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Climate Change Implications of the Brazilian Energy Outlook

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1. Introduction

1.1 Energy, poverty and climate change

The world faces a crucial decision at the beginning of the 21st century. For our own survival and that of the planet, it is essential to cut back greenhouse gas emissions in order to reverse, or even slow down, the current rate of global warming, and to simultaneously cut the current obscene levels of poverty.

Central to this context is the supply and use of energy in all its forms. Rich industrialized countries burn fossil fuels at a phenomenal and unsustainable rate and are primarily responsible for causing global warming. Meanwhile nearly two billion of the world's poorest people never get to switch on a light bulb and are suffering the worst impacts of climate change because poverty means they are least able to cope (EDF, 2002).

Energy is central to reducing poverty, providing major benefits in the areas of health, literacy and equity. More than a quarter of humanity has no access to modern energy services. In sub-Saharan Africa, 80 per cent of people have no access to electricity. In fact, energy and poverty are linked.

If the world continues to follow a "business as usual" energy path, current projections of increased energy demand threaten a massive disruption of the global biosphere. Climate change is a direct threat to sustainable development, especially in developing countries, which are the most vulnerable, yet least able to cope (DFID, EC, UNDP and WORLD BANK, 2002). In fact, poor people are most vulnerable to global warming because they lack the resources to cope with climate variation and extreme climate events resulting from global warming.

Thousands have already died and millions more have become homeless refugees as a result of extreme weather events caused by the changing climate. Impacts of climate change are being felt worldwide from the Arctic to the Antarctic. The recent Fourth Assessment Report (TAR) from the Inter-governmental Panel on Climate Change (IPCC) is the clearest scientific analysis yet of climate change impacts, which are already happening now and can be expected to be aggravated in the coming years. The impacts on millions of poor people living in the developing world are harsh (IPCC, 2007). Poverty limits the capacity to cope adequately with climate change impacts such as increased drought, famine, floods, threats of epidemics, cyclones, and other catastrophes.

The paradox is that those most vulnerable to climate change are least responsible for the planet's pollution and global warming. In fact, the buildup of the greenhouse effect has mainly been caused by the large scale burning of fossil fuels since the Industrial Revolution. Industrialized countries are not only the main consumers of such fuels today, but have been the largest consumer for over two centuries now.

Within this context, an adequate supply of energy is an important key to sustainable economic and social development and to curb the increase of GHG emissions for many countries. The role of renewable energies (RE) in this context is related to two main points: cutting greenhouse gas emissions in the industrialized world and getting cheaper energy to the world's poor in the long run.

The rapid expansion of clean and sustainable energy offers a win-win situation for the poor and the environment. For the poor, particularly the rural poor without basic energy services, renewable energy is often the cheapest option. For industrialized countries, a massive adoption of renewable energy will help to achieve the dramatic emissions cuts needed to avoid climate change. The growth of renewable energy is both necessary to provide energy services without choking the planet and to create the economies of scale necessary for a global expansion of renewable energy.

Energy as a key factor in development and climate protection has been given increasing prominence in public awareness internationally, leading to greater readiness among bilateral and multilateral donors to contribute to its promotion. Many developing countries (including Brazil, China, India, and South Africa) have taken active steps toward improving framework conditions in favor of sustainable energy systems. The lower product costs resulting from increased mass production and technological progress have made RE systems more competitive. International manufacturers and project developers are increasingly more willing to become engaged in the RE sector in developing countries.

1.2 The anthropogenic increase of greenhouse effects and the necessity for a "decarbonation" of national energy source

Following are essential aspects of Brazil's participation in the question of climate change (EIA, 2004):

- Status in Climate Change Negotiations: Non-Annex I country under the United Nations Framework Convention on Climate Change (ratified June 4th, 1992). Signatory to the Kyoto Protocol (April 29th, 1998).
- Emissions: Although Brazil's carbon emissions are fairly significant in the region carbon intensity, the amount of carbon emitted per dollar of GDP, is comparatively low. In 2000, carbon intensity measured an estimated 0.15 metric tons of carbon.
- Energy-Related Carbon Emissions (2000): 95.1 million metric tons of carbon (about 1% of world carbon emissions)

Per Capita Energy-Related Carbon Emissions (2000): 0.57 metric tons of carbon (vs U.S. value of 5.7 metric tons of carbon)

- Forest-Related Carbon Emissions: Deforestation in Amazonia alone releases an estimated 200 million tons of carbon (about 2.5% of world emissions) annually. This corresponds to 55% of Brazil's total emissions of greenhouse gases (MCT, 2004)

The results shown in the last set of IPCC (2007) reports confirm the already strong suspicions that were being raised by Panel scientists in their earlier reports about the causes of the global warming. According to the latest reports, these causes are actually to be attributed at least in great part to human activities, with certainty on the order of 90% (in the previous assessment report of the IPCC, published in 2001, this percentile was on the order of 66), mostly to growing carbon dioxide emissions. These emissions result from the burning of fossil fuels (fossil coal, oil, natural gas), which has been moving the world economy since the Industrial Revolution, but they also result from other human activities.

