Expansion Pressure

Energy Challenges in Brazil and Chile

IN LATIN AMERICA, PRIMARY ENERGY DEMAND IS PROJECTED TO GROW on average by 1.7% per year and to reach 830 million tons of oil equivalent (mtoe) by 2035, according to the International Energy Agency's 2011 *World Energy Outlook*. Demand for renewables in the power generation sector in the region will double over that period, reaching nearly 140 mtoe in 2035. Furthermore, the IEA projects that biofuels use in road transport will increase by more than 4% per year, reaching 1 million barrels per day (mb/d) by 2035, representing around 25% of fuel consumption in the sector. The economic giant in the region, Brazil, will increase its primary energy consumption to 420 mtoe in 2035, representing more than half of the regional total.

The region will have no difficulty obtaining sufficient energy resources to sustain its economic growth, and near-universal access to electricity is projected in the region by 2030. The region will remain a net oil, gas, and coal exporter; Colombia and Venezuela will benefit from their sizable coal resources, and Brazil will become the region's largest gas producer before 2025. The region will grow its hydroelectric resources, with hydroelectricity accounting for more than 60% of electricity generation by 2035—the largest percentage

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contribution worldwide. IEA also projects significant growth in solar photovoltaic and wind generation.

Energy resources are not necessarily located where they are needed, however. Some countries have more than they can use, and others are heavily dependent on foreign supplies. To provide an overview of the region's energy future and the common energy security and environmental challenges it faces, we will describe the energy profile of two countries: the giant of the region, Brazil, and Chile. These are two of the faster-growing economies in the region. The first is a country with plentiful resources and a significant amount of state intervention in energy development. The second has few indigenous resources but has a fully private sector driving its energy investments.

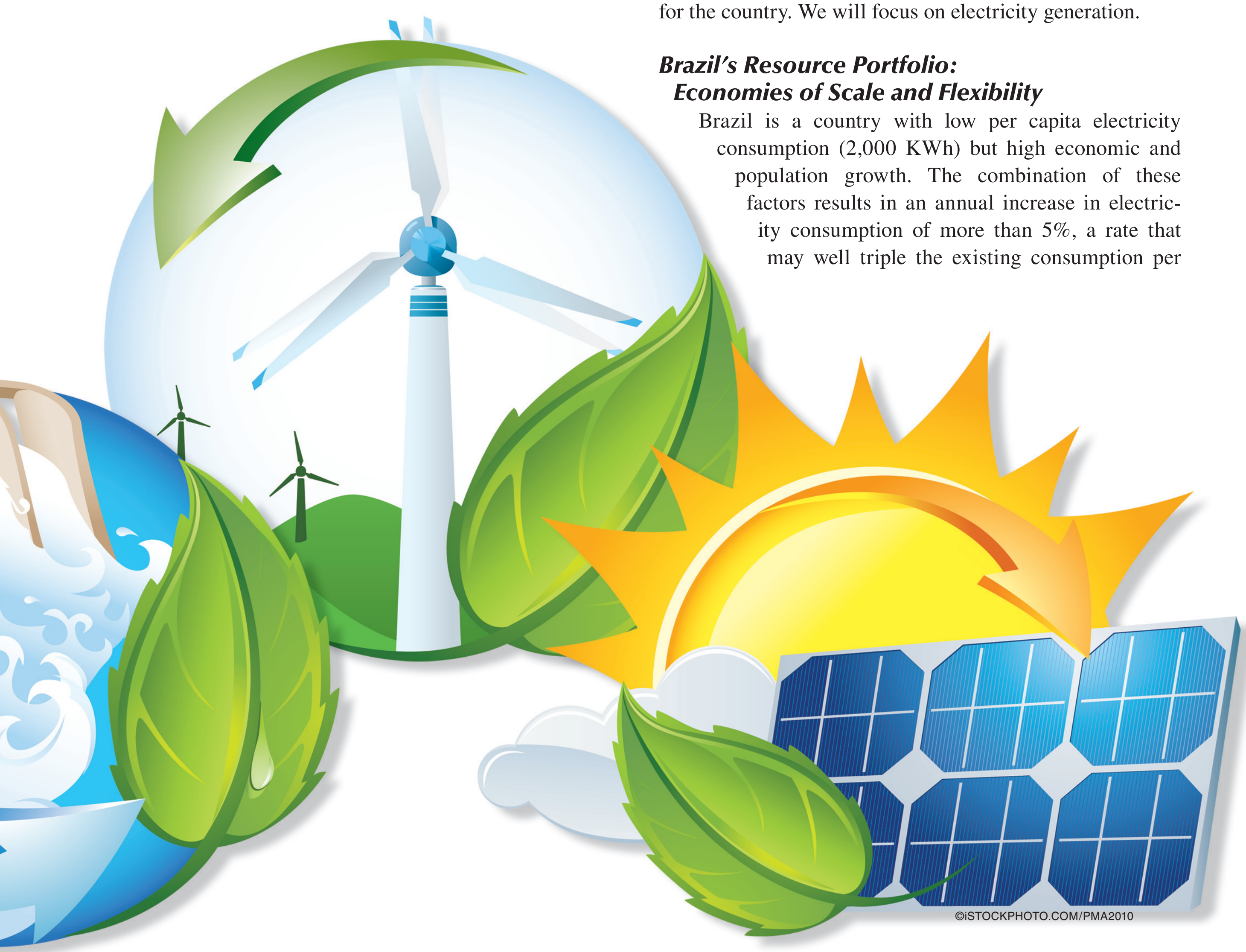
Brazil

Brazil benefits from a privileged position with respect to energy security and climate change. Local resources—such as recent giant gas and oil discoveries in offshore fields, sugarcane for ethanol and electricity production, and the large variety of resources available for electricity production—ensure the country's energy security and even allow for exports. With respect to climate change, Brazil is well placed for a low-carbon economy, as 45% of its energy matrix is already produced by clean energy (renewable and nuclear), against the world average of less than 20%. The country today has several competitive generation options available for a clean system expansion—in particular, hydropower, biomass cogeneration (mainly from sugarcane), and wind power. Local uranium reserves and Brazil's knowledge of uranium enrichment technology have allowed nuclear power to emerge as an option. In the middle term, it is possible that solar power will be added to the portfolio of competitive production sources, and international interconnections are also on the agenda. Finally, in the transportation areas the highlights are sugarcane-based ethanol and, in the future, biodiesel from sugarcane.

