PHOTOVOLTAICS VERSUS LINE EXTENSIONS: CREATING INFORMED CONSUMER CHOICES

by

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pvcost.sep

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Electric utility line extensions are sometimes used to supply power to remotely located customers when a stand-alone photovoltaic (PV) system may be cheaper. However, progress is being made regarding the applicability of photovoltaics. The utility regulatory agencies of Colorado, Arizona, and New Mexico have implemented guidelines on PV versus line extensions or are considering such guidelines and Idaho Power Company has proposed a pilot program to install PV systems at remote sites[1]. Photovoltaic systems have proven themselves in a variety of applications such as tower beacons, cathodic protection, microwave repeaters, metering of gas pipelines, residential power, water pumping, lighting for signs, and hydrological measuring stations[2].

This paper describes the trade-offs between line extensions and stand-alone photovoltaics[3] and discusses how consumers can be provided with information to help them decide between photovoltaics, a line extension, or neither one. The trade-offs involve service quality and costs. The need for continued analysis of PV - line extension trade-offs is illustrated by a recent Arizona matter in which the Corporation Commission had inadequate data to evaluate whether a utility's proposed line extension was less costly than stand-alone photovoltaics, taking into account limitations on PVs for meeting demands for energy and power[4].

Service Quality Trade-Offs

In many remote applications, PV can provide adequate energy and power. Lighting signs, powering repeaters, or pumping water for livestock or wildlife require limited amounts of energy and PV systems with or without batteries can provide the needed energy.

However, for some remote applications, such as residential applications, users of PV systems may have to give up some service quality. Because of cost, residential users of stand-alone PV systems often use less power and energy than grid-connected residential customers. Research conducted by Shugar and Hammond on 321 California households using various types of stand-alone power systems including PV indicates that stand-alone consumers often use multiple sources of energy and that typical residential customers live without microwave ovens, toasters, clothes dryers, hair dryers, and freezers because their systems do not have adequate capacity for such appliances in addition to other appliances or because their inverters do not have adequate capacity[5]. Hammond and Jennings reported an average daily energy usage of 2300 watt hours for a house located near Prescott, Arizona and Perez and Perez reported consuming 1130 watt hours per day in a stand-alone home and office[6]. In contrast, the average residential customers on Arizona Public Service Company's E-10 and E-12 rates use 21 to 25 kWh per day (depending on the season of the year).

We shall call the ratio of energy used by a stand-alone customer to the energy used by a grid-connected customer the "frugality factor." Frugality results from trading off costs and quality of energy service. A stand-alone consumer can reach the optimal amount of electric energy service given his or her budget by using combinations of photovoltaics and fuels such as propane, by substituting energy efficiency for energy consumption, and by doing without some appliances. If cost were not a consideration, grid power might be preferable, but when cost is a consideration, trade-offs have to be made. We do not have systematic data on energy consumption by stand-alone residential customers so we shall examine a range of values for the frugality factor.

Energy use for several residential applications is summarized in Figure 1 using information on stand-alone residences. There is a large variation in end use demands and usage will depend on site specific conditions. The data from the Hammond and Jennings study may be applicable to a vacation home because they pertain to a house that was occupied only one third of the time. The refrigerator energy usage from the Office of Technology Assessment[7] pertains to the average new refrigerator in 1990 which is far more efficient than older models.

Another aspect of service quality is the reliability of maintenance and repair services. PV systems are likely to be located in remote areas, and obtaining timely maintenance and repair services could be difficult. If maintenance and repair services can be obtained when needed, PV systems will be more attractive than if maintenance and repair are only sporadically available, leaving the consumer without power for days at a time.

Economics of Line Extensions and PV Systems

The choice of electricity supply systems of various attributes depends in large measure on the costs of the alternatives. The principal factors affecting the life cycle costs of grid power are the distance of the line extension, terrain, type of service (single phase or three phase), routing (underground or overhead), distribution line operating and maintenance costs, and usage charges for electricity. The principal factors affecting life cycle stand-alone PV costs are the capacity of the system, insolation, the ability of the PV system to track the sun, whether inverters are used, the type of back-up system used (batteries, generators), and operating and maintenance costs. We have not evaluated the incremental costs of obtaining more efficient appliances to use with a PV system, however.

Taking data on line extension costs from Arizona utilities and photovoltaics costs for Arizona sites from PVCAD, a computer model developed by Photovoltaic Resources International, we calculated the life cycle costs of grid power and stand-alone PV systems. The appendix contains the algebra and data sources.

Using the analyses described in the appendix, we developed the graphical relationships in the panels of Figure 2 showing the decision space for selecting photovoltaics or a line extension. *The vertical axis pertains to average daily watt hours of energy usage by a stand-alone user, not by a grid-connected customer* who is likely to use more electricity than a stand-alone customer.

Each panel has several lines corresponding to equal PV and line extension costs at different frugality factors (f = 0.1, f = 0.2 and f = 1.0). If a project is a long distance from the grid and uses relatively little electrical energy, it will fall below the lines indicating that PV is cheaper. Conversely, if a project requires a lot of electrical energy or is not distant from the grid, a line extension would be cheaper and it would fall above the lines. Site specific information should be obtained to judge a realistic value of the frugality factor; residences and ranches may have values around 0.1 or 0.2 and water pumping and repeaters may have values close to 1.0. Of course, the slopes and intercepts of graphs prepared for other regions would be different due to differences in lines extension costs, insolation, and other factors.

