Latin Power: Long-term trends in the efficiency of electricity production in Chile

ABSTRACT

Palabras clave: Electricidad, combustibles fósiles, eficiencia energética.

La generación de electricidad reditúa tanto beneficios extraordinarios para las sociedades humanas como impacto ambiental altamente significativo. La eficiencia de la producción de electricidad determina cuánto combustible primario será necesario para cubrir una demanda determinada. Se examina aquí la eficiencia eléctrica chilena relacionada con los combustibles fósiles durante el período 1973-2005, el cual cubre los cambios estructurales significativos producidos luego del programa de desregulación de 1982. Las eficiencias eléctricas de Latinoamérica y el mundo también son presentadas para ofrecer una perspectiva sobre el desempeño relativo de Chile en el sector de la electricidad.

Key word: Electricity, fossil fuel, electrical efficiency.

The generation of electricity has extraordinary benefits for human societies, as well as very significant environmental impacts. The efficiency of electricity production determines how much primary fuel will be necessary to fulfill a given demand. Chile's electrical efficiency for fossil fuels is explored over the period 1973-2005, which covers the significant structural changes resulting from the 1982 program of deregulation. Latin America and world electrical efficiencies are also presented to give a sense of the relative performance of Chile's electricity sector.

Latin Power: Long-term trends in the efficiency of electricity production in Chile

Matthew J. Eckelman
Naoko Maruyama
Francisco J. Espinoza
Yale University, School of Engineering,
School of Forestry and Environmental Studies

It is difficult to imagine the modern age without electricity. While fossil fuels revolutionized transportation and manufacturing early in the industrial revolution, electricity is the energy carrier most closely associated with our increased quality of life, powering telecommunications, computing, lighting, and many of the most useful time-saving appliances. In the context of development, access to electricity is seen as by far the most enabling; governments and international agencies regularly measure their achievements in terms of the percent of the population that is hooked up in some way. And yet the production of electricity is one of the most polluting and environmentally degrading activities that humans engage in, due to the preponderance of fossil fuels as the main energy sources. Globally, electricity production is responsible for 30% of the total anthropogenic atmospheric emissions of carbon dioxide, >60% of mercury, 35% of acid-rain causing sulfurous compounds, as well as a large share of the degradation that comes with coal mining and oil and gas drilling and exploitation.

One way that countries have avoided these environmental impacts is to source electricity from renewable sources, such as hydropower, wind, or solar. In Chile, more than 40% of electricity is generated from the country's rivers and streams, with a few percent coming from combustible fuels such as wood chips. However, not all countries are blessed with the hilly terrain and water resources needed for hydropower production, and solar and wind power have yet to assume their rightful place as dominant electricity sources (though growth in both sectors globally has been well into the double-digits for years). Nuclear power avoids some of the atmospheric emissions associated with fossil fuel combustion, but results in spent fuel rods that are still slightly radioactive, and uranium mining itself is hardly a benign activity.

For those countries that are forced to rely on fossil fuels for large-scale electricity generation, one of the best ways to reduce environmental impacts is through increases in conversion efficiency. Conversion (or electrical) efficiency is defined as how good a utility is in converting the latent heat energy (or enthalpy) in fossil

fuels into electrical energy. As efficiency increases, utilities need less fuel to produce equivalent amounts of electricity. Much of the past improvement in conversion efficiency can be attributed to improvements in technology. These can be improvements in materials, such as new ceramics and alloys for turbine blades that allow operation at ever-higher temperatures, or novel system designs, such as the introduction of combined cycle gas turbines in the mid-1970s.