We next discuss the main opportunities and challenges for Brazil over the long term—the next 20 years—as it seeks to transform this potential into reality, leveraging sustainable and low-carbon economic growth along with social benefits for the country. We will focus on electricity generation.

Brazil's Resource Portfolio: Economies of Scale and Flexibility

Brazil is a country with low per capita electricity consumption (2,000 KWh) but high economic and population growth. The combination of these factors results in an annual increase in electricity consumption of more than 5%, a rate that may well triple the existing consumption per



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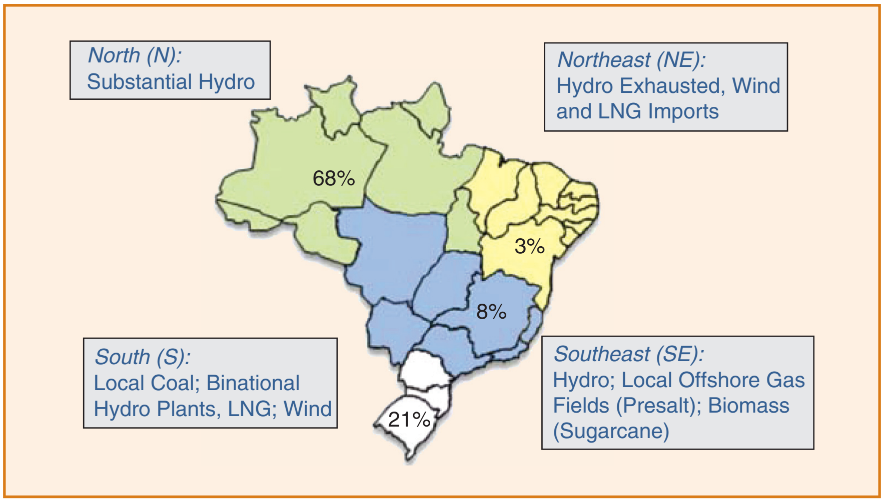

figure 1. Overview of generation options and hydro potential, by region (source: PSR).

capita by 2030. This annual load growth rate requires about 5,000 MW of additional generation capacity to be installed every year. The country currently has an installed capacity of 117,000 MW, where hydropower accounts for 77%; peak and total annual energy consumption are about 71 GW and 430 TWh, respectively. The hydropower system is composed of several large reservoirs, capable of multiyear regulation, organized in a complex topology over several river basins. Energy sources used by the existing thermal fleet include nuclear, natural gas, sugarcane bagasse, coal, and diesel. More recently, wind power began to penetrate the system, and Brazil's wind capacity is expected to grow eightfold from the current 1,000 MW by 2016. In order to exploit the development of hydro generation and to benefit from hydrological complementarities, Brazil in 1999 became fully interconnected at the bulk power level by means of a 100,000-km meshed high-voltage transmission network.

As shown in Figure 1, Brazil has a diversified portfolio of potential resources for generation expansion that are geographically located in a complementary manner.

In fact, less than 40% of Brazil's hydropower potential has been explored; the country still has an undeveloped hydro potential of more than 150,000 MW. Most of this is located in the environmentally sensitive Amazon region, the next frontier for hydro development. In order to benefit from economies of scale, large hydro plants with high capacity factors (over 60%), designed to optimize the low-head rivers of this region, will be the rule.

Brazil is also among the most promising lands for the future development of *nonconventional renewable energy* (NCRE), a term that for our purposes here is used to denote all renewables except large hydro. The strong and persistent wind flows, fertile soils, and thousands of sunny hours a year provide a significant potential for several types of NCRE. The country has a significant potential for biomass cogeneration (mainly sugarcane) and for wind (a resource potential estimated at 300,000 MW) that are located in a complementary manner: the south and northeast regions host wind, whereas the southeast has sugarcane cogeneration.

Local gas fields are mostly in the southeast (offshore) and midwest and north (onshore). Shale gas is available in the southern region, but extraction has never been made. In 2006, giant oil and gas fields were further discovered by local and private companies (British Gas was actually the leading company) in a geological formation known as the pre-salt layer, thought to contain significant volumes of oil and associated natural gas at competitive prices. The pre-salt layer lies below 2,000 m of water and 5,000 m of salt, sand, and rocks and is about 250 km off the coast of Rio de Janeiro. Conservative estimates put the accumulations encountered at a minimum of 36 billion barrels of recoverable oil and natural gas, which could triple Brazil's reserves and would place Brazil among the top five oil producers in the world (today it is the world's 11th-largest oil producer) and 18th-largest gas producer (today it is the world's 38th-largest gas producer). Brazil has the world's tenth-largest coal reserves and significant proven uranium reserves; it also possesses nuclear fuel processing capability, including uranium enrichment technology. In the long term, imports from international interconnections are also possible from Argentina (which has natural gas from shale reserves and thermoelectric generation), Peru (with hydro plants at the Brazilian border), and Bolivia (with conventional natural gas and thermoelectric projects at the border).

Given this abundance of resources, the most economical long-term generation capacity expansion strategy should follow two main development axes: renewables (hydro, biomass, and wind, with solar in the post-2020 horizon) and thermoelectric generation, where natural gas is the preferred option and coal and nuclear would be the alternatives. Next we detail the attributes of each of these sources that justify such a strategy.

Hydropower: Anchor for Sustainable Growth

Besides its great potential for electricity production, hydro generation has other well-known advantages: it is a renewable option and is among the most economically competitive generation technologies. In addition, hydropower benefits other production sources, as follows:

- ✔ The synergy between hydro and thermal resources allows operation in a complementary fashion that

> Brazil has several competitive generation options available for a clean system expansion—hydropower, biomass cogeneration (mainly from sugarcane), and wind power.

saves fuel costs for consumers and improves supply reliability.