Informing Consumers

The economic advantages of photovoltaics can be made more prominent by providing end users with comprehensive, reliable information. Remotely located consumers may be inadequately informed about alternatives to a line extension and the provision of useful information is important in encouraging cost-effective choices in power sources.

The Colorado Public Service Commission[8] was one of the first regulatory agencies to require provision of information about PV systems in remote locations. Figure 3 summarizes the Colorado approach and the experience of Public Service Company of Colorado: when the ratio of kWh demanded by the end users per month to mileage is less than 1000, the utility must conduct a cost analysis of PV versus line extensions, replacements or upgrades[9]. The utility requires an average of four hours to conduct a cost analysis comparing the cost of the PV system to the cost to the customer for a line extension. Customer costs are expressed on a monthly basis assuming a thirty year time period.

In general, for customers to make an informed choice, they need to have such information as:

- Estimated energy use.
- Lifestyle implications of using PV systems, including substitution of energy efficiency and other fuels for electricity.
- Preliminary estimates of PV system costs and line extension costs (as summarized in Figure 2 and the appendix).
- A list of the necessary components of a photovoltaic system.
- Variations in component reliability.
- The typical systems which one could employ for residential and nonresidential purposes and associated cost ranges.
- Applicability of back-up generators, domestic solar hot water, and other sources of energy to augment the photovoltaic system.

- Maintenance and repair needs.
- Safety and applicable electrical standards.

Consumers should be encouraged to consult with several suppliers of photovoltaic systems to arrive at a suitable design for their end uses and to obtain site - specific price quotes. Then the consumer can make a decision between a line extension, photovoltaics, or some other technology.

For comparing the costs of alternatives, it is necessary to consider all costs. Therefore, the consumer should be informed about the life cycle costs of purchasing electricity from the utility. A consumer might only compare first year costs, but paying a utility for electricity over thirty years can be very expensive relative to the life cycle costs of photovoltaics.

Managers of campsites, parks, and wildlife refuges should also be informed about how photovoltaics can possibly reduce their energy costs. They should be advised about designing energy systems compatible with the local environment, including aesthetic benefits of PV systems such as the absence of distribution lines intruding into the landscape.

Who should provide the information listed above? Electric utilities are a natural choice because consumers will contact them about line extensions[10]. As in Colorado, information on photovoltaics could be provided if the preliminary cost analysis using Figure 2 indicates that photovoltaics would be cheaper than the line extension. In Arizona, the utility regulatory commission, state energy office, and the solar energy industries association are developing consumer information to be distributed by utilities and others.

Some utilities may wish to furnish and maintain PV systems as part of a full range of energy services offered by the company. There are a number of tariff options such as: utilities requiring the customer to pay in advance for all facilities, to pay in regular installments for facilities (regardless of energy consumption), to pay per kWh, to pay for maintenance and repair as expenses are incurred, or to pay a regular maintenance and repair fee as an "insurance" policy (Table 1). The desirability of these options will depend on the circumstances in each individual case. The utility could provide a menu of options. Under the proposed Idaho Power Company pilot program[11], the utility will install and maintain the PV system at a monthly cost of 1.6 percent of the net installed cost of the PV system (total installed cost, including estimated operating and maintenance costs, minus a 5 percent initial fee). Outside contractors would be employed and paid by the utility. Idaho Power Company would own the PV system. The cost of a single PV system would be capped at $50,000 (net installed cost).

Summary

Photovoltaic power systems offer cost effective solutions to energy needs at some remote sites relative to line extensions. Stringing a distribution line for miles at a cost of $10,000 per mile or more and paying for electricity from utility power plants at about $0.09 per kWh does not make economic sense for many remote customers. However, a remote consumer choosing a stand-alone photovoltaic system will have to be frugal in his or her use of electricity. In residential applications, photovoltaics usually implies the need for energy efficient appliances and appliances run on propane or other fuels.

We have presented quantitative guidelines to determine the relative life cycle costs of photovoltaics and line extensions. When those guidelines indicate that photovoltaics are likely to be cheaper, utilities can inform remotely located end users about the characteristics of photovoltaics and line extensions and provide these individuals with sufficient information to intelligently shop around for PV systems and compare the life cycle costs and service quality of photovoltaics and line extensions. The utility itself may install and maintain a PV system itself if the consumer prefers photovoltaics to a line extension.

Appendix

The trade-offs between PV and line extensions considering life cycle costs are derived below.

Let

C_P	=	life cycle cost of PV (present value over 30 years)
C_L	=	life cycle cost of line extension (present value over 30 years)
Wh	=	average daily watt hours of electric energy used by a stand-alone consumer
f	=	frugality factor, i.e. the electric energy used by a stand-alone consumer divided by the electric energy used by a similar grid-connected consumer
D	=	distance of line extension, in feet
bill	=	present value of annual cost of grid-supplied electricity supplied at a charge of $r per kWh calculated by multiplying the present value factor PVF (assuming a given time horizon and discount rate) by annual kWh consumption and the electric rate, $r; since this term pertains to grid-connected energy supplies, the Wh consumption of the customer is adjusted by dividing by the frugality factor
kWh	=	daily Wh x .001 x 365 days per year

