A Delicate Balance

The Challenges of Balancing the Need for Hydroelectricity with the Impact on the Environment

ECONOMIC EFFICIENCY, ENERGY SECURITY, AND environmental sustainability are concerns that must be considered in any energy policy in any given country. These key aspects remain challenged currently in South America. High energy consumption growth (near 6%), worldwide rising fossil fuels prices, strong environmentalist pressure toward reducing greenhouse gas effects, and promotion of renewable energy production have been a common challenge in South American energy markets. The development of vast unexploited hydroelectric resources is also at the center of attention, where its renewable character is being confronted with its environmental impact.

Hydroelectricity has been present since the birth of the public supply systems, with the first hydro plants in the world built around 1880. South America soon followed, with hydro plants built a few years later; the Marmelos Plant at Juiz de Fora, Brazil, in 1889 and the Chivilingo Plant in Lota, Chile, in 1897 (Figure 1) are two examples. Hydro plant building continued in South America with its height taking place in the 1960s and 1970s and peaking with the commissioning of the Itaipu dam in 1992, a 14,000-MW binational project that is the largest of the world in terms of energy production (Figure 2).

The contribution of hydropower to modern society has grown significantly, supporting economic and social development worldwide. Hydropower nowadays contributes 6% of the world's primary energy supply (28% in South America, Figure 3). There are hydro plants in some 150 countries, with 24 of these countries depending on it for 90% of their electricity supply. South America shares 22% of the hydroelectricity generated worldwide in 2006, surpassed by Europe and Eurasia with 27% and Asia Pacific with 26%.

In South America more than 50% of the electricity generated comes from hydroelectricity, compared to a hydro participation of 17% of the total world electricity production. Hydro energy worldwide, and more so in South America, is by far the largest renewable source of electricity. Nevertheless, South America uses less than 20% of the exploitable hydro resources, making it,

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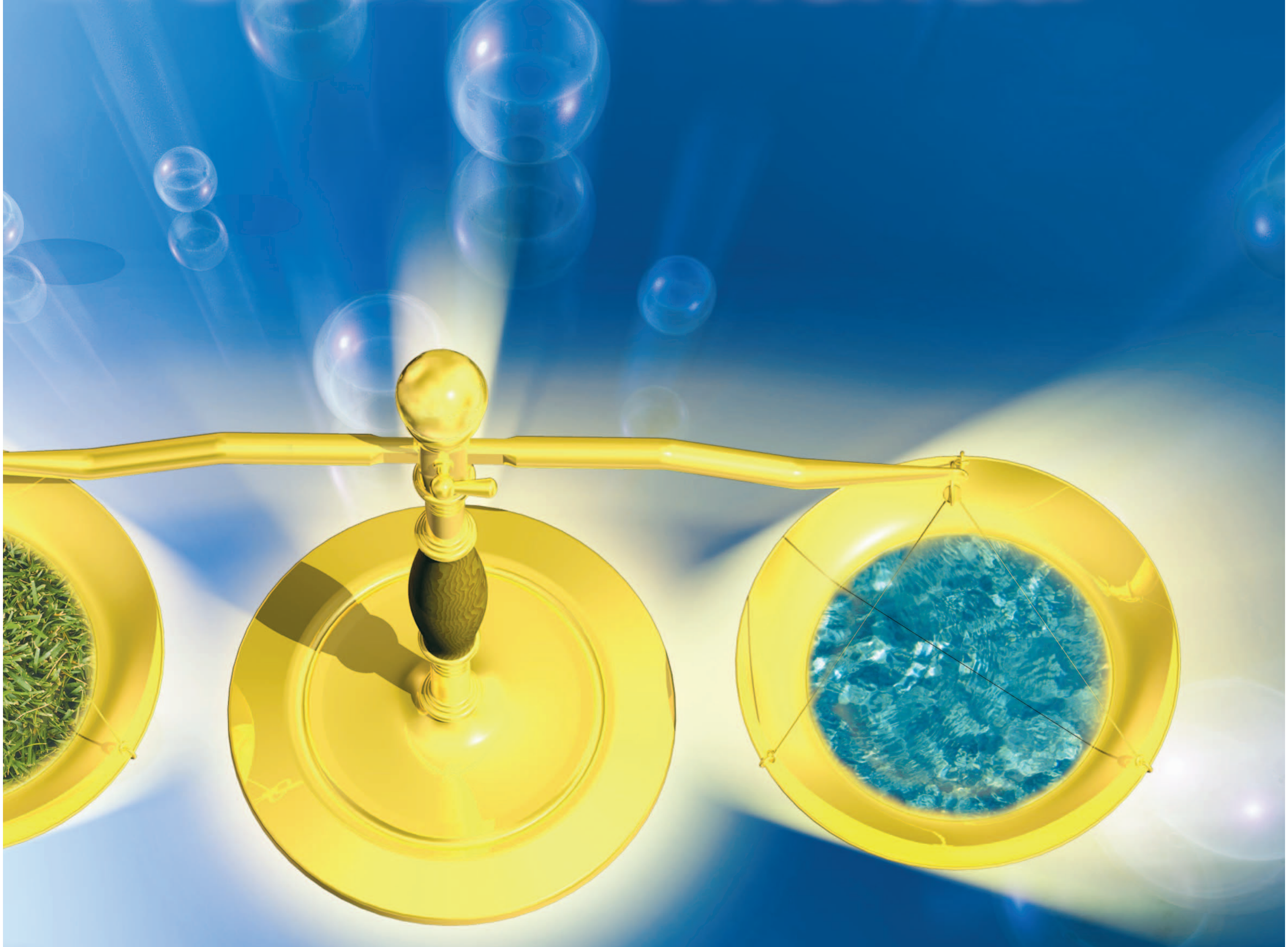
in South America



by Hugh Rudnick, Luiz A. Barroso, Sebastian Mocarquer, and Bernardo Bezerra

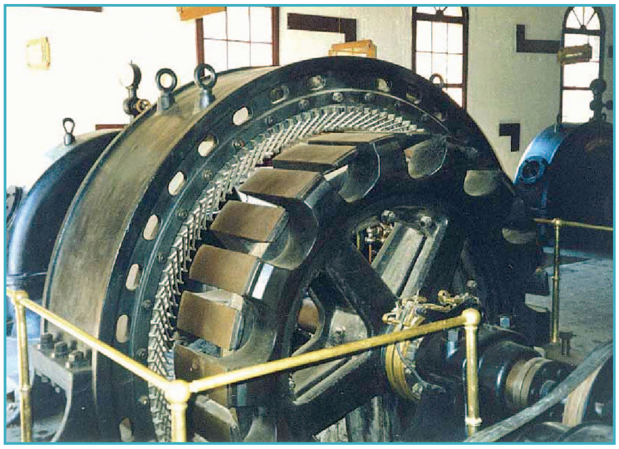


figure 1. A 1897 Chivilingo hydro 215-kW generator.

figure 2. A 1992 Itaipu 12,600-MW plant (14,000 MW in 2007) (photo courtesy of Caio Coronel/Itaipu Binacional).