- ✔ Hydro reservoirs serve as virtual energy warehouses that can store any type of MWh (gas, wind, biomass, and so on) besides the hydro MWh themselves and thus provide an operating flexibility that lets the system operator coordinate hydro and renewable operation.
- ✔ The flexibility of the hydro production eases the economic integration of seasonal and intermittent production sources such as biomass cogeneration, wind, and solar.

Figure 2 shows the estimated levelized energy price (with transmission cost, taxes, and sector charges; with a 70-30 equity-to-debt ratio; and for a rate of return of 11% after taxes) of the cumulative hydro potential in Brazil. The estimated energy prices of the other technologies are also shown. It can be observed that the potential for economically competitive hydro is quite significant: at least 20,000 MW of the potential generation should be available at a levelized energy price smaller than US$40/MWh, and about 40,000 MW could economically displace other technologies, even considering their significant technological developments.

Because of these characteristics, hydropower can be considered a "no regret" option for Brazil, i.e., one that should be developed irrespective of the benefits associated with emission reductions. As will be discussed later, there are nevertheless several challenges for the development of hydropower in the country, namely, environmental licensing, which has resulted in a lack of reservoirs in the new hydro developments and—in the longer term—the effect of climate change on hydro inflows.

Nonconventional Renewables: Flexibility in the Construction Period

A primary aspect of interest to Brazil in deploying NCRE is the geographical complementarity of resource potential. NCREs are also attractive due to a number of attributes not strictly related to emission reduction: from the security-of-supply perspective, NCRE provides the opportunity to diversify the current generation mix, which is heavily based on hydro facilities. From a portfolio management standpoint, the lack of a coherent policy for environmental licensing and strong opposition to reservoirs often lead to delays in the construction of conventional hydro plants, which can affect supply reliability. In contrast, renewable generation is usually spread out over several plants with smaller capacities, which provides a "portfolio" effect and thus a hedge against project delays. Also, the construction time for NCRE plants is short (about 18 months), in contrast to at least five years for conventional hydro. This allows flexibility in the entrance of new capacity—a valuable hedge against the country's load growth uncertainty. Because NCRE is sourced from smaller-sized projects, the number of candidate investors available to compete for their construction is larger, which helps create competition for this investment and promotes efficiency. Finally, the possibility of using Brazil's hydro reservoirs to smooth out production fluctuations of intermittent (wind and solar) or seasonal (biomass) energy sources provides an operational flexibility that facilitates their reliable and economic integration.

The mainstream NCREs at present are sugarcane cogeneration and wind, whose production patterns are counterseasonal to hydro inflows and thus help increase the system's effective storage capacity. Solar is coming in the next wave.

Thermal Plants: Hydro-Thermal Complementarity

Given the abundance of renewable resources in Brazil, one might ask, why build thermal plants? The answer is that thermal plants and renewables have complementary attributes: thermal plants complement the security of supply by hedging against weather variability, and renewables permit the saving of fossil fuel when conditions for production are favorable. The dispatchability of thermal plants (their capability to produce energy when needed) will become even more important in the presence of more run-of-river hydro

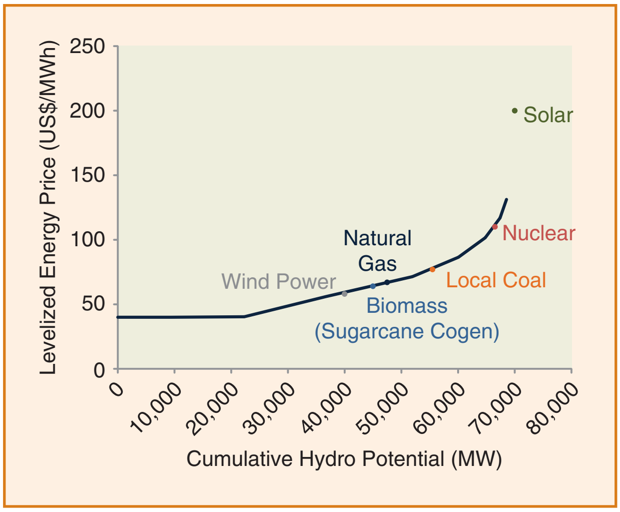

figure 2. Hydro cumulative potential and levelized price (source: PSR and EPE).

and intermittent renewable resources. Due to the availability of resources and the prospect of moderate gas prices in the international markets—which should put a cap on local prices—gas-fired plants should be the preferred technology to drive the thermal expansion during the next 20 years.

Coal and nuclear should be the alternatives to gas. The low heat value of Brazilian coal and its high ash content along with the presence of take-or-pay clauses in coal supply contracts imply a higher energy cost when compared with imported coal. Even so, coal's competitiveness is assured by its low production cost. The coal industry, however, has been facing very strong opposition from the government and environmentalists due to coal's high carbon emission, and coal's role in the future is unclear. On the nuclear side, Brazil is also well positioned: current nuclear installed capacity is about 2 GW, from two federally owned plants. A third plant (rated for 1,400 MW) is under construction, but the decision to invest in it was a political one, made well before the Fukushima disaster in Japan; it was taken basically so as to complete a nuclear plant whose construction was begun many decades ago and had been interrupted many times. While the development of nuclear power remains highly controversial all over the world, potential difficulties with the exploitation of gas in the pre-salt fields could create a window of opportunity for nuclear in Brazil in the post-2020 time frame. Brazil would easily be able to install some 5,000 MW of new nuclear capacity, which would triple the country's current capacity and provide economies of scale that would justify additional investments in the fuel-enrichment process. This could lead Brazil to absolute independence in nuclear fuel processing and perhaps even give it the ability to export nuclear fuel.

Brazil also has regulatory mechanisms in place that provide positive commercial and economic conditions for the several generation options. An organized market for short-, mid-, and long-term electricity contract auctions is in place and functions according to guidelines provided by the state for the development of the energy matrix. The state in Brazil not only acts as a regulator but also operates through state-owned energy and electricity companies.

