WORLD BANK STUDY

Wind Energy in Colombia

A Framework for Market Entry

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Preface

The urgent need to reduce the carbon footprint of human activities and the increased awareness of the consequences of climate destabilization have rekindled interest in renewable energy sources as important elements to consider in the expansion or retrofitting of power systems. This report, the second in a series aimed at assessing and addressing barriers to the market entry of wind energy in Colombia's power sector, is but one example of the renewed attention that is rightly being conferred to the potential for wind to become a forceful player in low-carbon futures in Latin America.

The role of wind will not only be a function of cost effectiveness and/or technology advances but also of the ability to address policy and regulatory barriers that in the past have hampered their entry into developing markets. Although the report refers to the specifics of Colombia, its approach and conclusions may be valuable to a wider audience in the region and worldwide.

If these barriers are successfully addressed, wind energy may contribute substantially to maintain the current, relatively low-carbon footprint of Colombia's power sector, aided by a strong hydro contribution. Furthermore, as the report suggests, the wind option may also contribute to the diversification of power sources without increasing their carbon footprint, while also addressing concerns related to the vulnerability of hydropower to increased climate variability.

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Acronyms and Abbreviations

AGC	Automatic Generation Control
ANH	*Agencia Nacional de Hidrocarburos* (National Hydrocarbon Agency)
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CERE	Real Equivalent Cost of the Capacity Charge
CFB	Circulating Fluidized Bed
CNG	Compressed Natural Gas
COLCIENCIAS	*Departamento Administrativo de Ciencia, Tecnología e Innovación* (Colombian Institute for the Development of Science, Technology and Innovation)
CREG	*Comisión de Regulación de Energía y Gas* (Regulatory Commission for Electricity and Gas)
CTF	Clean Technology Fund
DNP	*Departamento Nacional de Planeación* (National Planning Department)
EPM	*Empresas Públicas de Medellín ESP* (Public Companies of Medellín), one of Colombia's largest energy producers
ENSO	El Niño-Southern Oscillation
ESMAP	World Bank Energy Sector Management Assistance Program
ESP	Electrostatic Precipitator
FAZNI	*Fondo de Apoyo Financiero para la Energización de las Zonas No Interconectadas* (Fund for the Electrification of Off-grid Regions)
FDG	Flue Gas Desulfurization Gypsum
FGD	Flue Gas Desulfurization
GCM	General Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOC	Government of Colombia
IDEAM	*Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia* (Institute of Hydrology, Meteorology and Environmental Studies of Colombia)
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRR	Internal Rate of Return
ISA	*Interconexión Eléctrica S.A.*
ISAGEN	A major power producer and commercialization company in Colombia
JMA	Japan Meteorological Agency
LVRT	Low Voltage Run-Through

MDB	Multilateral Development Bank
MEM	Wholesale Energy Market
MRI	Meteorological Research Institute of Japan
NIS	National Interconnected System
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PM	Particulate Matter
PPP	Purchasing Power Parity
R&D	Research and Development
RE	Renewable Energy
RET	Renewable Energy Technologies
SC	Subcritical
SCR	Selective Catalytic Reduction
SDL	*Sistema de Distribución Local* (Local Distribution System)
SOPAC	Pacific Islands Applied Geoscience Commission
SOx	Sulfur Oxide Gases
SPC	Super Critical
SSPD	*Superintendencia de Servicios Públicos Domiciliarios* (Superintendency for Residential Public Services)
STN	*Sistema de Transmisión Nacional* (National Transmission System)
STR	*Sistema de Transmisión Regional* (Regional Transmission System)
TPC	Total Plant Cost
UNFCCC	United Nations Framework Convention on Climate Change
UPME	*Unidad de Planeamiento Minero-Energética* (Colombia's Energy and Mining Planning Unit)
URE	*Uso Racional de Energía* (Rational and Efficient Use of Energy)
USPC	Ultra Supercritical

List of Units

BTU	British Thermal Units
Cal	Calories
Cz	Ash
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hour
Kbpd	Thousand barrels per day
Kcal	Kilo calories
Kg	Kilogram
KTOE	Thousand tons of oil equivalent
KWh	Kilowatt hour (10^3)
Lb	Pounds
M/s	Meters per second
MBTU	Million British Thermal Units
Mbbl	Million barrels
MJ	Megajoules

MMT	Million metric tons
MTOE	Million tons of oil equivalent
MWa	Megawatt average
MWh	Megawatt hour (10^6)
QUADS	Quadrillion BTU
Tcf	Trillion cubic feet
TOE	Tons of oil equivalent
TWh	Terawatt hour
US$PPP	Purchasing power parity

Executive Summary

Objective

The purpose of this report is to provide decision makers in Colombia (and by extension other countries or regions), who are considering the deployment or consolidation of wind power, with a set of options to promote its use. The options presented are the result of an analysis of the Colombian market; this analysis included simulations and modeling of the country's power sector, and extensive consultations with operators, managers, and agents. More information on the analysis and simulations is presented in the appendixes. Wind was chosen to exemplify the range of renewable energy alternatives available to complement traditional power sector technologies on the basis of its technical maturity, its relatively low cost compared to other options, the country's experience, and its wind power potential. This report constitutes the second phase of a barrier analysis to wind energy in Colombia (Vergara et al. 2008).

General Context

Colombia has a rich endowment of energy sources. The natural gas reserves in 2008 were 7.3 tera cubic feet (of which 60 percent were proven reserves). At the current rate of utilization these reserves would last 23 years.[1] Likewise, Colombia's coal reserves are rated at seven billion tons (or about 100 years of production at the present mining rate). Most coal mined is anthracite, with very low ash and sulfur content, ideal for exports to the European market. Oil reserves are much more limited and may not be sufficient to maintain self-reliance in the short term. Reserves may only last eight years (Ministry of Mines and Energy 2008). The country has also a substantial, relatively low-cost hydropower potential resulting from its location in the tropical inter-convergence zone and its mountain ranges.

Within this context, the country has developed a power sector that relies heavily on installed, large-capacity hydropower units that provide cost-effective electricity. In 2008 the installed power mix in Colombia (13.5 GW) was 67 percent hydro, 27 percent natural gas, 5 percent coal, and 0.3 percent wind and cogeneration. The total power demand that same year was 54 TWh (UPME 2009), met with about 9 GW of installed capacity.[2] This structure also results in a low carbon footprint, among the lowest in the region, with 87 percent of power generated and delivered to the grid by hydropower plants, resulting in an estimated 350 tons of CO_2 per GWh generated (about half that of Mexico).

From a management perspective, Colombia's power sector is maturing quickly, with relative stability in its regulations, an unbundled system, and a dispatch mechanism that closely resembles a well-functioning competitive market. Competition is promoted and tools have been designed to attract cost-effective capacity expansions that would promote reliability[3] of service (a fuller description of the system and its dispatch mechanism was included in the phase one report).

The wind regime in Colombia has been rated among the best in South America. Offshore regions of the northern part of Colombia have been classified with class seven winds (winds over nine meters per second [m/s] at heights of 50 meters). The only other region in South America with similar wind intensity is the Patagonia region of Chile and Argentina. Colombia has an estimated wind power potential of 18 GW in the La Guajira region—enough to generate power to meet the national power demand twice over[4] (Pérez and Osorio 2002). However, the country has an installed capacity of only 19.5 MW of wind energy (Jepírachi Project) and several projects under consideration, including a 200 MW project in Ipapure, northern Colombia.

Under the current circumstances, and on its own, the interconnected system would not likely promote nonconventional renewable energy resources (for example, other than hydropower), such as wind, but would instead maintain its high-capacity share of hydro. Alternatively, the system may move toward a more carbon-intensive energy resource mix (likely reliant on abundant coal reserves) to meet any additional demand that cannot be met through hydropower and/or to strengthen the system's resilience to deal with the effects of droughts and El Niño years. Expanding the coal-based power generation capacity would result in an increase in the carbon footprint of the economy from its current relatively low level of greenhouse gas (GHG) emissions.[5]

Alternative Power Options for Colombia's Power Mix

A cost comparison of 37 alternative technology options for power generation in Colombia, using a levelized curve/netback analysis, indicates that, as expected, large hydropower is the least-cost power option with or without CO_2e emission reduction revenues over a wide range of capacity factors. After hydropower, the rehabilitation of existing (subcritical) coal power plants and the fuel switch from oil or natural gas to coal-fired power plants present some of the lowest levelized costs at any capacity factor; these options are not currently used in the country.

Allowing for CO_2 revenues does not significantly change the least-cost capacity expansion ranking. For 2007 investment costs (based on which the analysis was made) even at a CO_2e price of US$50, wind power is still not the least-cost option. Within this range of revenues, carbon credits fail to effectively affect the ranking of options, proving that the Clean Development Mechanism (CDM) alone at the 2007 price level is not enough to promote alternative zero-carbon energy under existing conditions in Colombia. Therefore, other policy options are required to facilitate market entry for wind power.

Wind Energy Capital Costs Are Expected to Decrease

Primarily because of the increased interest caused by climate concerns, wind power installations are experiencing rapid change and improvements. For example, the energy produced per unit of installed capacity (measured as the weighted average of capacity factors) went from 22 percent for wind power projects installed before 1998 to 30–32 percent for projects installed from 1998 to 2003 and to 33–35 percent for projects installed during 2004–2006 (LBNL 2008).

Investment costs have decreased in the last year after peaking late in 2008. Investment costs for wind energy projects experienced a decreasing trend, which was interrupted between 2004 and 2008 as consequence of high demand, limited production capacity, and the global high demand for raw materials. Recent information indicates that investment costs have continued the long-term downward trend, with mid-2009 average costs at around $1,800/kW.

Annual average operation and maintenance costs of wind power production have also continuously declined[6] since 1980. Most importantly, the capacity-weighted average of 2000–2007 Operation and Maintenance (O&M) costs for projects constructed in the 1980s was equal to US$30/MWh, but dropped to US$20/MWh for projects installed in the 1990s and to US$9/MWh for projects installed in the 2000s. These trends are expected to continue in the foreseeable future, gradually improving the relative competitiveness of wind power.

Wind and Hydro Energy Resources Are Complementary

The report examines the extent to which the wind resource is complementary to the hydro regime in Colombia.[7] Wind power appears to be available when its contribution to the national grid is most needed, that is, during the dry periods and to an extent during the early evening when demand peaks.

Large-scale droughts could affect Colombia's interconnected power system due to its high reliance on hydropower. Historically, critical drought conditions are linked to El Niño events, such as those of 1991–1992 and 2002–2003. Existing power generation data from Jepírachi (for the period from February 2004 to March 2009) and wind velocity records data from Puerto Bolívar were extended to cover the period from 1985 to 2008 to assess wind generation capacity during drought periods. The analysis considered four rivers with substantial hydropower development: Guavio, Nare, Cauca, and Magdalena. The most severe droughts in these basins correspond to the El Niño period from April 1991 to July 1992 when strict energy rationing occurred, and from April 1997 to May 1998 when pool prices reached very high spot prices, forcing regulatory changes in the market. During these periods the estimated generation from wind was well above the mean value. That is, during periods of extreme drought associated with El Niño, wind energy from northern Colombia was above average. This analysis is described in detail in Appendix 6.

Complementarity was also explored by analyzing the joint operation of a simple system consisting of a wind farm operating in tandem with a hydropower plant of similar size for each of the rivers studied and for a range of reservoir sizes. The analysis is summarized for each of the rivers and is also described in Appendix 6. Results suggest that firm energy from the joint operation of wind and hydropower plants surpasses the isolated operation of the hydropower plant and of the wind farm. This result holds for a wide range of possible reservoir sizes studied. The strong complementarity that the joint operation of wind and hydropower plants exhibits has not been recognized by the current regulatory system adopted by Colombia.

Options to Address Barriers to Entry

Despite the resource endowment and strategic advantages, under current circumstances wind-based generation faces considerable obstacles to participate in the nation's power mix. Key obstacles (described in the first-stage report[8]) include the current relatively high capital intensity and the structure of the regulatory system, which does not acknowledge wind's potential firm capacity.[9] Specifically, there is a mechanism in place that remunerates firm energy[10] (through auctions), in which wind power currently cannot participate. The first stage report identifies barriers that nonconventional renewable energy sources face in the country and proposes various sets of policy options that may lead to a wide market entry.

There is a wide range of potential instruments through which governments can guide the functioning of power markets. Many of these instruments would be applicable to the energy sector in Colombia. However, only a subset of options was explored in detail (those that are in agreement with the existing regulatory system in Colombia and have the effect of changing the financial results for a potential investor):

- Access international financial instruments to internalize *global* externalities in national and private decisions. The government can play an active role in promoting access to financial instruments aimed at reducing GHG emissions through:
  - *Active participation in the CDM* by engaging in the global carbon market. This is already mainstreamed into the environmental policy in Colombia, but it could be further strengthened within the energy policy; and
  - *Access to multilateral soft loans* earmarked for alternative energies or other concessionary funding sources for low carbon investments such as the Clean Technology Fund (CTF).
- Target subsidies through government fiscal mechanisms. The government could utilize fiscal measures for the benefit of potential investors. Specifically, the mechanisms identified are:
  - *Reduction in income tax.* As previously indicated, tax exemptions or reductions are policy mechanisms to guide investment toward areas of policy interest. From the investor's point of view, such policies are tools to improve the after-taxes returns; and
  - *Exemptions from system charges.* The government could use the regulatory system to reduce or eliminate charges paid for automatic generation control, environmental charges, and/or contributions to the Fund for the Electrification of Off-grid Regions (FAZNI).
- Reform the regulatory system. The regulatory system should be adjusted to promote a level playing field for wind power, and to guide the country toward low carbon intensity development. The existing regulatory system has developed mechanisms to steer the market in order to provide a more resilient interconnected system (measured by its capacity to deliver the demand even during the most difficult hydrological conditions). In doing so, Renewable Energy Technologies (RETs) have not received adequate compensation for their contribution. This situation could be remedied by:
  - *Adjustment of the reliability charge*. Colombia has developed a financial mechanism to produce an economic signal to investors as a price premium on reliable installed power capacity. Unfortunately, the existing regulation does not have clear rules to assess the potential contribution of wind energy to the overall reliability of the interconnected system and

thus favors conventional power plants. In practice this discriminatory treatment has been identified as a major barrier to further investments in the wind sector;

- o In relation to the above, an alternative policy option analyzed is *the possibility of reducing or eliminating Real Equivalent Cost of Capacity Charge (CERE) payment obligations for certain RETs,* as an extension of the existing option for small-scale investments;[11] and
- o The regulatory system could also be adjusted to *correct market failures by creating charges and payments to adjust for externalities*. To correct the economic signal for environmental externalities with impacts on local communities, ecosystems and economic sectors, a sustainability charge (green charge) has been proposed. Highly polluting technologies would be charged while clean technologies would receive a payment, making the system cost neutral to the government.

As found in discussions with decision makers and high-level policy advisors, the selected options are consistent with the existing regulatory system in Colombia and agreeable to the key stakeholders for further analysis. This analysis could likely take place when the government further fine-tunes its decision on policy instruments and policy options to guide the power sector in the future.

Impact of Policy Options

The assessment focuses on the identification of policy options (government intervention) that would enable a wind power plant to reach a 14 percent rate of financial return (independent investor decision). The main results of the assessment can be found in table 1. The table also summarizes the results of applying different options to a 300 MW wind power project, assuming three investment costs. For each investment cost, three scenarios are described, depending on the reliability factor used to recognize the project's contribution to firm energy during dry periods. The values include a worst-case assessment of firm energy contribution (reliability factor of 0.20), an intermediate value (reliability factor of 0.30), and a moderate estimate of the reliable firm energy (0.36).

Main results of the impact assessment of the policy instruments are:

- The single most effective policy instrument to promote wind power in Colombia is the granting of access to reliability payments, recognizing the firm energy and complementarity offered by wind. The implementation of this policy option is relatively easy to incorporate into the existing regulatory system.
- For new wind-power plants with costs in the range of $1,800/kW installed, the adoption of the reliability payments is enough to attract investors operating in wind fields with similar characteristics to that found in Northern Guajira.
- Higher capital costs require access to concessionary financial conditions, such as those provided under the CTF or fiscal incentives.

Lessons Learned

The principal lessons learned from this study are as follows:

- Wind-powered power plants are experiencing improvements in efficiency and reductions in operation and maintenance costs. Moreover, since 2008 investment costs have decreased, returning to the expected technology maturing behavior of cost reductions with time, a trend that is expected to continue.
- In certain locations, such as northern Colombia, wind resources are plentiful and could provide substantial complementarity to hydro-based power systems.
- Under existing conditions wind is not a competitive technology option in Colombia. Of the several barriers found, the most relevant is the difficulty in accessing payments for wind's contribution to firm energy.
- Governments have a wide range of policy instruments and policy options available to promote RET.
- To foster wind resources, governments should strengthen wind data collection as a public service, improve access to research and technology developments, and modernize grid access to wind power.
- Although the analysis has centered on Colombia and its energy sector, the approach and main results are applicable to other countries relying on hydropower.
- In summary, under existing conditions wind farms are not financially attractive in Colombia even considering the drop in investment costs recorded during 2009. However, wind investments would become financially attractive if the benefits of reliability payments are extended to wind power, even under current investment costs. The government has other multiple policy instruments to steer independent investors toward RETs. Adopting several of these options, as detailed in the report, seems relatively simple and will not distort the market. Improving the conditions for market entry of the wind option will serve to prepare the sector for the anticipated improvement of conditions as investment costs for wind decrease over time.
- Finally, deployment of the wind option would help the sector to strengthen its climate resilience and be better prepared to face climate variability, without increasing its carbon footprint.

Table 1. Actions Required to Reach a Financial Threshold for a 300 MW Wind Power Plant on the Northern Coast

Investment cost/kW (US$)	If reliability payment considered at %	Required actions to reach a 14% Internal Rate of Return (IRR)
$2,400	None[a]	Elimination of sector fees (AGC, FAZNI, CERE) and considerable financial support: i.e., 10% CTF financing and access to 60% soft loans[b]
	20%	Requires considerable financial support: i.e., 40% CTF[c] financing and access to 20% in soft loans
	30%	Requires considerable financial support: i.e., 30% CTF financing and access to 30% in soft loans
	36%	Requires considerable financial support: i.e., 20% CTF financing and access to 50% in soft loans
$2,100	None	Elimination of sector fees (AGC, FAZNI, CERE) and special financial support: i.e., access to 30% soft loans
	20%	Requires considerable financial support: i.e., 15% CTF financing and access to 55% in soft loans
	30%	Requires considerable financial support: i.e., 5% CTF financing and access to 65% in soft loans
	36%	Requires financing support: i.e., 60% access to soft loans
$1,800	None	Elimination of sector fees (AGC, FAZNI, CERE)
	20%	Requires financing support: i.e., 40% access to soft loans
	30%	No additional interventions required
	36%	No additional interventions required

Source: Authors' data.
Notes:
a. Waiving a project's obligation to make CERE contributions is financially equivalent to remunerating the project with a reliability factor of around 0.4, as is shown later in this analysis.
b. Soft loans here mean those with conditions typical of IBRD loans in Colombia: currently, a 17-year repayment period, interest rate LIBOR + 1.05%, front-end fee 0.25%.
c. The CTF is a climate change donor-driven fund seeking the implementation of transformational low carbon options. CTF financial conditions are typically a 0.65% interest rate with a 20-to 40-year repayment period and 10 years of grace.

