SCIENCE FOR A BETTER LIFE:
DEVELOPING REGIONAL SCIENTIFIC PROGRAMS IN PRIORITY AREAS
FOR LATIN AMERICA AND THE CARIBBEAN

VOLUME 3

SUSTAINABLE ENERGY IN LATIN AMERICA AND THE CARIBBEAN: POTENTIAL FOR THE FUTURE

DÉCIO LUIZ GAZZONI • IVAN AZURDIA • GABRIEL BLANCO • CLAUDIO A. ESTRADA • ISAIAS DE CARVALHO MACEDO

ICSU
International Council for Science
Regional Office for
Latin America and the Caribbean

CONACYT
Consejo Nacional de Ciencia y Tecnología

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ICSU-LAC • CONACYT

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FOREWORD

Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization that plans and coordinates interdisciplinary research to address major issues of relevance to both science and society. Over the years the geographical breadth of ICSU activities has changed. Increasingly a major emphasis for ICSU has been the development of scientific capacity in developing countries and the integration of these scientists in international research initiatives.

The creation of three ICSU Regional Offices, established in Africa, Asia and the Pacific, and Latin America and the Caribbean also marks a fundamental change in ICSU structure, the aim of which is two-fold. First, it should enhance the participation of scientists and regional organizations from developing countries in the programs and activities of the ICSU community. Secondly, it will allow ICSU to play a more active role in strengthening science within the context of regional priorities through scientific collaboration.

Especially in regard to Latin America and the Caribbean, this is an important step in bridging the 'islands of competence' that exist in every country and that together will be able to advance significantly the scientific research agenda in the region. The first step towards the establishment of a Regional Office was the appointment in 2006 of the Regional Committee for Latin America and the Caribbean, composed of renowned scientists of the region.

The Regional Office for Latin America and the Caribbean was the third to be established and was inaugurated in April 2007. It is hosted by the Brazilian Academy of Sciences, in Rio de Janeiro, Brazil, and supported by the Brazilian Ministry of Science and Technology, ICSU, and CONACYT Mexico. From October 2010 it will be hosted by the Mexican Academy of Science, with the support of CONACYT Mexico.

Based on the ICSU Strategic Plan 2006-2011, the Regional Committee has selected four priority areas to be developed:

- Mathematics Education;
- Biodiversity: knowledge, preservation and utilization of biodiversity of all countries of the Latin American and Caribbean region, and to ensure that the scientific community of the smaller countries of the region are fully integrated in DIVERSITAS;
- Natural Hazards and Disasters: prevention and mitigation of risks especially of hydrometeorologic origin with special attention to the necessary social science research;
- Sustainable Energy: assessment of the existing capacities in the LAC region and the social impact of the use and development of new energy resources.

Four Scientific Planning Groups were appointed to develop proposals that reviewed the current status of the priority area in the region and to formulate a set of detailed objectives and targeted areas of research to be developed in the next few years.

Engaging highly qualified scientists from Latin America and the Caribbean, the Scientific Planning Groups did outstanding work within a restricted time limit. We thank each and every one of the participants for their enthusiasm and dedication.

This document is the final report of the Scientific Planning Group in Sustainable Energy, which is being submitted to the scientific community with the expectation of effectively influencing the development of scientific research in this area in the years to come.

Alice Abreu
Director
Regional Office
for Latin America and the Caribbean

José Antonio de la Peña
Chair
Regional Committee
for Latin America and the Caribbean

EXECUTIVE SUMMARY

This document aims to address research, development, and innovation (RD&I) issues regarding the use of renewable energy resources in Latin America and the Caribbean (LAC). This is fundamental for decreasing natural risks and saving biodiversity. Besides, it will greatly improve the living conditions of communities that are not connected to power grids.

An overview of the global and regional energy situation is introduced, indicating the risks of maintaining the existing structure of the World Energy Matrix, with its highly depending on fossil fuels. Those risks include the quick depletion of proven oil reserves in relation to global oil consumption, the environmental hazards associated to fossil fuels —especially greenhouse gas emissions (GHG) and the consequent global climate change—, and the concentration of world's reserves in a small number of countries. On the other hand, the potential of the main renewable energy sources (biomass, wind, and solar energies) in LAC is discussed. And finally, a list of research and development priorities is presented.

Renewable energy made up roughly 100 percent of the available energy sources until the beginning of the Eighteenth Century. Scientific and technological development, together with the exploitation of accessible coal reserves and —at the end of the Nineteenth Century— the discovery crude oil and its derivatives, including natural gas, made our global society deeply dependent on fossil energy sources. During almost one century —from 1880 to 1970—, the adjusted price of crude oil on the international market oscillated around 15.00 USD/barrel, allowing our global society to embrace a dream of virtually infinite low-cost energy, or what may be called, a bonus without onus.

As of June 2008, oil price skyrocketed to 147.00 USD/barrel; more than 1000 percent increase in just one year.

As global society became aware of the costs and risks of maintaining the existing world energy matrix, several initiatives like the Kyoto Protocol, which represent nowadays a paradigm for international action, aimed to reduce the impact of greenhouse gas emissions into the atmosphere. National governments are issuing public policies to promote the use of renewable energy sources and the recycling of materials, in order to reduce the negative impacts of our widespread dependency on fossil fuels. These incentives encompass end users, business chains, and RD&I institutions.

Scientific and technological advances are essential to promote a progressive change, from the present energy matrix to a more sustainable one in the near future. Thus, analysis of the different renewable energy sources indicated that biomass, solar, and wind energies are promising alternatives for centralized or scattered power production in LAC. These, together with small-scale hydropower plants, are also important for small and isolated communities located in off-grid regions.

The successful development and implementation of a strategic plan for sustainable energy practices and technologies should be supported by three main building blocks:

- Research on specific scientific and technological issues that can contribute beyond present day technology and the industry's own development, and play a role in the adaptation of state-of-the-art technologies to local and regional scenarios in terms of energy resources characteristics, cultural aspects of the communities involved, and other local and regional circumstances.
- Capacity building at the institutional and individual levels, by means of joint research programs with world-renowned scientific and technological institutions in North-South and South-South cooperation schemes.
- Design and implementation of public policies based on scientific information to create the necessary enabling environment for the full implementation of sustainable energy practices and technologies.

A selected list of identified RD&I priorities includes:

Biomass

- Biomass productivity, which includes plant biology and agricultural practices.
- Processing biomass into end-use energy, or energy carriers, including heat and electric power production; biomass for domestic cooking; fueling Diesel engines with biofuels; hydrolysis and fermentation of sugarcane biomass; direct conver sion of sugar into fuels; and biogas.
- Biorefinery processes.

Solar energy

- Resource assessment.
- Passive solar heating, and daytime lighting of buildings.
- Solar thermal energy for heating and cooling.
- Solar photovoltaic power production.
- Solar thermal power generation.

Wind energy

- Wind resource estimation.
- Wind turbines.
- Wind farms

Related technologies, including energy carriers, and standards and certification

- Hydrogen production and utilization.
- Power grid integration, and connection protocols and procedures.
- Risk assessment methodology.

This document also proposes several activities that may contribute to institutional and individual capacity building, and it intends to offer useful information in order to help establish sound and sustainable public policies on renewable energy sources in the LAC region.

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CONTENTS

1. INTRODUCTION

The history of humankind is a corollary of energy sources availability and use, from the ancient eras to a visionary future. Civilization, culture, development, and other evolutionary aspects of human race, are consequences of the discovery and evolution of new —and generally better— energy sources, and the efficiency of their use in benefit of society (see Debeir *et al.*,).

Renewable energy sources represented roughly 100 percent of available energy until the early Eighteenth Century. Scientific and technological development, the exploitation of accessible coal reserves, and —at the end of the Nineteenth Century— the discovery of crude oil and its derivatives, including natural gas, made our global society dependent on fossil energy sources. During almost one century —from 1880 to 1970— the adjusted price of crude oil on the international market oscillated around 15.00 USD/barrel, allowing the world society to embrace a dream of virtually infinite low-cost energy, or what may be called, a bonus without onus. As of June 2008, oil price skyrocketed to 147.00 USD/barrel; more than 1000 percent increase in just one year, as shown on Figure 1.

Until the last quarter of the Twentieth Century, only a few academics had looked deeper into the externalities of the growing share of fossil fuels in the world energy matrix. Also, studies on the relationship between oil availability (reserves)

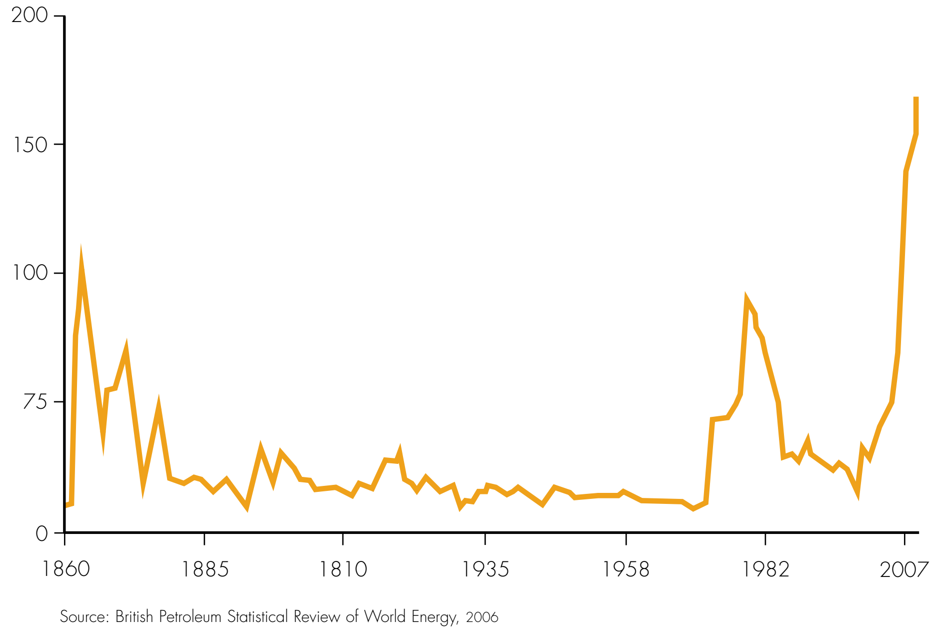


Figure 1. Historical prices of crude oil, 1861-2007.

and oil consumption were confined to academic mathematical models, since individuals and society do not react to long-range contingencies like the phasing-out of oil wells, even when statistics are clearly showing that oil production rate is exceeding the discovery rate of new proven reserves (Figure 2).

The uneven distribution of such reserves and the concentrated nature of the oil industry provoked also distortions and biases in geopolitics and income distribution, leading to disputes, whether open or masked, for the control of major oil reserves. And last, but not least, scientists established a strong connection between burning fossil fuels and the present global climate change, dramatically increasing the frequency of extreme climatic events (like snow, wind or rain storms;

tornados; droughts; or floods), and rising the Earth's temperature with a forecasted increase of 2-6 °C during this century.

Suddenly, the world is turning back to renewable sources. Our global society is becoming aware of the costs and risks of maintaining a world energy matrix that is highly dependent on fossil fuels. International organizations are looking for ways to reduce the impact of greenhouse gas emissions into the atmosphere, and the Kyoto Protocol was the first of such initiatives and a paradigm for international action. National governments are issuing public policies that promote the use

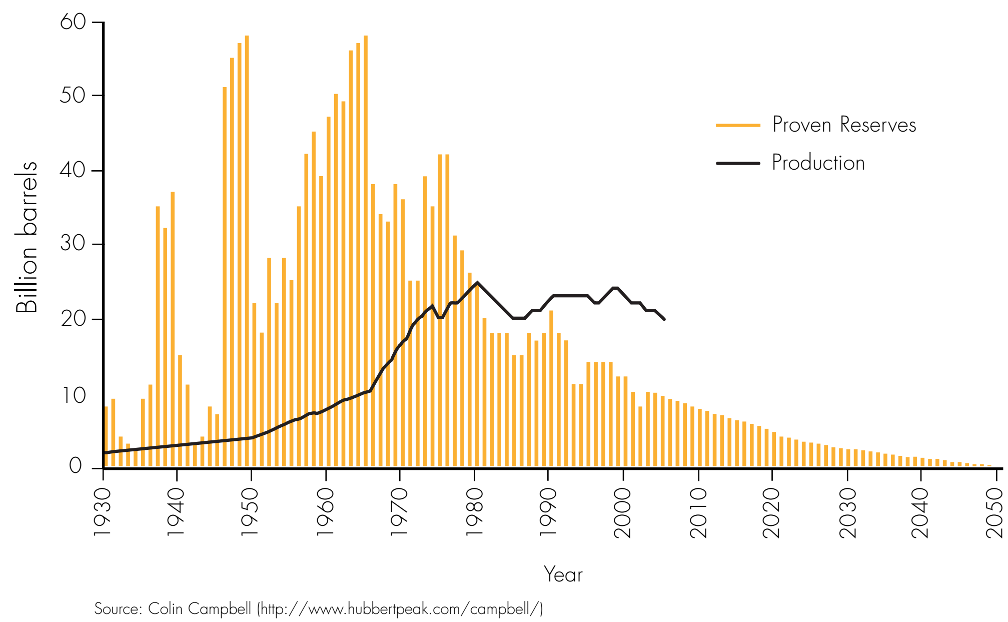


Figure 2. Annual incorporation of new oil reserve discoveries and oil production.

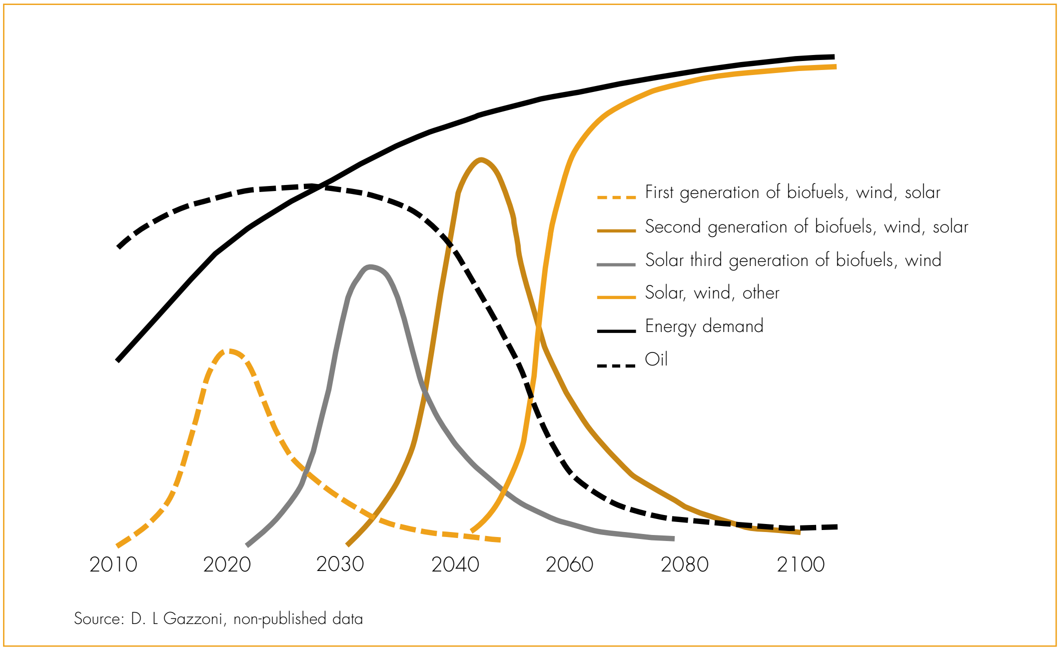


Figure 3. Timeline of energy demand, crude oil phasing-out, and introduction of renewable energy sources into the world energy matrix.

of renewable energy sources and the recycling of material, to reduce the negative impacts of our widespread dependency on fossil fuels. These incentives encompass end users, business chains, and research, development and innovation (RD&I) institutions.

The general feeling is that the world has to count on its present state-of-the-art technology to launch initial actions, but it also depends strongly on successive and innovative technological breakthroughs to overcome the negative effects of more than one and a half centuries of fossil fuel burning, and to look for a more sustainable future, where fossil energy sources will be replaced almost completely by renewable energy sources, as shown on the prospective energy timeline presented in Figure 3.

There are several energy issues, which are extremely diverse in their economic, environmental and social backgrounds and need to be addressed, and the challenge is to identify the RD&I connections to each one of those issues. Among them, it is worthwhile mentioning:

- Society is globally afflicted by quite a few problems, like environmental degradation (climate change, pollution), deforestation (dramatic tropical forest losses), depletion of ocean fisheries, poverty, human migration, famine, lack of energy security, and unemployment, among others. Governments must act to regulate conflicts and enforce the claims of the society. If our world must change from fossil to renewable energy sources, governments should issue public policies that restrict the use of the former while encouraging a larger market share for the latter and, at the same time, making the most of any opportunity to lower the unemployment rates. However, this should be done without paying non-affordable environmental costs, nor by reducing worldwide food production. While sustaining the present state of affairs, governments must look ahead into the future and build infrastructure in preparation for such change. Actions may include economic compensations, tax incentives to force migration to renewable, regulatory legislation, incentives for renewable energy generation, education, and most of all, paving the road to the future by financing RD&I on renewable sources.
- Our global society should openly discuss the access to present energy sources for an estimated 2 billion people who live in extreme poverty. A wise approach would be to initiate quick and intense actions to give them energy access based on the increment of renewable sources. This means that financial subsidies should be mobilized in order to avoid a more intensive use of fossil fuels. Also, grants from institutional donors should be directed toward

regional RD&I on renewable sources to support realistic programs. This is not a theoretical issue, since the phenomenon is already taking place in most developed countries, as well as in China, India, Vietnam, Cambodia, and other Asian nations, and it's quite likely to happen also in Africa and LAC. The same approach would be equally satisfactory to give energy access to the isolated communities that exist in nearly all the under-developed and developing countries.

- The present global way of life has been shaped on the premise of an endless energy supply in its current forms, which mean portability and a relatively low cost and without deleterious environmental impact. Sustainable development should be approached from all its primary dimensions —economic, environmental and social. In the past, development issues have tended to be considered more narrowly, and mainly restricted to the economic dimension. The momentum for the sustainable development movement is, in part, a reaction to that way of thinking. RD&I should not focus narrowly on economic arguments, but look more closely at local cultures, habits, sociological aspects, and autonomous scientific development, to help it move quickly to new levels of sustainable living standards and wellbeing.
- So far, no particular attention has been given to renewable energy development. Basic research, which means studies on basic science, should be performed to avoid imposing limitations on technological development. After the fossil fuel era, energy independence will be possible if based on its own technology. This approach includes the creation of mathematical models, prototypes, and small-scale pre-commercial evaluation pilot plants, among other comprehensive studies, not to mention basic scientific lines like physiology, synthetic biology, materials science, genetics, biochemistry, and theoretical physics, among others.

From this analysis, we may conclude that the bridge to a more sustainable energy future will be built on new technological paradigms, from present first-generation biofuels, early wind-driven and photovoltaic (PV) devices, and solar thermal energy, all the way up to a hydrogen era with extremely efficient wind-driven and PV devices, new approaches to extract energy from other renewable sources, coupled with portable low-cost, high-density energy storage means. The challenge we face is to build this bridge on time, before the phasing-out of oil and natural gas reserves, and before global warming caused by fossil fuel burning causes a worldwide decline in human wellbeing, and an increase in poverty. At the same time, biomass supply for other uses, like food, fodder, fiber, timber, ornate, pharmaceuticals, and raw materials for the chemical industry, must cope with the demand of our global society, and have at least the same priority given to energy production.

