Developing **countries**

& Global **climate change**

Electric Power Options in Argentina

Prepared for the Pew Center on Global Climate Change

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Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

The Republic of Argentina is positioning itself at the forefront of the climate change debate among non-Annex I countries. It initiated market reforms in the early 1990s that made the economy more efficient while providing mixed, but on balance, positive, environmental results. In 1999, Argentina set a voluntary target to lower greenhouse gas emissions to between 2 and 10 percent below the projected baseline emissions for 2012. Additional policy choices that it makes to improve economic growth and lower emissions could serve as important examples for others facing similar challenges.

Argentina's electric power demand is expected to more than triple over the next 15 years, expanding by 6 percent a year. Emissions of greenhouse gases, however, do not have to increase at the same rate. The successful implementation of the market-based reforms and increased competition in power generation could continue to play an important role in the near future in lowering emissions from projected levels. This report describes the context for new investments in this sector and identifies principal trends under three alternative policy scenarios. The report finds that:

- Under a business-as-usual scenario, electric power generating capacity, primarily from large natural gas turbines and combined-cycle plants, is expected to increase 170 percent, growing from 17 gigawatts in 1995 to 46 gigawatts in 2015, at a cost of $26 billion. Carbon dioxide emissions are expected to nearly triple, growing from 4.8 million tons in 1995 to 14 million tons in 2015.
- Natural gas combined-cycle plants have become the most competitive alternative over hydro and nuclear power, and are currently the main choice of private sector power developers in Argentina. These plants produce less than half the greenhouse gas emissions of similar coal-fired plants, and have essentially no emissions of sulfur dioxide and particulates. If low-cost natural gas resources become restricted due to shortages, however, investments would flow to nuclear and coal-fired power plants. This outcome could raise total costs to nearly $45 billion, although greenhouse gas emissions would remain essentially unchanged due to the offsetting characteristics of nuclear and coal-fired plants.
- Adopting policies that favor renewable energy sources and nuclear power cost $32 billion by 2015 — about 23 percent more than the baseline — and would decrease carbon dioxide emissions from 14 million tons in the baseline to 11 million tons in 2015.
- Increasing energy efficiency by end-users and demand-side management would reduce total costs by $6.3 billion and carbon dioxide, sulfur dioxide and nitrogen oxide emissions would all decline 20 percent compared to the baseline.

Developing Countries and Global Climate Change: Electric Power Options in Argentina is the last of a series commissioned by the Pew Center on Global Climate Change to examine the electric power sector in developing countries, including four other case studies in Brazil, China, India, and Korea.

The Pew Center was established in 1998 by the Pew Charitable Trusts to bring a new cooperative approach and critical scientific, economic, and technological expertise to the global climate change debate. We believe that climate change is serious business, and only through a better understanding of circumstances in individual countries can we hope to arrive at a serious response.

Executive Summary

Argentina boasts a distinctly market-oriented electricity generating system. Power sector reforms have progressed further than in most nations, including the United States, and hold important lessons for climate policy. Competition in Argentina has favored natural gas over hydropower and nuclear power, thus increasing emissions at the margin, but has also virtually eliminated coal from the market despite its abundance. While competition has lowered the price of electricity, and thereby increased demand, it has done so by reducing inefficiency that in turn reduced carbon emissions. Privatization and competition in the energy sectors of Argentina and several other South American countries is influencing power reform across the continent.

There are numerous trends driving growth in energy demand. The electric power sector consumes about 22 percent of Argentina's total energy supply. Today, overall energy demand growth is driven by transportation energy use, which increased by half since 1990. The residential sector grew by more than one-quarter over the same period. Abundant natural gas provides one-third of total energy use and continues to increase market share. Transportation and agriculture still rely on petroleum, but industry, commercial buildings, and residences have increasingly switched to direct use of natural gas. Argentina also exports petroleum and natural gas, currently about one-eighth of total production. The country has a relatively strong energy conservation and efficiency program focusing on cogeneration of heat and power, energy appliance labeling, and efficient lighting.

Argentina is emerging as a leader in environmental issues. In October 1999, Argentina announced a voluntary effort to restrict greenhouse gas emissions within a range of 2 to 10 percent below the projected baseline level during 2008-2012. Argentina became the first developing country under the United Nations Framework Convention on Climate Change to establish a voluntary target. The impact of this action on other developing countries is still not clear, but it could catalyze some of the relatively small emitters to take on similar voluntary targets.

While Argentinian power demand is expected to continue to grow rapidly at over 6 percent each year, growth will not necessarily mean a corresponding increase in emissions. Carbon emissions in particular can be offset by improving energy conversion efficiencies, promoting carbon-friendly renewable energy sources, and introducing policies such as the Clean Development Mechanism (CDM) or domestic actions to change fuel-choice decisions. This study explores these and other issues in four scenarios including a baseline of continuing policies and trends, an emissions mitigation case, a natural gas shortage scenario, and a scenario of end-use efficiency improvements.

The scenarios provided the following results:

Baseline Scenario. This scenario, which assesses power supply and demand based on current trends and fuel availability, projects installed power generating capacity to grow from about 17 gigawatts[1] in 1995 to 46 gigawatts in 2015, an increase of 170 percent. The share of power provided by hydroelectric resources will fall from half of all generation in 1995 to about one-quarter, while nuclear power will drop from 10 percent of supply to only 3 percent in 2015. Gas-fired plants provided about 46 percent of power in 1995, a share that will grow to 72 percent over the next decade-and-a-half. Total cost in the baseline scenario from 1995 to 2015, including discounted capital, operations and maintenance, and fuel components, is estimated to be $26 billion. Carbon dioxide emissions from the power sector grow from 4.8 million tons of carbon in 1995 to an estimated 14 million tons in 2015, almost tripling.

Emissions Mitigation Scenario. This scenario tests the impact of policies to reduce the capital cost of power supply in order to favor non-carbon energy sources such as hydropower and wind. The reduction in capital costs is simulated by lowering the discount rate from 12 percent in the base case to 5 percent, and would require an outright social or environmental subsidy. This approach might simulate the use of domestic subsidies and soft loans or investments from the CDM. In this scenario, hydropower's share continues to fall but only to 39 percent, while nuclear's share drops to 4 percent. Power supply grows 7 percent more than in the baseline, thus requiring a total of almost 49 gigawatts of capacity in 2015. The value of the "subsidy" would amount to $6 billion over the 20-year period as total costs increase by 23 percent to $32 billion. Carbon dioxide emissions are around 11 million tons, or one-fifth less than baseline levels.

Natural Gas Shortage Scenario. This scenario assumes that low-cost natural gas resources are restricted — compared to the baseline scenario — for use in the power sector starting in 2005. Methodologically, the scenario applies the 12 percent discount rate used in the baseline but severely constrains gas supply to reflect the assumed resource depletion. Consequently, the least-cost model simulation predicts investment flowing to nuclear and coal-fired power stations. Total power capacity reaches 48 gigawatts, 4 percent above the baseline, although actual power generation remains the same. Nuclear power's share in generation rises dramatically to over 15 gigawatts by 2015. The scenario also applies environmental externalities to coal use, and this accounts for the marked increase in nuclear power. Power demand would exceed 181 terawatt-hours, compared to roughly 55 terawatt-hours today. Total costs would rise to nearly $45 billion, over 70 percent higher than the baseline. Carbon emissions would decline by 2 percent, but sulfur dioxide and particulate emissions would increase dramatically due to the increased use of coal-burning power plants. The likelihood of a natural gas shortage this severe is remote so the scenario results should be viewed as an upper-end outcome.

Efficiency Scenario. This scenario tests the effect of demand-side energy-efficiency policies, including strengthening standards for appliances and buildings, increasing competition in energy-using equipment by liberalizing trade, and providing informational or financial assistance to industrial consumers. Efficiency is assumed to reduce energy use in the buildings sector by 9 percent and by 7 percent in the industrial sector by 2015 compared to the baseline. Industrial cogeneration plays a significant role in this scenario. Total power costs are $6.3 billion lower than in the baseline and more than 50 percent below the natural gas shortage scenario. Carbon dioxide, sulfur dioxide, particulate, and nitrogen oxide emissions would all decline by approximately 20 percent compared to the baseline.

Several of the above scenarios raise questions about implementation costs. While the CDM might be one option in the mitigation scenario, this study makes no claim to describe how such a mechanism could be implemented to achieve the major shift in private discount rates. The efficiency scenario, similarly, depends on policies with uncertain effectiveness and does not indicate the level of effort that would be required. Achieving the potential revealed in these scenarios will depend on major new policy initiatives and on policy research to describe an effective set of policies that decision-makers can adopt.

The impact of increased use of market forces on the environment and specifically on greenhouse gas emissions in Argentina has been mixed but, on balance, positive. While hydropower and nuclear are seriously disadvantaged by market economics, gas is highly favored over coal. Because the environmental and social considerations of hydropower, nuclear, and coal are substantial, it cannot be said that the market produces an unfavorable environmental result. More to the point, the market in Argentina has provided a prudent path for energy development and environmental protection, one that sensible public policy can build on to further protect Argentina's environment and the global climate.