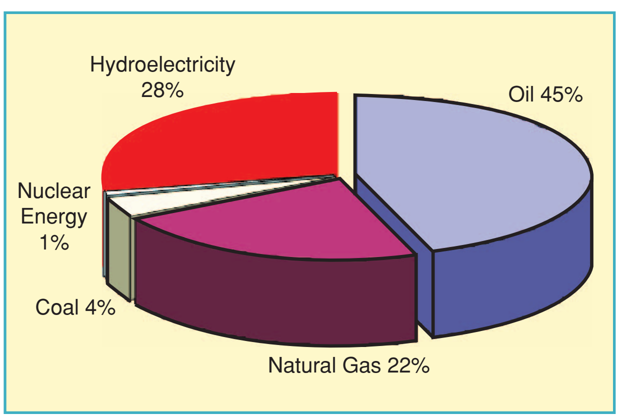


figure 3. Primary energy in South America by fuel (data from *BP Statistical Review of World Energy 2007*).

with Africa and Asia, one of the regions with the largest potential for hydro expansion.

Hydroelectricity has several advantages in the expansion of interconnected electrical system in the region, particularly when reservoirs are developed. The advantages correspond to an indigenous resource that makes countries more independent of foreign fuel supply, a growing concern in highly dependant countries. They can provide the single mean for energy storage along months or years, which can be most useful both for system operational control as well as for the economic dispatch of thermal generation, contributing to reduce the total cost of electricity generation. Hydroelectric plants are extremely flexible in their operation, allowing smooth frequency control and rapid response in emergencies. Further, the development of intermittent and seasonal renewable energy sources, such as wind energy, can benefit from the storage capacity available in hydro reservoirs.

Thus, hydro will continue to be the main source of electric energy in South America for the near future, along with coal and natural gas, but the development of new hydroelectrical plants is facing diverse challenges. They are not technical restrictions, as hydro expertise has been in the region long enough to make it a mature technology. The challenges of hydro development in the region arise in the development of more distant hydro (increasing transmission costs), the financing of major investments and, particularly, in controlling the impact on the environment. Reservoirs and run-of-river plants may affect flora and animal life as well as have an effect on local population when large extensions inundated with water are required. No minor challenge is the growing active opposition to any hydro development of international nongovernmental groups.

Hydroelectricity developments may have high economic risks in South America, not only because they are capital intensive with longs periods of construction and long repayment horizons, but also because the local energy spot prices may vary considerably. Because of the hydro predominance in the regions, prices can stay at very low values for long periods (Figure 4) and complement with hydro storage: when spot prices are high, storage is low and vice versa. While hydropower has almost no direct variable costs, as compared to coal or gas thermal plants, even with its higher capital costs, its total cost per kilowatt hour is lower than for coal plants; the challenge lies in its stochastic energy generation, highly dependent on rainfall. Figure 5 shows the evolution of stored water in hydroelectric reservoirs in Chile over 14 years and demonstrates how stochasticity of rain may dramatically impact the available resources for electricity generation.

These conditions have paved the way to the development of stochastic hydro scheduling models and algorithms for system operation and have motivated the design of electricity markets focused on long-term contracts for generators. Since 2004 South America has emerged into a second wave of market reforms that is focused on a market-based scheme to attract new investments. Contract auctions backed up by firm energy or capacity certificates form the backbone of new design, where auctions of long-term contracts are organized and carried out by distribution companies and investors bid on the contract price to build, operate, and deliver electricity from a given hydro plant. In countries in South America that have not advanced with this new market scheme, private investors have been cautious on hydro investment, and often the state has had to intervene to develop hydro resources.

It is clear that hydroelectricity does not have the adverse environmental effects on air of thermal generation, resultant from burning coal, natural gas, or diesel. Reservoirs may produce methane gas, but with no relation to the CO_2 impact of fossil fuels. The main impact of hydro plants is caused through their construction. In some cases, the impact arises because of the inundation of large areas that may have population that need eradication or fauna that may be affected. The impact on the geographic conditions and the landscape may be important, particularly for large reservoirs.

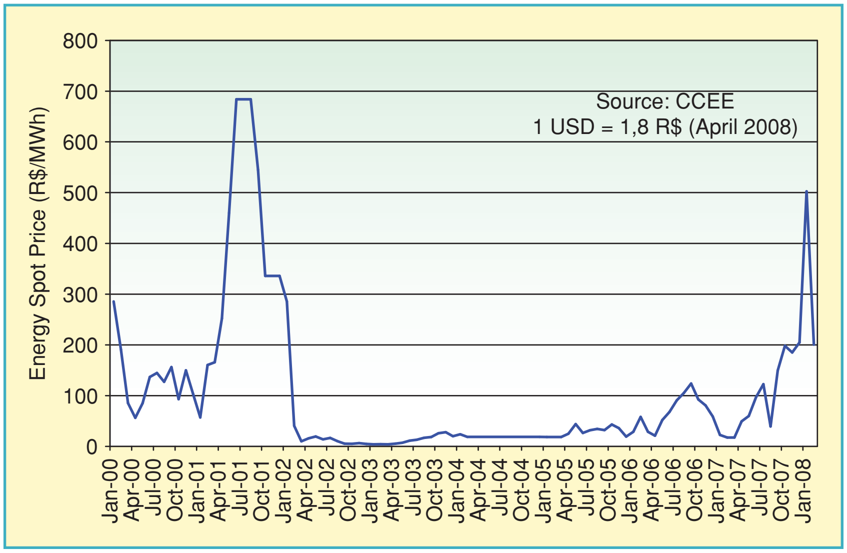


figure 4. Brazil's short-run marginal costs (R$/MWh).