Notes

[1] According to the National Hydrocarbon Agency of Colombia (*Agencia Nacional de Hidrocarburos,* ANH) in 2009.
[2] However, in 2008 there was an increase in registration of coal power projects (totaling 2,884 MW) and for the first time, fuel oil projects (totaling 305 MW of installed capacity). In contrast, 2,520 MW were natural gas, 7,770 MW were hydropower, and (as mentioned previously) 19.5 MW were wind.
[3] Generally, the term reliability refers to the certainty that operators may have with regard to the future power output of their power plant. In the context of conventional and nonconventional power sources, although some may claim that conventional power sources are more reliable,

others show that their reliability is hampered by the sudden shutdown of a power plant. Alternatively, nonconventional renewable power plants (such as wind farms) are claimed to be highly reliable because wind turbines do not all shut down simultaneously and instantaneously. As explained in this document, this is not a concept that has been integrated in the energy market in Colombia. It should be noted that in this document and for the case of Colombia, the term reliability is necessarily related to the reliability payment and the firm power output that power plants can produce during dry periods and in times of drought (this is further explained throughout the document).

[4] However, current technical constraints do not allow a system to be fully based on wind power.

[5] The level of emissions of the sector is well below the average in the United States, the European Union, Canada, and Mexico (0.35 ton CO_2e/MWh). Some power plants that utilize renewable energies have already tapped into the international carbon trade (Jepírachi Wind Farm, Amoyá Run-of-River Power Plant) at an individual level, and new mechanisms are being developed globally to promote low carbon development paths.

[6] Lawrence Berkeley National Laboratory (LBNL) estimates that this drop in costs could be due to the following: (a) O&M costs generally increase because as turbines age, component failures become more common; (b) as manufacturer warranties expire, projects installed more recently with larger turbines and more sophisticated designs may experience lower overall O&M costs on a per-MWh basis; and (c) project size. To normalize for factors (a) and (b) above, LBNL produces other figures and analyses that can be found in the original publication but nonetheless reveal O&M cost declines.

[7] The analysis is based on Jepírachi's operational record and wind data in meteorological stations in northern Colombia.

[8] Vergara et al., 2008.

[9] Note that the firm capacity of renewable energy is the capacity of conventional sources replaced, such that demands can be met with a specified reliability. The firm capacity of a renewable source depends on the correlated variations in demands and renewable supplies (Barrett 2007).

[10] Firm energy is defined as the maximum monthly energy that can be produced without deficits during the analysis period which includes El Niño occurrences (this is further explained throughout the document).

[11] It should be noted that simultaneously allowing for reliability charges and waiving CERE payments is not recommended. It would imply a logical contradiction because funds for the reliability charge come from CERE.

CHAPTER 1

Introduction

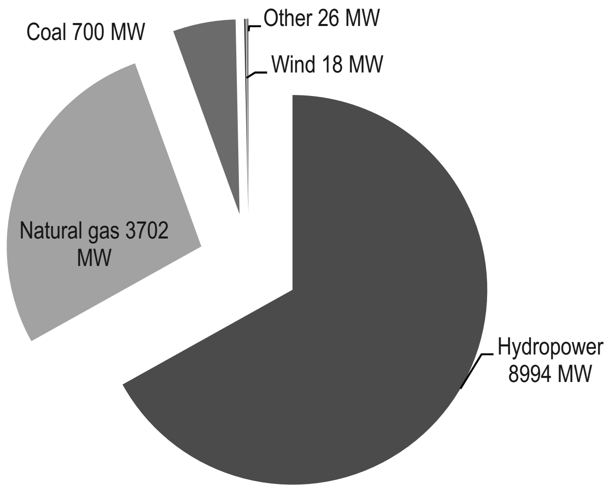
Context

This report constitutes the second phase of an effort to identify and address barriers to the deployment of wind energy in Colombia's power sector. The first phase was reported in a document entitled *Review of Policy Framework for Increased Reliance on Renewable Energy in Colombia*, completed in February 2008 and discussed with high-level energy authorities in Colombia. It concluded that (i) Colombia has a substantial nonconventional renewable energy resource endowment, in particular wind and solar but also significant prospects for geothermal, that complements the existing large hydropower potential; (ii) nonconventional energy options face important policy and regulatory barriers that prevent market entry; (iii) globally, several nonconventional renewable energy options are becoming financially more attractive as a result of a normal maturity process and commercialization of low carbon options; (iv) internalizing global and local externalities increases the competitiveness of selected nonconventional sources; and (v) options are available to decision makers to address barriers to the expansion of nonconventional power in the Colombian power mix. The report was designed to explore the impact of options identified for addressing these barriers.

The wind regime in Colombia has been rated among the best in South America. Offshore regions of the northern part of Colombia have been classified with class seven winds (winds over nine meters per second [m/s] at heights of 50 meters). The only other region in South America with such high wind availability is the Patagonia region of Chile and Argentina. Colombia has an average estimated wind power potential of 18 GW in the La Guajira region, enough to meet the national power demand twice over (Pérez and Osorio 2002). However, the country only has an installed capacity of 19.5 MW of wind energy (Jepírachi Project, supported by the Bank) with a few additional projects under consideration, including a 200 MW project in Ipapure. Consequently, wind power today represents a small fraction of the installed capacity. In 2008 the installed capacity in Colombia (13.4 GW) was 67 percent hydro (including small hydro), 27 percent natural gas, 5 percent coal, and 0.3 percent wind and cogeneration. Figure 1.1 illustrates the installed capacity per technology type.[1] The total annual electricity demand that same year was 54 TWh (UPME 2009).

Colombia also has substantial reserves of natural gas and coal, which could be used to generate power. The natural gas reserves in 2007 were seven tera cubic feet, including proven and unproven reserves (Ministry of Mines and Energy 2008). The La Guajira region of Colombia supplies most of the demand, 62 percent in 2007, compared to the next highest supplier (Cusiana) with 26 percent.

Figure 1.1 Installed Capacity per Technology Type



Source: UPME 2009.

Colombia's coal reserves are estimated at seven billion tons (or about 100 years of production at the present mining rate). These reserves are mostly located in the northern part of the country and are the largest coal reserves in South America. Most coal mined is anthracite, with very low ash and sulfur content, ideal for exports to the European market. Current production is 59 MMT (42 MTOE), with plans to increase production to 100 MMT by 2010.[2] Most of Colombia's coal production is exported. Of the coal used internally (2.4 MMT in 2000), more than 75 percent goes to industrial uses and the rest goes to the power sector (equivalent to 378 KTOE or ~4,400 GWh).

Colombia's power sector is maturing quickly, with relative stability in its regulations, an unbundled system, and a dispatch mechanism that closely resembles a well-functioning competitive market. Competition is promoted and tools have been designed to attract cost-effective capacity expansions that would promote reliability[3] of service. (A fuller description of the system and its dispatch mechanism was included in the stage-one report.)

However, the interconnected system, if unguided, is not likely to promote nonconventional renewable energy resources such as wind, but rather maintain a high capacity share of hydropower or alternatively move toward a more carbon-intensive energy resource mix (likely reliant on abundant coal reserves). In the latter case this would result in an increase in the carbon footprint of the economy from its current relatively low level of GHG emissions.[4]

The analysis focuses on wind power. Wind is currently the least-cost nonconventional renewable energy alternative. There is also the possible complementarity of the wind regime with periods of low hydrology, which is further explored in this report. The World Bank was an early supporter of the wind option in Colombia through its participation in the Prototype Carbon Fund of the Jepírachi Wind Power Plant in the province of La Guajira.

Structure of the Report

After the introduction, Chapter 2 summarizes the main findings of the first phase. It describes Colombia's energy profile and presents the main barriers that limit the development of nonconventional renewable energy sources. Chapter 3 presents a comprehensive comparison of 37 energy technologies through levelized cost analyses. The analysis permits the identification of the technologies most likely to participate in the future expansion of the interconnected system. It also studies whether CO_2 revenues change the least-cost capacity ranking. Chapter 4 summarizes the cost evolution of wind energy units over time and provides an overview of the trends that define the future of this technology. Chapter 5 presents the complementarity of joint operation of wind and hydro in Colombia and explores the possible contribution of wind to firm energy. Chapter 6 introduces different policy options to facilitate the market entry of wind power, and Chapter 7 reviews the effectiveness of the selected policy options in creating the adequate incentives (that is, expected financial returns on equity) to attract potential investors. Key findings and conclusions are summarized in the Chapter 8.

Notes

[1] In 2008 there was an increase in the registration of prospective coal power projects (totaling 2,884 MW) and, for the first time, of fuel oil projects (totaling 305 MW of installed capacity). In contrast, 2,520 MW were natural gas, 7,770 MW were hydropower, and (as mentioned previously) 19.5 MW were wind.

[2] Although there are plans to expand production, there is also a holdback based on fears that this would cause a drop in coal prices because Colombia is such an important player in the world's thermal coal market.

[3] Generally, the term "reliability" refers to the certainty that operators may have with regard to the future power output of their power plants. In the context of conventional and nonconventional power sources, although some may claim that conventional power sources are more reliable, others show that their reliability is hampered by the sudden shutdown of a power plant. Alternatively, nonconventional renewable power plants (such as wind farms) are claimed to be highly reliable because wind turbines do not all shut down simultaneously and instantaneously. As explained in this document, this is not a concept that has been integrated in the energy market in Colombia. It should be noted that in this document and for the case of Colombia, the term "reliability" is necessarily related to the "reliability payment" and the "firm power" output that power plants can produce during dry periods and in times of drought (this is further explained throughout the document).

[4] The sector's level of emissions is well below the average in the United States, the European Union, Canada, and Mexico (0.35 ton CO_2e/MWh). Some power plants that utilize renewable energies have already tapped into the international carbon trade (Jepírachi Wind Farm, Amoyá Run-of-River Power Plant) at an individual level, and new mechanisms are being developed globally to promote low carbon development paths.

CHAPTER 2

Summary of Findings from First Stage Report: Nonconventional Renewable Energy Barrier Analysis

This chapter summarizes the results of the first stage of the ESMAP-funded Review of Policy Framework for Increased Reliance on Renewable Energy in Colombia. Its objective was to identify barriers to the development of nonconventional renewable energy resources in Colombia. Large hydro is not included as part of nonconventional energy resources because it is a well-established option in Colombia. Large hydropower is also a relatively low-cost renewable energy source and already constitutes the bulk of the base load in the power sector. This document emphasizes nonconventional renewable energy sources.

Colombia is a net energy exporter. Colombia is not one of the world's leading energy producers, but it is a net energy exporter. Colombia's demand for energy has been increasing over the past decade and is expected to grow at an average of about 3.5 percent per year through 2020 (UPME 2009). The country's total energy production in 2006 was 3.3 QUADS (quadrillion[1] BTU),[2] while consumption was 1.2 QUADS, from which electricity consumption stood at 0.14 QUADS.[3] This highlights the energy export nature of the Colombian economy. The difference between its energy production and consumption has been due mostly to oil and large coal exports.

The country is a modest energy user and CO_2 emitter. The power sector in Colombia already has a very low carbon footprint (0.35 tons/MWh generated[4]). Energy demand is characterized by growing requirements in the transport sector, followed by the industrial and domestic sectors. The average power use per capita is 923 kilowatt hours (kWh)/year. National carbon dioxide (CO_2) emissions are 59.4 million metric tons (MMT), or 1.3 tons of CO_2 (tCO_2)/capita, less than half the world average. Colombia's energy intensiveness is 0.2 CO_2/GDP (PPP) (kg CO_2/2000 US$ PPP), according to the International Energy Agency (IEA) in 2006.[5] This is much lower than that of countries in Europe and North America.

Hydropower is the dominant source of energy and is likely to continue to characterize Colombia's power sector for the foreseeable future. Currently, about 64 percent of capacity and 81 percent of generation are hydro based. A generous hydrological regime and a favorable orography provide the basis for a large hydropower potential. The most recent bid for power supply resulted in an overwhelming supply of new hydropower plants to meet the projected increase in demand in the immediate future.

A largely hydro-based power system may be susceptible to anticipated climate variability affecting rainfall patterns. A projected increase in the intensification of the water cycle and the possible intensification of extreme events (El Niño-Southern Oscillation [ENSO] and La Niña) associated with temperature dipoles on the Pacific coast of Colombia may raise the vulnerability of the power sector by affecting the reservoir capacity of hydropower-based plants. It is therefore prudent to examine how the sector's climate resilience could be strengthened.

Colombia's oil reserves are limited and may not be able to maintain self-reliance in the short term. The country has long relied on a generous endowment of fossil fuels, oil, coal, and gas to meet domestic energy needs and to contribute substantially to the balance of trade in international markets. However, self-reliance on domestic oil is in question because reserves in number of years of supply have decreased and would only last seven years at the current rate of production (Ministry of Mines and Energy 2008). Natural gas supplies are sufficient for 27 years of supply at the current rate of consumption; however, bottlenecks in the gas distribution system limit its use in several areas of the country. The main transportation restrictions will be removed in the 2010–2012 period with new pipelines and transport loops that are under construction and that could facilitate natural gas transport from the main fields to the large natural gas markets.

Prior to the use of nonconventional renewable resources in the power sector, there is a need to address a number of barriers that impede the wide deployment of these resources. These include: capital intensity, local financial market limitations, lack of regulations and regulatory uncertainty, lack of adequate data to assess resource availability, lack of clear rules for nonconventional energy sources, bias toward conventional technologies (for example, with the firm energy reliability payment), and limited strategic planning.

The Government of Colombia (GOC) can play a significant role in facilitating the entry of nonconventional energy sources. Policy options include: (i) developing a strategic energy plan beyond 10 years that includes nonconventional energy resources; (ii) similarly, adopting least-cost planning that includes environmental and social costs in decision making; (iii) modifying the regulatory framework to address obstacles that prevent a level playing field for nonconventional renewable power resources; (iv) facilitating information sharing on wind endowment; and (v) facilitating access to financial instruments available under climate change investment funds.

This report focuses on alternatives to address (counter) the relatively higher capital intensity of the wind power option, which may result in a more attractive energy source in the country, provided that certain potential regulatory framework modifications are made.

Notes

[1] 10^{15}; SI prefix peta (P).

[2] 3.3 QUADS or 85 MTOE (IEA 2006).

[3] 0.14 QUADS or 42 TWh (IEA 2006).

[4] As estimated in the recently completed PDD for the Amoyá Environmental Services Project.

[5] http://www.iea.org/Textbase/stats/indicators.asp?COUNTRY_CODE=CO&Submit=Submit.

CHAPTER 3

Cost Comparison of Alternative Power Sources Based on the Expansion Plan for 2008–2025

Before a detailed assessment is made of policy options to facilitate market entry for wind power, this chapter provides a cost comparison of available technologies for power generation, based on the generation expansion plan for 2008–2025 prepared by the Mines and Energy Planning Unit (UPME) of the Colombian Ministry of Mines and Energy. For this purpose, the analysis includes simple screening curves of 37 power generation technologies to compare with the results of the wind option.

Hydropower is the dominant source in the National Interconnected System (NIS) and is expected to continue to be so for the foreseeable future. The large base-load hydro capacity is complemented today by thermal power, mostly from domestic natural gas-fired power plants and a much smaller amount from domestic coal-fired power plants.

Methodology for Technology Cost Comparison

Due to data availability restrictions, the analysis is limited to a simple static analysis to provide indicative values. Projections of increase or change in capital cost of power plants are beyond the scope of this study, especially considering the rapid growth and volatility in capital costs experienced since the early part of the present decade. Therefore, the most recent capital costs available are used (2007/2008). Price assumptions, in line with national projections, are made as follows: coal at US$35 per ton, natural gas at US$4/MBTU, and residual fuel oil for power plants at US$51 per barrel.

The calculation of levelized total plant costs (TPC) is based on the "Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies" (World Bank 2007). The 37 electricity generation options are listed in table 3.1. Coal-fired power plants are considered as equipped with flue gas desulfurization (FGD) and selective catalytic reduction (SCR). Although Colombia currently does not require FGD, equipping coal-fired power plants with FGD and SCR represents best international practice even when low-sulfur coal is used. In addition, equipping SCR and FGD is a prerequisite to make coal-fired power plants ready for carbon capture and storage (CCS). Coal-fired power plant options include those that are much less expensively made in China. Two metrics are used to assess the relative rating, as per the procedure mentioned above: the cost of capacity of the plant per year (US$/kW per year) and the cost of generation (US$/kWh).

Table 3.1. Power Generation Options Included in the Screening Curve Analyses

Plant Type	
Subcritical (SC) coal-fired 300 MW/550MW	Diesel 5 MW
Supercritical (SPC) coal-fired 550 MW	Hydro 400 MW/1200 MW
Ultra supercritical (USPC) coal-fired 550 MW*	Wind 10MW/300 MW
Subcritical (SC) 300 MW/550 MW coal-fired carbon capture and storage (CCS)	Subcritical (SC) Circulating Fluidized Bed (CFB) 300MW/500MW
Supercritical (SPC) coal-fired 550 MW carbon capture and storage (CCS)	Subcritical (SC) Natural Gas Steam 300 MW
Ultra supercritical (USPC) coal-fired 550 MW carbon capture and storage (CCS)	Subcritical (SC) Oil Steam to Coal 300 MW
Integrated Gasification Combined Cycle (IGCC) 300 MW/640 MW	Subcritical (SC) Natural Gas Steam to Coal 300 MW
Integrated Gasification Combined Cycle (IGCC) carbon capture and storage (CCS) 220 MW/555 MW	Subcritical (SC) 500 MW Rehabilitation
Simple Cycle Gas Turbine (GT) 150 MW	China subcritical (SC) 300 MW/550 MW
Combined Cycle Gas Turbine (CCGT) 140 MW/560 MW	China supercritical (SPC) 550 MW
Combined Cycle Gas Turbine (CCGT)	China ultrasupercritical (USPC) 550 MW
Combined Cycle Gas Turbine (CCGT) carbon capture and storage (CCS) 50 MW	China subcritical (SC) 300 MW/SC 550 MW carbon capture and storage (CCS)
Combined Cycle Gas Turbine (CCGT) carbon capture and storage (CCS) 482 MW	China supercritical (SPC) 550 MW carbon capture and storage (CCS)
Fuel Oil Steam 300MW	

Source: Authors' data.
Notes: CFB: Circulating Fluidized Bed. IGCC: Integrated Gasification Combined Cycle. CCS: Carbon Capture and Storage. CCGT: Combined Cycle Gas Turbine. SC: Subcritical. SPC: Supercritical. USPC: Ultra supercritical.
*According to the World Coal Institute website in 2009, new pulverized coal combustion systems—utilizing supercritical and ultrasupercritical technology—operate at increasingly higher temperatures and pressures and therefore achieve higher efficiencies and significant CO_2 reductions than those of conventional pulverized coal-fired units (www.worldcoal.org).