I. Argentina's Energy Picture

A. The Role of Energy in Argentina's Economy

Argentina's economy grew rapidly during the 1990s, but destabilizing periods of inflation and recession have plagued the nation over the past two decades. The country began to establish free market reforms in the late 1980s and early 1990s, and has now become a leading economic and political power in South America. The Asian financial crisis reached Argentina in late 1998, sparking high interest rates and a decline in exports, but the worst appears to be over.

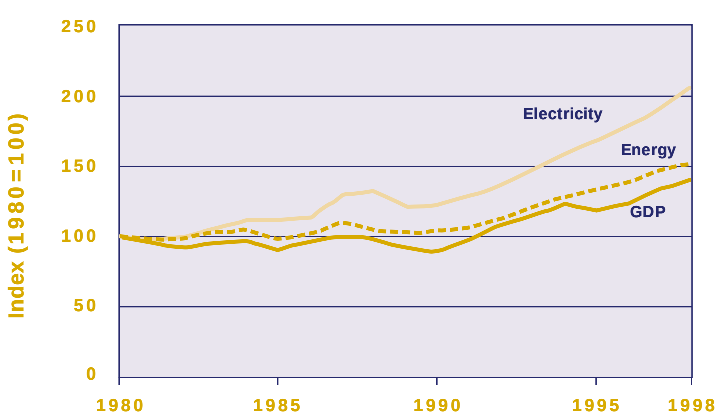
The relationship between energy consumption and economic growth has varied with the general health of the economy. (See Figure 1.) During periods of economic instability and high inflation (1985 and 1990, for example), growth in energy and electric power consumption exceeded that in the economy. Since 1990, however, consistent economic growth has been accompanied by moderate, steady growth in energy and electricity demand. Argentina is one of the few developing countries whose energy consumption grows at approximately the same rate as its economy.[2]

Argentina has extensive petroleum, natural gas, and hydroelectric energy resources, especially relative to its population. Natural gas reserves have doubled since the late 1970s, although low prices have recently reduced the incentives for developers to explore and develop additional gas fields. Oil resources are less plentiful than either natural gas or hydropower, but proven reserves have remained stable over the

Figure 1

Energy and Electricity Consumption

in Argentina's Economy



Source: Energy Secretariat, *Energy Balances,* 1999.

past two decades. Argentina has continuously reduced its dependence on imported petroleum by substituting natural gas, hydroelectricity, and uranium. Many of Argentina's most favorable, large hydropower sites have already been developed, but rising costs and public opposition stand in the way of new plants being built. Coal — almost all of which is imported — is limited to that used in iron and steel production. Nuclear power plays a larger role in Argentina than any other South American country, but further development of the industry has stalled due to high costs and public opposition.

Argentina's 36 million people use about 2.4 exajoules of energy, roughly 2.5 percent of the U.S. total.[3] The nation's per capita use of electric power averages about 1,800 kilowatt-hours per year, one-seventh the U.S. level. Per capita consumption of energy and electric power will likely continue to rise roughly in tandem with income, at least until Argentinians achieve a standard of living comparable to that of industrialized countries.

Restructuring, privatization, and increased private and foreign investment have revitalized the energy industry, but not without creating additional concerns related to energy security and environmental protection. Foreign firms have invested on average over $2 billion annually since 1991 as a result of favorable policies and the prospects of regional energy integration occurring in the southern cone of South America.[4] In June 1999, Argentina's largest petroleum and gas company, Yacimientos Petrolíferos Fiscales (YPF), was taken over by Spain's Repsol, creating the world's tenth largest petroleum and gas company. There is also concern that the government might be less able to influence environmental issues, including climate change, now that many energy resources are in private hands.

Emissions of both local pollutants and greenhouse gas emissions are relatively low due to the heavy reliance on low- and no-carbon fuels. Most of Argentina's sulfur dioxide and particulate emissions come from coal use in the iron and steel industry and petroleum products in the transport sector. In 1995, carbon dioxide emissions from the power sector were also low at 4.8 million tons of carbon, or 89 grams of carbon per kilowatt-hour of power produced.[5]

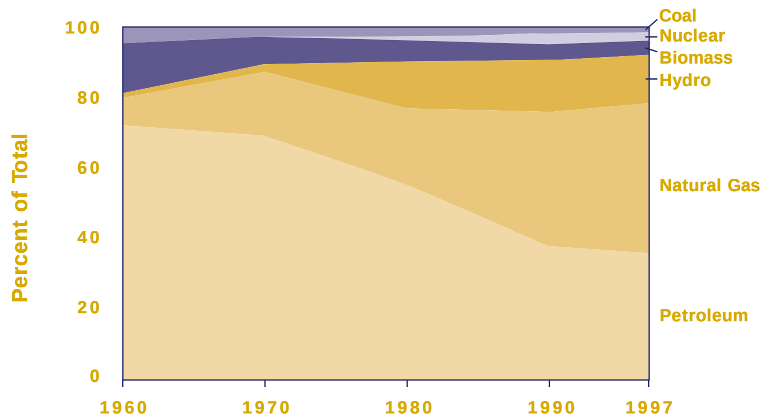
Natural gas use has grown rapidly and now constitutes almost 45 percent of Argentina's primary energy supply, twice the share in 1980. (See Figure 2.) After large natural gas deposits were discovered in the Comahue region in 1978, gas gained market share in both power generation and thermal applications. Growth in the use of natural gas has come at the expense of petroleum due to the difference in price.

Hydroelectric power supplies over 10 percent of total primary energy (and more than 45 percent of electric power generation), while coal and nuclear play minimal roles. Argentina also significantly reduced its use of biomass fuels, yet this form of renewables still provides more energy than either coal or nuclear.

Natural gas production associated with oil drilling grew more rapidly than gas consumption during the 1970s. About one-third of the gas produced was vented in 1978, but pipeline expansion and gas production independent of petroleum reduced venting steadily to about 5 percent today.[6] Crude oil production has grown at almost 8 percent per year, or 50 percent overall, during the past six years.[7] Recently, petroleum exports claimed 40 percent of Argentinian production.

Figure 2

Primary Energy Supply



Source: Energy Secretariat, *Energy Balances,* 1998.

Domestic production of petroleum products has remained practically unchanged since 1990 and product imports have increased 12 percent to satisfy increased demand associated with population and economic growth. Primary energy imports still account for less than 4 percent of total energy use, and mainly reflect natural gas imports from Bolivia and coking coal for the iron and steel industry. Exports of natural gas represent about 2 percent of domestic production. Since 1997, three pipelines have begun providing gas to Chile and new pipelines are being considered.

Industrial use accounts for about one-third of the country's energy consumption, a figure that had fallen slowly from 1970 through the early 1990s as the economy opened to trade. (See Figure 3.) Transportation's share has remained relatively constant at 35 percent, as has building's at 25 percent.

B. Supply and Demand in the Power Sector

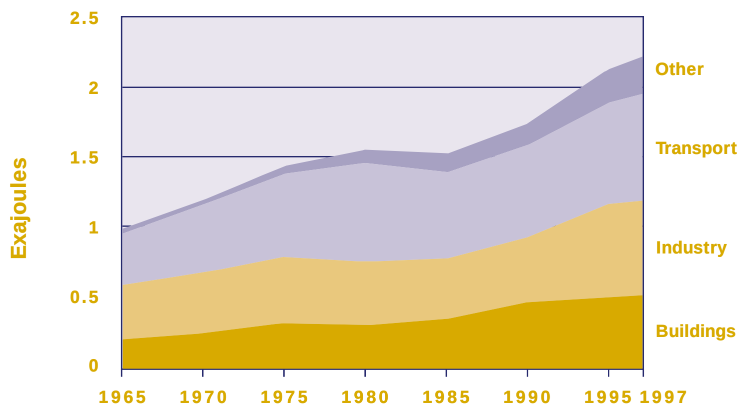
Over the past 30 years there has been a remarkable transformation in the fuels used to generate the electricity demanded by the growing economy.

Petroleum fueled less than 5 percent of power generation in 1997, down dramatically from its dominant role in the 1960s and 1970s. (See Figure 4.) Natural gas is now responsible for almost half of all the electricity produced in Argentina. The low price of natural gas relative to petroleum restrains use of the latter. Hydropower provides most of the rest and nuclear accounts for about 10 percent. Despite relatively abundant coal reserves, Argentina does not rely on this fuel for more than 1 percent of its power generation due to high economic and environmental costs.

