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ENERGY INNOVATION IN LATIN AMERICA: R&D EFFORT, DEPLOYMENT, AND CAPABILITY ACCUMULATION

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Energy Innovation and Economic Development in a Climate Constrained World:
Barriers and Opportunities for Ibero-America

[PRELIMINARY DRAFT – DO NOT QUOTE]

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Outline

1. Introduction

Ibero-America, just as the rest of the world, faces an increasing urgency to transform existing energy systems. In the past, incentives to develop energy systems were induced mainly by changes in demand (derived from industrialization and urbanization) and by price shocks in fuels. Diversification of energy sources followed a growing need of *use* of particular energy forms. For developing countries, innovating in energy systems meant fundamentally gaining control over natural resources and moving away from primary, export-oriented enclaves into industrial integration, as well as improving energy security. Today, however, environmental constraints and the pressing need to reduce energy poverty forge additional challenges and set new directions to change the ways in which we use *and produce* energy. Improving current technologies along the same trajectory is simply not enough. Fundamental changes must take place in our economic systems in order to combine energy efficiency with low-carbon, sustainable energy sources, for which new abilities and solutions need to be targeted.

This Background Paper reviews the state of energy technology innovation (ETI) capabilities in Ibero-America (IA) and examines the barriers and opportunities for upgrading and diversifying those capabilities. We identify four factors that will drive new directions in energy technology innovation (ETI). First, the fuel mix of both the regional

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and the world demand will continue to change, catalyzing new energy security issues. While security needs are more tangible for some energy-importing countries in Ibero-America (Spain, Portugal, Argentina, Peru), important shifts in demand towards gas and processed fuels will be felt all over the region. Relying on new renewable sources can add strongly to energy security both in terms of continuous access as well as a buffer for price fluctuations.

Second, expanding access to improved energy services will improve income inequality (Latin America is the most unequal region in the world) as well as rural conditions and human health. More than a focused, poverty-reducing policy, expansion of access to energy is a development policy in its own right with strong impacts in social development and economic security.

Third, developing countries cannot replicate the emission-intensive path of industrial economies. In order to avoid dangerous climate disruptions, a new global climate framework must be agreed in the next few years. Eventually and inevitably, new commitments for developing countries will be required, creating stronger pressure to decouple economic growth from green-house gas (GHG) emissions. Latin American countries, despite their relatively low emissions profile, are highly vulnerable to climate change and will face growing adaptation costs in the near future (de la Torre, et al, 2009; see also IPCC, 2007). The region must therefore balance their right to exploit their fossil resources for development with the strategic need to manage their own transition to sustainable energy.

Fourth, new energy technologies constitute an emerging wave of generic technologies and expanding markets. This "development wave" will offer technological and economic benefits for countries that develop suitable entry and catching-up strategies, and a missed opportunity for those who don't. Moreover, a very large market for energy goods and services is anticipated during the 21st century. It is not clear whether or when Ibero-America will be ready to capture a sizable fraction of this market. One recent report indicates that the global market for "diffusion" of carbon mitigation technologies will range from approximately $200-$440 billion annually through 2030. The market for diffusion of carbon mitigation technologies in developing countries is estimated at $80-$260 billion annually (UNFCCC 2009, 24). The International Energy Agency estimates there will be a 50 percent increase in world primary energy demand between 2005-2030, and that China and India alone account for 45% of the increase. Cumulative world investment in energy-supply infrastructure between 2006-2030 could be as large as $22 trillion, with China alone accounting for $3.7 trillion of this total (IEA 2007).

The first three factors correspond to what we discuss as three principles guiding ETI: a) energy security; b) improving human well being; c) enhancing the environmental sustainability. These principles complement and compete with each other in rather complex ways. The fourth factor highlights an additional principle guiding and facilitating ETI, that is, enhancing innovation capabilities for dynamic development. It stresses the fact that technological learning is a condition for sustainability in its economic, social, and environmental dimensions.

The focus on capabilities and learning is crucial when considering the nature of innovation in general. Innovation is not simply applying new inventions coming from scientific labs. It is a complex process, driven by the interaction of different agents within given structures, that requires the mobilization of many types of knowledge, skills, and resources (Lall, 2000). At the same time, technological innovation is uncertain and cumulative (Rosenberg, 1994, Ch. 5), which has very important consequences for decision making. First, outcomes cannot be planned, and each new step (including errors) provides new knowledge. Decisions must be sequential, and flexible to change course as learning advances. Second, innovations must be used and improved many times before they yield benefits. Capital and hardware are thus crucially complemented with the accumulation of knowledge and experience (Soete and Arundel, 1990). Even in the case of "imitation" processes, innovation decisions contain a considerable degree of uncertainty. Finally, cumulativeness also means self-reinforcement of existing trajectories and rigidity to depart from established solutions (Arthur, 1988, 1989).

Uncertainty and cumulativeness play a very strong role in ETI. Energy systems are large, complex, and capital-intensive technological systems, with strong resistance to change. Energy is used in all economic and social processes, with multiple specific applications and specific infrastructures. Durability of assets, high sunken costs, as well as high up-front investments make equipment turnover slow. Finally, performance criteria, rules and practices, as well as forms of organization (Unruh, 2002), all tend to correspond tightly with certain technologies. All these forces bias choices in favor of the technological status quo, making the introduction of new energy technologies more difficult. That is why energy transitions, in the form of successions of dominant fuels is a long-term process that can span for decades, as the infrastructures connecting supply and demand are parsimoniously adapted, installed and replaced (Grübler and Nakicenovic, 1988; Nakicenovic, Grübler, and McDonald, 1998).

Current energy systems are "locked-in" into a fossil fuel, carbon-intensive regime that is resilient to change. In order to become "competitive", new ETs must be developed in protected niches, discarding unsuccessful variants and improving on the best solutions, until they reach the performance and cost levels of incumbent technologies. But even then, adaptation costs on the demand side set barriers to adoption, especially when demand is fragmented or use depends on exclusive infrastructure. Institutional changes such as the setting of standards, interconnection contracts, feed-in tariffs and quotas, together with softer financial schemes are then necessary for new ET's to be deployed.

These features of ETI must be taken into account in order to assess the challenges behind four-pronged ETI principles depicted above. A transition towards low carbon, diversified renewables sources, that expand access to improved and safe energy services will entail a long process of learning and coordinated investments across a range of agents and institutions. National strategies must recognize and take advantage of local heterogeneity of needs and resources, and aim at balancing short-term efficiency with long-term resilience.

2. Energy technology innovation (ETI) and development[1]

Energy-technology innovation (ETI) is the "set of processes leading to new or improved energy technologies that can augment energy resources; enhance the quality of energy services; and reduce the economic, environmental, or political costs associated with energy supply and use" (K.S. Gallagher, Holdren, and Sagar 2006). Energy-

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[1] This section draws heavily upon Gallagher, Kelly S., Holdren, John P., and Ambuj D. Sagar 2006, "Energy-Technology Innovation," *Annual Review of Environment and Resources*, 31:193-237.

technology innovation for development encompasses all the processes just described, but implies a more explicit focus on cleaner industrialization, energy-related job creation, and the improvement of human and ecological well-being through economic development to achieve sustainable prosperity. Energy innovation systems should be thought of as part of "national innovation systems", though in fact, the important interactions among these various systems occur through networks (Nelson 1993).

For many, if not all, developing countries, there is nearly always a critical choice that must be made – whether to make or buy energy technologies. This "make or buy" choice is pervasive in every industry, and not unique to energy technologies. This decision is often made at the firm level, but national governments concerned with industrial policy must also decide which strategy to adopt. Consideration must be given to the existing technological capabilities within the firm or sector, the knowledge base, the cost of more advanced technologies, the appropriateness of foreign technologies for a given country, the ability to assimilate or adapt foreign technologies for local conditions, and so forth.

There is always a danger in assuming that technologies can simply be transferred from one context to another, because in practice, it takes considerable skill to imbed a new technology into a given system. Developing countries that decide to "buy" technologies from abroad have a range of options for how to do this, including licensing technologies, forming joint ventures with firms who own desirable technologies, or acquiring foreign firms. Developing countries will want to consider which types of technological capabilities they would like to acquire. Developing countries that decide to try to "make" their own technologies will have to assess their human resource base, and how to augment it. Some try to reverse "brain drains" to industrialized countries by luring talented and experienced scientists, engineers, and entrepreneurs back to their countries. Others invest in their education system so as to develop a highly skilled workforce, or both. In either case, creation of an industrial policy is often a pre-requisite to a successful technology acquisition strategy (Amsden, 2003).

Energy-technology innovation includes not only research and development (R&D), but also demonstration, early deployment (where government often has a special role to play), and widespread commercialization. In practice, these so-called "stages" of innovation are not isolated from each other or sequential, but instead overlap and include iteration. When understanding innovation capabilities, however, it is often useful to artifically break down innovation into these stages to better assess a country, sector, or firm's capabilities.

It is difficult to define exactly what is an "energy" technology because so many different kinds of technologies underpin the energy system. Energy technologies are not only wind turbines, automotive engines, solar collectors, and deep water oil drills, but they are also improved materials and coatings, electronic controls, and computers, and so forth, all of which enable improved functioning or efficiency of the production or consumption of energy. The term energy technology refers to the means of locating, assessing, harvesting, transporting, processing, and transforming the primary energy forms found in nature (e.g., sunlight, biomass, crude petroleum, coal, uranium-bearing rocks) to yield either direct energy services (e.g., heat from fuelwood or coal) or secondary forms more convenient for human use (e.g., charcoal, gasoline, electricity) (Goldemberg 2000). The term also includes the distribution of secondary forms to their end users and the means of converting these forms to energy services (e.g., electricity to light and refrigeration, electricity and gasoline to motive power). Technology should also be understood to mean not only the physical "hardware" but also the knowledge about how to develop, adapt, manufacture, and commercialize the relevant piece of hardware.

Energy technology is important because energy services like heating, cooking, and illumination are fundamental human needs and because energy for mining, manufacturing, materials processing, construction, transport, communication, computing, comfort, and illumination is essential to the functioning of an economy, and continued economic development. Energy expenditures tend to be a large fraction of the cost of living and gross domestic product (GDP). Lower income people tend to pay a much higher fraction of income for energy than high income people. And energy technology is important patterns of energy supply and demand can impose high environmental, political, and security burdens on societies (K.S. Gallagher et al. 2006).

Improvements in energy technology are technological changes that result in reduced costs, improved efficiency, improved quality, or reductions of environmental or political impacts of the provision of an energy service. Energy-technology innovation can reduce the costs of energy technologies we know about today, and also improve the menu of options for the future (Holdren 2000).

ETI over the past century and a half has led to "large improvements in the quality of energy services, large reductions in the quantities of primary energy forms needed to produce given services, large reductions in the real costs of those services, and, in many (but not all) instances, significant reductions in emissions and other environmental impacts per unit of service delivered" (K.S. Gallagher et al. 2006, 195). As we look towards the old, but persistent, and new challenges before us, energy innovation will certainly be a crucial ingredient of the policy solutions.

The hard questions, therefore, are not about whether or not energy-technology innovation is needed or worthwhile, but which types are needed and when, how to make it more efficient and effective, how it should be managed, what are the appropriate roles of government versus the private or non-governmental sector, to what extent should countries cooperate with each other, and how, which inputs are most important and at what levels, and what the goals of innovation should be.

Measurement of energy-technology is very important because private firms wish to understand how to maximize the returns of their investments, and governments and their publics wish to know how to improve the likelihood that innovation is bettering society. There are numerous ways to measure energy-technology innovation, but unfortunately no metric adequately encompasses the processes of innovation, spanning basic research to broad commercial deployment. Some metrics capture efforts on basic energy R&D, for example, whereas others serve as better indicators of technological deployment. Too often, one indicator (usually, levels of investment) is used to describe the performance of an innovation system, when the indicator only describes one aspect of innovation. Still, it is worthwhile to consider the different ways that innovation can be assessed through indicators (K.S. Gallagher et al. 2006).

One can assess technological innovation in general by using quantitative metrics and qualitative assessment techniques, and this is true of ETI as well. Quantitative metrics include spending or investments for innovation; the number of programs and partnerships; the number of technical publications; the number of patents filed, granted, and cited; and the use of life-cycle or S-curves; and the calculation of learning rates (Gruebler 1998). The diversity of the innovation system, coordination and management of technological innovation, and the successes and failures of programs and projects can be assessed with qualitative methods, including the use of surveys or case studies. Quantitative and qualitative measurement tools are highly complementary and should be used together to assemble a more complete and accurate picture of ETI.

Another way to group energy-technology innovation metrics is to classify them in three categories: input, output, and outcomes. There are pros and cons for using each of these metrics, and each will now be discussed in turn.

Input metrics are indicative of contributions to the innovation process. For R&D these inputs include financial investments, existing scientific and knowledge ("old stock"), and the practical problems and ideas from which new inventions arise. In later stages of innovation, inputs include funding for demonstration and deployment programs, materials, facilities, and fuels to run demonstration projects, and the developed inventions that are moving into the phases of demonstration and deployment. Human resources are essential to the inputs because many of the tacit contributions to innovation are embedded in people's minds owing to education, training, and learning from past innovative efforts (Nelson 1996, Freeman and Soete 2000, and K.S. Gallagher et al. 2006).

Perhaps the most commonly used input metric of trends in innovation, and for energy-technology innovation in particular, are levels of investments (see, for example, Dooley 1998, Margolis and Kammen 1999, and K.S. Gallagher and Anadon 2009). Although investments are frequently used as an indicator for energy innovation generally, this metric is only one of the many inputs to innovation. An estimate of Latin American public and private investments in energy R&D (not including demonstration or deployment) are depicted in Table 5.1 and Figures 5.1, and discussed below in section 5.

If data are available on energy-innovation investments, one can also measure ETI intensities (e.g., Brazilian energy R&D spending/GDP), as shown in Figure 5.2. The obvious benefit of investment-related metrics is that public spending data tend to be more readily available and can be tracked year to year, so that trends can be discerned, and regions, countries, and sectors compared (see, for example, Figure 2.1 which depicts the U.S. Department of Energy's investments in RD&D over time (K.S. Gallagher and Anadon 2009)). Using investments as a metric is problematic because public investments are relatively comprehensive for R&D but not necessarily so for demonstration, and even less so for deployment activities. When investment data are inclusive of demonstration and deployment, it is frequently impossible to ascertain how they are allocated among the different stages. Public investments tend to be collected and reported more readily in industrialized countries, but they are less frequently collected and reported in developing countries. The IEA collects data for member countries on energy RD&D expenditures, but these data do not encompass deployment activities.

Spending data for the private sector are notoriously poor because private firms are not required to report these data, and they often consider them to be proprietary information so they are reluctant to share them. Much industrial R&D is conducted by diversified corporations, and evaluating the portion of their R&D spending that is relevant to energy is difficult as a practical and theoretical matter (Sagar and Holdren 2002).

Another frequently used input metric is human resources, including the number of scientists and engineers in aggregate, by sector, or on a per capita basis. Data are reported in terms of the highest degree attained (e.g., bachelor's, master's, doctorate). This measure of R&D personnel is useful in a number of ways. The main drawback to using data on the number of people engaged in R&D activities is that this metric does not account for the quality or efficiency of the work. Although there may be a large number of people engaged in R&D, their output may be poor. Also, when comparing the number of people engaged internationally in ETI, one must be especially careful because there can be many more people employed in a developing-country setting where the cost of labor may be cheap, but the research infrastructure may be much poorer. This input metric is difficult in an energy context because it is hard to ascertain when scientists and engineers are working purely in the energy domain (K.S. Gallagher et al. 2006).