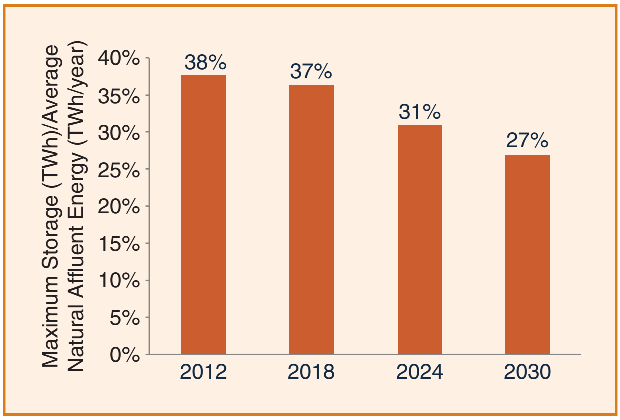

figure 3. Evolution of hydro storage capacity in Brazil, 2012–2030 (source: PSR).

Implementation Challenges: Hydro Vulnerability

There are several challenges that must be overcome in order to successfully implement the long-term strategy just described. Grid connection for renewables, the scarcity of sugarcane biomass as a result of the successful development of second-generation ethanol, and public policies that have been implemented unsuccessfully are just a few of these. The most important ones, however, concern the tension between energy development and the environment, which will ultimately create vulnerabilities for the hydroelectricity strategy. As hydropower is the anchor of Brazil's long-term resource energy plan, these are the risks that will be analyzed here.

Environmental licensing for hydros in Brazil has recently run up against a number of hurdles, resulting in environmental cost overruns and delays in the construction of plants. The licensing of a hydro project is a complex activity anywhere in the world, and in Brazil the complexity is compounded by several factors: poor studies prepared by developers are common; little time is provided for joint and public discussions with the local population (which increases people's negative perception of hydro installations); there is a complex regulatory regime (municipalities, state, and federal agencies interact, with overlapping functions); and there is a general negative perception of the environmentalists on the part of the power sector people and vice versa, which makes it difficult to the comprehend each group's activities, impedes communication, and does not make for clear debates.

The second challenge, also related to environmental problems, is the lack of reservoirs in the new hydro developments. In particular, the three largest new hydro projects under construction in Brazil—the Madeira complex in the Amazon and Belo Monte, totaling 18,000 MW of installed capacity—do not have reservoirs. The trend toward constructing run-of-river hydro does not result from economic optimization but from social and environmental constraints. As a consequence, the storage capacity of the Brazilian system will be significantly reduced in the coming years. Figure 3 provides an indirect measurement of this projected storage capacity, i.e., the percentage of natural energy flow that will be able to be stored and therefore transferred to subsequent years.

Concern about the absence of storage capacity in the new plants increases when we observe that the variability of the hydro inflows from the new plants is much greater than the country's average. For example, the ratio between the greatest and lowest monthly inflow energy for the Madeira river hydro plants in the Amazon is 6.6 to 1, as compared with an average ratio of 3.4 to 1 for the southeastern region (see Figure 4). In the case of the Belo Monte hydro plant, this ratio is 20 to 1.

The combination of the lack of storage capacity and increasing inflow variability will make the task of taking full advantage of the operational flexibility provided by hydro resources more complex. For example, thermal dispatch is likely to increase in order to compensate for the hydro valleys, which will increase greenhouse gas emissions in the power sector. Our internal studies indicate an increase of 23% in the emissions of the power sector for every percentage point of loss in storage capacity. It is then of crucial importance that the environmental entities present a quantitative estimate of the adverse environmental impacts of the reservoirs. This would allow a search for equilibrium among the different costs and benefits (environmental, emissions, fuels, and so on) of the various options.

Finally, a topic of major concern for the future of the Brazilian electricity matrix is the impact of climate change on hydro inflows. A recent study conducted by a consortium of Brazilian institutions, universities, and research centers—and funded by the British embassy—has provided an initial economic assessment of the impact of climate change in Brazil. Table 1, prepared using data from this study, shows the variations with respect to a scenario with no climate change of the average energy production and firm energy (the amount that can be delivered in the driest year of the historical record) for the hydro plants located in selected river basins in Brazil within the 2035 horizon. Results are shown for the 2007 Intergovernmental Panel on Climate Change (IPCC)–defined scenarios A2 and B2, which differ basically on the implementation of strategies to mitigate climate change. The HadRM3P model from the Hadley Centre's regional climate modeling system, Providing Regional Climates for Impact Studies (PRECIS), was used.

As it can be seen, in the Amazon the reductions in both firm and average hydro energy production are significant. In other basins, the average hydro productions are expected to increase but the firm production decreases, which indicates that besides impacts on the average inflows, significant impacts on the variability of inflows are likely with pronounced drought periods. One alternative to manage this greater variability of inflows would be to increase the hydro system's storage capacity. As discussed earlier, the outlook is exactly the opposite.

Given the importance of hydropower for Brazil, these results are, although preliminary, very alarming. We suggest concentrating efforts on institutional and financial support for the execution of more detailed studies on these issues that can be added to an integrated cost-benefit analysis of building hydro reservoirs in Brazil.

The Two Axes for the Transition to Low-Carbon Generation

The most economical long-term generation capacity expansion strategy should follow two main development axes: renewables (hydro, biomass, and wind) and thermoelectric generation, where natural gas is the preferred option. Overall, a portfolio of large hydro and small-scale renewable provides a good combination of economy of scale and flexibility. Figure 5 shows one possible path for development.

Policies with "no regret"—those that would be recommended independently of the concern with climate change—should be prioritized. Examples include undertaking discussions related to the further deployment of hydroelectricity in the country and the economic impact of prohibiting (in practice) the building of reservoirs, incentivizing cogeneration and energy-efficiency schemes, and fostering the use of ethanol and sugarcane biodiesel.

More knowledge about the effects of climate change should be obtained. As the prospects of developing hedges against climate change on the part of the world's largest emitters dim, it becomes more important to devote attention to the development of national policies to protect Brazil against the adverse effects of climate change.