The expected need for expanding natural gas production in the future, either for domestic market supply or for export, could be reduced if gas industry efficiency were further improved. In 1997, losses (mainly venting) and consumption (mainly re-injection) in the gas production sector accounted for about one-fifth of natural gas supply, an amount equal to three-quarters of all gas used in power plants in the country. Over 30 percent of such losses were due to

Figure 3

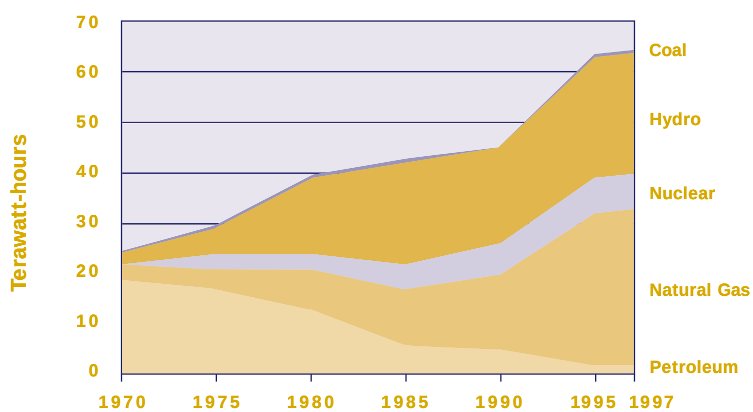
Energy Consumption by Sector



Source: Energy Secretariat, *Energy Balances,* 1998.

Figure 4

Electricity Generation by Fuel, 1970-1997



Source: International Energy Agency, 1999.

gas venting in gas fields. Making use of gas now vented would permit expansion of supply without necessarily increasing production. However, improving efficiency in the gas industry depends on production conditions and the effectiveness of regulations penalizing the waste of gas.

Domestic wholesale energy prices have declined significantly over the past few years, largely due to competition. Retail electricity rates, traditionally set by local authorities, varied widely even for the same category of consumers. More recently, retail market competition has reduced these disparities. While competition has been beneficial to consumers, the resulting price decrease may discourage the efficient end-use of electricity by large consumers.

Energy-efficiency and emissions mitigation programs have been implemented against this background, including substitution of compressed natural gas in the transport sector, promotion of cogeneration, and promotion of rational energy use in buildings and industry. The cogeneration and energy rationalization programs are based on market mechanisms. Lower prices and direct service to large industrial consumers have nevertheless reduced the practice of cogeneration. Despite these obstacles, some cogenerators have entered the market in recent years.

Energy-saving programs during the 1990s were less effective due to falling prices at the wholesale level and the restructuring of the power supply industry. Energy conservation efforts now are focused on making information available to consumers, especially by labeling electric appliances for energy consumption and opening the appliance market to foreign manufacturers. Competition from abroad is forcing local manufacturers to adopt higher efficiency levels.

II. Current Dynamics

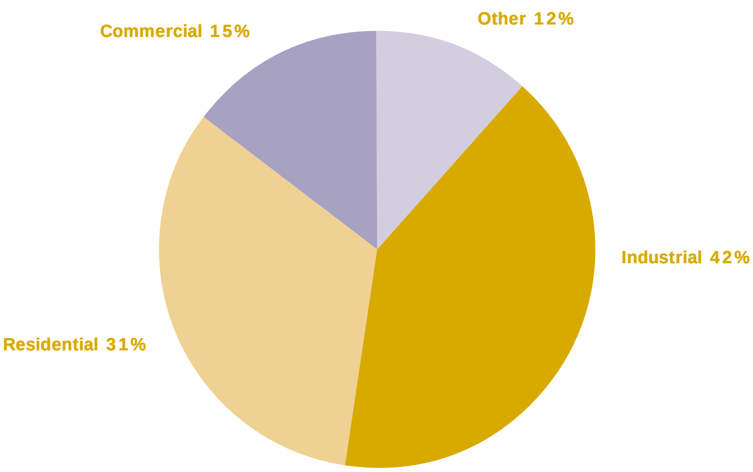
A. Evolution of Argentina's Power Sector

Demand for electricity during the 1990s has grown faster than 7 percent per year, resulting in a doubling of consumption in only 10 years. Power demand recently reached 62 terawatt-hours with a peak load of just under 11 gigawatts. Meeting peak load today, however, requires only about 60 percent of installed system capacity, indicating substantial over-capacity. The industrial and buildings (commercial and residential) sectors each account for over 40 percent of power demand, though power use in the buildings sector is growing more rapidly than in other sectors. (See Figure 5.)

Hydroelectric, natural gas, and nuclear plants supply almost all of Argentina's power needs. Power supply by energy source varies with rainfall. When rainfall is plentiful, hydropower is used more, thereby reducing the need for other power generation sources. Hydroelectric power contributed roughly 44 percent of electric supply in 1994, 1995, and 1997, but only 37 percent in 1996. Nuclear power provides about 10 percent of generated power, while thermal systems, mainly gas-fired steam plants, provide most of the rest. Government policies during the 1960s aiming to build large hydroelectric dams and nuclear plants began to change the structure of power generation by 1975 when the first of these plants were put in service.[8] However, with power sector reform, advanced combined-cycle gas turbine systems now provide almost 3,000 megawatts of power, going from zero to almost 13 percent of power supply in just a few years.

Figure 5

Electricity Demand by Sector, 1997



Source: Energy Secretariat, "Balances Energéticos, 1965 al 1997."

Argentina also abounds in renewable sources of energy, such as wind, photovoltaic, micro and mini hydroelectric turbines, geothermal, and bio-electricity. The use of wind farms and photovoltaic technology has increased during recent years. Wind has been promoted by electric cooperatives, mainly in the southern region and in areas isolated from the federal interconnection (grid) system. Wind energy is widely used in rural areas for pumping drinking water for cattle. Wind turbines for on-site power generation in remote rural areas without grid connection are less common.[9] Only recently have wind turbines been incorporated in public-service facilities in some areas, especially Patagonia, the far southern section of the country. Electricity cooperatives have installed about 12 megawatts in wind turbines, notwithstanding the fact that the cost of the energy produced in 1997 was more than double the spot price of power.[10]

Photovoltaic cells for power generation have also been installed in remote locations. Uses range from the electrification of rural schools to communications to waterway navigation markers. The present market for photovoltaic cells approaches 1 megawatt per year, a small fraction of the total energy supply. Capital costs for both wind and photovoltaic equipment has fallen sharply in recent years due to technological advances, contributing to their more widespread use in Argentina. At present, the price of wind stations ranges from $800-1,000 per kilowatt, while that of photovoltaic modules dropped to less than $5,000 per kilowatt. Despite the lower capital costs, total costs are still generally higher than natural gas-fired power because the availability of renewable sources of energy is low.

There are geothermal energy sources in the province of Neuquén and in the south of the Buenos Aires province, although they lack potential for electricity generation, at least with the degree of research developed to date. Biomass-fired power generation has been limited to agriculture and industrial co-generation including sugar mills and petroleum plants, which use industrial waste streams. Progress on the use of small hydropower stations has occurred in only a few provinces.

B. Power Sector Reform

Pressure for power sector reform developed during the 1980s when the electric supply system fell into crisis. Financial constraints limited system expansion and maintenance, while scant rainfall, technical flaws in the Chocón dam, and damage to fuel elements at the Atucha nuclear power station all combined to weaken electric service reliability.

Power sector reform began in 1990 with a new scheme of regulation and organization inspired by British and Chilean experiences.[11] Reform was intended to achieve better and cheaper service through competition. The government's goals were maximum separation of generation, transmission, and distribution functions, as well as the introduction of competition in generation. The state put public generating assets up for sale, but asset prices were set far below the replacement values and provided minimal revenues for the government. The government even agreed to accept prior debt of privatized public companies.

General supervision and regulation of the electricity and gas industries is in the hands of national regulatory bodies set up by statute as independent agencies within the scope of the Energy Secretariat. Their duties include enforcement of concession contracts, prevention of anti-competitive practices, public hearings, and protecting the environment and public safety.

Since major restructuring in 1992, about 6,900 megawatts of generating capacity has been installed, but two-thirds came from hydropower plants already under construction and financed with public funds. Private investors did add 2,400 megawatts of gas-fired capacity, substantially altering system economics and supply. These new plants provide operational advantages relative to the existing fossil-fueled power plants. Advantages include year-round availability and higher thermal efficiency, increasing the latter from an average of 34 percent to over 45 percent in new stations.

The wholesale electricity market is managed by the Wholesale Electricity Market Managing Company (CAMMESA). The company plans the operation of the interconnected system for six-month seasonal periods to meet the expected demand with a reserve agreed between all parties. The company also dispatches power plants using least-cost accounting.

The retail market was also divided into a regulated segment and another segment open to competition among suppliers. The former guarantees a monopoly to distributors granted concessions, but they have the obligation to supply any required demand under the terms of the concession contract. The competitive segment allows retail consumers to chose their supplier based on a range of costs and services offered.

In addition to business units set up for generation, six transmission companies were established — one for extra-high voltage and five for regional transmission. Two additional companies recently entered the market as independent transmitters operating on the extra-high voltage grid associated with the Yacyretá hydropower station. Twenty-two power distributors were operating in 1995, excluding electricity cooperatives. Thirteen were private. The remaining nine were owned by the respective provincial states, although some of them were later privatized.