Actually, the consumption of fossil energy is the main cause of greenhouse effect intensification (IPCC, 2007). Thus, any strategy focused on the mitigation of this environmental problem of global proportions requires the rationalization of this consumption.

Climate change makes us question, today, existing production and consumption patterns, since the causes of change are strongly connected to the consumption of fossil fuels. The solution of this problem demands radical changes in these patterns, requiring a progressive "decarbonation" of national energy sources, implemented by progressively increasing the share of renewable energy sources in replacement of fossil sources.

Each country has its own specific energy matrix, meaning that the energy available for consumption comes from different sources, shaped by the available resources as indicated by some international data shown on Table 1.

Significant contributions to the generation of greenhouse gases come from sources based on fossil fuels for generating electricity in all these countries, with their share of the national energy matrixes topping 50%. Actually, the "decarbonation" of national energy matrixes is a clear path to relieving the impacts caused by global climate change.

Table 1 - International data on power generation. Source: International Energy Data, National Energy Balance (BEN), 1999.

Country	Shares held by Power Generation Source, 1993 (%)				
	Oil Products	Coal	Natural Gas	Nuclear and Hydro	Other Sources
USA	49	4	27	15	5
Canada	42	2	28	23	5
France[1]	2	2	2	91	3
UK	48	7	29	16	0
Mexico	63	2	17	9	10
Chile	56	6	2	12	24

Emission reduction requires the elimination of waste, and the development of new production technologies and of alternative energy sources. Also, by reducing emissions, oil, energy and environmental stocks will be conserved, both locally and globally.

In this context, it must be pointed out that the above reduction has an important and fundamentally role in the international market of carbon credits – in which Brazil is participating through projects connected to the Clean Development Mechanism (CDM). This market, with the help of the flexibility mechanisms agreed upon in the third COP (Conference Of Parties) in Kyoto, Japan, will be able to total up to US$ 10 billion/year around the year 2010 (Point Carbon, 2007). It is estimated that the Brazilian share would be about US$ 1.2 billion in connection with sales of carbon credits (generated by CDM projects) to the countries included in Annex I in order to meet their targets for the first commitment period of the Kyoto Protocol, from 2008 to 2012. (Point Carbon, 2007). Projects connected to lower energy-intensive generation (in the case of Brazil, chiefly biomass, small hydroelectric and wind power plants) are eligible for inclusion in the CDM.

2. Brazilian energy: historical and recent evolution

In 1940, Brazil had a population of only 41 million people, 69% of which were living in rural areas, and overall domestic energy supply was 24.3 M toe (million tons of oil equivalent) / year. By 1990, half a century later, more than 70% of the total population of 145 million were living in cities and the country had nearly doubled its average energy consumption per capita (from 0.6 to 1.0 toe / year). From the end of the Second World War until the eighties, the face of the country changed dramatically and an accelerated economic growth was averaging 7% per year. Under the import substitution drive, in 2000, the industrial sector had reached about 30% of GDP, with services amounting to 60% and agriculture barely 10% (MME, 2001). The unprecedented pace of urbanization helped to bring demographic growth down to 1.4% per year from rates of above 3% per year in the fifties.

Together with industrialization and urbanization, the building of a road infrastructure coupled with the dominant role of a locally-based car industry, thanks to the country's modernization drive, completely changed its energy demand and supply profiles. In 1945, firewood supplied over 80% of Brazil's energy needs, compared to 5.5% oil, 5% coal and only 1.6% hydropower. In 1990, the two large centralized state-owned energy systems for oil and hydropower dominated two-thirds of the energy supply, while the share of firewood was reduced to 15%.

The large rise in the use of electricity could be met by the huge hydropower potential of the country, 70% of which still remained to be tapped in 1990. But as Brazil did not seem to be an oil-rich country (total known resources equated to some 10 years of domestic consumption levels), oil imports have met most increased domestic needs. In 1973,

France has either made the most or the least progress towards energy sustainability depending on one's point of view. For those who see nuclear as a sustainable option, France is a pioneer and leader. To those who see nuclear as dangerous and/or expensive, France, which depends on nuclear energy for 75 to 80% of its electricity supply, is setting itself up for an eventual mammoth conversion to a combination of fossil fuel and renewable energy sources, with the probable emphasis on the former. It has reasonably good biomass and wind resources, which it has only recently begun to develop. France will maintain a high degree of energy sustainability as long as its nuclear industry avoids accidents and problems, which might increase public resistance. If it is forced to convert to other electricity sources, it will face enormous costs.

the first oil shock caught Brazil with barely 17% of its oil needs met by domestic production. After the second oil shock in 1979-80, the oil bill amounted to the financial equivalent of more than half of Brazilian exports (LA ROVERE, 1983).