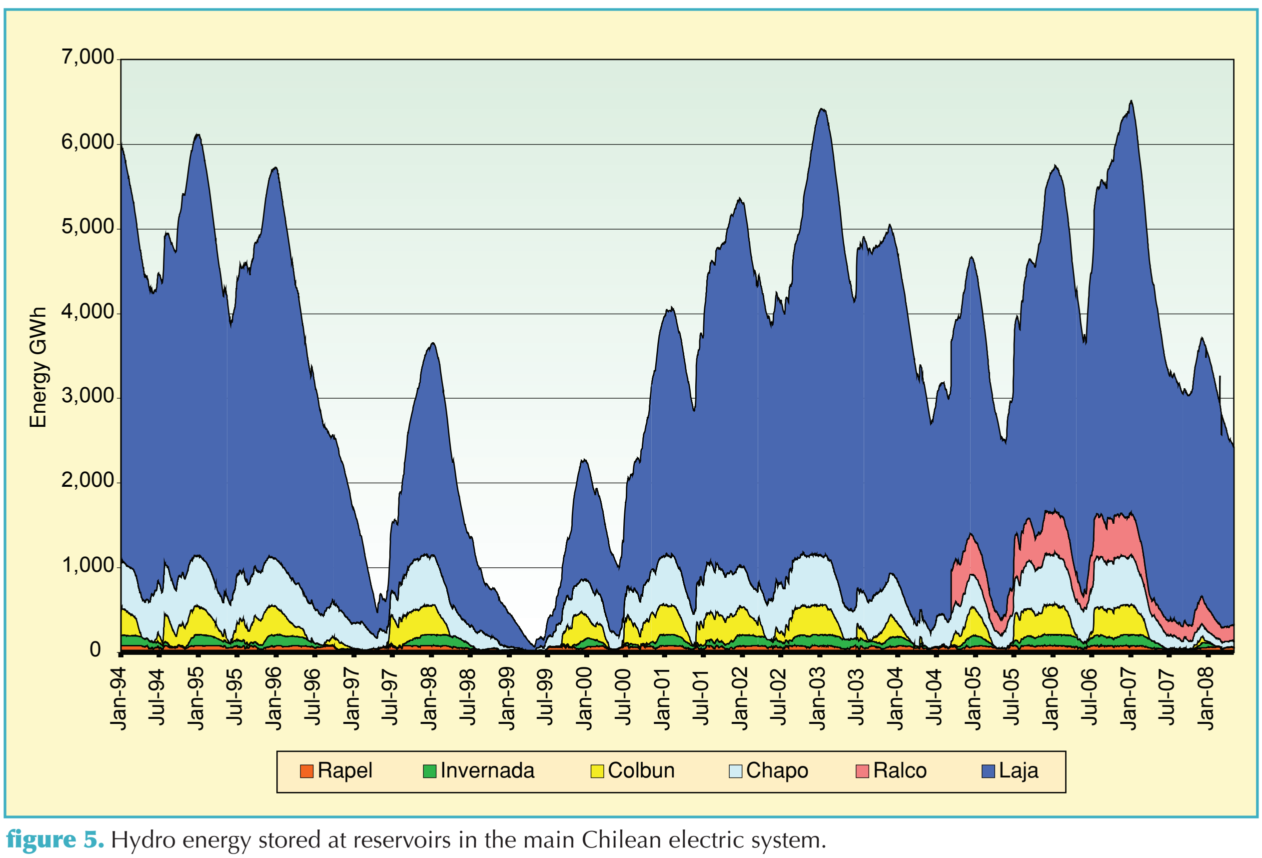


figure 5. Hydro energy stored at reservoirs in the main Chilean electric system.

table 1. Hydroelectricity in South America (source: *Survey of Energy Resources*, World Energy Council, 2007).

	In Operation 2005		Under Construction	Planned
	Capacity MW	Generation GWh	Capacity MW	Capacity MW
Argentina	9,921	34,192		2,400
Bolivia	458	1,424	90	700
Brazil	71,060	33,7457	4,997	36,635
Chile	4,695	25,489	300	3,000
Colombia	9,000	37,000	660	10,000
Ecuador	1,773	6,883	452	412
French Guiana	116	426		
Guyana	1	1	105	1,150
Paraguay	7,410	51,156		1,945
Peru	3,207	17,977	230	1,079
Surinam	120	600		532
Uruguay	1,538	6,684		
Venezuela	14,413	77,229	2,250	2,964
Total	123,712	596,518	9,084	60,817

Hydro Resources in South America

The potential of hydroelectricity worldwide is around 2,800 GW, with only one-fourth currently being exploited. South America has a very large hydroelectrical potential, with several countries relying importantly in its contribution. The largest generating country is Brazil (Table 1), with 57% of the installed capacity in the region, followed by Venezuela (12%), Argentina (8%), and Colombia (7%). The planned capacity, considering projects that have been proposed for eventual development, again focuses in Brazil, with 60%, followed by Colombia with 16%.

Figure 6 shows the significant growth of hydroelectricity generated in the region, with Venezuela growing 55 times over the last 40 years, followed by Argentina growing 34 times in the same period. Brazil grew only 12 times but its influence is demonstrated by the regional reduction that took place in 2001, caused by the major drought that affected that country.

A brief description of some of the markets in the region and the status of hydro development is made, partly based on full articles prepared for a panel session on "Hydro Developments, Generation Options and the Environment in Latin America" presented at the 2008 IEEE Power Engineering General Meeting in Pittsburgh, Pennsylvania (sources indicated).

Argentina

Argentina has an installed capacity of 24.2 GW, of which 54% corresponds to steam and gas thermal generation, 4% to nuclear, and 42% to hydro power. (For more details, see R. Varela in the "For Further Reading" section).

Argentina's hydroelectric potential is partially used, since of the 170,000 GWh/year identified only 38,000 correspond to power plants currently under operation, projected, or under construction. Hydro power potential can be grouped in two: small-scale hydro developments up to 15 MW and large hydro developments. Installed capacity of small-scale hydro developments interconnected to the main system is limited; it amounts to about 180 MW for 62 power plants. Further, there are about 140 new small-scale hydro projects with a total capacity exceeding 305 MW.

In relation to large hydro plants, the last one commissioned was Pichi Picún Leufú in 1999. There is significant hydroelectrical potential, with a total of 63 GW identified in 13 basins. Some of the largest projects, among 300 identified by the Secretariat of Energy, are summarized in Table 2. Most of them correspond to

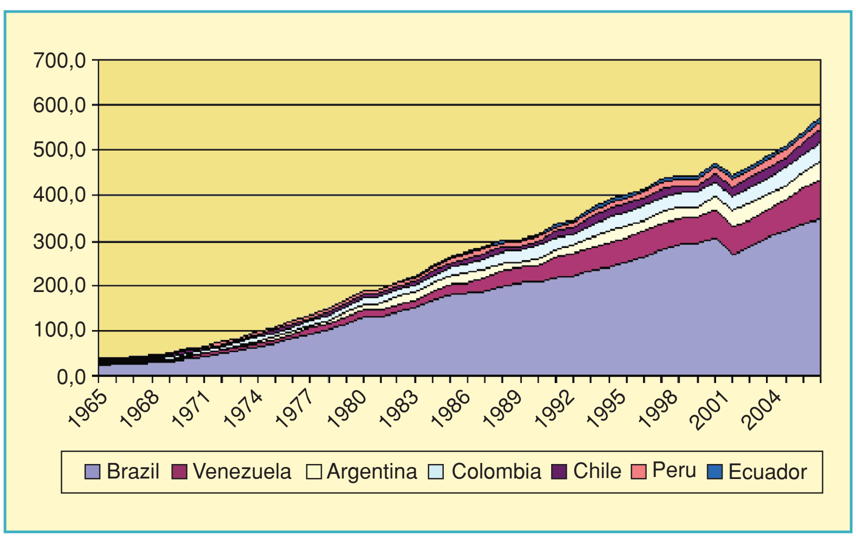


figure 6. Hydroelectric power generation in Terawatt-hours in South America (data from *BP Statistical Review of World Energy 2007*).

binational projects involving Argentina and neighboring countries. Corpus Chris is a binational development on the Paraná River jointly involving Argentina and Paraguay. In October 2007, the authorities of Brazil and Argentina signed a draft agreement to assess the feasibility of the Garabí project, which comprises two dams: Santa María and Garabí.

table 2. Hydropower projects in Argentina.

Project	Basin/River	Capacity (MW)
Corpus Christi	Paraná	2,800
Garabí	Uruguay	1,600
Condor Cliff	Santa Cruz	1,440
Yacyretá complement	Paraná	1,200
La Barrancosa	Santa Cruz	750

Brazil

Brazil has an installed electric generation capacity of about 100 GW, where hydro generation accounts for 90%, for a peak and energy demand near 65 GW and 53 average GW, respectively. The hydro system is composed of several large reservoirs, capable of multiyear regulation, organized in a complex topology over several basins with complementary hydrological regimes. Thermal generation includes nuclear, natural gas, coal, and diesel plants. Cogeneration from the sugarcane bagasse has emerged as an attractive option. In order to couple the development of hydro generation and to benefit from hydrological complementarities, the country became fully interconnected at the bulk power level by an 85,000-km meshed high-voltage transmission network. Because of the system's large reservoirs and the country's weather diversity, resources were heavily invested in the past for the development of stochastic optimization techniques for reservoir management. They have, in turn, enabled the system to carry out an integrated operation, where reservoirs are used to compensate dry periods and hydro generation is used to reduce the operation's costs for the consumer: a national power system operator utilizes fully every additional hydro generation to reduce production of thermal power plants, which are then operated in the hydroelectric production complementation mode. This way, fossil fuels are saved and the final consequence of such hydrothermal optimization is the cost reduction for the consumer.