Output metrics are indicators of the results of inputs to the energy-technology innovation process. Frequently-used output metrics include the number of papers published in journals, the number of patents filed, granted, or cited, blueprints developed, the number of "hard" technologies generated, and the number of process innovations, to name a few. In the energy domain, it is particularly hard to use outcome metrics because of how difficult it is to define what is an energy technology. If you cannot define an energy technology, then how can you measure how many related papers have been published, patents filed, and so forth? Thus, available indicators of energy-technology innovation outputs probably vastly underestimate the true number of energy innovation products. International comparisons of output metrics are risky because the propensity to publish in peer-reviewed journals or to patent a new technology varies widely among countries. In addition, many scientific journals are published in English, which might make English-speaking nations overrepresented (Archibugi and Coco, 2005).

Patents filed, granted, or cited are another metric of innovation in general and also for ETI more specifically. As with R&D investments, the main advantage of measuring patents is that data tend to be more easy to obtain, at least in industrialized countries. It is important to note that patents filed and granted are usually considered to be an output indicator of R&D (or invention) activity, not of wider innovative success because the invention may never be taken up by the marketplace and commercialized (Basberg 1987). The same problem one encounters with respect to defining an energy technology when considering which patents are energy related and which are not (and when patents filed in a non-energy sector might have implications for the energy sector) occurs in the patent realm (K.S. Gallagher et al. 2006).

Visible, tangible technologies produced are clearly outputs from the innovation process. For R&D managers in private firms, when a technology emerges from the lab and becomes embedded in a product, it is clear to management that the inputs to the innovation process in terms of financial and human resources were worth it. Private firms are likely to strongly emphasize this metric because technologies that emerge through the innovation process and end up being commercialized provide tangible, direct benefits to the company. Toyota's Hybrid Synergy Drive, for example, a set of technologies that is being commercially deployed, was the result of concerted innovative efforts by the company. But, this metric is problematic as well because it likely underestimates the products of the innovation process. All of the intangible, tacit technologies or improvements in knowledge on the part of the scientists and engineers are not counted. Much such knowledge cannot be codified into blueprints or patents. Energy technologies are also usually embedded in technological systems (such as an automobile or power plant), and knowledge about how to do the systems integration is essential, but hard to quantify. For many developing countries, the technological know-how for systems integration is the hardest technological capability to acquire (Amsden 2003; K.S. Gallagher 2006).

Extending the notion of innovation "outputs", one can also differentiate energy-technology innovation outcomes, and their associated metrics. If output metrics are the direct products of the innovation process, outcome metrics measure the results or impacts of these innovations. Outcome metrics "reflect the success of the deployment or diffusion of technologies generated in the innovation process" (K.S. Gallagher et al. 2006, 213). They can include environmental indicators such as carbon dioxide intensity or energy intensity, changes in the energy fuel mix, reductions in costs of different technologies or products, and knowledge accumulation. More qualitative metrics often include program or project-based outcomes.

It is highly tempting to try to quantify the costs and benefits of energy-technology innovation programs, but as noted by a major U.S. National Research Council study on the benefits of U.S. government efficiency and fossil energy R&D programs, there are many kinds of energy-related benefits, and many cannot be as easily quantified as to their costs (NRC 2001). The NRC notes that benefits of such programs can not only be realized as economic benefits of products that enter the marketplace, but also as environmental, national security, options (those technologies that have been invented that are on the shelf and available for commercialization), or knowledge (defined as knowledge resulting from R&D programs that may spill over into other sectors or be of use later) benefits.

With all the focus on global climate change, many have begun to assess GHG emissions intensity as an indicator of the success of energy-technology innovation projects and programs to reduce GHG emissions. If greenhouse-gas emissions are growing less fast than the economy, the emissions intensity of the economy is improving, and therefore cleaner and more efficient technologies must be penetrating the marketplace. Some countries have managed to decouple greenhouse-gas emissions or energy use from economic growth, whereas a close relationship between the two can still be observed in other countries.

The number of programs and partnerships in an area of innovation is another metric of interest for both governments and private firms, and between public and private entities – often termed "public-private partnerships" or PPPs. Of course, one could have a large number of very small programs or a small number of very large programs and have a similar impact. Nonetheless, one can measure the size of such programs and partnerships by the number of employees and investments. The quality of programs and partnerships is probably of most interest and can be assessed better through qualitative techniques. Still, if a country or corporation has no (or many) innovation programs or partnerships in a certain area of importance or interest, this is worth noting (K.S. Gallagher et al. 2006).

Given the availability of data for Ibero-America and scope of this paper, we will focus in the following section on R&D investment and innovation outcomes.

3. Energy use in IA countries in context

3. 1 Energy profiles: fuel mix and dynamics of reserves in Latin America

The energy supply mix in Latin America is dominated by fossil fuels, with a very strong presence of hydropower and biomass (Coviello and Altomonte, 2003). Spain and Portugal also rely heavily on fossil fuels, with a share of renewables of 6.5% and 17.0% respectively (IEA database, 2006). These European countries are net energy importers (imports account for 95% and 98% of total primary energy supply in Spain and Portugal respectively). As can be seen from figure 3.1, non-biomass energy use in Latin America is dominated by oil, with slightly raising shares of hydropower and gas, and a very small contribution of coal. The use of renewable energies is pervasive in many LAC's. Countries like Costa Rica, El Salvador, Guatemala, Haiti, Honduras, Nicaragua, and Paraguay, get most of their energy from renewable sources (mostly biomass and hydropower, but also geothermal), with wood accounting for more than 30% of their final energy supply (ECLAC, 2003; OLADE; 2006). Larger countries (exc. Brazil) and Caribbean Nations depend mainly on fossil fuels, but still with significant shares of renewables. In 2006, 25% of final demand in the residential sector was fulfilled with wood (OLADE, 2007).

{INSERT FIGURE 3.1 ABOUT HERE}

LAC has the highest share of hydropower in the world (Figure 3.2). The potential is still much higher: only 22% of estimated hydropower capacity is used (Figure 3.3). See also ECLAC (2004, p. 102).

{INSERT FIGURE 3.2 ABOUT HERE}

{INSERT FIGURE 3.3 ABOUT HERE}

As shown in Tables 3.1 and 3.2, LAC is fairly "secure" in terms of oil dependence, but for some countries time is running out on the ability to rely on domestic oil supplies for energy use. Spain and Portugal are entirely oil dependent, with Spain consuming more oil than any Latin American country except Brazil and Mexico.

Table 3.1 exhibits oil dependence in Latin America measured by national oil production divided by consumption. On average, the region produces 1.5 times as much oil as it consumes. Some nations such as Peru however, produce less than is consumed. Spain consumes 1,574 thousand barrels of oil per year, and imports all of it. At that level, Spain consumes more oil than all LAC nations except Brazil and Mexico. Portugal consumes 286 thousand barrels of oil per annum, lower than the average in LAC and comparable to Colombia.

{INSERT TABLE 3.1 ABOUT HERE}

{INSERT TABLE 3.2 ABOUT HERE}

While it is true that most LAC nations presently enjoy oil surpluses, the future is not as bright. Table 3.2 shows the level of proven reserves in each country, and the "reserve to production" (R/P) ratio. Dividing known proven reserves by the annual level of production can give one an estimate of the number of years until the resource would be exhausted without new discovery and innovation. The region has approximately 50 years of production left at current rates (not including Brazil's massive new discoveries discussed below). However, some key producers such as Mexico may have only 10 years.

3.2 Estimates of demand and future investments

One of the most widely used projections on energy consumption is IEA's Energy Investment Reference Scenario (IEA, 2003), which estimates trends in energy profiles up to 2030. The reference scenario for Latin America predicts a transition to an energy system based on gas and a rapid expansion of electricity. The total energy investment in the region needed to cope up with demand growth would amount to $1.3 trillion USD between 2001 and 2030, around 1.5-1.6% of total GDP every year (see Table 3.3). Despite its diminishing share in primary energy, oil consumption would grow at an annual rate of 1.8% in absolute terms every year, absorbing 1 in every 4 parts of energy investment. Almost 30% of all investment would be channeled to oil and gas exploration and development.

{INSERT TABLE 3.3 ABOUT HERE}

Electricity generation in IEA's reference scenario would almost double between 2010 and 2030, from 256 to 492 GW, with gas overtaking hydro as the main power source by 2030. The prediction of a strong deployment of gas-fueled electricity is based on the current superiority of combined cycle plants, which offer not only a higher thermodynamic efficiency but smaller optimal efficient size of plants, increasing modularity and flexibility in capacity expansion.[2] According to this scenario, hydropower's share in total capacity would diminish from 54% in 2010 to 41% in 2030. The IEA is not optimistic about the diffusion rate of non-hydro renewable electricity, which is projected to grow from 2.3 to 3.9% of total generation capacity between 2010 and 2030 (to be equivalent to coal). Without major deployment of CCS technologies, IEA's reference scenario is clearly at odds with mitigation schedules that advocate for developing countries to curb energy GHG emissions by 2020 (cfr. Baer, Athanasiou and Kartha, 2007).

{INSERT FIGURE 3.4 ABOUT HERE}

3.3 Energy-related and other GHG emissions

LA contributes with a small share of total GHG, although there is a strong heterogeneity in Per capita CO_2 emissions across countries. Energy-related emissions are relatively low with respect to the rest of the developing world, due to the extended use of hydropower and the low share of carbon. CO_2 emissions per unit of produced energy in LA's electricity sector is 40% smaller than the world average, and 74% smaller than in China and India (de la Torre, et al, p. 22). Land use change, on the contrary, is the main source of GHG emissions in the LA region, constituting 46% of total emissions (above the world average of 17%). This later factor raises serious concerns on the emissions impact of biomass as energy, and stresses the importance of environmental management of energy producing plantations.[3]

While LACs emissions are low compared to those of Spain and Portugal, the emissions' path as per capita augments is more intensive (Figure 3.10), mainly due to the fact that

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[2] IEA's Report calculates investment costs for electricity capacity (in general) to fall at a rate of 1.2 per cent a year between 2010 and 2030; investment costs for renewables (both hydro and non-hydro) are on the projected to diminish more slowly, at -0.40% a year.

[3] The share of wood and unsustainable biomass in total primary energy is high in Guatemala (59%), El Salvador (37%), Honduras (69%), Nicaragua (50%), and Haiti (73%). In Brazil, biomass represents up to 22% of the total energy supply (ECLAC, 2003; OLADE, 2006).

LACs are net energy exporters. The same pattern is to be found in the path of electricity use per level of income (see Figure 3.11). This would mean that, despite the strong share of low-carbon energy sources, a stronger effort to disengage emissions from economic growth would be needed in the region in order to compensate for the highly emissions-intensive energy exporting sector.

{INSERT FIGURE 3.5 ABOUT HERE}

{INSERT FIGURE 3.6 ABOUT HERE}

3.4 Biomass, deforestation, equity and energy access

The use of traditional biomass as energy fuel is widespread in Latin America (see Coviello and Altomonte, 2003), where firewood is the dominant fuel of low-income households. The use of traditional fuels, in other words, reflects the large socio-economic inequalities that plague the region. For a handful of countries, the percentage of population that lack access to electricity still remains in the range of 20-30% (Haiti, Honduras, Bolivia, Nicaragua, Peru, Guyana, Grenada, Panama and Guatemala). Almeida and De Oliveira (1995) showed clearly how firewood use is gradually replaced by liquid fuels and electricity as the level of income increases in Brazilian households. While per capita use of firewood in Latin America would have decreased between 1961 and 2006 from 0.77 to 0.50 cubic meters per person, the volume of firewood in the region increased 65% in the same period, contributing in a very important way to deforestation. But lack of access to modern energy sources means much more than a different fuel mix.

While fossil fuel consumption carries its own problems, solid fuels for cooking and heating also produce significant health and environmental impacts, and is associated with increased morbidity and premature death particularly because of incomplete combustion (Goldemberg and Johansson, 2004, p. 40). However, the use of biomass can become a sustainable option to liquid and other fuel sources when improved efficiency biomass is combined with forestry management and other sustainable energy sources (Nabuurs, et al., 2007; Massera et al, 2005)). Developing new sustainable energy futures for the rural areas and small towns means in this respect enormous challenges and opportunities for ETI in the region, and a necessary step for reducing both inequality and environmental impact.

4. The ETI System in Ibero-America

Oil, gas, and electricity sectors in Latin America are dominated by large companies, most of them state-owned, or by combinations of public and private oligopolies. Energy firms are among the largest firms in Latin America.[4] At the same time, rents from energy resources are a very important source of fiscal revenues in oil and gas exporting nations of the region, a factor that shapes strongly the autonomy and strategic direction of the sector. Although investment decisions tend to be more concentrated than in developed countries like Canada and the USA (see Moscardella and Hyott, 1998), the privatization and deregulation processes of the 1990's increased the participation of private agents, mainly in the form of independent energy producers.

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[4] Pemex, PDVSA, Petrobras and Mexico's CFE are the top 4 largest firms in Latin America's Top 500 Firms (Latin Trade, 2009). Other energy firm situated among the top 100 largest firms in the region are Ipiranga Conglomerate (Brazil), Electrobras (Brazil), Repsol YPF (Argentina), Copec (Chile), EcoPetrol (Colombia), ENAP (Chile), Shell (Brazil), Petroecuador (Ecuador), Chevron (Brazil), Esso Brasileira, AES Elpa, Eletropaulo, and Cemig (Brazil), Petrobras Argentina,

Most state-owned energy companies developed R&D facilities for acquiring critical technological capabilities during the 1960's and 1970's (IMP and IIE in Mexico, Intdev in Venezuela, CENPES in Brazil; see section 5). These public institutions up-graded the knowledge and capability bases needed for scaling-up energy production, distribution and transmission to industrial levels. However, just as with most industrial sectors in the LA region, energy innovation systems remain strongly dependent on foreign technology sources, namely the multinational firms in the oil, gas and electricity industries. The extent to which local firms carry on R&D is generally limited to technology transfer assessment, maintenance, and skill personnel training (see ECLAC, 2008 for the case of R&D in general in LA). However, many local R&D labs and firms have developed product and processes innovations, especially in the oil and electricity sectors.

The extent to which Latin American large energy companies can drive *alone* the necessary innovation impulse for an energy transition is questionable, and must be carefully assessed for each country strategy. As industrial incumbents, these firms will expectedly reinforce, rather than weaken the current technological regime, because of their rigidity to switch to a different technological base. Competencies also tend "lock in" (Levinthal and March, 1993). When the resources pushing the transition are alien to the incumbents, new comer entities must be set in place to foster change (Smith, Stirling and Berhout, 2005). However in some cases, like Petrobras' development of biofuels, these large incumbents are likely to push innovation in complementary technologies.

The local base of suppliers of manufacturing and capital equipment to the energy industries has been traditionally narrow (some notorious exceptions are oil pipes and oil-gas duct infrastructure in Mexico and Argentina through TAMSA and TERNIUM, and capital equipment in Brazil). A more or less defined division of labor tends to exist between local and foreign firms tends to exist in energy projects in general, with the first providing basic and civil engineering, while the latter carry on plant design and detail engineering (see Moscardella and Hyott, 1998, for the case of Mexico).

By means of extrapolation, one can plausibly expect that Energy Innovation Systems in Latin America replicate many of the features of National Innovation Systems described by ECLAC's Study on Productivity (ECLAC, 2008): a) they exhibit low R&D intensities (measure as R&D investment over gross domestic product; b) dominant share of capital expenditure in R&D expenditure; c) small share of private investment in total R&D; d) most R&D concentrated in large firms; e) absence of venture capital and other mechanisms for supporting private R&D investment; f) in patents, very low local patenting, (see figure 4.1), most patenting concentrated in independent inventors not if firms. Many of these features are identified and qualified in section 5.

{INSERT FIGURE 4.1 ABOUT HERE}

Outsourcing of technological services has been growing hand-in-hand with the diffusion of new models for financing energy projects. According to a recent study by the Cambridge Energy Research Associates, this is precisely the trend in the U.S. oil and gas industries.[5] This new investment schemes became frequent in the LA region after the collapse of financial models based on state-debt (Islas and Rodríguez, 1997). Outsourcing can have ambiguous effects on local technological capabilities: while on one side it allows energy firms to stay up-to-date with technological solutions, on the other

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[5] *Journal of Petroleum Technology*, "Industry Updates", 12 January 2009.

hand it reduces their absorptive capability, preventing learning. In the worst cases, it can substitute for local existing capabilities and accelerate their depreciation (as is the case of turn-key plant projects).