Finally, efficiency in the transition to a low-carbon society should be an overarching goal. This transition should

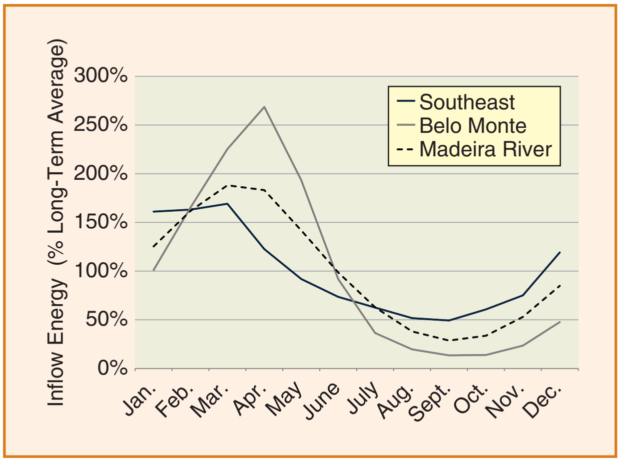

figure 4. Inflow variability of the Madeira River and Belo Monte hydro plants as compared with the southeastern region (source: PSR).

table 1. Impact of climate change on hydro production (source: Schaeffer et al., 2011).

	Scenario A2		Scenario B2	
River Basin	**Firm Energy**	**Average Energy**	**Firm Energy**	**Average Energy**
Amazon	−36%	−11%	−29%	−7%
Tocantins	−46%	−27%	−41%	−21%
São Francisco	−69%	−45%	−77%	−52%
Uruguay	−30%	4%	−20%	9%
Paraguay	−38%	4%	−35%	−3%

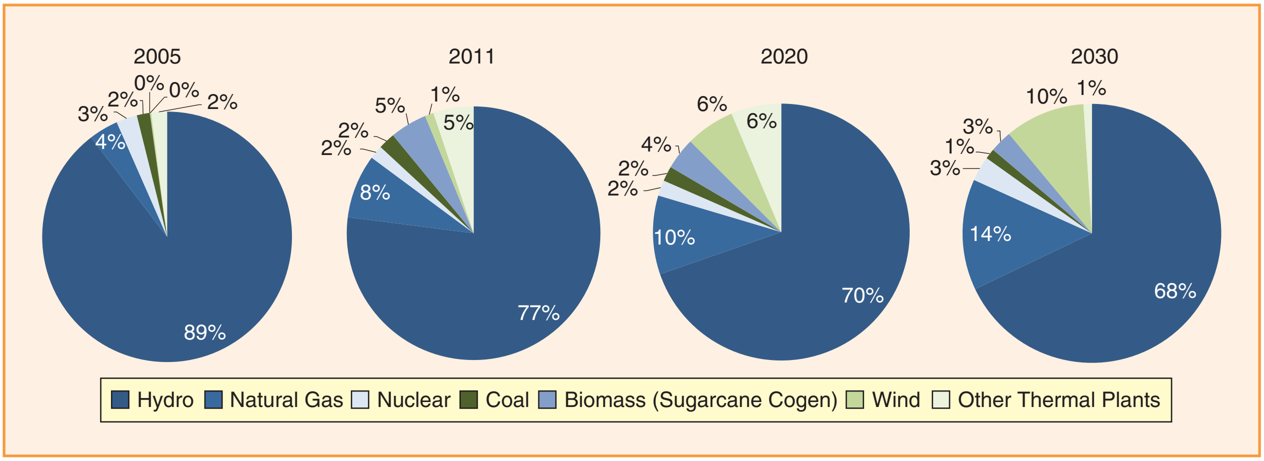

figure 5. Possible evolution of the Brazilian electricity matrix (source: PSR).

be accomplished in the most cost-efficient manner possible, i.e., making explicit the economic cost of emissions reduction policies in terms of cost per unit of CO_2 avoided and searching for the best relation between electricity costs (for all consumers and in particular for the industry) and emissions reductions. Otherwise, Brazil will run the risk of implementing policies that seem desirable but could in the end increase electricity costs unnecessarily and reduce the country's competitiveness.

Chile

Unlike Brazil, Chile is a country heavily dependent on foreign energy supply. More than 70% of its basic energy sources are imported. Chile has no significant oil, gas, or coal resources; its only nationally significant energy potentials lie in hydro and renewable energies. In recent years, Chile's electricity supply has become the center of lively public discussions that transcend all sectors of national life and have even provoked massive street demonstrations.

The other important way that Chile differs from Brazil is that over the last 30 years, Chile has developed its energy matrix—and much of its national growth—based on the existence of a totally private, competitive market driven by pioneering reforms introduced in the early 1980s. These reforms included completely separating the generation, transmission, and distribution segments. Generation investment decisions are fully private, with transmission following a centralized planning scheme that is also executed by private actors.

Restrictions with Supply

From the point of view of the adequacy of supply—understood as the existence of sufficient capacity to supply demand—in the Central Interconnected System (SIC), which serves the central and southern part of Chile, a dependence on hydroelectric power has made it necessary to issue rationing decrees as a result of droughts in the late 1990s and in recent years. Similarly, a lack of natural gas from Argentina due to unilateral curtailments beginning in 2004 has caused unreliable supply conditions, both in the Northern Interconnected System (SING) and in the SIC. Short-term supply security, defined as the ability to maintain power even under contingencies, has not been without its problems, either. Transmission facility failures and coordination problems have led to supply disruptions that have reached notorious levels. The disruptions, with a population accustomed to thinking of electricity as an infallible service, have led to unrest.

The environmental and social sustainability of the Chilean model of electrical development has also been questioned and frequently results in public demonstrations, political arguments, and judicial confrontations. On one hand, there has been growing opposition to local impacts resulting from the installation of electrical generation, such as large hydropower and thermal facilities and (more recently) wind farms. On the other hand, the growing contribution to climate change arising from greenhouse gases produced from thermal development based on coal has generated significant opposition among environmentalists and those who desire access to greener international markets for their products.

All this has been accompanied by what is probably the most sensitive issue, for both the population and most productive sectors: a substantial increase in electricity prices. It is not difficult to imagine how the uncertainty regarding investment, the large risks facing those who wish to tackle the urgent problem of finding a replacement fuel for gas, the barriers to investment, and the long delays in obtaining permits—among other factors—have resulted in higher electricity prices since 2007. Operating an economically efficient energy matrix and providing electricity at a competitive price that would promote Chilean development are goals that have been missed in recent years. These failures threaten Chile's ability to insert itself into a globalized world.

