3. RURAL ELECTRIFICATION AND ENVIRONMENTAL MITIGATION THROUGH RENEWABLES AND DISPERSED GENERATION

Saifur Rahman, Ph.D.* **and Concha Callwood****

3.1 Introduction

Renewable energy has historically been used all over the world for centuries to perform simple tasks such as drying crops and pumping water. In modern times, as steam and gas turbines powered by fossil fuels began to be used to electrify urban areas with large, centralized populations, the use of renewables was largely abandoned in favor of the more convenient use of energy in the form of electricity. Grid–interconnection in industrialized countries further spread electricity to rural areas, deeming continued use of renewable energy for many applications as less practical, less economical, and less reliable than electricity. For rural areas of less-industrialized countries today, however, the use of renewables has never seemed more suitable.

Given the current state of technology development, renewables are more befitting than ever to provide sustainable economical and developmental stimuli to remote areas that are isolated from the infrastructure of large metropolitan areas. Renewable energy holds promise to run sectors like education, health care, and employment more efficiently, to reduce a country's contribution to global environmental pollutants, and to provide a means to attract outside resources from more industrialized countries, all of which will serve to alleviate poverty and improve the quality of life in a country.

Advances in recent years have made it possible to adapt several renewable energy technologies for use with distributed generation of electricity. With distributed generation, electricity sources can be located close to the center of the load, eliminating the need for long power lines and drastically reducing the costs of transmission and distribution equipment. These advantages, combined with the efficiency improvements due to lower voltage drops and less transmission losses, make distributed generation a practical solution to the particular rural electrification needs of developing countries. The need for low-cost distributed power systems to

---

* Professor and Director of Center for Energy and the Global Environment Virginia Tech, USA.
** Research Assistant, Center for Energy and the Global Environment Virginia Tech, USA.

improve the quality of life in rural areas is urgent, in part to assure balanced economic development, and in part to help stem the tide of migration from the rural areas into the emerging and increasingly unmanageable megacities. The initial uses of electricity for basic lighting, communications, irrigation, clean water, and refrigeration make such vast differences in health, labor, learning, and convenience that even people at the margins of survival are willing to spend a significant part of their income for power. Along with solar, wind, biomass and micro-hydro are also among the renewable energy sources which can be used to provide electricity to rural areas.

3.2 Renewable Energy Technologies and Environmental Mitigation

The use of renewable energy for electricity generation makes efficient use of these cleaner sources of energy that may otherwise go unused or be wasted. Table 1 shows the existing and planned renewable energy capacities by electric producers in OECD countries. Tables 2 and 3 show solar, wind, and other renewable technology electric generating capacity and electric generation in selected countries and regions of the world. These projects when inmplemented in full will provide meaningful contributions to reducing the national carbon dioxide emission levels of these countries. By increasing their use of renewable technologies in more sustainable ways to electrify rural areas, developing countries will also be doing their share to address the global environmental pollution problems. While operating, renewable energy projects are carbon dioxide “neutral”, meaning they make no contribution to the net carbon dioxide concentration in the atmosphere. Such benefits can be instrumental for developing countries forming alliances with developed countries to help solve the global warming problem by initiating Activities Implemented Jointly (AIJ) projects.

3.3 Photovoltaics

Over 400 MW of PV systems now operate worldwide. With aggressive R&D, it will be possible to increase conversion efficiencies to 15-20 percent over the next few years, and reduce manufacturing costs by two-thirds. That would significantly expand the range of PV applications worldwide. The very factors that limit application of PV in energy and infrastructure intensive developed nations are precisely the ones that provide the advantage in infrastructure-poor nations. The real long-term promise of photovoltaics, however, rests on the fact that it is part of the family of solid-state technologies that still is in the early, robust stages of technological discovery and development. Research will likely continue to make great progress for decades to come.

In the meantime the use of photovoltaics is steadily growing around the world. The Agency for the Assessment and Application of Technology (BPPT) in Indonesia is currently implementing a plan to provide electricity to one million homes using 50-watt solar PV modules. 25,000 households in Kenya have purchased their own photovoltaic (PV) systems without subsides, in order to gain access to minimal levels of power at rates equivalent to 25 cents/kWh. In the United States, President Clinton recently announced the "Million Solar Roofs" program where the federal government will work with businesses and communities to use the sun's energy to reduce US reliance on fossil fuels by installing solar panels on one million more roofs around the country by 2010. More than half are slated to be photovoltaics and the rest solar hot water. Recently, the Enron Corporation announced a financing package for the multi-megawatt solar photovoltaic power plant in Rajsthan, India. This will be the largest such plant in the world.

