CORNELL
AGRICULTURAL ECONOMICS
STAFF PAPER

SOLAR POWER AND CLIMATE CHANGE POLICY IN DEVELOPING COUNTRIES

by

Thomas E. Drennen, Jon D. Erickson, and Duane Chapman

November 1993

SP 93-20

Department of Agricultural, Resource, and Managerial Economics
College of Agricultural and Life Sciences
Cornell University, Ithaca, New York 14853-7801 USA

SOLAR POWER AND CLIMATE CHANGE POLICY IN DEVELOPING COUNTRIES

Thomas E. Drennen, Jon D. Erickson, and Duane Chapman*

---

* Research Associate, Ph.D. Student, and Professor of Resource Economics, Cornell University, Warren Hall, Ithaca, N.Y. 14853. An earlier version of this paper was presented at the Western Economics Association International 68th Annual Conference, Lake Tahoe, NV, June 21, 1993.

TABLE OF CONTENTS

I. INTRODUCTION

The continued buildup of greenhouse gases in the atmosphere, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), is expected to result in a long term warming trend (IPCC, 1992). In light of the potential climatic changes and associated effects from this trend, the international community has begun a process to limit future greenhouse gas emissions. This task seems particularly difficult in recognition of the legitimate goal of developing countries to increase their use of services now provided by conventional energy. In fact, it appears that world policies which would significantly defer global warming would, with present technology, require developing countries to reduce their per capita use of energy below present levels (Chapman and Drennen, 1990). Consequently, technological innovation is viewed as one possible route to meet the challenge of continued growth in world energy demand without adding significantly to the atmospheric concentration of greenhouse gases. Solar energy would be particularly desirable because of its potential to provide significant and growing levels of electricity generation in developing countries without emitting CO_2 and other air pollutants.

The term 'solar energy' describes several technologies. Photovoltaic (PV) cells, which directly convert sunlight into electricity, are the technology most often associated with the phrase. Other solar technologies include: solar thermal systems, i.e. rooftop systems for heating hot water and systems which focus the sun's rays on a fluid and indirectly turn a turbine to produce electricity; passive solar systems, i.e. using construction methods to maximize the benefits of the natural solar radiation through the use of windows and other building materials; and biomass projects.

This paper focuses on PV systems as a means of directly offsetting future CO_2 emissions by replacing and displacing current and future fossil fueled electricity sources. Of all the solar technologies, PVs seem to have the greatest potential for reducing reliance on fossil fueled electricity. PV panels can be mounted on existing structures (such as rooftops) to provide decentralized power. With battery storage, reliable power can be available at night and on dark days. Estimated lifetimes of panels are in the range of 15 to 30 years, and maintenance of panels in systems, after proper installation, typically involves only minimal cleaning. Capital expenses for small PV systems are also suited for household investment, de-linking any reliance on government or industry power sources. These factors are particularly appealing to remote rural locations where grid electricity has been slow to expand and PVs compete mainly with other sources of decentralized, remote power.

The paper begins with an analysis of current and projected thermal electricity generation and resulting CO_2 emissions for four world regions. Next, a best case scenario, based on the assumption that PVs are currently cost competitive with fossil fuel options, is presented and the potential magnitude of CO_2 emissions offset ascertained. The discussion then turns to the current economics of PV applications, focussing on a current project in Zimbabwe. Finally, we discuss our conclusions about the overall direction for PV technology.

II. TRENDS IN ELECTRICITY CONSUMPTION AND RESULTING CO_2 EMISSIONS

A. *Past Trends*

Table 1 summarizes 1990 population, total electricity generation, and CO_2 emissions from thermal electricity generation for four regions of the world. ("Thermal electricity" here means steam generation from fossil fuels.) The four regions include: the industrialized countries, developing countries, the Commonwealth of Independent States (CIS) and Eastern Europe (EE), and China.[1] Total world electricity generation in 1990 was 10,227 billion kilowatt-hours (bkWh); of that, 6,861 bkWh was classified as thermal

Table 1
Electricity Generation, Annual Growth, and
Resulting CO_2 Emissions (1990)

	Indust.	Devel.	CIS/EE	China	World
Population (millions)	789	2849	448	1236	5322
Electric. Gen. (billion kWh)	6154	1679	1844	549	10227
Thermal Electric. Gen.					
Total (billion kWh)	3802	1072	1511	476	6861
Per Capita (1000 kWh)	4.8	0.4	3.4	0.4	1.3
Annual Growth (1981-90)	1.2%	7.3%	1.9%	7.7%	2.5%
CO_2 from Electricity					
Total (10^6 mt-C)	772	218	307	112	1408
Per Capita (mt-C)	0.98	0.08	0.68	0.09	0.26

Sources: Energy Information Administration (1992), United Nations (1991), and International Energy Agency (1992).

Note: Thermal electricity generation here means production by steam or gas turbine from oil, natural gas, and coal. Other major sources of generation are hydro and nuclear power.