5. ETI Capabilities in Ibero-America

5.1 ETI RD&D efforts in IA

As noted in the introduction, R&D investment is not sufficient for ETI in any sense. It is, however, a crucially necessary input. R&D is the main source of technological knowledge and a the central mechanism for revealing and specifying technological opportunities (Nelson, 2001). Research provides crucial functions with no close substitutes, by generating knowledge and understanding, training of personnel in problem solving activities, mapping of resources, problems, and solutions. Development, in turn, provides the link between knowledge and workable solutions and is the first step to applicability, concentrating the bulk of R&D investment (up to 67%) in developed countries (Rosenberg, 1994, p. 13).

Contrary to the late-comer advantage thesis (Krueger, 1991), countries that develop later cannot usually skip the stages of and costs of technological development. There are of course many important, non-technical barriers to technology transfer, including market and income size, entry barriers and strategies to control and manage technological assets, as well as asymmetries in the technology market (Kumar, 1998; Dunning, 1988; Katz, 1976; Vaitsos, 1970). But it is also clear that local efforts in search and development activities are crucial factors for international technology transfer (Mowery and Oxley, 1995). In order to exploit imported technologies firms must develop “absorptive capacity”, i.e. the capabilities to understand and apply those technologies internally (Cohen and Levinthal, 1990). Technological “leapfrogging” is possible, and the most famous case of this in the energy domain is Brazilian sugarcane ethanol (Goldemberg 1998). But, technological leapfrogging is far from automatic and limits to leapfrogging have also been observed. The absence of aligned domestic policy incentives is a key barrier for leapfrogging (K.S. Gallagher 2006). These capabilities are needed even for making correct choices for purchasing new technologies. It is also necessary to unpack tacit components of technology, both to explore new applications and ways to exploit them according to local needs, as well as for specifying opportunities for further advance. Internal R&D is for these reasons not a substitute, but a complement to contracting of external R&D (Mowery, 1983).

Public support in Energy R&D (ER&D) is necessary for many well known and accepted reasons. The argument, which refers to public investment in basic R&D was formulated by R. Nelson in 1959, and even earlier in the United States by Vannevar Bush: basic research provides many solutions to different problems and can produce higher social benefits than private benefits. Left to private decisions, the economy would invest fewer resources than socially beneficial (Nelson, 1959). Indeed, because the returns from basic research are so uncertain but also so potentially beneficial to society, only the government can be expected to support basic research, though at times large companies have been willing to also make such investments (e.g. Bell Labs). The private sector appears to have become more myopic over time, investing in increasingly applied research to chase short-term profits. The argument applies as well to applied R&D, even though the boundaries between one and the other tends to become more and more blurred with time. This does not mean of course that private firms do not find incentives to do basic R&D, a fact to be found in reality. While private R&D tends to concentrate on "applied" R&D, many times firms find it profitable to invest in basic knowledge. In the case of Energy R&D, there are even stronger incentives for public investment to go beyond research into development and even initial deployment: energy innovations face very large upfront costs and lab-to-plant upgrading costs. Additionally, as noted before, energy R&D provides very large social and strategic benefits.

Despite the pressing needs to find alternatives to fossil energy and improve energy efficiency, public ER&D in the developed world has decreased systematically since the late 1970's everywhere except in Japan (Kammen and Nemet, 2007; K.S. Gallagher and Anadon, 2009; Margolis and Kammen, 2009). And yet, R&D expenditure in LA is relatively low compared with international standards (see ECLAC, 2008; OECD, 2008).

The R&D profiles of the LA region tend to be concentrated in research rather than development, and to be state funded, which reflects very low private-firm engagement in active innovation activities. In turn, this reflect to a large extent the pattern of economic specialization of LA in lower-intensive manufacturing branches. Together with low patenting, and weak presence of innovative firms in every sector, R&D expenditure tend to be mostly investment in embodied technology, reflecting a very weak allocation effort to design, engineering, and other development activities (ECLAC, 2008).

Energy R&D (ER&D) investment data for LA countries is very scarce and scattered in time. Availability of data differs greatly by country and time-period. The database we constructed is obviously incomplete, and probably biased against certain countries (with the most notorious absence of the B. R. of Venezuela). As we explain in Table 5.1, we elaborated on existing data an updated image of the level of Energy R&D investment in the region.

{INSERT TABLE 5.1 ABOUT HERE}

In absolute terms, ER&D in Iberoamerica is concentrated in three countries: Brazil, Spain and Mexico (see table 5.1), which account for 95% of total ER&D in the region for the period 2000-2005. Argentina, Chile and Portugal come in a second group (we lack information for Chile after 2001).

In relative terms, Argentina, Brazil, Chile, Mexico, and Uruguay, show high shares of energy in total R&D, slightly higher than the ratio in the US (see figure 5.1). However, lack of information may induce biases in countries with few data points (e. g. Panama).

{INSERT FIGURE 5.2 ABOUT HERE}

Regarding the time pattern, we show that there is slight diminishing trend between the 1990's and the period 2000-2006, both in the time series (figure 5.2) as when comparing cumulative investment in these periods. Brazil is the big exception to the regional trend, with both public and private R&D growing in tandem. In the case of Spain, evidence on a diminishing trend is more solid, since the series that goes back to 1975. Public ER&D in Spain has been clearly diminishing all the way after 1982. However, ER&D investments made by Spanish firms increased boldly after 2000. The shift in relative weights between public and private R&D would reflect a process of national development of the knowledge base where initial public investment set the platform for increasing the perceived productivity of private R&D efforts (something that happened in Korean manufacturing industries, cfr. Kim, 1990)

{INSERT FIGURE 5.2 ABOUT HERE}

There are some important caveats about these figures on ER&D data. The most important one is that ER&D is aggregated, making it impossible to distinguish by energy source or even by industry within the energy sector. Secondly, ER&D tells us nothing about the nature of capabilities being developed. For example, these investments may very likely include exploration and development in conventional oil and gas resources (particularly, this is be the case of an important share of the accounted R&D in Mexico and Uruguay). Even more, it is not impossible to know if ER&D is an indicator of knowledge and technological development within an existing technological trajectory of oil production, or is actually devoted to develop new technologies for fossil energy (off-shore, deep-drilling, etc.) or to renewables. Third, we cannot specify if ER&D investment is carried on in-house (that is, within the firm) or outsourced (carried out by other firms within or without the country). In this latter sense, ER&D expenditures would be reflecting R&D effort but overestimating at the same time the accumulation of local capabilities. Again, external R&D is not a substitute of local R&D, or viceversa.

As noted above, R&D is necessary but not at all sufficient for ETI. Moreover, it is not sufficient for an ETI guided by the four principles proposed in the Introduction. First, only by developing skills and competencies in downstream activities like production, distribution and marketing can economic returns from local innovation be appropriated. Second, R&D can take place within the existing technological regimes (Kemp and Rotmans, 1999), actually reinforces existing technologies. More information is needed to assess the direction of R&D, a task towards which we turn in the following section.

5.2 Deployment of New Renewable Electricity Sources (RES)

In aggregated terms, LACs have a relatively strong foothold in New Renewable Electricity Sources (NRES) for Electricity Generation, particularly biomass and geothermal. One of the most comprehensive studies on Renewable Energy Sources in the Region (ECLAC, 2004) shows that the region has been gaining experience in a wide range of programs, institutions, and promotion policies for thermo-solar modules, photovoltaic systems, wind energy, biofuels and biomass, and renewable rural electrification. However, and with notable exceptions, these technologies have not been able to articulate the critical mass of resources, capabilities and enabling policies needed to deploy them beyond isolated niches of application. This fact is reflected in the negligible trace that these technologies leave at aggregated levels of energy use. Nonetheless, the LA region exhibits a relatively high degree of penetration of NRES.

In terms of the penetration of NRES in electricity production, LA is second only after Europe (Figure 5.3). This is relevant considering the region's abundance of fossil energy, a factor with a strong impact in other oil and gas rich regions like Eurasia and the Middle East. The early deployment of geothermal and biomass electricity of these two sources (the first in Mexico and the second in Brazil) made the region a leader (in relative terms) on new renewable electricity since late 1970's to mid 1980's. However, since 1987 and up until 2000 the share of NRES in LA stagnated around 2% of total electricity production. The penetration of NRES jumped again between 2001 and 2003 from 2 to almost 3%.

{INSERT FIGURE 5.3 ABOUT HERE}

However, both in absolute terms as in terms relative to population, the regions' NRES production is much less spectacular and much smaller compared to that of the US and Europe (Figure 5.4). Moreover, it seems like LACs have specialized in technologies with very slow pace of development and deployment (geothermal and biomass), while seems to be unable to develop the newer electricity sources with much stronger growth potential, notably wind energy, solar and fuel cells (see Table 5.2 and Figures 5.5 to 5.8).

{INSERT FIGURE 5.4 ABOUT HERE}

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{INSERT FIGURE 5.8 ABOUT HERE}

5.3 Illustrative examples of innovation outcomes in IA

This section highlights Brazil and Spain as ETI capability success stories and briefly juxtaposes these examples with the more limited case of Mexico. In the Brazilian case we focus on oil exploration and the development of biofuels. For Spain we discuss the development and deployment of wind energy. Mexico has attempted to build capabilities in both oil exploration and in wind but with much more limited results. The successes in Brazil in Spain are very different in nature, but three traits stand out: a long-run commitment on the part of the state to build capabilities, accessing technology and know-how from foreign firms, and government guarantees of price and market stability for energy suppliers.

5.3.1. Brazil: Turning Crisis into Opportunity

As the world considers options in the midst of the current financial crisis we would do well to look back at how Brazil turned its economic and energy crises of the early 70s into an opportunity to develop world class domestic oil and ethanol production capabilities. Brazil was hit hard by the oil shock of the early 1970s, and found itself with a shortage of foreign exchange. In response to the crisis Brazil embarked on a two pronged energy innovation strategy: invest in building technological capabilities for oil prospecting in deep waters, the fruits of which could be the cornerstone of a domestic production base; and to develop alternative energy sources.

The chief orchestrator of Brazil's energy innovation strategy is the country's state-owned energy company, Petrobras. Before the oil shock of the early 1970s Brazil was importing 80 percent of its petroleum and sugar prices simultaneously collapsed. Though the company was founded in 1954, it still maintained very sparse deep water drilling or ethanol capabilities in 1974. By 2009 Brazil's Petrobras ranked sixth among the world's largest oil companies and Brazil is now the second largest ethanol producer in the world. In both these areas, the company was able to develop such capabilities in a fairly rapid fashion through the strong and guiding hand of the state, learning effects from other types of industry in Brazil, and maintaining "embedded autonomy" (or partnering but maintaining authority) with the private sector.

Exploration

In the past few years, Petrobras has overseen the discovery of numerous oil deposits in ultra deep water. The crest of these discoveries was a 2007 discovery of what could turn out to be 5-8 billion barrels of oil and natural gas. The first oil drawn from the Tupi Fields of the Santos Basin off the coast of Rio de Janeiro where the oil and gas was discovered, occurred in May of 2009. Brazil says that these discoveries are the tip of the iceberg. They continue to make discoveries in the nearby Campos Basin, and the Santos Basin where the Tupi Fields were discovered have hardly been explored.

Thirty-five years is a long time for a government to think ahead, but that's just what Brazil did in the early 1970s. Indeed, it was a gamble, but one that paid off. Their two pronged strategy has made Brazil all but energy independent. If these latest oil discoveries bear fruit, Brazil will also be one of the largest exporters in the world. What exactly did Brazil do?

The antecedents of Brazil's oil exploration capability are in Brazil's larger industrialization strategy that started in the 1950s, Brazil did not decide to carry this strategy over to the energy sector until the crisis of the early 1970s. According to Surrey (1987), four factors assisted the development of Brazil's petroleum sector:

- The (relatively) rapid industrialization and the development of steel and shipbuilding, as well as civil and mechanical engineering;
- Oil import substitution which allowed domestic firms to establish in new domestic markets, alongside the careful selection and screening of FDI with specific technological capabilities;
- The ability to attract foreign firms to work in Brazil, especially alongside domestic firms; and
- The role Petrobras played in assisting national firms, such as vetting the technical expertise of firms, putting Petrobras staff in place to monitor contract quality, setting up an award system for domestic innovation, and R&D assistance through its dynamic R&D centre, CENPES. Indeed, Petrobras is ranked 5th in the world in terms of oil R&D and is the leading innovative firm in Brazil, having spent the largest amount of funds on R&D and is also the leading patent holder (Carvalho and Goldstein, 2008).

These factors helped jump start Brazil's efforts, and by 1977 Brazil discovered deep water deposits in the Campos Basin off the coast of Rio de Janeiro. Upon this discovery, for over thirty years since Petrobras has developed strategy for Campos Basin and now the nearby Santos Basin to proximate domestic firms alongside multinationals, university research centres, and government agencies to enhance agglomeration effects and build capacity over time. Table 5.2 exhibits the network of these firms, suppliers, and other entities in the Campos Basin region. Key to the success has been Petrobras' ability to act as the 'governor' of the complex mix of state and private actors from home and abroad (Silvestre and Tavares, 2009).

{INSERT TABLE 5.2 ABOUT HERE}

Biofuels

In tandem with efforts to build domestic oil capabilities Brazil also sought to develop alternative sources of energy other than oil. Their breakthrough in this area, also orchestrated by Petrobras, is sugarcane based ethanol. In November of 1975 Brazil started its National Alcohol Program (Proalcool). After thirty years, Brazil now substitutes ethanol for 20 percent of automotive fuel and 80 percent of Brazilian cars can run on blends of gasoline and ethanol.

Under Proalcool, Brazil set up the National Alcohol Commission (CNAL) was established to a favorable credit environment, guarantee a market for all the alcohol produced, and to stimulate production. In this environment, the following policies were designed by the government and have guided the development of the sector for thirty years (see Hira and Oliveira, 2009; BNDES and CGEE, 2008):

- Stipulate that Petrobras purchases a guaranteed amount of ethanol on an annual basis;
- That the Bank of Brazil provide low-interest loans to ethanol distilleries;
- Requiring the availability of ethanol at gas stations;
- Subsidize and regulate prices to stimulate consumer demand;
- Maintaining strategic reserves to stabilize supply;
- Support a Research and Development network

As mentioned earlier, Brazil's ethanol industry is the second largest in the world (to the US) and now employs 1 million workers (BNDES, CGEE, 2008). As in the case of oil exploration (see Table 5.2), the majority of effort and innovation in this sector has occurred in a geographically specific region with agglomeration effects. In the case of ethanol, Sao Paulo serves as the hub of activity given its approximation to the bulk of sugar production and a large portion of consumer demand in Brazil. R&D efforts range from genetics research and improving sugarcane breeding, to focusing on new varieties, pest control, milling capacity, and so forth. As a result of such efforts by the IAC and CTC (see Table, NUMBER?), average sugarcane yields in Brazil have increased from 3900 ha/annum in the early 1980s to 5600 in 2001 (Hira and de Oliveria, 2009).

The biggest breakthrough for Brazil came in 2003 when the Brazilian car industry developed flex-fuel vehicles and the run-up of global oil prices that occurred at about the same time. By early 2005, sale of flex-fuel cars outstripped sales of gasoline powered cars and accounted for 57 percent of all sales that year. By 2009, flex-fuel cars were close to 21% of Brazil's car fleet and ethanol now represents 16.7% of the country's total energy consumption by the automotive sector.

