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Solar power and climate change policy in developing countries

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Solar energy is one option for reducing future greenhouse gas emissions. Offsetting 50% of all future growth in thermal electricity generation by photovoltaics (PVs) would reduce annual global carbon dioxide emission from projected increased levels by 10% in 20 years and 32% in 50 years. Several projects are under way worldwide to demonstrate the feasibility of PV systems. This paper examines the economic competitiveness of PV systems and concludes that even after including externality costs, without significant technological breakthroughs, the economics of PV applications are unlikely to allow for an unsubsidized, widespread adoption of this technology in the near future. Further, if the goal of PV transfer programmes is to limit future greenhouse gas emissions, there are larger and cheaper opportunities available in industrialized countries to achieve reductions. Alternative measures for ensuring a market for photovoltaics, hence providing manufacturers with opportunities to improve the current technology, include mandating that utilities install a certain quantity of solar technologies by a certain date. Finally, moving towards a renewable energy future that includes PV systems requires a sustained R&D programme that will lead to improvements in panel and other system efficiencies.

Keywords: Climate change mitigation; Photovoltaic economics; Technology transfer

The continued build up of greenhouse gases in the atmosphere, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are 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, ie 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, ie 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 fuelled electricity sources. Of all the solar technologies, PVs seem to have the greatest potential for reducing reliance on fossil fuelled 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.

Table 1 Electricity generation, annual growth, and resulting CO_2 emissions (1990)

	Industrialized	Developing	CIS/EE	China	World
Population (millions)	789	2849	448	1236	5 322
Electricity generation (TWh)	6154	1679	1844	549	10 227
Thermal electricity generation[a]					
Total (TWh)	3802	1072	1511	476	6 861
Per capita (MWh)	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 (MtC)	772	218	307	112	1 408
Per capita (tC)	0.98	0.08	0.68	0.09	0.26

[a]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

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

Capital expenses for small PV systems are also suited for household investment, delinking 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 (Flavin and Lenssen, 1994).

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, focusing on a current project in Zimbabwe. Finally, we discuss our conclusions about the overall direction for PV technology.

Trends in electricity consumption and resulting CO_2 emissions

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 (TWh); of that, 6861 TWh was classified as thermal generation. CO_2 emissions associated with the thermally generated portion of electricity totalled over 1400 million tonnes of carbon (MtC).[2]

Over half (55%) 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.

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-fuelled 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 assumptions for the Table 1 CO_2 calculations (see note 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 6861 TWh in 1990 to 12 761 TWh in 2010, and 31 754 TWh

[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 the China and 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.

[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 (tC 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).

[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.

Table 2 Current and projected populations, thermal electricity generation, and resulting annual CO_2 emissions

	Industrialized	Developing	CIS/EE	China	World
Population (millions)					
1990	789	2 849	448	1236	5 322
2010	842	4 288	517	1507	7 154
2040	864	6 521	601	1784	9 770
Thermal electricity generation (TWh)					
1990	3802	1 072	1511	476	6 861
2010	4779	4 033	2159	1791	12 761
2040	6253	15 458	3180	6864	31 754
Per capita thermal electricity (MWh)					
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 (MtC)					
1990	772	218	307	112	1 408
2010	970	819	438	364	2 591
2040	1269	3 138	646	1393	6 446
Per capita CO_2 from electricity (tC)					
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.

in 2040. Aggregate CO_2 emissions from electricity generation increase from 1.4 to 6.4 GtC 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 tC 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 tC, and significantly lower than the projected level of 1.47 tC 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 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%.

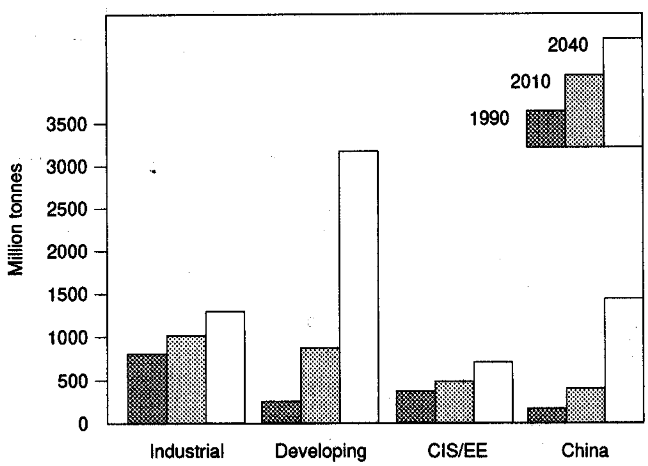

Figure 1 Trends in CO_2 emissions for the four world regions

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-fuelled 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 3654 TWh of thermal electric generation annually after 20 years and 18 691 TWh 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 GtC, increasing to 7.7 GtC in 20

Table 3 Potential solar electricity and CO_2 emissions[a]

	No PV case	PV case	Difference
Thermal generation (TWh)			
1990	6 861	6 861	0
2010	12 761	9 107	3 654
2040	31 754	13 063	18 691
Total CO_2 (MtC)			
1990	1 409	1 409	0
2010	2 591	1 849	742
2040	6 446	2 652	3 794
Per capita CO_2 (tC)			
1990	0.26	0.26	0
2010	0.36	0.26	0.10
2040	0.66	0.27	0.39

[a]See text for description of scenarios. Carbon is in units of megatonnes (Mt).

years and 11.7 GtC 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.