The existence of reservoirs has also allowed the system to integrate electricity sources with seasonal production patterns, such as the cogeneration from the sugarcane bagasse: these plants produce energy during the harvest, which coincides with the dry period of Brazil, where reservoirs are usually emptied at a faster pace. Hydroelectric plants can, on the other hand, compensate for the lack of this cogeneration production out of the sugarcane harvest, which coincides with the wet season. Alternatively, hydro reservoirs can also be used as a natural option to store "natural gas" whenever it is appropriate. For example, if gas prices are low or if there is a consumption reduction on the industries, gas-fired plants can produce power, displace hydro production, and retain a credit of natural gas stored in the hydro plants reservoirs in the form of water. This means that hydro storage can be used as a buffer by thermal plants so as to permit the storage of nonutilized natural gas, cheaper gas, or to accommodate uncertainty of thermal plant operation and liquefied natural gas shipping. Finally, hydro reservoirs can be used as an integration mechanism among countries with different shares of hydro and thermal resources in their mix. For example, Brazil's reservoirs could be used to meet Argentina's energy demand, who could return this energy to Brazil later (energy swap).

In summary, reservoirs are fundamental for other energy sources: i) they integrate seasonal production sources (sugarcane cogeneration) or intermittent generation (wind power); ii) they function as a virtual infrastructure for storage and transportation of gas; iii) they offer synergies with thermal plants, benefiting the consumer with the integrated operation.

Figure 7 shows an outlook of the country's available resources for each of its four main geographical regions (South, Southeast/Center-West, North, and Northeast) as well as the tapped hydro potential per region. The installed capacity of the hydro plants currently in operation in Brazil (about 74 GW, considering 50% of Itaipu Dam) does not

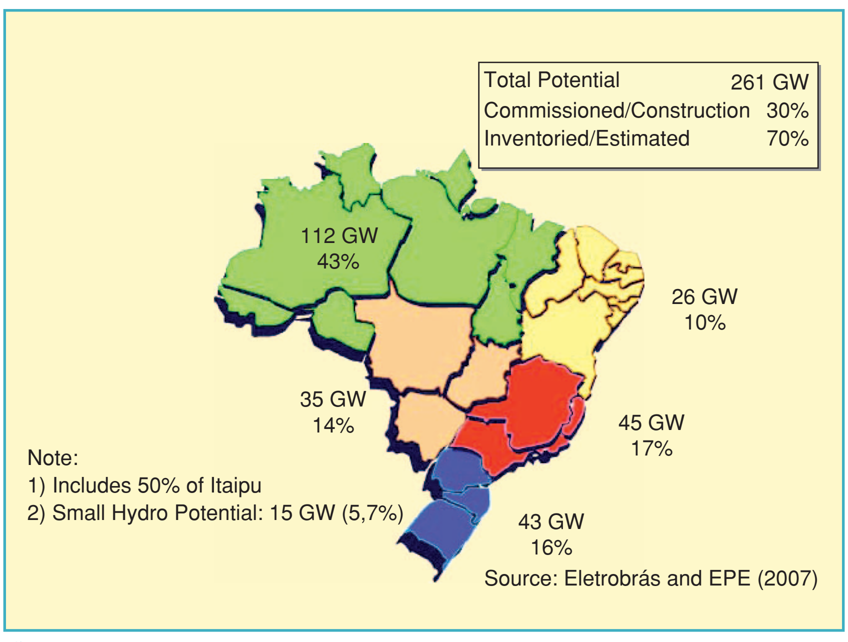


figure 7. Overview of generation options per region in Brazil.

South America uses less than 20% of the exploitable hydro resources, making it, with Africa and Asia, one of the regions with the largest potential for hydro expansion.

table 3. Hydroelectric resources in Chile (2007).

Zone	Installed Capacity (MW)	Nonexploited Capacity (MW)	% Exploited
North	27	232	10.4%
Central	2,193	3,613	37.8%
Central South	2,530	7,825	24.4%
Austral	18	9,609	0.2%
Total	4,767	21,279	18.3%

table 4. Hydroelectric projects in Chile.

Project	Company	Type	MW	Start Date
Pascua 2.1	Hidroaysen	Reservoir	770	2014
Baker 1	Hidroaysen	Reservoir	660	2015
Pascua 2.2	Hidroaysen	Reservoir	500	2016
Pascua 1	Hidroaysen	Reservoir	460	2018
Neltume	Endesa	Run of river	403	2014
Baker 2	Hidroaysen	Reservoir	360	2018
Alfalfal II	AES Gener	Run of river	250	2013
Las Lajas	AES Gener	Run of river	250	2014

represent more than 30% of the total hydro potential of the country, estimated at 260 GW. As shown in the figure, the country still has an undeveloped hydro potential of more than 150 GW, most of which is located in the environmentally sensitive Amazon region. The social and environmental consequences of the possibility of hydro developments in this region involve questions such as reservoirs in indigenous lands and preservation of biodiversity. For example, 28% (74 GW) of the country's hydro potential involves projects with environmental complexity, while 7% (18 GW) involves projects with great attractiveness but located close to indigenous territories. Repowering and installation of additional turbines in existing plants also represents an attractive, but limited, option.

On the economic side, the greatest challenge is the transmission cost: new hydro plants will be located within distances of about 2,500 km from the main load centers. Nevertheless, hydro developments in the Amazon region began in 2007, when the auction of the first (of two) hydro plant totaling 7 GW located in the Madeira River started. Other plants in the pipeline to be developed include the 11-GW Belo Monte project.

Several conditioning aspects will drive the development of hydro power generation in Brazil. They are discussed in the following paragraphs.

Increase of the Portfolio of Projects in the Medium Term

For 2012 to 2014 there are limited hydroelectric supply options besides large-scale plants in the Amazon. The reason is that the stock of hydro projects is depleted. Inventory studies of basins are under way. They will be concluded in late-2008/early 2009 and will increase the portfolio of new hydro projects to be offered to investors in the regular concession auctions from 2009 for delivery five years later.

Concentration of Hydro Developments in Large Projects

An eventual concentration of hydro supply in large hydroelectric projects has some concerns. These projects have a greater impact in case of delay, they demand larger investments (few financing agents) and higher transmission costs, and they have higher market (e.g., hydrological) risks. In the face of this, there has been much interest in developing additional supply alternatives that should preferably be "clean" generation sources, such as small hydroelectric plants (capacity smaller than 30 MW and reservoir area smaller than 3 km^2). They offer some advantages when compared to large hydro, such as smaller-size projects, which diversifies the risks of construction problems ("portfolio" effects); wider range of investors (including local, foreign, and hedge funds); short construction time, which results in a good attribute for uncertainty about growth of energy demand; easier environmental licensing; and carbon credits. Nevertheless, achieving the same volumes of large projects with small projects may at the end have a similar environmental impact.

Transmission Costs

As hydro developments move toward the Amazon region, transmission reinforcement costs associated with generation investments may be comparable to, and in some cases exceed, the generation costs themselves. This can threaten the economic competitiveness of hydropower in the long run.