Finally, Brazil is the country in the region with the largest set of university-based centers for developing New Renewable Energies.[6] The amount and quality of linkages

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[6] The list of center includes: CBEE - Brazilian Center for Wind Energy at the Federal University of Pernambuco; CENBIO - National Reference Center for Biomass at the University of São Paulo; CENEH - National Reference Center for Hydrogen at the University of Campinas; CERPCH - Reference Center for Small Hydropower at the Itajubá Federal Engineering School; CRESESB - Reference Center for Solar and Wind Energy at the Electric Energy Research Center, CEPEL; GREEN SOLAR - Brazilian Center

that communities, industry, finance sources, and governmental agencies develop in order to take advantage of this knowledge base will determine to a good extent the future innovation potential of Brazil in these areas.

Essential Role of Long-Run Financing

One of the key lessons from the Brazilian experience and pertaining to innovation in general is the need for a long-run commitment and sustained and below market financing for energy technology innovation. Since 1952 Brazil's National Development Bank, BNDES has been a pioneer in terms of energy and ETI financing. BNDES played a key role in kick-starting both the oil and biofuels industries in Brazil, and continues to support efforts in energy deployment and innovation.

BNDES has emerged as the largest development bank in LAC, larger than the Inter-American Development Bank. BNDES assets in 2008 were approximately $150 billion ($277 Real), while the IDB holds $69 billion. Interestingly BNDES's funds come from Brazil's labor ministry, so the end goal of all industrialization and energy programs through BNDES is employment creation. BNDES supports a variety of activities through loans, equity stakes, and grants. Some of these policies derive from BNDES initiative, but for the most part the push comes from Brazil's larger industrial policy, called the "Productive Development Policy" (PDP). BNDES serves a member of PDP'S executive secretary and plays the financing role of the PDP's implementation strategy. The strategic industries under Brazil's current industrial policy are energy, pharmaceuticals, software, among others. As shown in Table 5.4, currently, BNDES finances fixed investments throughout the energy production chain, for the reduction of waste in the sector, and for innovation activities.

{INSERT TABLE 5.4 ABOUT HERE}

Energy development and innovation activities reached $16, 570 in 2008 (approximately $ 8.2 billion US) and only slightly tapered off in 2009 in the wage of the crisis. This shows the commitment on the part of the government and BNDES to sustain financing throughout political and economic changes. For loan activities BNDES interest rates hover at 6.25 percent (basically covering transaction costs only). This is far below the 9 or more percent for similar loans in the private market since 2000.

Innovation in general is a cornerstone of the PDP and BNDES starting playing a role in such activities in 2006. Innovation loans support private firms to develop the capabilities to engage in ongoing innovative activities. Special emphasis focuses on technology projects aiming at the development of new or significantly improved products and/or processes.

BNDES also operates an innovation grant program, the Technology Fund (FUNTEC). The grants support research, development and innovation projects in the strategic industries under PDP. To be eligible, a project must be headed by a university or technological institute in cooperation with a private company. Energy is one of

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for the Development of Thermo-Solar Energy at the Catholic University of Minas Gerais, PUC-MG; CERBIO - Reference Center for Biofuels at Paraná Institute of Technology, TECPAR; NAPER - Support Center for Renewable Energy Projects at the Federal University of Pernambuco, UFPE; GEDAE - Development of Alternative Energies Studies Group at the Federal University of Pará, UFPA (Source: ECLAC, 2004)

FUNTEC's priorities. In this area, the fund supports mainly bioenergy (ethanol, biodiesel, energy forest and new environmentally friendly processes) and hydroelectricity. As Table 5.4 shows, funding for this program was initially small but has grown significantly to $R 63 million ($31 million).

5.3.2: Spain: Avoiding Crises and Making Opportunities

Whereas Brazil is a more comprehensive success with two cases of building capabilities from scratch and bringing them to fruition through the deployment and diffusion phases to become a globally competitive leader, Spain's success lies in its relatively recent ability to access foreign technologies, and absorb such capabilities to the extent that a vibrant domestic sector has begun to make inroads into global markets, such as Mexico.

Spain enacted an official policy to diversify its energy base after the second oil shock of the early 1980s. These policies continued but were reinvigorated in response to the diffusion of knowledge related to the climate crisis during the late 1990s. In 2009, eleven percent of Spain's energy came from wind sources. In 1995 wind was relatively non-existent (del Rio Gonzalez, 2009).

{INSERT FIGURE 5.9 ABOUT HERE}

Spain's 1980 entry into the renewable energy industry came in the form of public R&D, subsidies to local firms, and a "feed-in" tariff. Spain embarked on research and development on windmill technology, connectivity to grid issues and so forth. In terms of subsidies, Spain's utility would provide 50-90 percent of the investment costs. However, the feed-in tariff (a guarantee of energy purchase) was subject to change each year and thus seen as highly risky (Dinica, 2008). Deployment received a second wind in 1997 when the policy was modified in response to renewed concerns about energy dependence and new concerns about the natural environment, particularly climate change.

By 2005 Spain was second in the world in total installed wind power capacity (over 10,000 MW) and wind comprised 11 percent of all of Spain's energy demand. The two factors that led to the rapid deployment and diffusion of wind technology in Spain have been the nation's evolving "feed-in laws," the development by foreign firms linked with domestic firms and the engineering knowledge and resources available from Spanish utility companies. Feed-in laws are provisions that guarantee producers a fixed price above market prices for a number of years (referred to as the "feed in tariff" and/or a premium scheme that is also guaranteed for a set number of years. Spain's law also guarantees grid access for renewables. (Munoz et al, 2007).

Spain also acquired, deployed, diffused, and established backward linkages with foreign wind technologies. According to Stenzel and Frenzel (2008), the most illustrative example of the development of wind capabilities in Spain is the case of Iberdrola, a large utility in Spain. In 1994 one of the company's subsidiaries was to plan and install six wind farms. Another subsidiary of the company, Gamesa, was a firm with a long history of engineering and design capabilities through its experience in the manufacture of aeronautical and automobile components. Gamesa obtained a licensing agreement with

Vestas (a Danish firm) which gave Gamesa the exclusive right to construct and operate Vestas' 500 kW turbines. Yet another subsidiary conducted engineering and services for installation and grid connections, thus enabling Iberdrola in one way or another to be involved in all aspects of the value chain. This model and similar partnerships became the rule for Spanish wind deployment (Dinica, 2008)

5.3.3 Mexico: one step forward, two steps backwards

Mexico is a major oil exporter and its largest firm, Pemex, is the largest energy producing firm in the region.[7] The CFE, the public Electricity Facility is also among the largest and most efficient companies in the region. Both energy giants have devoted a great deal of effort to optimizing generation and extraction processes, and are mostly users of up to date technology. However, the Mexican energy innovation system is small, with a highly discontinuous level of innovative activity, weak internal relationships between and among universities, industry and government, and subjected to unstable programs and resource flows. The system works in general for guaranteeing operational tasks and securing external technology flows, sometimes at the expense of deepening local capabilities (Cimoli, 2000).

Oil exploration, development, and refining

Pemex's R&D institution, the Instituto Mexicano del Petróleo (IMP) was created in 1965, with the objective of augmenting local "technological autonomy for managing resources and technology, intensifying oil exploration, increasing the capacity for deep-drilling and satisfying growing local demand, by means of scientific and engineering programs that were up to date provided to Pemex by international firms" (Guajardo, 2007, p. 141). The IMP made possible the height of oil production in Mexico during the 1970's and 1980's, becoming rapidly one of the most important R&D centers in the Third World.

In its beginnings, Pemex transferred to the IMP its geology projects, and required from it solutions for secondary retrieval, as well as studies for valuing oils and improving performance. In a second phase, the IMP was assigned to the task of substituting imports by developing catalyzers for refining oil and petrochemicals, material research, as well as establishing quality controls and a system of productive linkages to the capital good industry, aiming at the maximal participation of local producers of materials, equipment, and instruments (Wionczek, Bueno and Navarrete, 1988; see also Aboites, et al.).

In its first ten years the IMP augmented and diversified its operations and projects, substituting successfully a range of engineering and R&D services previously contracted by Pemex to international firms. By 1972 the patent assets numbered 42 and its services extended to the private sector. By 1973, thanks to the production of the IMP, Pemex integrated the production of polyester fibers and increased plant scale and complexity in petrochemical and refining plants. With the oil boom of 1977-1981, the IMP increased strongly its technological assets, allowing Pemex to become a world leader in oil reserves and production, "mastering the sequence of technological development

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[7] In terms of assets, the four subsidiaries of Pemex worth $84.1 US billions in 2004; Petrobras was $19.4 and PDVSA $13.4 (World Bank, 2006; see Aykut and Goldstein, 2006)

from basic studies, lab level experiments and pilot plants to process engineering and final construction projects" (Guajardo, p. 144). By 1976, 90% of all detail engineering of Pemex' projects was developed in Mexico.

Pemex' contracting practices were based on direct allocation of projects to IMP and other local engineering and construction firms. IMP and Pemex relations changed drastically after the 1982 crisis and the reorientation of the economic model. Budgetary restrictions forced to switch from direct allocation to project contracting as services. From 1986 on the IMP started to sell projects to Pemex, instead of receiving fixed monthly resources (Guajardo, p. 145). The institute was slowly shifted to a position were it had to search for economic profits as just another supplier to Pemex. However, due to its legal and political constituency and frameworks, it could not freely commercialize its products. Its entrepreneurial activities were blocked politically and legally. By 1985, with a deepening crisis, a whole range of project were cancelled, as well as the acquisition of equipment, materials and personnel. Serious cutbacks were exerted on personnel in engineering and seismologic services, services to refineries, petrochemical plants and catalizers. Between 1996 and 2001, the number of projects by Pemex Exploración y Producción carried on in tandem with the IMP fell from 62 (of a total of 66) to 14 (of a total of 64) (Pemex, 2002)

This situation also shifted IMP from R&D into servicing Pemex' immediate operative needs. R&D orientation and criteria suffered a lack of political clarity and mis-information on the part of PEMEX directives. After 1992, when Pemex' subsisdiaries were separated, the IMP could no more work on pre-defined contracts but instead had to compete for them in the international market. Moreover, the subsidiaries scheme of subcontracting and proliferation of "turn-key plant" projects implied that Pemex ceased to be neither "a captive nor a secure market for the IMP"(Guajardo, p. 151). The reform created a Pemex that exported more, refined less, abandoned production of petrochemicals, reduced processing of gas, and started flaring gas at higher rates than before.

As a result of the deterioration of IMP's capabilities, Pemex's technological and knowledge bases also receded back. A qualitative assessment of Pemex Exploration and Production Division, carried on between 1996 and 2000 over 267 technologies showed that Pemex' capability base is in general falling behind the frontier. In consequence, the assessment concluded the firm had to engage in strong technological upgrading in order to avoid obsolescence and being able to reach a "strong follower" position in the industry's technological regime (PEMEX, 2001). As shown in figure 5.3.1, the firms has a less than favorable position in over 70% of the technologies assessed.

Despite its booming level of sales during the late 1990's, Pemex's R&D investment efforts during the period 1997-1999 averaged barely 2.46% of total investment and 0.533% of total sales (Pemex, 2001).

{INSERT FIGURE 5.3.1 ABOUT HERE}

Wind Energy

The decision for installing a first grid-connected plant in Mexico arrived in 1993, almost ten years after the first mapping of economic exploitable resource. Lack of policy guidance, dis-articulation of efforts, and the strong presence of fossil fuel and hydroelectric power prevented resources from flowing to wind energy (Huacuz, 2005).

The “La Venta I” project (an 8-turbine, 2 MW facility in the Oaxaca Isthmus) was carried on as a turn-key plant, built-on-lease project. The opportunity of starting up a more locally integrated industry was thus lost, despite the existence of basic local technological capabilities at the IIE in engineering areas closely related to wind turbine technologies, and the availability of detected local manufacturers that could have provided components. IIE produced lab-level aerogenerators of 1-1.5 kWh that constituted the first steps in a potentially fruitful trajectory of technological learning.[8] The project delivered very high plant operation factors (48% in the first two years of operation) at a cost of $0.04USD/kWh, very close to thermal electricity generation. The Electricity Company manages the plant after the lease, but privileging operation efficiency rather that learning. The plant is thus never really exploited as an experimentation site.

For another ten years, wind energy remained unjustifiable to the CFE. In 2004 is launched the first large plant connected to the grid (La Venta II, a plant with 98 generators of 850kWh, for a total 86 MW), under the same public bidding, turn-key plant scheme subcontracted to Gamesa and Iberinco (Borja-Díaz, et al. 2005). The deployment scheme that prevails form then on is one where foreign firms provide the generators, plant design and detailed engineering, while local firms participate in construction works. Only operational capabilities are being developed locally, following the established division of technological labor in which local firms work out the civil engineering parts of the projects, and foreign firms generate detail engineering and plant design. By 2008, scheduled investments under the same scheme are projected to provide additional 2,000 MW of capacity for both direct generation and self-generation for manufacturing industries (CFE, 2007).

Rural Electrification

Part of Mexico’s one step forward has been in terms of rural electrification, particularly in the case of photovoltaics and small-scale hydroelectric projects. In a relatively short period Mexico has been able to expand rural electrification to 90 percent of its population—much higher than most LAC nations. In addition to expanding supply in a new cleaner energy source, Mexico has increased access to electricity for some of the most underprivileged members of its population. Finally, Mexico has been able to leverage new public investment for renewable energy deployment in the rural sector.

Mexico’s success is in part due to physical and socio-economic circumstances. Mexico is blessed with ample sunlight for solar power. It also has a large rural population, much of which lives in poverty. These two traits, coupled with the interests of numerous international institutions and organizations, has made Mexico a testing ground for renewable energy electrification as part of poverty reduction strategies. As of 2006, Mexico had almost 400 MW of installed capacity in solar PV and small-scale hydro, mostly located in rural areas.

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[8] Personal communication with Marco Borja, Project Leader of the Wind Energy from the Instituto de Investigaciones Eléctricas IIE, CFE’s major R&D provider.

Mexico started a rural electrification program, operated under the CFE in 1977, which floundered but was then rekindled in 1988. In 1980 only twenty five percent of Mexico's rural population had access to electricity. By 2008 90 percent now have access. But Mexico is a large country, and 3.6 million rural inhabitants still lack electricity (Huacuz, 2005). What's more, those inhabitants dwell in remote areas where extending Mexico's energy grid would be extremely costly. Mexico is learning that rural PV applications become cost effective when juxtaposed against the costs of grid extension. To fund these efforts Mexico invested modest amounts of public investment but more importantly leveraged funds from international institutions. The World Bank, Global Environmental Facility, United States Agency for International Development, Sandia National Laboratories have together contributed approximately $ 1 billion over the past fifteen years (CEC, 2006).

While the Mexican rural electrification case is a success in that it has increased supply of a cleaner energy source, from an innovation perspective it is not clear that Mexico will make collateral innovation or adaptations to the underlying technology. Indeed, the government and donors appear to be content with simply importing the technology. Moreover, it is not clear how sustainable the external funding may be. Mexico will thus have to bolster investment to make sure there is still an incentive for international institutions to play a role there, and should focus collateral attention on developing capabilities to adapt to and improve upon imported technology.

6. Barriers and opportunities for ETI acceleration in IA

To a very large extent, international differences in technological activities depend on the way in which an economic system faces and processes uncertainty, cumulativeness, and irreversibility (Patel and Pavitt, 1988). In assessing barriers and opportunities for enhancing ETI it is therefore crucial to focus on the characteristics of the investment allocation processes that bound technological behavior.

At one extreme, a system is myopic to the opportunities of a set of technological activities when it cannot help but evaluate them in an "ordinary" way; ordinary project evaluation would imply the assessment of benefits according to: a) normal rate of return, corresponding to b) an existing and defined market demand, and c) stringent discount rates for risk and time.[9] This type of project valuation biases against cumulative, irreversible and uncertain investment. At the other extreme, in dynamic systems project evaluation "also includes the prospect of creating new market demands, and of accumulating, over time, firm-specific knowledge that opens up further applications and opportunities" (see Dosi, Pavitt and Soete, 1990, p. 102).