LO&M = present value of annual operating and maintenance costs of the line extension, \$ per foot

a_0 = PV constant

a_1 = initial (first year) marginal cost of PV system, \$ per average daily watt hour

a_2 = present value of subsequent year marginal cost of PV system, including O&M costs, \$ per average daily watt hour

b_0 = line extension constant

b_1 = marginal capital cost of line extension, \$ per foot

Assuming linear relationships, the costs of PV and line extensions can be expressed as follows:

$C_P = a_0 + (a_1 + a_2)Wh$

$C_L = b_0 + (b_1 + LO\&M)D + bill$

$C_P < C_L$ implies

$a_0 + (a_1 + a_2)Wh < b_0 + (b_1 + LO\&M)D + bill$

$bill = (PVF \times r \times .001 \times 365 \text{ days per year} \times (1/f))Wh$

Rearranging, $Wh < ((b_0-a_0)/Z) + ((b_1 + LO\&M)D/Z)$, where $Z = a_1 + a_2 - (PVF \times r \times .001 \times 365 \text{ days} \times (1/f))$.

The critical parameters are thus the coefficient of distance, $(b_1 + LO\&M)/Z$, and a constant equal to $((b_0-a_0)/Z)$. The coefficient of distance increases as the installed cost of adding one more foot to a line extension increases, increases as the operating and maintenance costs of line extensions increase, increases as the utility charge for electricity increases, decreases as the present value of photovoltaics costs increases, and decreases as the frugality factor increases.

Our objective is to estimate the coefficient of distance, $(b_1 + LO\&M)/Z$, and the constant, $((b_0-a_0)/Z)$, derived above.

To estimate b_0 and b_1, we obtained recent line extension cost data from several Arizona utilities and regressed the cost to the utility against distance, separating underground and overhead line extensions and taking into account single phase versus three phase line extensions (Table 2). Utilities typically charge customers less than the total cost of a line extension since customers are often allowed some line extension at no charge. However, the utilities reported the total cost of the extension they incurred, regardless of how much the customer paid the utility. In addition, for underground lines, customers must bear the costs of trenching and conduits. The utilities did not report trenching and conduit costs so we separately estimated these values from engineering guidelines (Table 2).

For overhead lines, the incremental cost per foot is about \$2.11. There is, however, considerable dispersion in overhead line extension costs, due in part to variations in terrain from case to case, as indicated by the large standard error of estimate and relatively low R squared. We found only seven instances of three phase overhead line extensions so we excluded them from the analysis. For underground lines, the incremental cost per foot is \$5.11 plus trenching and conduit costs of \$5.43 per foot for single phase lines and $7.45 per foot for three phase lines. In addition, single phase lines are $4896 cheaper than three phase lines because of transformer and related costs of three phase lines. (We found that expressing the phase variable in terms of interaction between distance and phase did not yield statistically significant results). R squared is higher for underground line extension costs than for overhead lines. We have no information on the confidence intervals for the engineering guide costs for conduits and trenching so the table does not provide dispersion measures for total underground line extension costs.

The price of electricity charged by the utility for grid service is assumed to be $0.09 per kWh. This value is within the range for residential service from Arizona utilities.

For annual maintenance costs for distribution lines we assumed $200 per mile. In its study for K.C. Electric, NEOS Corporation estimated costs to be $214 per mile per year[12].

To obtain present values of future streams of costs, we assumed a 7 percent real discount rate and a time horizon of 30 years.

The frugality factor may be between 0.1 and 0.2 for residential and ranch uses, indicating that the electric energy used by a stand-alone consumer is one tenth to one fifth of that used by a similar grid-connected consumer. For nonresidential uses, such as repeater stations, the frugality factor could be about 1.0, indicating that the electric energy use is the same for a PV consumer and grid-connected consumer. Because we have no hard coefficient for average daily watt hours derived from the output of PVCAD. The difference represents the present value of subsequent year costs, installation costs, and differences in the data bases used for the two equations.

Parameter estimates are provided in Table 4 for the slopes and intercepts of the graphs in Figure 2.

information on the frugality factor, we have assumed a range of values, from 0.1 to 1.0.

To estimate the present value of the life cycle costs of PV systems, we used PVCAD as stated in the text. Assumptions are summarized in Table 3. We found that, using the time horizon and discount rate assumed above, the trend of the present value of the life cycle costs for 29 stand-alone PV systems in Arizona is:

$C_p = 6091.624 + 8.500\ Wh \qquad R^2 = 0.96$

One more watt hour per day adds $8.50 to the present value of the life cycle costs of a PV system.

As a check on the results from PVCAD we estimated initial year costs of residential PV systems by regressing cost data from catalogs against average daily watt hours:

$$\text{Initial year cost} = -2593.96 + 6.077\ Wh \qquad R^2 = 0.88$$

based on 21 observations. On average, one additional watt hour of energy per day adds about $6.08 to initial year system cost. The data were obtained from 1992 catalogs of Photocomm, Real Goods, SunAmp and Integrated Power Systems. Where sufficient information was available, cost data were developed for Arizona locations. One vendor's data showed consistently lower costs due to his assumption that no inverters were needed. Finally, these data exclude discounts, shipping costs, installation costs, operating costs such as replacement of batteries, and special wiring for the house such as separate systems for ac and dc circuits. As expected, the coefficient of average daily watt hours is smaller than the

Notes

1. Idaho Power Company Application to the Idaho Public Utilities Commission for Approval of a Solar Photovoltaic Tariff under a Pilot Program, August 3, 1992, Case No. IPC-E-92-17, Schedule No. 60; Colorado Public Utilities Commission, Rule 31 (Service Connection and Distribution Line Extension), Section X (Photovoltaic Cost Comparison), adopted January 23, 1991.

