas. They should consciously avoid the tendency to adopt the path of least resistance, namely, existing urban designs that constitute "the way things have always been done." Utilities should reexamine their basic principles, question why designs have been adopted in the past, and ascertain whether the same rationale still exists when the focus has shifted to cost-effectively introducing electricity into rural areas. They should then develop a new set of standards designed both to reduce the life-cycle cost of grid extension and to suit conditions and needs in rural areas.

The benefits of electrification extend beyond the rural areas. An investment in more-effective RE can contribute significantly to the well-being of the nation as a whole and provide it with an increased financial return. A more vibrant rural economy can provide gainful employment; contribute to a broader, more secure, and financially productive agricultural base for the nation; and give rural people an alternative to migrating to increasingly crowded, polluted, and unmanageable urban areas.

Appendix A: Summary of Field Data

Table A-1. Cost Breakdowns for Single-Phase Lines

Table A-2. Cost Breakdowns for Three-Phase Lines

Table A-1. Cost Breakdowns for Single-Phase Lines

	Exch. Rate/US$=					28	Exch. Rate/US$=	40	Exch. Rate/US$=	40		
Country:	**Bangladesh-1p**		**USA(2)-1p**		**Philippines(1)-1p**		**Philippines(2)-1p**		**Philippines(3)-1p**		**USA(3)-1p**	
Utility (date):	REB (1997)		Mettler (1997)		NEA		Tarelco II		MORESCO I		Rapanhannock EC	
Country:	Bangladesh-1p		Colorado, U.S.A.		Philippines		Philippines		Philippines		Virginia, U.S.A.	
Average span, voltage:	70 m, 11 kV p-p		100 m, 14.4 kV p-g		70 m, ??? kV p-p		50 m, ??? kV p-p		100 m, ??? kV p-p		110 m, 7.2 kV p-g	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
Materials												
Poles (size, type, number/km)	14 @ mostly 30'-7, wood	1630	10 @ 35'-5, wood	1780	14 @ mostly 30'-5, wood	2250	20 @ mostly 30'-5, conc.	3640	10 @ 35'	2140	35', 40', and 45' wood[a]	1200
Conductor (size, length)	#3 ACSR, 2030 m	480	#4 ACSR, 2000 m	530	ACSR 1/0 +#2 neu, 2200 m	1320	ACSR #2, 2000 m	1180	ACSR #2, 2000 m	1500	ACSR #1/0, 2000 m	980
Poletop assembly		310		210		740		420		450		240
Guy assembly (number/km)		290	1-2	70	7	560	9	410	8	520	7.5[e]	270
Grounding		50	3	50	14[a]	80	19	180	10	130	9.3[b]	50
Misc.												
Sub-Total		**$ 2,760**		**$ 2,640**		**$ 4,950**		**$ 5,830**		**$ 4,740**		**$ 2,740**
Labor												
Pole setting				1500				240		430		3650
Conductor stringing				990				80		300		1640
Framing of structures				180				40		90		290
Guy assembly installation				190				50		100		970
Grounding installation				90				10		30		400
Misc.	Lump sum est.	300			lump sum	1590						
Sub-Total		**$ 300**		**$ 2,950**		**$ 1,590**		**$ 420**		**$ 950**		**$ 6,950**
Other												
Clearing											[c]	5100
Surveying and staking												
Transportation and tools												
Fuel												
Service												
Margin												
Contingency												
Other					eng'g,handling r-o-w,cont.	230					Overhead[d]	$ 490.00
Sub-Total		**$ -**		**$ -**		**$ 230**		**$ -**		**$ -**		**$ 5,590**
Total		**$ 3,060**		**$ 5,590**		**$ 6,770**		**$ 6,250**		**$ 5,690**		**$ 15,280**
Notes	Source: Colin Jack, NRECA/Dhaka		Source: Ron Mettler, Mettler, Inc.		Source: Mae Soriano(NEA) through GilMedina (NRECA/Manila) a. No ground wire included.???		Source: Gil Medina (NRECA/Manila)		Source: Gil Medina (NRECA/Manila)		Source: Ricky Bywaters, Engineering a. 4.7@35'-6, 3.1@40'-5, and 1.5@45'-4 b. Due to poor ground in service area, a ground rod is used at every pole c. 30' right-of-way, 2.7 km brush + 2.1 km with trees; with trees, $3.70; without trees, $0.50 d. 18% of materials cost e. Roughly 30% are each tangent, 30º, or 60º poletop assemblies with a few remaining 90º assemblies	