In this section we argue that opportunities for enhance innovative behavior in ET's depends crucially on macro-economic key variables, on the surrounding innovation system, and on the policy setup.

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[9] The argument resembles the notion of technological myopia by Atkinson and Stiglitz (1969): the case where a firm technical choice is based "solely on current factor prices," without taking "account of the value of the increase in knowledge associated with each technique" (op cit. p. 574).

6.1 Macro-economics, financing, and path dependency

Macro-economic instability has been a secular preoccupation in the region, which economic performance in the last decades has been characterized by a high degree of real economic volatility (Titelman, Pérez-Caldentey and Minzer, 2008) with strong impact on investment (Fanelli, 2008b). Macro-economic instability has as well affected negatively "financial development, the accumulation of human capital, the quality of institutions and the distribution of income" (Fanelli, 2008a). Clearly, the impossibility to establish the future movement of key macro-economic variables erodes the ability of the economic system to deal with long-term investment, irreversibility, risk and uncertainty.

In the case of deployment of ET's, where long-lived capital assets and long time horizons play a fundamental role in investment prospects, the cost of capital and the availability of credit is crucial. Secondly, and given its inherent uncertainty, innovative behavior highly sensitive to financing supply. Indeed, most innovation is so risky that it cannot simply be carried out through the traditional financing institutions, requiring venture capital or firm's internal funds. Financial opening occurred during the late 1980's and 1990's did not translate into higher growth rates nor in a deeper financial penetration in the region; on the contrary, the opening of capital markets may have very likely contributed to a much more stringent environment by setting up high interest rates and overvalued exchange rates (Nadal, 2007). Venture capital schemes are practically un-existent in the LA region. This, together with the overall dis-mantling of development banks (again, with the notable exception of Brazil), has set up a clearly adverse environment for engaging in generalized innovative behavior in LA.

Even large energy companies, with larger enough assets to rely on international capital markets, seem to have suffered credit astringency, subjecting their investment range to safer technology bets with shorter payoff times, especially when they used to rely on government debt for expanding their activities (as was the case of Pemex and CFE; cfr. Islas and Rodríguez, 1997).

Income constraints constitute definitively a barrier to ET's diffusion and deployment, but this time acting on the demand side. In the crudest case, households and firms would prefer to adopt less efficient technologies that result cheaper in the shorter term simply due to high up-front costs. At the same time, both industrial as household consumers of energy will resist the increases in prices that would be demanded by new ET's, reducing the policy space for introducing feed-in tariffs based on higher costs for consumers.

6.2 Systemic capabilities and constraints

As we stated above, innovation systems in LA tend to be dis-articulated, concentrated in basic research, with weak private involvement, and reduced to adaptive innovations. Several other constraints appear to play a role in shaping the landscape of technological opportunities related to ETI.

A salient fact is the process of relative de-industrialization all over the region with exception of Brazil, Mexico and some Central American countries (Katz, 2005; ECLAC, 2008, p. 73 and on). A closer look will show that even Mexico and Central American Countries have not really prevented de-industrialization, but rather occupied labor intensive niches within certain international production chains. Moreover, the reduction in the share of manufacturing in gross domestic product has been accompanied by a quality change, with a reduced orientation towards knowledge-intensive activities. As stated in ECLAC's report, "given the characteristics of technological progress, this could undermine future growth capacity." Finally, the share of engineering-, and science-based industries in manufacturing output is below the world average (ibid p. 74). These recent developments in the structural change profile of the region means that absorptive capacity in "surrounding" or complementary industrial technologies to ET's is profoundly weak.

There is thus strong evidence that LAC's have advanced into a new round of primary specialization, in terms of their position in the international division of labor (Katz, 2005). In the medium term, this means that growth opportunities will induce stronger pressures to exploit energy sources (especially those with strong international demand), not in the direction of sustainable ETI but in that of technology outsourcing and export-oriented enclaves. It is important to note that a strong endowment of natural resources is not necessarily positive or negative for growth and development per se. It depends on how their exploitation is integrated (or not) into the broader economic system. ECLAC (2008) proposes some guidelines to neutralize negative effects and increase positive ones: a) macroeconomic policies to counter-act the cyclical fluctuations in world prices; b) promotion of domestic linkages, from production clusters to import substitution; c) accumulation of skills and "human capital" to develop knowledge intensive activities; d) create incentives to innovation, from R&D support, venture capital and strong financial support to new enterprises; e) strong development-oriented institutional coordination.

Technology and innovation policy, finally, is only effective if it develops with a technology specific focus and in tandem with clearly defined industrial and energy policies. Attention to the different features of ETI Systems in every country, in consonance with the relative degree of local absorptive capacity must be carefully considered in policy design. Without specific strategies to build up system-specific absorptive capacities and secure a macro-environment that encourages long term planning, the energy future of the region will more likely depart from sustainable ETI and the more it will drift into technologically myopic, enclave-like regimes, driven by short-run maximization of rents.

BOX: Innovation Policies: The Systemic Approach

Linear models of innovation depicted it as a pipeline process: basic R&D, applied R&D, invention, marketing-testing, and diffusion imitation (see Rothwell, 1992). The normative derived from these models was that governments should invest massively in the first stage. Recent models of innovation focus on how each stage is linked to the next, paying particular attention to feedback loops and linkage effects within the chain (Mowery and Rosenberg, 1985; Soete and Arundel, 1993).

Following this approach ETI is the outcome of a system made up of networks of firms, public and private organizations specialized in technological services, R&D labs, households, public institutions, standards. Following a systemic approach to innovation policy implies that policy responses for enhancing ETI must be:

a) holistic: directed simultaneously to many interacting actors and rules

b) sequential: proceed progressively for short, medium, and long term goals

c) specific: depending on both country's and technologies' characteristics; and

d) adaptive: reviewed periodically to adjust to changing underlying conditions

Additional sources: Nelson and Rosenberg, 1993; Edquist, 1997

Finally, it is an open question as to whether the region's "incumbent" innovators in state-owned oil industries will be resistant to change or become change agents. Traditionally, incumbents are more comfortable with their current focus on innovation and in the particular sectors with which they engage. It can therefore be difficult for those same sectors to say, focus on something like wind power. However, Brazil's example offers some hope of another path. As we previously highlighted, Petrobras not only has been a key innovator in terms of oil extraction but has also focused on bio-fuels and energy innovation in non fossil burning sectors.

6.3 Policy space within international commitments

Regardless of whether nations in Ibero-America choose to "make" or "buy" the necessary technologies that will be key for energy innovation in this century, some 21st century international trade, investment, and finance regimes make it more difficult to mimic some of the success stories discussed above.'

The ETI standout in this study is of course Brazil. Brazil's capabilities have been built up over years of dedicated experimentation and guidance on the part of the government and the state-owned energy giant, Petrobras. Many of the policies that Brazil has deployed to build capabilities in such activities as ultra-deep water drilling and biofuels are simply not permitted under the WTO and more so under Preferential Trade Agreements with many other developed nations, particularly those with the United States. Any effort to single out a specific sector, and worse a domestic firm in a specific sector, are in fundamental violation of the principle of "national treatment." National treatment means that no domestic industry or firm can be treated more favorably than a foreign sector. What's more, as is shown in Table 6.1, many other aspects of trade agreements run up the abilities of countries to deploy key policies for industrial learning. And preferential trade agreements such as NAFTA offer even more limited space than the WTO.

{INSERT TABLE 6.1 ABOUT HERE}

As the table shows, requiring that foreign firms or patent holders transfer certain technologies or that such entities locate R&D facilities and train local personnel is now forbidden under investment and intellectual property provisions respectively—though not actionable under the WTO. In the table an "X" indicates that the policy is not permitted, a "." indicates that the policy is under consideration for elimination under current negotiations. Subsidizing learning is strictly forbidden under treaties such as NAFTA and DR_CAFTA. However, there is significantly more "policy space" under the WTO. This is good news for Brazil, Argentina, Uruguay, and a small number of other countries in the region who have yet to sign PTAs with the US. For countries that do have such treaties, they have to "buy" technologies at monopoly and oligopoly prices (K.P. Gallagher, 2005; K.P. Gallagher, 2008).

8. Summary and Conclusions

This Background Paper reviewed the state of energy technology innovation (ETI) capabilities in Ibero-America (IA) and examines the barriers and opportunities for upgrading and diversifying those capabilities. We identified four factors that drive new ETI: the fuel mix of both the regional and the world demand will continue to change, catalyzing new energy security issues; expanding access to improved energy services is needed to improve income inequality (Latin America is the most unequal region in the world) as well as rural conditions and human health. More than a focused, poverty-reducing policy, expansion of access to energy is a development policy in its own right with strong impacts in social development and economic security; developing countries cannot replicate the emission-intensive path of industrial economies; and new energy technologies constitute an emerging wave of generic technologies and expanding markets. This "development wave" will offer technological and economic benefits for countries that develop suitable entry and catching-up strategies, and a missed opportunity for those who don't. Ibero-American nations are poised to capitalize on this opportunity.

First we provided a framework for ETI and economic development and then provided a snapshot of energy use and consumption in the region. With the exception of a handful of countries (Spain, Portugal, Argentina, Peru and some others), the region has fairly secure sources of energy for some time to come. We also identify that this "cushion" can be a catalyst or a crutch. That depends on the policy environment and the ETI system in each nation.

Second we outlined the contours of ETI systems in the region. We find that there is a vast difference in the levels of ETI capabilities across Ibero-America. Brazil, Spain being among the leaders, Central American and Andean nations among the laggards, and nations like Mexico somewhere in the middle. Third we conduct an assessment of ETI capabilities in the region, creating a database or energy research deployment and development. From these data we learn that energy RD&D is fairly abysmal across Ibero-America—with most nations spending on the order of one percent of total RD&D on energy RD&D. That is one percent of a very small amount of total innovation spending, which is less than 1 percent of GDP in LAC.

We then provide illustrative examples of some of the leaders and laggards in ETI in Ibero America. We focus on Brazil's ETI capabilities in terms of ultra-deep water drilling and in biofuels. We also point out the import role of clustering and long-run financing has taken in Brazil. We then turn to a discussion of Spain's wind energy achievements in recent years, and Mexico's perils in terms of oil innovation but promise in terms of rural electrification. The final section discusses the opportunities and barriers for energy innovation in Ibero-America in decades to come.

Need for more research

This background paper is far from the last word on this subject. Its intent it to provide an over-arching framework and empirical context from which more research needs to be done. Indeed, each of the different sub-sections of this paper could be a short study in and of itself: a thorough analysis of energy profiles and projections of future demand; in depth case studies of ETI systems and RD&D in the region; combined with full fledged case studies of Spain, Brazil, and Mexico. Alas, this was beyond the scope of this paper.

In addition to giving full attention to these sub-topics however, two items were not given ample attention and need further work. First is innovation in the capital goods sector that reduces energy use and signals switches to cleaner technology. According to Poveda (2007), Latin America has a low average energy intensity (below the world average), but has seized very few opportunities to reduce it in the last decades. Energy efficiency in Latin America would had advanced at an annual rate of 0.2% between 1990 and 2005, a lower rate than, for example, that of the European Union in the same period (0.9%). While Brazil, Cuba, Costa Rica, Mexico and Peru have well developed energy efficiency programs, the rest of the region has failed in develop suitable institutions. Mexico shows the strongest advance in national energy efficiency in the region, although other studies have shown that this outcome has an important de-industrialization component (Aguayo and Gallagher, 2005).

A second area of significant research that is needed on is rural energy use and the energy-wellbeing nexus. Latin America is home to millions of rural inhabitants with little or no access to energy. What is the state of energy use in these regions and to what extent can policies be devised that expand access to poor rural populations, and helps poor people use access to energy as a source of productive capabilities?

Lessons for Policy

The findings in this paper have three very important lessons for policy. First, Ibero-America needs to seize and seek the opportunities that the new energy environment that it faces. Whether it be wind or solar power, ultra-deep water drilling, or biofuels, the region is blessed with the potential of ample new sources of energy, old and new. But rich endowments will turn into a curse if innovation capabilities are not developed. Second and importantly, nations in Ibero-America need to set the right policy environment so that production and consumption of new energy sources happens at all and does so in a way that spurs economic growth and equality with as little an environmental footprint as possible. That policy environment is putting in place the elements of a national ETI system. This leads to the third and final point, that ETI in Ibero-America will need significant and sustained levels of public investment and coordination. Externalities in the global market place, as well as the macro-economic, lock-in, and other limitations of ETI in the region make it all to clear that markets will not drive Ibero-American nations into a clean energy future. Long-run and sustained financing is essential, as witnessed by our discussion of BNDES in Brazil. Moreover, policies at the macroeconomic, finance, and innovation system levels need to be aligned and consistent, following a long-term perspective. Developing local technological capacity is the only way the region can manage an energy transition that fulfills the principles of sustainable ETI.

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Figures and Tables

Figure 2.1

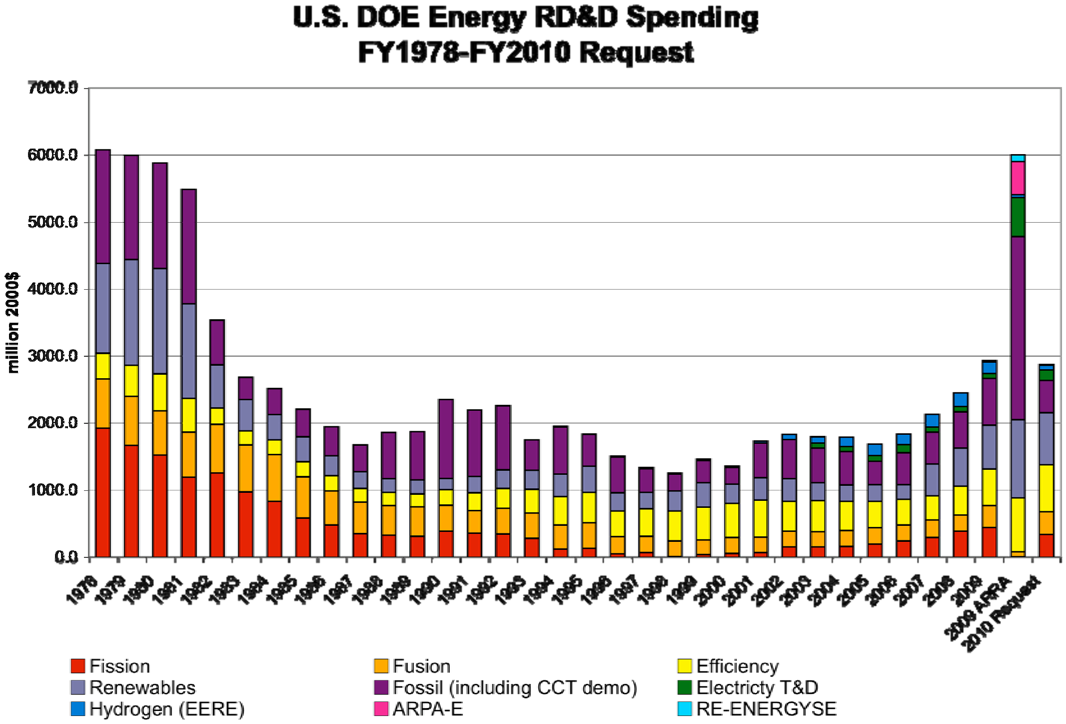


Table 3.1

Oil Dependence in Latin America

	1965	1975	1985	1995	2007
	(national production/consumption)				
Mexico	1.27	1.26	2.52	2.06	1.94
Argentina	0.63	0.92	1.27	1.92	1.48
Brazil	0.32	0.20	0.50	0.47	0.94
Colombia	3.01	1.25	1.18	2.50	2.68
Ecuador	0.62	5.43	3.54	3.98	3.25
Peru	0.90	0.62	1.64	0.84	0.76
Venezuela	19.66	10.31	5.25	7.63	5.00
Total Latin America	2.49	1.39	1.59	1.62	1.48