2. J. Thornton and L. Brown, *Photovoltaics: The Present Presages the Future*, 5 THE ELECTRICITY JOURNAL 34 (April 1992); T. Moore, *On-Site Utility Applications for Photovoltaics*, EPRI JOURNAL 27 (March 1991); J. Stevens, M. Thomas, H. Post, and A. Van Arsdall, PHOTOVOLTAIC SYSTEMS FOR UTILITIES (Sandia National Laboratories, 1990); and J. Zabukover, *Photovoltaic Systems for the Rural Consumer*, PHOTOVOLTAICS: NEW OPPORTUNITIES FOR UTILITIES, (Solar Energy Research Institute, July 1991).

3. For similar studies see, Electric Power Research Institute, COST-EFFECTIVE PHOTOVOLTAIC APPLICATIONS FOR UTILITIES AND THEIR CUSTOMERS, 1991.

4. Arizona Corporation Commission Decision No. 57407.

5. D. Shugar and B. Hammond, *A Profile of Stand-Alone Residential Power Systems*.

6. B. Hammond and C. Jennings, *Stand-Alone Remote PV Home -- Lessons Learned*; and R. Perez and K. Perez, *The PV/Engine*

System that Produces Home Power Magazine, 7 HOME POWER, October/November 1988, 9.

7. Office of Technology Assessment, U.S. Congress, BUILDING ENERGY EFFICIENCY, OTA-E-518 (Washington, D.C.: U.S. Government Printing Office, 1992).

8. Colorado Public Utilities Commission, *supra*, note 1; Public Service Company of Colorado, REPORT ON PUBLIC UTILITIES COMMISSION RULE 31, April 30, 1992.

9. We note that the guideline used by Colorado is far different than the ones we derived in Figure 2 and in the appendix. The Colorado criterion has an intercept of 0 and a slope of 6.3 average daily watt hours per foot. Thus, the Colorado criterion sits well above any of the lines in the panels of Figure 2 and many projects which our data indicate would be appropriate for line extensions would be analyzed for photovoltaics in Colorado.

10. One may question the need to have utilities involved in photovoltaics at all, since the market should provide consumers with information about photovoltaics. However, many manufacturers provide only components and not entire systems and, thus, they would not be in a position to market complete systems to potential consumers. More importantly, utilities are perceived to be credible sources of information by consumers and utilities have direct access to customers or potential customers.

11. Idaho Power Company, *supra.*, note 1; Idaho Power Company Fact Sheet, Photovoltaic Pilot Program.

12. Neos Corporation, FINAL REPORT: PHASE II TECHNICAL ASSISTANCE FOR K.C. ELECTRIC ASSOCIATION, 1991.

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Table 1

Tariff Provisions for Utility-Supplied Stand-Alone PV Systems

Tariff Provision	Advantages	Disadvantages
Customer pays all facility costs at time of installation	Customer considers full capital costs of PV system	Charge may be prohibitively high requiring customer to borrow money or forego PV
Customer pays facility costs in installments	Charges may be more affordable than one large payment	None if utility recovers interest in monthly charges
Customer pays for PV service at regular tariffed rate for power & energy for grid - connected customers (e.g $0.09 per kWh)	Customer gets cheap electricity	Other customers must subsidize stand-alone customer; utility must read meter at remote location increasing meter reading costs
Customer purchases O&M or repair or replacement of facility components from utility when needed	Utility will remain in business and will be available to provide service when needed	Utility may not wish to be in repair or replacement business unless guaranteed of steady stream of orders
Customer purchases O&M service contract from utility with regular "insurance" payments and utility provides service when required	Charges affordable since they are spread over many months; utility will remain in business and will be available to provide service when needed	Charges for service contracts may be more or less than actual expenses
Tariff does not provide for O&M or repair or replacement	Customer can shop around for better price or better service than utility would have offered	Suppliers may not remain in business or may be located far from customer

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Table 3

Cost Elements Included in PVCAD Photovoltaics Analysis

COST ELEMENTS
PV array and battery costs
PV array installation costs
PV system electronic/protection controls
Inverter related costs
Design cost and taxes
O&M costs - scheduled maintenance
O&M costs - unscheduled maintenance
O&M costs - operating costs
Assumptions: 30-year time horizon, 7% real discount rate, facility installed in 1992, net present value measured in 1992 dollars, 20-year module lifetime, 5-year battery lifetime, 2% annual decline in module cost, $20/hour labor rate.

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Table 2

Summary of Analyses of Line Extension Costs

(Dependent Variable = Utility Cost*)
(numbers in parentheses are t statistics)

	Case	
	Overhead	**Underground**
Constant	$2701.32 (9.18)	$7244.01 (9.21)
Distance (feet)	$2.11/foot (10.56)	$5.11/foot (11.33)
Phase (=1 if single phase, 0 if 3 phase)		-$4896.41 (-6.62)
Number of observations	142	78
Adjusted R square	0.44	0.71
Standard error of estimate	2442.57	2836.77
Trenching and conduit cost ($/foot) -- single phase**		$5.43/foot
Trenching and conduit cost ($/foot) -- three phase**		$7.45/foot

Data sources: Utility data from Arizona Public Service Company, Tucson Electric Power Company, Citizens Utilities, Navopache Electric Cooperative, and Sulphur Springs Valley Electric Cooperative

* Utility costs only: includes wire, transformers, and associated labor, regardless of whether customer pays utility for costs incurred. Trenching and conduit costs for underground line extensions not reported by utilities since customers must pay trenching and conduit costs for underground facilities.