Country:	Laos-1p		Laos-SWER		USA(1)-1p		ElSalvador-1p		Bolivia-1p	
Utility (date):	EdL (1996)		EdL (1996)		Benton REC (1997)		NRECA (1997)		?? (1997)	
Country:	Laos		Laos		Washington, U.S.A.		El Salvador		Bolivia	
Average span, voltage:	83 m, 22 kV p-p		170 m, 22 kV SWER		110 m[b], 7.2 kV p-g		120 m, 7.6 kV p-g		120 m, 19.9 kV p-g	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
Materials										
Poles (size, type, number/km)	12 @ 12 m, concrete	2,440	6 @ 12 m, concrete	1,220	9 @ 40', Class 5, wood	3,070	8.4 @35', concrete	1,600	8 @ 12 m, concrete	2,400
Conductor (size, length)	35 mm^2 ACSR, 2200 m	580	SC/AC 3/2.75, 1100 m	950	#2 AWG ACSR, 2000 m	930	#2 AWG ACSR, 2080	1,210	#4 AWG ACSR, 2080 m	710
Poletop assembly		1,360		630	[a]	100	[a]	600		530
Guy assembly (number/km)	3[a]	330		180	3	140	6	270	7	430
Grounding		0			3	20	3	210	4	160
Misc.	?	240		120		--		--		--
Sub-Total		**$ 4,950**		**$ 3,100**		**$ 4,260**		**$ 3,890**		**$ 4,230**
Labor										
Pole setting		--			[c]	3,370		810		470
Conductor stringing		--				150		400		12
Framing of structures		--				800		110		40
Guy assembly installation		--				670		160		103
Grounding installation		--				340		70		50
Misc.	lump sum[b]	480	lump sum[b]	480	Materials handling	850		--	general expenses[b]	91
Sub-Total		**$ 480**		**$ 480**		**$ 6,180**		**$ 1,550**		**$ 770**
Other										
Clearing	[b]	20	[b]	20						350
Surveying and staking										250
Transportation and tools	[b]	220	[b]	220						245
Fuel	[b]	320	[b]	320						
Service	[b]	380	[b]	380						
Margin									20% of labor & transport	182
Contingency									5% of grand subtotal	282
Other									taxes	226
Sub-Total		**$ 940**		**$ 940**		**$ -**		**$ -**		**$ 1,540**
Total		**$ 6,370**		**$ 4,520**		**$ 10,440**		**$ 5,440**		**$ 6,540**
Notes	Source: Design Standards, Subtransmission and Rural Electrification Project, SwedPower a. Cost includes 0.5 m3 of concrete per pole ($35/m3) used around its base. b. These costs were quoted as equal for all MV line configurations.		Source: Design Standards, Subtransmission and Rural Electrification Project, SwedPower a. Cost includes 0.5 m3 of concrete per pole ($35/m3) used around its base. b. These costs were quoted as equal for all MV line configurations.		Source: Stephen Anderson, Engineering Manager, Benton Rural Electric Association, Washington, U.S.A. a. Includes 2 deadend and l angle assembly. b. Minimum ground clearance is ???. Loading on line is 0.25" ice and 40 mph (4 lbs/sq. foot) wind. Sized to accommodate joint-use attachments. c. Labor averages $37/hour including overhead.		Source: Myk Manon, Project Manager, NRECA/El Salvador a. Includes 4 tangent, 1.6 A2-Ms, 0.8 A8s, and miscellaneous other assemblies.		Source; Fernando Haderspock, CRE, Santa Cruz, Bolivia a. Includes 5 tangent plus variety of other assemblies. b. 10% of labor plus transport.	