As of 2006, nine coal-fired power plants were installed in Colombia (totaling 700 MW); these were commissioned between 1963 and 1999. Although it is unclear whether these power plants have been rehabilitated to prolong their plant life, they are included in the analysis. Moreover, although a few hydropower plants operate at a high capacity factor of around 80 percent, it is assumed that, on average, the hydropower capacity factor is 60 percent. A 40 percent capacity factor is assumed for wind power.[1]

Within the screening curves, the electricity generation plants were ranked in order of least-levelized cost per kW for different capacity factors. The levelized cost analysis is done with and without consideration of carbon revenues. The results are presented below.

Least (Levelized) Cost Comparison

Clearly, the low cost of hydropower in Colombia is evidenced by the high hydropower capacity reserve of its power system, in which many hydropower plants function as base load. The total hydropower net effective installed capacity is 13 GW with a peak power demand at 9 GW. With or without CO_2e emission reduction revenues, large-scale hydropower is the least-cost power option.

The rehabilitation of subcritical coal power plants and the fuel switch from oil or natural gas to coal-fired power plants present the next lowest levelized costs at any capacity factor. However, these options do not add to installed capacity.

The next low-cost option is low-cost manufactured coal-fired power plants, without allowance for CCS. Likewise, Combined Cycle Gas Turbines (CCGT) are among the cheapest technology options. Wind power generation under current scenarios and conditions, and even with possible capacity factors of up to 40 percent, is not among the least-cost choices. Similarly, Integrated Gasification Combined Cycle (IGCC) and CCS technologies are also not among the least-cost options in Colombia.

The most cost-effective power generation options are presented in tables 3.2 and 3.3. The options presented are similar to the current generation picture of Colombia, but with more inclusion of coal power plants due to their lower cost. Abundant coal reserves would back up the development of this option. This assumes that the internalization of global environmental issues is not considered. Figures 3.1[2] and 3.2 provide a graphic representation of the results of the analysis. Figure 3.1 presents the results for the aggregate cost over a year; this figure increases as the capacity factor increases since it shows the amount of power generated over the year. Figure 3.2 presents the calculated generation costs, which decrease as the capacity factor increases.

Table 3.2. Least-Cost Capacity Expansion Mix (without CO_2e revenue)

Electricity generation	Base load	Medium load	Peak load
Major additions of new capacity	Large and medium hydropower with modest backup requirement of low-cost coal-fired SC, SPC and USPC power plants using most advanced clean coal technology	Large and medium hydropower	Large and medium hydropower
Minor additions of capacity	CCGT and old SC coal power plant rehabilitation using most advanced clean coal technology	CCGT (which could also operate both base load and peaking, as backup)	Gas turbines and diesel
Additional 15% for capacity reserve	Large and medium hydropower	Large and medium hydropower	Large and medium hydropower

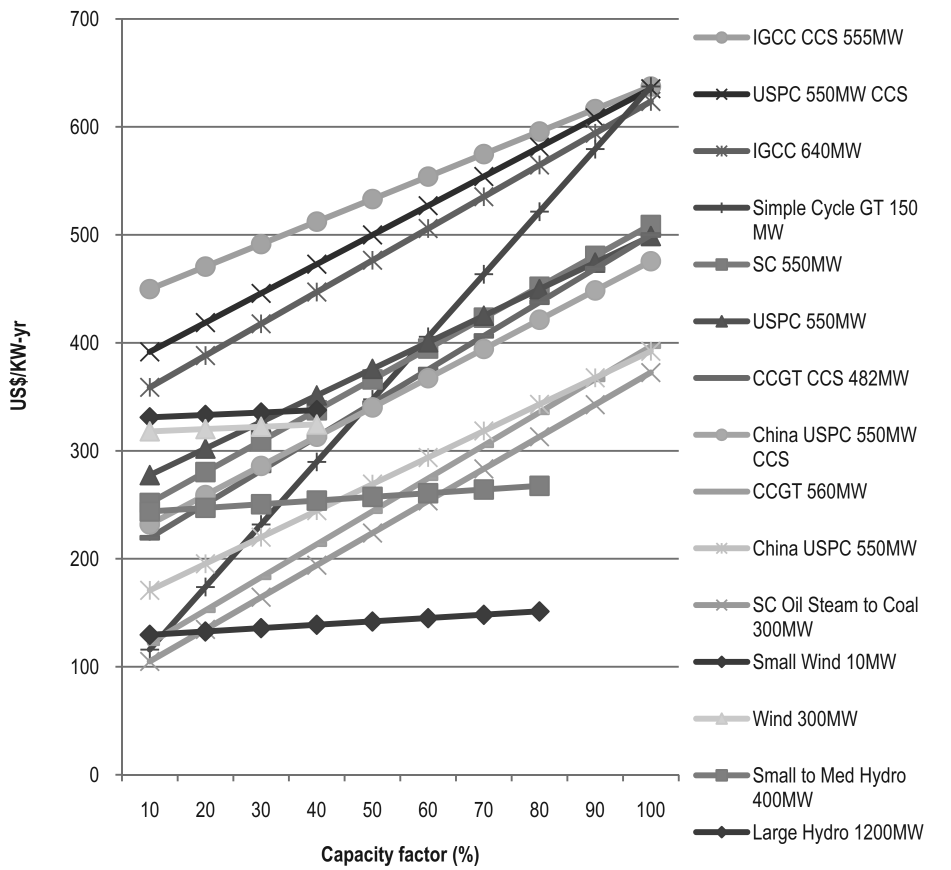
Source: Authors' data.

Table 3.3. Suggested Capacity Expansion Mix at US$18 per Ton CO_2e

Electricity generation	Base load	Medium load	Peak load
Major new capacity	Large and medium hydropower with modest backup requirement of low-cost coal-fired SC, SPC and USPC power plants using most advanced clean coal technology	Large and medium hydropower and wind power	Large and medium hydropower and wind power
Modest new capacity	CCGT and old SC coal power plant rehabilitation using most advanced clean coal technology	CCGT (which could also operate both base load and peaking, as backup)	Gas turbines and diesel
15% or more capacity reserve	Large and medium hydropower	Large and medium hydropower	Large and medium hydropower

Source: Authors' data.

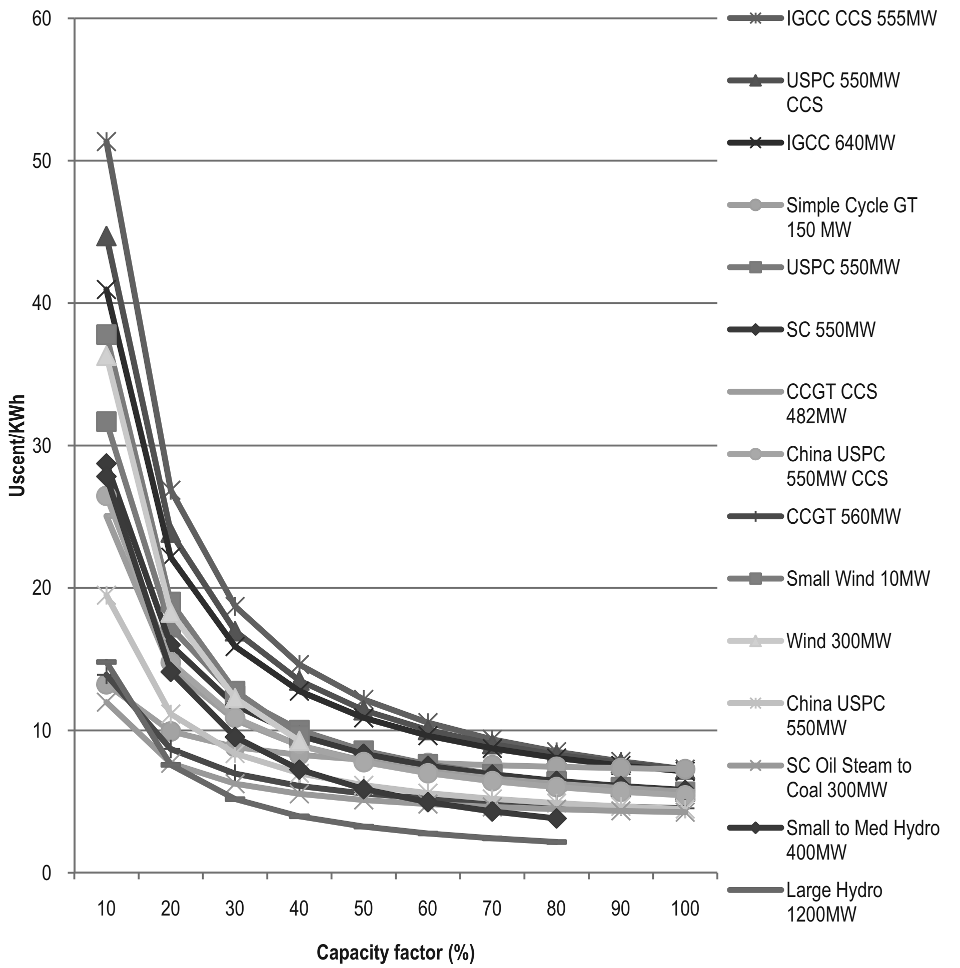
Figure 3.1. Screening Curve for Levelized Total Costs Measured in Cost of Capacity of a Plant per Year (US$/kW-yr) at Different Capacity Factors



Source: Authors' data.

Note: Coal price US$35/ton; emission reductions US$18/ton CO_2e.

Figure 3.2. Screening Curve for Levelized Total Costs at Different Capacity Factors Measured in Terms of Generation Costs (US cents/kWh)



Source: Authors' data.
Note: Coal price US$35/ton; Emission reductions US$18/ton CO_2e.

Coal Netback Calculations

For coal prices ranging up to US$60 per ton, the rehabilitation of existing coal-fired power plants (limited to a total of 700 MW) is among the least-cost options for adding capacity. Rehabilitating existing coal-fired power plants is a good option for the range of coal prices indicated.[3]

At a price of more than US$50 per ton of coal, and including US$18 per CO_2e ton, new coal power plants are not a least-cost option. Furthermore, if low-cost coal-fired power plant[4] options are excluded, coal-fired power plants become the least-cost options only at very low coal prices from US$10 to US$20 per ton.

Allowing for CO_2 revenues does not significantly change the least-cost capacity expansion ranking. For analysis purposes it is assumed that CO_2e is valued at US$18 per ton for the 37 options (the results are similar to those presented in table A1.2 of Appendix 1). For 2007 investment costs (base year used) even at a CO_2e price of US$50, wind power is still not the least-cost option. Within this range of revenues, carbon credits fail to effectively affect the ranking of options, proving that **the CDM alone at the 2009 price level is not enough to promote alternative zero-carbon energy under existing conditions in Colombia**. Therefore, other policy options are required to facilitate market entry for wind power.

From the results of the analysis, and under current and foreseeable conditions, large hydro remains the best option for power generation and guarantees a power sector that is relatively low in carbon footprint. Moreover, under the current scenario, coal seems an obvious backup option to the base load.

Since this is a limited estimate, based on secondary data, a more comprehensive modeling exercise and impact analyses on low carbon growth should be conducted; this would include all other relevant costs (for example, transportation costs, transmission pipeline and distribution costs, transaction costs, environmental and social costs, institutional costs, logistical costs, and so forth). Tools available to perform this analysis include MARKAL.[5] Moreover, although not directly assessed, the deployment of renewable sources, including hydro, reduces exposure to volatility in fossil fuel prices.

Notes

[1] A capacity factor of 40 percent is assumed: the winds on the northern coast of Colombia are class 7 and are constant. This number has been discussed with the utility that owns, maintains, and operates the only wind farm in Colombia. Values have been and can be obtained in the area (in a location near the site where a larger wind project can be located).

[2] Figure 3.1 shows the cost per year of operation of a power plant operating at different plant factors. The higher the plant factor the higher the costs (although the cost per unit of energy generated decreases). On the other hand, figure 3.2 presents the average generation costs, which decrease as the capacity factor increases.

[3] In Colombia, most coal power plants are old and have not been retrofitted (there has been a focus on building natural gas plants, rather than coal plants). These coal power plants could be modernized to achieve greater efficiencies.

[4] New low-cost coal-fired power plants (imported from China, with operational reliability yet to be defined) result in least cost; this is especially true if a supercritical (SPC) coal-fired power plant of 550 MW is installed.

[5] MARKAL is a generic model tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state, provincial or community level. MARKAL was developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency. Source: http://www.etsap.org/Tools/MARKAL.htm.

CHAPTER 4

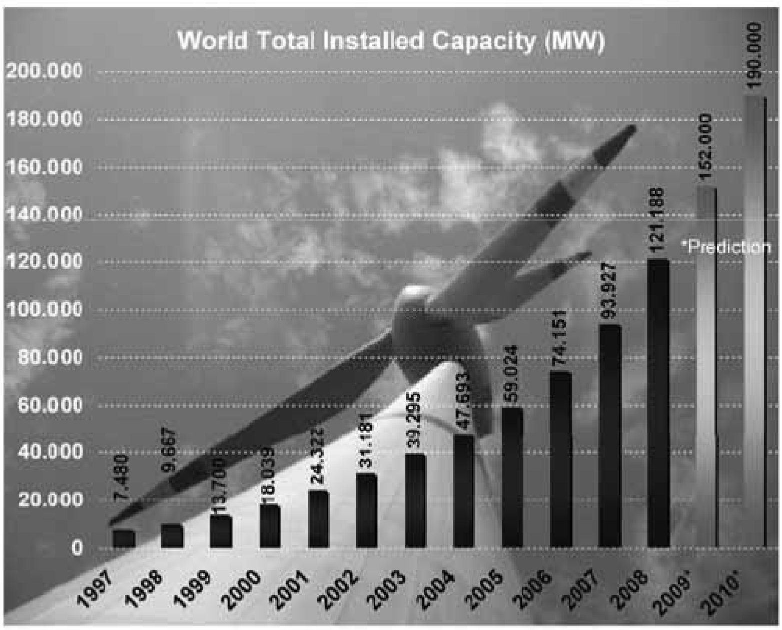
Wind Power Costs Outlook

The results of the technology cost comparison show that under existing conditions (base year 2007) wind power is not a least-cost option for power generation in Colombia, even at a CO_2e price of US$50/ton and high capacity factors. However, wind power costs are expected to decrease with time as the technology matures. This chapter examines the trends in wind power costs and performance.

Technical Viability of Wind Power

In early 2009 wind power installed capacity worldwide reached 121 GW. Since the late 1990s, wind power installed capacity has increased by over 20 percent annually and is expected to continue increasing in 2009 and 2010 by similar magnitudes (figure 4.1).

Figure 4.1. World Total Wind Power Installed Capacity (MW)

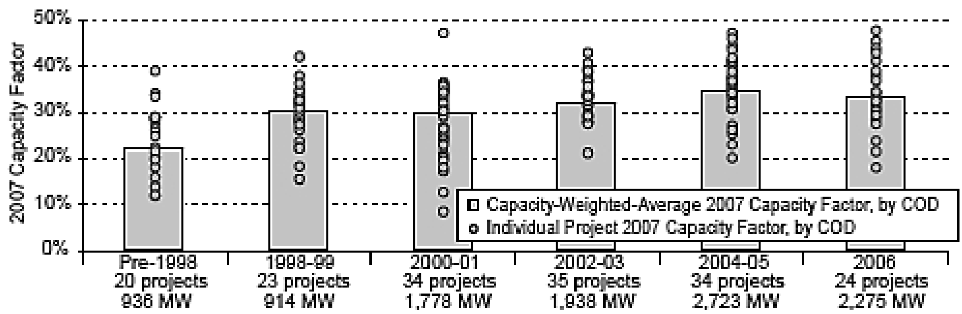


Source: World Wind Energy Association 2009.

Efficiency Gains over Time

Project capacity factors have increased in recent years due to technological advancements, higher hub height, and improved siting. The weighted average of capacity factors went from 22 percent for wind power projects installed before 1998 to 30–32 percent for projects installed from 1998 to 2003 and to 33–35 percent for projects installed from 2004 to 2006 (LBNL 2008). Even capacity factors above 40 percent can be found in excellent wind resource areas, such as those in northern Colombia. The following figure (4.2) presents the evolution of capacity factors by commercial operation date in the United States.

Figure 4.2. Project Capacity Factors by Commercial Operation Date



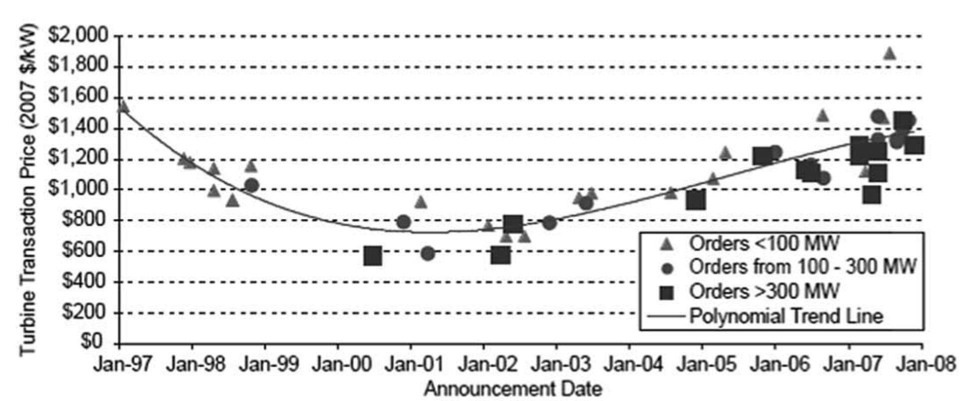
Source: Berkeley Lab database.

A cost study conducted by the U.S. Department of Energy (DOE) Wind Program identified numerous opportunities for reductions in the life-cycle cost of wind power (Cohen and Schweizer et al. 2008). Based on machine performance and cost, this study used advanced concepts to suggest pathways that integrate the individual contributions from component-level improvements into system-level estimates of the capital cost, annual energy production, reliability, operation, maintenance, and balance of station. The results indicate significant potential impacts on annual energy production increases (estimated with an average efficiency increase of 45 percent) and capital cost reductions of 10 percent. Changes in annual energy production are equivalent to changes in the capacity factor because the turbine rating was fixed.

Capital Cost Evolution

Figure 4.3 provides the trend in turbine costs in the U.S. market. Wind power project costs are a function of turbine prices. Turbine prices went from US$700/kW in 2000–2002 to US$1240/kW in 2007; these costs were even higher in 2008 (US$2,200/installed kW). Higher costs in 2006–2008 were likely due to the high demand for technology (shortages in certain turbine components and turbines, greater demand than supply), the high cost of materials/inputs (such as oil and steel), a general move by manufacturers to improve their profitability, the devaluation of the dollar in comparison to the euro, an upscaling of turbine size and hub height, and improved sophistication in turbine design such as improved grid interaction (LBNL 2008).