3.4 Wind

The wind energy conversion technology has made remarkable progress over the last 20 years to the point that it is a commercially viable energy technology today in many countries. For example, in the United States over four billion kilowatt-hours of electricity is produced from wind miils per year. There are significant amounts of electricity generation from wind in Denmark, Germany, the Netherlands, Spain and the United Kingdom (see Table 2). The year 2005 prices are slated to be in $600/kilowatt range (see Table 7). A 50-megawatt wind farm (with 84 turbines) is planned for installation in Tanger, Morocco starting in 1998.

3.5 Biomass

The use of biomass would require development of sustainable feedstocks with special care taken to ensure proper long-term soil and forest management and agricultural practices to minimize the environmental effects. Biomass accounts for about one-third of all primary energy used in developing countries today, but is often used inefficiently in individual households as raw fuel. When converted to other forms of energy before use, such as gas, liquid, or electricity, biomass becomes a cleaner, more efficient source of energy. Additionally, biomass has the benefit of serving as a carbon dioxide sink while trees and crops are growing, and its use produces no net release of carbon dioxide into the atmosphere. [1]

3.6 Microhydro

Micro-hydro can be used in rural areas where water resources are available and adequate. The initial capital costs can be offset through a project's 40 or 50-year lifetime by its low operating costs and the use of local labor and materials. In contrast to large hydroelectric plants, micro-hydro plants can be built quickly, can be operated without flooding large areas, and have less environmental impact. The output from hydro plants is highly variable due to seasonal changes in the water flow, so long term flow data for a projected site is necessary to predict reliable energy outputs. Micro-hydro plants have been used successfully to electrify remote villages in Pakistan at a cost of $250-$400 per kilowatt. The use of local materials and labor helped to make the costs so low. [1]

3.7 Global Emissions

The US, China, Russia, Japan and Germany are responsible for about 3.2 billion tons of carbon emissions per year which is over half of the world total [6]. Share of world's emissions by percentage in 1995 were: United States 23% (1.39 billion tons), China 13.9% (807 million tons), Russia 7.2% (437 million tons), Japan 5% (302 million tons) and Germany 3.8% (234 million tons). Shares of world's emissions calculated on a per capita basis in 1995 are: United States 5.3 tons, Russia 2.9 tons, Germany 2.9 tons and Japan 2.4 tons. The figures for key developing countries are: China 0.7 ton, Brazil 0.4 ton and both Indonesia and India 0.3 ton. Emission growth in percentage between 1990 and 1995: United States 6.2%, Japan 8.7%, Russia - 27.7%, Germany -10.2%, China 27.5%, India 27.7%, Indonesia 38.8% and Brazil 19.8%. The fall in emissions in Russia is attributable to a collapse in its industries, particularly the energy-intensive ones, since the fall of the Soviet Union. In Germany, the absorption of the former communist east into a united country allowed the federal government to close down numerous inefficient industries, especially the coal-burning ones.

3.8 Activities Implemented Jointly (AIJ)

Such huge contributions to global warming through carbon dioxide emissions, and their inability to significantly reduce this output, have encouraged many industrialized countries to collaborate with less industrialized countries and find joint opportunities to address this issue. This has led to a mechnism now known as Activities Implemented Jointly (AIJ). In AIJ ventures, industrialized countries assist less-industrialized countries in establishing sustainable projects. Tables 4 and 5 list planned or ongoing AIJ projects sponsored by the United States (called United Stated Initiative on Joint Implementation or USIJI projects) and the Netherlands. Figures 1, 2, and 3 illustrate the carbon benefits of AIJ in these countries.

Less-industrialized countries can take advantage of renewables and advanced energy technologies in their plans for electrification resulting in lower carbon dioxide emissions per kilowatthour of electricity produced. The US costs of electric capacity for some of these technologies are shown in Tables 6 and 7. AIJ can provide technology transfer, technical training, and economic resources to a country. These added resources can be used in developing countries for poverty alleviation and continued development.