Latin America and the Caribbean (LAC) have to be a part of this global effort, but with some significant peculiarities. Presently, this region is placed midway between the intensive-energy-use countries from the developed world, and the poorest countries from Africa and Southeast Asia. This means that our average per-capita energy consumption rate is not too high, so changes will not be especially painful, although they point to the need to scale up. Also, most of our countries' national energy matrixes are not extremely dependent on fossil fuels, except for Argentina, Ecuador, Mexico, and Venezuela (oil-producing countries), as well as some Caribbean Islands that did not have the chance to effectively mobilize their natural renewable energy resources up to the moment.

However, considering that not only "hard" engineering and technological sciences are involved, we must also look more closely at the environmental and sociological aspects of the energy issue, including the traditional knowledge accumulated over millennia. Many issues related to comprehensive natural resource management and biodiversity conservation, as well as to their sustainable use, require a combination of technological and traditional knowledge. Traditional knowledge holders tend to view people, animals, plants, and other elements of the universe, as interconnected by a network of social relations and roles. For the purposes of this report, we consider that *traditional knowledge is a cumulative body of wisdom, know-how, practices, and interpretations, which is maintained and developed by people with long traditions of interaction with the natural environment. These sophisticated sets of understanding, interpretation, and meaning are part and parcel of a cultural complex that encompasses language, naming and classification systems, resource use practices, rituals, spirituality, and a vision of the world. Typically, the worldview embraced by traditional knowledge holders emphasizes the symbiotic nature of the relationship between humans and the natural world.*

While the relevance of science and technology (S&T) for sustainable development is acknowledged in general, a large gap persists between what the S&T community thinks it can offer, and what society demands and supports. In recognition of this gap, the S&T community is calling increasingly for a "new contract" between science and society in order to reach sustainable development. In order to be a good partner to society in the proposed "new contract," the S&T community needs to look for sources of inspiration, and complete its traditional approaches with several new orientations. Research and development (R&D) priorities should be set and implemented, so S&T can contribute to the solution of our most pressing sustainability issues.

Finally, we have to take into account that there are several research, development and innovation (RD&I) institutions in the region, including a network of important universities, technological and technical institutes, private enterprises, and R&D departments dedicated to the study of biomass for food and fodder, that can be instrumental in coordinating the global effort to drive an energy matrix change toward a sustainable future. Networking (at the national, regional, and global levels), financial support from important donors and local governments, technical assistance, and social support will be the cornerstones of such R&D actions, envisioning a new energy arrangement with sound social, environmental, and economic fundaments.

2. A GLOBAL AND REGIONAL OVERVIEW OF THE ENERGY SITUATION

Fossil fuel use, especially crude oil, expanded very quickly throughout the world because of its portability, ease of use, low cost and relative abundance. As a consequence, the world experienced very high development rates during the Twentieth Century, in regard to better living standards, based on a more intensive use of energy for transportation, heating, cooking, healthcare, culture, and educational services. At the same time, crude oil turned out to be the basis of new chemistry branches that lead to new materials, like plastics, polymers, pharmaceuticals, pesticides, and fertilizers, among others.

Currently, a direct relation between Human Development Index (HDI) and energy consumption is clearly observed. One UNDP study (UNDP, 2006) demonstrated that while the world's average HDI was 0.741 (2004), the countries with highest HDI (between 0.9 and 1) also had the highest electricity consumption levels; for instance, Japan, France, the Netherlands, Italy, the United Kingdom, Germany, Israel, and South Korea (ca. 7 GWh/person/yr), Australia (11 GWh/person/yr), the United States (14 GWh/person/yr), Canada (18 GWh/person/yr), and Norway (25 GWh/person/yr). On the lowest HDI side, Niger and Zambia, whose HDIs are 0.3 and 0.4, respectively, showed per capita electricity consumption rates below 200 kWh/person/yr. The best ranked Latin American countries, Brazil, Argentina, and Mexico, with HDIs between 0.8 and 0.85, reported electricity consumption levels below 2 GWh/person/yr.

For logical economic reasons, crude-oil companies focused for decades on the extraction of the easiest-to-reach, cheap crude oil. At first, oil was extracted near the surface of the ground. Typically, this oil was of the "light-and-sweet" type —i.e., oil very easy to refine into products such as unleaded gas and heating oil. However, during the last three decades, the global rate of new oil fields discovery has been lower than the actual consumption rate. In recent years, new proven reserves account only for 27 percent of the actual consumption.

Energy consumption and use efficiency vary dramatically in different parts of the world. In 2005, global annual per-capita average energy consumption (i.e., excluding traditional biomass and waste) was 1 519 kg of oil equivalent (kgoe). While high-income countries average 5 228 kgoe, low-income countries only

Table 1. Crude oil statistics related to oil peaks

Measurement	Measure
Estimated overall oil reserves	3 000 Gb
Produced to dateha	873 Gb
Reserves	928 Gb
Discovered to date	1 801 Gb
Yet to find	149 Gb
Yet to produce	1 077 Gb
Ultimate recovery	1 950 Gb
Current consumption rate	22 Gb/año
Current discovery rate	6 Gb/año
Current depletion rate (ann. prod. as a % of Yet to produce)	2%

Source: Colin J. Campbell (http://greatchange.org/ov-campbell.outlook.html)

Table 2. Statistics for oil production
and reserves/production rate in years - Latin America and the Caribbean

	1986	1996	2005	2006	World	
Country	Gb	Gb	Gb	Gb	Share	R/P
Argentina	2 233	2 600	1 972	1 972	0 14%	7 55
Brazil	2 358	6 681	11 772	12 182	0 89%	18 45
Colombia	1 700	2 798	1 453	1 506	0 11%	7 39
Ecuador	1 235	3 453	4 866	4 664	0 34%	23 45
Mexico	54 880	48 472	13 670	12 908	0 94%	9 60
Peru	0 536	0 774	1 078	1 078	0 08%	25 56
Trinidad and Tobago	0 564	0 723	0 809	0 809	0 06%	12 77
Venezuela	55 521	72,667	80 012	80 012	5 83%	77 62
Other	0 455	1 109	1 269	1 270	0 09%	24 91
LAC	119 482	139 276	116 902	116 401	8 48%	41 21

Source: BP Annual Report 2007

average 250 kgoe. Traditional biomass and waste account for 10.6 percent of total global primary energy supply. In low-income countries, such sources represent, on average, 49.4 percent of the supply, with some countries approaching 90 percent.

Energy consumption depends primarily on population growth rate and per-capita income increase. According to FAO, human population will keep growing, in spite of its progressively declining annual rates, until 2050, when it will supposedly stabilize, and then decrease toward the end of the century. On the economic field, the world is experiencing an unprecedented period of steady high economic progress, especially in developing countries. Table 2 presents the statistics for LAC's oil production and reserves.

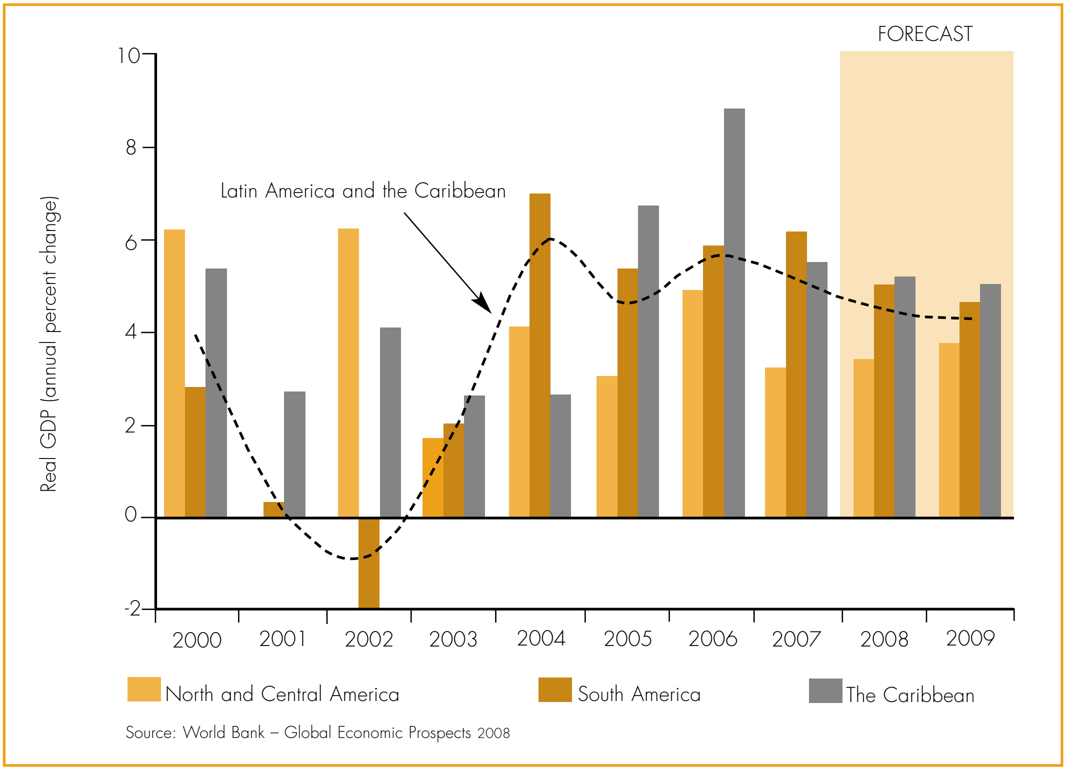


Figure 4. Economic growth in LAC (real GDP, annual percent change).

In the last five years, world's average GDP growth fluctuated between 3.5 and 4.5 percent. During this period, LAC's GDP growth exceeded the world's average, and the forecast for 2008-2009 is a 5 percent growth rate (Figure 4).

According to the EIA's 2008 World Energy Outlook basic scenario, and assuming that current energy policies will not shift markedly in the medium run, in 2030 the world energy needs will be more than 50 percent higher than today. According to general consensus, China and India will account for 45 percent of the increase in the demand. These trends would lead to a continued increase in energy-related greenhouse gas (GHG) emissions and to a greater reliance of consumer countries on oil and natural gas imports —mostly from the Middle East and Russia. This scenario would heighten concerns about climate change and energy security. The key conclusions on global climate change of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), released in early 2007, were astonishing and point to an increase of extreme weather events (severe snow storms, tornados, droughts, and flooding), as well as an escalation in ocean level rise and global average temperature.

Most GHG emissions (Figure 5) are attributed to the use of fossil fuels —coal being the most hazardous one, and natural gas the less harmful to the environment. The challenge is to initiate a transition toward a more secure, lower-carbon

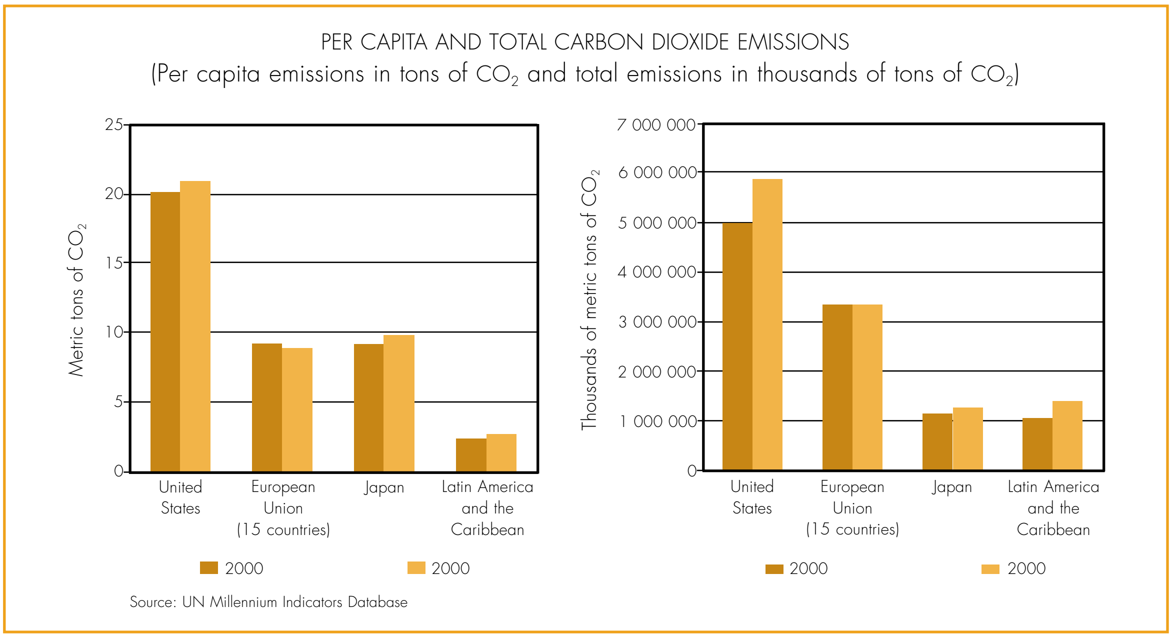


Figure 5. Global per capita and total carbon dioxide emissions.

energy system, without undermining our economic and social development. Nowhere will this challenge be tougher, or more relevant for the rest of the world, than in China and India. Vigorous, immediate, and collective policy action by all governments is essential to lead the world to a more sustainable energy path. Measures to improve energy efficiency stand out as the cheapest and fastest way to curb oil demand and emission increases in the short run.

Considering all aspects mentioned above, the major threats for humankind derived from its dependence on fossil fuels are: a) Reduction of the world's oil reserves and climbing oil prices; b) uneven distribution of fossil fuel reserves; c) GHG emissions leading to global climate change.

In LAC, the annual per capita energy consumption varies significantly from country to country; for instance, around 300 GJ per capita in Trinidad and Tobago, but only 10 GJ per capita in Haiti. Another indicator that points to the extremely diverse nature of the region is the energy intensity of the different countries, which varies from 36 MJ/$ (PPP) in Trinidad and Tobago (a major exporter of natural gas) to a mere 4 MJ/$ (PPP) in Barbados. LAC's average energy intensity fluctuates around 11 MJ/$ (PPP), which is slightly higher than the world's average —about 10 MJ/$ (PPP). The region's overall energy consumption is presented on Table 3, and LAC's energy matrix is shown on Figure 6.

It's worth mentioning that better living conditions are needed in LAC, which means higher energy per-capita consumption. The strategy to achieve this is based on saving energy (i.e., avoiding unnecessary energy waste), and substituting fossil fuel by renewable sources, rather than on reducing the overall, or per capita energy consumption rate.

Population and income growth are key drivers for global energy consumption. Population growth forecasts for the LAC region indicate that peak annual

Table 3. Energy consumption in LAC

COUNTRY	POPULATION 10³ Inhab (A)	P/B 10³ USD (B)	FINAL ENERGY CONSUMPTION 10³ Boe (C)	PER CAPITA GDP USD/Inhab (D/A)	PER CAPITA FINAL CONSUMPTION Boe/Inhab (C/A)	ENERGY INTENSITY Boe 10³ USD (C/B)
ARGENTINA	38 971	340 315.95	361 886.41	8 732.54	9.29	1.06
BARBADOS	270	1 914.03	2 067.76	7 089.00	7.66	1.08
BOLIVIA	9 627	10 193.52	26 613.39	1 058.85	2.76	2.61
BRAzIL	190 127	764 552.24	1 355 368.32	4 021.27	7.13	1.77
COLOMBIA	46 772	105 573.95	169 013.85	2 257.20	3.61	1.6
COSTA RICA	4 399	21 028.85	24 049.31	4 780.37	5.47	1.14
CUBA	11 240	56 347.54	69 005.45	5 013.13	6.14	1.22
CHILE	16 436	96 533.33	159 150.66	5 873.29	9.68	1.65
ECUADOR	13 408	21 319.73	60 132.19	1 590.08	4.48	2.82
EL SALVADOR	6 991	15 248.18	23 961.46	2 181.12	3.43	1.57
GRENADA	104	476.51	507.01	4 581.83	4.88	1.06
GUATEMALA	13 018	20 968.72	53 938.43	1 610.75	4.14	2.57
GUYANA	752	534.65	5 519.43	843.95	7.34	8.7
HAITI	9 317	3 648.03	17 238.40	391.55	1.85	4.73
HONDURAS	7 518	7 614.79	24 674.87	1 012.87	3.28	3.24
JAMAICA	2 662	8 123.96	28 843.09	3 051.83	10.84	3.55
MEXICO	107 537	665 522.24	800 331.46	6 188.77	7.44	1.2
NICARAGUA	5 594	4 772.22	18 570.15	853.10	3.32	3.89
PANAMA	3 284	15 474.40	22 809.06	4 712.06	6.95	1.47
PARAGUAY	6 365	8 391.03	26 674.34	1 318.31	4.19	3.18
PERU	28 349	70 661.88	86 611.98	2 492.57	3.06	1.23
DOMINICAN REP.	9 240	31 120.65	36 935.43	3 368.04	4.00	1.19
SURINAME	453	1 067.04	4 495.53	2 355.50	9.92	4.21
TRINIDAD AND TOBAGO	1 311	13 800.60	79 014.96	10 526.77	12.77	5.73
URUGUAY	3 478	22 504.08	18 390.02	6 470.41	5.29	0.82
VENEZUELA	27 031	146 638.03	326 320.32	5 424.81	12.07	2.23
TOTAL	564 254	2 454 446.15	3 802 123.27			
REGIONAL AVERAGE				4 349.90	6.74	1.55

Source: OLADE, 18th Energy Economic Information System, 2007

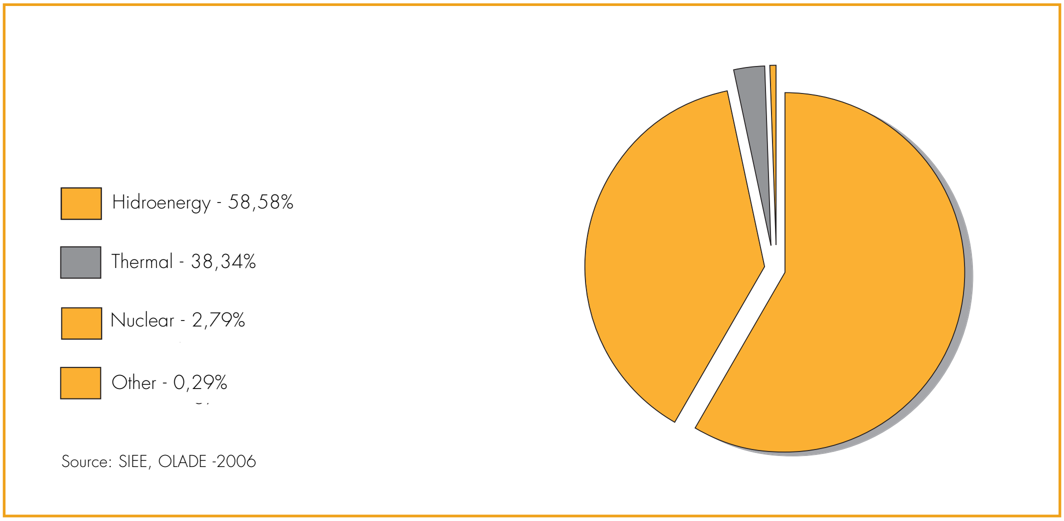


Figure 6. LAC's power generation sources.

population growth was achieved in the 1960s (2.8 percent), and that the future trend is a continuous decrease, from our present 1.2 percent to an estimated 0.25 percent in 2050. Studies indicate a direct and linear relationship between population growth and energy consumption. Under current social and economic conditions, each point on the population growth index means one point on the energy consumption index.