---

[1] The industrialized countries consist of North America, Western Europe, Japan, Australia, and New Zealand. Developing countries include those in Latin America, Africa, and Asia outside of China and the CIS group. The CIS/EE group includes the countries of the former Soviet Union, as well as the countries of Eastern Europe (excluding the former East Germany), Cuba, and Mongolia.

generation. CO_2 emissions associated with the thermally generated portion of electricity totaled over 1,400 million metric tons of carbon (mmt-C).[2]

Fifty-five percent of global thermal electricity was generated in the industrialized countries. During the 1980s, annual growth in thermal electricity generation averaged 1.2% and 1.9% for the industrialized and CIS/EE regions. Growth rates exceeded 7% for the developing country region and China. Despite higher growth rates, per capita thermal electricity consumption in developing countries remains a small fraction of the industrialized region average. China, with nearly 25% of the world's population, accounts for only 7% of the world's thermal electricity. Average per capita Chinese consumption was just 8% of the industrialized region average for thermal electricity.

B. *Future Projections*

Table 2 summarizes thermal electricity generation projections to 2010 and 2040 for the four regions. These estimates provide a framework for determining the potential role of PVs in offsetting continued growth in fossil-fueled electricity. The population projections assume population growth is in decline for all regions over time in accordance with forecasts of the United Nations (1991).[3] The generating mix is assumed consistent with

---

[2] Emissions in this paper are expressed on a carbon content basis; to convert to CO_2, multiply by 3.667. Carbon emissions calculations assume carbon content values (metric ton C per MBtu) for coal, oil, and natural gas of 0.0231, 0.0191, and 0.0132 (Marland and Rotty, 1983). Further, an average carbon emission of 0.203 kg C/kWh from thermal electricity for the industrialized region, developing region, and CIS/EE region is assumed. This corresponds to a thermal generating mix for coal, oil, and natural gas of 67.7%, 14.7%, and 17.6% (the current OECD thermal generating mix average (EIA, 1992)). For China, an emission rate of 0.236 kg C/kWh was used, reflecting China's heavier reliance on coal, assumed equal to 95% of all thermal electricity generated.

[3] By region, the assumed growth rates decline from 1990 to 2025 with the following starting and ending rates (United Nations, 1991): industrialized (0.4 to 0.07), developing (2.33 to 1.35), CIS/EE (0.91 to 0.49), and China (1.47 to 0.54).

Table 2
Current and Projected Population, Thermal Electricity Generation, and Resulting Annual CO_2 Emissions

	Indust.	Devel.	CIS/ EE	China	World
Population (millions)					
1990	789	2849	448	1236	5322
2010	842	4288	517	1507	7154
2040	864	6521	601	1784	9770
Thermal Electric. Generation (billion kWh)					
1990	3802	1072	1511	476	6861
2010	4779	4033	2159	1791	12761
2040	6253	15458	3180	6864	31754
Per Capita Thermal Electr. (1000 kWh)					
1990	4.8	0.4	3.4	0.4	1.3
2010	5.7	0.9	4.2	1.2	1.8
2040	7.2	2.4	5.3	3.9	3.3
Total CO_2 from Electricity (10^6 mt-C)					
1990	772	218	307	112	1408
2010	970	819	438	364	2591
2040	1269	3138	646	1393	6446
Per Capita CO_2 from Electricity (mt-C)					
1990	0.98	0.08	0.68	0.09	0.26
2010	1.15	0.19	0.85	0.24	0.36
2040	1.47	0.48	1.07	0.78	0.66

Source: See text.

assumptions for the Table 1 CO_2 calculations (see footnote 2). Growth rates in thermal generation are assumed to decline in all four regions over the 50 year period.[4]

Given these assumptions, thermal generation grows from 6,861 bkWh in 1990 to 12,761 bkWh in 2010, and 31,754 bkWh in 2040. Aggregate CO_2 emissions from electricity generation increase from 1.4 billion to 6.4 billion tons C in 2040.

Despite more than quadrupling total thermal generation, per capita generation levels in developing countries, including China, remain significantly below industrialized country levels for both the 20 and 50 year projections. The same is true of per capita CO_2 emissions; in China, per capita CO_2 emissions increase from 0.09 to 0.24 mt-C in 20 years and to 0.78 in 50 years. Even in 50 years time, China's per capita CO_2 emissions would be lower than the current industrialized region per capita emissions of 0.98 mt-C, and significantly lower than the projected level of 1.47 mt-C in 2040. Note, however, that Chinese per capita emissions would exceed the world average in 50 years.

Despite low per capita emissions relative to the industrialized region, the potential magnitude of aggregate emissions from the developing region have forced the international community to recognize the importance of climate change policy in developing countries. Figure 1 illustrates the problem: over the 20 year horizon, the relative share of CO_2 emissions from the

---

[4] Over the 50 year time period, growth rates in electricity generation are assumed to decline from 1.2% to 0.8% in the industrialized region, from 7.3% to 3.65% in the developing region, including China, and from 1.9% to 1.1% for the Commonwealth of Independent States and Eastern Europe.