AIJ projects allow two countries to tailor-make a mutually beneficial relationship, while simultaneously taking measures to protect the global environment. The specific benefits of the use of certain renewable technologies to the global environment is yet to be determined, however, as is in the case of biomass. It is quite difficult to quantify the amount of carbon dioxide that is stored in growing plant matter, and because of this it is difficult to ensure that biomass crops remain growing long enough to provide an adequate carbon dioxide sink. Nevertheless, the use of sustainable practices and renewables do provide a more efficient, convenient, cleaner source of energy than would fossil fuels or extending power lines to remote areas. Their use should be exploited more widely to provide electricity for development, efficiency improvements, and poverty alleviation.

3.9 References and Notes

1. U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries*, OTA-E-516, pp. 12, pp. 206-208, 214, U.S. Government Printing Office, Washington, D.C., April 1992.
2. International Energy Agency, *Electricity Information 1995*, OECD/IEA, Paris, July 1996.
3. International Energy Agency, Energy Balances of OECD Countries 1993-1994, OECD/IEA, Paris, 1996.
4. International Energy Agency, Energy Statistics and Balances of Non-OECD Countries 1993-1994, OECD/IEA, Paris, 1996.
5. *Assumptions for the Annual Energy Outlook 1993*, Department of Energy/Energy Information Administration, pp.92, January 1993.
6. Worldwatch Institute, Washington, D.C., 1996.

Table 1: Existing and Planned Renewable Capacity by Electric Producers in OECD Countries

Country	Public Utilities 1994 (MW)		Auto-producers 1994 (MW)		Renewables* 1995-2000 (MW)		
	Solar	**Wind**	**Solar**	**Wind**	**Under Const-ruction**	**Planned**	**Total Operating in 2000**
Belgium	0	10	0	0		10	
Canada	<10	0	0	20			
Denmark	0	530	0	0			850
France	0	0	0	0			240†
Germany	0	190	0	0			700
Greece	0	30	0	0		30	60
Iceland	0	0	0	0		30	80
Ireland	0	0	0	10		140	150
Italy	0	<10	0	0			
Japan	0	<10	0	0	130	90	600‡
Mexico	0	<10	0	0			

Blank cells indicate none or not available
*Includes geothermal, solar, wind, non-conventional hydro (tidal, wave, ocean thermal) and fuel cells
† 100% non-conventional hydro
‡ At least 390 MW of geothermal
# 100% geothermal
Source:[2]

Table 1: Existing and Planned Renewable Capacity by Electric Producers in OECD Countries (continued)

Country	**Public Utilities 1994 (MW)**		**Auto-producers 1994 (MW)**		**Renewables* 1995-2000 (MW)**		
	Solar	**Wind**	**Solar**	**Wind**	**Under Construction**	**Planned**	**Total Operating in 2000**
Nether-lands	<10	140	0	20	620		780
New Zealand							260#
Norway	0	<10	0	0			10
Portugal	0	10				60	80
Spain	10	80			110	210	400
Sweden	< 10	20	0	0			
Switzerland			10			10	20
Turkey							20#
United Kingdom	0	0	0	70			
United States	0	10	350	1740	1240		6360

Blank cells indicate none or not available
*Includes geothermal, solar, wind, non-conventional hydro (tidal, wave, ocean thermal) and fuel cells
† 100% non-conventional hydro
‡ At least 390 MW of geothermal
# 100% geothermal
Source:[2]

Table 1: Existing and Planned Renewable Capacity by Electric Producers in OECD Countries (continued)

Country	Renewables* 2001-2005 (MW)			Renewables* 2006-2010 (MW)		
	Under Construction	Planned	Total Operating in 2005	Under Construction	Planned	Total Operating in 2010
Belgium						
Canada					100	100
Denmark			1050			
France						
Germany			1100			1100
Greece		30	80		100	180
Iceland		30	110			
Ireland		150	300		150	450
Italy						
Japan			1300			2800
Mexico						

Blank cells indicate none or not available
*Includes geothermal, solar, wind, non-conventional hydro (tidal, wave, ocean thermal) and fuel cells
† 100% non-conventional hydro
‡ At least 390 MW of geothermal
# 100% geothermal
Source:[2]

Table 1: Existing and Planned Renewable Capacity by Electric Producers in OECD Countries (continued)

Country	Renewables* 2001-2005 (MW)			Renewables* 2006-2010 (MW)		
	Under Construction	**Planned**	**Total Operating in 2005**	**Under Construction**	**Planned**	**Total Operating in 2010**
Nether-lands		560	1330			
New Zealand	50	60	370		180	550
Norway			10			10
Portugal		30	110			110
Spain						
Sweden			100			
Switzerland						
Turkey			20			10
United Kingdom						
United States	1200		7240	2500		10110