Figure 6 depicts the marginal electricity price from 2007 to 2011, together with the breakdown of the energy generation by technology for the SIC. The replacement of natural

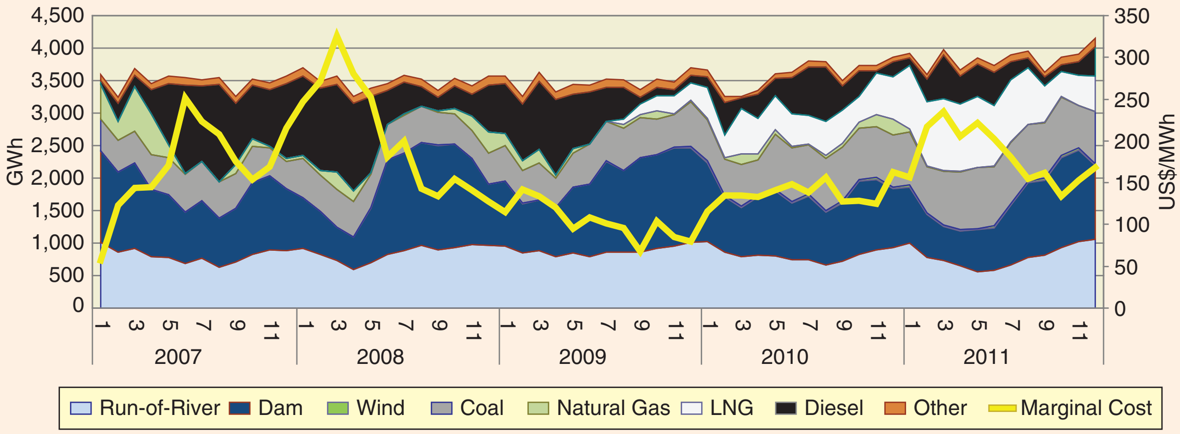

figure 6. Generation by technology and marginal electricity cost in the SIC, 2007–2011 (source: Systep).

gas with diesel accounts for the energy price boost, together with lower hydro production due to severe droughts.

Energy Resources

As noted, Chile has a great potential for hydro developments and renewable energy and is highly dependent on fossil fuel imports. The country has many options for the future development of its energy matrix, but all bring trade-offs among cost, reliability, and environmental impact.

Table 2 shows the levelized cost of energy for all the alternatives currently available in Chile. Investment and operational costs were obtained from typical values observed in projects developed in Chile, and international references were used for technologies not currently in use there. A weighted average cost of capital of 7.43% was used to calculate present values for all projects, assuming a 70-30 debt-equity ratio. Transmission costs were included, using average distances to the grid and investment costs.

The use of average costs, however, imposes important limitations on the analysis due to the range of capacity factors that can be found in renewables and hydro, with the site-specific nature of the investment costs, among other factors. Figure 7 shows an analysis in which investment costs, fossil fuel contributions and capacity factors were varied within observed values to produce a range within which levelized costs could vary. Energy efficiency, i.e., the use of demand-side incentives, was included using publicly available information, becoming the most cost-efficient alternative.

There are still important unexploited hydro resources in Chile. These resources are located either in indigenously populated areas, in regions with high tourism potential, or in unexploited natural reserves, however. Building these power plants would provide access to great volumes of clean energy of domestic origin that would contribute to reducing the foreign fuel dependency, but their exploitation is not yet a reality.

table 2. Levelized cost of various alternatives for power generation expansion in Chile (source: IEA 2011, SEIA 2011, CNE 2011, and Systep 2012).

Technology	Capital cost [US$/kW]	O&M Variable Cost US$/MWh	O&M Fixed Cost US$/MW-Year	Load Factor	Levelized Cost US$/MWh
Hydro run of the river	4,260	2.0	20.0	85%	69.7
Hydro dams	3,050	5.0	12.5	55%	69.8
Geothermal	3,000	5.0	12.5	58%	71.1
Small hydro	3,500	5.0	12.5	60%	75.5
Coal fired	2,350	46.9	37.0	89%	91.0
Wind	2,300	7.7	0.0	25%	111.1
LNG CCGT	1,000	109.5	15.0	35%	154.5
Photovoltaic solar	3,600	5.0	36.0	25%	198.2
LNG OCGT	680	162.2	10.0	20%	218.4
Concentrating solar	3,850	21.5	0.0	20%	236.5
Oil fired	740	191.0	10.0	15%	270.9