Table A-2. Cost Breakdowns for Three-Phase Lines

Country:	Laos-3p		USA(1)-3p		El Salvador-3p		Bolivia-3p		MPSEB(1)-3p	
Utility (Date):	EdL (1996)		Benton REC (1997)		NRECA (1997)		?? (1997)		MPSEB (1997)	
Country:	Laos		Washington, U.S.A.		El Salvador		Bolivia		Madhya Pradesh, India	
Average span, voltage:	66 m, 22 kV p-p		100 m, 12.5 kV p-p		120 m, 13.2 kV p-p		110 m, 34.5 kV p-p		80 m, 11 kV p-p	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
Materials										
Poles (size, type, number/km)	15 @ 12 m, concrete	3,050	10 @ 40', Class 5, wood[b]	3,410	8.6 @ mostly 35', conc.	1,720	9 @ 12 m, concrete	2,480	~13 @ 8 m conc., 140 kg[c]	320
Conductor (size, length)	35 mm^2 ACSR, 3,300 m	870	#2 AWG ACSR, 4,000 m	1,870	#2 AWG ACSR, 4080 m	2,370	#4 AWG ACSR, 4,100 m	1,280	30 mm^2 ACSR, 3100 m	950
Poletop assembly		2,730	[a]	940	[a]	1,480	[a]	2,570		390
Guy assembly (number/km)	3[a]	380		140		270	11	710	6[a]	190
Grounding		0		20		320	5	150		60
Misc.	(undefined)	200		--				--		
Sub-Total		**$ 7,230**		**$ 6,380**		**$ 6,160**		**$ 7,190**		**$ 1,910**
Labor										
Pole setting		--	[c]	3,740		830				
Conductor stringing		--		300		780				
Framing of structures		--		1,890		250				
Guy assembly installation		--		670		160				
Grounding installation		--		340		70				
Misc.	lump sum	480	Materials handling	1,280		--	lump sum[b], 20% of mat.	1,460	lump sum & supervision[b]	500
Sub-Total		**$ 480**		**$ 8,220**		**$ 2,090**		**$ 1,460**		**$ 500**
Other										
Clearing		20						350		
Surveying and staking								250		
Transportation and tools		220								80
Fuel		320								
Service		380					"other"	440	storage @ 3%	60
Margin										
Contingency							5%	470	3%	60
							taxes	280	"T&P" @ 2%	40
Sub-Total		**$ 940**		**$ -**		**$ -**		**$ 1,790**		**$ 240**
Total		**$ 8,650**		**$ 14,600**		**$ 8,250**		**$ 10,440**		**$ 2,650**
Notes	Source: Design Standards, Subtransmission and Rural Electrification Project, SwedPower a. Includes 0.5 m3 of concrete at the base of each pole.		Source: Stephen Anderson, Engineering Manager, Benton Rural Electric Association, Washington, U.S.A. a. Includes 2 deadend and I angle assembly. b. Extra height for joint usage of pole. Loading on line is 0.25" ice and 40 mph (4 lbs/sq. foot) wind. Sized to accommodate joint-use attachments. c. Labor averages $37/hour including overhead.		Source: Myk Manon, Project Manager, NRECA/El Salvador a. About half non-tangent assemblies.		Source: Fernando Haderspock, CRE, Santa Cruz, Bolivia a. Uses 6 suspension insulators per pole. b. Presumably includes transporation.		Source: Ashok Ahuja, New Delhi (from MPSEB Standard Specs) a. Includes boulders for backfilling and concrete for guys and pole base pad. b. Includes 10% for H.O. and general supervision c. Working load. Assumes 12 poles/km plus one double-pole structure every mile.	