** Costs based on a trench two feet wide and three feet deep. Costs include excavation, backfill, removal of spoil, compaction and PVC conduit, type EB, four inch diameter for three phase and two inch diameter for single phase. Phoenix City Cost Index used. Source: R.S. Means Co., Means Site Work Cost Data 1991. (Kingston, MA): pp 199, 249-251, 350-351.

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Table 4

Estimates of Decision Parameters

Frugality Factor	Line Extension	Constant	Slope
f = 0.1 (typical of residences and ranches)	Overhead, single phase	-766.374	0.583
	Underground, single phase	-846.332	2.489
	Underground, three phase	260.495	2.945
f = 0.2 (typical of residences and ranches)	Overhead, single phase	-524.652	0.399
	Underground, single phase	-579.390	1.704
	Underground, three phase	178.332	2.016
f = 1.0	Overhead, single phase	-418.941	0.319
	Underground, single phase	-462.650	1.361
	Underground, three phase	142.401	1.610

Note: insufficient data for estimating parameters for overhead three phase power.

Figure 1

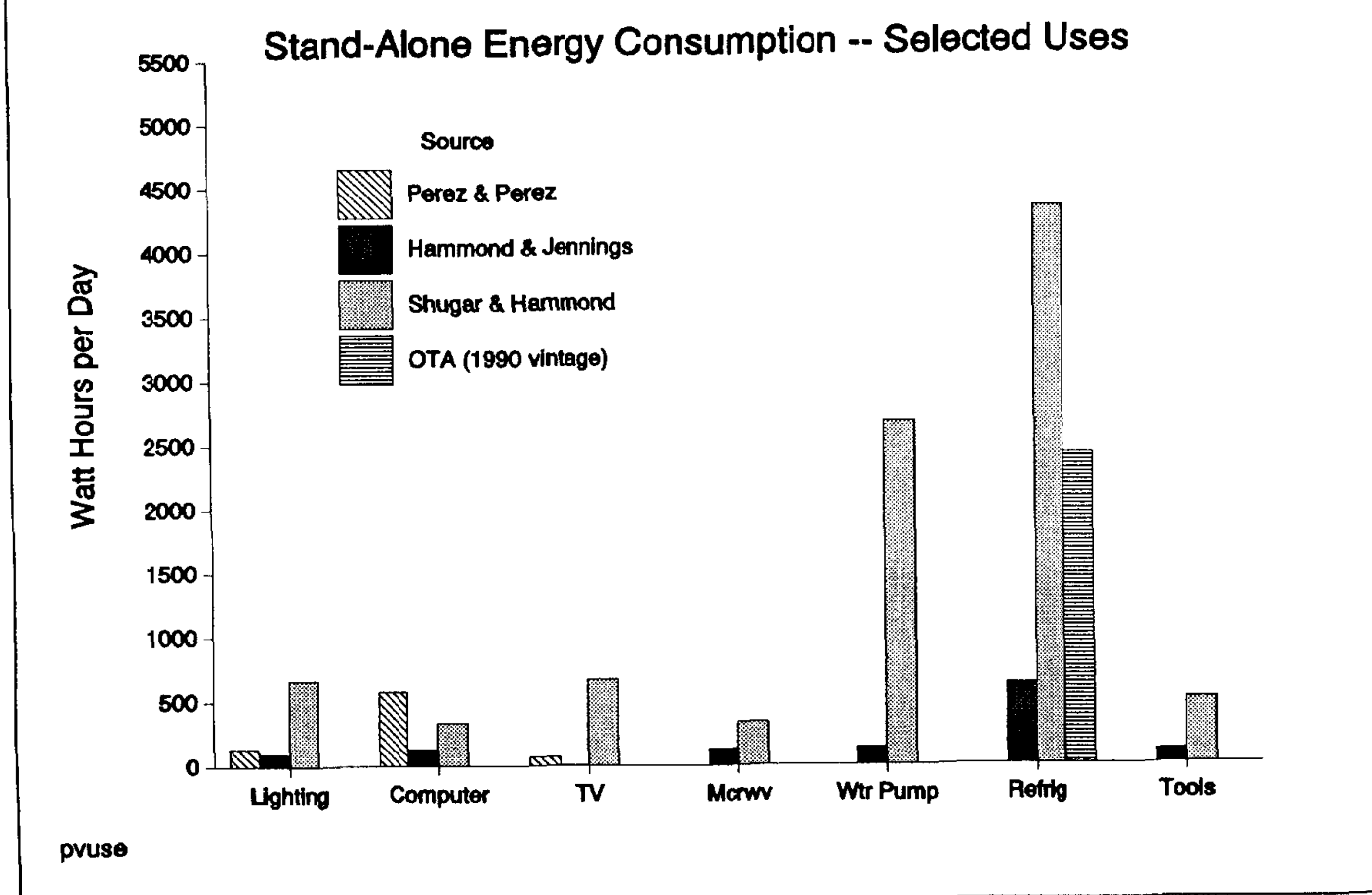

Stand-Alone Energy Consumption -- Selected Uses
Watt Hours per Day
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Source
Perez & Perez
Hammond & Jennings
Shugar & Hammond
OTA (1990 vintage)
Lighting
Computer
TV
Mcrwv
Wtr Pump
Refrig
Tools
pvuse