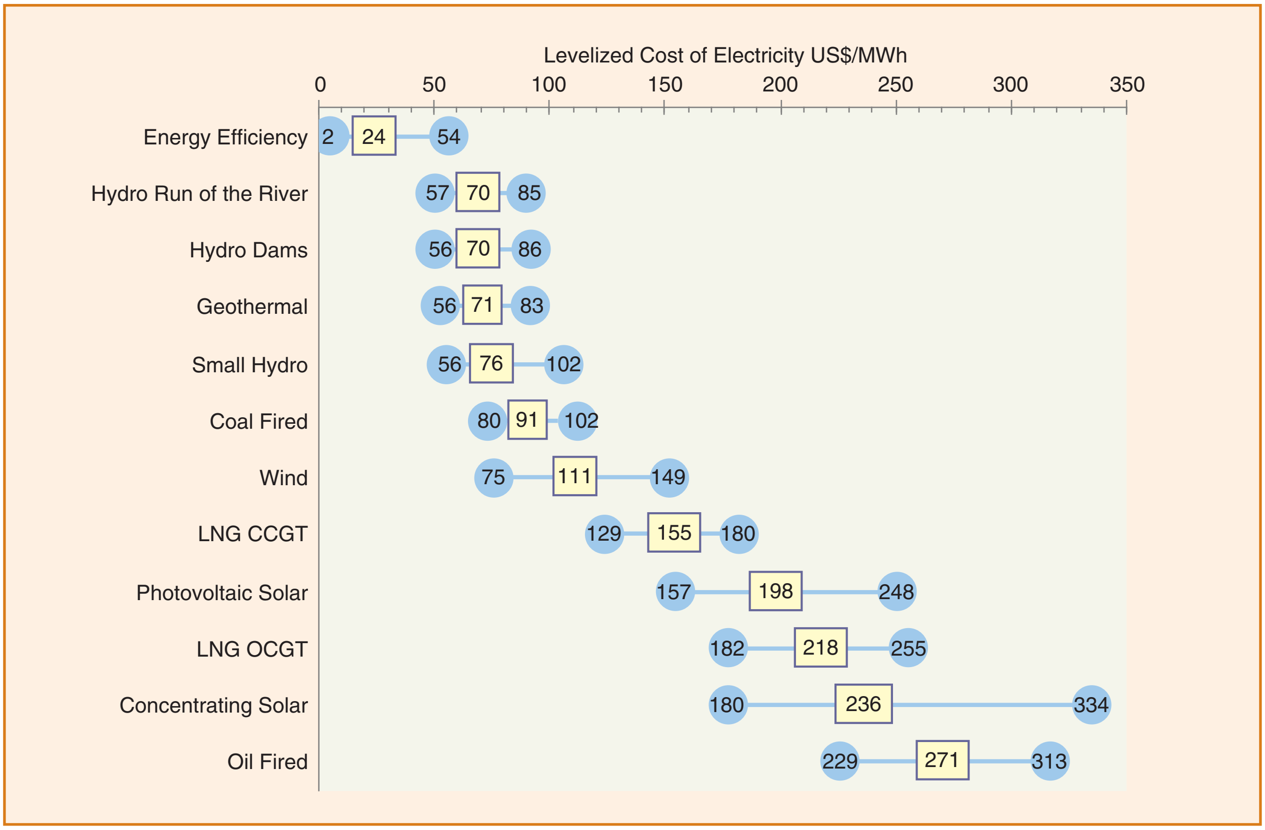

figure 7. Range of levelized cost of different alternatives for power generation expansion (source: Systep).

A very heated discussion about renewable energy has been taking place in the country for some time. A 2008 Chilean NCRE law mandates power traders, distribution companies, and generators that make energy withdrawals from the system in order to supply regulated and nonregulated consumers to certify that at least 10% of the energy being traded comes from NCRE (self-produced or purchased from other generators). This law established that the requirement would start with a 5% obligation from January 2010 until 2014. From then on, there will be an increase of 0.5% annually up to 10% in 2024.

There has been strong pressure, however, to increase the final share to 20% and advance the goal to 2020. This push has been driven mainly by parliamentarians, NGOs, and project developers. If passed, such a change of quotas would be a very important stimulus for NCREs. But it seems necessary to ask some preliminary questions—questions for which those who promote this initiative do not seem to have answers. First, is it possible for Chile to achieve this goal by 2020? At what cost? What will the impact of this measure be on the price of supply? And finally, is it in fact necessary for Chile to take measures like those implemented by European countries, but several years later and in an absolutely different context? Apart from all this, such a discussion is making renewable energy projects—particularly the least competitive ones—postpone their investment decisions in expectation of a new, more favorable future context.

Alternatives for the Future

To assess the implications of different future development paths for the Chilean electricity market, simulations were performed through the year 2030. The aim was to compare two alternative scenarios for renewable penetration in the SIC's future energy matrix. In the business-as-usual (BAU) scenario, the evolution of the system does not change radically, and the generation technologies maintain approximately the same proportion as in the current situation. Further, the BAU scenario merely complies with the legal requirement that a certain proportion (10% by the year 2024) of the energy traded must be generated using NCRE sources. In the high-renewable-penetration (HRP) scenario, there is a stronger development of the installed capacity in renewable energies, such that approximately 20% of the total energy produced in the year 2030 is generated using renewable technologies. This requirement is fulfilled with an assortment of renewable sources, including mini hydro, geothermal, biomass, and wind.

The methodology used to obtain the generation expansion plan is intended to reproduce investor behavior in a competitive electricity generation market and then simulated in a multimodal hydrothermal scheduling model. A comparison

table 3. Comparison of the BAU and HRP scenarios (source: Systep).			
Description	**BAU Case**	**HRP Case**	**Variation [%]**
New installed capacity [MW]	13.355	13.945	4.4%
New capacity investment cost [MMUS$]	20.920	21.990	5.1%
O&M costs [MMUS$]	23.940	23.761	−0.7%
Total costs [MMUS$]	44.860	45.751	2.0%
Average supply cost [US$/MWh]	68.2	69.5	1.9%
Average CO_2e emissions [kg CO_2e/MWh]	302.6	297.7	−1.6%

of the two scenarios using CO_2 emissions, total investment and operational costs, and capacity installed by technology over the study horizon is shown in Table 3 and Figure 8.

The results show that a higher renewable penetration implies a higher investment cost (5.1%) that though compensated for by a reduction in O&M costs of 0.7% results in an increase in total costs of 2.0%, equivalent to 0.45% of Chile's gross domestic product. Similarly, an increase of 1.9% in the average supply cost is observed when compared with the BAU scenario. On the sustainability side, the higher renewable penetration produces a reduction of 1.6% in average CO_2 emissions.

The biggest trade-offs with environmental sustainability are the economic effects and the resulting social sustainability, since higher renewable penetration in the Chilean market conveys a higher energy price and a higher total cost. Great caution must be exercised if higher penetration of renewable generation is to be pursued with regulatory changes, as is currently being discussed.

In a highly contentious environment, where diagnoses and proposals regarding energy strategies have been formulated along a broad spectrum, Chilean president Sebastian Piñera called in May 2011 for a group of prestigious specialists to form the Advisory Commission for Electricity Development (CADE). Subsequently, various political and civil organizations that questioned the independence of the government commission created the Citizen Parliamentary Technical Commission (CCTP), which has taken a more political view, both in its conformation and in the proposals it has made.