Environmental Issues

The environmental licensing process in Brazil involves the issuing of three licenses: prior, installation, and operation. Depending on the plant's location, the licensing process involves several institutions with the federal and municipal levels in a complex process that has resulted in delays of the license issuing and increase of environmental costs or compensations. For example, the Luis Eduardo Magalhaes hydro

> Hydro will continue to be the main source of electric energy in South America for the near future, but the development of new hydroelectrical plants is facing diverse challenges.

plant (900 MW, located at the Tocantins River, auctioned in 1996 and started operation in 2001) had an increase in its environmental costs of 22% of the project's total value, resulting in cost overruns of about 500% with respect to the project's total planned budget for environmental issues. Another emblematic case is the licensing of the Barra Grande project, a 690-MW hydro whose operation license was once suspended due to inadequate studies on vegetation impact investigated just before the filling of the reservoir. A recent World Bank study concluded that the average cost overruns on hydro plants due to environmental issues are significant and about 15% of total costs.

In addition, there has been a strong opposition against reservoirs, which have difficulties with the licensing projects. The practical consequence is that new plants are being developed with much smaller reservoirs, which ends up reducing the system's flexibility and storage capability.

The main approach that is being adopted to solve this deadlock is an integrated environmental assessment (IEA) of inventories and planning of hydro plants gathered with a better coordinated process among authorities to speed up the environmental licensing process and reduce compensations. The IEA aims at looking to the cumulative and synergic environmental impacts in the whole basin instead of the standard project-by-project approach. The methodology takes into account impacts on biodiversity, water quality, sustainable development, and social aspects (i.e., stronger participation of the society through workshops and seminars among institutions, investors, and population). IEA is being carried out by Empresa de Pesquisa Energética, the body responsible for planning studies, in the context of the new inventories described earlier. The most fundamental challenge is to allow the society to participate in a debate to conciliate environment, economic growth, and social justice in the context of hydroelectricity development.

Economic Attractiveness

It is felt that, in order for hydro plants to remain an attractive generation option, investment costs should stay in the range of US$1,200–1,800/kW with a capacity factor of 55%. As a reference, it is estimated that 28% (74 GW) of the remaining hydro potential will have costs around US$1,500/kW while 31% (82 GW) will have costs around US$1,800/kW. The challenge is to define the economically feasible projects, so as to assess the real potential for hydro generation in the country.

Chile

Chile has an installed electric generation capacity of 12.8 GW, where hydro generation accounts for 38% (and 53% in the main system, which supplies 93% of the population). Nevertheless, ten years ago supply presented a markedly hydroelectric component, with a participation of 78% in the total installed capacity. In 1997, an important trade agreement was subscribed between Chile and Argentina, which created a significant and economic Argentinean natural gas supply, which made viable the construction of gas pipelines for supplying gas to residential and industrial clients, and the development of an important electricity generation capacity with combined-cycle power plants. The cancellation of gas transfers from the neighboring country has implied revisiting some of the long-known hydro projects. There are still important unexploited resources in the country (see Table 3); however, these resources are located either in indigenous populated areas, in regions with a high tourist potential, or in unexploited natural forest reserves.

Table 4 summarizes the main hydro projects under consideration at present. Opposition to projects in Aysén, Neltume, San Pedro, Alfalfal II, and others has already surfaced.

Peru

Peru is a mainly hydroelectrical system, with over 66% of energy produced coming from plants with a total of 3,135 MW. New projects being developed will add up to 2,459 MW before 2015. The country has a theoretical potential of hydro resources for the future of 206 GW, of which 58 GW are economically exploitable in the short- and mid term. Some of the

table 5. Large hydropower projects in Peru.

Project	Basin/River	Capacity (MW)
ENE40	Ene	2,227
MARA570	Marañón Medio	2,009
INA200	Inambari	1,355
PAM240	Pampas	1,329
TAM40	Perene	1,287
MARA500	Marañón Medio	1,181
HUAL210	Huallaga	1,095
URUB320	Urubamba	941
APUR737	Apurimac	905
VNOTA295	Vilcanota	850
HUAL190	Huallaga	844
HUAL170	Huallaga	841
HUAL90	Huallaga	801

> The resources of tropical rainforests could be secured with the development of hydropower generation projects, but the financial requirements are enormous.

largest projects, among 328 identified by the government, are summarized in Table 5. (For more information, see D. Camac in the "For Further Reading" section).

On the other hand, recently the Peruvian government started supporting the development of hydropower projects not only to supply the domestic market but to export to neighboring countries since Brazil is the one with the bigger load potential among them. Specifically, there are 15 projects that add up to 19 285 MW, and the largest ones are detailed in Table 6. However, under the current regulation, no projects have been developed during the last decade.

The Financial and Regulatory Challenges of Hydro Development

Access to funds from international agencies like the World Bank for the development of hydro projects has been declining in the last decade, reducing lending from the bank from US$1 billion dollars a year in the 1990s to one-tenth of that figure in the 2000s. More recently, local development banks have led the financing process, providing funds for the development of new projects. Multilateral institutions such as the International Finance Corporation and Inter-American Development Bank (IADB) have started looking at hydro power again in the region. The most common financing model is the project financing structure, where the project offers all guarantees to the lenders. On one hand, this financing structure constrains resource availability for merchant projects; i.e., those with spot sales only. On the other hand, the new electricity market structure in the region that promotes long-term contracts is an attractive scheme to foster financing for hydro development.

Hydro projects have several characteristics that make them more risky financially. First, they often correspond to very capital-intensive projects, with high costs for their civil works and equipment, costs that have risen over recent years in the region as they compete with other industrial developments such as mining. The need to build long transmission lines to reach major load centers adds a significant sunken cost to most projects. Construction risks are more significant than in the building of thermal generation plants. Performance risk, geological risk, hydrology risk, foreign exchange risk, and regulatory/political risk are the other key risks for the financing of hydro power. The financial requirements extend for decades, as hydro projects require long pre-investment studies and long construction periods, so that horizons of commission may go over ten years.

table 6. Hydropower projects for exporting to Brazil.

Project	Capacity (MW)
Pongo de Manseriche	7,550
Rentema	1,525
Paquitzapango	1,379
Ina 200	1,355
Sumabeni	1,074
Urub 320	942
La Balsa	915
Cumba 4	825
Cuquipampa	800
Vizcatán	750

Finally, hydro developments require higher regulatory requirements. Given that water is often considered a public natural resource, governments require concessions for the development of hydro projects, which often take long periods in being approved. The need for concessions is also a must for these projects, so that right-of-ways are provided to build access roads, develop disruptive civil works, and inundate, in the case of dams, large extensions of land. The need to acquire water rights in the case of Chile is an additional requirement that makes hydro development more difficult.

Thus, in some countries in the region, given the high financial requirements and the limited long-term funding, hydroelectrical developments by private investors have not prospered, and it is the state that has had to take the initiative. Private investors center in natural gas and coal thermal plants, with lower investment costs required in shorter periods. The situation is different in Brazil and Chile, where private investors and self-producers have been actively participating in the investment of hydro plants. It is true that for most projects in Brazil financing has become available through the local National Development Bank but more sophisticated arrangements for financing, involving mulitlateral institutions and commercial banks, have also been developed.