A significant result of reforms in the power sector has been a marked over-capacity in the system. This, in conjunction with competition, caused prices for power to fall rapidly. Wholesale power prices dropped from approximately 3.5 cents per kilowatt-hour in late 1993 to 2.5 cents in 1997.[12] In Argentina's interconnected power system, total installed capacity was over 18,000 megawatts in 1997 while peak load reached only 10,200 megawatts. Hydroelectric dams and gas-fired plants brought on-line in the early 1990s resulted in most of the over-capacity.

C. Environmental Issues in the Power Sector

The environmental record of the Argentinian power sector is mixed. Sulfur dioxide emissions have remained at the same level as in 1939 despite a ten-fold increase in thermal generation, due to replacement of coal with petroleum, gas, and hydropower. Similarly, particulate emissions have been reduced by five-sixths. (See Table B-1 in Appendix B.) Argentine Law 24065 (1991) sets maximum emission levels for thermal power plants. Carbon dioxide emissions, as stated earlier, are low due to the heavy reliance on low- and no-carbon fuels to generate power.

On the other hand, hydroelectric dams have displaced 45,000 persons, and significant (but unquantified) environmental impacts have been associated with the large dams.[13] Argentina's nuclear power stations are regulated based on standards recommended by the International Atomic Energy Agency, and no significant accidents have occurred, although present and future problems include nuclear waste storage and water pollution associated with uranium mining. Radioactive waste is currently stored in temporary pools on-site. No means of permanent disposal has yet been identified. Increased fish mortality due to uranium mining operations has been identified, though no quantitative information is available on the scope of this problem.

Argentina would not be required to impose restrictions on greenhouse gas emissions even if the Kyoto Protocol of the Framework Convention on Climate Change were to take effect. Nevertheless, Argentina possesses mitigation alternatives that may be beneficial to the nation and the global community. In late 1999, Argentina announced a voluntary target to reduce greenhouse gas emissions between 2 and 10 percent below the projected baseline emissions by 2012.[14] Argentina became the first non-Annex I country to set such a voluntary target.

III. Comparing Alternatives

A. Methodology and Baseline Assumptions

Alternative sources of power generation are evaluated in this section in four steps:

- Baseline power demand is chosen from among existing estimates.
- The annualized cost of power generation technologies, including capital, fuel, operations, and associated environmental costs, are estimated and converted to costs per kilowatt-hour.
- The demand projection and the various power supply cost estimates are incorporated into a linear programming model to determine the least-cost combination of technologies under different scenarios through 2015.[15]
- The results indicate increased or reduced economic cost compared to the baseline, along with changes in power plant capacity, utilization, and emissions. The authors draw conclusions from the results of these experiments.

The authors used a simple linear programming (LP) model to analyze the cost and environmental impacts of possible electric power futures.[16] (See Box 1.) This LP model is driven by a set of economic growth assumptions developed exogenously (outside of the model). The LP model selects the least-cost combination of technologies based on the details of costs, emissions, and other constraints defined by the modelers. For example, the authors can set limits on the amount of natural gas available in each region. The model then determines the least-cost set of power sources that will satisfy demand without violating the limit on fuel availability. Cost and performance details are assumed separately and are presented in Table 1. A flowchart of the model is provided in Appendix C.

This approach to modeling and analysis is not without drawbacks, but is considered to be the best available tool for use in the Argentinian power sector, especially for the relatively short time period considered. Macroeconomic general equilibrium modeling might have been a preferred analytical method but much of the rich technical details — essential in a study covering only 20 years — would have been lost. Optimization programs like this one poorly reflect the reality of consumer behavior. No model can fully account for investor preference, such as risk mitigation or financial guarantees, or ensure that energy security and diversity issues are addressed without input from the modeler. Some of the drawbacks noted in bottom-up models are at least partially offset by expert input from the country team modelers. It should be noted, however, that the costs used in this application of the least-cost analysis represent only one possible approach. They probably underestimate real mitigation costs because they do not include all barriers that must be overcome.

Box 1

A Guide to Linear Programming for Power Sector Analysis

Analysts use linear programming (LP) models to optimize combinations of inputs whose values are valid only over specific ranges. For example, power planners and electric utilities use LP models to determine the types of power plants required to meet least-cost power demand over time while meeting limitations in pollution emissions, energy sources, and manufacturing capacity. Models can help planners analyze alternatives, but non-quantitative factors must also be considered when designing real-life systems.

Researchers use two classes of models to analyze energy systems. LP models are often called “bottom-up” models because they contain detailed information about technology and costs. They have rich engineering detail and rely on user input to simulate broader economic conditions. “Top-down” models, on the other hand, begin from a higher level of economic reality by simulating the interaction of supply and demand in the main sectors of an economy. While top-down models have less detailed information about energy technologies and costs, they capture the reality of consumer behavior better than bottom-up models. Some models, like MARKAL-MACRO, try to integrate the economic reality of top-down models with the engineering detail of bottom-up models.

Researchers at Battelle created a generic LP model which each of the country teams in this study modified to analyze least-cost power options according to the conditions in their specific countries. The model can choose among 17 different types of power plants (coal, petroleum, natural gas, nuclear, hydroelectric, and renewable) to meet power demand. The model divides the country into as many as five regions to capture the variation in energy availability, fuel cost, and environmental limitations. Simulation begins with a base year (1995) and then determines the amount of new capacity from each type of power plant needed to meet demand over 5-year intervals.

After analysts enter technology and cost characteristics of the power plant options, the model calculates the levelized, or lifecycle, costs of power generation. Levelized cost analysis accounts for all the costs of building, fueling, operating, and controlling pollution from power systems and spreads them out over the economic life. In this way, the costs of delivering power to users from nuclear plants (with high construction and low fuel costs) can be compared directly with the costs of providing power from combined-cycle plants (low construction costs and high fuel costs). Analysts also enter the regional power demand over time. These values are calculated separately according to estimates of economic growth and power demand intensity.

The actual linear program will then find the minimum cost combination of power plants needed to meet the demand. Additional constraints can include emission caps on pollutants such as sulfur dioxide, manufacturing limitations for power generation equipment such as nuclear reactors, energy supply limitations such as hydropower capacity, and transmission line characteristics that limit the amount of power that can be sent from one region to another. For a given time period, the LP model will select the least-cost power source available and continue to use that technology until a constraint prevents its use. LP models need expert input to define when constraints are needed to simulate reality.

Economic and Social Drivers

Power demand forecasts are based on assumed changes in economic growth, energy costs, technological efficiency, population and demographics, and multiple secondary drivers. Frequent economic crises in Argentina over the last 20 years have left their mark on domestic energy demand. An otherwise general upward trend of energy demand growth was interrupted by the deep economic recessions of 1975, 1985, and 1989. Additionally, cyclic recessions between 1974 and 1990 also produced deep structural changes in the economy, which have become evident only in the last few years. In the early 1990s, the economy was characterized by price stability, foreign capital inflows, and reduced demand for public financing due to privatization; economic growth in the first half of the decade averaged 5.6 percent. By the end of 1994, however, financial imbalances deepened due to capital flight stemming from the Mexican financial crisis. This produced a recession that lasted until mid-1996. The reduction in domestic consumption during this period exceeded the drop in GDP, estimated at 4.4 percent in 1995 and 3.2 percent in the first quarter of 1996, due to a remarkable increase in exports. Although indicators have shown an upswing in production since mid-1996, domestic market recovery has been noticeably slower due to the loss of purchasing power caused by high unemployment.

The Southern Cone Common Market (MERCOSUR) agreement among Argentina, Brazil, Paraguay, and Uruguay should help stabilize the economy but will require coordinated economic policies among its members. Integration is intended to increase trade flows and competitiveness in relation to the rest of the world, and provide greater market complementarity, product quality, and reduced production costs. Argentina will likely remain oriented towards agriculture and mining to support growing demand for raw materials, foodstuffs, and agro-industrial goods in Asian nations. Rising exports would help check the region's growing external debt, but flexibility from lender nations and trading partners is essential to achieve this outcome. Argentina's trade policy will directly impact industrial energy efficiency by influencing manufacturing options and equipment use.

Future development prospects depend on Argentinian integration into the world economy.[17] The main niches for Argentine industry are restricted to food and agriculture. Regarding exports, the most significant are related to exploitation of liquid and gaseous minerals, metals, and commodities associated with natural or industrial resources, with a high share of natural resources as raw materials. That is, low value-added products will continue to dominate exports. It is to be expected that industrial exports will continue to diversify, although at a lower growth rate, except for the producers of industrial commodities — especially iron and steel, petrochemicals, and aluminum — and the automotive sector. Mining exports are expected to rise dramatically.