Country:	Bangladesh-3p		USA(2)-3p		Exch. Rate/US$=	28	Exch. Rate/US$=	40	Exch. Rate/US$=	40
					Philippines(1)-3p		Philippines(2)-3p		Philippines(3)-3p	
Utility (Date):	REB (1997)		Mettler (1997)		NEA		Tarelco II		MORESCO I	
Country:	Bangladesh-3p		Colorado, U.S.A.		Philippines		Philippines		Philippines	
Average span, voltage:	90 m, 11 kV p-p		100 m, 24.9 kV p-p		70 m, ??? kV p-p		50 m, ??? kV p-p		100 m, ??? kV p-p	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
Materials										
Poles (size, type, number/km)	11 @ mostly 35'-5, wood	1840	10 @ mostly 35'-5, wood	1880	15 @ mostly 35'-4, wood	2970	20 @ 35', concrete	4600	35' and 2 ea. @ 40',45'	2520
Conductor (size, length)	4/0+1/0 neu ACSR, 4060 m	3310	#3 ACSR, 4000m	1060	ACSR 1/0 +#2 neu, 4400 m	2950	ACSR #2, 4000 m	2690	ACSR 2/0, 4000 m	3830
Poletop assembly		800		1220		2700		1370		1680
Guy assembly (number/km)	4	340	2-3	130	10	750	8	180	11	700
Grounding	2-3	50	3	50	14	140	20	190	10	130
Misc.										
Sub-Total		**$ 6,340**		**$ 4,340**		**$ 9,510**		**$ 9,030**		**$ 8,860**
Labor										
Pole setting		100		1500				270		500
Conductor stringing		190		1980				210		770
Framing of structures		30		470				130		340
Guy assembly installation		30		380				20		140
Grounding installation				90				20		30
Misc.					lump sum	3130				
Sub-Total		**$ 350**		**$ 4,420**		**$ 3,130**		**$ 650**		**$ 1,780**
Other										
Clearing										
Surveying and staking										
Transportation and tools										
Fuel										
Service										
Margin										
Contingency										
					eng'g,handling r-o-w,cont.	380				
Sub-Total		**$ -**		**$ -**		**$ 380**		**$ -**		**$ -**
Total		**$ 6,690**		**$ 8,760**		**$ 13,020**		**$ 9,680**		**$ 10,640**
Notes	Source: Colin Jack, NRECA/Dhaka		Source: Ron Mettler, Mettler, Inc.		Source: MaeSoriano(NEA) through Gil Medina(NRECA/Manila)		Source: Gil Medina (NRECA/Manila)		Source: Gil Medina (NRECA/Manila)	

	Exch. Rate/US$=	610	Exch. Rate/US$=	58	Exch. Rate/US$=	550			Exch. Rate/US$=	580
Country:	**Mali-3p**		**Kenya-3p**		**Senegal(1)-3p**		**USA(3)-3p**		**Senegal(2)-3p**	
Utility (Date):	Société Energie du Mali				SENELEC		Rapanhannock EC		SENELEC	
Country:	Mali		Kenya		Senegal		Virginia, U.S.A.		Senegal	
Average span, voltage:	80 m, ??? kV p-p		100 m, 11 kV		30 kV		110 m, 12.5 kV p-p		150 m, 30 kV	
	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
Materials										
Poles (size, type, number/km)	13 @ 12 m class A conc.	5970	10 @ 11 m medium	790	10 wood and 3 steel @ 12 m[a]	2950	35', 40', and 45' wood[a]	1560	12 m concrete	2820
Conductor (size, length)	Aster 34.4 mm^2	4810	150 mm^2 ACSR	2670	ACSR 54.6 mm^2, 3150 m	1770	ACSR #1/0, 4000 m	1970	Almelec148 mm^2, 3200 m	5420
Poletop assembly		4390		1780				940		2570
Guy assembly (number/km)				710			11[e]	560		
Grounding							9.3[b]	50		
Misc.				10	b	3830				
Sub-Total		**$ 15,170**		**$ 5,960**		**$ 8,550**		**$ 5,080**		**$ 10,810**
Labor										
Pole setting		1120		570		440		3650		690
Conductor stringing		780		970		130		3280		670
Framing of structures				60				920		110
Guy assembly installation				400				1420		
Grounding installation								400		
Misc.		690		20		400				
Sub-Total		**$ 2,590**		**$ 2,020**		**$ 970**		**$ 9,670**		**$ 1,470**
Other										
Clearing							c	6750		10
Surveying and staking				1210		590				730
Transportation and tools					c	540				990
Fuel										
Service										
Margin			"CWS cost"	2210						
Contingency				920						
		1310	"T&P"	230			Overhead[d]	$ 910.00	Overhead[d]	#######
Sub-Total		**$ 1,310**		**$ 4,570**		**$ 1,130**		**$ 7,660**		**$ 3,680**
Total		**$ 19,070**		**$ 12,550**		**$ 10,650**		**$ 22,410**		**$ 15,960**
Notes	Source: "Travaux Neufs" of the Société Energie du Mali, from Ismail Toure via Willem Floor 7/28/98		Source: From rates found in Kenya DCS b construction units prices 1997, via Robert v der Plas, World Bank		Source: Mr. Chelkhou Cisse of SENELEC/HANN through Eduardo Villagran 5/98 a. Steel pole (1400 daN) at 2.5 times the cost of wood pole (140 daN) b. Cost for guys, insulators, clamps for 10 wood poles is $1770 and for 3 steel poles is $2540. c. Transportation cost is $0.22/tonne/km		Source: Ricky Bywaters, Engineering a. 3.4@35'-5, 3.7@40'-4, and 2.2@45'-3 b. Due to poor ground in service area, a ground rod is used at every pole c. 40' right-of-way, 2.7 km brush + 2.7 km with trees; with trees, $3.70/m2; without trees, $0.50/m2 d. 18% of materials cost e. Roughly 35% are each tangent and 30º and 15% each are 60º and 90º poletop assemblies with a few remaining assemblies		Source: SENELEC via Willem Floor; from costs for 80 km line recently bid by three Senegalese companies	