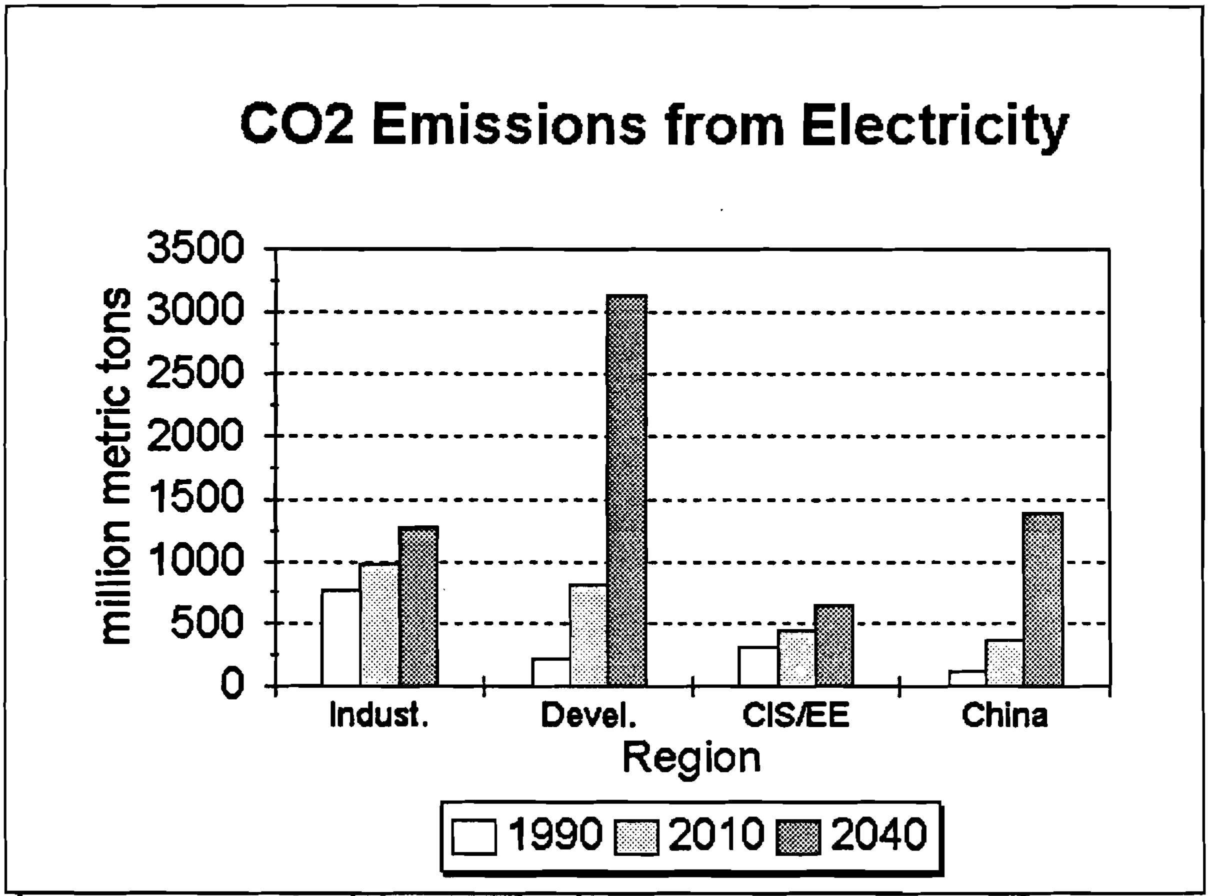

Figure 1. Trends in CO_2 emissions for four world regions. See text and footnotes 3 - 4.

developing world, including China, increase from 19% to 48%. If developing countries achieve the level of electrification projected in Table 2 by 2040, their relative share increases to over 70%.

III. THE POTENTIAL ROLE FOR PVs IN CLIMATE CHANGE POLICY

The previous section demonstrated that greenhouse gas emissions associated with electricity generation could grow by a factor of 1.9 in 20 years and 4.6 in 50 years. This has serious implications for policy aimed at limiting these emissions. This section looks at the potential role for PVs in offsetting this large projected growth in emissions.

Whether or not PV technology can, or will, play a role in climate change policy depends in part on its economic feasibility. But to understand the potential magnitude of this role, suppose PVs are currently economically competitive with fossil-fueled electricity sources. Further, assume that the practical implication of their cost competitiveness leads to PVs offsetting 50% of all future growth in thermal electricity generation.

The result, Table 3, is that PVs offset 3,654 bkWh of thermal electric generation annually after 20 years and 18,691 bkWh annually after 50 years. In terms of total thermal generation, this PV scenario holds the growth in thermal electricity generation to 1.9 times in 50 years compared to 4.6 times projected for the no-PV scenario. How would this affect total annual global emissions? Drennen (1993) estimates 1990 world carbon emissions from fossil fuel use of 5.6 billion metric tons (Gt-C), increasing to 7.7 Gt-C in 20 years and 11.7 Gt-C in 50 years.[5] Based on these projections, offsetting 50% of all future growth in thermal electricity generation by PVs would reduce annual global CO_2 emissions from projected increased levels by 10% in 20 years and 32% in 50 years.