Blank cells indicate none or not available
*Includes geothermal, solar, wind, non-conventional hydro (tidal, wave, ocean thermal) and fuel cells
† 100% non-conventional hydro
‡ At least 390 MW of geothermal
# 100% geothermal
Source:[2]

Table 2: 1994 Electricity Generation from Solar and Wind in OECD countries

Country	Solar (GWh)	Wind (GWh)	% of Total Electricity Generated	
			Solar	Wind
Belgium	0	9	0	<1
Canada	3	38	<1	<1
Denmark	0	1137	0	3
Germany	0	1420	0	<1
Greece	0	37	0	<1
Ireland	0	18	0	<1
Italy	0	1	0	<1
Japan	0	1	0	<1
Mexico	0	4	0	<1
Netherlands	2	237	<1	<1
Norway	0	7	0	<1
Portugal	0	17	0	<1
Spain	10	142	<1	<1
Sweden	6	72	<1	<1
Switzerland	5	0	<1	0
United Kingdom	0	342	0	<1
United States	784	3791	<1	<1

Source: [3]

Table 3: 1994 Electric Generation from Renewables* in Selected non-OECD Regions and Countries

Region	Generation (GWh)	% of Total Electricity Generated
Africa	329	<1
Latin America	1363	<1
Asia	7701	1
Middle East	5114	1.6
Country	**Generation (GWh)**	**% of Total Electricity Generated**
Costa Rica	342	7
El Salvador	500	16
Ethiopia	68	5
India	55	<1
Indonesia	1935	4
Israel	5113 (100% solar)	16
Jordan	1	<1
Kenya	261	7
Nicaragua	521	31
Philippines	5711	21
Russia	28	<1

* Includes geothermal, solar, wind, and non-conventional hydro (tidal, wave, ocean thermal).

Source:[4]

Table 4 : Planned and Ongoing USIJI Projects

2nd Country	Primary Company or Project Name	Project Description	Project Cost
Costa Rica	CARFIX	Sustainable Forest Management of 105,000 hectares	$12.5 million
Czech Republic	Decin District Heating	Fuel Switching coal to natural gas/ Cogeneration	$8 million US investment: $600,000
Costa Rica	ECOLAND	Forest Preservation of 2,000-3,000 hectares	Unknown
Costa Rica	Plantas Eolicas	20 MW Wind Power Plant	$30 million US investment: $7 million
Belize	Rio Bravo	Sustainable Forest Management of 15,000 acres	$2.5 million
Russian Federation	RUSAFOR	Afforestation of 500 hectares	$100-200/ hectare or $2/ ton carbon plus land cost
Honduras	Solar Rural Electrification	Replacement of kerosene lamps with solar-based electric lights	Unknown
Costa Rica	Aeroenergia	6.4 MW Wind Power Plant	Unknown
Honduras	Bio-Gen	10-15 MW Biomass Power Plant	$26 million US investment: 20.5 million
Costa Rica	BIODIVERSIFIX	Reforestation of 74,500 hectares	Unknown
Costa Rica	Dona Julia	16 MW Hydroelectric Power Plant	Unknown
Nicaragua	El Hoyo-Monte Galan	105 MW flashed steam Geothermal Power Plant	Unknown
Costa Rica	KLINKIFIX	Reforestation of 6,000 hectares	Unknown

Table 4 : Planned and Ongoing USIJI Projects (continued)

2nd Country	Primary Company or Project Name	Project Description	Project Cost
Russian Federation	RUSAGAS	Fugitive Methane Gas Capture	Unknown
Costa Rica	Tierras Morenas	20 MW Wind Power Plant	Unknown
Belize	BEL/Maya	18 MW Biomass Power Plant	Unknown
Honduras	Bio-Gen Phase II	15 MW Biomass Power Plant	Unknown
Russian Federation	District Heating	Efficiency improvements in district heating	Unknown
Mexico	Halophyte Cultivation	Cultivating native halophyte plants for biomass, food, and income on 30 hectares	Unknown
Bolivia	Noel Kempff	Forest Management	Unknown
Rep. of Panama	Reforestation of Chiriqui Province	Reforestation of 500 hectares	Unknown
Ecuador	Bilsa Reserve	Forest Conservation of 2,000 hectares	Unknown
Mexico	Scolel Te	Sustainable Land Management of 2,400 hectares	Unknown
Indonesia	RIL	Implemantation of Reduced Impact Logging techniques on 600 hectares	Unknown
Russian Federation	Reforestation in Vologda	Reforestation on 2,000 hectares	Unknown
Costa Rica	Consolidation of Biological reserves	Forest Preservation	Unknown