Appendix B: Making Rural Electrification More Affordable

As they extend electricity grids into rural areas, utilities face two challenges: (1) reducing cost and (2) increasing the ability of rural households to cover their share of this cost as well as the cost of energy. This appendix proposes a synergy between RE and forestry that provides one approach to addressing this pair of challenges and offers various environmental advantages as well.

Using Fuelwood: The Pros and Cons

It is widely recognized that fuelwood will continue to be a dominant source of energy in rural, and even some urban, areas in many developing countries in the foreseeable future. There are good reasons for this: it is an indigenous, low-cost or free source of energy that, if properly managed, is a renewable resource. Its use requires neither the use of new or costly stoves or cookware nor a change in cooking habits. In short, for the rural population, it is the most appropriate solution to meeting their critical need for energy for cooking and space heating.

However, this dependence on fuelwood has contributed to degradation of the forest environment in many countries as well as to increasing fuelwood scarcities, an increased burden on the women and children who gather the wood, increased runoff and decreased rainfall retention and groundwater availability in the area, reduced rainfall, loss of topsoil and impoverishment of the soil, and reduced wildlife due to the destruction of their habitat—all factors that disrupt human, animal, and eventually a nation's life.

Is Electrification the Solution?

In a number of countries, a widely heralded solution to this problem is increased electrification and the use of electricity for cooking. Although this is clearly an alternative to fuelwood, reliance on electricity is not without its drawbacks for this purpose, drawbacks that are even more pronounced in rural areas. These disadvantages include the following:

- *Increased cost of the line needed to cater to cooking.* Power distribution systems must be considerably oversized simply to meet cooking needs that tend to coincide not only with cooking loads throughout the service area but also with other evening loads, such as lighting and TV. Using only a single hot plate (rated at 1,000 W) in each rural home increases the village load by at least 400 percent (because, in many countries, the typical coincident rural load served by the grid during the evening hours is no more than 250 W). This would mean that the conductor for the MV and LV distribution lines (one of the costliest components of a distribution system) and transformers would require at least five times the capacity than would otherwise be the case without cooking. Conductor costs would therefore increase by a factor of five, as would the voltage drop during peak demand, and any line losses would increase by a factor of 25. Additional costs would also accrue from heavier pole construction, poletop hardware, and guying.
- *Increased cost of generation.* The investment required for the increased electricity-generating capacity to cater solely to cooking needs would be difficult to justify because this increased capacity would remain unused most of each day. Assuming a typical cost of power at a marginal cost of $10 per kW per month, the additional generation capacity on the grid to serve each hot plate would cost the user $10 each month.

- *Increased cost of energy.* In addition to the cost of heavier line construction and the cost of generation, each consumer must cover the considerable additional costs of the energy consumed in cooking. This becomes difficult for a rural population that has largely obtained this energy free by using of fuelwood and agricultural residues (at the expense of the environment).

The reason why electric cooking is appealing in a number of countries is its apparent low cost. But in these cases, the tariff does not represent the true costs of electrification. As noted in the previous paragraphs, the consumers would have to cover considerable additional costs if they were to cover the true costs incurred in using electricity for cooking.

An Integrated Solution

The two principal energy needs in a vibrant rural economy are the following:

- Energy for powering light, radio, and TV; water pumps for domestic consumption, agriculture, and animal husbandry; grain mills and other agro-processing equipment; vaccine refrigerators and health posts; and a range of other appliances; and
- Energy for cooking and space heating.

Clearly the first need is most effectively met with electricity, whereas the second is most easily and cheaply met with fuelwood. This begs the following question: Why not integrate RE with reforestation to exploit each energy source to maximum advantage at least cost to the individual and to the nation?