Between 1970 and 1980, economic growth was accompanied by lower energy use per output unit (lower energy intensity), which pointed to efficiency gains and better use of energy resources. The trend was reversed, however, between 1980 and 1985 (per capita income waned, while energy intensity increased), and the same adverse pattern continued between 1987 and 1990. This suggests that improvements in energy efficiency were absent during the economic recession of the 1980s. In the first three years of the 1990s, income levels recovered, but energy intensity remained high. There was scarcely any improvement in energy intensity between 1990 and 2000. While energy intensity indicators have followed fairly similar trends in the different sub-regions, their absolute values vary considerably. Energy intensity is highest in the Caribbean countries, due mostly to the more frequent use of energy-intensive, low-efficiency equipments. Southern Cone countries have the lowest absolute values due to the use of more advanced equipments and energy technologies in their production processes. The Andean countries did not show any significant changes throughout the period considered.

3. GENERAL OBJECTIVES

The successful development and implementation of a strategic plan for sustainable energy practices and technologies should be supported by three main building blocks: **A**. Research on specific scientific and technological issues that can contribute beyond present day technology and the industry's own development, and play a role in the adaptation of state-of-the-art technologies to local and regional scenarios in terms of energy resource characteristics, cultural aspects of the communities involved, and other local and regional circumstances. **B**. Capacity building at the institutional and individual levels, by means of joint research programs with world-renowned scientific and technological institutions in North-South and South-South cooperation schemes. **C**. Design and implementation of public policies based on scientific information, to create the necessary enabling environment for the full and sustainable implementation of sustainable energy practices and technologies.Scientific information necessary for policy makers may include, among other things: **life-cycle environmental analysis** of renewable and conventional energy technologies, including energy and GHG emission balances (carbon footprint); **life-cycle cost analysis** of technological implementation; **multi-criteria analysis of environmental**, social, and economic impacts; **development of sustainability** criteria and indicators for the use of energy resources; **design of public policies**, and their economic, social and environmental impacts, and **regulatory frameworks** necessary for the implementation of public policies.

BOX I

ELAC'S POWER MARKET – FACTS AND STATISTICS

The key findings of the OLADE's document, "A Review of the Power Sector in Latin America and the Caribbean: Evolution in the Market and Investment Opportunities for CFTs," issued in March 2005, is summarized below. The complete document can be accessed at www.olade.org.

- In 2003, the total installed power generation capacity in LAC neared 253 GW.
- Out of the 2003 installed power generation capacity: 52 percent was hydroelectric; 45 percent, thermoelectric; 2 percent, nuclear; and only 1 percent was based on geothermal, wind, solar, and biomass energy sources.
- Total power generation in the 26 OLADE countries reached 1 021 TWh in 2003, which meant a 42.5 TWh (4.3 percent) increase when compared to 2002.
- The power market is growing at an annual rate of 4-5 percent; i.e., approximately 12 GW per year.
- Many LAC countries report high levels of transmission and distribution power loss, which average about 19 percent in the region.
- In 2003, power consumption in LAC reached 820.7 TWh, which meant a 34.2 TWh (4.3 percent) increase when compared to 2002.
- Coal-based power met only 5 percent of Latin America's primary energy demand in 2003; 65 percent of this was used in Brazil. Latin America's proven recoverable coal reserves are estimated in 16 billion tons.
- About 42 percent of all coal production is exported to the EU and the US.
- LAC's proven natural gas reserves were estimated around 7.5 10^{12} m^3 in 2003; this represents 5 percent of the world's total. Venezuela owns 54 percent of those proven reserves, followed by Bolivia (10 percent), Argentina (10 percent), Mexico (8 percent), and Trinidad and Tobago (7 percent).
- In 2003, LAC's natural gas production reached 197 10^9 m^3. Production is expected to expand significantly over the next three decades, to reach 516 109 m^3 in 2030.

- The region's proven oil reserves were estimated at 114.5 billion barrels at the end of 2003; this represents 10 percent of the world's total.
- LAC's production of crude oil and liquefied natural gas (LNG) averaged 9.4 M b/d in 2003; this is expected to increase to almost 12 M b/d by 2030. Today, production is dominated by Venezuela, Mexico, and Brazil.
- LAC owns almost 9 percent of the world's total oil-refining capacity.
- LAC's electric power sector is dominated by South European and US companies.
- In many countries, electric power prices allow power utilities to make some profits. However, political uncertainty and legal framework instability, which are prevalent in the region, increase financial risks.
- LAC is split in two operating power networks with different frequencies: southern countries operate at 50 Hz, whereas northern countries operate at 60 Hz.
- LAC countries —including Central American nations— are moving toward the integration of power networks by implementing the project called Central American Countries' System of Power Interconnection (Sistema de Interconexión Eléctrica de los Países de América Central, SIEPAC), part of the Central America Power Market Framework Agreement (Tratado Marco del Mercado Eléctrico de América Central) and the creation of the Regional Power Market (Mercado Eléctrico Regional).
- In order to meet the growing power demand, roughly 12 GW of new power generation facilities have to be installed annually.
- Seventy-three percent of LAC's power plants have nominal outputs under 50 MW; 23 percent are in the range of 50-400 MW; and 4 percent, in the range of 400-1 000 MW.
- In LAC, most power generation is done by Diesel engine plants (primarily for decentralized power production in remote areas) and conventional steam or gas turbine power plants.
- Natural gas turbines account for 27 percent of power generation; steam turbines for 56 percent; gas combined-cycle plants for 7 percent; and Diesel engine power plants for 6 percent. The remaining 4 percent is produced by geothermal and nuclear power plants.
- 85 percent of all power generation is based on oil and natural gas. Though large coal reserves are present in the region, coal plays a minor role in LAC's power sector.
- Replacement potential close to 9 GW can be identified for the current decade.

The general goal of this document is to provide a basis for research, development, and deployment of sustainable energy practices and technologies that can be integrated to the primary energy matrix of Latin America and the Caribbean (LAC).

The following chapters offer an overview of state-of-the-art renewable energy technologies, as well as the current deployment status of these technologies in LAC, including research and development activities, and the main institutions involved. Besides, future short- and medium-term priority research areas are highlighted in this document.

The report also proposes several activities that may contribute to institutional and individual capacity building.

Hopefully, those proposals will help establish effective public policies for the implementation of renewable energy programs in LAC's countries, as a crucial corollary of the activities discussed.

4. RENEWABLE ENERGY TECHNOLOGIES

This chapter describes the present status of several technologies used to transform renewable natural resources into useful energy forms. The chapter also includes the situation of these technologies in Latin America and the Caribbean including development level, research activities, main institutions involved, and priority research areas.

Renewable energy resources, and their associated technologies included in this analysis are solar energy, wind, biomass, and small hydropower plants, for both on-grid and off-grid schemes. These sources are the most significant for the region in terms of potential and availability. Energy resources such as geothermal and oceanic power (in all its forms) were excluded from this document. However, research and development (R&D) activities on hybrid systems that integrate two or more technologies and energy resources are also suggested.

Beside technology-related research areas, this chapter also mentions other research needs, such as the integration of renewable energy technologies to our current energy systems and energy storage means. System integration includes areas of study such as allocated generation, and grid connection and control. The energy storage R&D issues that are mentioned in this chapter deal mostly with hydrogen production, storage, transport, distribution, and use.

Energy efficiency, though recognized as a major component of rational energy scenarios, is not included as a direct research topic in this document, since energy efficiency involves not only technological issues, but also —and primarily— public policies and measures associated to social behavior.

4.1. BIOMASS

4.1.1. Present status of biomass-derived energy production in LAC

Brazil's story of success in biofuel production and use sparked considerable interest in biofuels across LAC. Several countries have launched important regulatory and legal initiatives to lay the groundwork for future expansion and investment. A few countries

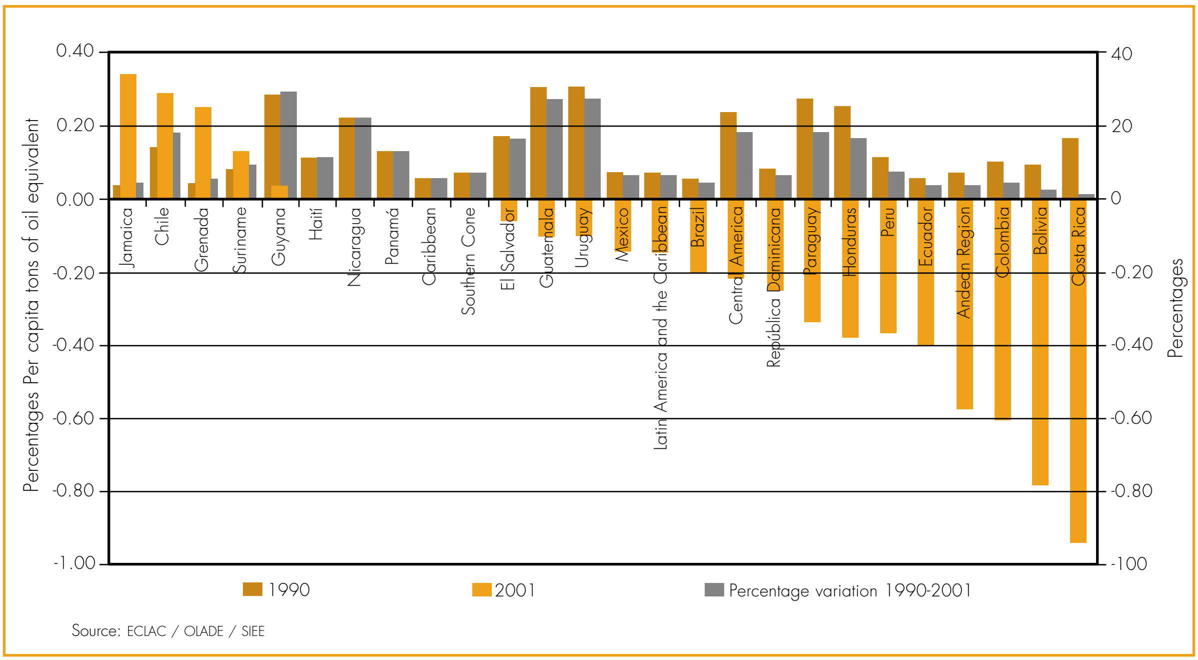


Figure 7. Per-capita household consumption of biomass.

have begun attracting international investors, and others have announced plans for major expansions in their biofuel industry. In some places, the Brazilian government has actively forged relationships that are yielding joint projects and research studies. Figure 7 presents the per-capita household consumption of biomass in the LAC region.

Many of the necessary ingredients for a vibrant biofuel industry are already present. The abundance of arable land, the existence of optimal climatic conditions in the region, and the surplus of biofuel raw materials in many LAC countries increase the regional potential to become a productive center for global biofuel trade. In addition to their natural endowments, the concentration of activity and labor in the agricultural sector means that biofuels are an attractive rural development strategy, as can be seen in Table 4 and Figure 8.

Biofuel-related R&D in the region is unevenly distributed. Brazil leads R&D in LAC. A broad range of research activity exists in Colombia, including public/private partnerships and research sponsored by Ecopetrol, the state-owned oil company. There is also ongoing academic research on palm oil-based biodiesel, and studies performed by sugar and palm oil producers associations to improve crop yields and to identify optimum cultivars for raw material production. In Costa Rica, a promising ethanol initiative between Petrobras and RECOPE is underway. In Argentina, with its long history of interest in biofuels, private sector investors have established a biofuel research center. Several universities are promoting biofuels —particularly biodiesel— through research and involvement in initiatives like the Mesoamerican Network for Biofuel Research and Development (Red Mesoamericana de Investigación y Desarrollo en Biocombustibles). R&D efforts are more limited elsewhere in the region. Brazil launched a long-term joint research initiative, which includes the public and private sectors, on the ethanol production chain (agronomic and industrial innovations), and more recently on biodiesel and other energy carriers.

Table 4. Actual and potential available arable land in LAC

	Total area (1000 ha)	Potential arable Land (1000 ha)	Equivalent Potential Arable Land (1000 ha)	Equivalent Potential Arable land/total area	Actual arable land 1994 (1000 ha)	% of potentialiv arable land actually in use (1994)	Total Population 1994 (1000)	Agricultural population 1994 (1000)
Argentina	277 685	90 571	71 161	26	27 200	30.0	34 182	3 847
Belice	2 063	984	709	34	57	5.8	205	65
Bolivia	108 903	61 917	46 067	42	2 380	3.8	7 237	3 258
Brazil	853 637	549 389	393 802	46	50 713	9.2	159 143	30 978
Chile	75 202	3 327	2 003	3	4 250	127.7	14 044	2 518
Colombia	113 184	65 536	47 690	42	5 460	8.3	34 545	8 429
Costa Rica	5 200	1 205	858	16	530	44.0	3 347	783
Cuba	11 068	7 494	5 788	52	3 370	45.0	10 960	1 768
Dominican Republic	4 879	2 169	1 418	29	1 480	68.2	7 691	1 634
Ecuador	25 263	12 864	9 194	36	3 036	23.6	11 220	3 347
El Salvador	2 015	864	573	28	730	84.5	5 641	1 904
Falklands	1 203	0	0	0	0	NA	2	2
French Guayana	8 038	6 627	5 127	64	12	0.2	141	141
Guatemala	11 045	3 710	2 821	26	1 910	51.5	10 322	5 266
Guyana	20 907	13 305	9 739	47	496	3.7	825	167
Haití	2 723	846	511	19	910	107.6	7 035	4 390
Honduras	11 490	3 424	2 162	19	2 030	59.3	5 493	2 008
Jamaica	1 132	156	108	10	219	140.4	2 429	636
Mexico	196 062	52 162	36 471	19	24 730	47.4	91 858	22 906
Neth. Antilles	92	17	11	12	8	47.1	197	NA
Nicaragua	12 909	5 546	3 663	28	1 270	22.9	4 275	1 013
Panamá	7 569	2 363	1 584	21	665	28.1	2 585	585
Paraguay	39 905	21 589	13 257	33	2 270	10.5	4 830	1 798
Perú	928	114	68	7	77	67.5	23 331	8 281
Puerto Rico	128 922	43 363	30 567	24	4 140	9.5	3 646	122
Suriname	14 429	9 273	6 736	47	68	0.7	418	85
Trinidad y Tobago	514	321	226	44	122	38.0	1 292	119
Uruguay	17 907	14 245	12 522	70	1 304	9.2	3 167	437
Venezuela	92 388	55 092	38 411	42	3 915	7.1	21 378	2 285
Total	**2 047 262**	**1 028 473**	**743 243**	**36**	**143 352**	**13.9**	**471 439**	**108 772**

Source: FAO - Land resource potential and constraints at regional and country levels - world soil resources report 90

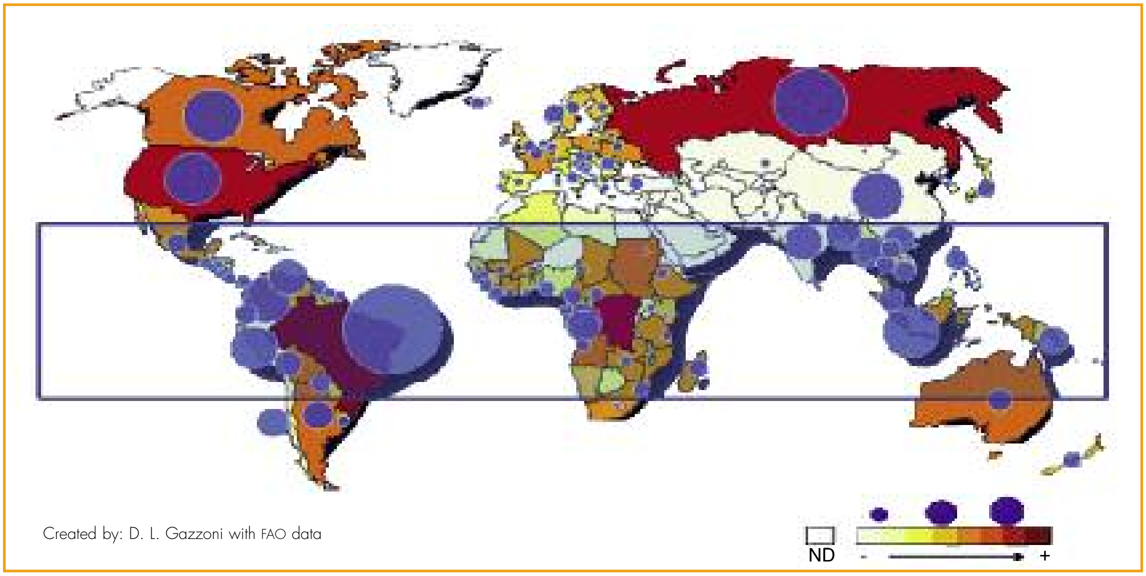


Figure 8. Distribution of potential arable land and water availability for biomass production.

As a whole, the region has made important advances toward establishing a regulatory framework for biofuels. And a number of countries, including Colombia, Guatemala, and Argentina, have progressed well beyond the initial steps. However, governments and regional institutions will need to coordinate and facilitate investment and research. On the other hand, some parts of the region still demand large quantities of firewood and charcoal for household and industrial purposes. Besides being an inefficient and polluting energy source, this resource comes mostly from native forests not always close to the point of consumption, which implies high firewood or charcoal transportation costs.

This process also destroys a valuable CO_2 sink. The most serious aspect related to the use of firewood, including charcoal production, is the accelerated deforestation of certain regions, which causes enormous damage to the environment and contributes significantly to the region's CO_2 emission. The indiscriminate use of this energy source is due to poor accessibility to modern energy sources.

Environmental issues of local nature, such as those related to hydroelectric generation or the use of monoculture crops as energy sources, are common in most of the region's countries. Environmental issues of global nature, particularly the emissions from fossil fuel combustion, are common to all countries, all of which must introduce measures to reduce such global impacts.