While a fair amount of discrepancy of opinion was expected between these two groups, the findings and recommendations contained in their respective studies have shown a surprising degree of consensus as to diagnosis, although there are some differences in proposed solutions. Some of the key areas of agreement can be summarized as seeing:

Regulatory Reforms on the Horizon

Given the problems of energy supply that Chile has been facing, many have been calling for a detailed review of the electricity market and its regulation. In particular, the private market's ability to develop a suitable and sustainable electricity system has been questioned, and as a result, market competitiveness has been tested. The market has been characterized as an oligopoly, where although the existence of competition can't be ruled out *a priori*, it is possible to infer that a larger number of participants would increase the intensity of competition and produce more efficient prices. Similarly, questions about the role of the state have been raised, accompanied by the traditional disquisitions promoting more market or state involvement.

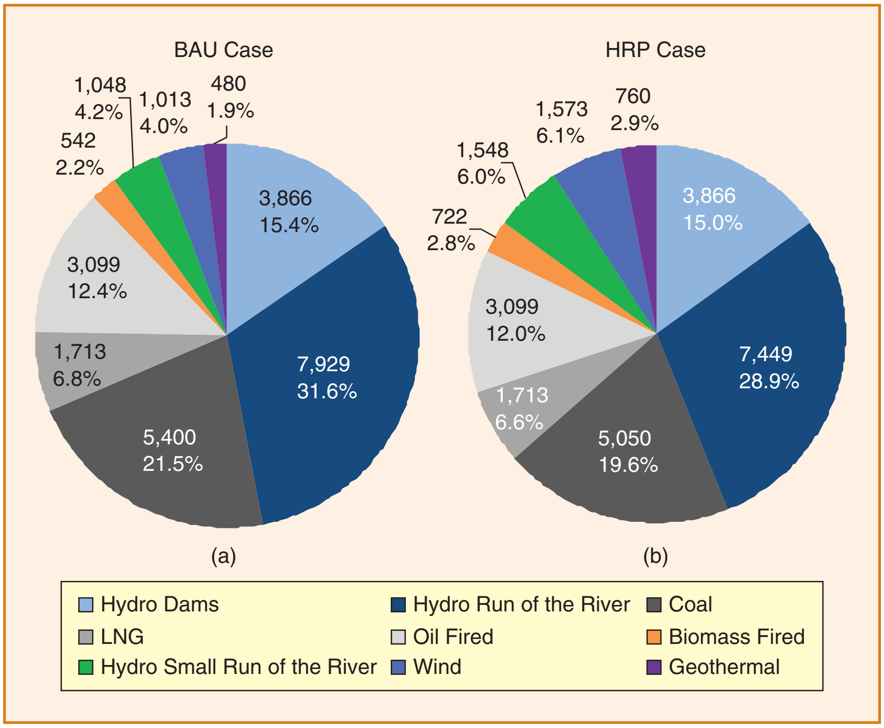

figure 8. Energy matrix composition in 2030 for the (a) BAU and (b) HRP scenarios (in MW).

- ✔ high concentration in the sector and the need to create more competition in generation
- ✔ the need to create an independent system operator
- ✔ the need to create mechanisms of citizen participation in the development of electrical infrastructure
- ✔ the need for the state to assume a strategic role in planning and expansion of transmission networks
- ✔ the need to establish a land-use strategy to reconcile the location of energy projects with environmental protection
- ✔ the need for compensation schemes to municipalities or local communities where power plants are located
- ✔ the need to promote energy efficiency, including mechanisms such as revenue decoupling for distributors
- ✔ the need for further transparency in the sector with respect to costs and competition
- ✔ the need for demand management schemes, flexible rates, and net metering
- ✔ the need for access to the spot market for all market participants (only generators participate today).

It is significant that both studies call for greater state involvement, requiring the definition of an energy strategy at the national level, in which all necessary regulatory changes are intended to meet the master plan. They do not imply a return to central planning, however.

It can be concluded that the studies published by CADE and CCTP complement each other and are very important tools for the discussion of Chile's energy future. Chile, however, must be extremely careful and agile as it considers what road to take, as an undesirable ghost can begin to appear that scares away investment: regulatory uncertainty. It is well known that investment in electricity assets is characterized by long periods of study and long construction times and is also capital-intensive, accompanied by long periods of recovery. Taking into account that major changes are being considered in areas such as transmission, increased penetration of renewable energy, land-use planning, and even taxes on negative externalities, uncertainty will induce a conservative approach from investors and developers. This approach could imply two possible courses: first, that there will be a delay in investment on the part of those still undecided, who are waiting for calmer times; or second, that the uncertainty will result in higher energy prices in an attempt to transfer potential higher costs, thereby mitigating the risk. Whichever occurs, neither possibility is in line with what Chile urgently needs.

So while Chile now has a diagnosis of the improvements and reforms it needs, it faces the challenge of implementing them without delay and generating the necessary investment confidence, although many of the reforms will require parliamentary approval. No doubt this is a job for government, which must very quickly exhibit the leadership required to create a consensus as to the reforms needed and provide a clear timetable for implementation.

Conclusions

While Brazil, with a mixed state-private energy market model, seems to be on a secure path for energy development, Chile appears to be at a standstill as far as defining how to implement energy growth in an environment where planning is based exclusively on private decisions. The challenges to energy security and the environmental issues are similar in both countries, although differences in the local availability of energy resources may imply significant dissimilarities with respect to the routes that will be chosen in moving forward.

Common to both countries is the challenge of developing abundant hydro resources that are attractive due to low greenhouse gas emissions but are being questioned because of the physical environmental impact of such development. Both societies are receiving messages from outspoken NGOs that hydros are not needed because wind and solar can supply the entire load in the long term. Environmentalists are in fact constraining hydro generation development and consequently economic growth, aiming at preserving nature at all costs. As new hydro development is accomplished by means of projects that are more and more complex, involving multiple interactions with the environment and increasing interactions with local population in poor areas, a major restructuring of the environmental licensing process is needed in both countries. This should include enhancement of the technical skills of environmental agencies, regulatory harmonization, and cooperation between the electricity sector and environmental activists during the planning phase for hydro facilities. Other countries in the region are facing similar conditions, though the situation is not as extreme as in Chile and Brazil.

For Further Reading

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