One scenario could be as follows.[17] It would have to be clearly understood and agreed that a precondition for the introduction of electricity into a community would be the sustained involvement in a community woodlot of each household that accesses electricity. Failure to maintain this project would result in disconnection from electricity service. (If electricity is in considerable demand—as it is in rural areas throughout the world—this eventuality would rarely have to be considered because the communities would have such a strong incentive to continue its use.) To ensure that tree seedlings become well established, one community's use of electricity initially could be for waterpumping for watering the trees (and for domestic consumption).

This scenario would increase the financial justification for RE by reducing its costs and increasing its financial returns and benefits to the utility and the consumers as follows:

- As previously noted, avoiding the cooking load considerably reduces the required capacity and cost of distribution systems as well the need to construct additional generating capacity on the grid where this would otherwise be necessary.

[17] This scenario assumes that electricity is in demand for non-heat-generating end uses and that there is a clear, justifiable rationale for rural electrification.

- Although villagers often have too little disposable income to cover the costs of housewiring, connection, and the electricity itself, they now have the option of making an investment of time and effort ("sweat equity"). This would have major returns not only to the nation (possibly in return for access to life-line tariffs) but also to themselves and their communities in such forms as timber for construction or sale, fuelwood, fodder for livestock, nuts and fruit for consumption or sale, increased wildlife, decreased loss of topsoil and improved land quality, and improvement in groundwater availability.
- After the forests have been established, processing and adding value to products that are extracted from the forests would provide the feedstock for cottage industries powered by electricity, increase the load factor on the distribution system, and generate financial returns for the consumers as well as for the utility that made the initial investment.
- Forestry could also reduce the cost of RE by using locally produced wood poles to replace poles, often made of concrete, that must be imported into the area. Individuals who have limited financial resources could cover connection costs by selling the locally produced poles.
- Access to local forests would reduce the time and energy women and children currently waste in searching for fuelwood and would permit these efforts to be channeled into less exhausting and more productive and rewarding activities.[xxiii]

Integrating RE and forestry in this manner would give households access to the lowest-cost electricity possible for lighting, agro-processing, social amenities, and other high-value uses, as well as access to free fuelwood for cooking, space heating, pottery and brick-making, baking, and other energy-intensive end-uses. Equally important, it would improve the natural environment and provide both a variety of livelihoods and a mechanism for sustainable development in countries that otherwise will witness the continued degradation of their natural environment and decline in their quality of life.

End Notes

[i] Gadi Kaplan, "Appropriate Technologies," *IEEE Spectrum*, October 1994; and Christopher Flavin and Molly O'Meara, "Solar Power Markets Boom," *World Watch*, September/October 1998, respectively.

[ii] Allen R. Inversin, "New Designs for Rural Electrification: Private-Sector Experiences in Nepal" (Arlington, Virginia: NRECA, 1994).

[iii] Allen R. Inversin, "Off-grid Rural Electrification: Summary, Analysis, and Recommendations Following Field Visits to Lao P.D.R., February-March 1997," prepared for the World Bank, March 25, 1997, Annex A. Although the high cost of manpower in the United States can significantly increase the cost of line construction, these labor costs do not reflect the cost of construction encountered in many developing countries.

[iv] Michael J. Shiel, "Rural Electrification in Ireland" (U.K.: The Panos Institute, 1988); and Voravate Tig Tuntivate and Douglas Barnes, "Rural Electrification in Thailand: Lessons from a Successful Program," draft copy (Washington, D.C.: Industry and Energy Department, World Bank, 1995).

[v] R. Masmoudi, "Rural Electrification in Tunisia" (proceedings of the World Bank Electric Power Distribution Design Workshop held on May 27, 1993, in Washington, D.C.).

[vi] See Figure 30 on p. 52.

[vii] *High-Voltage Earth Return Distribution for Rural Areas*, fourth edition (Electricity Authority of New South Wales, revised June 1978).

[viii] N.P. Drew and D.J. Postlethwaite, "Single Wire Earth Return Distribution Systems: Economic Rural Electrification" (paper presented to the 7th CEPSI Conference, Brisbane, October 1988).

[ix] Correspondence with James A. Taylor, wood pole specialist.

[x] *REC Specifications and Construction Standards* (New Delhi: Rural Electrification Corporation, Ltd., 1994).