Figure 2a

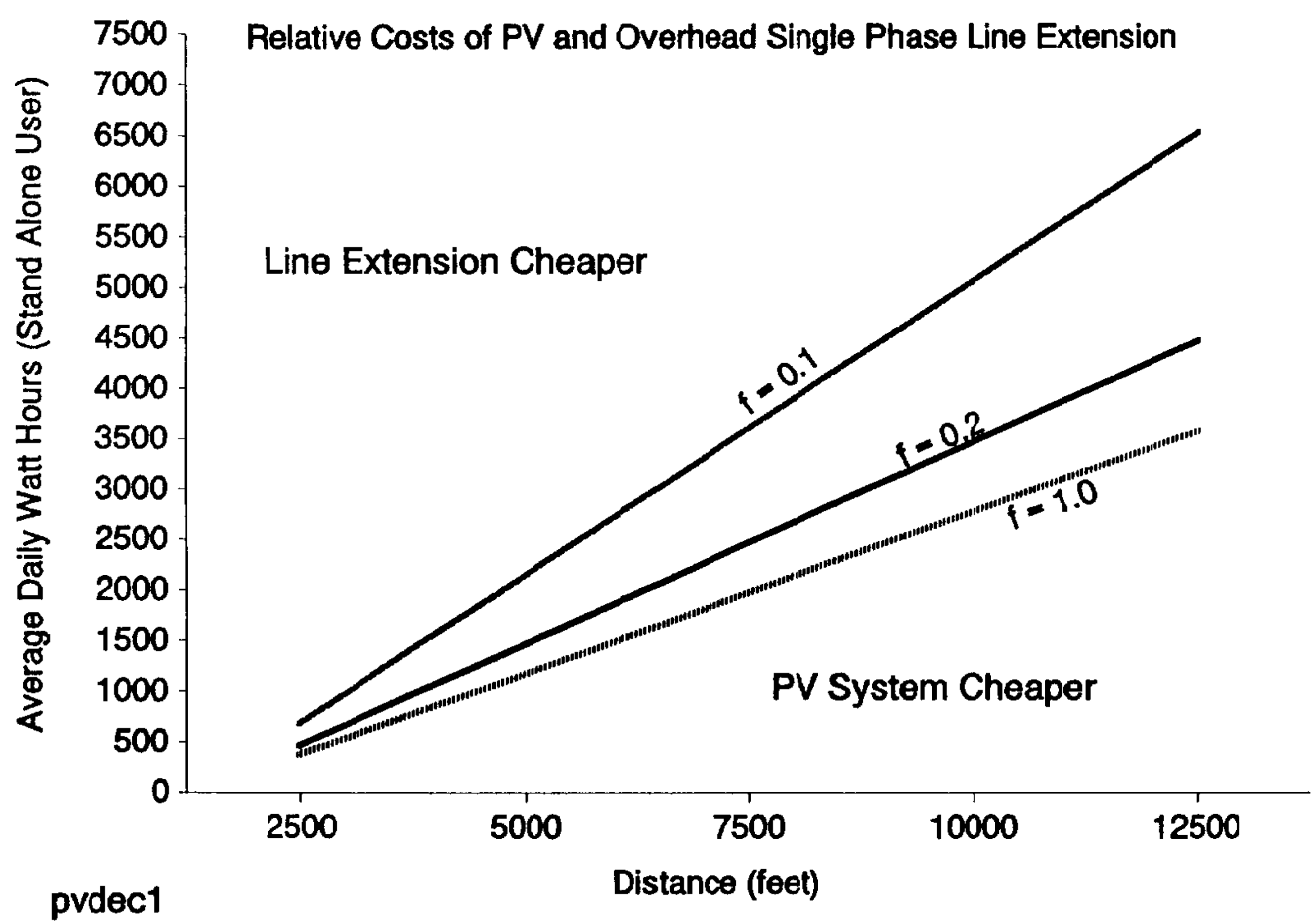

Relative Costs of PV and Overhead Single Phase Line Extension
Line Extension Cheaper
PV System Cheaper
f = 0.1
f = 0.2
f = 1.0
Average Daily Watt Hours (Stand Alone User)
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2500
5000
7500
10000
12500
Distance (feet)
pvdec1