Table 3

Potential Solar Electricity and CO_2 Emissions

	No PV Case	PV Case	Difference
Thermal Gen (bkWh)			
1990	6861	6861	0
2010	12761	9107	3654
2040	31754	13063	18691
Total CO_2 (mmt-C)			
1990	1409	1409	0
2010	2591	1849	742
2040	6446	2652	3794
Per Capita CO_2 (mt-C)			
1990	0.26	0.26	0
2010	0.36	0.26	0.10
2040	0.66	0.27	0.39

Note: See text for description of scenarios.

Thus, PV systems could play a major role in limiting future CO_2 emissions. Unfortunately, the current economics are such that the PV market today is very small. Without significant technological breakthroughs, such as

---

[5] Drennen's (1993) reference case assumes that consumption of CFCs will be phased out in accordance with the terms of the London Amendments to the Montreal Protocol. The assumptions include moderate per capita income growth rates of 1.0%, 0.5%, 1.35%, and 2.0%, respectively, for industrialized countries, developing countries, the CIS/EE, and China. Population growth rates are assumed to decline in all regions over time, consistent with projections of the United Nations (1991) and the assumptions of the no-PV scenario presented in this paper.

increases in PV panel efficiency,[6] or improvements in existing power storage and conversion technologies, the economics of PV applications are unlikely to allow for an un-subsidized, widespread adoption of this technology in the near future. There are additional reasons why PVs could face a limited market and why it is unlikely that PVs could offset more than 50% of future growth in electric demand. First, PVs require adequate solar incidence and can only be used without power storage during available daylight hours. Second, PV applications are not appropriate in all regions or for all users. For instance, household PV applications require a fair amount of knowledge and effort on the part of the user to provide reliable power (Erickson and Chapman, 1993).

The following sections discuss the current economics of PV systems and the attempts to develop new markets for PV technologies in developing countries.

A. *Current Economics*

The basic reason for the high cost of PV power is the high capital cost for the relatively small amount of power produced. Caldwell (1993) reports direct costs of 3.25 $/W (factory price) for a 55 watt, 14% efficient module. Excluding other system costs, this module cost is equivalent to 0.33 $/kWh for a southwestern U.S. location (Caldwell, 1993). To be economically competitive, the module cost needs to be reduced to at least 0.5 $/W (0.05 $/kWh). This level was the original goal of the government sponsored PV

---

[6] The efficiency of PVs in converting the sun's energy into electricity. The best available modules have an efficiency of 16%. Efficiencies in the lab have reached as high as 37% (Caldwell, 1993). However, there is a direct trade-off between increased efficiency and cost. Caldwell (1993) predicts that practical considerations, such as cost, will limit efficiencies to 25% for crystalline silicon cells and 20% for thin films.

research and development programs of the 1970s and early 1980s (Solar Energy Research Institute, 1988). However, federal R&D funds were drastically reduced when PV costs were only at the 5 $/W level, a price that remains the average factory price today (Erickson and Chapman, 1993).

Current economic estimates for PV power vary considerably. Utility experience in the U.S. indicates PV central station costs in the 0.30 - 0.40 $/kWh range, about 10 times higher than natural gas alternatives (GAO, 1993). While solar thermal electricity generation is not the focus of this paper, Hall (1992) notes utility costs of 0.10-0.15 $/kWh.[7] For stand-alone PV systems in the Dominican Republic, Kenya, and Zimbabwe, Erickson and Chapman (1993) estimate average kWh costs to customers of $1.82, 2.27, and 2.11 respectively.[8]

These private cost comparisons could be considered misleading since they ignore the negative externalities associated with burning fossil fuels.[9] The American Solar Energy Society estimates the externality cost of conventional energy technologies to be 0.02 $/kWh (Larson et al., 1992). These costs are based on U.S. energy consumption and include costs due to corrosion, crop loss, health impacts, radioactive waste, military subsidies, and jobs lost. Even if actual externality costs associated with climate change double or

---

[7] These are the estimated costs for a 80 MW parabolic trough system in Southern California. Larson et al. (1992) estimate these costs to be slightly higher, 0.15-0.20 cents/kWh, noting that the company (Luz) benefited from considerable subsidies.

[8] These results assume a 10 year investment period, 10% discount rate, cost estimates for components from Hankins (1993), a 20% inefficiency factor, 5% repair cost, and battery replacement every 1.5 years. Even under assumptions of 0% discount rate and a 30 year lifetime, the average PV cost for the Dominican Republic drops only to $0.77/kWh, significantly higher than conventional alternatives.