An ambitious programme was thus launched by the government to substitute alternative domestic energy sources for imported oil. Domestic oil production increased to 60% of total consumption in 1990. And from the mid-seventies to the mid-eighties renewables gained momentum in Brazil to reduce the skyrocketing foreign exchange expenditures that were the result of the high international prices and the large oil imports. The construction of large hydropower plants was accelerated. Aside from this, the surface area covered by reforestation programmes has continuously increased at fast-growing rates, providing renewable sources of firewood.

Today, hydropower accounts for the majority (75.9 %) of all electricity generated (data to 2006 year, as follow EPE, 2007). Ethanol from sugarcane secures about 25% of the energy consumed by car transportation (*Diretrizes da Política de Agroenergia*, 2005). Energetic product derivatives from sugarcane supply 14.1% of the Brazilian Energy Outlook (MME, 2004). Renewable firewood and forest waste are estimated to provide up to 80% of domestic firewood consumption. Residential (52.3%) and industrial (34.2%) sectors are the most important consumers of primary wood. In Industry this high participation is mainly because of the important role of charcoal as a fuel and feedstock for pig iron manufacturing. Up to 20% of the wood used in industry is estimated to be renewably produced. The Alcohol Programme has become the symbol of the struggle for energy self-sufficiency. In 2003, ethanol production from sugarcane has reached 14.5 billion litres to supply gasoline blending at 25% ethanol content and fuels 4.2 million cars that run on pure alcohol (MME, 2004).

It should be pointed out that this energy strategy, which incidentally was very effective in avoiding CO_2 emissions, which lead to global environmental benefits, was not free from negative social and ecological impacts at the local and regional levels. High environmental costs had to be supported by the Brazilian society due to the way hydropower (LA ROVERE, 1993) and ethanol production (LA ROVERE, 1981) were implemented.

During the eighties, the economic picture deteriorated progressively with snowballing foreign debt and high inflation rates contributing to a decade of economic recession. Government deficits and negative balance of payments meant that the government no longer had the capacity to maintain the same energy policy. Then, in the mid-eighties, a sharp decrease in oil prices on the international market seriously affected the cost-effectiveness of the extensive efforts aimed at reducing oil imports, such as the Alcohol Programme.

Population growth rate continued to decline in the nineties, reaching an annual average of 1.4% for the decade. Per capita GDP is currently 7 to 10 times less than it is in industrialized countries. Energy consumption per capita is much lower than in OECD countries. The energy-intensity of GDP (energy demand of 0.3 toe / US$1000 of GDP) in the nineties was higher than in OECD countries, given the relative weight of energy-intensive industries in the economy and the high demand for transportation. Energy consumption increased at a faster pace than economic activity during the nineties, fuelled by sustained growth of oil, natural gas and power consumption.

The evolution in the nineties showed a sharp increase in the consumption of oil and natural gas – a growth of more than 50% in the decade – which made the fossil fuel share of the national energy balance grow from 38% in 1990 to almost 43% in 2000, as shown on Table 2. It's also relevant to mention that this expansion (in the share of fossil fuels) is not only due to the relative decrease of international oil prices and the significant increase in domestic oil and gas production following the discovery of important Brazilian offshore resources. Financial constraints on the public budget have also severely affected the support of renewable energy production.

Hydropower development has been delayed and the building of new plants nearly stopped. Due to the inability of public funds to meet the huge investment required for expansion, the power sector is now being privatised. The new trend points to the building of gas-fired thermopower plants by the private sector, as a less capital-intensive option generally coupled with the availability of foreign funding facilities.

Table 3 shows that in the generation of electric power in Brazil, renewable sources are particularly predominant, due to large-scale hydroelectric power plants. Comparing this data with Table 1 data,

Table 2 - Domestic Energy Supply in Brazil from 1945 to 2005, 10^3 toe10^3 toe*2 (% in the total Brazilian domestic energy supply)
* Part of the wood comes from deforestation and is not renewable
** Others includes nuclear, new renewable (biomass, small hydro plants and aeolian energy) and non-renewable energy.Source: MME, 2006.