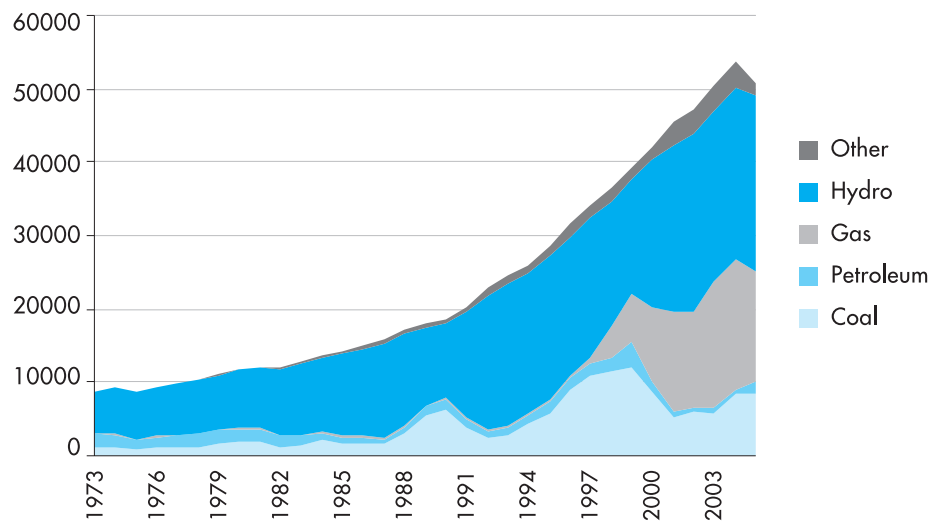
It is impossible to squeeze all of the energy out of fuels and into electricity; the theoretical maximum is called the Carnot efficiency and is generally well below 100%. This maximum efficiency is a function just of the temperatures of the input and output gases that run through the generator:

$$\eta = 1 - \frac{T_C}{T_H},$$

where T_C is the exhaust temperature and T_H is the input steam temperature (in Kelvins).
For a typical gas-fired power plant running at 1000° C (1273 K) with cooling water at 35° C (308 K), the Carnot efficiency is about 76%. Practical considerations such as friction reduce the efficiency of real-world utilities to around 60%, at best. The quality of the input fuel affects the efficiency, not because the heat value is lower (naturally making less heat available for conversion to electricity) but because of the high proportion of ash or contaminants that disrupt operations in the power plant. While they are absolutely necessary for maintaining air quality, pollution controls can also reduce the efficiency of a power plant by consuming local electricity (called parasitic loss) or by introducing back pressure into the system. In many countries, both heat and electricity are produced together in combined heat and power (CHP) plants. In this case, the calculation of efficiency must make allowances for that portion of the fuel that is used to produce heat, giving an effective electrical efficiency. Above all, the initial quality, design, and ongoing maintenance of generating equipment determine the long-run efficiencies of utilities.

In Chile, as in many parts of the world, electrification began with a wave of private investment in the early 20th century, with the state largely assuming control and responsibility shortly thereafter. The country currently enjoys an electrification rate of 99%, with both supply and demand increasing steadily. Coal and hydro have traditionally been the main sources of power, with natural gas increasing in importance since about 1997.

Figure 1
Generation of electricity (GWh), 1973-2005



Beginning in 1982, Chile began a program of deregulation in the electricity sector, moving from large, vertically integrated providers of generation, transmission, distribution, and delivery to multiple companies in each step of the process. This early deregulation program was largely successful and is hailed as a model for other developing countries, as it improved the performance of the sector across measures, from prices to reliability to labor efficiency. Over the same period, it is instructive to look at the electrical efficiencies of generating units in Chile, compared to the Latin America and world averages, as shown in figures 2a-c.