Figure 4.3. Reported US Wind Turbine Transaction Prices over Time



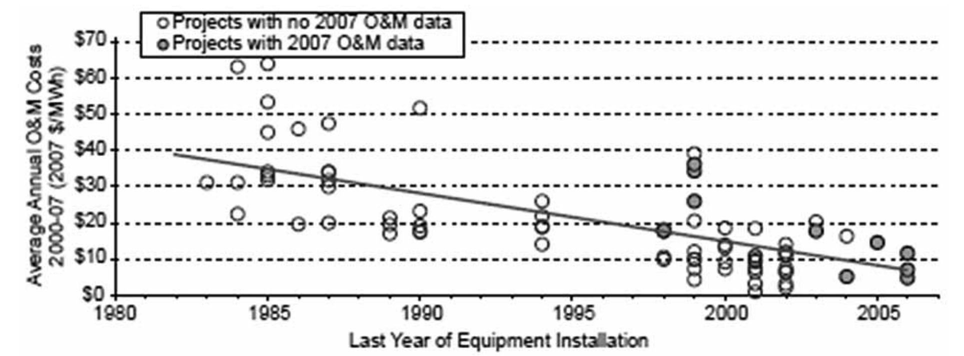
Source: LBNL 2008.

After the peak values reached in 2008 (equivalent to unit investment costs around US$2,400/kW), new transactions indicate a return to a more competitive market. As of March 2009, the European Wind Energy Association reported that the average cost of recent projects is now back to around the level of €1,225/kW. This translates to approximately US$1,800/kW as the average 2009 transactions in the European market. This would continue the long-term trend in capital cost reductions observed earlier.

Operation and Maintenance Costs Are Decreasing

Annual average O&M costs of wind power production have declined[1] substantially since 1980. O&M cost declines can be observed in figure 4.4 for projects that were installed in 1980, until 2005. The figure specifically suggests that capacity-weighted average 2000–2007 operation and maintenance costs for projects constructed in the 1980s equal US$30/MWh, dropping to US$20/MWh for projects installed in the 1990s, and to US$9/MWh for projects installed in the 2000s.

Figure 4.4. Average Operation and Maintenance Costs for Available Data Years from 2000 to 2007, by Last Year of Equipment Installation



Source: Berkeley Lab database; five data points suppressed to protect confidentiality.

Wind Power Grid Integration

Integration of large capacities of wind energy into power systems is increasingly less of a concern (there is growing literature in this respect[2]). In fact, as an example, the European Wind Energy Association considers that integrating 300 GW of wind power by year 2030 into European power systems is not only a feasible option for the electricity supply, but it has the benefits of increasing the security of supply and could contribute to low and predictable electricity prices (European Wind Energy Association 2008). Furthermore, wind power has also been stated to help with system stability by providing Low Voltage Run-Through (LVRT)[3] and dynamic variable support to thus reduce voltage excursions and dampen swings (UWIG 2007). Moreover, by integrating wind power into the energy grid, the aggregation of wind turbines reduces variability in power generation;[4] simultaneous loss of capacity does not occur in a broad geographic region (as shown by extensive modeling studies). Meso-scale wind forecasting could provide some predictability of plant output within some margin of error; similarly, forecasts are improving (UWIG 2007).

Turbine orders larger than 300 MW tend to result in lower costs than turbine orders of less than 100 MW (likely due to economies of scale and lower transaction costs/kW) (LBNL 2008). However, there seems to be a small difference in costs for projects between 30 and 200 MW; in general, variations in costs of wind projects are more likely due to regional differences such as development costs, site and permitting requirements, and construction expenses (URS 2008).

Outlook

Wind power has undergone a fast developmental phase. The unprecedented pace of growth during this decade has outpaced manufacturing capabilities, creating a seller's-side market. Prices have also been affected by commodity price fluctuations, associated with the increasing levels of economic activity seen in the last five years and more recently by changes in the worldwide economy. Wind power capacity is expected to continue to rise significantly worldwide and to play an increasingly relevant role in meeting the growing energy demands of the future.

Wind power installed capacity in Latin America is very low and is increasing slowly. However, the slow pace of growth is expected to change once the downward trend in prices induces more stable market conditions. The financial crisis might allow the industry to find opportunities for development and to deal with demand expectations.

The threshold price for the wind power option (300 MW) to become competitive with large hydro power (1,200 MW), which is currently the least-cost option, without reliance on incentives or other subsidies with the 30 or 40 percent capacity factor is when the levelized cost of wind energy is at US$940/KW and hydro power at US$1,200/KW. Both options then total for either US$136/KW/year at the capacity factor of 30 percent or US$139/KW/year at the capacity factor of 40 percent.

Notes

[1] LBNL estimates that this drop in costs could be due to the following: (a) O&M costs generally increase because as turbines age, component failures become more common; (b) as manufacturer warranties expire, projects installed more recently with larger turbines and more sophisticated designs may experience lower overall O&M costs on a per-MWh basis; and (c) project size. To normalize for factors (a) and (b) above, LBNL produces other figures and analyses that can be found in the original publication but nonetheless reveal O&M cost declines.

[2] See, for example, Boyle (2007).

[3] Also called ride-through faults, LVRTs are devices that may be required to be available when the voltage in the grid is temporarily reduced due to a fault or load change in the grid. Wind generators can serve as LVRTs.

[4] Aggregation provides smoothing in the short term. However, there are significant benefits to geographical dispersion because dispersion provides smoothing in the long term.

CHAPTER 5

Wind and Hydro in Colombia: Complementarity Analysis

Although the levelized cost analysis indicates that under current conditions wind is not competitive with hydro, wind power under proper circumstances could complement the sector's large hydro-based capacity. This chapter examines the extent to which the wind resource complements the hydro regime in the country. It also characterizes some of the climate vulnerabilities of a hydro-based power sector to future climate change.

Complementarity of the Wind and Hydro Regimes

Does the wind energy potential in northern Colombia have a distribution that is complementary to the availability of hydropower? This question can be examined on the basis of Jepírachi's[1] power generation records, available since it started operations in 2004,[2] and on the analysis of wind data in meteorological stations in northern Colombia. Complementarity could also be measured by wind availability during extreme drought conditions associated with El Niño events, and through the analysis of independent and joint operation of the Jepírachi wind farm and hydropower plants on selected rivers in Colombia. This chapter presents the results of these analyses.

Generation Data from Jepírachi

Power generation data at hourly level were available for the Jepírachi plant during its operation period.[3] These data make it possible to estimate the distribution of the average monthly generation under peak, medium, and base loads (table 5.1). For the dry period of December 1 to April 30 (as defined by the regulatory agency, CREG), Jepírachi produces 10 percent more energy than its yearly average. The historical generation in Jepírachi during the first four months of the year is 17 percent above the yearly monthly generation.

Table 5.1. Jepírachi Monthly Power Generation

	Jepírachi average generation (MWh)				Ratio of average generation		
		Demand Block			Demand Block		
	Total	Peak Load	Med Load	Low Load	Peak Load	Med Load	Low Load
Jan	5098	232	4074	792	1.08	1.13	1.00
Feb	5338	258	4269	811	1.20	1.18	1.03
Mar	6414	313	5041	1060	1.46	1.40	1.34
Apr	4893	230	3737	926	1.07	1.03	1.17
May	4515	215	3439	861	1.00	0.95	1.09
Jun	4531	218	3558	755	1.01	0.99	0.96
Jul	6392	290	4768	1334	1.35	1.32	1.69
Aug	5123	248	3939	936	1.15	1.09	1.19
Sep	4046	194	3115	737	0.90	0.86	0.93
Oct	2492	107	1979	406	0.50	0.55	0.51
Nov	2830	130	2307	393	0.61	0.64	0.50
Dec	3722	143	3119	460	0.67	0.86	0.58
Total	55394	2578	43345	9471	1.00	1.00	1.00
"dry" period	25465	1176	20240	4049	1.09	1.12	1.03
"wet" period	29929	1402	23105	5422	0.93	0.91	0.98

Source: Consultants' study (see Appendix 6).
Note: The calculations assume that peak load corresponds to the generation during the 20th hour of the day, medium load corresponds to generation during the 6th to 19th and 21th to 23rd hours, and base load corresponds to the remaining hours of the day. This distribution is very important since the medium and peak load hours (when energy is more costly) have a larger plant factor than the base load hours.

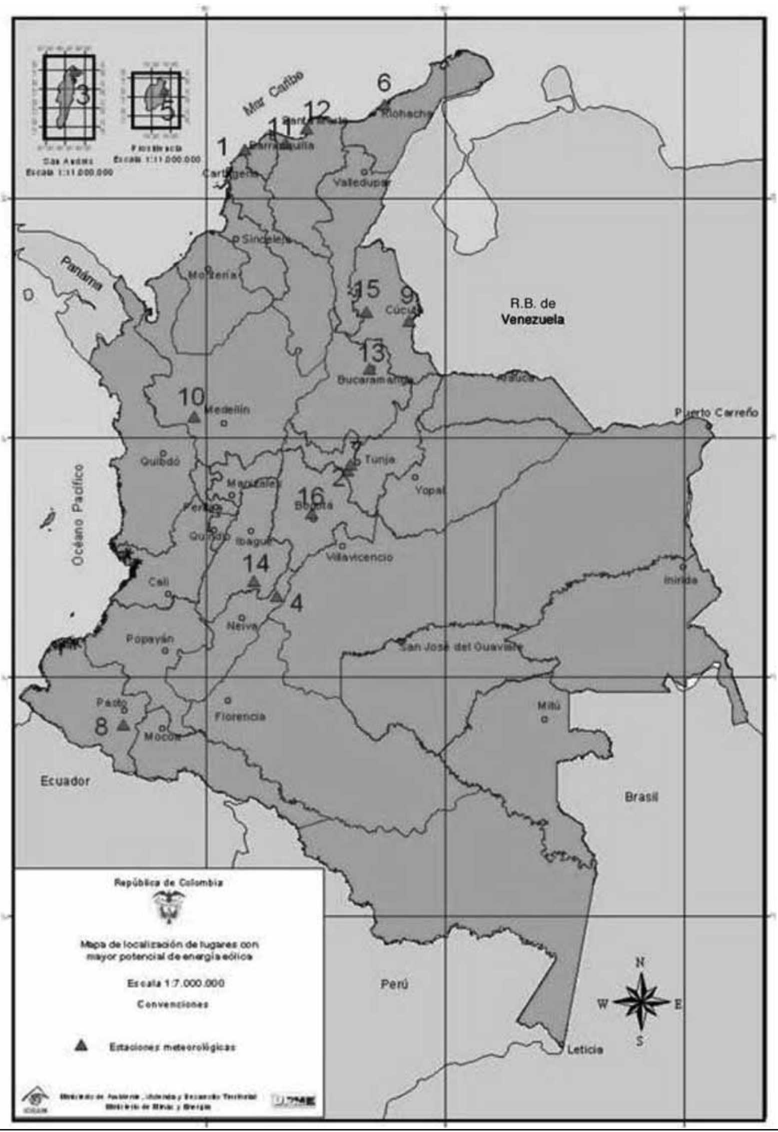
Table 5.1 also shows the distribution of energy production during the NIS Peak Load, Medium Load, and Low Load periods. During the Peak Load period, defined as the hour of peak demand (8 p.m.), Jepírachi produces 17 percent more energy during the dry season in relation to production during the wet season. This could be interpreted as an indication of the ability of wind-based power plants to contribute to peak demand when it is most needed. The contribution of wind farms is also higher during the dry season for all load conditions. While the hydro-based system undergoes the dry season (low availability of water for generation), the wind farms in northern Colombia could produce well above their average output.

Wind Data from Reference Stations

Figures 5.1 to 5.3 present a graphic representation[4]of the temporal characteristics of the northern coast wind field in Colombia. Figure 5.1 illustrates the distribution of the reference stations used to describe the wind potential on the northern coast of Colombia. Wind data are summarized from Almirante Padilla airport in La Guajira (Station 6 in figure 5.1), the closest climate station to Jepírachi reported in the Wind Atlas, and three other climate stations along the northern Caribbean coast of Colombia (Galerazamba, Bolívar; E. Cortizzos Airport, Atlántico; and S. Bolívar Airport, Magdalena).

The Almirante Padilla Airport station provides data that are representative of the wind field found in Northern Guajira. Its graphic representation is shown in figure 5.2. The figure shows wind availability (speed above 4.0 m/s) from 8 or 9 a.m. until 5 to 7 p.m. on a consistent basis. Lower speeds are measured from August to December. Higher speeds are measured from December to April and then again during June and July.

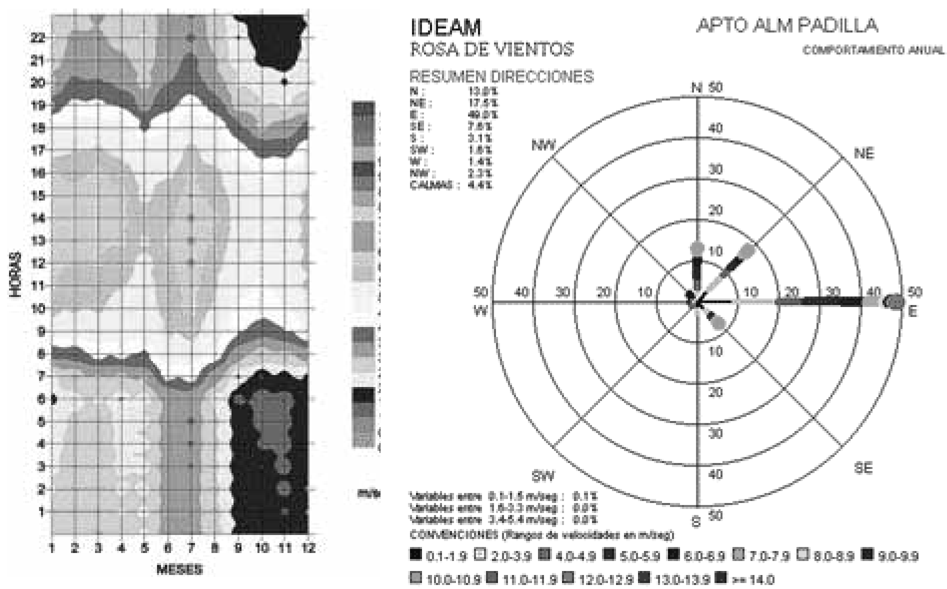
Figure 5.1. Stations Used to Characterize Wind Power in Colombia



Source: UPME and IDEAM.

Note: Station 6, Almirante Padilla Airport, Guajira; Station 12, Simón Bolívar Airport, Magdalena; Station 11, Soledad Airport, Atlántico; and Station 1, Galarezamba, Bolívar.

Figure 5.2. Almirante Padilla Airport, Guajira



Source: UPME and IDEAM.

Data collected at other coastal sites along the Caribbean coast of Colombia were also analyzed (figure 5.3). The trade winds follow Colombia's northern coast from the northeast to the west during most of the year. This general circulation pattern remains year around, with changes in intensity (wind speeds). In all cases, wind intensity peaks between February and March. This is indicated in table 5.2.

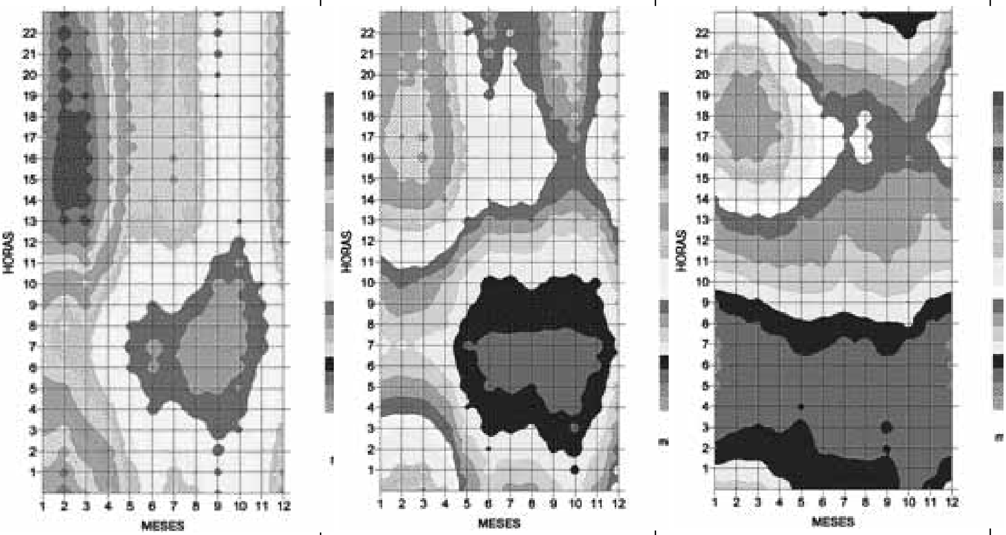
Table 5.2. Wind Speed as a Fraction of Mean Yearly Wind Speeds

Month	1	2	3	4	5	6	7	8	9	10	11	12
Load												
Peak	1.27	1.38	1.34	1.15	1.00	0.88	0.96	0.88	0.61	0.69	0.81	1.04
Med	1.32	1.36	1.34	1.17	0.94	0.87	0.93	0.85	0.67	0.69	0.81	1.04
Low	1.36	1.39	1.26	1.13	0.99	0.81	0.90	0.81	0.69	0.75	0.88	1.04
W speed avg	7.78	8.05	7.77	6.80	5.60	5.01	5.42	4.94	3.95	4.15	4.86	6.13
Ratio to annual avg	1.33	1.37	1.32	1.16	0.95	0.85	0.92	0.84	0.67	0.71	0.83	1.04

Source: Authors' data.

On average, wind speed at 8 p.m. is above the annual average by 11 percent, and during the "dry" months of December to April the wind speeds are 37 percent above the annual average, a large increase given the fact that the power of wind energy is proportional to the cube of the wind speed. Wind power is available when its contribution to the national grid is most needed, that is, during the dry periods and to an extent during the afternoon when demand peaks. Figure 5.3 presents the wind conditions in three wind measuring stations.

Figure 5.3. Graphic Representation of Wind Conditions in Northern Colombia



Galerazamba, Bolívar	E. Cortizzos Airport, Atlántico	S. Bolivar Airport, Magdalena
Wind intensities above five m/s are observed year around in the afternoon, with higher values—above 8 m/s—observed during the first three months of the year. Wind direction is predominantly from the northeast.	Wind speeds above 5 m/s are observed in the afternoon, with average values close to 8 m/s. These strong winds are observed until early morning, especially during the first four months. Wind direction is mostly from the northeast, although winds from the north are significant.	From 2 p.m. until 8 p.m., this station exhibits wind speeds above 5 m/s, with average values near 8 m/s for the months of January through April. Winds are predominantly from the north.

Source: UPME and IDEAM.
Note: E. Cortizzos Airport, Atlántico, and S. Bolívar Airport, Magdalena stations are strongly affected by the Sierra Nevada de Santa Marta, which interrupts the wind flow to the stations (for which reason the winds blow predominantly from the north).

Complementarity during El Niño Southern Oscillation (ENSO) Events

Colombia's interconnected hydro-based system is severely affected by large-scale droughts. Historically, critical drought conditions are linked to El Niño events, such as those of 1991–1992 and 2002–2003. Table 5.3 shows the period of occurrence of El Niño events and their length. Thus, a key element for this analysis is whether there are complementarities between wind- and hydropower during dry periods. Based on existing power generation data from Jepírachi (for the period from February 2004 to March 2009) and wind velocity records data from Puerto Bolívar, wind and generation data were extended to cover the period from 1985 to 2008. For the El Niño periods, the wind data were normalized so that positive values indicate above-average conditions measured in standard deviations, and negative values indicate below-average conditions.