	Oil and Gas	Coal	Hydro Power	Wood*	Sugarcane	Others**	Total
1945	1456 (5.5%)	1333 (5.0%)	413 (1.6%)	22631 (85.7%)	579 (2.2%)	0 (0.0%)	26411 (100%)
1950	4280 (12.9%)	1583 (4.8%)	536 (1.6%)	25987 (78.1 %)	892 (2.7%)	0 (0.0%)	33278 (100%)
1955	6574 (20.9%)	1760 (4.3%)	925 (2.3%)	28428 (69.3%)	1318 (3.2%)	0 (0.0%)	41004 (100%)
1960	12668 (25.7%)	1412 (2.9%)	1580 (3.2%)	31431 (63.9%)	2131 (4.3%)	0 (0.0%)	49222 (100%)
1965	16354 (28.7%)	1833 (3.2%)	2193 (3.8%)	33692 (59.0%)	2992 (5.2%)	0 (0.0%)	57064 (100%)
1970	25420 (38.0%)	2437 (3.6%)	3420 (5.1%)	3182 (47.6%)	3593 (5.4%)	223 (0.3%)	66945 (100%)
1975	44289 (48.5%)	3201 (3.5%)	6219 (6.8%)	33195 (36.3%)	4161 (4.6%)	363 (0.4%)	91386 (100%)
1980	56485 (49.2%)	5902 (5.1%)	11063 (9.6%)	31083 (27.1%)	9217 (8.0%)	1010 (0.9%)	114761 (100%)
1985	52185 (39.8%)	10021 (7.6%)	15499 (11.8%)	32925 (25.1%)	17877 (13.6%)	2500 (1.9%)	131006 (100%)
1990	62085 (43.7%)	9615 (6.8%)	20051 (14.1%)	28537 (20.1%)	18988 (13.4%)	2724 (1.9%)	142000 (100%)
1995	76210 (46.8%)	11984 (7.4%)	24866 (15.3%)	23266 (14.3%)	22814 (14.0%)	3834 (2.4%)	162975 (100%)
2000	96999 (50.9%)	13571 (7.1%)	29980 (15.7%)	23060 (12.1%)	20761 (10.9%)	6245 (3.3%)	190615 (100%)
2001	100523 (51.8%)	13349 (6.9%)	26282 (13.6%)	22443 (11.6%)	22916 (11.8%)	8414 (4.3%)	193927 (100%)
2002	100176 (50.4%)	13005 (6.5%)	27738 (14.0%)	23639 (11.9%)	25431 (12.8%)	8748 (4.4%)	198737 (100%)
2003	96612 (47.9%)	13145 (6.5%)	29494 (14.6%)	25997 (12.9%)	27085 (13.4%)	9370 (4.6%)	201704 (100%)
2004	96580 (47.8%)	13527 (6.7%)	29477 (14.6%)	25973 (12.9%)	27093 (13.4%)	9284 (4.6%)	201934 (100%)
2005	102708 (48.1%)	14225 (6.7%)	30804 (14.4%)	28203 (13.2%)	28775 (13.5%)	9030 (4.2%)	213744 (100%)

it's possible to see that the Brazilian energy matrix is typically "clean" (high participation of RE).

Today, Brazil has a relatively clean energy supply mix thanks to the strategy developed during the seventies to replace imported fossil energy with renewable sources such as hydropower and biomass. Nevertheless, the sustainability of the Brazilian energy supply mix deteriorated during the nineties. This was for the most part due to the adoption of structural adjustment policies. Several renewable sources were no longer attractive after the market was opened to foreign capital and after energy companies, as well as energy-intensive industries such as the steel industry, were privatized.

There is, however, a certain tendency to reverse this scenario for the closing years of this first decade of the 21st century. This tendency is based on the following main aspects:

Implementation of government programs that can effectively help the increased use of renewable energy in Brazil (especially, the PROINFA);

A clearly possible expansion of projects connected to the Clean Development Mechanism (originated by the ratification of the Kyoto in 2005 and the influence of this fact on the growth and strength of the international market of carbon credits);

*2 Tons of oil equivalent

Table 3 - Installed capacity for electric power generation – Brazil, September 10th 2007.Source: ANEEL, 2007.

Hydroelectric power plants	76,760 MW
Gas Natural	10,171 MW
Gas (process)	1,151 MW
Oil (Diesel)	2,904 MW
Oil (residual)	1,442 MW
Biomass (sugarcane bagasse)	2,832
Biomass (black liquor)	795 MW
Biomass (wood)	224 MW
Biomass (biogas)	20 MW
Biomass (residues from rice culture)	19 MW
Nuclear	2,007 MW
Mineral coal	1.415 MW
Aeolian energy	237 MW
Imports (from Paraguay, Argentina, Venezuela and Uruguay)	8,170 MW
Total	108,147 MW

Existence in the country of know-how for the development of technologies aimed at the implementation of projects for renewable energy generation.

In addition to these aspects, a large international context must be mentioned, in which governments of several industrialized countries (especially in Europe), are defining the inclusion of renewable energy sources in their energy matrixes as relevant targets.

3. CO_2 Emissions from the energy system

In the energy sector, according to Brazil's Initial National Communication to the United Nations Framework Convention on Climate Change (MCT, 2004), at present (September, 2007) the only source for official Brazilian emissions data, all anthropogenic CO_2 emissions from energy production, transformation, and consumption are estimated following the IPCC guidelines adapted to Brazilian circumstances (IPCC, 1996). These emissions result from fuel combustion[3] and fugitive emissions in the chain of production, transformations, transmissions, and consumption. Table 4 shows CO_2 emissions from the Brazilian energy system.