Firewood

Estimating the amounts of firewood used for domestic cooking and heating is not an easy task. Therefore, data are normally extrapolated based on the average con-

Table 5. Number of people that rely on traditional biomass for cooking and heating

	Million	% of global population
China	706	56
Indonesia	155	74
Rest of East Asia	137	37
India	585	58
Rest of South Asia	128	41
Latin America	96	23
North Africa/Middle East	8	0.05
Sub-Saharian Africa	575	89
Total, Developing Countries	**2 390**	**52**

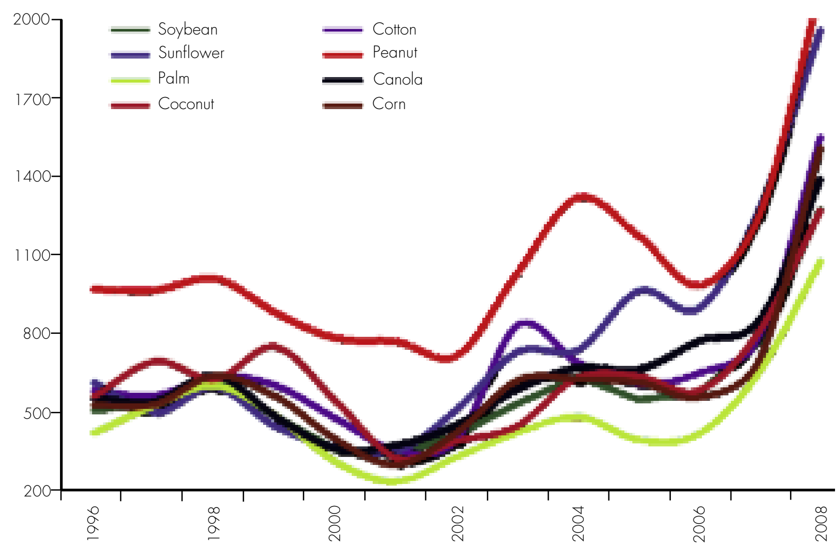
Source: UNDP Energy Services for the Millennium Development Goals, 2005 sumption of populations that still use firewood. According to the UN, the world average consumption is 500 kg of biomass/person/year. Considering that LAC has 575 million inhabitants, and that an estimated 23 percent of those people depend on firewood as their primary energy source, it is estimated that the region burns annually 66 million tons of firewood for cooking and heating purposes (Table 5).

Biodiesel

Starting on 2001, a series of laws and regulations established fuel-blending mandates, regulatory standards, and incentives for biofuel production. Two major countries are involved in biodiesel production and use. In Argentina, legislation will require a minimum mandatory blend of 5 percent biodiesel with diesel oil starting on 2010, which means a market of 750 million liters of biodiesel. However, this country, which produced 200 million liters in 2007 and seeks to produce 800 million liters in 2008, has plans to export 2 billion liters of soybean biodiesel in 2010.

The development of biofuels in Argentina is receiving strong incentives from the government. While exports of soybean oil, for example, are taxed at 24.5 percent, sales of biodiesel pay only a 5 percent tax, and 2.5 percent is refundable in form of tax credits. Brazil has legislation which requires mandatory blending starting with 2 percent biodiesel with diesel oil (effective from January 1st, 2008), meaning an estimated 840 million liters market. In 2010, the blending rate increased to 5 percent, which will require over 2 billion liters of biodiesel per year. Colombia's fuel oxygenation program comprises now 57 percent of the country. Peru has established an initial legal framework for the promotion of biofuels, and to put in place a biofuel promotion program and a Biofuel Technical Commission. Chile is just beginning to address the biofuel subject. Currently there's no biofuel production in Chile, and the Renewable Energies Law, passed in 2003, still awaits the necessary regulatory guidelines. With its significant production of wood chips, it's quite likely that Chile's greatest potential will be on cellulosic biofuel research. Ecuador has instituted policies to promote fuel diversification, and has significant raw material potential in its sugar and palm oil industries.

There's also potential in biofuel production based on vegetable oils or animal fats, though this is considered a threat because the continuous and high global economic growth has led to a dramatic increase in the demand of these products for the nutritional market. In average, oil prices have raised from 300 USD (2001) to 1 400 USD (2008), making it too costly to produce biodiesel from nutritional raw materials, as demonstrated by the fluctuation of major vegetable oil prices on the Chicago Board of Trade (Figure 9).



Source: http://www.fas.usda.gov/psdonline/circulars/oilseeds.pdf

Figure 9. Vegetable oil prices.

Table 6. Present and future estimated soil use in Latin America and the Caribbean

Soil use	Food	Exports	Biofuels	Firewood	Total	Increase	Potential area	Potential area corrected
ha	M ha	M ha	M ha	M ha	M ha	M ha	%	%
2005	114	-	2	5.5	122	-	-	-
2010	139	2	4	4.8	150	28	4.9	11.4
2015	149	12	5.7	4.2	172	49	8.4	19.8
2020	156	25	9.5	3.6	194	72	12.3	28.9
2025	162	31	9.7	3.1	207	85	14.4	33.8
2030	171	36	10	2.7	220	98	16.7	39.3

Source: D.L. Gazzoni, non published data.

As for the conflict between the use of soil for biofuel production instead of other agricultural products, Table 1 shows that, in 2010, only 4.9 percent of the potential arable land established by FAO was in use in LAC's countries. And out of the total cultivated area, only 3 percent was dedicated to biofuel production. A forecast study anticipated that, by 2030, an estimated 16.7 percent of arable lands will be farmed, and about 10 percent of those lands will be dedicated to biofuel production. Even considering that FAO's figures were not ambitious as far as environmental protection, global climate change and urbanization are concerned, the study considered that only 40 percent of the total could be realistically converted into agricultural lands. In that case, approximately 11.4 percent of the potential arable land will be cultivated in 2010, and the figure should increase to 39.3 percent in 2030. Based on this study, it may be asserted that no conflicts can be foreseen for combining the production of food and other high-demand crops with biofuel production in LAC.

BOX II

ETHANOL FROM SUGARCANE IN BRAZIL

After Brazil's initial growth period, spurred by the Pro-Álcool program (to 12.5 M m^3/year, in 1984), ethanol production leveled until 2002, when flex-fuel cars led to a new period of intense growth (from 12.5 M m^3 in 2002, to ~24 M m^3 in 2008). Internal demand scenarios point to 40 M m^3 in 2020, with exports in the 10-15 M m^3 range.

In 2006, 425 M tons of sugarcane were processed by 325 sugar mills (6.6 M ha), with a total yield of 26 M tons of sugar and 15.7 M m^3 of ethanol (derived from 50 percent of the sugarcane). Brazil is the world's second ethanol producer, and the largest exporter of sugar and ethanol (2005). Ethanol substitutes up to 45 percent of gasoline-based fuels for a global fleet of 22 million vehicles. In 2008, flex-fuel vehicles represented 90 percent of all new unit sales.

In 2006, the technological level reached by Brazil's Center-South Region led to an average crop of 82.4 tons of sugarcane/ha (without irrigation), and 35 percent of this was mechanically harvested. Each ton of sugarcane yielded 85 liters of ethanol, plus 2.1 kWh of electric power. Greenhouse gases (GHG) net emission during ethanol production was 0.27 tons of CO_2 equivalent/m^3 of ethanol, which meant a GHG reduction of more than 80 percent when substituted for gasoline. The ratio between renewable energy and fossil energy used for ethanol production was 9.2.

Substantial improvements made in sugarcane productivity, conversion efficiency, and management since 1975, led Brazil to be the world's lowest-cost ethanol and sugar producer. However, new technology for energy production (fuels and electric power) based on sugarcane biomass (bagasse and refuse) may become available in the next years. Full integration of such technology to sugar mill operations may represent a 50 percent increase in total energy output.

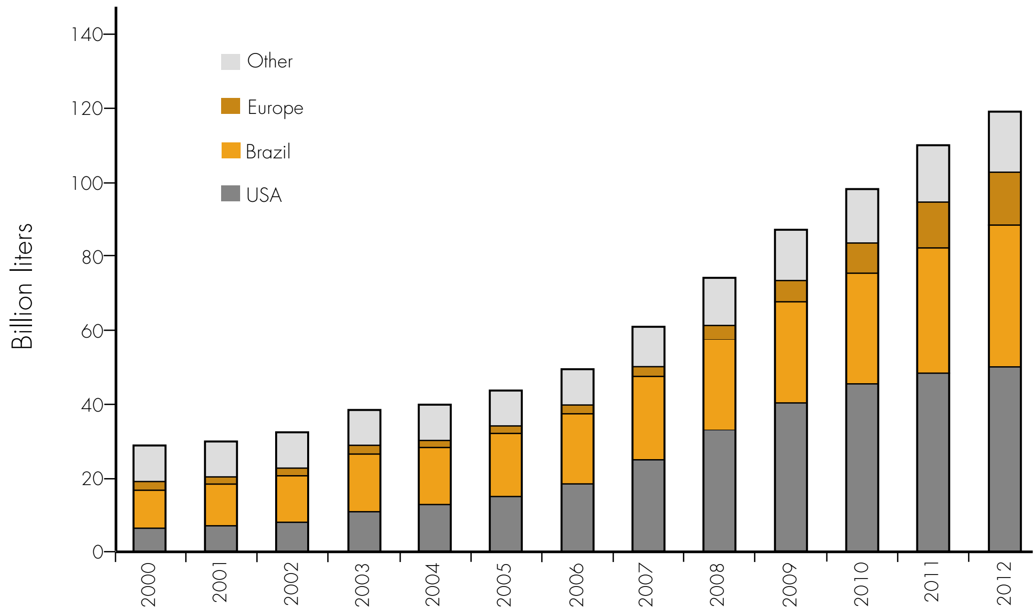


Figure 10. World ethanol production for fuel and other uses.

Ethanol

Fuel ethanol production and use is growing worldwide. In 2006, world production reached 50.4 Mm^3, with 36 percent in the US (corn), 34 percent in Brazil (sugarcane), 8 percent in China (corn); 4 percent in Europe (where other grains and beet are also used as raw materials) (Figure 10). The main drivers for the use of biomass-based ethanol as fuel have been: the need to reduce GHG emissions from burning fossil fuels; and the long- and short-term issues associated with oil-based fuel availability and costs.

In many areas of the world, public policies are leading to a rapid expansion of production: E-10 blends (gasoline mixed with 10 percent ethanol) are targets that many regions set for 2010, and higher blends are proposed (or already in use) in many other regions. In 2007, the US 2015 target for ethanol use was already 35 billion gallons/year; and the EU has plans to substitute 20 percent of its total primary energy sources by renewable ones in 2020. Brazilian sugarcane-based ethanol production is expected to grow to 40 Mm^3 by 2015.

Public policies are essential to spark biofuel programs anywhere. For instance, the modern Brazilian ethanol program began in 1975 with a mandate to blend 10 percent of ethanol in all kinds of gasoline (actually, the mandatory use of ethanol and gasoline blends as automotive fuel began in 1931). The government s obligation to buy a specified amount, at a price based on an independent evaluation of production costs, in addition to the allocation of low-interest loans, fostered the construction of ethanol-producing plants. Large increases in conversion efficiency and productivity led to strong cost reductions in the following years. Therefore, when all subsidies ended (after being reduced gradually until the 1990s), ethanol production was competitive with gasoline at international prices.

The perspective of cellulosic ethanol technologies may boost global production during the next decade. Actually, the present technological constraints posed by some of the raw materials (low energy density and poor energy balance) indicate that, by 2020, sugarcane and other cellulosic materials may become the main biomass sources for ethanol production. Cellulosic ethanol development would also contribute greatly to sugarcane ethanol production and economics, since it would make possible the efficient use of sugarcane refuse and bagasse.

Sugarcane is produced in 100 countries worldwide —among them, all countries in the LAC region. Sugarcane production technology is commonplace in the region, since sugar is a main product everywhere (except in Brazil, where ethanol exceeded sugar production last season). In all countries, some ethanol is produced

Table 7 List of institutions devoted to sugarcane R&D in LAC

Country	Institution	Variety development	Farming practices	Industrial
Argentina	Chacra Experimental Santa Rosa	X		
	Estación Experimental Agrindustrial Obispo Colombres	X	X	
Brasil	Rede Interuniversitaria para o Desenvolvimento Sucroalcooleiro (RIDESA; network formed by 11 federal universities)	X		
	Instituto Agronômico de Campinas (IAC)	X	X	
	Instituto de Pesquisas Tecnológicas (IPT), São Paulo			X
	Embrapa Tabuleiros Costeiros		X	
	Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ/USP; Polo de biocombustíveis)		X	X
	Universidade Estadual de Campinas (UNICAMP; NIPE)		X	X
	Universidade de São Paulo (USP; CENBIO)		X	X
	Universidade Estadual Paulista (UNESP)		X	X
	Centro de Tecnologia Canavieira (CTC)	X	X	X
	Centre for Absorption and Transfer of Technology (NATT), Alagoas		X	X
	Allelyx, Canavialis	X	X	
	Petrobrás (hydrolysis, thermo-chemical processes)			X
	Oxiteno (alcohol chemistry)			X
	Braskem (alcohol chemistry)			X
Colombia	Centro de Investigación de la Caña de Azúcar (CENICAÑA)	X	X	X

Country	Institution	Variety development	Farming practices	Industrial
Cuba	Instituto Cubano de Investigaciones de los Derivados de la Caña de Azúcar (ICIDCA)			X
	Instituto Cubano de Investigaciones Azucareras (ICINAZ)			X
	Instituto Nacional de Investigaciones de la Caña de Azúcar (INICA)	X	X	
Ecuador	Centro de Investigación de la Caña de Azúcar del Ecuador (CINCAE)	X	X	
México	Estación de Hibridación de Tapachula, Chiapas	X		
	Centro de Investigación Científica y Tecnológica de la Caña de Azúcar (CICTCAÑA)		X	X
	Universidades (Veracruz, UNAM, and others)			X
Venezuela	Fundación Azucarera para el Desarrollo, la Productividad y la Investigación (Fundacaña)	X	X	
Guatemala	Centro Guatemalteco de Investigación y Capacitación de la Caña de Azúcar (CENGICAÑA); patrocinado por la Asociación de Azucareros de Guatemala (ASAZGUA) (A + I)		X	X
	Universidad del Valle de Guatemala, Instituto de Investigaciones, Laboratorio de Ingeniería Bioquímica			X
Costa Rica	Liga Agrícola Industrial de la Caña de Azúcar (LAICA) supports technology transfer			
Total	2 047 462	1 028 473	743 243	36

from molasses, and more recently from sugarcane juice. The increase in sugarcane ethanol production promoted significant technological advances that also benefited sugar production, leading to a raw sugar of higher quality.

Co-generation

Today, the most important perspective for sugarcane industry is the availability of technology for a more thorough and efficient use of the ligno-cellulosic fraction of sugarcane for energy production, whether as biopower or biofuels. In general, even the implementation of large-scale co-generation plants depends on government policies. And not only for subsidies, but also for changing the legal frameworks that govern the power sector in the region, in order to allow the creation of more scattered energy sources. In Brazil, the expectancy is that sugarcane industry will supply between 10 and 15 percent of the country's electric power by 2020; and this industry may increase its energy production/area ratio in nearly 50 percent during the next decade, by using today's residual biomass. In some cases, the considerable variety of possibilities calls for strong R&D efforts.

Potential for biomass-based energy production

Production of biomass for energy purposes should not conflict with traditional uses of biomass (namely, food, fodder, fiber, timber, and pharmaceuticals). Modern agricultural produce demands include flowers, fuels, and raw materials for the chemical industry. Energy derived from biomass can be used for domestic consumption or exported to the international market. In both cases, there are five important considerations that will help establish the potentiality and sustainability of biomass production:

a) land availability; b) water availability; c) climate; d) environmental restrictions; and e) present area used by energy crops.

Although other raw materials —like sweet sorghum— are quite suitable and have large potential for most LAC countries, sugarcane is the most efficient one for energy production purposes. The technology for sugarcane production was brought to the region centuries ago; however, during the last 40 years it has shown major advances, primarily in the cane-growing areas of many countries. In most cases, technological centers participated in the sugarcane varieties program and other agronomic research goals. Agricultural engineering, and most industrial R&D efforts, were left to farming equipment manufacturers. With a few and relevant exceptions, most programs were carried out by national institutions. The development of ethanol large-scale production led to the need of more industrial research. However, just a handful of countries have engaged this area until now. Some technology centers in the region are listed below (Table 7).

4.1.2. Priorities overview

For ethanol production, the proposed priorities include:

- Agronomic technology: Sugarcane genetic engineering; precision agriculture; and recovery and conditioning of sugarcane refuse.
- Industrial technology: Biomass (sugarcane refuse and bagasse) gasification for electric power or biofuel production; and biomass hydrolysis for ethanol production.
- Technology transfer.

In the case of other biomass sources, it has been rather difficult to establish priorities, considering that they are in different levels of technological development;

biomass can be obtained from other sources, such as forest species, agricultural refuses, and animal wastes; and the need to identify new species with special attributes for energy production. Technological improvement of plant species has been done from the perspective of the food industry, rather than the perspective of the power industry. In general, priorities in vegetable biomass production have included areas such as variety development to improve yield and pest resistance; plant nutrition; pest control; and harvesting procedures.

Most R&D institutions are agronomic research institutes (broadly known as INIA, or Institutos Nacionales de Investigación Agrícola), and universities.

4.1.3. Specific research areas

General biomass

I. Biomass productivity

i. Plant biology

Prospection of new species: Identification of new plants with outstanding energy yield/area indexes; identification of algae with the desired traits for energy production purposes.

Plant physiology: Identification of photosynthetic pathways, and means to enhance solar energy capture; lignin and cellulose-producing metabolic pathways; metabolic pathways for plant resistance to biotic and abiotic stresses.

Molecular biology and breeding: Creation, characterization, and maintenance of plant DNA banks; identification of plant genes linked to resistance or tolerance to major biotic or abiotic stresses, and to improved soil nutrient uptake and use; identification of genes that code chemicals of social and economic importance; introduction of the desired traits into crop plants.

Energy balance and carbon flow: Optimization of energy output/input for various target plants; identification of methods for altering carbon flows into higher energy compounds, like lipids; control of the carbon flow and GHG emission of different agro-energy raw materials.

ii. Agronomic practices

Plant nutrition: Understanding symbiotic plant-bacteria associations for atmospheric nitrogen fixation, and finding new microorganisms able to associate with non-leguminous plants; investigation of plant-microorganism associations with growth-promoting capabilities; deeper understanding of plant hormone biochemical pathways, and identification of substances that act as hormonal bio-activators; studies on plant-soil-water interactions.

Environmental impact: Validation of soil-carbon impact on crop waste removal; identification of the potential environmental impacts of intensive agriculture.

Improvement of sustainable agricultural practices: Establishment of optimal agronomic practices for sustainable farm production, including sustainable rates of waste removal; promotion of studies on plant-pest-predator relationships and the biological control of pests; promotion of studies on the life-cycle and energy-balance of biomass raw materials, aimed to reduce the energy consumption of the systems; identification of the most suitable soils and regions to grow energy-rich crops; and intensive use of composts produced from cone-filtered and pressed biological sludge.

Agro-forestry: Advancement of basic studies on forestry parameters (spacing, fertilization, rotation, growth rate, net photosynthesis, etcetera); development of technologies that enable the planting and management of energy-rich forests in areas unsuitable for agriculture, and degraded areas; identification of the requirements to establish small-scale agro-forestry projects.

Precision agriculture: Use of technology and satellite images to improve sugarcane production.

Sugarcane waste recovery: Integration of waste recovery to harvesting; waste conditioning.

II. Processing of biomass into energy carriers

Biomass for domestic cooking and heating: Optimization of biomass stoves; mitigation or elimination of health and environmental problems created by burning firewood inside dwellings; promotion of studies aimed to stabilize the cycles of firewood demand; sustainable production and access to firewood.