Table 5.3. El Niño Periods

Start	Jul-51	Mar-57	Jun-63	May-65	Oct-68	Aug-69	Apr-72	Aug-76	Aug-77
Finish	Jan-52	Jul-58	Feb-64	May-66	Jun-69	Feb-70	Feb-73	Mar-77	Feb-78
Months	6	14	8	13	8	6	10	7	6
Start	Apr-82	Jul-86	Apr-91	Feb-93	Mar-94	Apr-97	Apr-02	Jan-04	Aug-06
Finish	Jul-83	Mar-88	Jul-92	Aug-93	Apr-95	May-98	Apr-03	Mar-05	Feb-07
Months	15	20	15	6	13	13	12	8	6

Source: IDEAM.

A similar analysis was conducted for four rivers with hydropower development: Guavio, Nare, Cauca, and Magdalena. Results show negative values for the four rivers during most El Niño occurrences, while the Jepírachi generation resulted mostly in positive values. The most severe basin response corresponds to El Niño from April 1991 to July 1992 when energy rationing occurred, and from April 1997 to May 1998 when pool prices reached very high spot prices, forcing regulatory changes in the market. During these periods of extreme drought, the hydrology of the country was severely affected, resulting in a reduction of mean reservoir capacities, and the system had to rely on alternative generation capacity provided through the use of thermal capacity.

During these periods the estimated generation from Jepírachi is well above the mean value. That is, during periods of extreme drought associated with El Niño phenomena, wind energy from northern Colombia is above average, emphasizing the possible role of wind power during these critical periods. This analysis is described in a separate report which can be found from Appendix 6.

Table 5.4 shows that El Niño periods have historically lasted between 6 and 20 months; on average in the 1951–2006 period they have lasted 10.5 months.

Table 5.4. Wind and Hydro Complementary during El Niño

ANALYSIS OF EL NIÑO OCCURRENCES Departure from mean value expressed as number of standard deviations								
	El Niño occurrences							
	Jul. 86 Mar. 88	Abr. 91 Jul. 92	Feb. 93 Ago. 93	Mar. 94 Abr. 95	Abr. 97 May. 98	Abr. 02 Abr. 03	Jun. 04 Mar. 05	Ago. 06 Feb. 07
Guavio River	1.03	−0 .5 3	0.64	1.50	−0.87	0.6 6	0.94	−1.02
Nare River	−0.73	−1.39	−0.71	−0.64	−1.86	−0.90	0 .6 8	0.08
Cauca River	−1.48	−1.14	−0.17	−0.48	−1.53	−1.52	−0.07	−0.90
Magdalena River	−0.51	−1 .0 7	0.00	0.80	−1.69	−1.08	−0.81	−0.52
Jepirachi Powerplant	1.23	1.20	0.20	1.23	0 .56	1 .1 9	−0.91	−0.80

Source: Consultants' study (see Appendix 6).

Wind and Hydro Generation Complementarity

Complementarity was also explored through an analysis of the joint operation of a simple system consisting of a wind farm that operates with a hydropower plant of similar size for each of the rivers studied and a range of reservoir sizes. The results for each of the rivers are described in Appendix 6. Table 5.5 below presents the results from the joint analysis of Jepírachi and the Nare River. These results are similar to those found when Jepírachi is combined with the other rivers. The firm energy from the isolated operation of the hydropower plant and the wind farm is far below the firm energy resulting from their joint operation. This result holds for the wide range of possible reservoir sizes studied. It is therefore concluded that the joint operation of wind- and hydropower plants exhibits a strong complementarity, which is not rewarded in the current regulatory system adopted by Colombia.

Table 5.5. Complementarity of Joint Operation of Hydro Plant and Wind Farm; the Case of the Nare River

FIRM ENERGY FOR NARE AND JEPIRACHI IN ISOLATED AND JOINT OPERATION Firm Energy/Mean Energy						
	Reservoir volume expressed as a fraction of mean energy inflow to Nare					
	0	**0.2**	**0.4**	**0.6**	**0.8**	**1**
Nare River(isolated)	0.179	0.369	0.435	0.459	0.471	0.480
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Nare River + Jepirachi in isolated operation	0.268	0.458	0.524	0.548	0.560	0.569
Nare River + Jepirachi in joint operation	0.410	0.811	0.943	0.972	0.994	1.009

Source: Consultants' study (see Appendix 6).

Firm Energy and Joint Operation of Wind and Hydroelectric Projects

An analysis was conducted to understand the firm energy obtained from hydroelectric plants (with and without reservoir) in conjunction with the Jepírachi power plant under scenarios of joint and isolated operation (Colombian regulation estimates the reliability of individual power plants and does not consider joint operation). Firm energy is defined as the maximum monthly energy that can be produced without deficits during the analysis period which would include El Niño occurrences. The same results were obtained for the total energy obtained from the joint operation of the hydropower plants and the Jepírachi plant.

The analysis was conducted using a simulation model that operates the plants and the reservoirs to provide a given energy target, adjusting this target until no deficits are generated. For this purpose, hypothetical hydroelectric plants with capacity similar to that of wind power plants were analyzed. Mean multiannual inflow to the hydroelectric power plants (expressed in energy) at the plant sites is equal to the same value for Jepírachi generation. This was done by multiplying river discharges by a factor to convert them to energy such that mean inflows are equal to mean Jepírachi generation. In order to avoid confusion with existing hydroelectric plants, the hypothetical plants analyzed will be named Guavio River, Nare River, Cauca River, and Magdalena River.

Several reservoir sizes were analyzed; reservoir size (expressed as a fraction of mean annual inflow to the reservoir in energy) varies between 0 (run-of-river plant) to 1 (substantial regulation capacity). Results are shown below.

An Example: The Guavio River

Table 5.6 and figure 5.4 show results for the Guavio River. Firm energy has been normalized, with actual firm energy divided by the sum of mean energy for the Guavio River and Jepírachi.

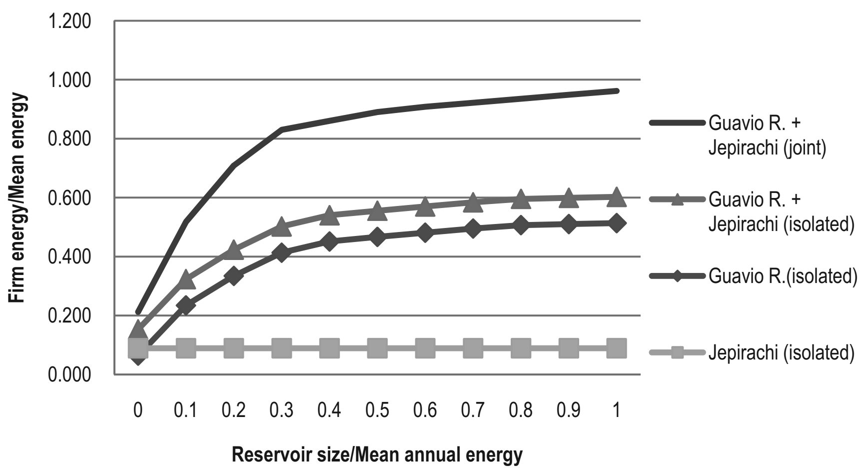
Table 5.6. Firm Energy Results for Guavio River Analyzed in Isolated and Joint Operation

FIRM ENERGY FOR GUAVIO AND JEPIRACHI IN ISOLATED AND JOINT OPERATION
Firm Energy/Mean Energy

	Reservoir volume expressed as a fraction of mean energy inflow to Guavio					
	0	0.2	0.4	0.6	0.8	1
Guavio River (isolated)	0.064	0.334	0.451	0.481	0.507	0.514
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Guavio River + Jepirachi in isolated operation	0.153	0.423	0.540	0.570	0.596	0.602
Guavio River + Jepirachi in joint operation	0.212	0.709	0.860	0.908	0.935	0.962

Source: Consultants' study (see Appendix 6).

Figure 5.4. Firm Energy for Guavio River as a Result of Isolated and Joint Operation

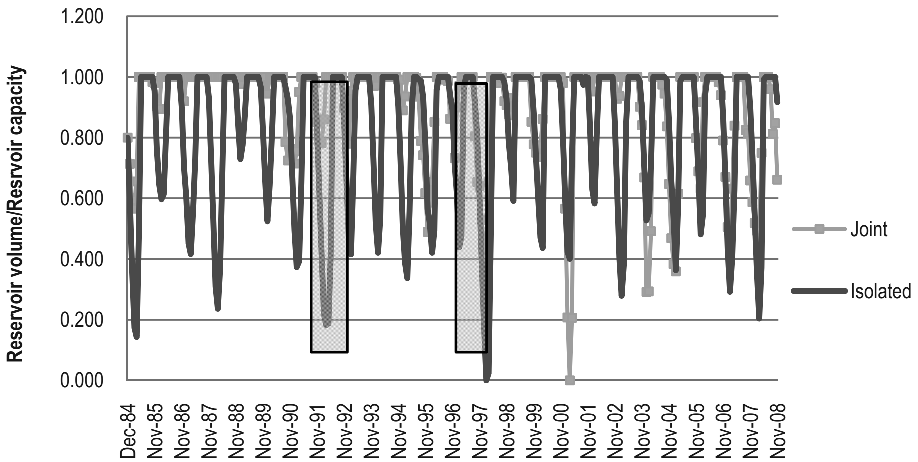


Source: Consultants' study (see Appendix 6).

In this case, the firm energy that results from the joint operation of the wind farm and the hypothetical hydropower plant is greater than the sum of the isolated operation of the two individual projects.

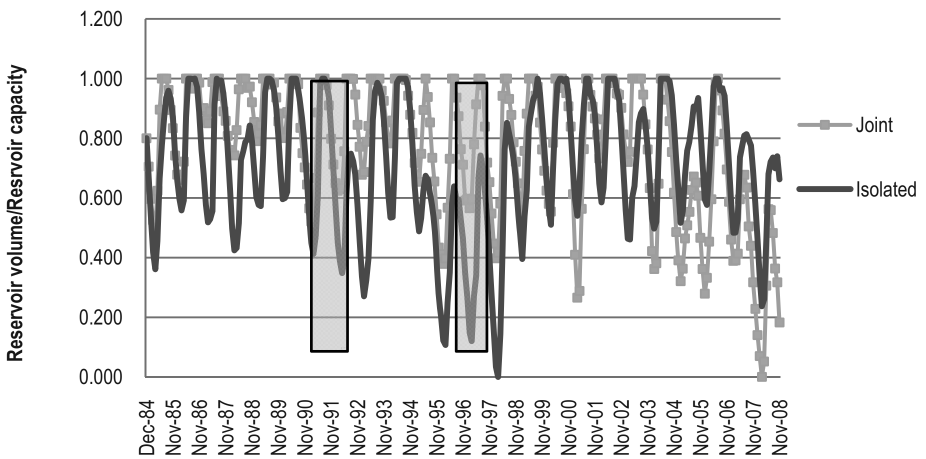
Table 5.6 and figure 5.4 indicate an increase in firm energy when joint operation is considered. This is because critical periods for the Guavio River do not coincide with Jepírachi generation during the same period. Figures 5.5 and 5.6, showing reservoir operation both in isolated and joint operation, illustrate this in greater detail. Figure 5.5, corresponding to a reservoir size of 0.2, shows that in isolated operation the reservoir is emptied during the El Niño occurrence of April 1997–May 1998, while in joint operation the reservoir is emptied in April 2001. The El Niño occurrence of April 1997–April 1998 is balanced by large-scale generation in the Jepírachi power plant, showing the complementarity of river discharges in the Guavio River and wind generation in the Jepírachi power plant. The analysis is also performed for the Nare and Magdalena Rivers and the results are similar to those presented here for the Guavio River (that is, in joint operation the firm energy is greater than in isolated operation). For purposes of simplification, only the Guavio River example, with a reservoir size of 0.2 and 0.5, is shown.

Figure 5.5. Guavio River Reservoir Operation with a Reservoir Size of 0.2 in Isolated and Joint Operation



Source: Consultants' study (see Appendix 6).
Notes: 0=run-of-river plant to 1=substantial regulation capacity. The bars represent El Niño occurrences.

Figure 5.6. Guavio River Reservoir Operation with a Reservoir Size of 0.5 in Isolated and Joint Operation



Source: Consultants' study (see Appendix 6).
Notes: 0=run-of-river plant to 1=substantial regulation capacity. The bars represent El Niño occurrences.

Impact of Extreme Events on Hydropower Capacity

Although there is still no consensus on how climate change may affect average precipitation in Colombia, there is a generally accepted notion that global warming will result not only in changes in mean conditions but also in increases in the extent and frequency of extreme precipitation events. Changes in extremes would have an impact on the country's hydrological regime. Appendix 2 presents a summary of the results of an analysis conducted with the use of runoff data, derived from rainfall projections by the Earth Simulator to estimate the likelihood of extreme weather events around the end of the century (2090). This would result in an increase in stream flow during the high-flow season and a decrease in the low-flow season. The annual range of stream flow becomes larger, implying more floods in the wet season and droughts in the dry season. The anticipated changes in surface hydrology will affect hydropower potential by reducing the potential firm capacity of reservoirs.

Notes

[1] Jepírachi is a small wind farm, with 19.6 MW of nominal capacity, located in Northern Guajira, owned by EPM and in operation since 2004.

[2] Note that the capacity factor of Jepírachi during the 2004–2008 period was lower than expected, nearly 32 percent. Communication with the wind farm's owners reveals that some wind turbines were turned off for maintenance and that there were periods (normally between midnight and 6 a.m.) in which the wind farm did not generate due to tension imbalances in the transmission lines to which the wind farm is connected. These issues have now been resolved but it is believed that without these issues the capacity factor for Jepírachi could have been higher than that experienced.

[3] Data are from the Neon database with historical operation data created by Expertos en Mercados S.A. E.S.P. (XM), the Colombian hydrothermal system operator.

[4] The information was compiled and published as a joint effort by Unidad de Planeamineto Minero-Energética (UPME) and Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM), part of the Ministry of Environment, Housing, and Territorial Development.

CHAPTER 6

Options to Aid Market Entry of Wind Energy in the Country's Power Mix

Introduction

Under current circumstances wind-based generation faces considerable obstacles to participate in the nation's power mix. Key obstacles, as described in the first-phase report, include the current relatively high capital intensity and the structure of the regulatory system which does not acknowledge wind power's potential firm capacity.[1] However, the wind resource along the northern coast appears to complement well the country's hydrological regime and could be part of a strategy to strengthen the climate resilience of the hydropower-based sector. To promote wind power generation, the actions required would result in a positive impact on the financial performance of projects while minimizing distortions in the existing power market and the overall economy. This chapter reviews the typology of available options to address the higher capital cost of the wind option as well as an option to address the variable nature of wind energy.

This chapter follows a microeconomics approach. The analysis is focused on potential investors as the key economic agents sought by the GOC. These investors base their investment decisions on important regulatory and financial aspects. This chapter describes the tools available to guide the market and the tools for government intervention in guiding the independent investors' decisions, while chapter 7 describes the financial analysis upon which the effectiveness of such tools is assessed. The interpretation of results provides guidance to decision makers on regulatory work.

Options to Facilitate Market Entry of Wind Energy

A number of options could be used to facilitate the market entry of wind power in Colombia. This chapter describes a typology of policy instruments, out of which a selection is made for further use in the analysis. The options are categorized in four groups: (i) price-based policy instruments; (ii) policy options guiding renewable energy output (quantity-based policy instruments); (iii) adjustments in the regulatory system; and (iv) instruments that provide incentives other than price. In addition, a proposal is detailed, providing a simple methodology to assess the contribution of wind-powered plants to firm energy, an opening through which wind farms could be recipients of reliability payments.

Price-Based Policy Instruments

Although many practitioners find these instruments very effective in promoting RET, their implementation may generate financial distortions. These instruments or policy tools have so far not been considered in Colombia, nor are they favored by market players and policy makers, because the country's generation requirements are currently being met by independent power producers without the need for government financing or intervention.

Feed-in tariff system or price-based instrument. This approach forces utility companies to purchase all the electricity produced by renewable energy producers in their service area at a tariff determined by the authorities and guaranteed for a specific period of time (typically 10 to 20 years). Feed-in tariffs offer a financial incentive for renewable project developers to exploit all available generating sites until the marginal cost of producing energy equals the proposed feed-in tariff. Costs are recovered through a levy on all electricity consumers who purchase power from utilities.

Fixed premium system (environmental kWh premium). This price-based mechanism adds a fixed premium to the basic wholesale electricity price, making the total price received per kWh produced less predictable than in the feed-in tariff described above.

Valuing carbon emissions. Valuing carbon emissions could be achieved by taxing power plants' emissions of pollutants in accordance with standard principles of tax policy, or by imposing a discriminatory sales tax on electricity generated by polluting fossil fuels and using the revenue to pay a premium to generators that utilize nonpolluting renewable energy sources.

Production tax credits. A production tax credit provides the investor or owner of a qualifying generating facility an annual tax credit based on the amount of electricity generated by that facility to encourage improved operating performance.

Policy Options Guiding Renewable Energy Output (Quantity-Based Policy Instruments)

Renewable energy mix targets. This instrument establishes a minimum percentage of renewable energy as part of the national energy portfolio. Electric utilities are required to procure a certain quantity of their electricity from renewable technologies as a percentage of the total or to install a certain capacity of renewable power. The renewable-based generation increases with the overall increase in electricity demand. Producers could then decide either to implement the projects themselves or to put them out to tender from independent power producers. Suppliers may also choose competitive bidding from independent power producers and participate in green certification systems. However, inadequate administrative capacity for verification mechanisms, record keeping for transactions, and compliance may complicate their implementation. Several countries have adopted or are proposing national renewable energy targets. The European Union has collectively adopted a target of 22 percent of total electricity generation from renewables by 2010, with individual member states selecting their own targets. Japan has adopted a target of 3 percent of total primary energy by 2010. Recent legislative proposals in the United States would require 10 percent of electricity generation from renewables by 2020.

Competitively awarded subsidies. Competitively awarded subsidies, that is, through auctions, could be offered to promote certain technologies and achieve predefined output targets. In Poland, the World Bank's Global Environment Facility (GEF) helped to develop markets and reduce costs for products through subsidies given to technically qualified domestic manufacturers.

Adjustments in the Regulatory System

Exemption from systems charges. Colombia has an unbundled electricity market. The concept of unbundling—separately pricing all of the services that comprise a utility service—could be a disadvantage for producers of nonconventional power when they have to pay transmission charges on a per-capacity basis. Some countries, such as Brazil, have experimented with reducing prices of transmission wheeling for producers of renewable energy. To this end, exemption from systems charges could be implemented, exempting renewables from generation surcharges and considering these alternatives as load-reduction technologies. For the Colombian system several policy instruments could be devised under this heading to encourage new renewable plants: waiving the charges paid for automatic generation control; elimination or reduction of environmental charges and/or contributions for the electrification of off-grid regions; and excluding new renewable power plants from CERE payment obligations.