Regarding the data shown on Table 4, it is important to note that CO_2 emissions from the smelting process in steel plants were aggregated to emissions from combustion and considered in the Energy Sector, because it was not possible to separate such emissions (MCT, 2004).

In 1994, CO_2 emissions in the Energy Sector made up 23% of total CO_2 emissions, having increased by 16% (compared to 1990). Only one subsector, Transport, was responsible for 40% of CO_2 emissions in the Energy Sector in 1994 and 9% of total emissions (MCT, 2004).

Emissions from industrial processes other than steel plants accounted for only 1.6% of total emissions, with the production of cement and lime representing the greatest share (80%). In the period from 1990 to 1994, emissions from industrial processes did not vary too much (MCT, 2004).

The greatest share of CO_2 emissions was due to the Land-Use Change and Forestry Sector (75%). Conversion of forests for other uses, particularly agricultural use, accounted for the greatest share

Table 4 - CO_2 emissions from the energy system, 1990 and 1994.Source: MCT, 2004.

Fossil Fuel Combustion	1990	1994	1994 Share	Variation 1990/1994
	(10^3 tCO_2/year)		(%)	
Fossil Fuel Combustion	***197,972***	***231,408***	***22.5***	***17***
Energy Industries	22,91	25,60	2.5	12
Manufacturing Industries	61,26	74,07	7.2	21
Iron and Steel	28,74	37,890	3.7	32
Chemicals	8,55	9,040	0.9	6
Other Industry	23,96	27,140	2.6	13
Transport	82,02	94,320	9.2	15
Civil Aviation	5,82	6,200	0.6	7
Road	71,15	83,300	8.1	17
Other Transports	5,051	4,818	0.5	-5
Residential	13,750	15,176	1.5	10
Agriculture	9,998	12,516	1.2	25
Other	8,030	9,723	0.9	21
Fugitive Emissions	***5,381***	***5,096***	***0.5***	***-5***
Total (Energy Sector)	**203,353**	**236,514**	**23.0**	**16**

3 Flaring of gas in platforms and refineries, and spontaneous combustion of coal in deposits and waste piles are included.

of total CO_2 emissions, including the CO_2 removal from the regeneration on abandoned managed lands and change in soil carbon stocks (MCT, 2004).

The Brazilian per capita emissions ratio is still kept below the U.S. level thanks also to a very low pattern of CO_2 emissions per unit of energy consumed. This can be explained by the very large share of renewable energy in the Brazilian energy matrix, as shown on Table 2.

To put it in an international perspective, Brazil ranks somewhere between fifteenth and twentieth place for CO_2 emissions from energy consumption, a level which corresponds to roughly 1% of total global emissions (IEA, 2004). Brazilian CO_2 emissions per MWh of electricity generated are less than a tenth of US levels and in the car transportation sector, CO_2 emissions per energy used are half of U.S. figures.

However, the evolution in the last twenty years shows a sharp increase in the consumption of oil and natural gas which rose the share of fossil fuels (basically, oil, coal and natural gas) of the national energy balance from 47.4% in 1985 to around 54.4% in 2003, as shown on Table 2.

The reversal of the trend that was observed in 1990 is not only due to the relative decrease of international oil prices and the significant increase in domestic oil and gas production following the discovery of important Brazilian offshore resources. The financial constraints on the public budget have also severely affected the support of renewable energy production. Recent evolution trends of Brazil's energy system are now an increase in CO_2 emission growth rate.

Hydropower development has been delayed and the building of new plants nearly stopped. Due to the insufficiency of public funds to meet the huge investment required for expansion, the power sector has been partially privatized. The new trend points to the building of gas-fired thermopower plants by the private sector as a less capital-intensive option generally coupled with the availability of foreign funding facilities.

The Alcohol Programme was frozen after the international oil price drop in 1986. Sales of new ethanol-powered cars went down to nearly zero (from more than 90% in 1985). Soft loans directed to increase the area of sugarcane plantations and ethanol production were cut. Eventually, the ethanol content blended with gasoline had to be increased to from 22% to 25% in order to absorb ethanol stocks. However, the number of purely ethanol-driven cars has been decreasing due to the phasing out of old vehicles, from more than 5 to around 4.2 millions cars now.

If the trends observed in the nineties persist and in the last years of the present decade (2001-2010) persist, CO_2 emissions from the energy system are bound to overtake emissions from deforestation in the long run. Economic growth will substantially increase energy needs and the consumption of oil and natural gas is increasing faster than renewable energy production.