A Case Study: The Madeira River Complex in Brazil

The Madeira River is the principal tributary of the Amazon River, with its basin covering about one-quarter of the Brazilian Amazon. The complex consists of two hydroelectric dams: Santo Antonio (3.1 GW) and Jirau (3.3 GW). The construction of the project, plus two additional dams upstream, would open a 4,200-km industrial waterway for barge passage, permitting transport of soybeans, timber, and minerals to Atlantic and Pacific ports. A consortium led by the Brazilian group Odebrecht (holding with businesses in engineering and construction, petrochemicals, and public concessions) and the state-owned power generator Furnas won the auction carried out in December 2007 for the construction of Santo Antonio, the 3,150-GW first plant of the complex. A 35-year energy contract was granted to the winners through the acution process. The same companies had obtained concession rights to study the area and initiate environmental licensing procedures some years before, which guaranteed a great competitive advantage in the auction. The composition of the winning consortium also includes another engineering company, a state-owned utility (Cemig) and private equity funds (Santander, Spain and Banif, Portugal).

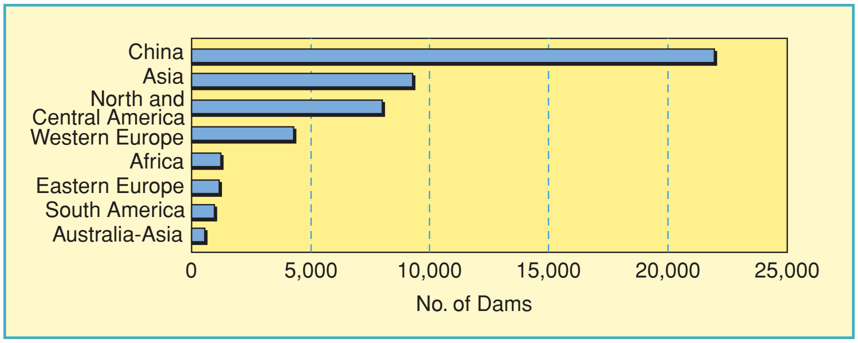


figure 8. Regional distribution of large dams in 2000 (data from World Commission on Dams, 2000).

Financing of the project will be done under the project finance's mode. It is a challenging financing structure, involving the first project after years in the Amazon and involving investment costs of about US$5 billion. Brazil's National Bank for Economic and Social Development, has already announced its interest in financing the project through equity (up to 20%) and debt (up to 75%) instruments. The interest rates for the project finance deal were lowered and maturity was prolonged as the Madeira Dam was listed on Brazil's GDP Growth Acceleration Plan. The IADB is also reported to plan partial financing of the project. Other federal and state-owned banks, along with the largest Brazilian private banks, are currently analyzing the project to grasp financing opportunities. In addition, Brazilian second and third pension funds, based on assets under management, are also considering the project through private equity or debt funds.

The consortium is now finalizing financing and insurance arrangements and negotiating the entry of new shareholders. Banks are currently performing their environmental, social, and financial due diligences, most under the framework of the Equator Principles. If the consortium succeeds to deliver the 33 conditions set by the preliminary environmental license, the final license is estimated to be granted in the last quarter of 2008, with construction beginning immediately afterward for energy delivery in 2012.

The Environmental Challenges of Hydro Development

Although South America contributes little to the world's total pollutant emissions, societies are increasingly becoming aware of the impact that electricity production may have on the environment, and more concerned on its local impact than in the greenhouse effect. It is not unusual today that local habitants and environmentalists join efforts to challenge new coal- or gas-fired thermal power plants that they argue would be harmful for people and for the economic activity near the site of the power plants.

The development of hydroelectricity is also being questioned in the region, with controversy arising and with growing ferocious opposition to some projects due to their environmental and social impacts. Projects are being questioned because of their impact on downstream habitats, on population settlements and on indigenous communities, on cultural and natural heritage, on water quality and erosion, and, more recently, on the landscape of untouched regions.

The concern for hydroelectric generation originated worldwide as there had been some cases, particularly with large dams, that implied unacceptable and unnecessary high costs and social and environmental impacts. The lack of fairness in the distribution of benefits of large dams has been behind their questioning. Thousands, and even millions, of people have had to be transferred from inundated areas, causing major social unrest. As dam building accelerated after the 1950s, opposition to dams became more widespread, vocal, and organized. Dams were not only used for hydroelectricity but also for irrigation, as half the world's large dams were built exclusively or primarily for irrigation. The concerns on the impact of dams grew to finally give birth to the World Commission on Dams (WCD) in 1998. The WCD was an independent, international, multistakeholder process that addressed the controversial issues associated with large dams. It was given the mandate to review the development effectiveness of large dams and develop internationally acceptable criteria, guidelines, and standards for large dams. The result was a framework within which to examine dams, both existing and planned. The Commission's final report, "Dams and Development: A New Framework for Decision Making," was launched in November 2000, and the Commission disbanded.

Most of the problems identified by the WCD were located in Asia, particularly China (with 46% of total dams worldwide) and India (9%), with a minor presence in South America (Figure 8), and where only 24% of dams in the region correspond to hydropower. Brazil has the largest number of large dams, with 1.2%. The United States contributes significantly to the statistic, with 14% of all dams.

Another dimension of environmental controversy in the region is the interest of several countries to use the hydro potential of the Amazon, the world's largest river basin, which represents over half of the planet's remaining rain-

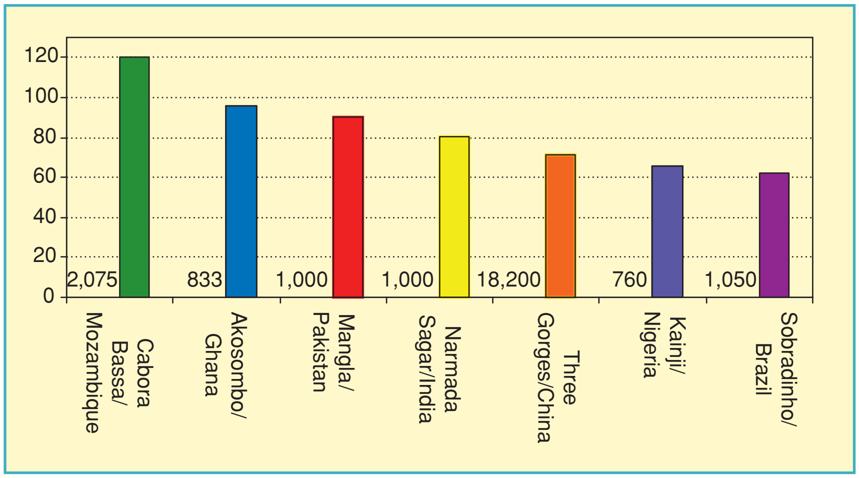


figure 9. People displaced per installed megawatt in large hydro plants worldwide (installed capacity in megawatts also indicated).

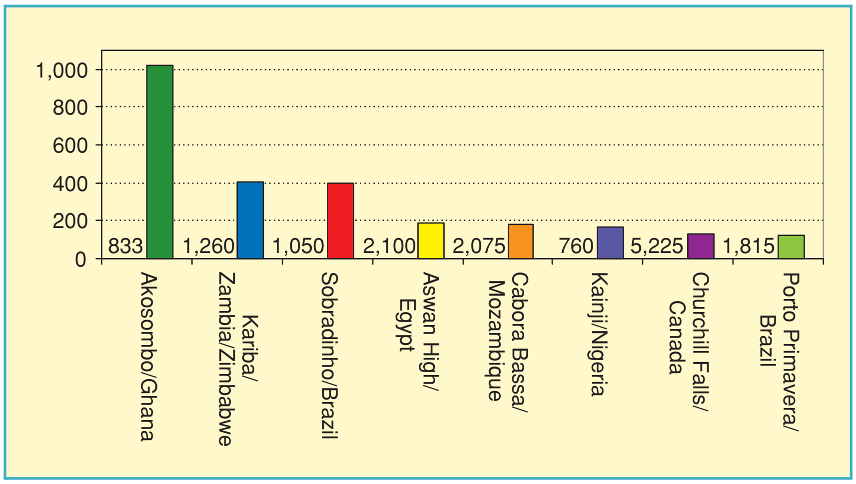


figure 10. Hectares flooded per installed megawatts in large hydro plants worldwide (installed capacity in megawatts also indicated).

forests. International actions have been organized in the United States and Europe to defend the rain forest and attack any action by the different countries, particularly Brazil, to use it for economic development, be it soy farms and cattle ranches or hydroelectric plants. The argument is often to defend indigenous populations and the rain forest's biodiversity treasure, or even the oxygen that the forest provides for the world, arguing that it is the "Earth's lungs."