Adjusting the "reliability payment" regulation. Colombia has developed a financial mechanism to produce an economic signal to investors as a price premium on reliable installed power capacity. This instrument aims at increasing the resilience ("firmness) of the national interconnected system to extreme weather events, especially during unusually dry periods. The reliability payment, or firm capacity charge, should promote an efficient mix of energy sources, without discriminating renewable sources. Unfortunately, the existing regulation does not have clear rules to assess the potential contribution of wind energy to the overall reliability of the interconnected system and thus favors conventional power plants. In practice this discriminatory treatment has been identified as a major barrier to further investments in the wind sector.[2] Fortunately, however, it is straightforward enough to include all resources in a nondiscriminatory manner. All that is required is an objective method of estimating the firm energy capacity of the resource. The issue of reliability payment is analyzed in detail below.

Policy Instruments that Provide Incentives other than Price

These policy tools provide incentives for voluntary investments in renewable energy by waiving taxes and/or reducing the costs of investments through financial mechanisms. There are at least five broad categories of instruments that (i) reduce capital costs after purchase (through tax relief) or offset costs through a stream of payments based on power production (through production tax credits); (ii) reduce investment costs up front (through credits, subsidies, and rebates); (iii) provide public financing or public facilitation through concessionary loans, grants, and other financial assistance; and (iv) reduce capital and installation costs through economies of bulk procurement (Valencia 2008). The following policy instruments are applicable in the case of Colombia.

Property tax incentives. These incentives are generally implemented in one of three ways: (i) renewable energy property is partially or fully excluded from property tax assessment, (ii) renewable energy property value is capped at the value of an equivalent conventional energy system that provides the same service, or (iii) tax credits are awarded to offset property taxes. Experts have long argued in favor of imposing corporate and sales taxes on electricity on the grounds that it is a fairly price-inelastic product.

Reduction or elimination of import duties. Much of the equipment for renewable generation must be imported to host countries. High capital import duties and tariffs distort the market, artificially raising the price of renewable technologies and discouraging their adoption. Temporary or permanent waivers may contribute to reduce the impact of high initial investment costs and allow renewable technologies to compete in the market. Such waivers may be justified either on the basis that renewables are a pioneer (or start-up) industry or on the basis that payment of such duties and tariffs by a generating company ultimately would have been passed on to the final consumer. Tax exemptions encourage investment.

Financing of renewable energies. These may include: imposing a surcharge on electricity consumption, to be collected in a special-purpose fund for renewable energy support (in which case larger consumers bear most of the burden); providing a tax credit to be assigned at the local and central levels on renewable energy produced; and taxing pollution, which raises the incremental cost of thermal generation and decreases the cost of competing renewable energy, as mentioned above. Other options could include a change in culture in which consumers would be willing to pay more for "green" electricity. Mexico has established a green fund to promote renewable energy. In this case a tax is collected from all power services and goes into a fund to support renewable energy projects.

Grants and low-cost loans. Many countries have offered grants for renewable energy purchases. In some developing countries, notably China, India, and Sri Lanka, multilateral loans by lenders such as the World Bank have provided financing for renewable energy, usually in conjunction with commercial lending (Valencia 2008). The newly established CTF falls into this option.

Proposal to Address the Reliability Issue for Wind Energy

As briefly explained earlier, the Colombian electricity market includes a reliability payment for each resource based on its ability to generate energy during unusually dry periods; this is called "firm energy." The product needed for reliability in Colombia's hydro-dominated electricity market was introduced in Colombia to minimize the probability of brownouts and blackouts in the interconnected grid as a consequence of hydrological variability. This firm energy is expected to meet user demand under critical conditions (when the wholesale market price is larger than the scarcity price[3]). This is found in CREG Resolution 071 2006.

In 2008, Colombia introduced an innovative and effective market in which auctions[4] are held to commit enough firm energy to cover its needs (Cramton and Stoft 2007, 2008).[5] The firm energy market coordinates investment in new resources to assure that sufficient firm energy is available in dry periods. The firm energy product includes both a financial call option and the physical capability to supply firm energy. The physical capability assures that there will be sufficient energy during dry periods. The call option protects load from high spot prices and improves the performance of the spot market during scarcity.

To promote an efficient mix of resources and for the firm energy market to succeed in providing reliable electricity at least cost, **all resources, including** variable resources such as **wind power, should be eligible to receive the same reliability payment based upon the resource's ability to provide firm energy.** Including wind power and other variable resources in the firm energy market has three important benefits for Colombia. First, it leads to a more efficient mix of resources and thereby could eventually reduce electricity costs. Second, it reduces risk by establishing a more diversified portfolio of fuel types. Third, it reduces Colombia's reliance on coal and other fossil fuels to generate electricity during dry periods, thereby reducing Colombia's emissions from fossil fuels.

At present, the economic signal favors conventional power plants, but fortunately, it is straightforward enough to include all resources in a nondiscriminatory manner. The key input required in the firm energy auction is an estimate of the resource's ability to supply firm energy. This is already done for all hydro and thermal resources. What is required is an analogous methodology to estimate firm energy for variable resources. For purposes of simplicity, the analysis focuses on wind power as a variable resource, but the same approach applies to all variable resources—all resources of any type. In many respects, wind power is actually simpler than hydro or thermal, since it is straightforward enough to estimate the energy output of the wind resource. This is a step already taken as part of the due diligence for any wind project.

For hydro resources, the regulator estimates the firm energy of a hydro project using a time series of hydrological data, ideally five or more decades. For thermal resources, the firm energy rating is based on the unit's nameplate capacity, which is then reduced based on sustainable utilization rates. Estimating the firm energy of a wind resource is similar to that of a hydro resource, although it is suggested that a much shorter time series (perhaps initially based on Jepírachi's five-year record of operation) should be sufficient to determine a good estimate of firm energy capability. Such a series would be produced as part of the standard due diligence of an investor in a wind-power project. No investor would build a wind project without first having a fairly good idea of the project's average energy output. Even if this initial estimate is biased, there is little economic harm, since as described below the rating would be adjusted so that it reflects the project's long-run performance, which is measured automatically by the system operator.

As with other resources, the firm energy rating should be updated based on actual performance. This is difficult for hydro resources given the low frequency of unusually dry periods, roughly once every 10 years. Wind power does not face this problem. The operation of wind farms generates meaningful data on firm energy that integrates local site-specific wind conditions with turbine efficiency. For this reason, it would make sense to have a periodic (yearly) automatic adjustment to the firm energy rating of wind resources based upon historical performance.

For purposes of simplicity, it is recommended that the firm energy rating of a wind resource be adjusted annually based on the following exponential smoothing formula:

firm energy rating in year t + 1 = ½ (firm energy rating in year t)
+ ½ (energy produced in year t).

The initial period for locating wind plants along the northern coast could use the five-year period recorded by Jepírachi, to be updated annually thereafter. This simple approach assures that the firm energy rating of wind power closely tracks its actual performance. The key assumption in the formula is that wind power is not correlated with dry periods; that is, wind resources on average generate the same amount of energy in unusually dry periods as in normal periods. If the seasonality for wind power is correlated with dry seasons, then it would make sense to modify the formula above by replacing "energy produced in year t" with "energy produced in dry season of year t" and then scale up the level of output to an annual measure by multiplying by 12/(number of months in the dry season).

Under this simple approach, the firm energy rating and therefore the reliability payment will quickly converge to the long-run average firm energy capability, even if the firm energy rating in the initial year is poorly measured.

An exercise was conducted to calculate the results of the firm capacity factor for the Jepírachi wind farm in Colombia, using the method proposed above.

The analysis is based on observed wind data recorded at meteorological stations in northern Colombia. These data, together with generation data from Jepírachi, allowed the reconstruction of a 24-year data series on monthly wind data and generation. This database was then used to estimate the corresponding firm energy rating in Jepírachi. On average, the yearly firm energy rating was estimated at 0.38, with a range between 0.25 and 0.47.[6] For the dry season, the average firm energy factor found was 0.4 (with an initial-year rating of 0.3[7] and a maximum firm energy factor of 0.47). When this firm energy rating is acknowledged for the entire year, the project owners could receive an annual average of US$975,000 from the reliability payment, based on the auction-defined value of US$13.9 per MWh. This of course translates into very attractive earnings, especially when the lifetime of the project is taken into consideration. For the 24-year time series considered here, this could mean total project earnings of US$23.4 million.

The suggested approach to assess the reliability factor for wind farms is risk neutral. If the yearly estimate is used during the "dry period," the difference between the annual mean and the dry period mean could be interpreted as a risk reduction strategy. A more formal option, in tune with the general risk aversion characteristic of Colombia's regulatory framework, is to subtract standard deviation affected by some factor of the historical performance.

Importantly, for wind power the call option portion of the firm energy product is the same as the call option for thermal resources. During scarcity periods in which the spot price exceeds the scarcity price, the wind resource has an obligation to generate energy over the day consistent with the resource's firm energy rating. Deviations from this daily obligation are resolved at the spot energy price. As a variable resource, the energy output of the unit will surely differ from the obligation on any particular day, but over the course of many days the unit should produce an amount roughly equal to its firm energy rating. Thus, the resource should meet its obligation on average, and if it does so, then its net payment for deviations would be approximately zero.

Notes

[1] Note that the firm capacity of renewable energy is the capacity of conventional sources replaced, so that demands can be met with a specified reliability. The firm capacity of a renewable source depends on the correlated variations in demands and renewable supplies (Barrett 2007).

[2] For a thorough discussion of the effects, advantages and disadvantages of, and barriers to distributed generation, see COLCIENCIAS, ISAGEN, Universidad Nacional, and Universidad de los Andes 2006.

[3] The scarcity price is determined by CREG and updated monthly, determining the wholesale market price from which firm energy obligations become mandatory and establishing the maximum price at which this energy is remunerated.

[4] The firm energy auction under the reliability payment (*cargo por confiabilidad*) is a scheme that establishes long-term commitments and is expected to be a component of the wholesale energy market indefinitely. The auctions are held during various years prior to firm energy obligations (time is provided between auctions and the start of firm energy obligations to allow new projects to be able to enter into operation). To this end, each year the Regulatory Commission (CREG) evaluates the balance of supply and demand of the firm energy projections and if necessary calls for an auction (XM 2009). Available online at: www.xm.com.co/Informes%20Empresariales/InformeAnual_XM.pdf. The next firm energy auction has not been scheduled.

[5] It is worth noting that although the reliability payment has been successful in getting projects registered and assigned to provide firm energy, many of the projects that participated in the firm energy auction lacked an environmental assessment of alternative projects (UPME 2009). This can lead to system, environmental, and investor risks (for example, if it is later found that the projects cannot be implemented due to more environmentally friendly alternatives). However, it is important to keep in perspective the lessons from similar cases in other countries where hydropower projects are waiting in the pipeline and are being replaced by coal power projects because it takes a long time to produce the environmental licenses of hydropower projects. This, of course, may lead to dire and unintended consequences. For this reason, to avoid the possible risk described above, it is recommended that there be high-level coordination among ministries and expedited action by the Ministry of Environment to review environmental licenses (including a review of possible alternatives).

[6] Lower values are associated with the start of the project and the technical learning curve of the operating agency. The range highlights the variability of the wind field.

[7] As stated previously, even if the firm energy rating in the initial year is poorly measured, the initial firm energy rating (and therefore the reliability payment) of 30 percent will quickly converge to the long-run average firm energy capability.

CHAPTER 7

Assessing the Effectiveness of Policy Instruments and Policy Options: Impact on a 300 MW Wind-Powered Power Plant Operating in the Wholesale Energy Market

This chapter aims at exploring the effectiveness of alternative policy instruments in facilitating market entry of the wind option. The consequences of the alternative instruments are measured in terms of the financial result expected by potential investors. A hypothetical 300 MW wind power project is used to estimate the impacts from the different alternatives. Wind resources were defined using historical records and data from Jepírachi. Performance and operational data are based on this pilot wind farm. (Details are available upon request.) Scenarios of the expected price-energy production response of the Colombian wholesale energy market (MEM) from 2008 to 2025 are used. This step is both a necessary input for assessing the financial sustainability of the wind project and a useful methodology to help evaluate other projects. These estimates rely on UPME's July 2008 forecasts for the national energy market, and include the analyses of demand forecasts, natural gas prices, and the expected optimal (minimum-cost) generation expansion adjusted to include the characteristics of the Colombian transmission grid.

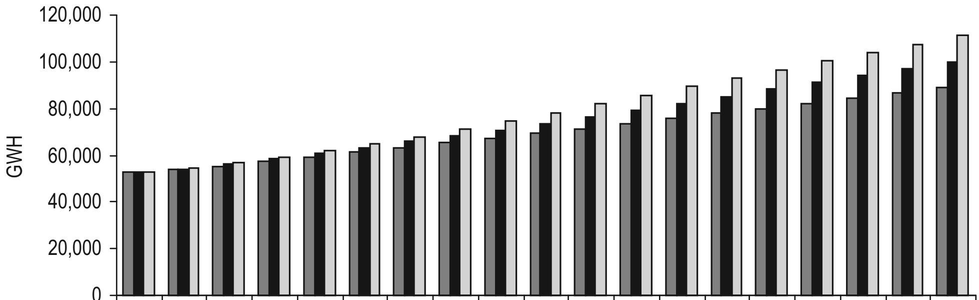
For the purpose of assessing the attractiveness of the wind farm investment through its financial return, the study kept the value of the reliability payment for plant energy remuneration constant at US$13.05/MWh up to November 2012, and then increased this to US$14.00/MWh through the planning horizon.[1] The following chapters summarize the analyses made, relegating the more detailed technical studies to technical appendixes and supporting documentation. This section concludes with an examination of the options available to the government for the promotion of increased RET participation in the country's energy mix.

Baseline Information

Domestic Demand Forecasts

As stated above, demand forecasts for the National Interconnected System (NIS) were obtained from UPME's latest forecasts dated July 2008 (figure 7.1), before the global financial crisis ensued, and thus may be currently characterized as somewhat optimistic.

Figure 7.1. Colombia NIS Demand Forecasts, 2007–2028



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
LOW	52,851	53,882	55,398	57,435	59,392	61,261	63,221	65,274	67,318	69,338	71,415	73,498	75,693	78,067	80 ,066	82,109	84,393	86,727	89,016
MEAN	52,851	54,086	56,060	58,567	60,907	63,313	65,754	68,279	70,897	73,611	76,372	79,297	82,386	85,218	88,136	91,377	94,203	97,006	100,128
HIGH	52,851	54,290	56,608	59,247	62,100	65,027	68,01 3	71,142	74,466	77,953	81,954	85,358	89,471	92,821	96,279	100,35	104,02	107,58	111,556

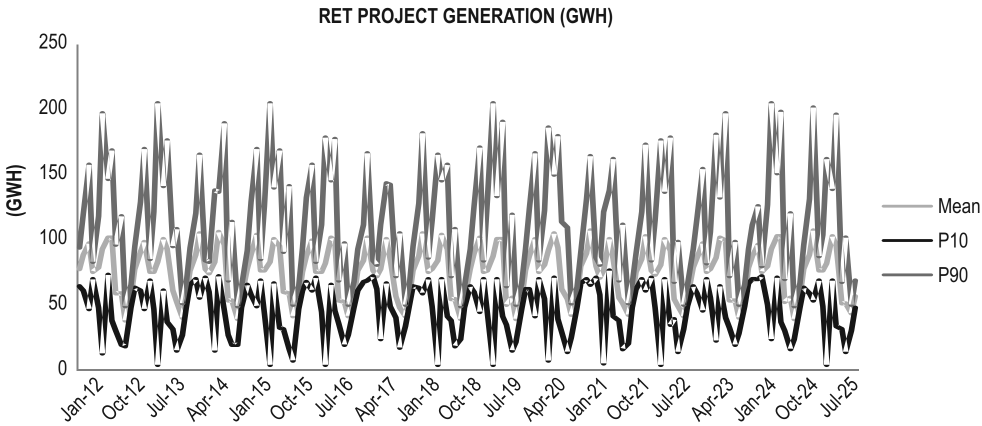
Low Mean High

Source: UPME, July 2008.

Wind Project Generation

Based on the MEM projections, figure 7.2 shows the estimated monthly values for wind-power generation, including average, low (P10), and high (P90) estimates.[2] Wind conditions are average conditions, estimated based on the existing Jepírachi records.

Figure 7.2. Wind Project Generation Estimates 2012–2025

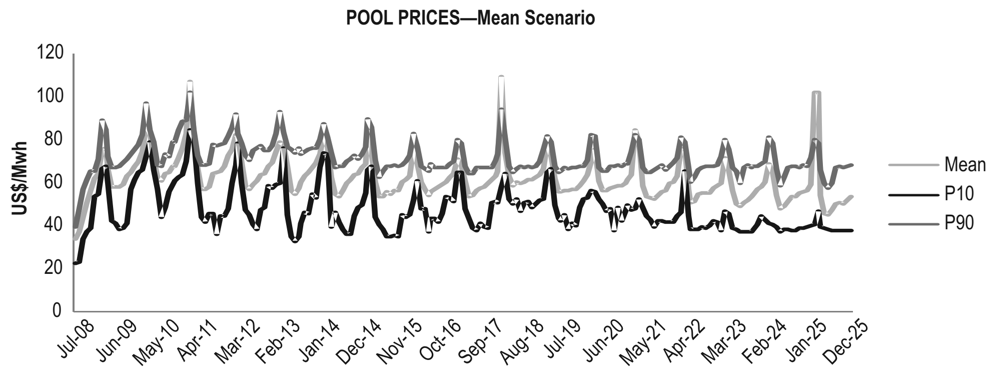


Source: Authors' data.

Pool Prices

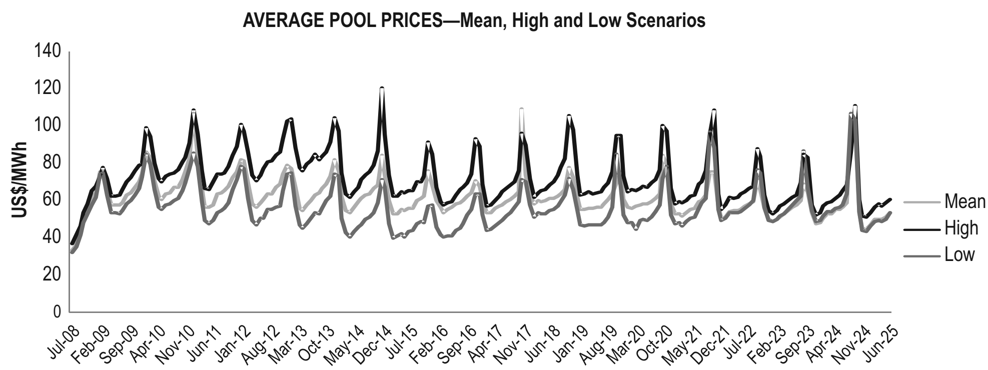
Pool prices in the wholesale market are formed by adding other variable costs (CERE, FAZNI, environmental, and Automatic Generation Control [AGC]) to the pure marginal cost. This is presented for the mean case scenario in figure 7.3 (the other scenarios analyzed are included in Appendix 3). Pool price comparisons of the mean, high and low scenarios are presented in figure 7.4.

Figure 7.3. Pool Prices, Base Scenario



Source: Authors' data.

Figure 7.4. Comparison of Pool Prices for Base, High, and Low Scenarios



Source: Authors' data.