On the other hand, given the huge amount of natural resources available in the country, the potential for renewable energy production remains largely untapped. Similarly, there is still significant potential for energy conservation. So, considering reducing the impacts of Global Climate Change means a diversification in the national energy supply (and consumption) matrix.

3.1 Future Emission Trends

Given the huge uncertainties about the current level of GHG emissions from land-use change, it is very difficult to make any forecast about future emissions. Merely indicative scenarios can be posited upon the basis of past and current trends.

The rate of increase of CO_2 emissions from the energy system will depend upon the evolution of key variables such as population and economic growth, the energy intensity of the economy, and the carbon intensity of the energy system. In some scenarios found in the literature (LA ROVERE, coord. 1993; LA ROVERE et al. 1994), CO_2 emissions from the combustion of fossil fuels range from 550 to 726 Mt C / year in 2010 and 729 to 1,512 Mt C / year in 2025.

4. Diversification of the Brazilian energy as an option to relieve global climate change.

Renewable energy is a basic ingredient for sustainable development. The use of Renewable Energy Technologies (RETs) in Brazil and in the world is especially important in the context of minimizing global climate change (and, at the same time, providing off-grid energy access for the poor). The replacement of diesel-based isolated systems by renewable energy can contribute to reducing pollutant emissions and carbon emissions and will be entitled to access the incentives from the carbon market being created by the perspectives of the Kyoto Protocol.

In fact, expanding the use of new RETs (with, as a consequence, the diversification of the energy matrix) is one of the best policy options to reduce greenhouse gas emissions. RETs can be provided with local resources to remote communities, guaranteeing the necessary energy supply with much lower environmental impacts than transporting energy produced in distant places. Another advantage, among many others, is achieving energy independence (Goldemberg, Coelho and Lucon, 2003).

4.1 Current Situation of Renewable Energies in Brazil

Wind

There are just 237 MW of wind power capacity installed in Brazil (ANEEL, 2007), corresponding to a small share of the total power capacity. Almost 90% of this value represents the capacity connected to the grid and in these cases windmills of medium to high capacity are used. This technology is available in Brazil from some international manufacturers.

The best wind potentials are concentrated on the coastline of the Northeast region and, to a lesser extent, on the coastline of the South and Southeast of Brazil. Moreover, some very good sites located far from the coast have been reported in the states of Minas Gerais and Paraná (Brazilian Wind Energy Atlas, 2001).

Biomass

According to ANEEL (2007), in September 2007 there were 277 biomass-based thermoelectric plants with an installed capacity of 3,890 MW. The majority of these plants (233) use sugarcane bagasse.

Large-scale electricity production from sugarcane bagasse would help to improve diversification and to further reduce production costs of its traditional products – sugar and ethanol.

Small hydro

In the case of isolated communities, the most significant possibility for expanding energy access is small hydro plants. By early 2004, small hydroelectric plants (less than 30 MW) accounted for almost 1.2 GW generated by 242 plants. In the short term, an additional 3.5 GW could be built. According to Eletrobras, small hydro represents a potential of 9.5 GW, an evaluation that could be even higher considering the lack of existing information. The assessment of small hydro's potential is still under development.

Generally, this technology minimises adverse environmental impacts from large hydro plants, also improving the economy and quality of life of areas alongside rivers.

Photovoltaic

Although PV technology has been developed and used in Brazil for almost 2 decades for off-grid suppliers, only in recent years was it actually recognized as a potential option to help the country to overcome the challenge of improving quality of life for citizens living far from urban centres. PV is finally being seen as an alternative for electricity generation for basic needs (lighting, water pumps, refrigerators etc.) in remote areas. Today there are around 12 MWp installed in the country. Government programs, electricity distribution utilities, private entrepreneurs and a few NGOs are gradually paving the road that will lead to a broader dissemination of PV technology. Large initiatives are already on course but still need very close attention in this initial stage.

In fact, photovoltaic (PV) generation is gaining increased importance in Brazil as a renewable source due to advantages such as the absence of fuel cost, little maintenance and no noise and wear due to absence of moving parts. But there are still two principal barriers to the use of photovoltaic systems: high installation cost and low energy conversion efficiency.

Biomass energy sources

Brazil has a high potential for the use of biomass[4]. The main modern sources of biomass are sugarcane products, agricultural residues, wood from reforestation and vegetable oils.

The use of biomass residues for electricity generation in isolated systems is especially important and desirable when it substitutes fossil based generation. It is important to mention that the use

4 "biomass" considered as sustainable biomass: agricultural and forest residues, solid waste and biofuels (Goldemberg and Coelho, 2003).

of biomass should take place sustainably.

In isolated regions, most of the sources of residues from agricultural activities, forest residues (branches, leaves, etc) and sawmill by-products (sawdust, wood chips etc) can be used as fuel to generate electricity with technologies commercially available in the country, including gasification and small-scale steam cycles.