International nongovernmental organizations are working to stop plans for 70 new hydro dams in the Amazon region, including the Madeira and Xingu rivers. The Madeira project was described above. Another plant, Belo Monte, is being planned in the Xingu river, with 11 GW costing around US$7 billion.

Two basic measures to identify the impact of large hydro dams are the land area flooded and the number of people displaced. Table 7 shows these figures for major hydro plants in South America. South American hydroelectric plants do not rank high worldwide in relation to people displaced per megawatt installed, as Figure 9 illustrates, where a Brazilian plant only ranks seventh in plants over 700 MW. However, their presence in the ranking of area flooded is larger,

table 7. Land area flooded and people displaced in large hydropower projects in South America (source: *Good Dams and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects*, The World Bank, 2003).

Project	Country	Installed Capacity (MW)	Reservoir Area (hectares)	People Displaced
Itaipu	Brazil/Paraguay	12,600	135,000	59,000
Gurí Complex	Venezuela	10,300	426,000	1,500
Kararao/Belo Monte	Brazil	8,381	116,000	
Tucurui	Brazil	3,980	243,000	30,000
Ilha Solteira	Brazil	3,200	125,700	6,150
Yacyreta	Argentina/Paraguay	3,100	165,000	50,000
Salto Grande	Argentina/Uruguay	1,890	78,300	
Porto Primavera	Brazil	1,815	225,000	15,000
Sobradinho	Brazil	1,050	415,000	65,000
Guavio	Colombia	1,000	1,530	4,959
Betania	Colombia	510	7,370	544
Pehuenche	Chile	500	400	
Pangue	Chile	450	500	50
Urra I	Colombia	340	7,400	6,200
Salvajina	Colombia	270	2,030	3,272
Balbina	Brazil	250	236,000	1,000

> Brazil still has an undeveloped hydro potential of more than 150 GW, most of which is located in the environmentally sensitive Amazon region.

with two Brazilian plants in third and eighth places, as shown in Figure 10.

An Emblematic Case of Hydroelectric and Environmental Controversy: Aysén

New hydro plants are not questioned as much because of their size but because of their geographical impact. A project that is becoming an icon in the region is the Aysén project in Chile, even with the *New York Times* taking position in its editorial. The hydroelectric power stations will be located in the Baker and Pascua rivers, located in the extreme south of Chile in the Aysén region. The investor group has announced that the project consists of the construction, from 2009 until 2022, of five hydroelectric power plants with a joint installed capacity of 2,750 MW. In addition, the project involves the construction of a dc transmission line of 2,000 km to unite the power stations directly to Santiago, the capital of Chile and the largest demand center. The project involves an investment superior to US$4,000 million. These power plants will imply the access to energy of clean production in great volumes, energy of a domestic origin that will contribute to reduce the foreign fuel dependency, which is a long-desired objective in Chile. A major advantage of these plants is that, due to their latitude, the hydrology of both rivers is complementary to the rivers that currently feed the main Chilean interconnected system. Thus, during periods of extreme drought in the central zone, the Baker and Pascua rivers have been wetter than the average for the zone. The interannual variation of the river basins in the main interconnected system is 21%, which will be reduced to 12% when adding the Baker and Pascua rivers.

These projects will also imply, during their construction, an important economic contribution to the zones where they will be located. It is important also to recognize that these power stations will be inserted in zones of great natural beauty not yet touched by man (Figure 11). The construction without a doubt will cause alterations to the ecosystems of the zone, where the total flooded surface will be 5,910 ha, corresponding to 2 ha per megawatt, much lower than those illustrated in Figure 8.

It is clear from the important resources that are being mobilized to fight the construction of the Aysén project that it has become a strategic objective for environmentalists worldwide, and particularly from the United States. The Natural Resources Defense Council, International Rivers Network, and Forest Ethics are a few of the U.S. environmental groups that have jointly orchestrated an onerous campaign for this purpose. The discussion is heating up before the required environmental studies are finished. It has also become a source of political fighting with government ministers being questioned for taking one position or the other. Unfortunately, the attackers of these projects offer an alternative that is not a way out for the country. As coal arises as the only economic alternative in the mid term, and nuclear energy for the long term, neither one attractive for environmentalists, they offer renewable energies like wind or solar as the path. This is a fallacy, as neither of them is economical enough today to supply the large volumes of energy a developing country like Chile needs. Even the United States supplies its consumers with no more than 2% from renewable sources (solar, wind, geothermal, biomass, and waste), hydroelectricity excluded, which contributes 10%. U.S. groups, the *New York Times* included, are in fact requesting the country to take an expensive path that their own country did not choose. No economic external support is offered either if that path is taken.

Similar international outroars have taken place worldwide in relation to deforestation for energy in the Amazon region.

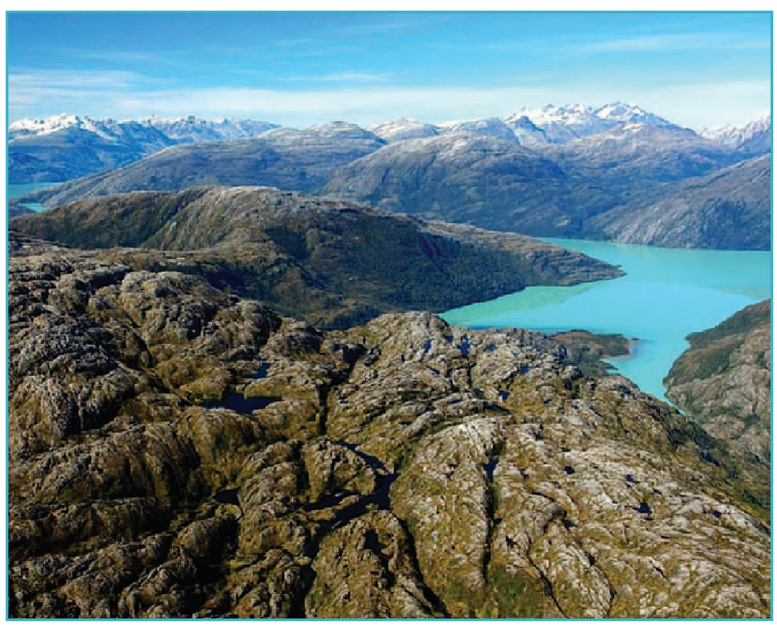


figure 11. The Aysén landscape (photo reused with permission from Hydoaysen, www.hidroaysen.cl).

> Given that water is often considered a public natural resource, governments require concessions for the development of hydro projects, which often take long periods in being approved.