Annual NIS Balances

This analysis also projects annual energy balances for the NIS under the four scenarios considered. These projections show the magnitude of the effect of reduced hydrology generation versus official expected hydrology generation, with the corresponding increase in the gap to be met by alternative means, that is, thermal generation. (These balances can be found in Appendix 4, tables A4.1 to A4.4.)

Baseline Results

A threshold of 14 percent Internal Rate of Return (IRR) was used to indicate adequate return to potential investors based on experience with previous operations (Amoyá, Jepírachi) and on a comparison with international markets.

Three scenarios were used to define the overall energy demand and its relation to fuel prices. The outcomes of these scenarios determine for an "investment project" the set of prices that the investor might expect. The overall indicative prices range from US$39.41/MWh for the base high hydro scenario (see table 7.1) to US$66.70/MWh for the high demand–high fuel prices scenario. The baseline scenario has an indicative price of US$50.60/MWh. Although all the cases were analyzed for all the basic scenarios, the presentation will focus on the baseline conditions.

Table 7.1. Demand Scenarios for the Interconnected Grid and Resulting Indicative Prices

Scenario	Demand	Fuel prices	Hydro	Indicative price [a] (US$/MWh)
Low	Low	Low	Revised	43.3
Baseline	Base	Base	Revised [b]	50.6
High	High	High	Revised	66.7

Source: Authors' data.

a. Indicative average energy price over the 2007 to 2028 simulation period.

b. Energy production factor for hydropower plants estimated from historical generation records from the NEON database.

Table 7.2 presents the results obtained for the baseline analysis. The expected returns on equity are shown for each of the general scenarios considered for Colombia's interconnected system. In addition, given the importance of the investment costs in the policy analysis and in the financial returns, table 7.2 presents results for a wide range of unit investments (expressed in US$/kW). These results indicate that returns are sensitive to the general growth scenario and the general economic environment. Because investments in the power sector are long term, average conditions should be expected to dominate. The selected baseline scenario provides a conservative picture of potential returns, although with a medium risk.

Table 7.2. Expected Returns on Equity before Taxes for a 300 MW Wind Farm in Colombia—Business-as-Usual Results (no government intervention)

	Capital cost per kW installed		
National Base Scenarios	$2,400	$2,100	$1,800
Low	4.7%	6.2%	8.1%
Medium/Baseline	5.8%	7.6%	9.9%
High	9.2%	11.5%	14.8%

Source: Authors' data.

Note: The results assume access to Carbon Emission Reductions of US$18/t$CO_2$.

As the unit investment costs decrease, the return increases should be expected. Nevertheless, it should be emphasized that under the business-as-usual scenario—that is, without policy intervention—wind energy investments are not attractive to potential investors. Thus, if the GOC aims to increase the proportion of its electricity from renewable sources, it is required to adopt policies to aid market entry of RET by creating the enabling environment for independent investors to develop nonconventional renewable source power projects.

Impact of Selected Policy Options

Not all of the available policy instruments are applicable to the case of Colombia. A selection was therefore made, considering those that would fit the regulatory framework and that focus on actions that would not distort the wholesale market.

In order to assess the effectiveness of the options, the financial results of their deployment are quantified. The assessment of financial results from different options assists in the selection of policy instruments and the adoption of a coherent set of alternatives that individually or jointly accomplish the desired results for the potential investors.

Selected Policy Options

The options were grouped under common policy themes:

Group I. Access international financial instruments to internalize *global* externalities in national and private decisions. The government can play a leading and active role in accessing bilateral and multilateral financial instruments aimed at reducing GHG emissions, such as the CDM (this instrument is already mainstreamed into Colombia's environmental policy). This would be complemented through:

- The government acting as a bridge to attract multilateral soft loans earmarked for alternative energies; and
- The government facilitating access to clean technology concessionary financing.

Group II. Target subsidies and government fiscal mechanisms. Under this group of policy options the government uses fiscal measures for the benefit of potential investors. Specifically, the mechanisms identified include tax subsidies and waiving of dispatch control charges (like AGC).

Group III. Reform the regulatory system. Under this policy package, the regulatory system is adjusted to be technologically neutral (creating a level playing field among technologies), and could be complemented to guide the country toward low carbon intensity development. The existing regulatory system has developed mechanisms to steer the market in order to provide a more resilient interconnected system (expressed by its capacity to deliver the demand even during the most difficult hydrological conditions). In doing so, RETs have not received adequate compensation for their contribution. This situation needs to be adjusted and new tools could be included to give greater flexibility to the government in fostering RET. This includes:

- Complementing the scope of the reliability charge to include RET, and wind in particular;

- Waiving payment of CERE to carbon-free power options, as an extension of the existing option for small-scale investments; and
- Creating an environmental sustainability charge (to internalize local environmental and social impacts) and support a low carbon development path.

Within the Colombian energy regulatory system the CERE plays a pivotal function in fostering a more resilient interconnected system. The CERE payment (contribution by the generators) is the revenue source used to pay for the reliability payments. Each electricity generator contributes to a fund in proportion to the energy produced. At the same time each power plant receives payments from this fund, based on its contribution to the "firmness" of the system, to avert the possibility of brownouts and blackouts.

If new policy options are developed, the approach followed could easily be replicated. This analysis would likely take place as the government further fine-tunes its decision on how to proceed.

Table 7.3 shows the institutional responsibilities associated with the selected options. For each the key implementation stakeholders are identified, their responsibilities are described, and the general source of funding, or who bears the costs, is also described. Not all options have similar implementation characteristics.

Table 7.3. Policy Options, Allocation of Responsibilities and Associated Costs

Policy instrument	Stakeholders	Responsibility	Source of revenues
Group I. Access to soft loans	Min Energy Min Finance	Negotiations with Multilateral Development Banks (MDB), donors; national debt	Pass through costs Might impact national debt availability for other activities, thus competing with other allocation needs
Group I. Access to concessionary funds (CTF)	Min Energy Min Finance Min Planning, National Planning Department (DNP)	Negotiate with MDB/donors Targeted commitments Allocate national debt	Pass through costs Might impact national debt availability for other activities, thus competing with other allocation needs
Group II. Waiving system charges	Regulators (CREG)	Promote and enact regulation adjusting system charges	Other wholesale market participants Final consumer
Group III. Adjust the "reliability charge"	Regulators (CREG)	Promote and enact regulation adjusting methodology to assess the "reliability factor"	Cost neutral
Group III. Waiving CERE payment	Regulators (CREG)	Promote and enact regulation changes	Other wholesale market participants Final consumer
Group III. Income tax breaks	Min Energy Min Finance Min Planning (DNP)	Might require approval by Congress	Impact on fiscal resources Final consumer
Group III. Green charge	Min Environment Min Finance Min Planning (DNP) Regulator (CREG)	Promote the internalization of environmental externalities Might require a new law	Final consumer

Source: Authors' data.

For example, access to concessionary funds might require the country to make targeted commitments as to GHG emission reductions to achieve by defined dates, as well as potential impacts on the national debt ceiling, with potential allocation conflicts with other sectors and national needs. Table 7.3 shows that in general the selected policy instruments are relative easy to implement, especially those related to adjusting the regulatory system.

Results

Tables 7.4a, b, and c present the calculated returns on investments resulting from the application of the policy instruments. The results are presented for a range of unit investments from US$1,800/kW to US$2,400/kW. Table 7.4a presents the results with 20 percent, table 7.4b with 30 percent, and table 7.4c with 36 percent reliability payment.[3] The policy instruments used are classified in three types: financial instruments; government fees, including taxes; and regulatory instruments. The internal rate of return is calculated for the project and for equity, before and after taxes. The threshold to judge the policy effective is 14 percent. The tables are divided between two policy options: policy option A with using the reliability payment and policy option B without using the reliability payment. Both policy options use the same base and carbon revenues (US$18/t$CO_2$) as a basis, and add one or more policy instruments when going toward the right in the columns. For purposes of simplicity, the results are summarized only for the medium-case scenario. The analyses were also conducted for each market scenario, the results of which can be found in Appendix 4. The term "base" in the table indicates the status quo.

Tables 7.4a, b, and c provide a summary of a possible set of policy options open to the GOC. The selection of the set of policy instruments needed depends on the expected level of investment costs associated with wind-power projects in Colombia. The industry outlook seems to be that costs will decrease with time, but the reduction of costs alone does not make the wind power sector financially feasible. If wind receives reliability payments for its contribution to firm energy, the need for complementary inducements is a function of the methodology adopted to assess such contribution. If the suggested methodology is adopted, no further inducement is required. If a more risk-averse estimate is used, other policy instruments are required, at least until the investment costs catch up the difference.

The results indicate:

- All options considered improve the financial return on wind investments.
- Wind farms become attractive to the Colombian energy market when their unit investment costs (US$ per kW installed) are such that independent investors reach the target IRR of 14 percent. Under existing market and regulatory conditions (wind plants are not recipients of reliability payment), the investment cost threshold is estimated to be $1,250/kW. If wind farms benefit from reliability payments, the threshold unit investment cost increases as follows: for reliability factors of 20, 30, and 36 percent, the corresponding threshold unit investment costs are $1,660/kW; $1,820 /kW, and $1,880/kW, respectively. In the latter two cases, investment in wind projects becomes financially viable for existing wind technologies.

- Adjusting the reliability payment (leveling the regulatory playing field for nonconventional renewable energy technologies) is a very effective incentive. A reliability factor greater than 30 percent by itself allows wind farms to be financially feasible for low investment costs, such as those recently reported for Europe.
- Eliminating income taxes does not seem to be an effective instrument to attract investments to RET, given the criteria utilized to judge financial feasibility. It does not lead to a 14 percent IRR under the conditions considered.
- If reliability payment is not used, also eliminating fees (AGC, FAZNI, CERE) makes wind power attractive at a US$1,800/kW investment cost.
- Access to concessionary financing has a significant effect. This option requires clean technology concessionary funding[4] for up to 40 percent of the total unit investment to reach a 14 percent IRR.
- As expected, the reduction in unit investment (US$2,400 versus US$1,800) improves return on investment. However, a reduction in investment costs alone falls short of reaching the 14 percent IRR target.

In summary, under existing conditions wind farms are not financially attractive in Colombia even considering the drop in investment costs recorded during 2009. However, wind investments would become financially attractive if the benefits of reliability payments are extended to wind power, even under current investment costs. The government has other multiple policy instruments to steer independent investors toward RETs. Adopting several of these options, as detailed in the report, seems relatively simple and will not distort the market. Improving the conditions for market entry of the wind option will serve to prepare the sector for the anticipated improvement of conditions as investment costs for wind decrease over time.

Finally, deployment of the wind option would help the sector to strengthen its climate resilience and be better prepared to face climate variability, without increasing its carbon footprint.

To complement the incentive structure, the government has various instruments at its disposal. If it uses the capacity to partially waive CERE payments, the attractiveness to potential investors is increased and wind power projects could be implemented at a faster pace and for a wider set of international investment costs.[5] The results for each set of policy instruments integrated into a policy option illustrate the advantages and limitations of such an approach. The GOC would do better by mixing policy options to obtain the desired results. This is the analysis introduced in the next section.

Table 7.4a. Financial Results for a 300 MW Wind Farm In Northern Colombia after Use of Financial Instruments; Reliability Payment Considered with a 20 Percent Firm Energy Factor

Policy option A: with reliability payment							Policy option : with no reliability payment	
If Reliability Payment Considered at %	Investment Cost/kW (US$)	Internal Rate of Return (equity before/after taxes)	Base + Carbon Revenues (US$18/ tCO_2)	+ Reliability Payment	+ Special Financing	+ *Tax reduction	Base + US$18/ tCO_2 + Reduction in Fees	Base + US$18/ tCO_2 + Reduction in Fees + Special Financing
20%	$2,400	*BEFORE TAXES*	5.8%	8.0%	**14.0%**	**14.0%**	10.6%	**14.0%**
		AFTER TAXES	4.3%	6.1%	11.6%	13.0%	8.4%	11.5%
					(40% clean tech concessionary, 20% soft loans, 10% commercial credits)	(40% clean tech concessionary, 20% soft loans, 10% commercial credits)		(10% clean tech concessionary, 60% soft loans)
	$2,100	*BEFORE TAXES*	7.6%	10.0%	**13.9%**	**13.9%**	13.0%	**14.1%**
		AFTER TAXES	5.8%	7.8%	11.4%	12.8%	10.6%	11.6%
					(15% clean tech concessionary, 55% soft loans)	(15% clean tech concessionary, 55% soft loans)		(30% soft loans, 40% commercial credits)
	$1,800	*BEFORE TAXES*	9.9%	12.7%	**14.2%**	**14.2%**	**16.5%**	**16.5%**
		AFTER TAXES	7.8%	10.3%	11.6%	13.1%	13.7%	13.7%
					(40% soft loans, 30% commercial credits)	(40% soft loans, 30% commercial credits)		

Source: Authors' data.

Note: If no financing terms are mentioned, it is assumed that the investor must finance 70 percent of the project costs through commercial credits.

*Income tax reduction of 15% after 2017.

Table 7.4b. Financial Results for a 300 MW Wind Farm in Northern Colombia after Use of Financial Instruments; Reliability Payment Considered with a 30 Percent Firm Energy Factor

Policy option A: with reliability payment							Policy option b: with no reliability payment	
If Reliability Payment Considered at %	Investment Cost/kW (US$)	Internal Rate of Return (equity before/after taxes)	Base + US$18/ tCO_2	+ Reliability Payment	+ Special Financing	+ *Tax reduction	Base + US$18/ tCO_2 + Reduction in Fees	Base + US$18/ tCO_2 + Reduction in Fees + Special Financing
30%	$2,400	*BEFORE TAXES*	5.8%	9.0%	**14.1%**	**14.1%**	10.6%	**14.0%**
		AFTER TAXES	4.3%	7.0%	11.6%	13.0%	8.4%	11.5%
					(30% clean tech concessionary, 30% soft loans, 10% commercial credits)	(30% clean tech concessionary, 30% soft loans, 10% commercial credits)		(10% clean tech concessionary, 60% soft loans)
	$2,100	*BEFORE TAXES*	7.6%	11.2%	**14.1%**	**14.1%**	13.0%	**14.1%**
		AFTER TAXES	5.8%	8.9%	11.6%	13.1%	10.6%	11.6%
					(5% clean tech concessionary, 65% soft loans)	(5% clean tech concessionary, 65% soft loans)		(30% soft loans, 40% commercial credits)
	$1,800	*BEFORE TAXES*	9.9%	**14.2%**	**14.2%**	**14.2%**	**16.5%**	**16.5%**
		AFTER TAXES	7.8%	11.6%	11.6%	13.1%	13.7%	13.7%

Source: Authors' data.
Note: If no financing terms are mentioned, it is assumed that the investor must finance 70 percent of the project costs through commercial credits.
*Income tax reduction of 15% after 2017.

Table 7.4c. Financial Results for a 300 MW Wind Farm in Northern Colombia after Use of Financial Instruments; Reliability Payment Considered with a 36 Percent Firm Energy Factor

Policy option A: with reliability payment							Policy option B: with no reliability payment	
If Reliability Payment Considered at %	Investment Cost/kW (US$)	Internal Rate of Return (equity before/after taxes)	Base + US$18/ tCO_2	+ Reliability Payment	+ Special Financing	+ *Tax reduction	Base + US$18/ tCO_2 + Reduction in Fees	Base + US$18/$tCO_2$ + Reduction in Fees + Special Financing
36%	$2,400	*BEFORE TAXES*	5.8%	9.6%	**14.0%**	**14.0%**	10.6%	**14.0%**
		AFTER TAXES	4.3%	7.5%	11.6%	13.0%	8.4%	11.5%
					(20% clean tech concessionary, 50% soft loans)	(20% clean tech concessionary, 50% soft loans)		(10% clean tech concessionary, 60% soft loans)
	$2,100	*BEFORE TAXES*	7.6%	11.9%	**14.0%**	**14.0%**	13.0%	**14.1%**
		AFTER TAXES	5.8%	9.5%	11.5%	12.9%	10.6%	11.6%
					(60% soft loans, 10% commercial credits)	(60% soft loans, 10% commercial credits)		(30% soft loans, 40% commercial credits)
	$1,800	*BEFORE TAXES*	9.9%	**15.1%**	**15.1%**	**15.1%**	**16.5%**	**16.5%**
		AFTER TAXES	7.8%	12.4%	12.4%	13.9%	13.7%	13.7%

Source: Authors' data.

Note: If no financing terms are mentioned, it is assumed that the investor must finance 70 percent of the project costs through commercial credits.

*Income tax reduction of 15% after 2017.

Key Findings: Options to Foster Investment in Wind Power

The analysis of the information generated in the previous section illustrates the alternatives available to the GOC for promotion of wind power. The higher the investment cost, the greater government intervention is needed to promote investment in RET. Moreover, for investors not paying for CERE it is the same as having a reliability factor of 0.4. This should be obvious: CERE is the fund used to remunerate the guaranteed firm energy. Recognizing the contribution of wind power to firm energy allows it to benefit from reliability payments, thus offsetting the expenditure incurred in paying CERE. At the conceptual level, policy makers have the option of either waiving CERE payment from wind-power producers, or recognizing their project's firm capacity. In this case, it may be simpler to recognize the firm capacity of each project.

Table 7.5 summarizes alternative enabling environments conducive to investments in the wind-power sector under the three cases of reliability payments.

Table 7.5. Key Findings: Combination of Policy Instruments to Reach a Financial Threshold

Investment cost/kW (US$)	If reliability payment considered at	Required actions to reach a 14% IRR
$2,400	20%	Need 40% clean tech concessionary financing + 20% soft loans [6]+ 10% commercial credits
	30%	Need 30% of clean tech concessionary financing + 30% soft loans + 10% commercial credits
	36%	Need 20% clean tech concessionary financing + 50% soft loans
$2,100	20%	Need 15% clean tech concessionary financing + 55% soft loans; or 20% of clean tech concessionary financing + 40% soft loans + 10% commercial credits
	30%	Need 5% clean tech concessionary financing + 65% soft loans; or 20% of clean tech concessionary financing + 10% soft loans + 40% commercial credits
	36%	Need 60% soft loans + 10% commercial credits
$1,800	20%	Need 40% soft loans + 30% commercial credits
	30%	No concessionary financing is needed
	36%	No concessionary financing is needed

Source: Authors' data.

If the GOC decides to promote wind power under a pessimistic investment cost outlook, high reliability factors, reduction in fees, and concessionary financing are required (individually or in conjunction). On the other hand, if investment costs are US$1,800/kW, then less concessionary financing and fewer policy instruments would be required. The results summarized in table 7.5 provide a guideline for the GOC in the selection of a long-term policy option for various wind technology investment costs. A potential transition strategy would be to develop and apply long-term policy options—to capture all the complementarity benefits to the interconnected system—while creating conditions for some early entrants to give the energy market players and operators the opportunity to learn and gain experience in the operation and system maintenance of large-scale wind projects.

Conclusions of the Estimated Impact of Alternative Policy Options for a 300 MW Wind Energy Power Plant in the MEM

The analysis conducted and the results summarized in previous sections allow the following general conclusions and results:

In conclusion, the analysis from the viewpoint of potential investors provides a good foundation for understanding the relative strength of different options.