Source: BP Statistical Review, 2008

Figure 3.1

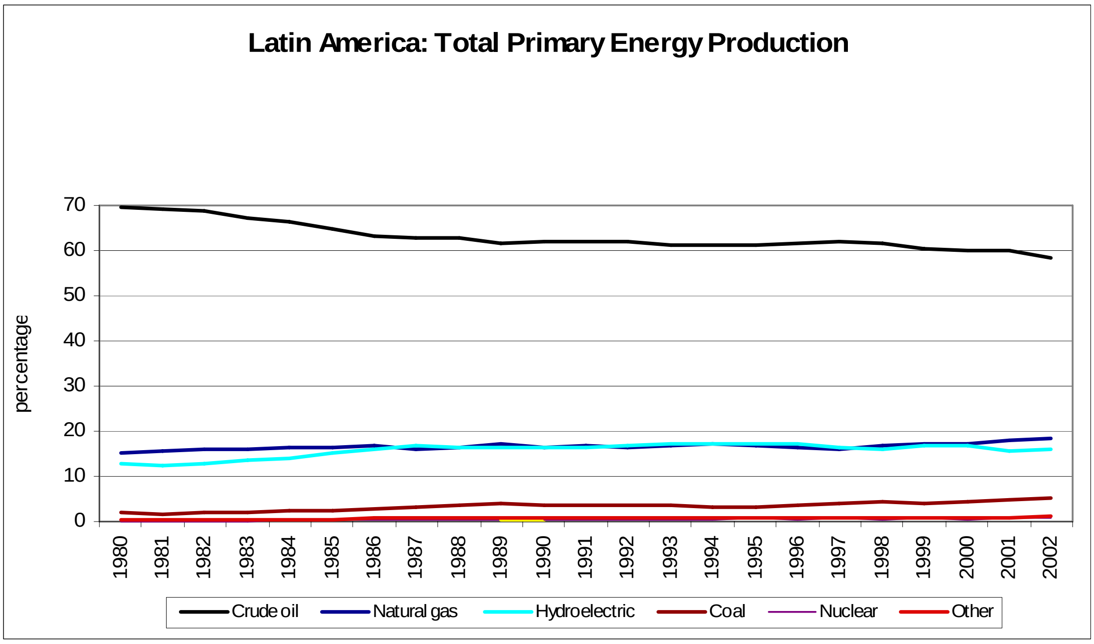


Table 3.2

Proven Reserves of Oil in Latin America

	1988	***2008***		
	Thousand Million Tonnes	Thousand Million Tonnes	Share of LAC total	R/P ratio
Mexico	53.0	11.9	9.6%	10.3
Argentina	2.3	2.6	2.1%	10.5
Brazil	2.8	12.6	10.3%	18.2
Colombia	2.1	1.4	1.1%	6.0
Ecuador	1.5	3.8	3.1%	20.3
Peru	0.9	1.1	0.9%	25.5
Trinidad & Tobago	0.6	0.8	0.7%	15.2
Venezuela	58.5	99.4	80.7%	*
Other S. & Cent. America	0.6	1.4	1.1%	27.7
Total LAC	**69.2**	**123.2**		**50.3**

Source: BP Statistical Review, 2009

Figure 3.2

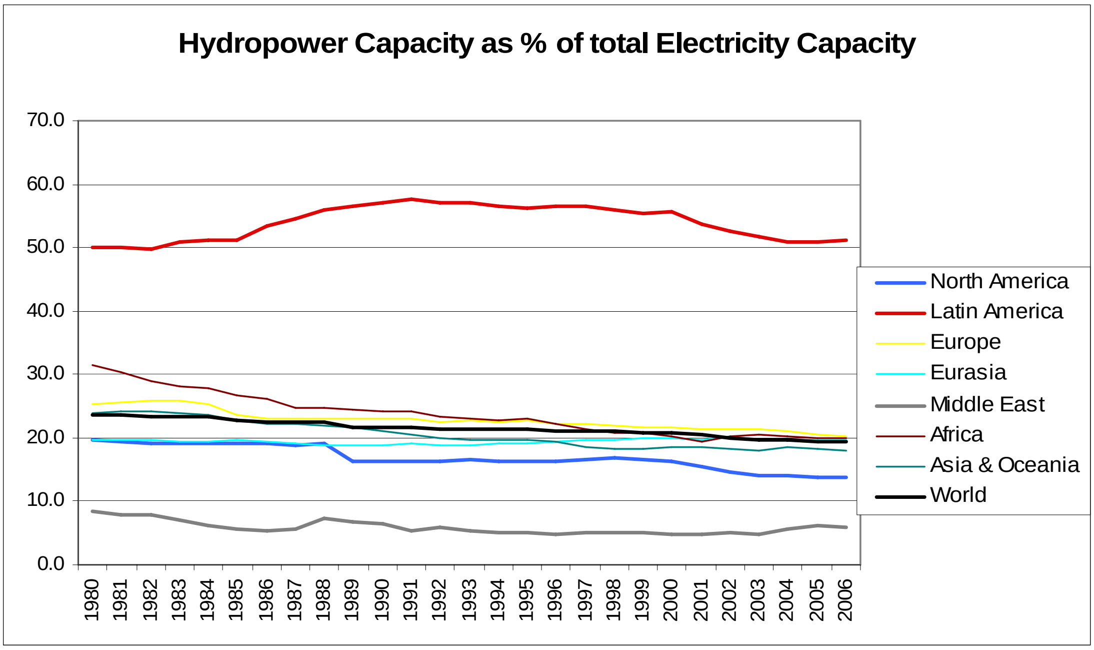


Figure 3.3

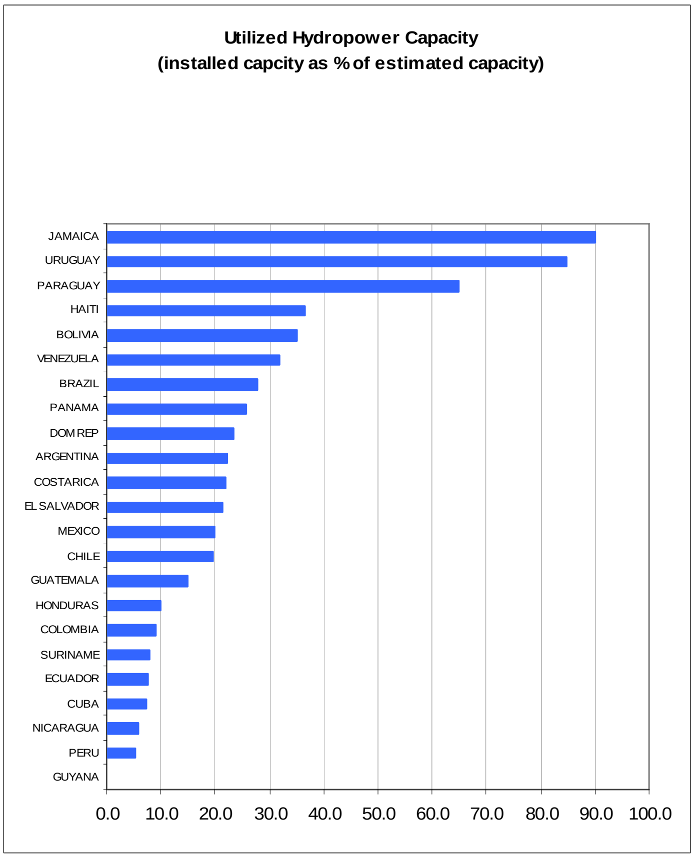


Table 3.1

Reference Scenario: Energy in Latin America 2000-2030					
	Investment				**Capacity Growth**
	2001-2010	**2011-2020**	**2021-2030**	**2001-2030**	**2000-2030**
	(billion USD)				(average annual growth)
Oil	**91**	**112**	**133**	**336**	**0.0**
Exploration and development	70	81	90	241	
Non-conventional oil	15	17	27	59	
Refining	6	14	17	37	
Gas	**54**	**78**	**115**	**247**	**1,852.8**
Exploration and development	28	45	68	141	
LNG liquefaction	7	3	4	15	
LNG regasification	-	-	-	-	
Transmission	10	16	23	49	
Distribution	9	12	19	39	
Undergroud storage	0	1	1	2	
Coal	**3**	**3**	**4**	**10**	**2,271.9**
Total mining	3	3	3	9	
New mining capacity	2	2	2	6	
Sustaining mining capacity	1	1	1	3	
Ports	0	0	1	1	
Electricity	**191**	**247**	**306**	**744**	
Generating capacity	86	111	120	317	**2,723.4**
Renewables	63	78	69	211	**3,262.9**
Renewables as % of Generating Capacity	*73.3*	*70.3*	*57.5*	*67*	
Refurbishment	5	6	8	19	
Transmission	32	41	55	128	
Distribution	69	89	124	281	
Total Regional investment	**339**	**440**	**558**	**1337**	
as % of GDP	***1.65***	***1.59***	***1.50***	**1.53**	
Per Capita GDP Annual Growth	**1.6**	**1.9**	**2.0**		

Source: Authors' calculations based on World Energy Investment Outlook 2003

Figure 3.4

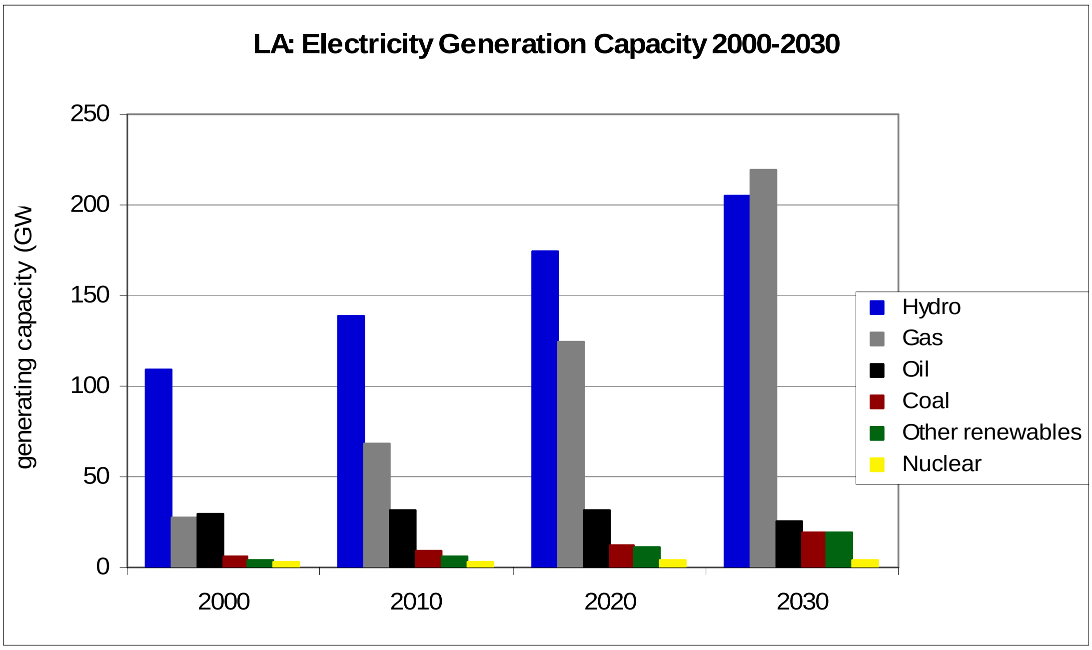


Figure 3.5

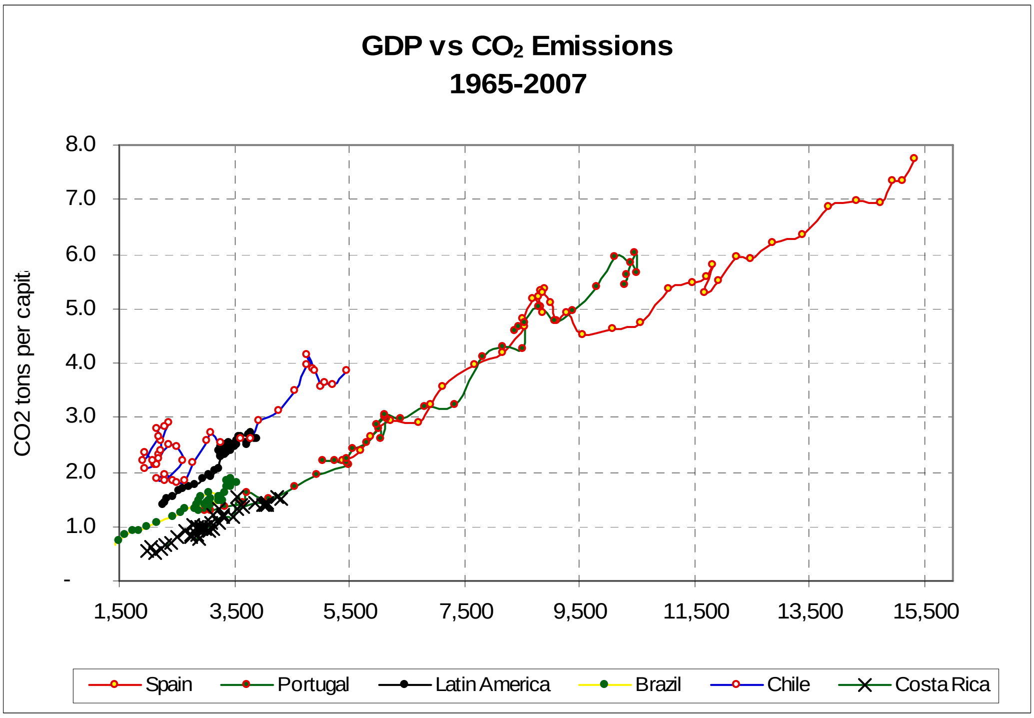


Figure 3.6

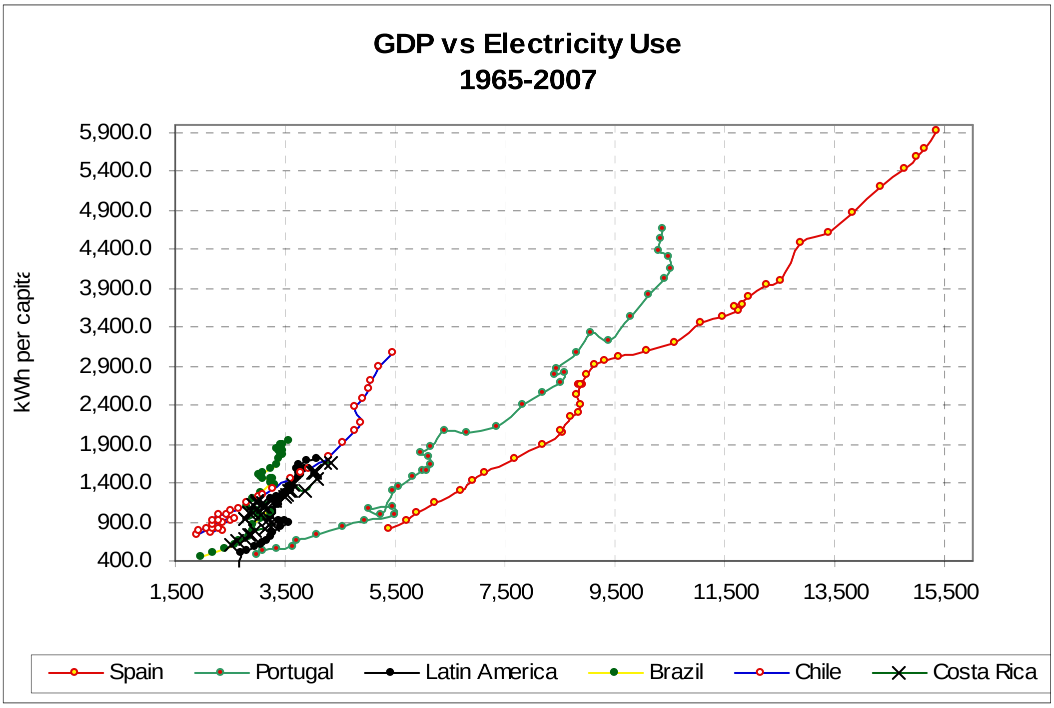

GDP vs Electricity Use
1965-2007
kWh per capit
5,900.0
5,400.0
4,900.0
4,400.0
3,900.0
3,400.0
2,900.0
2,400.0
1,900.0
1,400.0
900.0
400.0
1,500
3,500
5,500
7,500
9,500
11,500
13,500
15,500
Spain
Portugal
Latin America
Brazil
Chile
Costa Rica