[9] Throughout the paper, externalities (either negative or positive) are viewed as costs or benefits at the societal level (i.e. the cost of climate change on society). Private costs (or benefits) are viewed at the individual level (i.e. the cost of energy to consumers). Total social costs (or benefits) are the sum of externalities and private costs (or benefits).

triple this estimate, it would make only a small movement toward bringing current PV costs in line with current conventional energy costs.

In regard to a potential solar-based climate change policy, valuing externalities has a dual nature. There are clearly positive externalities (benefits) associated with reducing CO_2 emissions, including offsetting damage from future climate change and reducing other pollution associated with anthropogenic CO_2 emissions. These benefits associated with offsetting future climate change are typically viewed as global. However, the benefits that come with rapid development of traditional energy supplies in the most inexpensive manner can overwhelm the environmental benefits of offsetting emissions from traditional energy supplies. For instance, it can be argued that energy development literally fuels a society's industrialization, bringing with it improvements in income and standard of living. If the private cost differential between polluting and non-polluting sources of energy is great, then for a low-income, developing nation, the cheaper path of traditional energy development seems optimal to that nation.

Despite the apparent high private costs of solar electricity, PVs are making inroads in developing countries. The developing world seems like a logical location for PV use because large areas lack access to electric grids. An additional reason has been the willingness of aid agencies to fund solar projects. The effort to promote PV systems in Zimbabwe is a case in point.[10]

---

[10] Many other developing countries are also being targeted for PV projects. For example, the DOE is sharing the cost of a $1.4 million PV lighting project in Brazil to install 800 U.S. made systems (Public Power Weekly, 1993). The World Bank is providing a $55 million loan for PV development in India (Asia Alternative Unit, 1993). Other markets include China and Latin America.

B. *Zimbabwe, the Global Environment Facility (GEF), and Efficiency*

Roughly 20% of households in Zimbabwe are connected to the grid; about 0.2% of rural areas have access (Hankins, 1993). These percentages are expected to increase only marginally over time due to the high per capita costs associated with grid extension. Hence, to many, the prospect of PVs offers the possibility of a real improvement in the quality of life. An estimated 3000 households in Zimbabwe now have PV systems, installed since the mid-1980s. Solarcomm, a Zimbabwe firm, is the largest PV supplier with about 50% of the current market. Solarcomm imports PV cells and assembles modules. Assistance in establishing and running Solarcomm has come from a Swedish aid organization (SIDA), a Danish aid organization (DANIDA), and the Japanese government (supplier of silicon cells). More recently, the Global Environmental Facility (GEF) announced its intention of financing the purchase and installation of a minimum of 9,000 stand-alone PV systems in Zimbabwe. The GEF, which is jointly managed by the World Bank, the United Nations Development Program, and the United Nations Environment Program, was established in 1989 to provide assistance to developing countries in dealing with issues relating to global warming, ozone depletion, international waters, and biodiversity. One of the stated objectives of this solar project is to limit future emissions of greenhouse gases in Zimbabwe (GEF, 1992). The GEF notes that Zimbabwe has vast reserves of coal and that electrification of the country using this coal would "do irreversible damage to its own environment and would add to the global warming problem." The GEF also envisions this project as a model for the rest of Africa: providing clean, safe electricity to rural and urban areas.

The GEF project clearly falls under the concept of technology transfer as discussed in the Framework Convention on Climate Change (1992). This international agreement, which emerged from the 1992 United Nations Conference on Environment and Development, has been signed by 164 countries and will enter into force three months after ratification by 50 countries. This is expected to occur during the first six months of 1994. Such widespread support would not have been possible without assurances that any obligations under the Convention would not limit a developing country's "right" to economic development, even if this development requires large increases in greenhouse gas emissions.[11] To avoid widespread emissions increases, the Convention notes the importance of technology transfer as a means for developed countries to assist developing countries in meeting their obligations under the Convention (Art. 4.1.c; Art. 4.3).[12]

In the case of Zimbabwe, industrialized countries, through PV dissemination, are helping a developing country expand its electricity supply without increasing emissions of greenhouse gases. However, we have concluded that this is not a good model for technology transfer. There are two main reasons for this conclusion. First, current economics suggest that PVs are one of the most expensive energy supply technologies available. Second, if the chief goal is to limit future greenhouse gases, then there are far better and cheaper options available.

---

[11] The overall tone for differentiating between the developed and developing countries is established in the Preamble, which notes that (in part): "...the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development need..."

[12] Article 4.1.c. (Commitments) requires that all Parties "Promote and cooperate in the development, application and diffusion, including the transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases..."