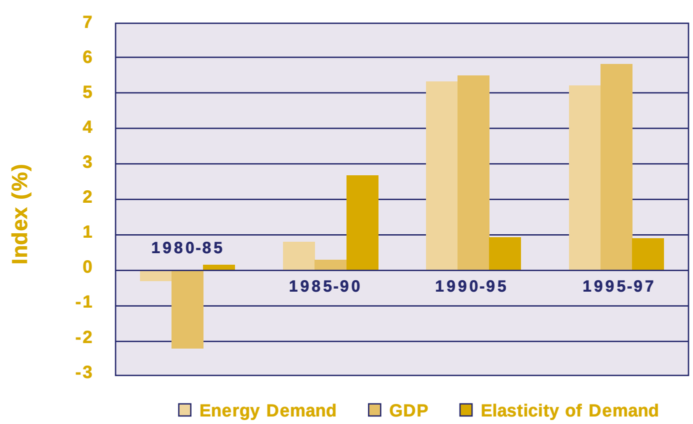
Achieving these export policies successfully would keep energy elasticity stable. Overall Argentinian energy demand has grown more slowly than the economy, averaging about 0.8 percent for every 1 percent increase in GDP during the 1990s. (See Figure 6.) This income elasticity of energy demand, however, rose to 1.4 percent during periods of severe economic stagnation, reflecting the inefficiencies created by economic recession and upheaval.

Energy markets will continue developing on the basis of privatized petroleum, gas, and power companies. The state will be restricted to establishing general policies and controlling operation of the system through regulation. It is assumed that prices for domestic petroleum products will follow international prices, expected to be $25.50 per barrel in 2015.[18] In the case of natural gas, the long-term price will tend to follow the prices of other substitute fuels (mainly petroleum products). As electricity expansion is based increasingly on thermal generation, the price of electric power will be linked to the natural gas market and, to a lesser degree, the evolution of international crude oil prices.

Figure 6

Growth in Energy Consumption

and the Economy



Source: Energy Secretariat, *Energy Balances,* 1998.

Policies governing the interconnection of domestic electricity transmission systems and the import and export of electricity over international transmission lines will affect development of Argentina's power system. Multiple benefits would result from the interconnection of domestic and international power transmission systems. Interconnection allows generators to share reserves, optimize dispatch, and capitalize on the supply and demand differences in different hydropower basins. This improves system efficiency and reliability while lowering costs. Importing large quantities of power can potentially lower energy security, but stronger trade ties can minimize these risks.

Electricity demand is also strongly tied to population growth. Official studies estimate that the total population will grow at a rate of 1.34 percent per year during the next decade. Thereafter, the rate is expected to decline slowly, reaching 1.28 percent by 2010. By 2015, Argentina's population is estimated to be 46.3 million, up from the present level of approximately 36 million.[19]

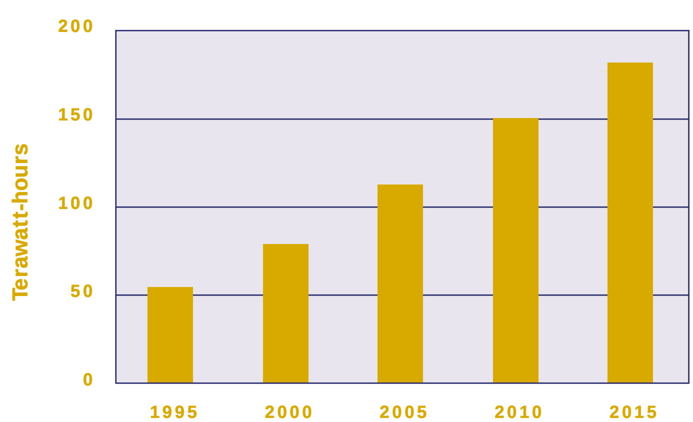
Electricity demand projections used in this study are based on the mid-level scenario of "Prospects for the Electricity Sector 1998," issued by the Argentine Energy Secretariat. The methodology used in the projections follows that of the Model for Analysis of Energy Demand (MAED), a module of the Energy Power Evaluation Program (ENPEP) package developed by the Argonne National Laboratory.[20] An econometric model was also used to further refine and calibrate electricity demand projections. The model's baseline year is initialized to 1995, with projections to 2000, 2005, 2010, and 2015.

Electricity demand scenarios were totaled for the nation from a regional analysis. Nationwide, power demand is projected to increase by 235 percent between 1995 and 2015, from 54 terawatt-hours to 181 terawatt-hours, or by 6.25 percent a year. (See Figure 7.) Needless to say, rapid growth in the power sector depends on a stable, growing economy.

Some of the most critical assumptions used in the modeling relate to natural gas pricing, availability, and technology. Natural gas power systems currently enjoy many advantages over coal, nuclear, and hydroelectric power in Argentina. Continued improvement of combined-cycle gas turbines have driven the efficiency of these units to 55 percent, compared to only 35 percent for steam-cycle gas or coal systems. (See Table 1.) Combined-cycle gas units can be installed and started quickly, further reducing generating costs. Moreover, the capital cost of

Figure 7

Forecast of Argentina's Baseline Power Demand



Source: Energy Secretariat, "Prospects for the Electricity Sector 1998."

these machines has declined dramatically. Natural gas itself is readily available, resulting in relatively low fuel prices.[21] Gas price projections follow from reference values published by CAMMESA in 1995 and correspond to $2.63, $2.76, $2.90 and $3.00 per gigajoule in 2000, 2005, 2010, and 2015.[22] Natural gas consumption for electricity exports of up to 5,000 megawatts to Brazil can be sustained without raising Argentinian prices.[23] Total natural gas reserves include proven reserves plus 50 percent of likely reserves, and are over 1.3 trillion cubic meters.

Table 1

Cost and Performance of Selected Technologies in 1997

Technology	Investment ($/kW)	O&M Cost ($/kW/year)	Efficiency (%)	Lead Time (years)
Small Steam Turbine (Natural Gas)	900	18	35	4
Large Steam Turbine (Natural Gas)	850	17	35	4
Pulverized Coal	800	20	35	4
Small Gas Turbine	450	10	20	1
Mid-Size Gas Turbine	380	10	30	1
Large Gas Turbine	310	12	34	1
Small Combined-Cycle	450	20	45	2
Large Combined-Cycle	400	18	53	2
Nuclear	1,800	30	34	5
Small Hydro	1,100	12	—	5
Large Hydro	1,300	15	—	7
Wind	950	13	—	1.5
Photovoltaic	4,800	7	8	1

Note: The efficiency of hydroelectric plants is not measured in the same way as other plants.

Sources: Bariloche Foundation, 1999; Energy Information Administration, 2000.

Steam and hydropower plants are at a disadvantage due to lower efficiencies or higher capital costs. The only hydroelectric projects considered in this exercise are those currently under construction. These include Pichi Picún Leufú, transferred to a private company in November, 1997 and expected to enter the system in 2000, and Yacyretá, located on the Paraná River on the Paraguayan border. The only nuclear project incorporated in this scenario is the Atucha II station, whose construction has been halted due to financial difficulties stemming from construction cost overruns. Over $700 million in additional investments will be required to complete the project. At a nominal capacity of 745 megawatts, the station is expected to start up in 2004.

B. Scenarios and Results

Baseline Scenario. The baseline scenario assumes that current economic trends persist, including continued opening of the economy to world trade, free competition in petroleum products, natural gas, and electricity, and privatized public services. A mid-range GDP scenario was chosen, with annual growth averaging 5.6, 4.8, and 4.6 percent per year during 2000-05, 2005-10, and 2010-15, respectively. The scenario also assumes sufficient availability of natural gas at low prices. (See Table B-2 in Appendix B.) The scenario applies a discount rate of 12 percent and existing environmental regulations, but no emission fees are assumed to be enforced.

Although no specific climate change policies were included in the baseline, the modeling does reflect a rise in energy efficiency and fuel substitution. This is a frozen dynamic efficiency scenario.[24] This scenario assumes replacement of old generating units with newer and more efficient models available in the market but not the introduction of new technologies unavailable in the base year. In other words, a trend is kept with respect to energy consumption and a constant improvement in efficiency that could be expected without any change in policy. In fact, the search for business opportunities within a competitive environment reveals opportunities for technological innovation, contributing to increased energy efficiency both in the supply and demand sectors.

Regulations set by the Energy Secretariat will reduce venting of natural gas at the wellhead, lowering the risk of gas shortages. Generation will increasingly use combined-cycle gas-fired technology with improving efficiency.[25] Improvements are also expected in distribution due to higher load factors and reduced line losses and theft.[26] Regarding the foreign trade of energy products, crude oil exports will tend to fall gradually after 2005, and Argentina could eventually become an importer should discovery efforts prove unsuccessful.

Older, less efficient power generating systems totaling more than 4,000 megawatts are being considered for retirement, particularly smaller units. Given the current overcapacity in Argentina's power system, these retirements would not harm the functioning of the system, but political barriers could stand in the way.

Coal price assumptions also reflect CAMMESA's 1995 reference value of $32.14 per ton. This value remains constant from 2000 to 2015 based on current prices and an assumption that fixed, long-term contracts can be arranged. Uranium prices are assumed to stay constant throughout this period corresponding to $0.005-0.0065 per kilowatt-hour depending on the region.

In this model, large gas turbines (100 megawatts and above) and combined-cycle plants (400 megawatts and above) are more cost competitive than other options. (See Table 2.) The lifecycle costs grow steadily over time due to a gradual decrease in utilization hours and the rise in natural gas prices. The only environmental costs included in these numbers are those corresponding to the decommissioning of nuclear power plants.