Table 4 : Planned and Ongoing USIJI Projects (continued)

2nd Country	Project Status	Project Lifetime	Est. Carbon benefits (metric tons of Carbon)
Costa Rica	Approved: Feb 1995	25 years	2.1 million
Czech Republic	Approved: Feb 1995 Began operation: Sep 1996	Unknown	7,082
Costa Rica	Approved: Feb 1995 Significant land acquired as of: Dec 1995	Unknown	Unknown
Costa Rica	Approved: Feb 1995 Began operation: Jun 1996	Unknown	71,390 over 5 years
Belize	Approved: Feb 1995	Unknown	741,417
Russian Federation	Approved: Feb 1995 Began operation: 1994 Replanting: Spring 1996	Unknown	Unknown
Honduras	Approved: Feb 1995	Unknown	Unknown
Costa Rica	Approved: Dec 1995	Unknown	8,897 over 4 years
Honduras	Approved: Dec 1995	Unknown	Unknown
Costa Rica	Approved: Dec 1995	50 years	5 million
Costa Rica	Approved: Dec 1995	Unknown	85,636 in first 5 years
Nicaragua	Approved: Dec 1995 Feasibility study: Mar 1996-Jan 1997 50 MW on line: mid-1999 105 MW on line: mid-2001	Unknown	Unknown
Costa Rica	Approved: Dec 1995	40 years	544,959

Table 4 : Planned and Ongoing USIJI Projects (continued)

2nd Country	Project Status	Project Lifetime	Est. Carbon benefits (metric tons of Carbon)
Russian Federation	Approved: Dec 1995	25 years	20 million
Costa Rica	Approved: Dec 1995	Unknown	24,714 per year
Belize	Approved: Dec 1996	30 years	954,545
Honduras	Approved: Dec 1996	20 Years	627,273
Russian Federation	Approved: Dec 1996	30 years	440,000
Mexico	Approved: Dec 1996 Began operation: Dec 1996	Unknown	599
Bolivia	Approved: Dec 1996	30 years	14.5 million
Rep. of Panama	Approved: Dec 1996	25 years	58,000
Ecuador	Approved: Dec 1996	Unknown	316,800
Mexico	Approved: Dec 1996	27 years	230,000
Indonesia	Approved: Dec 1996	40 years	56,400
Russian Federation	Approved: Dec 1996	60 years	240,000
Costa Rica	Approved: Jul 1997	25 years	15 .6 million

Table 5: Ongoing and Planned AIJ Projects in the Netherlands

2nd Country	Primary Company or Project Name	Project Descript. hectares	Project Cost (in Dutch guilders) M = million	Project Status	Proj Life time	Estimat. Carbon benefits (metric tons of carbon)
Czech Repub/ Poland	Sumava/ Kosmonatow, NowyDwor/ Krkonose	Reforestation 14,110	50 M Netherlands investment: 21.3 M	Start up: Apr 1994 By 1997: 37% area planted	120 years	10 M
Malaysia	Infapro	Reforestation 14,000	13 M Netherlands investment: 6.1 M	Start up: Jun 1992 By 1998: 36% area planted	70 years	13 M
Ecuador	Profafor	Reforestation 75,000	35 M Netherlands investment: 2 M/ year	Start up: Jun 1993 By 1997: 19% area planted	25 years	35 M
Uganda	UWA-Face Mt. Elgon, UWA-FaceKibale	Reforestation 27,000	10 M Netherlands investment: 3.8 M	Start up: Jul 1994 By 1997: 19% area planted	70 years	20 M
Indonesia	In Prep.	Reforestation 35,000	-	In prep.	-	34 M

“-“ = Unknown

Table 6: 1993 Estimated Average Capital Costs for Electric Capacity in the US

Type of Generating Capacity	Capital Cost (1991 $/KW)
Coal-Fired Steam with Flue Gas Desulfurization	1,479
Oil-Fired Steam	937
Gas-Fired steam	824
Combined Cycle	590
Combustion Turbine	342
Conventional Hydroelectric	1,067
Pumped Storage Hydroelectric	1,209
Nuclear	1,548