[xi] Allen R. Inversin, "New Designs for Rural Electrification: Private-Sector Experiences in Nepal" (Arlington, Virginia: NRECA, 1994).

[xii] This is illustrated in Table 2 (p.37).

[xiii] Promoted by Prof. F. Iliceto of the University of Rome. See F. Iliceto *et al.*, "MV distribution from insulated shield wires of HV lines, Experimental applications in Ghana" (Symposium 11-85, CIGRÉ/UPDEA Symposium, Dakar, 1985) (112, boulevard Haussmann, 75006 Paris).

[xiv] René Massé and Hervé Conan, "Distribution de l'électricité en zone periurbaine dans les pays en développement: Note de synthèse" (France: GRET, APAVE, and BURGEAP, January 1997).

[xv] The manufacturer of written-pole motors is Precise Power Corporation, P.O. Box 9547, Bradenton FL 34206-9547, USA (http://www.precisepwr.com). Electronic drive technology is available from Unico, Inc., 3725 Nicholson Road, Franksville, WI 53126-0505, USA (http://www.unicous.com).

[xvi] Glen R. Benjamin, Paul J. Stary, and J. Mike Deans, "A Comparative Analysis: Three-Phase 400/230 V vs. Single-Phase 230 V LV systems" (Arlington, Virginia: NRECA International, Ltd., circa 1979).

[xvii] Monica Gullberg, Maneno Katyega, and Björn Kjellström, "Local Management of Rural Power Supply in Tanzania: Experiences from the First Pilot Project in Urambo, July 1994–August 1997," draft (Stockholm: Stockholm Environment Institute, June 1998).

[xviii] Suppliers of this equipment include Arkansas Electric Cooperatives, Inc., tel: 501-570-2388 and fax: 501-570-2389; and Mid Central Electric, Inc., tel: 608-835-3513 and fax: 608-835-5246.

[xix] Note that in all scenarios, the costs of the service drops are equal and therefore have not been computed. The same is roughly true with the poles required to serve the community.

[xx] Glen R. Benjamin, Paul J. Stary, and J. Mike Deans, "A Comparative Analysis: Three-Phase 400/230 V vs. Single-Phase 230 V LV systems" (Arlington, Virginia: NRECA International, Ltd., circa 1979).

[xxi] "Specifications and Drawings for 12.5/7.2 kV Line Construction," REA Bulletin 50-3 (Washington, D.C.: Rural Electrification Administration, U.S. Department of Agriculture, 1983).

[xxii] Assuming an acceptable voltage drop not exceeding 4 percent along a MV line, the line costed in Table 8 could supply a load of 20,000 kW-km at a distribution voltage of 22 kV (e.g., a load of 500 kW located at the end of a 40-kilometer line or 1 megawatt uniformly distributed along that same line).

[xxiii] A final note: Rather than seeing the creation of rights-of-way for distribution lines as contributing to deforestation in wooded areas, it could be added that this could be seen as a additional renewable source of fuelwood. Clearing the right-of-way would provide an initial source of fuelwood. Furthermore, maintaining a clear right-of-way on an on-going basis would provide a continuing source of fuelwood and would remove a significant cost usually incurred by the electric utility in maintaining proper clearance under distribution lines.

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
	Commercilizing Natural Gas: Lessons from the Seminar in Nairobi for Sub-Saharan Africa and Beyond	01/00	225/00
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

Region/Country	*Activity/Report Title*	*Date*	*Number*
Côte d'Ivoire	Project of Energy Efficiency in Buildings (English)	09/95	175/95
Ethiopia	Energy Assessment (English)	07/84	4741-ET
	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

Region/Country	Activity/Report Title	Date	Number
Mauritius	Energy Sector Review (English)	12/94	3643-MAS
Mozambique	Energy Assessment (English)	01/87	6128-MOZ
	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

Region/Country	*Activity/Report Title*	*Date*	*Number*
Tanzania	Power Loss Reduction Volume 2: Reduction of Non-Technical Losses (English)	06/98	204B/98
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

Region/Country	Activity/Report Title	Date	Number
Indonesia	Energy Assessment (English)	11/81	3543-IND
	Status Report (English)	09/84	022/84
	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)

Region/Country	Activity/Report Title	Date	Number
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

Region/Country	*Activity/Report Title*	*Date*	*Number*
Bangladesh	Small Scale Uses of Gas Prefeasibility Study (English)	12/88	--
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)