Table 2

Projected Levelized Costs of Selected Power Options in the Baseline (cents per kilowatt-hour)

	2000	2005	2010	2015
Large Turbine	3.9	4.0	4.2	4.6
Large Combined-cycle	3.5	3.2	3.4	4.0
Coal	5.8	5.8	5.8	5.8
Nuclear	6.2	6.2	6.5	6.8
Large Hydro	6.7	6.7	6.7	6.7

Results from the least-cost baseline scenario indicate that total installed power generating capacity will grow from over 17,000 megawatts in 1995 to over 46,000 in 2015. (See Table 7 and Figure 8.) Supply will shift from 46 percent gas-fired, 48 percent hydroelectric, and 6 percent nuclear to 72 percent gas, 25 percent hydroelectric, and 3 percent nuclear. (See Table B-3 in Appendix B for more detailed results.) Renewable energy sources such as wind and photovoltaic do not have a measurable impact on the least-cost outcome, although they will clearly become cheaper and more attractive in some regions if costs continue to decline. The best wind sources in Argentina are located in Patagonia, far from any large city or demand center. This increases costs and explains why wind power isn't a part of the least-cost solution in any of the scenarios.

Discounted capital, operations and maintenance, and fuel costs will total $26 billion. Carbon dioxide emissions from the power sector will grow to 14 million tons of carbon in 2015, up from 4.8 million tons in 1995, a three-fold increase. Under this scenario, Argentina's power sector would consume almost 23 billion cubic meters of natural gas in 2015, nearly three times as much as in 1997.[27]

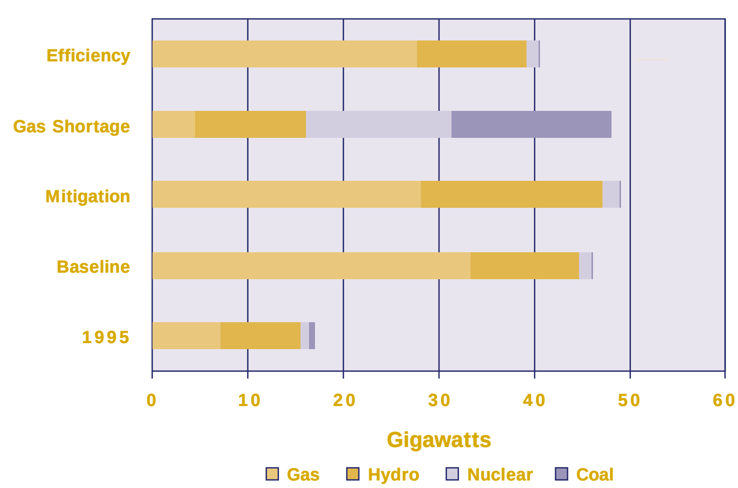
Emissions Mitigation Scenario. The mitigation scenario assumes the implementation of policies to avoid greenhouse gas emissions. The organization of energy industries and their reform priorities would mimic the baseline scenario, although strategies to develop business would adapt to official climate change mitigation policies. Power demand is assumed to remain the same as in the baseline. This assumption could be overstated in reality if the type of policy created to mitigate emissions results in significantly higher energy prices. Additionally, this scenario does not simulate Argentina's voluntary target to lower emissions to between 2 and 10 percent below the baseline level in 2012. The impact is minimal, however, since most of the target's reductions will likely come from sectors other than electric power.

The mitigation scenario estimates substitution of natural gas by hydroelectric and nuclear energy, both carbon-free sources of electric power.[28] These measures are implemented in the model by reducing the discount rate from 12 to 5 percent for low and no-carbon fuels, which could be comparable to using the CDM. The CDM is intended to increase investment flows from developed to developing countries in exchange for carbon mitigation credits.

This scenario also penalizes thermal stations for air pollution emissions, and hydroelectric and nuclear plants for adverse land-, water-, and waste-related impacts. These environmental and social impact estimates were included in the model from 2005-2015. (See Table 3.) These fees, or externalities, are used in the model to simulate more accurately the full environmental costs of power generation. A value of $14 per kilowatt per year in unaccounted damages was adopted for hydroelectric stations. This calculation was based on the investment of $700 million made at the Yacyretá hydroelectric station to cover the cost of coastal protection walls, sanitary equipment installations, and relocation of individuals living in the affected area. Actual costs would be much higher if all environmental impacts were

Figure 8

Least-Cost Power Capacity by Scenario, in 2015



included. A nuclear decommissioning fee of $0.002 per kilowatt-hour is also assumed, amounting to 20 percent of the initial investment. Damages from sulfur dioxide, particulate, and nitrogen oxide emissions were also estimated for Argentina based on a recent study by the European Commission.[29] Note that only the shadow costs of air emission externalities are used in the calculations. These costs are used only for planning the least-cost future power mix and have been subtracted from the total cost figures summarized in Table 7.

Table 3

Externality Costs in Electricity Generation

Sulfur Dioxide ($/ton-$SO_2$)	Particulate ($/ton-$RO_x$)	Nitrogen Oxide ($/ton-$NO_x$)	Hydro ($/kW/yr)	Nuclear Decommissioning ($/kWh)
420	1,130	2,200	14	0.002

Source: European Commission, 1999; Bariloche Foundation estimates.

The low discount rate for carbon-free power sources and externality costs change the lifecycle costs significantly. Hydropower stations become more competitive than combined-cycle stations, resulting in a reduction in the fossil fuel share from 75 percent to 67 percent of power generation compared to the baseline scenario. (See Table 4.)

Table 4

Sources of Power Generation by Scenario, in terawatt-hours

	1995				2015			
	Thermal	Hydro	Nuclear	Total	Thermal	Hydro	Nuclear	Total
Baseline	21	27	7	54	135	40	6	181
Mitigation	—	—	—	—	122	52	7	181
Gas Shortage	—	—	—	—	66	40	75	181
Efficiency	—	—	—	—	109	40	6	155

The least-cost mix of power capacity grows from over 17,000 megawatts to 49,000 in 2015. (See Table 7 and Figure 8.) The higher capacity in this scenario compared to the baseline results from the fact that more hydropower is used and it has a lower capacity factor, meaning that fewer kilowatt-hours are produced per kilowatt of installed capacity. The reserve margin declines to only 17 percent. Supply capacity shifts to 59 percent thermal (13 percent less than the baseline scenario), 37 percent hydroelectric (12 percent more than the baseline), and 3.8 percent nuclear. (See Table B-3 in Appendix B.)

Total cumulative discounted costs in this scenario reach $32 billion, 23 percent more than the baseline. Included in these costs are the approximately $6 billion in subsidies that would be required to lower the discount rate on carbon-friendly power sources to 5 percent. A description of how this $6 billion subsidy would be obtained and deployed to shift power supply options goes beyond the scope of this study, although the CDM might be one option.

Natural Gas Shortage Scenario. The natural gas shortage scenario is identical to the baseline except that natural gas resources are restricted for new power generation in the event that new supplies are not developed quickly enough to meet domestic demand. This scenario thus estimates the supply shifts, economic costs, and environmental externalities associated with losing the gas option. A 12 percent discount rate is again assumed. Shadow environmental externalities (for planning purposes only) are used, as in the previous scenario. Values for environmental externalities limit the amount of coal that would be used in place of gas and thus comply with Argentinian legislation.

Power generation in this scenario for 2015 exceeds 181 terawatt-hours, compared to 54 terawatt-hours today. This scenario assumes that increased coal mining capacity (although remaining limited) makes Argentinian coal competitive. Coal reserves are plentiful and could satisfy much greater power demand. The major caveat is that coal transport — railroads and individual trains — would need to be constructed throughout the country, and the cost of transport would be substantial, perhaps half the price per ton or more. The price of coal used in the model thus rises gradually beginning in 2005 from $32 per ton, reaching $45 per ton in 2015.

Nuclear and coal become the next cheapest alternatives after low-cost gas supplies are used. Total installed power capacity reaches 48,000 megawatts, 4 percent above the baseline, comparable to the mitigation case. Thermal and hydroelectric generation shares fall in this scenario, while nuclear rises 11 times with respect to the baseline. Stated otherwise, nuclear power capacity rises from 1,390 megawatts today to more than 15,000 megawatts in 2015. (See Table B-3 in Appendix B.) Nuclear is even less expensive than coal because of the costs of coal's environmental impacts and the added transportation infrastructure costs.

Total fuel consumption for power generation will exceed 1.4 exajoules, translating to an annual growth rate of 7.9 percent in the gas shortage case. (See Table 5.) In comparison, the mitigation scenario yields an annual fuel growth rate of 5.3 percent. Much of the difference in fuel use depends on the contribution of hydropower — which does not consume fuel — to the mix. The efficiency of fossil fuel plants increases from 30 percent today to 55, 52, and 37 percent in 2015 in the baseline, mitigation, and natural gas shortage scenarios, respectively.