Figure 2b

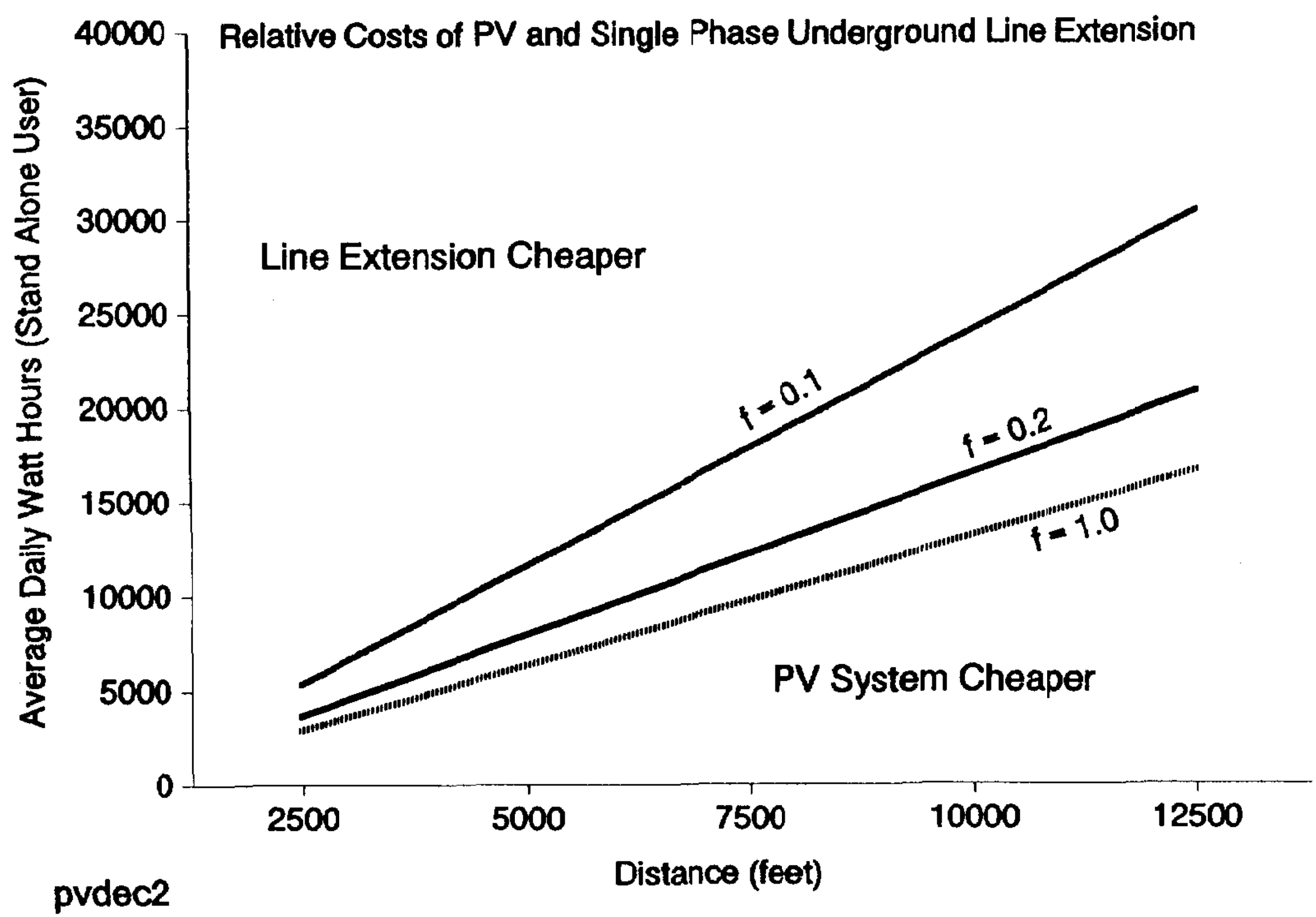
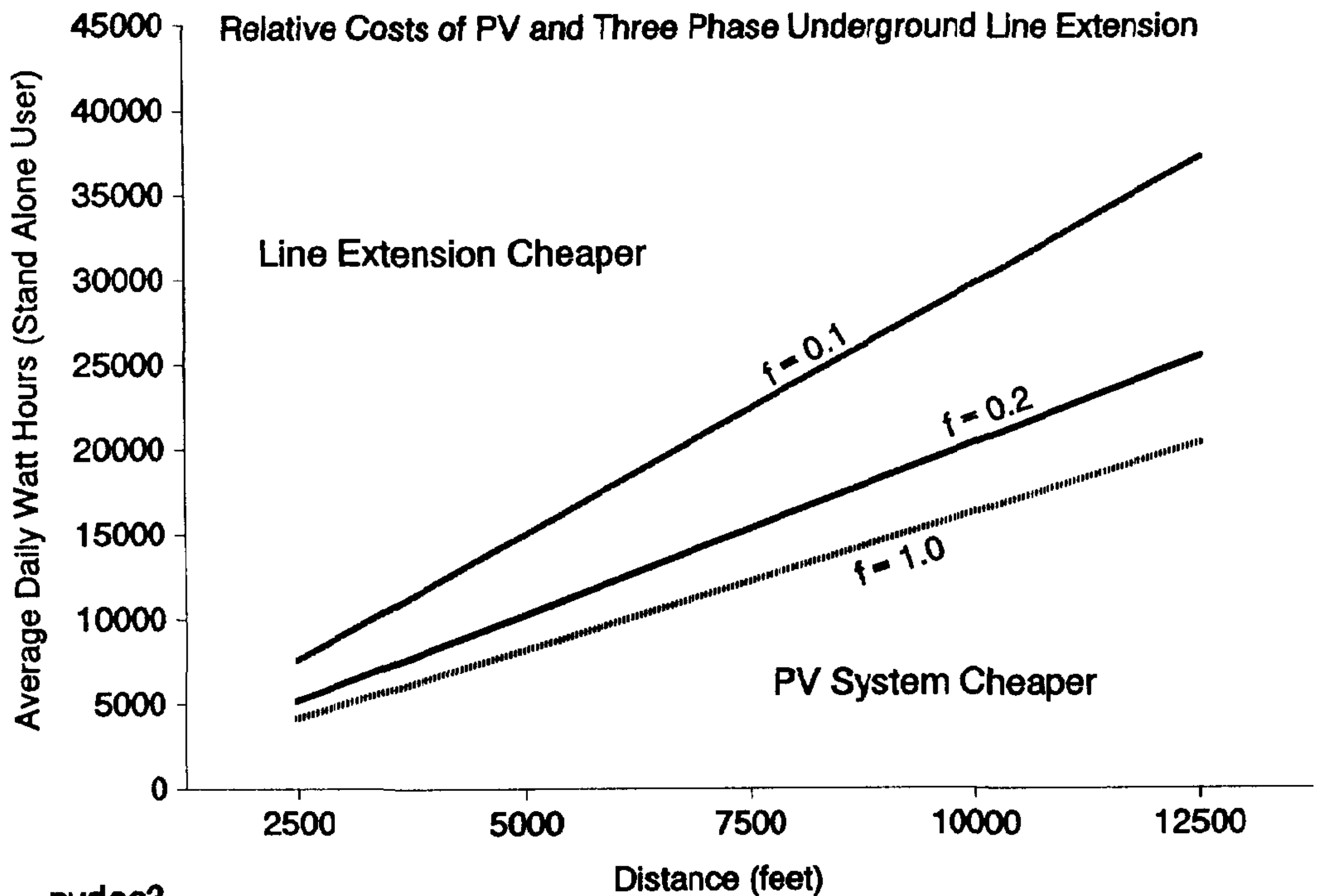