Thus, PV systems (or other non-carbon emitting sources) 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 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 unsubsidized, widespread adoption of this technology in the near future. There are additional reasons why PV 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 (Chapman and Erickson, 1995; Sinha, 1994).

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

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 (1994) reports direct costs for a 55 W, 14% efficient module of US$3.25/W (factory price). Excluding other system costs, this module cost is equivalent to US$0.33/kWh for a south-western US location (Caldwell, 1994). To be economically competitive, the module cost needs to be reduced to at least US$0.5/W (US$0.05/kWh). This level was the original goal of the government sponsored PV research and development programmes of the 1970s and early 1980s (Solar Energy Research Institute, 1988). Recently, solar manufacturers have hinted at possible production prices as low as US$1/W using thin film technology (Flavin and Lenssen, 1994), although this is not yet reality.

Current economic estimates for PV power vary considerably. Utility experience in the US indicates PV central station costs in the US$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 US$0.10–0.15/kWh.[7] For stand-alone PV systems in the Dominican Republic, Kenya and Zimbabwe, Chapman and Erickson (1995) estimate average kWh costs to customers of US$1.82, US$2.27 and US$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 US$0.02/kWh (Larson *et al*, 1992). These costs are based on US 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 triple this estimate, it would only make a small movement toward bringing current PV costs in line with current conventional energy costs.[10]

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

[5]Drennen's (1993) reference case assumes that consumption of CFCs will be phased out in accordance with the terms of the London Amendment 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.

[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, 1994). However, there is a direct trade off between increased efficiency and cost. Caldwell (1994) predicts that practical considerations, such as cost, will limit efficiencies to 25% for crystalline silicon cells and 20% for thin films.

[7]These are the estimated costs for a 80 MW parabolic trough system in Southern California. Larson *et al* (1992) estimates these costs to be slightly higher, US¢0.15–0.20/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 US$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 (ie the cost of climate change on society). Private costs (or benefits) are viewed at the individual level (ie the cost of energy to consumers). Total social cost (or benefits) are the sum of externalities and private costs (or benefits).

[10]For a complete discussion of estimating and incorporating externality costs, see Hohmeyer and Ottinger (1994).

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 incomes 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. Firor, Vigotti and Iannucci (1993) indicate that the largest number of PV systems are in developing countries. Indeed, the developing world seems like a logical location for PV use because large areas lack access to electric grids. Flavin and Lenssen (1994) estimate that the greatest short-term impact of solar PVs will be to provide power to as many as 2 billion rural people in developing countries, providing basic energy needs to some of the world's poorest people.

India is a good example of a country with an ambitious photovoltaic programme, described by Sinha (1994) as possibly the largest in the world. Unlike most other developing country programmes, India has its own solar manufacturing capability, with a total manufacturing capability in 1994 of 5.75 MWp per year with an additional 2.75 MWp under construction. India plans to commit Rs900 million (about US$30 million) during the course of the Eighth Plan (1992–97) and expects an additional contribution of about US$55 million from the Global Environmental Facility (GEF).

However, despite the apparent success of this programme and the emergence of a domestic PV supply capability, Sinha (1994) notes that this has happened only because of substantial guaranteed funds, both from the government and multilateral donors. He further notes that existing PV applications have suffered a high failure rate. For example, he quotes a 1990 survey that shows a 37% failure rate of street lights and a 85% failure rate for water pumps. Sinha attributes such problems to a lack of involvement by local people, an overall lack of training on proper maintenance, and overall lack of interest. He is also critical of the economics, noting that the Rs900 allocated for solar in the Eighth Plan could buy either 3 MW of PV, 100 MW of wind, or 170–200 MW of hydro. Another study conducted by Tata Energy Research Institute (Ghosh and Puri, 1994) estimates total system costs for a stand alone solar PV system of Rs19.98/kWh (about US$0.66, significantly lower than costs estimated in this paper for other countries) compared to just Rs1.45/kWh for biomass gasification.

Despite these and other drawbacks, the developing world continues to attract donor agencies and foreign governments interested in investing in solar projects. The next section discusses plans and key goals for a PV dissemination programme in Zimbabwe.[11]

Zimbabwe, the Global Environment Facility, 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 9000 stand alone PV systems in Zimbabwe. The GEF, which is jointly managed by the World Bank, the United Nations Development Programme, and the United Nations Environment Programme, 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 (United Nations, 1992). This international agreement, which emerged from the 1992 United Nations Conference on Environment and Development, entered into force 21 March 1994 and has been ratified by 118 countries (Interim Secretariat of the UN Climate Change Convention, 1995). 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.[12] To avoid widespread emissions increases, the Convention notes the importance of technology transfer as a means for developed countries to assist developing countries in

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

[12]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'.