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

Region/Country	*Activity/Report Title*	*Date*	*Number*
	MIDDLE EAST AND NORTH AFRICA (MNA)		
Arab Republic of Egypt	Energy Assessment (English)	10/96	189/96
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

Region/Country	*Activity/Report Title*	*Date*	*Number*
Colombia	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
	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

Region/Country	Activity/Report Title	Date	Number
Trinidad and Tobago	Energy Assessment (English)	12/85	5930-TR

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
	A Review of the Renewable Energy Activities of the UNDP/ World Bank Energy Sector Management Assistance Programme 1993 to 1998	11/99	223/99
	Energy, Transportation and Environment: Policy Options for Environmental Improvement	12/99	224/99
	Privatization, Competition and Regulation in the British Electricity Industry, With Implications for Developing Countries	02/00	226/00
	Reducing the Cost of Grid Extension for Rural Electrification	02/00	227/00

2/10/00

ESMAP

The World Bank

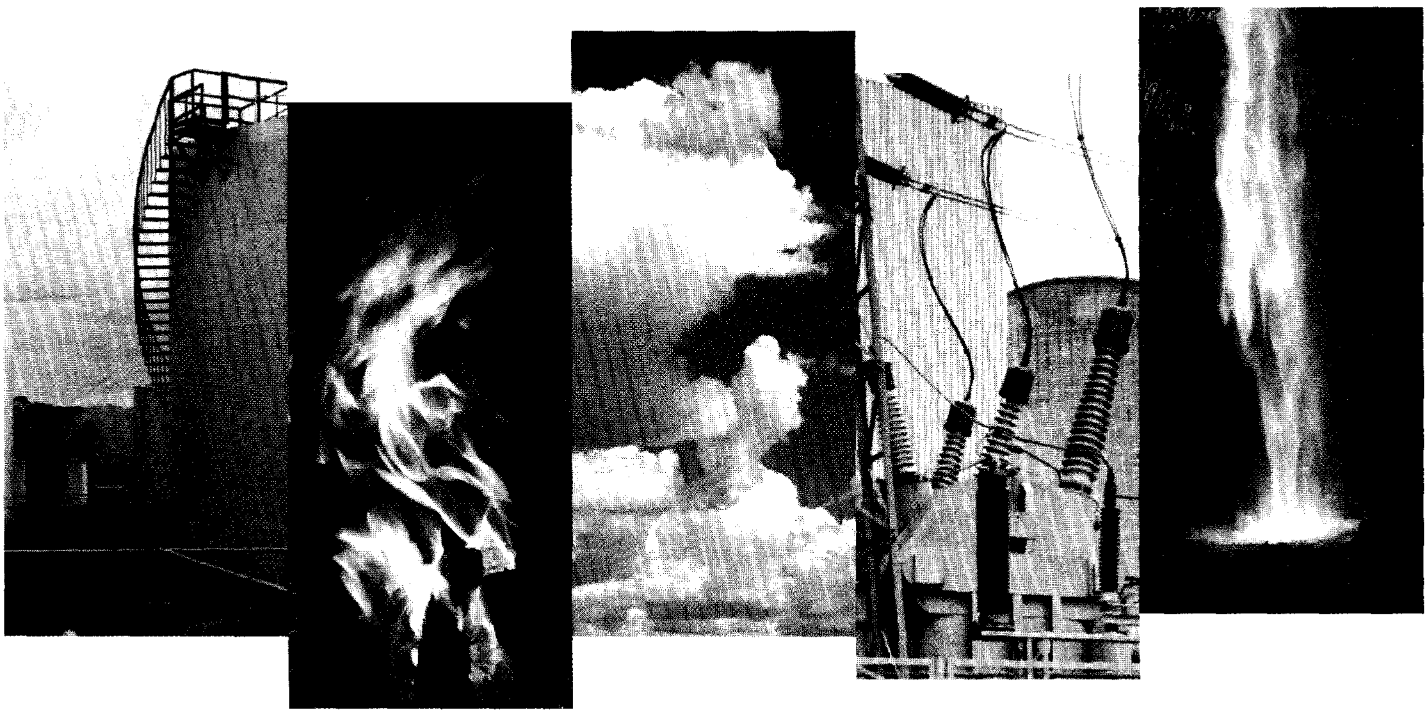
1818 H Street, NW

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