Table 4
PV vs. Portable Generator Costs in Zimbabwe ($/kWh)

	Base Case[c]	Sensitivity Analysis, Varying: Discount Rate:			System Lifetime:[d]		Gas Tax:		All[e]
		5%	15%	30%	15 yr	30 yr	50%	150%	
PV System[a]	2.056	1.72	2.43	3.67	1.76	1.51	2.06	2.06	1.97
Port. Gen.[b]	0.338	0.32	0.36	0.43	0.32	0.32	0.45	0.66	0.66

[a] System costs estimated by Hankins (1993); assumes 48W panel ($14.34/Wp), 90 amp battery ($53) replaced every 1.5 years, charge control unit ($11.4), installation ($60), 5% yearly repairs, and 20% inefficiency power derate (i.e. temperature induced voltage drop, module inefficiencies, power storage losses). Total output is calculated as 6.0 average solar hours/day (6.0 kWh/m²/day + 1000 W/m² of sun's energy) times 48W, derated by 20%. The inefficiency is taken as a minimum and can be considerably higher, particularly with high temperatures.

[b] Assumes 650W Honda portable generator ($519), $40 accessory cost, $40/year oil cost, 5% inefficiency derate, 10% yearly repairs, and daily generator run time of 5 hours.

[c] Assumes 10% discount rate, 10 year investment period, and gasoline base cost of $1/gal.

[d] 30 year system lifetime assumes replacing the generator in the 15th year.

[e] Discount Rate = 15%; System Lifetime = 30 years; Gas Tax = 150%.

Table 4 compares the costs of two remote power options for Zimbabwe: PV systems and portable generators. The basic conclusion is that PV generated power costs 2.06 $/kWh compared to 0.34 $/kWh for the generator. The reason for this cost differential is that the generator produces 13.5 times more power for very similar capital costs. The most influential factor in the PV assumptions is the discount rate; varying this rate between 5% and 30% changes the calculated costs from 1.72 $/kWh to 3.67 $/kWh. The most important cost for generators is the fuel; adding gas taxes of 150% increases the estimated costs to 0.66 $/kWh, still far below the lowest estimate for PV of 1.51 $/kWh. (This lowest estimate assumes a 30 year lifetime and a 10% discount rate.)

A recent study of the options and costs for reducing greenhouse gas emissions in Zimbabwe concluded that a wide range of opportunities exist that would keep emissions growth to a minimum. The Southern Centre for Energy and Environment (1993) identified options, including reduced tillage of agricultural lands, boiler improvements, conservation methods, and biogas generation, that are available now to reduce greenhouse gas emissions. Eight of the 17 options considered had a negative net private cost (i.e. positive net private benefit). In contrast, the three most expensive options, centralized PV electricity, efficiency improvements in the fertilizer industry, and PV water pumping, have estimated costs ranging from 32 to 906 $/mt-C. The estimated cost of the GEF program is 2600 $/mt-C.[13] Even if all the GEF capital cost is recovered through interest bearing loans, the estimated administrative costs of the program alone amount to 532 $/mt-C.[14]

Despite this study, conducted under the auspices of the United Nations, the Global Environment Facility has decided to focus on PV technologies - the most expensive option. This is a good example of a supply "push" by the developed world. The apparent purpose is to create and maintain a market for the solar industry. James Caldwell, former president of ARCO Solar, sees this as a legitimate reason in itself (Caldwell, 1993). He argues that in order to drive PV prices down in the long run, the solar industry needs a market to

---

[13] This assumes a policy whereby donor agencies subsidize the costs of 50W PV systems for household use. Estimate assumes a cost of $813 per system (up front costs from Table 4), providing 77 kWh electricity per year for 20 years. This offsets 313 kg C/unit at a cost of 2597 $/mt C.

[14] Assumes administrative costs of $1.5 million (Agras, 1993) and the eventual installation of 9000 50W systems.

promote economies of scale and R&D breakthroughs. It is in the field, says Caldwell, that advances and cost reductions will occur. However, in every respect, this policy pushes one of the most expensive energy technologies upon the poorest people in the world.

The need for a strong solar industry does not justify this push towards developing countries. A more rational policy would be to take action through legislation to first create industrial world markets. For example, utilities could be required to install a minimal amount of solar capacity within a certain time frame.[15]

C. *Targeting Developed Country Emissions*

The final pertinent question addresses the reduction priorities for greenhouse gas emissions for developing and industrialized countries in the near term. As demonstrated previously, per capita emissions in the developing world are far below industrialized levels. It would be more equitable and efficient to worry about industrialized country emissions now, and develop technologies that will diffuse to the rest of the world. For example, Hall (1992) presents a plausible scenario for achieving emissions reductions in the U.S. over the next 50 years (see Table 5). This analysis demonstrates that options already exist to reduce annual U.S. emissions by 500 mmt-C by the year 2050 at a negative social cost. (This includes both private and externality costs). Hall also notes that, with a push towards solar thermal applications at utilities, reductions could total 650 mmt-C annually by 2050. This latter option has a social marginal cost for reducing CO_2 emissions of 12 $/mt-C.

---

[15] New York, for example, has mandated the installation of 300 MW of renewable electric generating capacity by 1998 (GAO, 1993).

Table 5
Hall's (1992) Scenarios for CO_2 Reductions in the U. S.