Another huge opportunity for biomass use is the electricity generation from *in natura* vegetable oils in specially-adapted diesel engines. The Amazon region in Brazil has an enormous diversity of native oil plants, favourable conditions of soil and weather for the cultivation of highly productive exotic oil plant specimens with environmental and social advantages.

Nuclear energy

During the seventies, eighties and nineties, nuclear energy lost its importance as a global alternative for electric power generation on account of the social and environmental risks it presents, in view of the public reaction caused by very grave accidents which occurred in various countries (especially in Europe), and of the high costs of building and de-activating atomic power plants. It's important to mention that in today's context, considering the growing relevance of the global warming theme, nuclear energy has been considered a viable and appropriate source of energy by many countries.

Fuel Cells

A new energy source has been recently put forward as a definite alternative: the hydrogen fuel cell. A technology already a few decades old, it has been drawing the attention of research groups all over the world, including in Brazil (COPPE/UFRJ and FEM/UNICAMP).

It is possible to generate electric power using fuel cells. By means of a chemical reaction, hydrogen is extracted from fossil or renewable-source fuels, and generates electricity that is immediately consumed, moving a motor without the need for a battery. From the environment point of view, it is important that in the final use there is no emission of greenhouse gases. An important objective of researchers is to extract hydrogen from water by reactions that generate electricity (hydrolysis). Thus we will have water-supplying hydrogen, which through chemical reactions generates electricity and water again.

Because of the natural depletion of the world's oil reserves, these alternatives will have to be implemented more and more in future decades, and most probably we will see a gradual substitution of fossil fuels by diversified, renewable sources of energy, thus contributing to reduce global climate change, leading ultimately to the planet's sustainability.

4.2 Other alternatives

In addition to the change of national energy matrixes, for the purpose of minimizing global climate changes, the following strategies are being pursued:

- To improve efficiency in the production and utilization of fossil fuels;
- For the transportation sector:
  - Research and development of new, alternative and/or more efficient fuels
  - Change to less polluting fuels;
  - Inter-modal substitutions (such as using high-speed trains instead of airplanes for distances below 1,000 Km, according to IPCC, 1999).

The improvement of the diversification of Brazil's energy matrix will depend on the implementation of adequate public policies. In this context, two important government programs must be mentioned:

- **PRODEEM** → The *Programa de Desenvolvimento Energético de Estados e Municípios* is the main government-sponsored off-grid electrification program. From 1996 to 2000, PRODEEM provided 3MW in PV panels to 3,050 villages, meeting the needs of 604,000 people from a total investment of R$ 21 million financed by National Treasury funds;

- **PROINFA** → Program for Incentives for Alternative Electric Energy Sources → The first phase of PROINFA will support the increase of installed capacity of renewable generation capacity to the grid system by 3,300 MW (1,100 MW wind, 1,100 MW biomass and 1,100 MW small hydro plants). The second phase will be developed to ensure that, after 20 years, wind, biomass and SHP supply 10% of annual electric power consumption in Brazil. The purchase of energy will be made through public bids, ensuring that a minimum of

15% of the annual power market growth be supplied from these three sources. The contracts will be signed with Eletrobras for 20 year periods.

5. Climate change as an opportunity to promote sustainable development through the expansion of renewable energy sources: an analysis of the second phase of PROINFA and the use of bio-diesel oil.

Second phase of PROINFA

Even though the second phase of PROINFA is still uncertain, we will make a quick calculation of the CO_2 removal in the case of its implementation.

A projection was made by the preceding government (MME, 2002) of 5% yearly growth for the electric power market. 15% of the demand generated by this growth should be supplied by the second phase of PROINFA, so that, by year 2020, 10% of the yearly electric power consumption would be supplied by alternative energy sources. This implies an expansion of alternative energy sources from 16.4 TWh in 2005 to 77.7 TWh in 2022, which means an increase of 61.4 TWh generated by alternative energy sources.

If we accept that the three main alternative sources (wind, biomass, SHP) will have the same share of the total increase, the emission removal in the last year of PROINFA (2022) will be 34.3 million tCO_2/year (hypothesis 1) or 19.9 million tCO_2/year (hypothesis 2). By calculating emissions for the period from 2006 to 2022 and considering a conservative estimate of US$ 5.00 for Certified Emission Reduction (CER[5]), we find a CO_2 removal of 350 million tCO_2, for a value of US$ 1.75 billion for hypothesis 1, and a removal of 204 million tCO_2, for a value of US$ 1.17 billion for hypothesis 2. If we only consider the second phase of PROINFA we will have in the 2006 – 2022 period a total CO_2 removal of between 134 and 230.5 tCO_2, for a value of US$ 0.670 billion to US$ 1.15 billion (NAE, 2005).