Table 5

Energy Consumption by Scenario, in petajoules

	1995					2015				
	Gas	**Coal**	**Petrol**	**Uranium**	**Total**	**Gas**	**Coal**	**Petrol**	**Uranium**	**Total**
Baseline	230	20	0	70	320	890	0	0	60	950
Mitigation	—	—	—	—	—	710	0	0	60	770
Gas Shortage	—	—	—	—	—	140	510	0	820	1,470
Efficiency	—	—	—	—	—	720	0	0	60	780

Note: A petajoule is $1x10^{15}$ joules.

While the base case projects a 33 percent decline in sulfur dioxide emissions with respect to the current level due to strong growth in natural gas use, the natural gas shortage scenario projects a significant increase in both sulfur dioxide and particulate emissions. (See Table 6.) This result stems from a large increase in coal use — to nearly 35 percent of power generation in 2015 — in this scenario. Carbon dioxide emissions, however, remain essentially unchanged from the baseline since nuclear power — with no carbon dioxide emissions — offsets a large amount of natural gas-fired power. Nitrogen oxide emissions also remain relatively stable for the same reason. All other policy scenarios exhibit a reduction in carbon dioxide emissions relative to the baseline due to the increased use of low-carbon or carbon-free sources of power.

Table 6

Emissions by Scenario

	1995				2015			
	Sulfur Dioxide (thousands of tons)	**Particulate (thousands of tons)**	**Nitrogen Oxide (thousands of tons)**	**Carbon Dioxide (millions of tons)**	**Sulfur Dioxide (thousands of tons)**	**Particulate (thousands of tons)**	**Nitrogen Oxide (thousands of tons)**	**Carbon Dioxide (millions of tons)**
Baseline	15.7	52.8	71.5	4.8	10.7	1.8	206.1	14.0
Mitigation	—	—	—	—	8.6	1.6	165.0	11.2
Gas Shortage	—	—	—	—	316.0	1,352.0	225.2	13.7
Efficiency	—	—	—	—	8.7	1.6	166.9	11.3

Total costs in the natural gas shortage scenario reach $45 billion, nearly twice as much as the baseline. The higher expense is due to heavier reliance on expensive nuclear and coal-fired power plants.

Although the chance of a natural gas shortage this severe is limited, the results indicate likely trends should gas use in the power sector become constrained. Variables that will influence the degree of change under this scenario include incentives to use natural gas outside the power generation sector, trade issues that affect imports and exports of natural gas, and the response of exploration and development companies to growing risks of natural gas shortages.

Energy-Efficiency Scenario. This scenario tests the impact of improving energy-efficiency technology throughout the economy, but is in all other respects similar to the baseline case. This work draws heavily on the Energy Secretariat's development of a "Rational Use of Energy" scenario in the Secretariat's 1998 *Prospective Report.* The total demand for power drops by 14 percent to 155 terawatt-hours in 2015 compared to the baseline demand of 181 terawatt-hours. (See Table 7.)

Table 7

Scenario Results in 2015

Scenario	Cost ($Billion)	Generation (Terawatt-hours)	Capacity (Gigawatts)	Carbon Dioxide Emissions (Million Tons Carbon)	Sulfur Dioxide Emissions (Thousand Tons)	Natural Gas Use (Billion Cubic Meters)
Baseline	26.0	181	46.3	14.0	10.7	22.9
Mitigation	32.1	181	49.1	11.2	8.6	18.4
Gas Shortage	44.8	181	48.1	13.7	316.8	3.5
Efficiency	19.6	155	40.7	11.3	8.7	18.6

The most important energy end-use technologies in buildings are lighting, refrigerator-freezers, and video equipment. These devices represent more than 75 percent of the building sector's power consumption. The efficiency improvement potential in these uses has been assessed for programs to a) affix an energy use label on refrigerators and freezers and finance purchase of more efficient equipment; b) improve lighting systems, particularly to encourage use of compact fluorescent lights; and c) evoke behavioral changes through tariffs and regulations. The result of these programs would be a projected 16 percent reduction in residential sector demand.

In the industrial sector, motors and to a lesser extent, lighting, consume the most energy. The programs proposed by the Energy Secretariat to promote the rational use of energy in industry include improving electric motors and motor power systems and upgrading lighting systems through financial incentives. A 7 percent reduction in consumption in 2015 compared to the baseline is estimated. Cogeneration would have to play a more important role in the Argentinian economy to meet this projection. Various studies by the Institute of Energy Economics at the Bariloche Foundation indicate that the cogeneration potential in 2000 amounts to 1.7 terawatt-hours.

Results from the energy-efficiency scenario show a 19 percent drop in both sulfur dioxide and carbon dioxide emissions by 2015 compared to the baseline due to the reduction in energy use. The least-cost model estimates the total cost of this scenario at $20 billion, less than each of the other scenarios and less than half the cost of the gas shortage scenario. (See Table 7.) Additional costs would be incurred to overcome the barriers of meeting this lower power demand, although these costs could be largely balanced by the associated benefits of energy conservation such as emission reductions.[30]

IV. Conclusions

Through 2015, Argentina's electric power sector is likely to exhibit three trends. First, natural gas will play an increasingly important role in power generation. Second, growth in power demand will largely follow that of the economy. Finally, emissions of greenhouse gases will grow, but market reform and competition in power generation will keep levels relatively low.

- Natural gas combined-cycle power plants are the most competitive alternative in a framework of decentralized decision-making because such technologies minimize capital costs and risk while maximizing profitability. Without considering the global impacts of greenhouse gas emissions, least-cost analysis indicates strong growth in the use of natural gas for power generation.

- The low cost of natural gas and gas turbines combined with apparently abundant domestic gas resources hinders the development of carbon-free sources of electric power. However, continued availability of large supplies of low-cost natural gas is critical to Argentina's baseline growth scenario. The possibility of a natural gas shortage could limit the number of combined-cycle power plants constructed, creating huge new expenses for the country due to the added costs of other options, including increased emissions of local pollutants such as sulfur dioxide and particulates.

- Without additional policies oriented toward carbon mitigation, energy sector reform — both regulatory and institutional — will result in higher levels of emissions per kilowatt-hour of power generated and higher total emissions overall. The mitigation scenario determined that accounting for environmental externalities alone will not make natural gas so expensive that other energy sources are chosen by the least-cost model.

- Hydropower and nuclear power plants could play an important role in reducing carbon emissions but with significant additional costs. The feasibility of relying on either power source would require a political decision and additional incremental funding. Lack of social acceptance for hydropower or nuclear technology should not be underestimated.

- Demand-side management and increasing energy efficiency by end users is one of the best options for reducing power demand and carbon emissions. Since electricity distributors in Argentina have no incentive to support reductions in consumer demand, new policies would need to be crafted to achieve such reductions. Policies would have to be constructed carefully to avoid high transaction costs and extra expenses for consumers.

The privatization of state energy companies, together with regulations to create competitive energy markets, has led to a substantial reduction in governmental participation in electricity supply. Many decisions on supply expansion and the use of Argentinian energy resources have been left to private companies. This situation may restrict the government's ability to implement an effective climate change mitigation policy. Still, the impact of the market on the environment to date, and specifically on greenhouse gas emissions, has been positive. New technologies and policies hold hope that the market will continue to offer greater environmental benefits after 2015.

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Appendix B: Selected Data and Results

Table B-1

Average Annual Change in Specific Emissions from Public Power Plants in Argentina

	Sulfur Dioxide	Particulates	Nitrogen Oxides	Carbon Dioxide
1970-1980	-3.5	-1.5	-1.1	-4.5
1980-1992	-6.9	-7.2	1.1	-2.0
1993-1997	-6.5	-0.4	3.4	-2.1
1966-1997	-5.2	-3.0	0.1	-3.5

Note: Specific emissions refer to emissions per kilowatt-hour of electricity generated.

Source: Energy Secretariat, 1998.