Figure 4.1

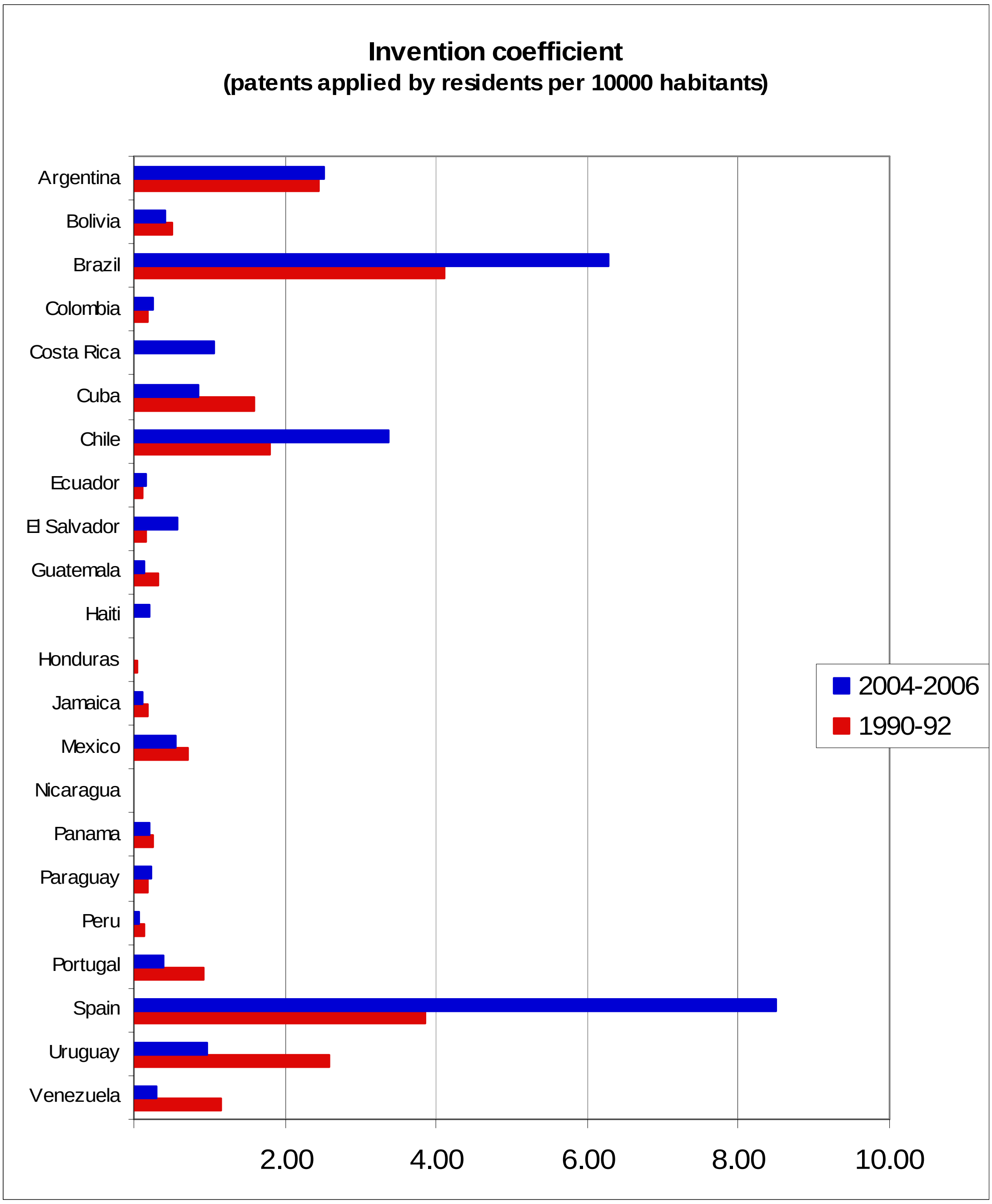

Invention coefficient
(patents applied by residents per 10000 habitants)
Argentina
Bolivia
Brazil
Colombia
Costa Rica
Cuba
Chile
Ecuador
El Salvador
Guatemala
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Portugal
Spain
Uruguay
Venezuela
2.00
4.00
6.00
8.00
10.00
2004-2006
1990-92

Table 5.1

R&D Expenditure in Energy*

millions 2005 $US

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Argentina[1]							67.0	84.4	69.1	78.8	59.6	25.8	38.7	12.0	15.7	14.8	20.2	29.2
Brasil[2]							376.2				393.3	338.2	267.8	289.5	366.1	513.6	615.8	675.4
Chile	16.3	17.4	25.7	23.8	24.0	27.1	27.9	25.1	30.2	23.5	15.6	12.6						
Ecuador						0.2	0.1	0.2	0.1			0.1	0.1	0.1			1.7	
El Salvador									0.09									
Guatemala																0.1		
México[3]	0.0	0.0	0.0	160.0	102.1	78.4	117.1	438.0	276.9	183.3	202.5	177.1	204.4	183.5	123.3	117.5		
Panamá			0.3								0.7	1.0	0.1	0.0	2.5	2.4		
Paraguay													0.012	0.010	0.013	0.003		
Uruguay	5.9	0.0	0.1	8.1	8.1	3.5	5.9	14.4	0.4	0.1	0.1		0.1				0.6	
Portugal								11.9		10.0		20.6		16.5		21.5		
Spain[4]	155.2	238.5	216.7	206.7	208.3	261.5	184.7	213.1	177.2	164.8	143.3	175.8	180.1	243.9	178.8	58.5		
Latin America	**22.2**	**17.4**	**26.1**	**191.9**	**134.1**	**109.2**	**594.3**	**574.0**	**376.8**	**295.7**	**671.8**	**575.4**	**511.3**	**501.7**	**507.6**	**670.0**	**638.2**	**704.6**
Ibero America	**177.4**	**256.0**	**242.9**	**398.6**	**342.4**	**370.7**	**779.0**	**787.1**	**554.1**	**460.4**	**815.1**	**751.2**	**691.4**	**745.6**	**686.5**	**728.5**	**638.2**	**704.6**

Source: Inter-American Network on Science and Technology Indicators (RICYT), except when indicated. Exchange rates from International Financial Statistics, IMF.

* All figures are public R&D, except when indicated. Blank cells are undetermined data.

[1] Public R&D expenditure, from Science and Technology Indicators (several years), Ministry of Science and Technology of Argentina.

[2] 2000-2007 figures include both Public and Firm Energy R&D Expenditures. Public R&D expenditure from Sistema Integrado de Administração Financeira do Governo Federal (Siafi). Firm R&D investment corresponds to R&D in the production of coke, oil refining, nuclear fuels and alcohol production, from Pesquisa Industrial de Inovação Tecnológica (Pintec) 2000 do Instituto Brasileiro de Geografia e Estatística (IBGE). Firm R&D for years 2001, 2002, and 2004 are averaged from 2000, 2003, and 2005 point observations; 2006 and 2007 firm R&D was projected from the 2000-05 annual growth rate and added to public R&D expenditure.

[3] 1995 -2005 figures from CONACYT. Includes the total budget of three major public energy R&D Institutes (Instituto Mexicano del Petróleo, Instituto de Investigaciones Eléctricas, and Instituto de Investigaciones Nucleares), as well as Pemex's R&D expenditure. Source: Indicadores de Ciencia yTecnología 2005, Science and Technology Council (CONACYT), Mexico.

[4] Includes Public and Firm Energy R&D Expenditures, from International Energy Agency and OECD, EAS (ANBERD database), June 2006, respectively.

Agglomeration and Innovation Networks for Brazilian Oil and Ethanol

Oil Exploration		***Ethanol production***	
	Government		
ANP	National Agency for Petroleum, Natural Gas & Biofuels	FABESP	Research Support Foundation of the State of Sao Paulo
CENPES	Petrobras' Research Centre	PLANASLUCAR	National Program for the Improvement of Sugarcane
SERRAE	Brazilian Service for Supporting SMEs		
	quasi-public entities		
FIRIAN	Rio de Janerio State Federation of Industries	IPT	Institute of Technological Research
CREA-RJ	Engineering and Architecture Council of Rio de Janeiro	IAC	Agronomic Institute of Campinas
SENAI	National Service for Industrial Learning	ITAL	Food Technology Institute
ONIP	National Organization for the Petroleum Industry	CETESB	Environmental Waste Management Technology Company
IBP	The Brazilian Oil Institute	CTC	Sugarcane Technology Center
REDE-PETRO BC	The Network of Oil Firms of the Campos Basin		
REDE-TEC	Rio de Janerio's Technology Network		
PROMINP	National Oil Industry's Mobilization Program		
ASSESPRO	Brazilian Association of the Information Technology Firms		
	University Research efforts		
PUC-Rio	Pontifical Catholic University of Rio de Janerio	USP	Sao Paulo State University School of Agronomy Luis de Queroz
UFRJ	Federal University of Rio de Janeiro	UNICAMP	Campinas State University
UFF	Fluminenses Federal University	UNESP	Paulista State University
UFRRJ	Federal Rural University of Rio de Janeiro	UFSCAR	Sao Carlos Federal University
UNI-Rio	Federal University of the Rio de Janeiro State		
UENF	State University of Norte Fluminense		
UERJ	State University of Rio de Janeiro		

Source: author's depiction based on (Silvestre and Tavares, 2009; BNDES and CGEE, 2008)