Biofueling of Diesel engines: Improvement of existing processes, or development of new ones, to substitute vegetable oils or animal fat as raw materials for biodiesel production; adaptation of Diesel engines to run on bioethanol; promotion of studies on the catalysts and reagents used for industrial processes; improvement of oil extraction methods especially adapted to small- and medium-sized plants. However, biodiesels derived from conventional oils, oilseeds or animal fat can not possibly satisfy our realistic needs, since they can only meet a small fraction of the existing fuel demand. In addition, extensive and expensive acreage is needed to produce enough oilseed crops, or to compensate the cost of feeding animals in order to produce raw oil. Therefore, oleaginous microorganisms can be used to substitute conventional oils for biodiesel production. Most oleaginous microorganisms —like microalgae, bacilli, fungi, and yeasts— are suitable for biodiesel production. However, the mechanisms that regulate oil accumulation in microorganisms, as well as the appropriate methods necessary to get microbial diesel to compete economically with petrodiesel, should be understood and transformed into innovative processes.

Biomass for heat and power production: Research and development aimed to create fuel-flexible, energy-efficient, and cost-optimized gasification systems; creation of technology to recover condensable gaseous products during the wood carbonization process; improvement of the energy uses of black liquor; promotion of studies on the quality of coal used for blast furnaces, with emphasis on carbon penalty studies; set up of protocols, as well as certification and technical standards, for technologies associated with the supply and use of energy derived from forest biomass.

Sugarcane biomass hydrolysis and fermentation to ethanol or other energy carriers: Advanced conversion technologies are needed to produce ethanol, and its derivatives, from a wider range of resources, including ligno-cellulosic biomass. A variety of ligno-cellulosic biomass wastes from agricultural, forestry, timber, and paper industries can be considered (e.g., straw, corn stubbles, sugarcane bagasse). Cellulose and hemi-cellulose can be converted into alcohol by first transforming them into sugar; however, the process needs to be proven on an industrial scale. Although lignin can't be converted directly by such biochemical process, this is feasible via a thermo-chemical step. Today, commercial production of ethanol —and ethanol derivatives— from cellulosic biomass is minimal, but R&D on this subject is being done in Canada, the United States, Europe, and Brazil.

Direct conversion of sugar into fuel: Research in underway to get common ethanol-producing yeasts to yield, by saccharolysis, linear-chain hydrocarbon substances with fuel properties similar to diesel, like farnesen.

Biogas: Development of domestic, multiple-feedstock, modern, high-rate biomethanation systems; development and evaluation of anaerobic digestion kinetics in different biodigester models and systems, for the final treatment of liquid wastes; evaluation of the quantitative and qualitative characteristics of biogas, as a function of climatic seasonality and the type of animal production system; development of equipment for the use of biogas as heating fuel in swine and poultry production facilities; development of equipment to compress and transport low-pressure biogas; evaluation of bio-fertilizers derived from biodigester wastes; adaptation of Diesel and Otto engines to run on biogas. Also, the use of innovative processes, like aerated and ferricyanide catholytes in bioelectricity production, via a chambered

Figure 11. Annual solar radiation map for LAC (kWh/m2/day).

microbial fuel cell (MFC) (mediator-less anode; graphite electrodes) and employing selectively enriched hydrogen-producing mixed microbial consortia as anodic inocula, has tremendous potential.

Bio-refineries: Identification of chemicals present in biomass of interest to the chemical industry; identification of chemicals extracted nowadays from fossil sources, that can be obtained from biomass; identification of chemical pathways to expand oil and ethanol chemistry; development of innovative uses for the glycerol produced by biodiesel plants, as well as for the wastes and/or byproducts of biomass-based energy production; development of new nutritional uses for the wastes and/or byproducts of biomass-based energy production.

4.2. SOLAR ENERGY

4.2.1. Present status, potential, and prospective scenarios

Solar energy can be used directly to heat, cool, or illuminate dwellings and buildings, and to provide a domestic hot water supply that meets all basic thermal and hygienic requirements, for the rich and the poor from developed and developing nations alike. Also, solar radiant energy can generate directly very hot water and steam for industrial processes, as well as heat fluids, by concentration, to temperatures high enough to produce power in thermal-electric generators, to run directly heat engines, or to generate power by photovoltaic effect.

Besides, solar radiant energy can be used directly to enhance public safety; to bring lighting and food and/or drug refrigeration to the 1.8 billion people who still lack electric power around the world; to provide communications for all remote regions in LAC; and to generate clean power by means of grid-connected photovoltaic systems. It can also be used to produce fresh water from the sea water, to pump water and energize irrigation systems, and to detoxify contaminated waters, addressing perhaps the world's most critical needs of clean water for drinking purposes and growing food crops. It can be used even to cook on solar box-stoves, replacing the endless burden of firewood gathering that falls primarily on the shoulders of women, strips ecosystems, and pollutes the air of low-income homes.

This wide array of possibilities is what makes solar energy such an attractive option, with so many critically important potential applications in all cultures, regions, economies, and human conglomerates of the world, particularly in LAC countries. The region is very rich in solar resources. In most of the territory, average solar radiation exceeds 4 $kWh/m^2/day$. Besides, there are special areas with even higher radiation indexes, like the northwestern part of Mexico, with values of 6 $kWh/m^2/day$, as well as Honduras and some parts of Cuba, the Dominican Republic, Peru, Bolivia, and Brazil, where solar radiation indexes reach 5 $kWh/m^2/day$ or more. The highest world solar radiation indexes are found in Northern Africa and Australia, with figures close 7 $kWh/m^2/day$. Solar radiation is the renewable energy source with highest potential in LAC countries. Therefore, the region in general is considered especially adequate for the use of solar energy technologies (Figure 11).

However, although solar resources and their potential applications are abundant, the use of solar energy technologies in LAC has been quite limited, being restricted mostly to solar water-heating and photovoltaic power generation. For example, in Mexico some local companies produce flat-plate solar water-heating collectors for the local market, while others import them, generally from China, for distribution in the country. The cumulative area of flat-plate solar collectors installed in Mexico neared 840 000 m^2 in 2006, but this figure is small in comparison to the installed capacity of countries like Turkey or Israel. Other nations in the region lack data on the total area of flat-plate solar collectors installed, but we presume that the figure is quite low.

Regarding the use of photovoltaic systems (PVS) in LAC countries, several national and international programs have been implemented to install PVS for lighting and water pumping in small villages. One of those initiatives was the Mexican Renewable-Energy program, conducted by Sandia National Laboratories, and sponsored by the US Department of Energy and the US Agency for International Development. This program has been a successful model for the implementation of pumping and power generation systems based on renewable energy sources; therefore, the model has been implemented in other Latin American countries as well. Under this program, more than 200 water-pumping systems were installed in rural communities, and intensive professional training was provided to more than 30 local engineers, who became experts in renewable energy.

Estimations suggest that by 2006, 17 633 kWe of PVS were installed in Mexico. Besides, training was provided to dozens of Mexican professionals from the public and private sectors. Nowadays, Mexico has a national program for the productive use of PVS in rural areas, which is supported by the Shared-Risk Trust Fund (Fideicomiso de Riesgo Compartido, FIRCO), a federal financing agency. There are few examples of such programs elsewhere in LAC.

Other isolated applications —like food drying, solar refrigeration for food or vaccine preservation, and solar liquor stills— have been implemented in the region, but with no duplication efforts, and scarce information.

The prospective scenarios for the use of solar energy in LAC are optimistic. Due to the implementation of adequate polices to promote renewable energy technologies, a significant increase of renewable energy (RE) markets is expected in the short run (five years). Then, in the long run (10-15 years) —as research groups become stronger, national and international businesses emerge and grow, and RE technologies are developed in LAC— the use of RE should be massive and comprise at least 20 percent of all primary energy consumption.

4.2.2. Priorities overview

Solar thermal device development has utmost importance for LAC. Those devices can be used to warm water for domestic use, saving great amounts of natural gas; to produce hot water or steam for industrial processes; and to heat fluids, by concentration, to generate power in thermal-electric plants. Also, they can be used with relative ease in small villages, and even in medium and big cities, to produce fresh water from sea water, to detoxify contaminated waters for drinking and growing crops, to cook with solar box-stoves, and to power water pumps and irrigation systems. Most of these technologies can be developed and manufactured in the region. Therefore, the incipient industry for these solar devices should be supported in LAC by several means, among them, solving properly the political issues in order to let the market grow, as well as giving specific support to scientific and technological development to promote innovation in this sector.

Photovoltaic cell development is equally important, since solar energy has the greatest potential for power generation in the region. An important characteristic of photovoltaic energy is that electricity can be produced right where it's needed, especially in our region, with its above-average solar radiation. Research aimed to take full advantage of this potential is crucial. Avoiding the need to import technology from developed countries to transform solar energy into power is fundamental to increase the region's ability to satisfy independently its energy needs. On the other hand, the modular design, ease of installation, and simple maintenance requirement of PVS make them ideal for non-grid-connected remote communities. In this regard, PVS may play an important role in bringing education, culture, and even better health to such communities.

Training personnel and building research facilities is badly needed in order to fulfill proposals for PVS development and production goals. Existing PVS applications in the region are based on imported PV panels (with the exception of Cuba, which produces panels using imported solar cells). Solar cell research is conducted by some universities in Mexico, Brazil, Cuba, and Argentina. In all cases, small research groups contribute their publications to the advancement of basic knowledge, but the latter has no connection with the industry.

Though the use of solar energy has been low in LAC, for nearly 30 years there have been some research groups, chiefly in universities, that have done scientific and technological research on several solar energy topics, like solar collector technology, thermal and chemical energy storage, photovoltaic power generation, solar water heating, passive indoor heating and cooling, integration of solar collectors to buildings, solar systems for steam production, food drying, water desalination, mapping solar radiation and other energy resources, and solar radiation models.

There are several institutions from different countries in LAC, which have being doing research on solar energy. The most important ones are mentioned below.

In Mexico, the major institutions with groups working on solar energy are:

- Center for Energy Research (Centro de Investigación en Energía, CIE), Universidad Nacional Autónoma de México (UNAM). This is the only Mexican institution dedicated to renewable energy research, particularly solar energy.

They have worked on solar refrigeration systems, heat pumps for solar-powered heating and cooling, solar drying of agricultural products, solar concentration in low and high concentration ratios, sea water desalination, passive solar indoor heating and cooling, component and system testing, solar water purification, solar detoxification, solar cooking, solar thermal electricity, solar photovoltaic power generation, energy storage, batteries, hydrogen production and storage, fuel cells, thin film technology, and energy planning studies.

- Institute of Engineering (Instituto de Ingeniería, II), Universidad Nacional Autónoma de México (UNAM). A small research group that has worked mostly in the area of solar thermal systems: solar ponds, cylindrical-parabolic collector technology, direct steam generation, first-surface mirrors, sea water desalination, passive solar indoor heating and cooling, energy planning studies, and resource assessment.
- Center for Research and Advanced Studies (Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, CINVESTAV – IPN). They have worked primarily on solar photovoltaic materials, solar cell and solar panel development, and photovoltaic solar systems and applications.
- Electrical Research Institute (Instituto de Investigaciones Eléctricas, IIE). They do research on photovoltaic solar systems, solar ponds, and more recently, on hydrogen and solar concentration technology, like cylindrical-parabolic collectors, and dish stirling systems.
- National Association of Solar Energy (Asociación Nacional de Energía Solar, AC, ANES; also known as ISES – Mexico). During the Annual Congress of this 28-year-old association, solar researchers have the chance to meet and exchange technical information on all topics related to renewable energy. It has been a catalyst for solar research in Mexico.

In Argentina, the major institutions with groups working on solar energy are:

- Non-Conventional Energies Research Institute (Instituto de Investigación en Energías no Convencionales, INENCO), Universidad Nacional de Salta (UNSA). This is Argentina's most active center for solar energy research. They have worked on resource assessment, solar drying of agricultural products, greenhouses, drinking water production, water heating for domestic and industrial applications, flat-plate solar collectors, solar ponds, solar stoves, solar architecture, daytime lighting, and passive cooling.
- Solar Energy Group, National Atomic Energy Commission (Comisión Nacional de Energía Atómica, CNEA). They have worked on the area of selective surface, concentrating collectors, and photovoltaic cells and systems.
- Human Environment and Housing Laboratory (Laboratorio de Ambiente Humano y Vivienda, LAHV), Regional Center for Scientific and Technological Research (Centro Regional de Investigaciones Científicas y Tecnológicas, CRICYT). They have worked on the area of solar stoves, solar architecture, eco-design, daytime lighting, and passive cooling.
- Argentinean Association for Renewable Energies and Environment (Asociación Argentina de Energías Renovables y Ambiente, ASADES; also known as ISES – Argentina). This 28-year-old association has annual meetings that take place in the locations with research groups working on renewable energy forms. It has been a catalyst for solar research in Argentina.

In Brazil, the major institutions with groups working on solar energy are:

- Solar Energy Laboratory, Universidade Federal de Santa Catarina (UFSC).

They have worked in the area of resource assessment, refrigeration systems, passive solar indoor heating and cooling, solar photovoltaic power generation, and energy efficiency in buildings.

- Solar Energy Laboratory, Universidade Federal da Paraíba (UFPB). A small group working on medium-temperature solar collectors, sea water desalination, radiation in semitransparent materials, thermal characterization of materials, and solar drying.

In Colombia, the major institution with groups working on solar energy is the Universidad Nacional de Colombia. They have worked on the area of resource assessment, low- and medium-temperature solar collectors, solar stoves, refrigeration systems, and fuel cells.

In Cuba, the major institutions with groups working on solar energy are:

- Materials Science and Technology Institute (Instituto de Ciencia y Tecnología de Materiales, IMRE) and the School of Physics, both at the Universidad de La Habana (UH). They have worked on thin-film technology (PLD, CSS, and chemical bath), and semiconductor devices for solar cells (silicon, dye-sensitized solar cells, nano-crystalline solar cells).
- Center for Solar Energy Research (Centro de Investigaciones de Energía Solar, CIES). They have worked on solar thermal systems (water heating, solar drying applications, etc.), PVS applications, and demonstrative projects.
- Center for Studies on Renewable Energy Technologies (Centro de Estudios de Tecnologías Energéticas Renovables, CETER), Instituto Politécnico Superior "José Antonio Echevarría". They work on solar thermal systems, and photovoltaic applications.

- Center for Energy Information and Development Management (Centro de Gestión de la Información y Desarrollo de la Energía, Cubaenergía), Ministerio de Ciencia, Tecnología y Medio Ambiente (CITMA). They work on solar thermal systems for water heating, air conditioning, and water detoxification.

In Mexico, Argentina, Brazil, Colombia, Cuba, Guatemala, and other LAC countries, a few researchers from different institutions are working on solar energy, whether independently or in small groups, but all of them with very low budgets. In LAC, R&D activities on solar energy began in the early 1970s; during the following years, they gained increasing interest, along with a steady flow of specific governmental funding support. Then, after a lull that lasted from the late 1980s to the early 1990s, these days we are seeing a renewed interest in this area.

Apparently, the origin of present-day research funds has shifted to national universities and non-specific national foundations. The private sector, probably due to its higher public environmental awareness, as well as the requirement of environmental impact analyses when requesting international loans for development projects, tougher global competition, and its own awareness of fossil fuel depletion, is showing increasing interest in this kind of initiatives. Considering this, it can be said that we're going through a transition period.

4.2.3 Specific research areas

Resource assessment

- Standardization and benchmarking of international solar-resource data sets for LAC, to ensure worldwide comparability and recognition.

- Improvement of data reliability, availability, and accessibility in formats that address specific user needs.
- Development of methods to improve the quality of customized solar energy products, as well as their spatial and temporal coverage, including reliable solar radiation forecasts.

Passive solar heating and daytime lighting of buildings

- Development of new design approaches for buildings.
- Research of new construction methodologies.
- Integration on new component-recycling technologies to building design (use of new non-polluting and recyclable materials, high-tech glass, etc.).
- Development of standards to regulate energy quality and emission levels in buildings.

Solar thermal systems for heating and cooling

- Development of new components to reduce the costs of parabolic-cylinder collectors while increasing their commercial competitiveness.
- Development of low-cost absorber tubes.
- Development of new coatings for solar concentration system applications.
- Development of structures which are lighter and easier to install in the field.
- Manufacture of concentrators with innovative materials.
- Characterization of components in real conditions, using specific experimental facilities.
- Evaluation of absorber tubes in vacuum chambers.

- Evaluation of new mirror and solar-tracking systems in real conditions, using specific experimental facilities.
- Development of industrial applications and processes with good potential for solar energy use in the 125-450 ºC range (electric power generation, process heating, and industrial air-conditioning).
- Development of standards to determine the energy efficiency of components and systems.
- Development of software to design and simulate solar thermal systems.

Solar thermal power generation

- Development of innovative and cost-effective components for solar collectors, thermal systems, and electric power generating plants, as well as competitive technologies for solar energy applications in the 250-1,500 ºC range.
- Development of large-scale solar thermal power plants with a 10 MWe minimum equivalent solar capacity.

Solar photovoltaic electric power generation

- Development of innovative solar cells, modules and systems to speed up the current tendency toward cost reduction.
- Reduction of physical thickness and production costs for crystalline silicon cell, while enhancing their efficiency.
- Cost reduction and surface enlargement of thin-film and hetero-union devices.
- Development of new devices, such as organic cells, polymer cells, and cells with level III-IV solar concentration.

- Design of new comprehensive, low-cost, easier to install PVS with higher durability (25-30 years).

4.3. WIND ENERGY

4.3.1. Present status and potential

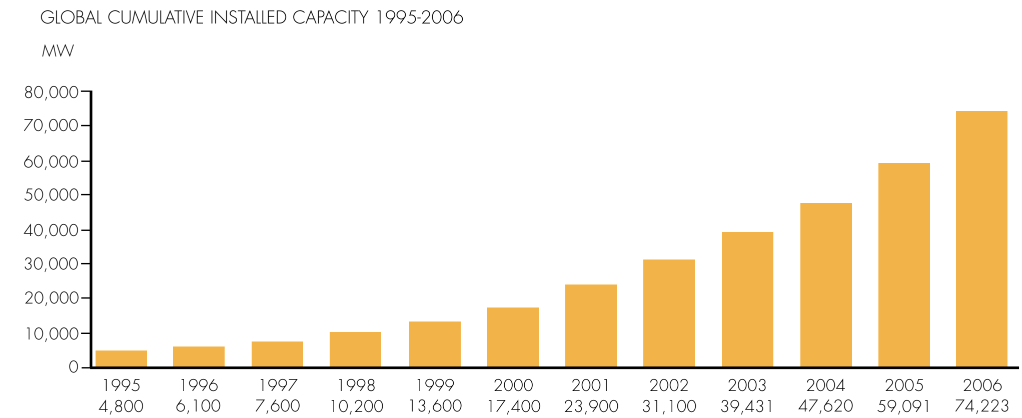
Modern commercial wind energy started in the early 1980s, on the wake of the 1970s oil crisis, when security and diversification of energy supply issues, and to a lesser extent, long-term sustainability concerns, triggered the interest in renewable energy sources. Significant design consolidation has taken place since the 1980s, although new types of wind generators have also introduced further diversification. Many developments and improvements have taken place since the initial commercialization of wind technology in the early 1980s, but the basic architecture of mainstream design has changed little. Most wind turbines (WTs) have upwind rotors, and are actively yawed to keep them aligned with the prevailing wind direction. The three-bladed rotor that proliferated has a separate front bearing and a low-speed shaft connected to a gearbox, which provides output speeds suitable for a four-pole generator. Commonly, blade pitch is actively and continuously adjusted in the largest WTs to regulate the output at higher operational wind speeds. Apparently, there's a consensus that pitch regulation will be adopted for all future large WTs.