Relative Costs of PV and Single Phase Underground Line Extension
Line Extension Cheaper
PV System Cheaper
f = 0.1
f = 0.2
f = 1.0
Average Daily Watt Hours (Stand Alone User)
40000
35000
30000
25000
20000
15000
10000
5000
0
2500
5000
7500
10000
12500
Distance (feet)
pvdec2

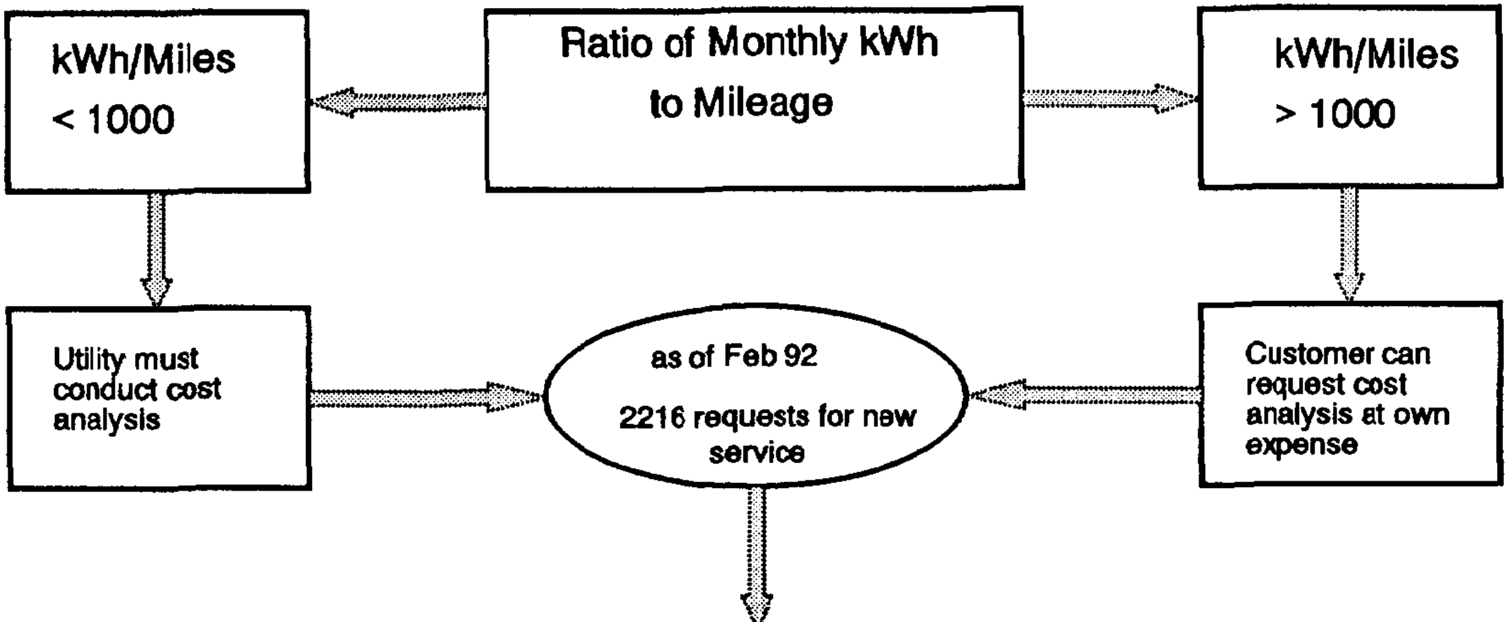
Figure 2c



pvdec3

Figure 3

Overview of Public Service of Colorado Experience: Line Extensions vs PV



Applications	Analyses	Cost-Effective Cases	PV Installed
Residential	7	3	none yet
Irrigation	6	1-5	none yet
Lighting	21	0	none
Siren	1	0	none
Total	35	4-8	none yet

pvcolo