5 CERs are climate credits (or carbon credits) issued by the CDM EB (Executive Board of the Clean Development Mechanism) for emission reductions achieved by CDM projects and verified by a DOE under the rules of the Kyoto Protocol. CERs can be used by Annex-I countries in order to comply with their emission limitation targets or by operators of installations covered by the European Union Emission Trading Scheme (EU ETS). CERs can be held by governmental and private entities on electronic accounts.

Biodiesel oil

The possibility of the production of Biodiesel oil as a Clean Development project is quite significant, in view of the existing financial and operational barriers involving scale and planting problems to be considered that may justify improvements. Furthermore, according to tests made on vegetable oils and reprocessed cooking oil, the GHG emission reduction is about 78% (OLIVEIRA, 2003)

The quantity of Diesel oil imported is about 6.0 billion litres per year, costing the country around US$ 1.2 billion. The introduction into this sector of 2% Biodiesel oil would demand a production of 800 million litres (MME, 2004a), generating yearly savings of US$ 160 million.

In addition, the replacement of 2% Diesel oil by Biodiesel will reduce CO_2 emissions by about 1.7 tCO_2/year, considering that Diesel oil has a CO_2 emission rate of 2.7 tCO_2/m^3 and that Biodiesel oil has a 78% lower rate. Considering a price of US$ 5.00 per CER (Certified Emission Reduction) unit, we would obtain a value of US$ 8.5 million/year. This could be used as a stimulating factor for the production of Biodiesel oil in the country. However, according to the report "Preliminary evaluation of Biodiesel oil in Brazil" (MACEDO and NOGUEIRA, 2004) the sale of carbon credits at US$ 5.00 would correspond to only 3% of production cost (considering the cost of soybean oil and a potential reduction of greenhouse gas emissions of 40% to 60%, according to data of canola biodiesel oil in Europe). Since studies made in Brazil point to emission reductions of about 78%, the sale of carbon credits may represent more than 3% of production costs. Other recent studies, though, show that for soybean oil the potential for GHG emission reductions would be near the value found for canola biodiesel oil.

6. Final discussion

According to the analysis shown in the present work, the Brazilian energy matrix is

particularly "clean", with a large share of renewable energy sources (see Table 2). However, in Brazil, as in most countries, the participation of fossil sources in the matrix is still very large, especially if we consider its effects on global climate change.

The diversification of the energy matrix undoubtedly appears to be an important strategy to mitigate the emission of greenhouse gases, reducing the effects of many problems connected to global warming. In the case of Brazil and of most developing nations, to diversify the energy matrix will accrue other important benefits, such as: reliability of internal energy supply, stimulation of supply alternatives that expand the potential of each region (generating, as a sub-product, social, technological and economic developments), independent energy sources (helping to reduce the foreign debt), a sustainable long term energy supply and the reduction of local pollution.

The path to a cleaner energy matrix will generally require the adoption of four macro-strategies: (a) expansion of production and consumption of renewable source energy (in the case of Brazil, especially biomass, hydroelectric, solar and wind energy);(b) research for alternative or more efficient fuels for transportation; (c) introduction of inter-modal substitution; (d) improvement in the production and final use of fossil fuels. This path will unavoidably lead to a reduction of greenhouse effect gas emissions and an improvement of global climate changes.

It is important to mention, in connection with the increase in the use of renewable energy in the country, the "demand pull" caused by recent regulations enforced by the Brazilian Federal Power Regulatory Board (ANEEL) that require utilities to ensure electricity supply to all households of the country by 2015 (or 2008, considering the targets of the Light for All Program). This "demand pull" provides a good opportunity for decentralized power generation from renewables (small hydropower, biomass, solar and wind energy) to complement conventional options to achieve this goal (grid extension and diesel generators). Environmental, social and economic co-benefits of this "leapfrogging" of renewable energy development can thus translate into more sustainable patterns of energy supply. In some cases, the use of renewables would also help to accelerate the achievement of targets to ensure full coverage of electricity needs of low-income populations living in remote locations. In order to tap the potential of renewables to contribute to this development goal, an appropriate regulatory framework must be established, allowing for building capacity and appropriate incentives to motivate action by different stakeholders. The Clean Development Mechanism is one potential tool that can be helpful towards this end, illustrating a "win-win" synergy between sustainable development and climate change mitigation. Actually, the CDM results in a real opportunity for Brazil to promote its sustainable development and at the same time to increase its technological and financial capacity, attracting capital to implement "clean" projects that would not be considered otherwise.

Actions aimed at reducing greenhouse gas emissions in developing countries will no doubt offer opportunities. However, the challenge to slow down the increasing anthropogenic emissions that cause the greenhouse effect requires worldwide awareness that becomes highly complex in view of the necessity of coordinated actions on the international level. In this context, the adoption of a wide policy of increasing conservation and more efficient use of energy by industrialized countries, which are responsible for 84% of the total energy consumption (LA ROVERE, 2000), is an urgent necessity.

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