Table B-2

Average Fuel Prices Across Regions Used in the Modeling

1995				2015			
Gas ($/GJ)	Coal ($/ton)	Petrol ($/GJ)	Uranium ($/kWh)	Gas ($/GJ)	Coal ($/ton)	Petrol ($/GJ)	Uranium ($/kWh)
2.12	32.1	2.6	0.0058	2.79	32.1	3.0	0.0058

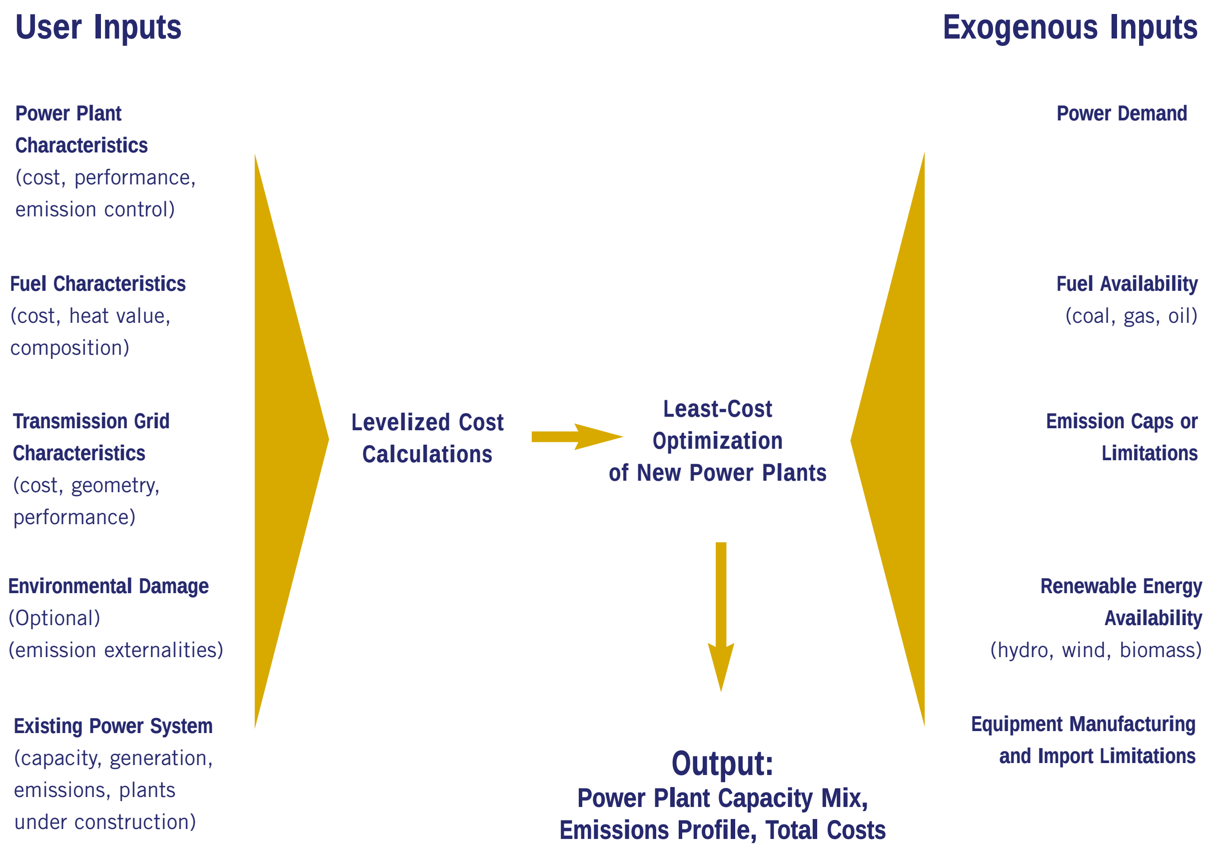
Source: Bariloche Foundation, 1999.

Table B-3

New Capacity Additions by Type and Scenario, in 2015

	Units	1995	Baseline	Mitigation	Gas Shortage	Efficiency
Generation	TWh	54.1	181	181	181	155
Capacity	GW	17.2	46.3	49.1	48.1	40.7
Gas	GW	7.2	33.3	28.2	4.5	27.7
Coal	GW	0.6	0.01	0.01	16.7	0.01
Hydro	GW	8.3	11.6	19.1	11.6	11.6
Petroleum	GW	0.1	0	0	0	0
Nuclear	GW	1.0	1.4	1.9	15.4	1.4

Appendix C: The Linear Programming Model



Endnotes

1. A gigawatt equals one million kilowatts or the energy capacity of a typical, large central power plant.

2. Energy economists define the ratio of growth in energy consumption to growth in Gross Domestic Product (GDP) as income elasticity of energy demand. Since growth in Argentina's energy consumption generally tracks the growth rate in the economy, the country's elasticity is approximately 1.0. In India and South Korea, however, the income elasticity of energy demand is approximately 1.5, meaning that a 1 percent increase in GDP growth results in a 1.5 percent rise in energy consumption. The income elasticity of power demand is even higher in these countries. See "Developing Countries and Global Climate Change: Electric Power Options in Korea" and "Developing Countries and Global Climate Change: Electric Power Options in India," Pew Center on Global Climate Change, Arlington, VA, October 1999.

3. Energy Information Administration, 1999. Washington, DC. December. Available at http://www.eia.doe.gov/international.

4. "Country Analysis Brief: Argentina." 1999. Energy Information Administration: Washington, DC. August. Available at http://www.eia.doe.gov/emeu/cabs/argentina.html.

5. In the United States, the carbon intensity of power generation is approximately 133 grams per kilowatt-hour; in Brazil, 13 grams per kilowatt-hour; in South Korea, 114 grams per kilowatt-hour; in India, 226 grams per kilowatt-hour; and in China, 182 grams per kilowatt-hour.

6. IDEE/FB-UNEP-RISØ, 1997. "Economics on GHG Limitations: Argentine Case Study." UNEP Collaborating Centre on Energy and Environment, Country Study Series. Roskilde: Denmark.

7. This figure is from 1992 to 1997. British Petroleum-Amoco. 1999. "Statistical Review of World Energy 1999." Available at http://www.bpamoco.com/worldenergy.

8. Plants built during this period include some of the largest in the country, namely Chocón, Futaleufú, Río Grande, Planicie Banderita, Alicurá, Salto Grande and Yacyretá. In 1974, Argentina completed construction of Atucha I, the country's first nuclear power plant.

9. See Energy Information Administration, "Country Analysis Brief: Argentina," 1999.

10. Some of Argentina's wind turbines achieved a utilization factor (percent of time spent generating power) close to 34 percent in 1997, which shows the abundance of the resource. Sixty percent of the installed wind turbine capacity is located in Patagonia, where wind resources are abundant. Most of the turbines belong to the Comodoro Rivadavia electricity cooperative association. The remaining 40 percent are found in the province of Buenos Aires. Should the retail market fully open to competition, the permanence of these units could be jeopardized unless specific subsidies are provided. The price difference could lead consumers to contract their supply with other generators, and the current rate protection enjoyed by electricity cooperative associations would disappear. The Argentinian Congress approved a bill in the late 1990s to set a federal subsidy to wind energy of some US$10 per generated MWh (one cent per kilowatt-hour). See Energy Secretariat, 1998.

11. See “The Transformation of Argentina’s Electricity Sector” in “Electricity Reform Abroad and U.S. Investment,” Energy Information Administration, 1997. Available at http://www.eia.doe.gov/emeu/pgem/electric/ch4.html.

12. Bariloche Foundation, Institute for Energy Economics. 1999. “Electric Power Sector: Recent Evolution and Present Situation — Argentine Report.” Unpublished.

13. Concerns about large hydroelectric plants include destruction of fish and wildlife habitats, altered hydrogeological cycles, and relocation of towns and villages that are located where the dams would be built.

14. Secretariat for Natural Resources and Sustainable Development. 1999. “Revision of the First National Communication: Argentine Republic.” Buenos Aires. October.

15. This type of least-cost analysis, also referred to as lifecycle costing, spreads out discounted capital, operations and maintenance, and fuel components over the economic life of the plant, enabling cost comparisons between different options.

16. For a review of linear programming, see *Linear and Nonlinear Programming* or *Introduction to Linear Optimization.*

17. See Katz, 1996.

18. See Energy Information Administration, “International Energy Outlook 1999.”

19. United Nations Population Fund. 1999. “The State of the World Population 1999: 6 Billion, A Time for Choices.” United Nations Publications: New York.

20. See Argentinian Energy Secretariat, “Prospects for the Electricity Sector, 1988.”

21. ENARGAS (Argentina’s gas sector regulator) prices for power stations were established for the year and for each region affected by the resolution. For the purposes of this work, gas prices across ENARGAS regions were averaged, resulting in the values given in the first column of Table B-1. Projections were made following guidelines given in V. Bravo and R. Kozulj, “Expected Evolution in the Prices of Fuels for Electricity Generation in Argentina,” 1996.

22. CAMMESA, 1998-99.

23. Ibid.

24. See UNEP/RISØ, “Improving Energy Efficiency and Protecting the Environment,” 1997.

25. The hypothesis on the technology to use in electricity generation assumes a business-as-usual approach, in which the decision-maker chooses the technology that minimizes investment, speeds investment returns, and reduces risks and operation costs. In the baseline case, combined-cycle plants using natural gas prove to be the best alternative.

26. For further information on the evolution of technology and its efficiency, refer to UNEP- RISØ, “Economics on GHG Limitations: Argentine Study Case,” 1997.

27. Energy Information Administration. 1999. “Country Energy Balance: Argentina.” Available at http://www.eia.doe.gov/emeu/world/country/cntry_AR.html.

28. In reality, both sources are responsible for at least some emissions. Decomposing organic matter submerged under hydroelectric dams emits both methane and carbon dioxide, while the manufacturing process to produce the cement used extensively in both forms of generation emits additional greenhouse gases to the atmosphere. Compared to carbon dioxide emissions from a coal-fired power plant, these emissions are minor, but not unsubstantial.

29. “ExternE-Externalities of Energy Use: A Research Project of the European Commission.” 1999. Available at http://externe.jrc.es.nletter6.html.

30. For a more complete discussion of the options and costs, see G. Dutt, F. Nicchi, and M. Brugnoni, 1997.

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