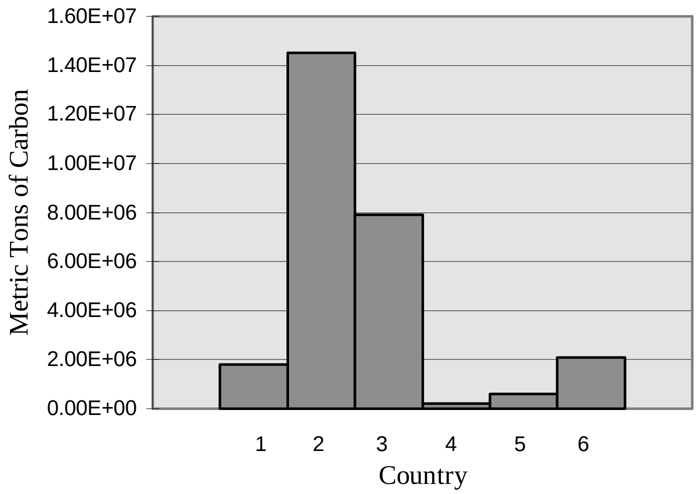
Source: [5]

Table 7: Costs for Wind Capacity and Solar Modules in the US

Type of Unit	Capital Cost		Price per kilowatt-hour
	Year	**Cost**	
Photovoltaic Module	1992	$5000 per peak kilowatt	
	1994	$4460 per peak kilowatt	
	2002 (projected	$3000 per peak	$0.08-0.10
Wind	1992		$0.06-0.09
	1993	$1072 per kilowatt	$0.05
	2005 (projected	$620 per kilowatt	$0.035-0.05

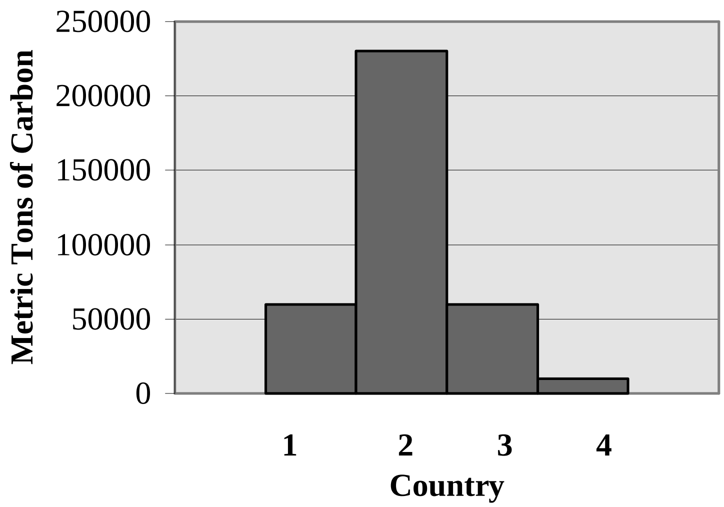
Source: [5]

Figure 1: Carbon Benefits of USIJI in Selected Countries



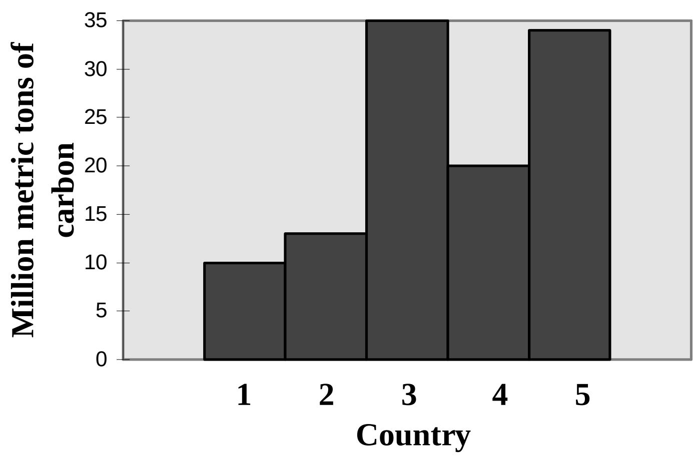
1 Belize
2 Bolivia
3 Costa Rica
4 Equador
5 Honduras
6 Russian Federation

Figure 2: Carbon Benefits of USIJI in Selected Countries



1 Indonesia
2 Mexico
3 Republic of Panama
4 Czech Republic

Figure 3: Carbon Benefits of Selected Netherlands AIJ Projects



1 Czech Republic/Poland

2 Ecuador

3 Indonesia

4 Malaysia

5 Uganda