Figure 2a

Electrical efficiency for coal-fired power

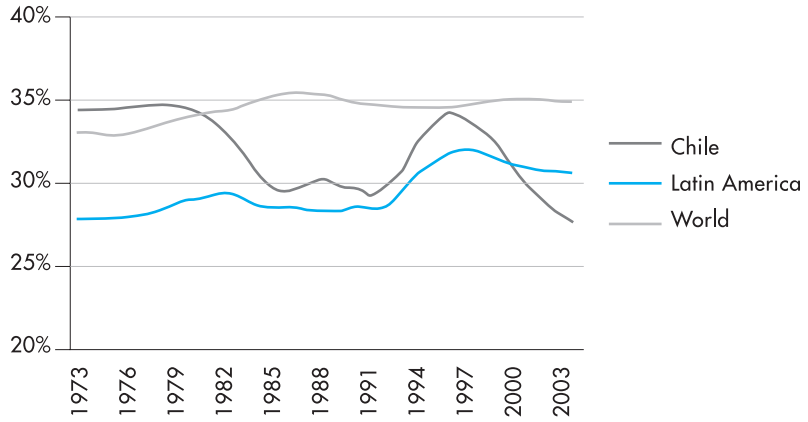


Figure 2b

Electrical efficiency for oil-fired power

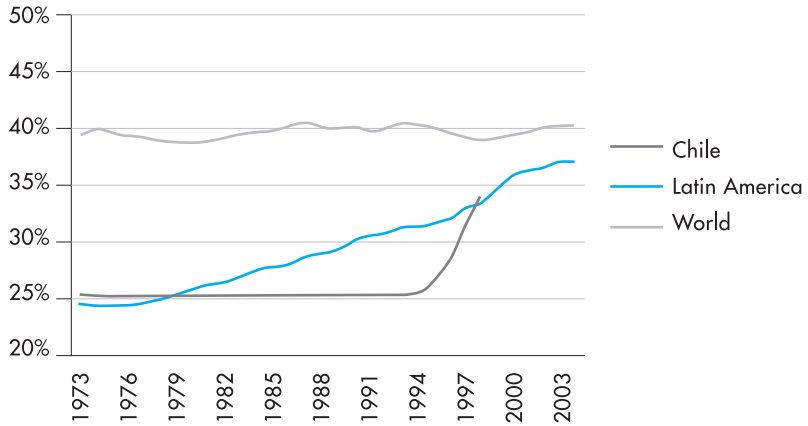
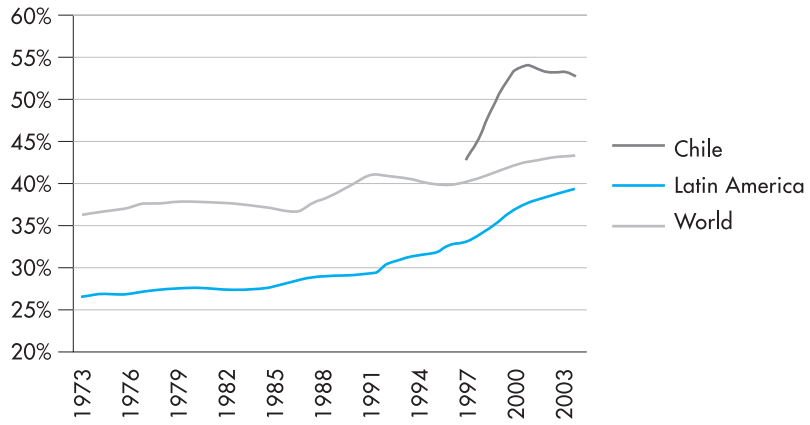


Figure 2c
Electrical efficiency for natural gas-fired power



Source: International Energy Agency (IEA)

The IEA largely collects information from national reports and interpolates to fill data gaps. Energy statistics for Chile prior to 1992 were derived from a single statistical compendium published in 1986. After this year, the Comisión Nacional de Energía began publishing national energy balances. Years for which the proportion of a particular fuel in the electricity mix was less than five percent were omitted, due to potential rounding errors.

For all fuels and years, average electrical efficiencies for Latin America are less than the world average, though both increase monotonically, which the recent exception of coal. The efficiency of Chilean coal- and oil-based generation has historically been less than the world averages. The period of deregulation coincided with a drop in the efficiency for coal-based power, while oil-based efficiencies stayed largely flat until 1995. This was the year that Chile locked in a treaty agreement with Argentina regarding natural gas supplies, and as a result, the gas-fired power sector grew dramatically in the following years. The purchase of modern gas turbines during this period is the likely reason for the high electrical efficiencies in Chile, far exceeding Latin America and even world averages. The fuel with the highest environmental impacts is coal, however, and the low efficiencies currently enjoyed by that sector in Chile are cause for concern and investment, especially considering that recent restrictions to gas delivery from Argentina have driven an increase in the use of this fuel.

REFERENCES

- Compendio Estadístico Chile 1985. Ministerio de Economía, Fomento y Reconstrucción, Instituto Nacional de Estadísticas, Santiago: 1986.
- Energy Information Administration. Chile Energy Data, Statistics, and Analysis. United Status Department of Energy, Washington DC: 2006.
- Emission Database for Global Atmospheric Research. Netherlands Environmental Assessment Agency, Bilthoven: 2008. Available online at Http://www.mnp.nl/edgar/
- International Energy Agency. Energy Balances of non-OECD Countries, all years. Organization for Economic Cooperation and Development, Paris: 2007.
- International Energy Agency. Energy Balances of OECD Countries, all years. Organization for Economic Cooperation and Development, Paris: 2007.
- Pacyna, E.G.; Pacyna, J.M.; Steenhuisen, F.; Wilson, S., 2006. "Global anthropogenic mercury emission inventory for 2000." Atmospheric Environment 40(22), 4048-4063.
- Pollitt, Michael, 2004. "Electricity reform in Chile: Lessons for developing countries." Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, Cambridge, MA, USA.