		Annual Reductions Possible (mmt-C) by Year:				
	Social Marginal Cost ($/mt-C)	1990	2000	2010	2020	2050
Scenario A	-$0.30	0	339	367	392	499
Scenario B	+$12.00	0	353	515	541	650

Notes:

Social marginal cost is defined as the sum of marginal private costs and externality costs. The externality costs consider those expenses relating to: air pollution, acid rain, and national security (such as defense and the strategic petroleum reserves). A negative cost implies a net savings when costs and benefits are taken together.

Scenario A includes 18 energy efficiency measures given in Table 2 of Hall (1992), plus a 34 mpg CAFE standard, increased cogeneration, and fuel switching.

Scenario B includes all options in Scenario A, plus incorporation of thermal solar power.

Other studies, including Rubin et al. (1992), NAS (1991), and Cline (1992) have reached similar conclusions. Rubin et al. (1992) present an analysis of opportunities for greenhouse gas reductions in the U.S. From their analysis of current consumption patterns, they identify potential carbon reductions totalling 508 mmt-C annually, achievable at a negative or zero net private cost, meaning that savings in energy costs outweigh the combination of capital and operating and maintenance costs.[16] The authors contend that these options are currently available but have not been implemented due to

---

[16] Rubin et al. (1992) estimate savings from several sectors: residential and commercial energy use (243 mmt-C with an average cost of -16.91 $/mt-C); industrial energy use (144 mmt-C with an average cost of -7.64 $/mt-C); transportation energy use (79 mmt-C at an average cost of -11.73 $/mt-C); and power plants (15.5 mmt-C at an average cost of $0).

institutional or other barriers. Further, the Rubin et al. (1992) study, unlike Hall (1992), does not consider externality costs associated with the burning of fossil fuels; inclusion of these costs would have increased the apparent attractiveness of cost-effective CO_2 emissions reduction.

Note that the magnitude of potential immediate annual emissions reductions by the U.S., in both the Rubin and Hall studies, is comparable to that which would be offset annually after 20 years in all developing country emissions from the ambitious PV program analyzed above.

IV. CONCLUSIONS

The use of PV technologies for electricity generation is unlikely to offset significant quantities of CO_2 in the near term. Current economic estimates suggest costs of 0.30 - 0.40 $/kWh for central station electric utility generation in the U.S., and on the order of 1.75 $/kWh at the household level in developing countries. Our conclusion is that expanded programs aimed at providing existing solar power technologies to developing countries as a means of offsetting greenhouse gas emissions should not be encouraged. The end result of these projects is to push the most expensive energy technology upon those least able to afford it. Basing development on renewable energy technologies before economically sustainable applications have developed will likely result in minor, short-run development at major international aid costs. An aid agency subsidized market push keeps PV production on the increase, while ignoring the central need for further research and development. These programs confuse scale economy with technological change (Chapman and Erickson, 1993).

If the underlying goal of these projects is to ensure a market for solar manufacturers to support field level research and development, then this goal should be pursued through other means, such as industrialized country legislation requiring utilities to install a certain quantity of solar technologies by a certain date.

Attention to premature PV technology transfer also neglects the substantial reductions in greenhouse gas emissions that can be attained through energy efficiency and conservation efforts throughout the world. Conservation and efficiency improvement strategies, many available at a net cost savings, such as those proposed by Hall (1992), NAS (1991), Cline (1992), and Rubin et al. (1992), provide a more reasonable near term approach to limiting the atmospheric buildup of greenhouse gases.

However, total fossil energy demand will continue growing in the near future. Projected emissions increases may overwhelm any reductions possible through conservation and efficiency improvements. Significantly reducing emissions of CO_2 will require a move away from a fossil-fuel based economy and towards either a nuclear or renewable energy future. Moving towards a renewable future will require advances in existing renewable energy technologies, such as PV panels. In the longer term, what is needed is a sustained R&D program that will lead to improvements in panel and other system component efficiencies.

Such an R&D program should have multiple goals. First, efforts need to be made to promote university level research on solar technologies. Not only might this lead to important breakthroughs, but it will motivate the next generation of researchers to consider the renewable options. Another component should focus on the manufacturing process, as suggested by Caldwell

(1993). Over the past 20 years, the U.S. federal government has spent twice as much money on the development of fossil fuel technologies, and four times as much on nuclear technologies, than was invested in research and development of all renewable technologies combined (GAO, 1993). (Renewable here includes solar, wind, biofuels, and ocean energy technologies.)

The path to a renewable energy future requires a reversal of the R&D priorities of the past and a realistic assessment of current costs and market direction in the present. It implies the education of a new generation of energy specialists that see the current difficult situation with realism and entertain ambitious goals for the future.

V. REFERENCES

Agras, J. 1993. Personal Communication, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY.

Asia Alternative Energy Unit. 1993. Personal Communication, World Bank, Washington, D.C.

Caldwell, J. 1993. "Photovoltaic Technology and Markets: An Assessment for the Technology Advancement Office of the South Coast Air Quality Management District," Paper presented at the Western Economics Association International 68th Annual Meeting, Lake Tahoe, NV, June 21-24, 1993.