Most WT blades are made of compound glass fiber-polyester or glass fiber-epoxy materials. Although the manufacturing process involves some automation, its labor-intensive procedures can be traced back to their boat-building origins. In general, the supporting structures are tubular steel towers with some kind of tapering, both in metal wall thickness and in base-to-top diameter. Concrete towers, concrete bases with upper sections made of steel, and latticework steel towers are also used, but are much less prevalent. Tower height is rather site-specific, and WTs are commonly available with three or more tower-height options.

Considering the range of WT sizes, the increase in diameter/rating ratio for the most recent turbines has been a consistent trend. This parameter is important because turbine height grows proportionally with increasing diameter. The relationship between diameter and rating is due to wind shearing forces, which increase as wind speed intensifies with height. In the drive train, the rotor is attached to a main shaft, which drives the generator through a gearbox. This gearbox has undergone significant improvements in basic architecture with a tendency toward direct drive generators. In these new designs, the gearbox is removed and the aerodynamic rotor drives the generator directly. Hybrid arrangements involving a single-stage gearbox and a multi-pole generator are also appearing.

Direct-drive systems for WTs, which avoid the cost and maintenance of a gearbox, are attracting increasing interest. Historically, gearboxes have presented challenges; hence, their substitution by direct-drive systems seems desirable. However, there's a possibility that mechanical difficulties are simply being replaced by electrical ones. It's far from clear which of these configurations is optimal. The effort to minimize costs and maximize reliability is persistent; the ultimate goal is minimizing the cost of wind-generated power.

Operation at variable speed offers the possibility of increased "grid friendliness," load reduction, and some minor energy benefits. Thus, this is an attractive option. Among WTs with ratings over 1 MW, out of 52 distinct models, produced by 20 different manufacturers, only three had fixed speed, 12 were two-speed systems, and 37 employed variable speed. This shows that, for MW-scale WTs, having some degree of speed variation is almost mandatory, and continuously variable speed is the predominant choice.



Source: Global Wind Energy Council, 2007, with original information from the International Energy Agency.

Figure 12. Global cumulative wind-energy installed capacity.

The development of WTs is a remarkable success story, though an unfinished one. Wind industry has reached a stage in which some people would regard it as a mature technology, able to stand commercially on its own. While such status is a great achievement, it's important to realize its potential for greater growth, which can be furthered by continuous and vigorous R&D efforts. Here, the main design drivers are cost-reduction and increased reliability.

4.3.2. Current and prospective scenarios

Global wind energy industry has been growing at a staggering annual rate of nearly 30 percent for the last 10 years, and experts predict that the end of this boom is out of sight. While a large proportion of this development is taking place in Europe, other markets, especially Asia and North America, are catching up fast. The worldwide success and tremendous growth of wind energy put unprecedented pressure on the manufacturers of WT components such as towers, rotor blades, gearboxes, bearings, generators, etc., and the industry has been struggling to keep up with the demand. For the moment, developers of wind farms have to wait up to 12 months for the turbines to arrive, and present trends show that this timeframe could expand to 18 or even 24 months.

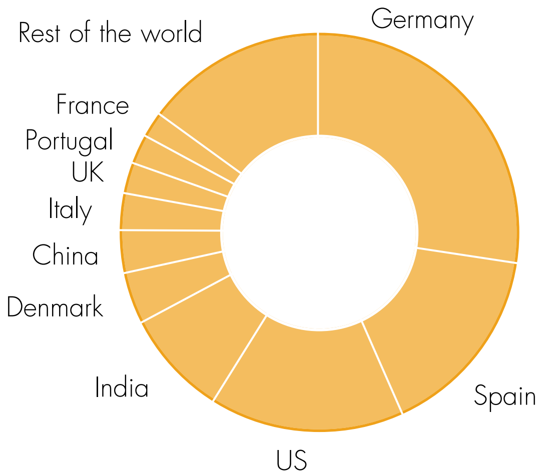
In 2006, the booming global wind-energy market exceeded all expectations and the sector experienced yet another record year with the installation of 15,197 MW. This increased the total installed wind-energy capacity to 74 223 MW (Figure 12).

Despite the constraints faced by wind turbines' supply chains, the annual market for wind energy kept increasing at a staggering rate of 32 percent, just a little behind the 2005 record year, in which the market grew 41 percent. Such development level shows that global wind-energy industry is responding fast and appropriately to the manufacture challenge, and has managed to keep up with its sustained growth. From the economic perspective, the wind-energy sector has become firmly established as one of the major players in the energy market, in which the total value of new installed power-generating equipment reached 23 billion USD (18 billion Euros) in 2006.

The countries with highest total installed capacity are: Germany (20 622 MW), Spain (11 615 MW), the United States (11 603 MW), India (6 270 MW), and Denmark (3 136 MW). Thirteen other countries can be counted among those with over 1 000 MW of wind-power capacity; e.g., France and Canada, which reached this threshold in 2006. In terms of new installed capacity during 2006, the United States kept leading with 2 454 MW, followed by Germany (2 233 MW), India (1 840 MW), Spain (1 587 MW), China (1 347 MW), and France (810 MW). This shows that new players, such as France and China, are gaining ground (Figures 13 and 14).

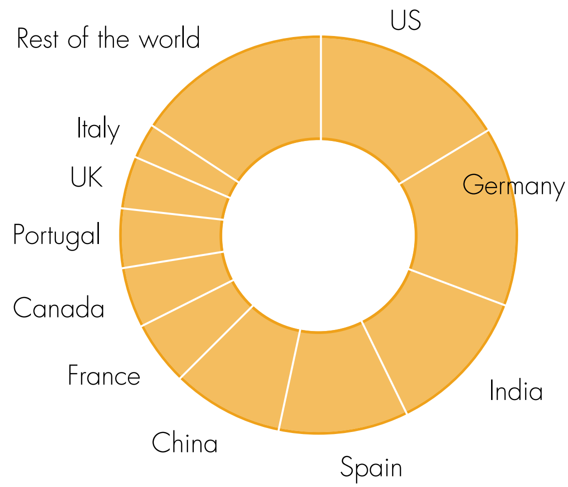
In Latin America and the Caribbean (LAC), the market is starting to show signs of

TOP 10 TOTAL INSTALLED CAPACITY



	MW	%
Germany	20 622	27.8
Spain	11 615	15.6
US	11 603	15.6
India	6 270	8.4
Denmark	3 136	4.2
China	2 604	3.5
Italy	2 123	2.9
UK	1 963	2.6
Portugal	1 716	2.3
France	1 567	2.1
Rest of the world	11 005	14.8
Total top 10	**63 218**	**85.2**
Total	**74 223**	

TOP 10 NEW CAPACITY



	MW	%
US	2 454	16.1
Germany	2 233	14.7
India	1 840	12.1
Spain	1 587	10.4
China	1 347	8.9
France	810	5.3
Canada	776	4.6
Portugal	1 716	2.3
UK	634	2.7
Italy	417	2.7
Rest of the world	2 405	15.8
Total top 10	**12 792**	**84.2**
Total	**15 197**	

Figure 13. Installed wind energy capacity by major countries. Source: Global Wind Energy Council, 2007, with original information from the International Energy Agency.

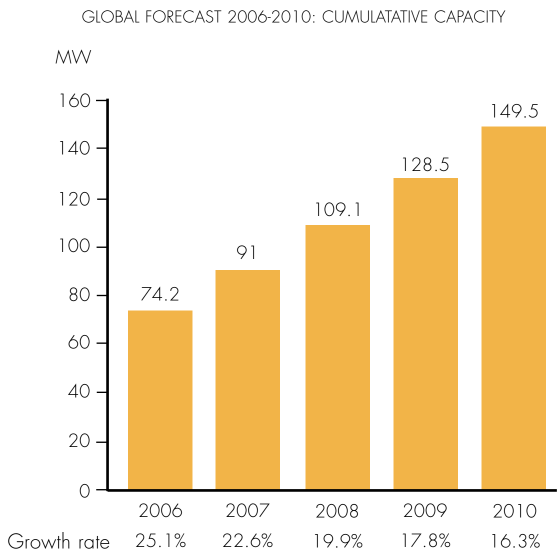
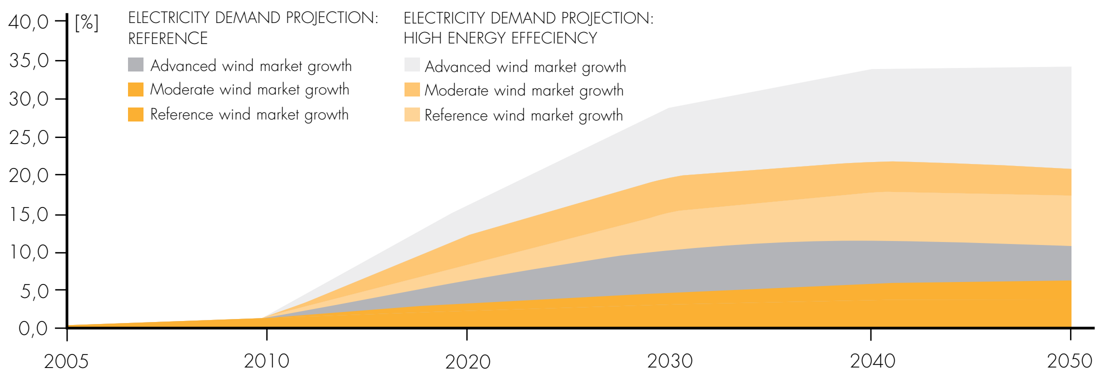


Figure 14. Global forecast for wind-energy cumulative capacity. Source: Global Wind Energy Council, 2007, with original information from the International Energy Agency.

healthy growth, particularly in Brazil and Mexico. Overall, the region accumulated 296 MW of new installations in 2006, compared to only 6 MW during the previous year. In Brazil, the governmental program called Incentives for Alternative Electric Power Sources (Programa de Incentivo às Fontes Alternativas de Energia Elétrica, PROINFA) is showing its first signs of success with the recent installation of 208 MW, which brings Brazil's total capacity to 237 MW, while the infrastructure for another 220 MW is being constructed. Besides, Brazil's federal government is expected to announce a 5 000 MW wind energy program that will be completed between 2009 and 2015.

In Mexico, which has also great potential for wind energy, 85 MW of new capacity were installed in 2006, bringing the total to 88 MW. According to the

WIND POWER PENETRATION OF WORLDS ELECTRICITY SUPPLY



3 DIFERENT WIND MARKET DEVELOPMENT SCENARIOS- WITH WORLD ELECTRICITY DEMAND DEVELOPMENTS

		2005	2010	2020	2030	2040	2050
WIND MARKET GROWTH- IEA PROJECTION (REFERENCE)							
Wind power penetration of Worlds electricity in % - Reference (IEA Demand Projection)	%	0.8	1.5	2.7	3.5	4.1	4.0
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	1.8	3.6	5.0	6.3	6.6
MODERATE WIND MARKET GROWTH							
Wind power penetration of Worlds electricity in % - Reference	%	0.8	1.8	6.6	10.8	11.8	10.8
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	2.2	8.6	15.6	18.1	17.7
ADVANCED WIND MARKET GROWTH							
Wind power penetration of Worlds electricity in % - Reference	%	0.8	2.1	12.1	20.1	22.1	20.9
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	2.4	16.5	29.1	34.0	34.2

Figure 15. Wind energy penetration in the world s electric power supply. Source: Global Wind Energy Council, 2007, with original information from the International Energy Agency.

Mexican Wind Energy Association (Asociación Mexicana de Energía Eólica, AMDEE) a minimum capacity of 3 000 MW will be reached in 2014. Figure 15 shows the wind-energy share of global power generation.

According to some predictions, the cumulative capacity of wind energy installations will reach 149.5 GW at the end of this decade; i.e., more than twice the present installed capacity. The average annual cumulative growth rate during the period

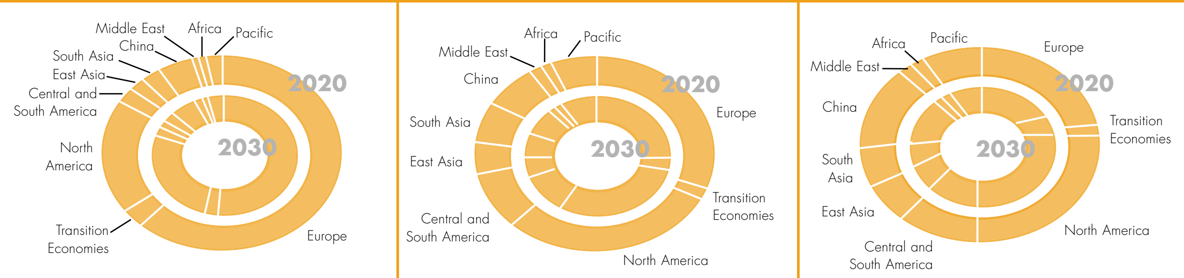
2006-2010 will be 19.1 percent, compared to 24.3 percent for the period 2002-2006. The annual installed capacity is predicted to reach 21 GW in 2010, a 38 percent increase from the 15.2 GW installed in 2006. This implies an average annual growth rate of 8.4 percent for the global wind energy market. Such growth could be bigger, but it will be limited —at least in the near future— by the manufacturers' production capacity. In most markets, the current delivery time for WTs is around two years.

In 2006, the first encouraging developments were noticed in LAC with the new installation of 296 MW. According to some predictions, the market will take off during the period 2007-2010 with Brazil leading the way, and followed closely by Mexico. Smaller developments will also take place in some Central American countries, as well as in Argentina and Chile. Despite its large potential, LAC will remain a limited market until the end of this decade, when progress toward a more significant development will begin.

Three different worldwide scenarios are outlined for the future growth of wind energy (Figure 16). The most conservative scenario —called "Reference"— is based on the projection of the 2004 World Energy Outlook report published by the International Energy Agency (IEA). This projection includes the growth of all renewable sources —wind power among them— up to the year 2030. The "Moderate" scenario takes in consideration all policies created to support renewable energy sources, both currently under way and planned around the world. It also assumes that the goals set by many countries, either for renewable sources or wind energy, are being successfully reached. The assumption here is that the success achieved in Europe by meeting the wind energy installation goals set by the EU, will be repeated globally.

The most ambitious scenario —the "Advanced" version— would follow a path similar to the one outlined in the series of reports —Wind Force 10 and 12— pro-

REGIONAL BREAK DOWN REFERENCE SCENA [GW] | REGIONAL BREAK DOWN: MODERATE SCENARIO [GW] | REGIONAL BREAK DOWN: ADVANCED SCENARIO [GW]



REGIONAL BREAK DOWN REFERENCE SCENA [GW]

2020	GW	%
Europe	142	62
Transition Economies	7	3
North America	43	13
Central and South America	6	3
East Asia	5	2
South Asia	6	3
China	11	5
Middle East	2	1
Africa	2	1
Pacific	5	2
2030		
Europe	186	51
Transition Economies	12	3
North America	94	26
Central and South America	10	3
East Asia	7	2
South Asia	9	2
China	25	7
Middle East	4	1
Africa	5	1
Pacific	12	3

REGIONAL BREAK DOWN: MODERATE SCENARIO [GW]

2020	GW	%
Europe	174	31
Transition Economies	7	1
North America	167	30
Central and South America	54	10
East Asia	27	5
South Asia	39	7
China	41	7
Middle East	9	2
Africa	8	1
Pacific	34	6
2030		
Europe	295	26
Transition Economies	28	2
North America	334	30
Central and South America	123	11
East Asia	59	5
South Asia	75	7
China	87	8
Middle East	18	2
Africa	20	2
Pacific	90	8

REGIONAL BREAK DOWN: ADVANCED SCENARIO [GW]

2020	GW	%
Europe	245	23
Transition Economies	13	1
North America	284	27
Central and South America	100	9
East Asia	71	7
South Asia	61	6
China	159	15
Middle East	24	2
Africa	17	2
Pacific	90	8
2030		
Europe	392	19
Transition Economies	116	6
North America	570	27
Central and South America	198	9
East Asia	142	7
South Asia	128	6
China	328	16
Middle East	47	2
Africa	48	2
Pacific	140	7

Figure 16. Wind energy scenarios. Source: Global Wind Energy Council, 2007, with original information from the International Energy Agency.

duced since 1999 by the European Wind Energy Association (EWEA), the Global Wind Energy Council (GWEC), and Greenpeace. These reports examined how feasible it would be that 10 percent of the world's electric power supply initially, and 12 percent later, would came from wind energy by 2020. The assumption here is that all policy options in favor of renewable energy, along the guidelines set by this document's recommendations, have already been adopted and the political will necessary to carry them out is already in place.

Then, the three global wind energy market scenarios are set against two alternative pathways for the future growth of electric power demand. Most importantly, these projections avoid the simple assumption that growing demand by consumers will inevitably need to be matched by supply options. Based on the assumption that power demand must be reduced if the threat of climate change is to be seriously tackled, they take in consideration an increase in energy efficiency. Again, the more conservative of the two global electric demand projections is based on data from the IEA's 2004 World Energy Outlook, which were extrapolated up to 2050. This is the "Reference" projection. It does not take into account any possible future policy initiatives, and assumes, for instance, that national policies about nuclear power will remain the same.

The IEA's assumption is that, "In the absence of new government policies, the world's energy needs will raise inexorably." Therefore, global demand would practically double its baseline —set at 13 423 TWh in 2003— to reach 25 667 TWh in 2030, and keep growing to 37 935 TWh in 2050. Then, IEA's expectations about this growing energy demand are set against the outcome of a study, developed by DLR and Ecofys (a consultant company), on the potential effect of energy efficiency savings. This describes an ambitious development path to take advantage of such energy efficiency measures. It focuses on our current best practices and the technologies that will be available in the future, and assumes that there will be continuous innovation. Under the "High energy efficiency" projection, input from the DLR/Ecofys models shows the effect of such efficiency savings on the global electric demand profile.

Although this assumes that a wide range of technologies and initiatives have been introduced, their extent is limited by potential cost barriers and other likely obstacles. However, this still results in a nearly 30 percent global demand increase, which will reach 17 786 TWh in 2030. By the end of the projected scenario —in the year 2050— demand will be 39 percent lower than the Reference scenario.

The results of the Global Wind Energy Outlook scenarios show that, even under the conservative IEA view of the potential global market, wind energy could supply 5 percent of the world's power in 2030, and 6.6 percent in 2050. This assumes that the "high energy efficiency" projection has been introduced. Under the Moderate wind energy growth projection, coupled with ambitious energy saving measures, wind power could supply 15.6 percent of the world's power in 2030, and 17.7 percent in 2050. Under the Advanced wind energy growth projection, coupled again with ambitious energy saving measures, wind power could supply 29.1 percent of the world's power in 2030, and 34.2 percent in 2050.

4.3.3. Research priorities

All major wind energy research and development (R&D) priorities are related to wind resource estimation, wind turbines (WTs), wind farms, grid integration, environment, public support, and standards and certification. The most important scientific institutions in Latin America and the Caribbean (LAC) that deal currently with wind energy are:

- Centro Brasileiro de Energia Eólica (CBEE), Brazil.
- Instituto de Investigaciones Eléctricas (IIE), Mexico.