Figure 5.1

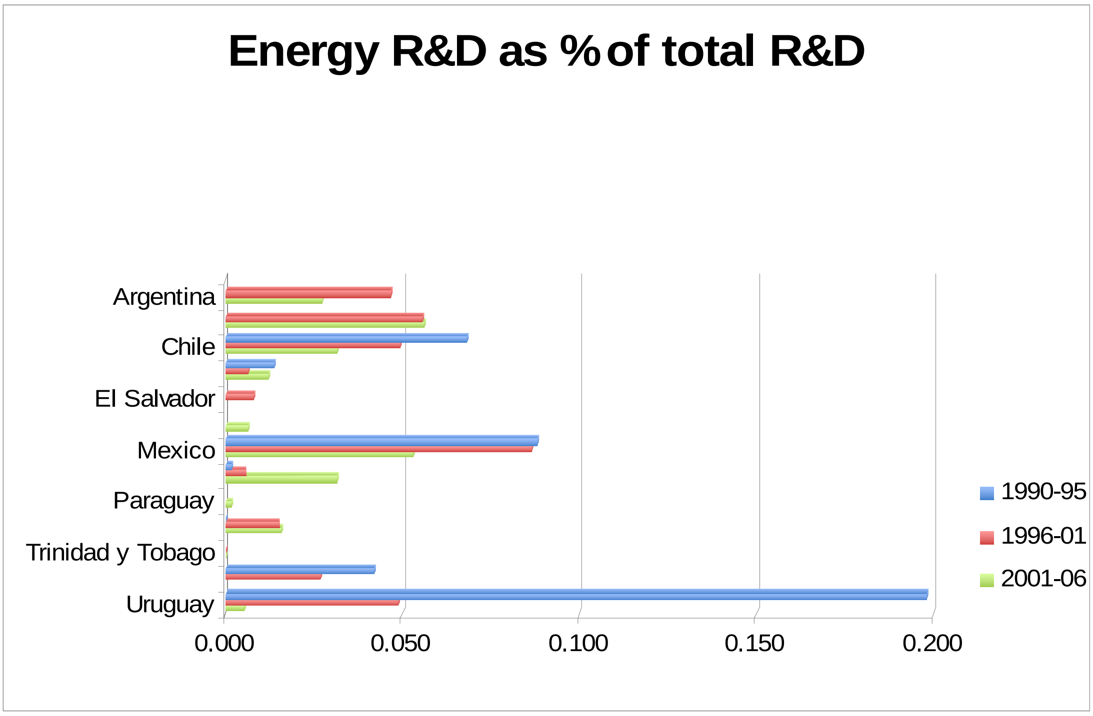


Figure 5.2

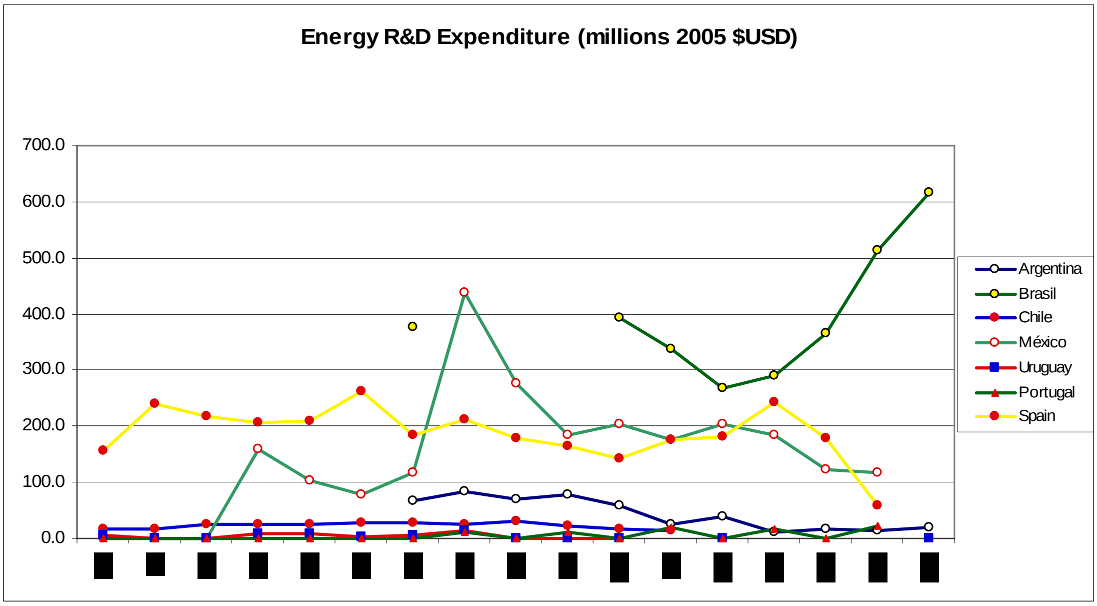


Figure 5.3

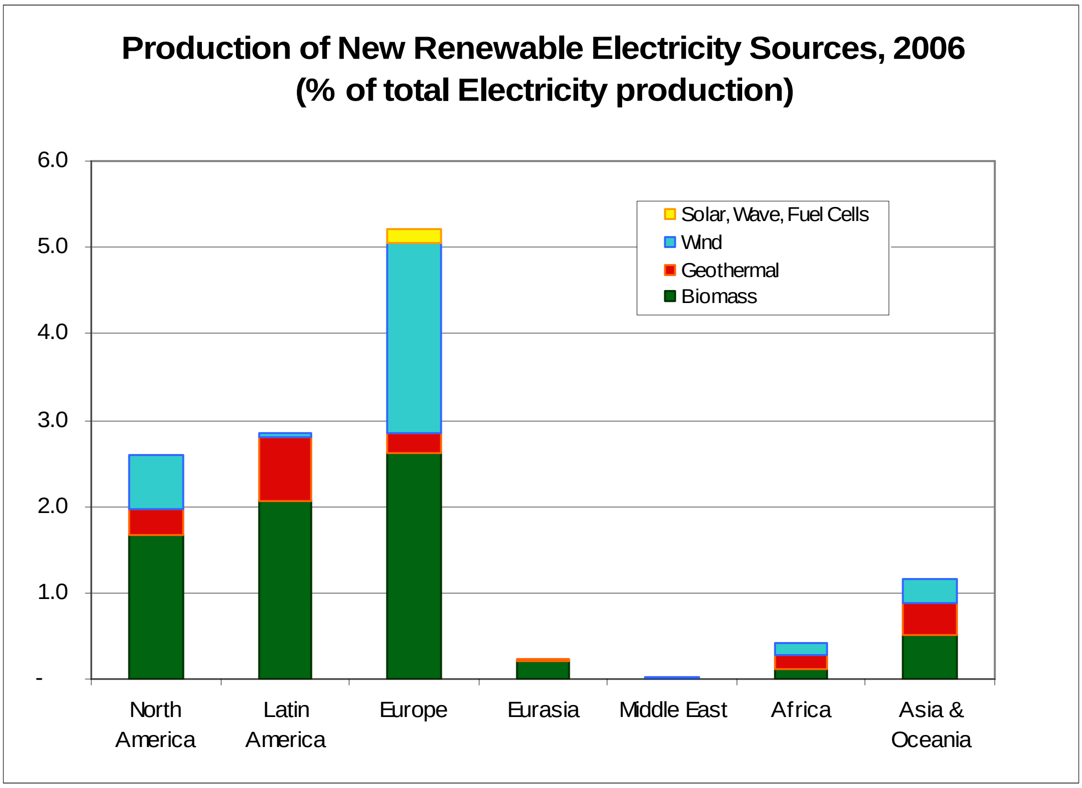


Figure 5.4

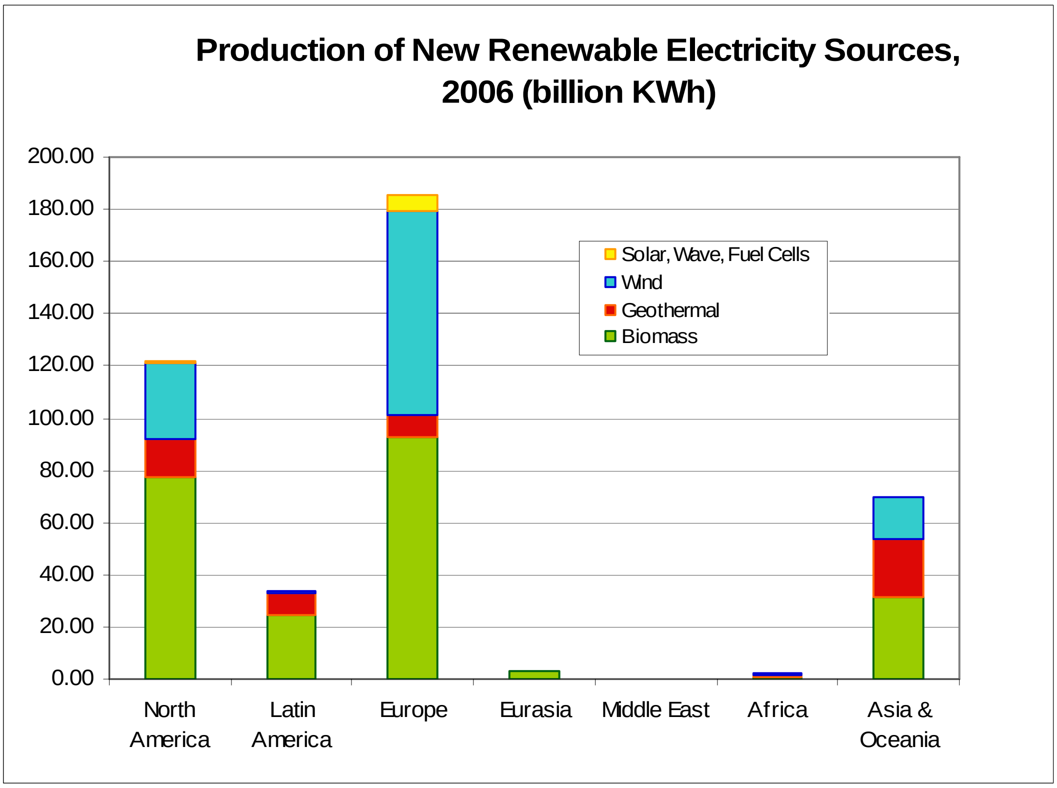


Table 5.3

World NRES for Electricity Production, 2006

	Wind	**Geothermal**	**Solar, Wave, Fuel Cells**	**Biomass**
		(billion KWh)		
North America	28.96	14.57	0.66	77.35
Latin America	0.67	8.87	0.01	24.39
Europe	78.55	7.92	5.69	93.01
Eurasia	0.17	0.44	0.00	2.72
Middle East	0.13	0.00	0.00	0.00
Africa	0.83	0.86	0.00	0.61
Asia & Oceania	15.62	22.42	0.23	31.41
World	124.93	55.07	6.59	229.49
Growth rate*	26.9	1.8	13.5	6.3

* Corresponds to the technology's production average annual growth rate in the world during 2000-2006.

Source: Energy Information Administration, USDOE.

Table 5.4

BNDES Financing of Energy Development and Innovation

-	2006	2007	2008	2009
-		*(R$ million)*		
Oil & Gas	4,481.6	4,091.4	4,807.6	4,380.3
Ethanol	446.7	1,661.0	3,079.6	1,212.1
Electricity Generation	2,125.4	2,910.4	6,545.4	9,262.5
Cogeneration	276.3	134.0	858.8	217.7
Hydroelectricity	1,303.9	2,416.7	5,207.0	8,938.6
Thermoelectricity	5.7	179.2	28.4	4.5
Solar-Wind etc.	382.2	67.0	229.0	10.0
Indirect financing	157.2	113.5	222.2	91.8
Electricity - Transmission	379.2	2,431.4	698.3	364.9
Electricity - Distribution	673.3	1,033.8	1,378.8	1,152.1
FUNTEC	2.8	20.6	60.6	63.3
Total	8,108.8	12,148.7	16,570.2	16,435.3

Source: BNDES, 2009

Figure 5.5

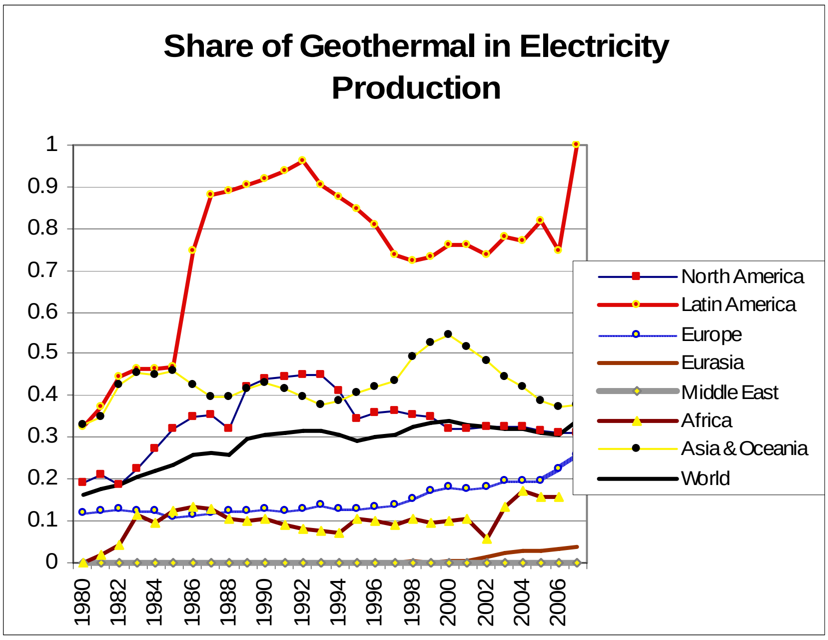


Figure 5.6

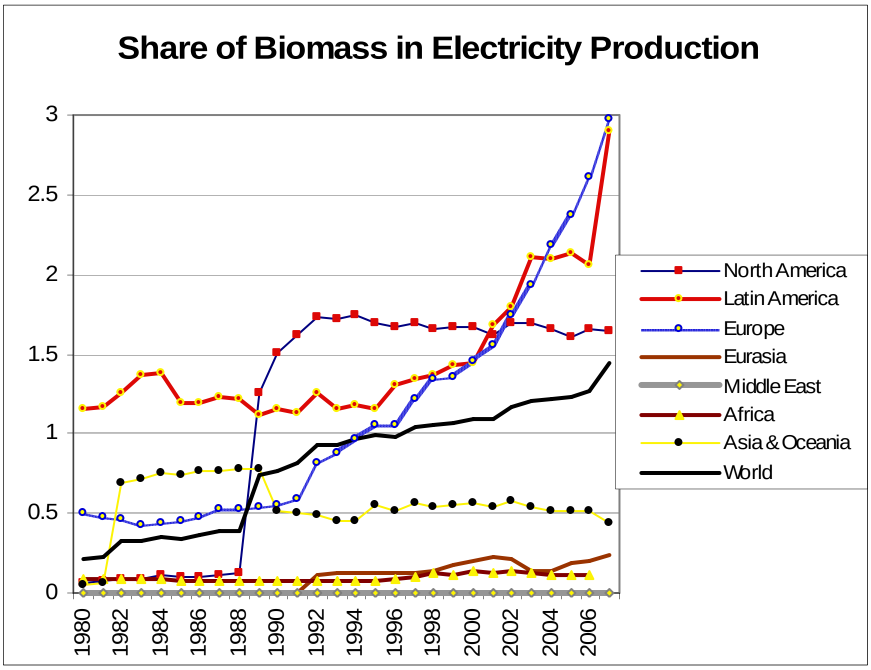


Figure 5.7

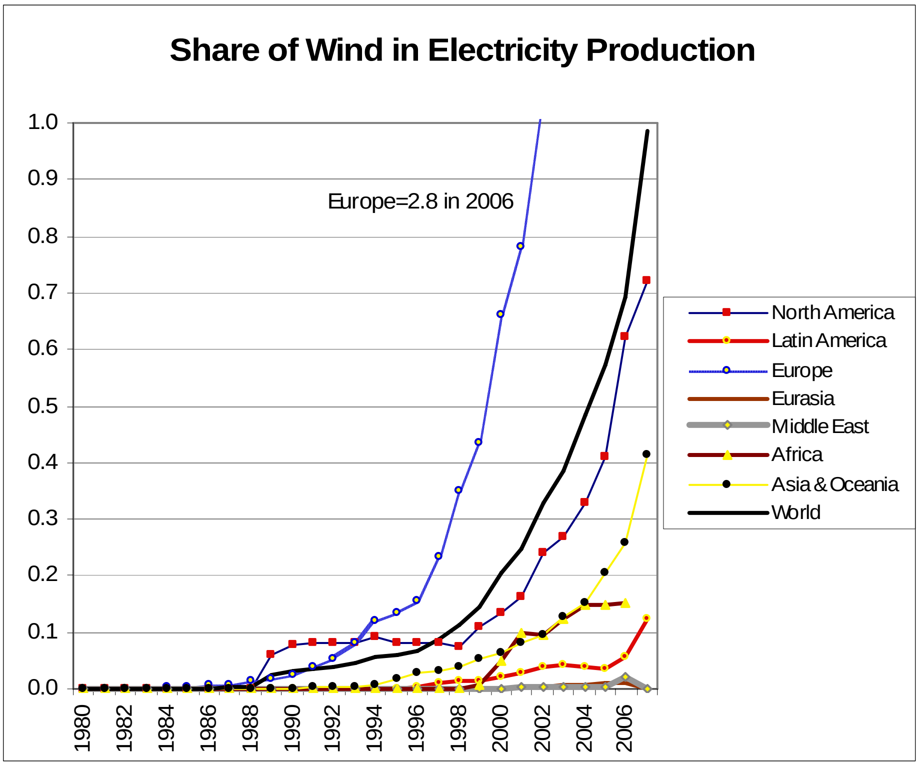


Figure 5.8

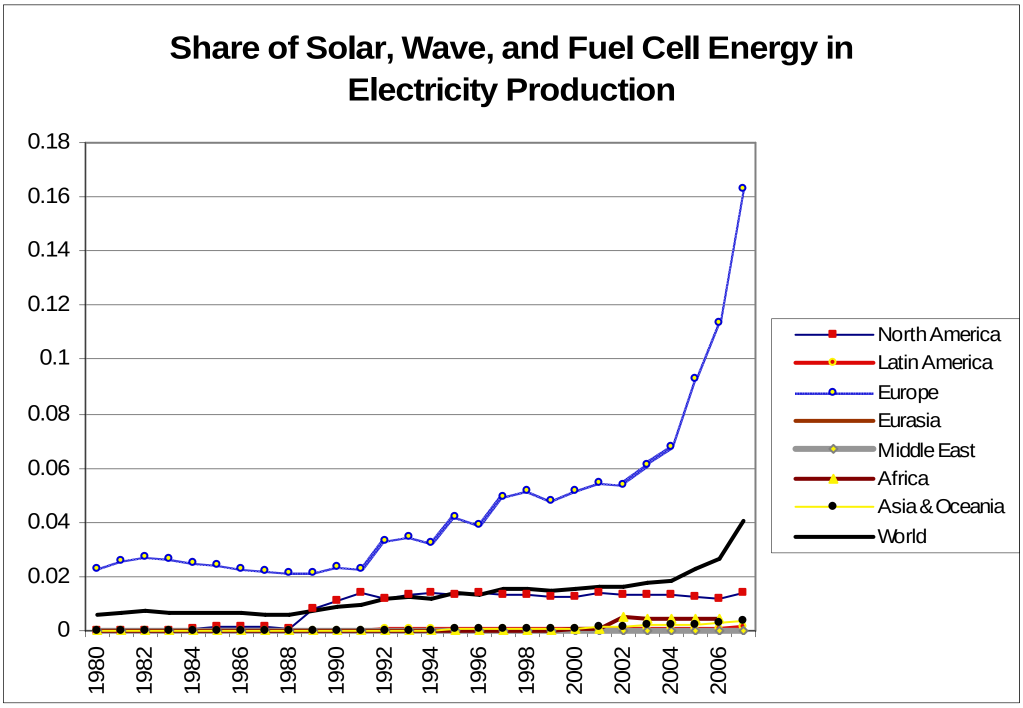
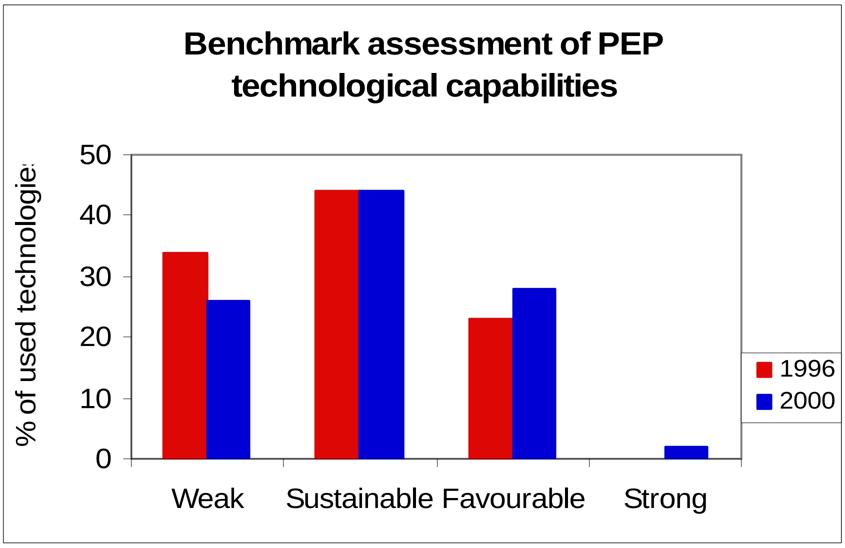


Figure 5.3.1


Benchmark assessment of PEP technological capabilities
% of used technologie
50
40
30
20
10
0
Weak
Sustainable
Favourable
Strong
1996
2000