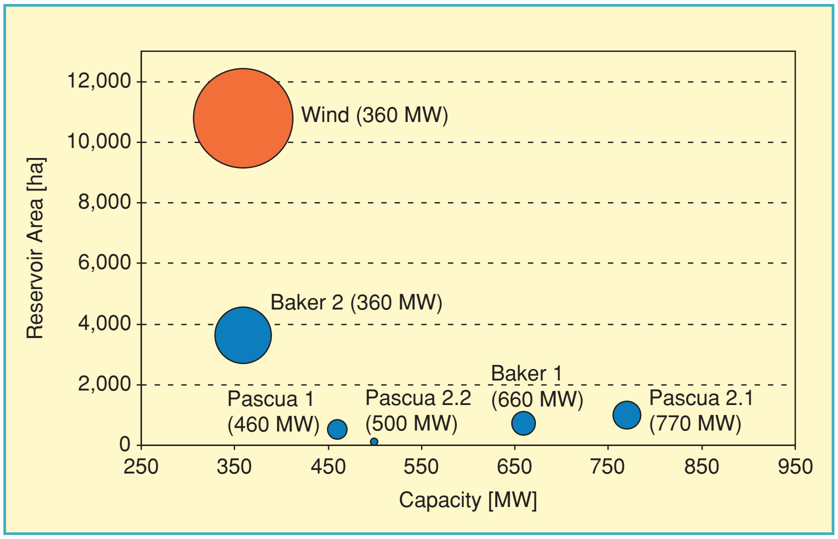


figure 12. Land impact of hydro and wind plants.

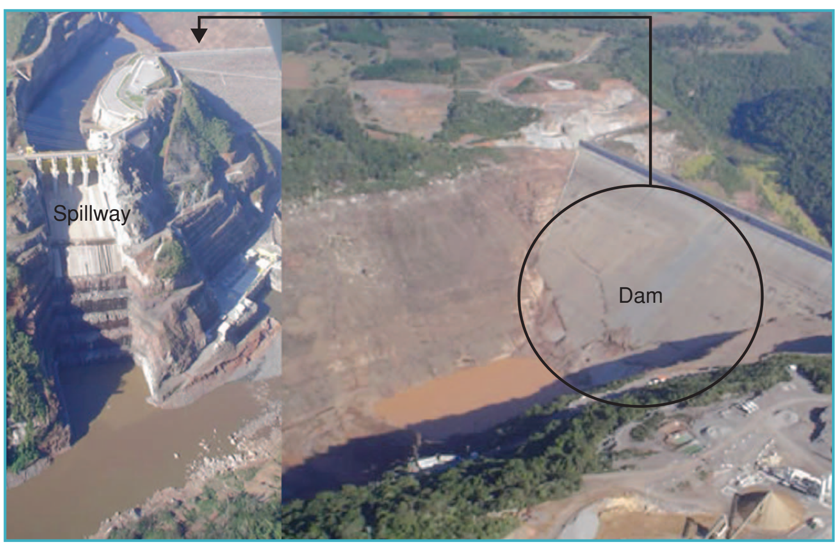


figure 13. Aerial photographs of Campos Novos (source: Kathia Vasconcellos, NAT/Brasil).

Energy in that region is extremely expensive if oil derivates are used, so that locals have often gone to wood usage, with significant negative environmental consequences. The resources of the tropical rain forests could be secured with the development of hydropower generation projects, but the financial requirements are enormous.

Finally, it must be emphasized that opposition to the Aysén project does not indicate that renewable projects also have an impact on land, as compared in Figure 12, where the land impact of the Aysén hydro plants is compared to that of a medium-size wind park.

Without doubt the development that finally achieves the Aysén project will be a test of maturity for the Chilean society and its energy regulatory model. As never before, Chile will need a long-term vision that oversees far beyond the short-term particular interests or necessities. The benefits or costs that come with the construction of these hydraulic power plants will remain in time for several generations of Chileans to come.

Another Case of Environmental Controversy: Campos Novos

Another case commonly mentioned as environmentally complex refers to the US$700 million, 880-MW Campos Novos dam, located in southern Brazil. It is the world's third tallest dam built with a concrete face filled in with rock. This design has become increasingly common in recent years for very high dams. This hydro plant had a serious accident in its construction. After the construction of the dam had been concluded and the reservoir started filling up (2006), it slowly began leaking. It was found out that a faulty diversion tunnel gate collapsed. Water in the reservoir had to be released from the 202-m tall structure (the reservoir emptied, falling over 53 m in a few days). That water raced down the parched riverbed and into the reservoir of a dam downstream that was almost empty due to a severe regional drought. Aerial photographs (Figure 13) showed major cracks at the base of the dam, suggesting severe damage. The damage was fixed by constructors about one year later, with a delay in the commercial operation of the plant. A common misunderstanding in this episode refers to a blame posed on the environmental licensing process. The responsibility on this episode was felt to lie on the project construction itself as well as on the (lack of) inspection on the civil work. Environmental impacts of the project were evaluated without major problems by the environmental body. On the other hand, the accident observed does not have to do with environmental issues but surely brings on uncertainty on the environmental process with respect to the security of dams.

A Case of Environmental Success: Itapebi Dam, Brazil

The Itapebi is a 450-MW hydro plant located in the lower level of the Jequetinhonha river. The plant was built by Iberdrola, and it is run-of-the-river (with a reservoir of 6,200 ha) and started commissioning in 2003. It affects a region that has already been environmentally altered. The largest part of the flooded area is composed by pasture. Besides the usual impacts of hydro plants, the impact on the population living in the city of Salto Divisa, located at the end of the reservoir, must be highlighted. About 100 families were affected by the construction of the dam and they had to be reallocated for a wholly new planned borough built to accommodate them. This case can be considered a success. The complete environmental due diligence was carried out with an active participation of the affected communities. For example, the location of the new borough was chosen jointly between these affected communities and local authorities. Community structures such as school, recreation areas, urban equipment, etc., were also jointly chosen. A new station for draining and sewer treatment with the capacity to remove the entire sewer from the city of Salto Divisa was constructed. Finally, the project received the operation license without any additional environmental demand. It has been operating as originally planned and recently received an award for its work on the reallocation of the local population.

The Main Challenges for South America

Hydroelectricity produces worldwide about 2,600 TWh/year of electricity; but there are economically viable potential resources for twice as much; 90% of this potential is in the developing world, and much of it in South America.

The primary challenge faced by South American countries is to ensure sufficient capacity and investment to serve reliably their growing economies. Social and environmental impacts are an inherent part of electric markets and cannot be swept under the rug. The concern with the environment is absolutely legitimate but in some cases has resulted in the construction of more expensive equipment, such as oil-fired plants. The interest of local population obviously should be considered and respected, but the also legitimate interest of the society to have energy at the lowest possible cost should not be ignored. The most fundamental challenge is to allow the society to know through lively participation in the studies of the licensing process of hydro and thermal plants that there is no competitive energy without environmental impact. A policy of zero environmental impact has obviously a very high economic cost and the society must be aware about this tradeoff, so that the best choice to conciliate environment, economic growth, and social justice can be chosen.

The developed world must be cautious about pressing the undeveloped world for standards beyond their economic possibilities that would limit their actions to reduce poverty. Those environmental groups that oppose the hydro development in the region live in countries with much higher energy consumption levels and higher impact in the environment. Latin America, with 8% of the world population. contributed only 5.5% of the world's total 2002 CO_2 emissions while the United States contributed almost 34% with 4.5% of the world population. Emissions of CO_2 from power generation in the region are very low if compared worldwide, and that is mainly due to the high hydropower component in electricity generation.

For Further Reading

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