Table 4 PV versus portable generator costs in Zimbabwe (US$/kWh)

	Sensitivity analysis, varying:								
		Discount rate (%)			System lifetime (years)[d]		Gas tax (%)		
	Base case[c]	5	15	30	15	30	50	150	All
PV system[a]	2.056	1.72	2.43	3.67	1.76	1.51	2.06	2.06	1.97
Portable generator[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 48 W panel (US$14.34/Wp), 90 amp battery (US$53) replaced every 1.5 years, charge control unit (US$11.4), installation (US$60), 5% yearly repairs, and 20% inefficiency power derate (ie temperature induced voltage drop, module inefficiencies, power storage losses). Total output is calculated as 6.0 average solar hours/day (6.0 kWh/m^2/day at 1000 W/m^2 of sun's energy) times 48 W, derated by 20%. The inefficiency is taken as a minimum and can be considerably higher, particularly with high temperatures. [b]Assumes 650 W Honda portable generator (US$519), US$40 accessory cost, US$40/year oil cost, 5% inefficiency derate, 10% yearly repairs, and daily generator run time of five hours. [c]Assumes 10% discount rate, 10-year investment period, and gasoline base cost of US$l/gal. [d]30-year system lifetime assumes replacing the generator on the 15th year. [e]Discount rate = 15%; system lifetime = 30 years; gas tax = 150%.

meeting their obligations under the Convention (Article 4.1.c; Article 4.3).[13]

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.

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 US$2.06/kWh compared to US$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 US$1.72/kWh to US$3.67/kWh. The most important cost for generators is the fuel; adding gas taxes of 150% increases the estimated costs to US$0.66/kWh, still far below the lowest estimate for PV of US$1.51/kWh.[14] (Flavin and Lenssen (1994) argue that for solar PV to become economical, countries need to level the playing field in terms of subsidies for grid extension, fuel, and diesel generators.)

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 (ie 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 US$32 to US$906/tC. (For a good review of estimates for several countries, including Zimbabwe, see Sathaye and Christensen (1994)). The estimated cost of the GEF programme is US$2600/tC.[15] Even if all the GEF capital cost is recovered through interest bearing loans, the estimated administrative costs of the programme alone amount to US$532/tC.[16]

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, 1994). He argues that in order to drive PV prices down in the long run, the solar industry needs a market to 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.[17]

Targeting developed country emissions

The final pertinent question addresses the reduction priorities for developing and industrialized countries greenhouse gas emissions in the near term. As demonstrated previously,

[13]Article 4. l.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'.

[14]This lowest cost estimate assumes a 30-year lifetime and a 10% discount rate.

[15]This assumes a policy whereby donor agencies subsidize the costs of 50 W PV systems for household use. Estimate assumes a cost of US$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 US$2597/tC.

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

[17]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 USA[a]

	Social marginal cost (US$/tC)	Annual reductions possible (MtC) by year 1990	2000	2010	2020	2050
Scenario A	–0.30	0	339	367	392	499
Scenario B	+12.00	0	353	515	541	650

[a]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 defence 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.

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 USA over the next 50 years (see Table 5). This analysis demonstrates that options already exist to reduce annual US emissions by 500 MtC 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, these reductions could total 650 MtC annually by 2050. This latter option has a social marginal cost for reducing CO_2 emissions of US$12/tC.

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 US. From their analysis of current consumption patterns, they identify potential carbon reductions totalling 508 MtC 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.[18] The authors contend that these options are currently available but have not been implemented due to institutional or other barriers. Further, the Rubin *et al* 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 US, 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 programme analysed above.

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 US$0.30–0.40/kWh for central station electric utility generation in the USA, and on the order of US$1.75/kWh at the household level in developing countries. Our conclusion is that expanded programmes 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 programmes confuse scale economy with technological change (Erickson and Chapman, 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 programme that will lead to improvements in panel and other system component efficiencies.

Such an R&D programme should have multiple goals. First, efforts need to be made to promote university-level research on solar technologies (in addition to existing funding to the national laboratories). Not only might this lead to important breakthroughs, but it will motivate the next generation of researchers to consider the renewable options.

[18]Rubin *et al* estimate savings from several sectors: residential and commercial energy use (243 MtC with an average cost of US$–16.91/tC); industrial energy use (144 MtC with an average cost of US$–7.64/tC); transportation energy use (79 MtC at an average cost of US$–11.73/tC); and power plants (US$15.5 MtC at an average cost of US$0).

Another component should focus on the manufacturing process, as suggested by Caldwell (1994). Over the past 20 years, the US 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.

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