Chapman, D. and T. Drennen. 1990. "Equity and Effectiveness of Possible CO_2 Treaty Proposals," *Contemporary Policy Issues*, July, pp. 16-28.

Chapman, D. and J. Erickson. 1993. "Economic Evaluation of Residential Solar Electricity in Developing Countries," Staff Paper, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY.

Cline, W. 1992. *The Economics of Global Warming*, Institute for International Economics, Washington, D.C.

Drennen, T. 1993. *Economic Development and Climate Change: Analyzing the International Response*, Ph.D. Dissertation, Cornell University, Ithaca, N.Y.

Erickson, J. and D. Chapman. 1993. "Photovoltaic Technology: Markets, Economics, and Development," Paper presented at the Western Economics Association International 68th Annual Meeting, Lake Tahoe, NV, June 21-24, 1993; and Staff Paper 93-18, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY.

Framework Convention on Climate Change. 1992. United Nations, New York.

General Accounting Office (GAO). 1993. *Electricity Supply: Efforts Under Way to Develop Solar and Wind Energy*, GAO/RCED-93-118, Washington, D.C., April.

Global Environment Facility (GEF). 1992. *A Selection of Projects from the First Three Tranches*, Working Paper Series, Number II, United Nations Development Program, Washington, D.C.

Hall, D. 1992. "Social Cost of CO_2 Abatement from Energy Efficiency and Solar Power in the United States," *Environmental and Resource Economics*, 2:491-512.

Hankins, M. 1993. *Solar Rural Electrification in the Developing World -Four Country Case Studies: Dominican Republic, Kenya, Sri Lanka, and Zimbabwe*, Solar Electric Light Fund, Washington, D.C.

International Energy Agency. 1992. *Energy Balances of OECD Countries*, Paris.

Intergovernmental Panel on Climate Change. 1992. *Climate Change 1992, The Supplementary Report to the IPCC Scientific Assessment*, J.T. Houghton, B.A. Callander, and S.K. Varney, eds., Cambridge University Press, Cambridge, U.K.

Larson, R.W., F. Vignola, and R. West, eds. 1992. *Economics of Solar Energy Technologies*, American Solar Energy Society, Boulder, CO.

Marland, G. and R. Rotty. 1983. *CO_2 Emissions from Fossil Fuels: A Procedure for Estimation and Results for 1950-1981*, DOE/NBB-0036, U.S. Department of Energy, Washington, D.C.

National Academy of Sciences. 1991. *Policy Implications of Greenhouse Warming*, National Academy Press, Washington, D.C.

Public Power Weekly. 1993. "DOE Collaborating on Photovoltaics Project to Bring Lights, Refrigeration to Rural Brazil," *Public Power Weekly*, No. 93-16.

Rubin, E., R. Cooper, R. Frosch, T. Lee, G. Marland, A. Rosenfeld, and D. Stine. 1992. "Realistic Mitigation Options for Global Warming," *Science*, Vol. 257, pp. 148-149, 261-266.

Solar Energy Research Institute. 1988. *Flat-Plate Solar Array Project: Government and Industry Responding to National Needs*, SERI/SP-320-3382, Golden, CO.

Southern Centre for Energy and Environment. 1993. *UNEP Greenhouse Gas Abatement Costing Studies: Zimbabwe Country Study, Phase II*, Harare, Zimbabwe.

United Nations. 1991. *World Population Prospects: 1990*, United Nations, New York, NY.

U.S. Energy Information Administration. 1990, 1992. *International Energy Annual*.

U.S. Energy Information Administration. 1993. *Monthly Energy Review*, May 1993.

OTHER AGRICULTURAL ECONOMICS STAFF PAPERS

No. 93-11	Prior Information, General Information, and Specific Information in the Contingent Valuation of Environmental Risks: The Case of Nitrates in Groundwater	Gregory L. Poe Richard C. Bishop
No. 93-12	Characteristics of Small Business Succeeding in the Next Century	Robert A. Milligan
No. 93-13	Financial Management on Large Dairy Farms	Eddy L. LaDue
No. 93-14	Incorporating Price Regulation in Causality Tests for Dairy Markets	Paula A. Emerick Lois Schertz Willett Andrew M. Novakovic
No. 93-15	Dynamics of Price Changes: Implications for Agricultural Futures Markets	William G. Tomek
No. 93-16	The Effect of Selected Farm Characteristics on Dairy Farm Profitability: A Logistical Regression Analysis	Kevin E. Jack
No. 93-17	Analyzing the Impacts of the Proposed North American Free Trade Agreement on European-North American Dairy Trade Using a Joint-Input, Muti-Product Approach	P.M. Bishop J.E. Pratt A.M. Novakovic
No. 93-18	Photovolataic Technology: Markets, Economics, Development	Jon D. Erickson Duane Chapman
No. 93-19	The Effect of Deferred Taxes on Market Value Balance Sheets	Eddy L. LaDue