- Centro de Investigación en Energía de la Universidad Nacional Autónoma de México (CIE – UNAM), Mexico.
- Centro de Estudios de Tecnologías Energéticas Renovables (CETER), Cuba.
- Universidad de la República (UDELAR), Uruguay.
- Escuela de Ingeniería Eléctrica, Universidad de Costa Rica (UCR), Costa Rica.
- Instituto de Investigación en Energías no Convencionales (INENCO), Universidad Nacional de Salta (UNSA), Argentina.
- Instituto Universitario Aeronáutico (UIA), Argentina.
- Universidad Nacional del Centro de la Provincia de Buenos Aires (UNCPBA), Argentina.
- Universidad Nacional de la Plata (UNLP), Argentina.

Other LAC non-academic institutions that deal with wind energy are:

- Asociación Mexicana de Energía Eólica (AMDEE), Mexico.
- Centro Regional de Energía Eólica (CREE) Argentina.
- IMPSA – Wind Division, Argentina.

4.3.4. Specific research areas

Wind resource estimation

- Maximum availability of wind resource data, in the public domain where possible, to ensure that financial, insurance, and development companies can design efficiently high-quality projects, avoiding project failures caused by inaccurate data.

- Resource mapping of areas with above-average high wind potential, but yet unexplored.
- Development of cost-effective, easily transportable monitoring units, including communication and processing features, such as LIDAR, SODAR, and satellite observation, to assess wind resource characteristics.

Wind turbines

- Comprehensive design tools for very large WTs that will operate in extreme climate conditions and/or rough terrains.
- State-of-the-art laboratories for quick testing of large components under realistic (external) climate conditions.
- Development of component-level design tools, and multi-parameter control strategies.

Wind farms

- Research and development of wind farm-level storage systems.
- Understanding wind flow in large wind farms and around them.
- Control systems to optimize power output and load factor at wind farm-level
- Development of risk assessment methodologies.

Environment and public support

- Research on the effects of large-scale wind power-plants on ecological systems, aimed to inform policy makers and the public.

- Inclusion of specific recommendations for wind farm design and planning practices.
- Effects of wind energy sites on the surrounding ecosystems.
- Development of automatic equipment to monitor bird collisions in particular.
- Economic evaluation of externalities.
- International exchange and communication of the results of studies on ecological impacts.

4.4. SMALL AND MICRO HYDROPOWER FACILITIES

4.4.1. Present status, potential, and prospective scenarios

This is an old and proven technology that needs to be fully integrated into LAC's energy matrix. The total hydropower potential for Latin America exceeds 659 531 MW, and out of this total, approximately 21 percent is being used; in Central America, the potential reaches 23 625 MW, and the region is using only 17 percent of the total. Therefore, it's very important for the region to develop its hydropower potential for several reasons:

- Hydropower is a local natural renewable resource that can be developed, in countless locations, by means of environmentally sound technologies
- Development of hydropower facilities can induce recognition of watershed environmental services, which then can be preserved by comprehensive forest and rainwater management techniques.
- Once watershed management is induced by the development of hydropower plants, this can reduce the vulnerability to extreme hydrometeorological phenomena

- This technology is labor intensive and, therefore, can create employment opportunities, both for technical and skilled workers, as well as for non-skilled local workers.
- Most of the untapped hydropower potential is located at the end of the national interconnected system, which makes scattered electricity generation a sound energy policy while introducing, at the same time, renewable energy sources into the national energy matrix.
- Renewable energy sources avoid or displace fossil fuel-based power generation projects; therefore they are eligible for the clean development mechanism (CDM) or other voluntary carbon trading instruments.
- Small-scale hydropower facilities are compatible with indigenous peoples' view of the world, since it's based on the cyclical recreation of energy by tapping natural resources without polluting or destroying them.
- Small and micro hydropower facilities can be off-grid or grid connected; thus they can provide electricity to isolated communities, or feed it to national grids.

It will be necessary to explore other small renewable energy technologies such as hybrid projects; i.e., projects that include sun, wind, and water as energy sources. In some locations there's a mix of natural resources that vary with the seasons: for instance, during the rainy months there's no wind, but the dry season can be quite windy; likewise, where precipitation is high, solar radiation can be limited. Therefore, the creation of hybrid projects with more than one technology can be a solution for off-grid and remote areas, where national energy grids are unlikely to reach communities in the short-term. In other areas, close-to-the-surface (low enthalpy) geothermal resources can be used to power cottage industries, and to produce heat for drying crops and heating homes.

4.4.2. Priorities overview

In the case of micro hydropower generation, the following aspects should be considered:

- Improved component design based on World Commission on Dams' best practices should focus on lowering the cost of the kW installed capacity, from the current 3 000-4 000 USD range to a range between 2 000-2 500 USD, by increasing turbine efficiency (new materials), improving automation equipment, and including a load factor based on productive uses of electricity (PUE).
- Research on multipurpose reforestation, including the use of firewood species in watershed management, should focus on native species to promote ecosystem and germplasm protection.
- Improved small hydropower component design and integration for key components such as derivation and intake ducts, compensation chambers, penstocks, turbines, generators, and control and protection devices. Here, learning from experiences in China, India, and Europe is crucial, but we should learn also from the experience gained in Peru and Cuba.
- Research should involve practitioners, manufacturers and experts from ALC and other regions, all of whom should set an in-service training process to improve the blueprints of machinery such as Francis Banki, Pelton, and other models.
- Other specific goal should be setting up synchronic equipment to allow the interconnection of small hydropower facilities to national grids. This will entail close coordination between practitioners, vendors, and equipment manufacturers, as well as the power regulating bodies responsible for establishing guidelines and threshold criteria for safe interconnection at capacities of 200 kW or more.
- Implementing such research and improvements will require changes in the current

legal framework in order to scatter energy generation; therefore, the creation of a market-participation protocol for scattered power generation is something that can be expected.

- In parallel to the improvements and cost reductions required to improve the efficiency of hydropower equipments, it will be necessary to launch an electric productive-use initiative that not only incorporates high-efficiency appliances and machinery into value-added local production chains, but also takes in consideration the traditional knowledge of indigenous communities.
- The main focus for this kind of R&D should be using this energy to power production chains that are environmentally friendly and culturally sensitive. For example, R&D should integrate the best practices of hydropower facilities to natural resource local transformation, in such a way as to increase the market value of agroforestry products such as organic coffee and cardamom, certified timber, dairy products, handicrafts, fruit and vegetable canning and/or preserves, and so on.

4.5. RELATED TECHNOLOGIES

4.5.1. Hydrogen

Present status, potential, and prospective scenarios

The chronological variability of renewable energy resources determines the need for energy storage means in order to match the timing of use of those resources with the economic and social activities. Thus, the primary energy obtained from renewable resources, such as solar, wind, and biomass energy can be accumulated, and then transported and used whenever is necessary, regardless of when the renewable resource is available.

Among energy storage means and carriers —apart from fossil fuels—, electric batteries are perhaps the most common and widely used ones, but the energy they can store per volume unit is very low. Nowadays, biofuels are becoming popular because being transportable, they can substitute hydrocarbons with similar efficiency; however, due to the low efficiency of photosynthesis and the processing costs, biofuels will not be able to meet all future energy needs. Consequently, hydrogen —the most common element on Earth, which can be obtained from water or biomass— has the potential to come out as a key energy player in the distant future, once several issues, such as cost, safety, and storage are solved by research and development (R&D).

However, it's important to underscore that hydrogen is not a primary energy source, and for that reason, its production requires a primary energy source.

Hydrogen can be obtained directly (by photolysis), or by means of electricity (electrolysis) obtained from renewable energy sources. Its development will also be supported by its potential to transform transportation and stationary energy systems worldwide. Remote sources of renewable energy in areas with good wind, solar or geothermal energy potential can become hydrogen factories. Transportation of hydrogen will then allow delivering the original renewable energy, in form of electrical power and heat on demand, for use in local, scattered fuel cells [which should function also as combined heat and power (CHP) devices]. Artificial photosynthesis pathways or biomass fermentation by specific hydrogen generating microorganisms is another way to produce molecular hydrogen.

Widespread and large-scale application of energy storage technologies will not be necessary before 2020, and perhaps not before 2030. Meanwhile, the development of hydrogen fuels and applications should proceed independently of the renewable energy transition, pulled by the attractive economic benefits of the hydrogen transition, and pushed by aggressive government programs. Then, hydrogen technology and infrastructure can be expected to evolve enough to support higher renewable energy penetration levels.

The corollary of this argument is that the environmental success of the hydrogen transition will depend entirely on the utilization of renewable energy resources, instead of the conventional energy sources used to produce hydrogen nowadays. A declared goal for the EU is achieving a fully integrated hydrogen economy, based on renewable energy sources, by the year 2050 [directives of the European Parliament and the Council on promotion of the use of energy from renewable sources, COM (2008) 30].

Priorities overview

For LAC countries, participation in hydrogen technology R&D should be a priority, particularly as part of the ongoing international effort. The synergy between hydrogen development and the application of renewable energy technologies will be significant. Hydrogen —a clean energy carrier when burned— should be produced by means of renewable energy resources. And the energy from those resources should be converted into fuel for on-demand clean energy applications, fully independent from renewable energy source fluctuations. The economic and social value of hydrogen and renewable energy resources alike will be enhanced by that synergy. The parallel between renewable energy and hydrogen transitions should be mutually supportive.

Specific research and development areas

- Characterization of adequate materials and devices for production, storage and use of hydrogen, particularly in fuel cells.

- Mathematical modeling of fuel cell processes to improve their design.
- Creation of hydrogen-producing fuel cell prototypes and systems for practical applications.
- Development of methodologies to store hydrogen in solid form.
- Development of high-temperature solar energy-based thermochemical processes for hydrogen production.
- Characterization of materials and peripheral devices for hydrogen-related processes (e.g., batteries, supercapacitors).
- Development of hydrogen standards and protocols to regulate all aspects of such technology.
- Implementation of educational programs on hydrogen technologies.
- Creation of prototype units able to produce hydrogen at high temperatures
- Planning and prospective studies on the economy of hydrogen.

4.5.2. System integration

The integration of renewable energy resources and their associated technologies into present and future energy systems is a complex problem that is far from being solved, especially when the participation of renewable energy in such systems is relatively large.

This integration into energy supply systems —such as power grids, heating and natural gas networks, and liquid fuels— requires R&D in areas such as:

- Load management.
- Grid management.
- Energy transportation

- Interaction with conventional systems.
- Necessary back-up power systems.

R&D is also required to address the issue of scattered versus centralized deployment of renewable energy sources, and its relation to energy efficiency.

In addition, the integration of renewable energy into current and future energy systems will require the creation of standards and protocols to regulate both technologies, as well as the development of supporting criteria.

Grid integration

- Creation of control strategies and requirements to make wind farms fully grid-compatible, and able to support and maintain a stable grid.
- Development of electric and electronic components and technologies for grid connection.

Standards and certification

- Performing energy yield calculations.
- Development of grid connection protocols and procedures.
- Creation of risk assessment approaches.
- Development of design criteria for components and materials.
- Standardization of operation and maintenance mechanisms.
- Accelerated conclusion of ongoing standard development activities, such as certification processes, test procedures, design criteria for offshore WTs, and project certification

5. ECONOMIC AND SOCIO-CULTURAL ISSUES

At the beginning of the Twenty-first Century, we are still far from achieving an intergenerational and trans-temporal dynamic equilibrium between humans, other life forms, and the Earth itself. On the contrary, we have created an unbalanced economic growth, based on a profit maximization that relays on negative economic externalities which are not considered as part of the total cost of transforming natural resources into goods to satisfy human requirements and needs. What we experienced in the world is an unsustained economic growth based on fossil fuel consumption, and intensive mining activities. The present world development models are rely on a linear mindset that accumulates capital over time, based on natural resource exploitation, while leading to pollution, and human and ecological stress.

In terms of energy consumption, over two billion people worldwide still lack access to modern energy supply. On the other hand, humanity seems to be addicted to oil, which shows in the fact that the oil barrel price tripled in just one year. A good effect is that consumers are starting to worry about such cost, which means more pressure for automotive industry change. Though time is too short to achieve measurable results, indicators such as the demand for fuel-efficient cars have skyrocketed, and multiple solutions are sprouting worldwide.

Regardless of the increased investment on renewable energy technology for power generation, the main energy projects that are being built worldwide are still based on burning fossil fuels such as oil and coal. Furthermore, since recently, money allocated to energy research and development (R&D) had being focused primarily on nuclear energy (56 percent) and fossil fuels (32 percent), with only 12 percent focused on the development of renewable energy technology. With such amount of investment on old energy technology development, leveling the ground to achieve a fair share of renewable energy participation will be quite difficult. However, change is in the air: during his address to the World International Renewable Energy Conference, held in Washington DC, in 2008, President Bush pledged to assign a sizable portion of the available funds to research on greener fuels.

The economics of wind energy show that financial costs, operation and maintenance costs, taxes, insurances, and other expenses, along with the expected profit margin, comprise the unit price of electric power. Depending on the market, and perhaps on additional promotional measures, wind energy may be competitive or not. In general, the consensus is that, while wind energy and other renewable energy sources have environmental benefits in comparison to conventional power generation, those benefits may not be fully reflected by the market prices of electric power.

Energy generation externalities could answer these questions in order to estimate the hidden, not-accounted-for benefits/damages of power production within the existing pricing system. Costs are considered "external" because they will be paid by third parties (government, users and non users of energy, no matter the intensity of energy used) and future generations. In order to establish a fair comparison of the different power production activities, all costs for society, both internal and external, must be taken into account.

For instance, in wind turbine (WT) manufacturing, employment can be direct and indirect. Employment in the whole manufacturing sector has been increasing considerably in the EU since the 1990s. In Europe, direct and indirect employment related to WT manufacture and installation for the internal market grew 185 percent in 1998-2002, while employment for WT maintenance grew 268 percent, reaching 72 275 work positions.

Despite the uncertainties and debates about externalities, it can be stated that with the exception of nuclear power and the long-term impacts of greenhouse gases (GHG) on climate change, the results of the different research groups coincide, and can be used as a basis for developing policy measures aimed at internalizing even further the different external costs of power generation.

The use of new solar energy technology in LAC countries is on its way, and though the market is still very limited, its growth will mean new factories and therefore, new jobs. The fact that solar energy is a low-density energy source implies that, to supply the same energy load that conventional energy systems do, a great collection area is needed. Therefore, it will be necessary to manufacture a large amount of solar collectors. This should include not only the creation of new companies to produce thermal solar and photovoltaic solar collectors, but also the design of new power plants and buildings, and even new cities with an integral concept of sustainability. LAC countries can be part of this revolution. Political vision and action are needed to foster this potential.

It will be necessary to transform the way our society thinks about energy, from its present notion as an infinite source, to a more realistic view where energy is finite and must be used in a sustainable way. This will require the implementation of persuasive energy-saving measures and a great education effort.

Simultaneous R&D on technical issues to improve the performance and efficiency of small and micro-hydropower facilities, while reducing the final cost of power production, will require the use of such generated power to create local employment. This can be achieved by combining traditional indigenous knowledge with high-tech options, in such a way that local businesses and agroindustries can transform the local natural-resource base and add value to their natural products. Socioeconomic R&D should be undertaken by interdisciplinary research teams including anthropology, gender studies, sociology, economics, business administration, and ecology, in order to create specific case studies to illustrate successful high-tech and traditional knowledge combinations.

Nowadays, public policies and political leadership are dramatically required —rather than technology and/or economics— to move ahead the widespread application of solar energy technologies and approaches. Obviously, technology and economics should improve along the time, but at present, they are sufficiently advanced to allow a wider participation of solar energy in mainstream energy infrastructure and society. Besides, significant goals can be set at this moment based on the assumption that major improvements in energy efficiency, as well as increases in solar and renewable energy applications, will be achieved during the next 50 years. By then, our world should be satisfying over 50 percent of its total energy needs from locally available renewable energy resources, and most of these will be direct and indirect solar energy applications. There are no resource limitations for this scenario as solar radiation is infinite, by definition.

5.1. Actions with high social impact

Follow concrete actions with high social impact and visibility that the ICSU and its Regional Office can promote, as well as propose ways in which the ICSU family and its strategic partners can be involved in the implementation of those actions.

- Integration with other thematic areas.
- Involvement of regional institutions such as IADB, OAS, CAN, Procisur, Procitropicos, etc.
- Involvement of national governments.
- Integration with EU institutions and financing sources.
- Identification of financing mechanisms like EU funds (involvement of different countries, networking).

6. CAPACITY BUILDING AND OTHER NEEDS

Capacity building is required at different levels in the renewable energy field. First, it is necessary at the government level to strengthen institutions linked to the energy sector, as well as the industrial, trade and financing sectors. These institutions are essential to create an adequate environment for private capital and public funds mobilization toward a full implementation of renewable energy sources in each country.

Capacity building may also be necessary for other actors, including engineers working in the academic or private sectors; e.g., project developers, etc. This necessity may be satisfied in several ways, such as workshops, seminars, or comprehensive courses on renewable energy. Capacity building and specific training may also be supported by didactic visits to manufacturing facilities and renewable energy installations.

The following aspects should receive top priority:

- Network organization, implementation and operation to congregate LAC institutions, which should be linked to other networks.
- Adaptation of academic, field-specific programs to cover renewable energy and other related disciplines.
- Granting scholarships and other incentives to undergraduate, specialized,

and graduate students pursuing careers on renewable energy resources and other related fields.

- Lab improvement to create adequate R&D conditions.
- Giving financial incentives to prototyping, project incubation, and technological diffusion activities.

In-depth study of the model created by the International Consortium in Sugarcane Biotechnology (ICSB), which currently involves 12 countries, is proposed in order to develop a "virtual" institution that promotes specific R&D, at the pre-commercial level, in LAC. The ICSB's model is being used by Brazil, Argentina, and Colombia, so having a version for LAC would be quite useful.

6.1. COMMUNICATION AND TECHNOLOGICAL DIFFUSION

Actions to involve all social sectors in the discussion and adoption of renewable energy sources are required. Among others, the following actions are recommended:

- Financing discussion panels and mass technological diffusion activities, like congresses, seminars, workshops, and technical meetings.
- Integration of private and public sectors to foster large-scale renewable energy generation and applications.
- Prototype creation and demonstration.
- Supporting science fairs for renewable energy demonstration activities at high-school level.
- Public communication and improved interaction with the media to promote renewable energy sources.

- Capacity building in the areas of renewable energy generation, accumulation and distribution.
- Expanding and strengthening IDB's initiative for sugarcane technology diffusion in ALC, to include South American countries.
- Creation of a "virtual" tech information institution capable of defining and implementing programs.

6.2. FUND RAISING

Major donors like the Japan International Cooperation Agency (JICA), private institutions like the Bill & Melinda Gates Foundation, the Rockefeller Foundation, and the Fulbright Foundation, as well as government-supported financing agencies which allocate funds for renewable energy and climate change R&D, should be approached. Development agencies like the Inter-American Development Bank (IDB) are also excellent program financing options.

6.3. FOLLOW UP

The creation of a Scientific Committee specialized in renewable energy research, development and innovation is proposed to report on specific advances within the strategic plan, such as:

- Organization of regional R&D networks.
- Adaptation of academic disciplines to include renewable energy teaching.
- Increasing the number of graduate students linked to renewable energy areas.

- Escalating the number of approved renewable energy projects and the amount of financial support they receive.
- Increasing the number of communication and technological diffusion events.
- Advancing renewable energy generation and use in national energy matrixes.

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GLOSSARY OF ACRONYMS

AMDEE: Mexican Wind Energy Association (Asociación Mexicana de Energía Eólica)
CAN: Andean Community (Comunidad Andina)
CHP: Compound Heat and Power
CPC: Compound Parabolic Concentrator
CSS: Close-Spaced Sublimation
ECLAC: Economic Commission for Latin America and the Caribbean
EIA: Energy Information Agency
FAO: UN Food and Agriculture Organization
Gb: Giga barrels
GDP: Gross Domestic Product
GHG: Greenhouse Gases
GW: Giga watts
GWh: Giga watts per hour
HDI: Human Development Index
IADB: Inter-American Development Bank
IEA: International Energy Agency
JICA: Japan International Cooperation Agency
kgoe: Kilograms of oil equivalent
kW: Kilo watts
kWe: Kilo watt equivalent
kWh: Kilo watts per hour
M b/d: Million barrels per day
M ha: Million hectares
MJ: Mega joules
M m^3: Million cubic meters
M tons: Million tons
MW: Mega watts
OAS: Organization of American States
OECD: Organization for Economic Cooperation and Development
PLD: Pulsed Laser Deposition
Pol: Apparent Sucrose Content
PPP: Purchase Power Parity
Procisur: Agricultural Technological Development Cooperation Program for the Southern Cone (Programa Cooperativo para \el Desarrollo Tecnológico Agroalimentario y Agroindustrial del Cono Sur)
Procitropicos: Agricultural Research, Development, and Innovation Cooperation Program for the South American Tropics (Programa Cooperativo de Investigación, Desarrollo e Innovación Agrícola para los Trópicos Suramericanos)
PV: Photovoltaic
toe: Ton of oil equivalent
TW: Tera watts
TWh: Tera watts per hour
UNDP: United Nations Development Program
WCS: World Conference on Science
WT: Wind Turbine

APPENDIX
WORLD AND REGIONAL BACKGROUND

Fossil fuel consumption —especially crude oil— expanded very quickly throughout the world due to its portability, ease of use, low cost, and relative abundance. As a consequence, the world experienced amazingly high development rates during the Twentieth Century, which meant better living standards based on a more intensive use of energy for transportation, heating, cooking, healthcare, culture, and education. At the same time, crude oil became the basis of a whole new chemical branch, which meant the discovery of new materials like plastics, polymers, pharmaceuticals, pesticides, and fertilizers, among others.

Today, a direct relation between Human Development Index (HDI) and energy consumption is clearly observed. A study developed by the UNDP (UNDP, 2006) demonstrated that, while the world's average HDI was 0.741 in 2004, the countries with highest HDIs (between 0.9 and 1) had also the maximum power consumption, like Japan, France, the Netherlands, Italy, the United Kingdom, Germany, Israel, and South Korea (ca. 7 GWh/person/yr), Australia (11 GWh/person/yr), the United States (14 GWh/person/yr), Canada (18 GWh/person/yr), and Norway (25 GWh/person/yr). On the other extreme, Niger and Zambia (with HDIs of 0.3 and 0.4, respectively) showed per-capita power consumption levels below 200 kWh/person/yr. The best-ranked Latin American countries, Brazil, Argentina, and Mexico, had HDIs between 0.8 and 0.85, with power consumption levels below 2 GWh/person/yr.

For logical economic reasons, crude oil companies have focused for decades on extracting the easiest-to-reach cheap crude oil. At first, oil was extracted near the surface of the ground. Typically, this oil was of the "light and sweet" type, or put more simply, very easy to refine into products such as unleaded gas and heating oil. As this process continued and land-based crude oil became —and will become— progressively harder to find and extract, production rates of crude oil decreased substantially. Additionally, all oil fields reach a point in their life cycle where they become economically unsuitable to keep producing oil, unless prices skyrocket. Moreover, when the extraction cost for each oil barrel equals the cost of producing energy equivalent to a barrel of crude oil from other sources, the oil well becomes obviously fruitless.

During the last three decades, the world has discovered new oil reserves at a rate lower than the consumption rate. In recent years, new proven oil reserves account for only 27 percent of global oil consumption. Currently, over 50 crude oil producing countries, such as Russia and the United States, are producing less oil than in the past. Additionally, the North Sea region, a prolific oil region twenty years ago, has witnessed sharp declines in crude oil production. Furthermore, many other crude oil producing nations may be getting closer to their peak crude oil production. Brazil, which incorporated recently new and important oil wells, is a global exception, but there are serious issues regarding the suitability of technologies t extract oil 7,000 m below sea surface and the environmental hazards associated to the extraction.

Energy consumption and efficiency vary dramatically in different parts of the world. In 2005, the global average annual per-capita consumption of modern energy (i.e., excluding traditional biomass and waste) was 1,519 kg of oil equivalent (kgoe). While the average in high-income countries is 5,228 kgoe, low-income countries average only 250 kgoe. Traditional biomass and waste account for 10.6 percent of global primary energy supply. In low-income countries, these sources average 49.4 percent of the supply, though in some countries they approach 90 percent.

Energy consumption depends primarily on population growth and per capita income level. According to FAO's estimations, world population will keep growing —in spite of its progressively declining annual rates— until 2050, when it will theoretically stabilize, and then begin to decrease toward the end of the century. On the economic field, our world is experiencing an unprecedented steady period of high economic growth, especially in developing countries.

Presently, Latin America and the Caribbean (LAC) are getting closer to the world's average growth rate. According to the EIA's World Energy Outlook 2008 Basic Scenario, and assuming that current energy policies will not shift markedly in the medium run, our world's energy needs in 2030 will be more than 50 percent higher than today. In general, China and India are expected to account for 45 percent of that increase in the demand. These trends will lead to a continued raise in energy-related greenhouse gas (GHG) emissions and to a greater reliance of consumer countries on oil and natural gas imports —mostly from the Middle East and Russia. This scenario would heighten concerns about climate change and energy security.

Regarding global climate change, the key conclusions of the IPCC's Fourth Assessment Report, published early in 2007, were:

- Warming of the global climate system is unequivocal.
- Quite likely, a major part of the global average temperature rise recorded

since mid-Twentieth Century is due to the observed increase in anthropogenic GHG concentrations.

- Anthropogenic warming and sea-level rise are expected to continue for centuries due to the timescale associated with climate processes and feedbacks, even if GHG concentrations were stabilized today. However, potential increases in temperature and sea level will vary greatly, depending on the intensity of fossil fuel-based human activities during the next century.
- The probability that this is caused by natural climatic processes alone is less than 5 percent.
- During the Twenty-first Century, world temperatures could rise between 1.1 and 6.4 °C, causing the following changes:

    1. Sea level will probably rise between 18 and 59 cm.
    2. Statistically, warm spells, heat waves, and heavy precipitations will be more frequent (confidence level: >90 percent).
    3. Droughts, hurricanes, and extreme high tides will also increase (confidence level: >66 percent).

- Past, present and future anthropogenic carbon dioxide emissions will keep contributing to global warming and sea-level rise for more than a millennium.
- Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide resulting from human activities have been increasing markedly since 1750, and now exceed, by far, the pre-industrial values accumulated over the past 650,000 years.

Most GHG emissions are caused by the use of fossil fuels, coal being the most hazardous one, and natural gas the less harmful to the environment. The challenge is to initiate the transition toward a more secure, lower-carbon energy system, without undermining our economic and social development. Nowhere will this challenge be tougher, or of greater importance to the rest of the world, than in China and India. Vigorous, immediate, and collective policy actions by all governments are essential to move the world toward a more sustainable energy path. Measures to improve energy efficiency stand out as the cheapest and fastest way to curb oil demand and emission increases in the short run. Considering the aspects mentioned above, the major threats for humankind derived from its dependence on fossil fuels are:

- Reduction of the world's oil reserves and climbing oil prices. The international network called Association for the Study of Peak Oil and Gas (ASPO; http://www.peakoil.net), set as its mission: (1) Defining and evaluating the world's endowment of oil and gas; (2) Modeling its depletion, taking due account of demand, economics, technology and politics; and (3) Raising awareness of its serious consequences for mankind. This network does annual calculations to establish the number of years that proven reserves could keep supplying the world at its current demand rate. As of 2007, those reserves could still supply the world for 39 years. The problem with this calculation is that energy demand is increasing year after year, and at high rates, making this forecast somewhat unrealistic. According to Aleklett and Campbell (2003), for every 4 barrels produced each year, only one is incorporated to proven reserves. Price forecasts vary according to the source, but experts agree that oil prices will never be as low as they were before 2005.

In such scenario, two challenges are posed:

1. How to compensate for the energy demand that will not be covered by oil if production is reduced.
2. How to avoid widening the gap between developed and poor countries, in terms of wellbeing, progress, development, opportunities, and increased income, considering a scenario of very high-priced energy.

- Uneven distribution of fossil energy reserves. Oil, coal, and natural gas reserves are unevenly distributed in the world. According to Radler (2005), the world's proven oil reserves (crude oil, natural gas, liquids, condensates, and non-conventional oil) neared 1,293 billion barrels at the end of 2005 — 14.8 billion barrels (1.2 percent) more than the previous year's calculation. Reserves are concentrated in the Middle East and North Africa (MENA), and together account for 62 percent of the world's total. Saudi Arabia's oil reserves are the world's largest, and represent 20 percent of the total. Seven of the 20 countries with the largest reserves are located in the MENA region. In LAC, only Venezuela (5th place), Brazil (10th place), and Mexico (13th place) appear in the list of major oil producing countries. In the case of natural gas and coal, the concentration is even more unevenly distributed, since Russia, Iran, and Qatar own together 56 percent of all proven natural gas reserves; likewise, 76 percent of coal reserves are concentrated in five countries (China, Russia, the United States, Australia, and India). On the contrary, land (biomass), wind, and solar radiation are far more democratic and LAC is particularly favored by the presence of these natural resources.

- GHG emissions leading to global climate change. According to a recent report of the UN/IPCC, serious actions are needed to mitigate the ongoing climate change. One of the most urgent ones is giving financial incentives to the use of renewable energy sources that replace fossil fuels.

From the social standpoint, much of the R&D needed to promote sustainable development should focus on the complex, dynamic interactions between nature and society (socio-ecological systems), rather than on the individual social or environmental sides of this interaction. Moreover, some of the most important interactions will occur in particular locations, or in certain companies and times. Therefore, science and technology (S&T) for sustainable development must be "location-based" or "company-based", and embedded in the particular characteristics of distinct locations or contexts. This means that S&T should be broadened to look for knowledge, going beyond the essential bodies of specialized learning to include endogenous knowledge, innovations, and practices.

Devising methods for evaluating which lessons can be transferred usefully from one setting to another is a major challenge for the field. Both the S&T community and society in general are committed to devise a new set of strategies to meet the challenges that lie ahead. Building on Chapter 31 of the Agenda 21, the S&T community proposal is that such strategies should be based on the following principles:

- A new contract between science and society: Addressing social inequity, poverty, and other social issues must be a part of any scientific, engineering, and technological endeavor.
- Reorientation and investment: Science and engineering must assign higher priority to finding solutions to our most pressing environmental and de-

velopmental challenges, and receive greater support from our society and governments.

- Accumulating and maintaining capacity: Scientific and technological capacity, as an elaboration of knowledge and new tools, must be accumulated and maintained in all countries, but especially in the nations that lack a minimum critical mass of S&T capacity.

LAC background

Annual per capita energy consumption varies significantly from country to country; for instance, 300 GJ/person in Trinidad and Tobago, but only 10 GJ/person in Haiti. Another indicator that points to the highly diverse nature of the region is the energy intensity of the different countries, which varies from 36 MJ/$ (PPP) in Trinidad and Tobago (a major exporter of natural gas) to a mere 4 MJ/$ (PPP) in Barbados. LAC's energy intensity average fluctuates around 11 MJ/$ (PPP), which is slightly higher than the world's average —about 10 MJ/$ (PPP).

It's worth mentioning that better living conditions are required in LAC, which means higher energy per-capita consumption. The strategy to achieve this is based on saving energy (i.e., avoiding unnecessary waste of energy), and substituting fossil fuel by renewable sources, rather than on reducing the overall, or per capita energy consumption rate.

Population and income growth are key drivers for energy consumption in the world. Population growth forecasts for the LAC region indicate that peak annual population growth was achieved in the 1960s (2.8 percent), and that the future trend is a continuous decrease, from our present 1.2 percent, to an estimated 0.25 percent in 2050. Studies indicate a direct and linear relationship between population growth and energy consumption. Under current social and economic conditions, each point on the population growth index means one point on the energy consumption index.

In the case of economic growth, things are different. The relationship between per capita income growth and energy consumption tends to be a logarithmic one, biased by inflation rates and income distribution inequity (Gini index). Gross domestic product (GDP) figures based on PPP indicate that LAC's economies account for 8 percent of the world's economy, opposed to 5 percent when based on GDP converted to US dollars at current exchange rates. Brazil and Mexico are the largest economies in the region, and account for nearly two-thirds of LAC's GDP, and 61 percent of its population. The region's average GDP per capita is 9,064 USD in PPP terms. Chile, Mexico, and Argentina have the highest GDP per capita in the region, while Paraguay and Bolivia have the lowest. LAC's current individual energy consumption exceeds the world average. Country values range from 1.0-1.5 times the world average for Mexico, to less than 0.5 times the world average for Bolivia.

Regional GDP annual growth is expected to slow in the years ahead, reaching 4.5 percent in 2008, and only 4.3 percent in 2009. This estimation is supported by Brazil's continued and strong growth, and the rebound from a weak 2007 for Mexico. In other countries —especially Ecuador, Bolivia, Argentina and Venezuela— growth is likely to slow down. Excluding those countries, regional GDP growth is expected to slow down only marginally, from 4.4 percent in 2007 to 4.2 percent in 2008 —due to the United States' economic weakness—before recovering to 4.3 percent in 2009.

Should these predictions become a reality, they would represent the longest positive growth spell for LAC since the 1960s. Despite the gradual worsening of current account balances due to increasing commodity prices and slower global demand escalation, strong growth is likely to persist, supported by a continuous consumption and investment expansion, and buoyed by a low-inflation environment (excluding Argentina and Venezuela), improved taxing policies (particularly in Mexico), and continuous and strong capital inflows (especially to Brazil).

Between 1970 and 1980, economic growth was accompanied by lower energy use per output unit (lower energy intensity), pointing to efficiency gains and a better use of energy resources. The trend was reversed, however, between 1980 and 1985 (per capita income contracted, while energy intensity increased), and the same unfavorable pattern continued between 1987 and 1990. This suggests that energy efficiency didn't improve at all during the economic recession of the 1980s. During the first three years of the 1990s, income recovered, but energy intensity remained high. There was scarcely any improvement in energy intensity between 1990 and 2000. The energy intensity indicator has followed fairly similar trends in the different sub-regions, but its absolute value varies considerably. Energy intensity is highest in Caribbean countries, primarily because of the more frequent use of energy-intensive, low-efficiency equipment. Southern Cone countries have the lowest absolute values, due to the use of more advanced equipment and energy technologies in their production processes. Andean countries didn't show significant changes during the period considered.

Therefore, LAC countries have made only modest advances in reducing energy intensity. Besides, during some periods they have even experienced setbacks. After a 9 percent drop between 1970 and 1980, energy intensity went up during the 1980s. In 1999, LAC's energy consumption per output unit was 7 percent higher than in 1980. On the contrary, OECD countries reduced 20 percent their energy intensity, over the past 20 years, by imposing energy policies geared to diversify energy supply and enhance energy efficiency by reducing waste and using energy in a more cost-effective way. If given appropriate technologies, support, and policies, LAC has significant potential to achieve the same results.

Despite the region's potential for progress, energy intensity projections up to 2015 are less than promising. According to OLADE, and barring any major structural changes such as the incorporation of more efficient technologies, the region is unlikely to show significant improvements in its energy intensity. Some countries may achieve gains in this respect, but others are tending to increase their energy intensity.

The region owns 10 percent of the world's oil reserves, 4.3 percent of the world's natural gas reserves, and 1.6 percent of the world's coal reserves. Moreover, 22.7 percent of the world's hydroelectric potential is found in LAC. The region's energy demand represents approximately 6.6 percent of the world energy market.

On the other hand, the 10 percent share for renewable energy sources established as a worldwide goal for 2010 is already a reality in Latin America. This was achieved mostly by huge hydroelectric dams. Nearly 26 percent of LAC's energy comes from renewable sources, and 15 percent of this energy is hydroelectric, according to the Economic Commission for Latin America and the Caribbean (ECLAC). Renewable does not mean sustainability, say activists and experts who want to see fewer gigantic dams, and more regulation on the use of firewood (which represented 5.8 percent of the energy used in the region in 2002) and incentives for non-conventional sources.

Argentina, which is highly dependent on natural gas, is the only country in the region with less than 10 percent renewable energy sources; and four are in the critical 10-20 percent zone: Mexico, Ecuador, Venezuela, and Chile. On the other extreme, we find Paraguay, Honduras, Haiti, and El Salvador, whose energy matrixes include more than 80 percent of renewable energy sources. But even in this group, all is not positive. Paraguay is almost totally dependent on hydroelectric power, while Honduras, Haiti, El Salvador, Nicaragua, and Guatemala rely heavily on firewood. Costa Rica produces 99 percent of its electricity from renewable energy sources, but total renewable energy share in the country matrix is ca. 25 percent.

In recent years, automotive companies have developed flex-fuel engines that use either gasoline, alcohol, or any mixes of these, and are working on “'trivalent'” models that would also run on natural gas. Brazil produces annually more than 2,500,000 flex-fuel vehicles (which run on any proportion of ethanol and gas-oline). Today, Brazil has 700,000-800,000 vehicles that run on natural gas, a figure surpassed only by Argentina.

In Cuba, the energy matrix is tending toward sustainable energy development. Cuba relied heavily on Soviet Union’s oil until the early 1990s. The collapse of the Soviet Union led to an interruption in the supply, and pushed Cuba into an energy crisis. Since then, this country has been developing its own hydrocarbon resources, energy conservation plans, and pursuing research into renewable energy sources. However, Cuba still depends on oil, which represents 56.1 percent of its total primary energy supply (TPES). Renewable sources comprise only 37.9 percent and are based mostly on sugarcane byproducts (34.5 percent), which tend to be used in low-efficiency combustion processes.

Another point that should also be considered is that, given the skyrocketing prices of crude oil, substitution of fossil fuels by renewable energy sources should not only be induced in LAC, but worldwide. In such scenario, some countries will not have the conditions required to produce all the energy —especially biofuels— necessary to supply their domestic demands. Therefore, they will need to look for suppliers elsewhere, and even move their industries to places with cheaper energy. Consequently, renewable energy generation in LAC would not only mean a more sustainable future, but also an important economic opportunity.

However, energy discussions should always be conducted side by side with environmental considerations such as greenhouse gas emission, especially carbon dioxide.

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