- Under current policy, regulatory and market conditions, wind-power projects are not attractive for private investment.
- The starting point to promote wind power should be to review the existing regulatory system in detail and remove any biases against renewable energy technologies.
- Of all the options available to the GOC to improve the financial performance of wind-power plants, the reliability payment has the greatest influence on returns. If the reliability charge is applied at levels reflecting the historical contribution of Jepírachi's energy generation during the dry period, financial performance for wind power improves significantly.
- If investment costs for wind power continue decreasing from the high values observed in late 2008, as expected in the near future, the returns improve considerably. Therefore, some options could be seen as a bridge mechanism to be ready for future conditions under which wind power would be more competitive.
- Access to concessionary resources, such as those associated with clean technology multilateral funds and soft loans, could be very useful to promote early investments; and exempting some charges and payments used in the regulatory system is shown to be very effective in increasing the IRR. Internalizing costs of global externalities through clean technology concessionary loans would be enough to provide returns on equity over the selected threshold, for basically all investment costs (in the analysis the maximum US$2,400/kW is used). This holds true even if the generators have to pay all MEM charges.
- The results also indicate that the GOC has the possibility to target future expectations regarding the investment costs associated with wind energy technology. At one extreme the regulators might study the possibility of fostering RETs even at investment prices above US$2,200/kW, for example. Or they might consider a more conservative approach targeting wind projects only if investment costs fall below US$1,900/kW or a similar value. As previously indicated, the higher the investment costs, the greater the government intervention required.
- Waiving the payment of CERE by RET generators is equivalent to remunerating the contribution of wind-power projects (for the conditions of the easterly wind fields in northern Colombia) at a reliability factor of around 0.4. That is, from the potential investor's viewpoint (expected financial returns on investment), waiving a project's obligation to make CERE contributions is financially equivalent to remunerating the project with a reliability factor of

0.4. However, it should be noted that policy makers have the option of either waiving CERE payment from wind-power producers, or recognizing their project's firm capacity. In this case, it may be simpler to recognize the firm capacity of each project.

- The GOC could also consider temporary incentives for RET initiatives. That is, the energy sector could benefit from the early implementation of wind projects as a mechanism to gain experience in operating the interconnected system for the possible case of when wind energy becomes a more significant contributor to the grid. Similarly, the energy sector would also benefit from having a well-functioning regulatory system for this power technology. After a well-defined "promotion and experimentation period," sufficient to give the technology time to further reduce its investment needs, the incentives could be eliminated or adjusted.

Notes

[1] As previously indicated, the reliability payment seeks to provide independent investors with an economic signal of the relative importance of reliable installed (firm) power capacity. The GOC conducted a public auction to allocate "reliability payments" for future power plants. A value of US$13,998/MWh has resulted from the firm energy auction held in May 2008.

[2] P10 indicates the energy generated with a 10 percent probability of values being lower, and P90 indicates the value with a 90 percent probability of values being lower. These probabilities refer to monthly values and cannot be assumed for longer periods.

[3] As explained in previous sections, estimates using the available information from Jepírachi, complemented by observational records from nearby wind measuring stations from 1985 to 2008, produced a reliability factor of 0.415 with a standard deviation of 0.055. For illustration, a reliability factor of 0.36 is used in this analysis, equivalent to the mean value reduced by one standard deviation.

[4] The Clean Technology Fund (CTF) is a climate change donor-driven fund seeking the implementation of transformational low carbon options. CTF financial conditions are typically a 0.65% interest rate with a 20- to 40-year repayment period and 10 years of grace.

[5] It should be noted that simultaneously allowing for reliability charges and waiving CERE payments is not recommended. It would imply a logical contradiction because funds for the reliability charge come from CERE.

[6] CTF conditions are those defined for the CTF (typically, a 0.65 percent interest rate with a 20-year repayment period and 10 years of grace. Soft loans here mean those with conditions typical of IBRD loans in Colombia: currently a 17-year repayment period, interest rate LIBOR + 1.05 percent, front-end fee 0.25 percent.

CHAPTER 8

Conclusions

Colombia has a power sector that is quickly maturing, with relative stability in its regulations, an unbundled system, and a dispatch mechanism that closely resembles a well-functioning competitive market. Competition is promoted and tools have been designed to attract cost-effective capacity expansions that would promote reliability of service (a fuller description of the system and its dispatch mechanism was included in first stage of this project's report).

The Colombian energy sector is characterized by low carbon intensity, below the world average. For the foreseeable future, hydropower will likely continue to provide the backbone of the power sector. However, a highly hydro-dependent power system makes the system intrinsically vulnerable to severe droughts. This vulnerability could be addressed by diversification of the power mix.

Wind Energy Resources Could Become an Important Energy Option in Colombia

Colombia has considerable wind resources, estimated to exceed 14 GW, mostly on its northern coast. However, the potential development of this resource is limited by the high initial investment costs and provisions in the regulatory system that affect this energy source.

Wind technology costs reached a historical low of US$1,600/kW in 2002 and since then costs soared to a high of US$2,400/kW by September 2008. This trend was reversed in 2009, with recent figures reporting average values around US$1,800/kW.[1] This decreasing cost trend is expected to continue. The research in this study showed that costs of US$1,800 or below make wind a viable option even with less heavy intervention from the government. However, under current policy, regulatory, and market conditions, wind-power projects are still not attractive for private investment. Some reforms and changes in the market conditions could therefore also be seen as a bridge mechanism to be ready when wind power becomes a more competitive option with decreasing investment costs in the future.

The report highlights ways to assess the complementarity between wind and water resources and the potential contribution to firm energy production during "critical" dry periods. For the Colombian case, the results indicate that during the dry season (when water resources availability becomes a concern and electricity prices rise) the wind resources could produce above average, at least in the northern part of Colombia. More importantly for Colombia, during critical El Niño events wind contribution exceeds non-El Niño years. This contribution should be recognized and remunerated as well as rewarded in the current regulatory system adopted by Colombia.

Policy Instruments

There is a wide range of instruments through which governments could guide the functioning of selected markets. However, not all of the available instruments are applicable to the case of Colombia. Therefore, only a reduced subset was explored, namely those instruments that are compatible with and relatively easy to incorporate into the existing regulatory system in Colombia and have the effect of changing the financial results for a potential investor. The instruments have been classified as: (i) financial instruments; (ii) payments to government, fees, and charges; and (iii) adjustment to the existing regulatory system.

Policy Options

The existing regulatory system needs to be assessed and any biases against renewable energy technologies need to be removed in order to create a level playing field for all technologies. In addition, changes in financial and fiscal conditions could also make wind power competitive in Colombia. There is a wide range of options through which governments could guide the functioning of the sector. The instruments explored in this study have been classified as: (i) price- and quantity-based instruments; (ii) adjustment in the regulatory system; and (iii) financial incentives other than price.

From assessing the effectiveness of the instruments, it was found that the single most effective policy instrument to promote wind power in Colombia is the granting of access to reliability payments, recognizing the firm energy and complementarity offered by wind. The implementation of this policy option is relatively easy to incorporate into the existing regulatory system.

For new wind-power plants with costs in the range of $1,800/kW installed, the adoption of the reliability payments is enough to attract independent investors, operating in wind fields with similar characteristics to those found in Northern Guajira.

Higher capital costs require access to concessionary financial conditions, such as those provided under the CTF or fiscal incentives. Likewise, internalizing costs of global externalities through certified emission reductions, already used to some extent, would help to make the projects more viable. Exempting some charges and payments used in the regulatory system is also shown to be a very effective way of increasing the returns on investments. This is true in particular if CERE charges are exempted. However, it should be noted that CERE payments and reliability charges are two sides of the same coin, since the funds for reliability charges come from CERE. Temporary incentives for wind and other renewable energy could also be considered in order for the sector to benefit and gain experience from the early implementation of wind projects before wind energy becomes a more significant contributor to the grid.

Lack of access to the benefit of "reliability (firm energy) payments" for wind-powered plants is a serious limitation to their development. A simple method for calculating the firm energy rating of wind-powered plants was introduced. It is recommended that the firm energy rating of a wind resource be adjusted annually based on the following exponential smoothing formula:

$$\text{firm energy rating in year } t+1 = \tfrac{1}{2}\,(\text{firm energy rating in year } t) + \tfrac{1}{2}\,(\text{energy produced in year } t).$$

Under this approach, the firm energy rating, and therefore the reliability payment, will quickly converge to the long-run average firm energy capability, even if the firm energy rating in the initial year is poorly measured. The suggested approach to assess the reliability factor for wind farms is risk neutral. If the yearly estimate is used during the “dry period,” the difference between the annual mean and the dry period mean could be interpreted as a risk reduction strategy. A more formal option, in tune with the general risk aversion characteristic of Colombia’s regulatory framework, is to subtract standard deviation affected by some factor of the historical performance.

Other Findings

Reliable data are needed to assess the specific potential of wind throughout Colombia. Without these data, promoters and investors face high uncertainties, which translate into an additional barrier to future investments. For this reason, the governments of Colombia and of other countries in the region are encouraged to assign resources to the proper mapping of their wind resource endowment and to make this information available to the public.

Other actions required to improve access to the market include open access to research and technology developments, as well as promotion of medium-scale developments (at 100 MW or more installed capacity), allowing the grid operator to be prepared for necessary system adjustments and plan strategically for greater transmission requirements when investments in wind power are increased.

Applicability of the Analysis Conducted

Although the analysis has focused on Colombia, the approach is applicable to other countries, which could further explore their nonconventional renewable resources. Other countries could benefit from performing a similar analysis to understand possible complementarities and how renewable energy technologies can also play a larger role in energy provision.

Notes

[1] As of March 2009, the European Wind Energy Association reports that the average of recent projects fluctuates around €1,225/kW. This translates to approximately US$1,800 (see explanation of turbine cost reductions in chapter 4).

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Appendixes

Appendix 1. Technology Cost Comparison

In relation to chapter 3 of the report, the following tables provide a cost ranking of various technologies according to capacity factors.

Table A1.1. Least Levelized Cost Ranking of Electricity Generation Plant by Capacity Factor (%) without the Cost of CO_2 Emissions

	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	Large Hydro 1200 MW	Large Hydro 1200 MW	Large Hydro 1200 MW	Large Hydro 1200 MW	Large Hydro 1200 MW	Large Hydro 1200 MW
2	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation
3	Simple Cycle GT 150 MW	SC Nat Gas Steam to Coal 300 MW	Large Hydro 1200 MW	Large Hydro 1200 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW
4	SC Nat Gas Steam 300 MW	Large Hydro 1200 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW
5	CCGT 560 MW	CCGT 560 MW	CCGT 560 MW	China SC 550 MW	China SPC 550 MW+ China SC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW
6	CCGT 140 MW	CCGT 140 MW	China SC 550 MW+ CCGT 140 MW	China SPC 550 MW	China SC 550 MW+ China USPC 550 MW	China SC 550 MW	China SC 550 MW	China SC 550 MW	China SC 550 MW	Small to Med Hydro 400 MW
7	Large Hydro 1200 MW	Simple Cycle GT 150 MW	China SPC 5 50 MW	CCGT 560 MW	CCGT 560 MW	China USPC 550 MW	China USPC 550 MW	China USPC 550 MW	China USPC 550 MW	China SC 550 MW+ China USPC 550 MW
8	Diesel 5 MW	China SC 550 MW	China SC 300 MW	China SC 300 MW	CCGT 140 MW	China SC 300 MW	China SC 300 MW	China SC 300 MW	Small to Med Hydro 400 MW	China SC 300 MW
9	China SC 550 MW	China SPC 550 MW	China USPC 550 MW	China USPC 550 MW+ CCGT 140 MW	Small to Med Hydro 400 MW	CCGT 560 MW	Small to Med Hydro 400 MW	Small to Med Hydro 400 MW	China SC 300 MW	CCGT 560 MW
10	China SPC 550 MW	China SC 300 MW	Simple Cycle GT 150 MW	Simple Cycle GT 150 MW	China SC 300 MW CCS	CCGT 140 MW	CCGT 560 MW	CCGT 560 MW	CCGT 560 MW	CCGT 140 MW
11	China SC 300 MW	China USPC 550 MW	Diesel 5 MW	Small to Med Hydro 400 MW	SC 550 MW	Small to Med Hydro 400 MW	CCGT 140 MW	CCGT 140 MW	CCGT 140 MW	SC 550 MW+ SPC 550 MW
12	China USPC 550 MW	Diesel 5 MW	China SC 300 MW CCS	Diesel 5 MW	SPC 550 MW	China SC 300 MW CCS	China SC 300 MW CCS	SC 550 MW	SC 550 MW	USPC 550 MW+ China SC 300 MW CCS
13	China SC 300 MW CCS	China SC 300 MW CCS	SC 550 MW + China SC 550 MW CCS	China SC 300 MW CCS	SC 300 MW	SC 550 MW	SC 550 MW	China SC 300 MW CCS	SPC 5 50 MW	SC CFB 500 MW

Source: Authors' data.

Table A1.2. Least Levelized Cost Ranking of Electricity Generation Plant by Capacity Factor (%) with US$18/Ton CO_2 Emissions

	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	SC Oil Steam to Coal 300 MW	SC 500 MW Rehabili-tation	Large Hydro 1200 MW+	Large Hydro 1200 MW+	Large Hydro 1200 MW+	Large Hydro 1200 MW+	Large Hydro 1200 MW+	Large Hydro 1200 MW	Large Hydro 1200 MW	Large Hydro 1200 MW
2	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	Small to Med Hydro 400 MW+ SC 500 MW Rehabili-tation	Small to Med Hydro 400 MW	Small to Med Hydro 400 MW	Small to Med Hydro 400 MW
3	Simple Cycle GT 150 MW	CCGT 560 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation	SC 500 MW Rehabili-tation
4	CCGT 560 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	Small to Med Hydro 400 MW+ SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	SC Oil Steam to Coal 300 MW	China USPC 550 MW
5	SC Nat Gas Steam to Coal 300 MW	CCGT 140 MW	CCGT 560 MW	CCGT 560 MW	CCGT 560 MW	CCGT 560 MW	CCGT 560 MW	SC Nat Gas Steam to Coal 300 MW	SC Nat Gas Steam to Coal 300 MW	China SPC 550 MW
6	CCGT 140 MW	Simple Cycle GT 150 MW	CCGT 140 MW	CCGT 140 MW	CCGT 140 MW	CCGT 140 MW	CCGT 140 MW	China USPC 550 MW	China USPC 550 MW	CCGT 560 MW
7	Large Hydro 1200 MW+	China SC 550 MW	China SC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SPC 550 MW	China SC 300 MW CCS
8	Diesel 5 MW	China SPC 550 MW	China SPC 550 MW	China SC 550 MW	Small to Med Hydro 400 MW+ SC Nat Gas Steam to Coal 300 MW	China USPC 550 MW	China USPC 550 MW	CCGT 560 MW+ China USPC 550 MW	CCGT 560 MW	China SC 300 MW
9	China SC 550 MW	China SC 300 MW	China SC 300 MW	China USPC 550 MW	China SC 550 MW	China SC 550 MW	CCGT 140 MW	China SPC 550 MW	China SC 550 MW	SC 300MW CCS
10	China SPC 550 MW	China USPC 550 MW	China USPC 550 MW	China SC 300 MW	China USPC 550 MW	China SC 300 MW	China SC 550 MW	China SC 550 MW+ CCGT 140 MW	CCGT 140 MW	CCGT 140 MW
11	China SC 300 MW	Diesel 5 MW	China SC 300 MW	Small to Med Hydro 400 MW	China SC 300 MW	China SC 300 MW CCS	China SC 300 MW	China SC 300 MW CCS	China SC 300 MW CCS	China SC 550 MW CCS
12	China USPC 550 MW	Small to Med Hydro 400 MW+ China SC 550 MW CCS	Simple Cycle GT 150 MW	China SC 300 MW CCS	China SC 300 MW CCS	China SC 550 MW CCS	China SC 300 MW CCS	China SC 550 MW CCS	China SC 300 MW	China USPC 550 MW CCS
13	China SPC 550 MW CCS	CCGT CCS 50 MW	Diesel 5 MW	Simple Cycle GT 150 MW	China SC 550 MW CCS	SC 300 MW CCS	China SC 550 MW CCS	China USPC 550 MW CCS	SC 300 MW CCS	China SPC 550 MW CCS
14	China USPC 550 MW CCS	China SPC 550 MW CCS	Small to Med Hydro 400 MW	Diesel 5 MW	China SPC 550 MW CCS + CCGT CCS 482 MW	China SPC 550 MW CCS	China SPC 550 MW CCS		China USPC 550 MW CCS	SPC 550 MW + USPC 550 MW

Source: Authors' data.

Appendix 2. Use of Earth Simulator to Estimate the Likelihood of Extreme Weather Events

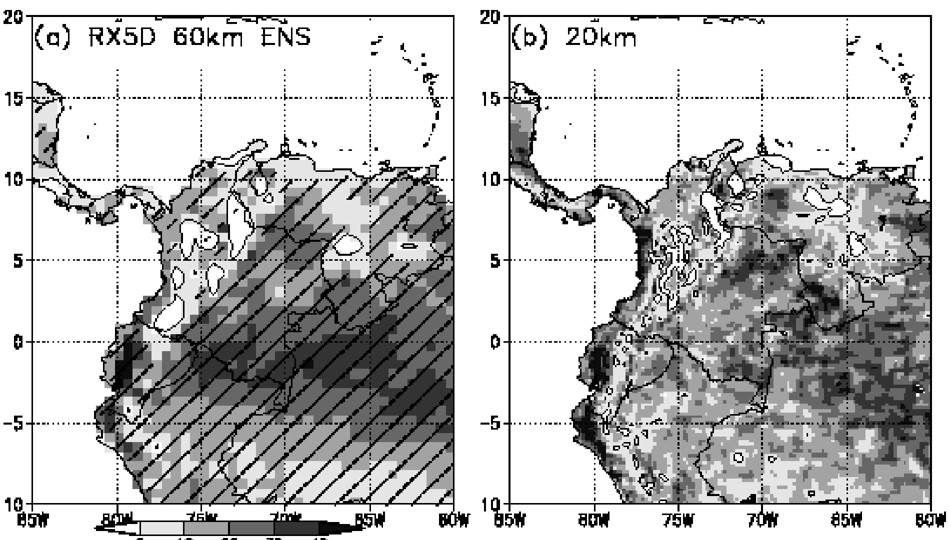
Earth Simulator AGCM (atmospheric general circulation model) runs, developed by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA), were used to estimate the likelihood of extreme weather events to the end of the century. The Earth Simulator is a super-high resolution atmospheric general circulation model with a horizontal grid size of about 20 km, offering an unequaled high-resolution capability. The use of the Earth Simulator made this super-high resolution model's long-term simulation possible.[1]

Although the global 20-km model is unique in terms of its horizontal resolution for global change studies with an integration period up to 25 years, available computer power is still insufficient to enable ensemble simulation experiments; this limits its application to a single-member experiment. To address this caveat, parallel experiments with lower resolution versions of the same model (60-km, 120-km, and 180-km mesh) were performed. In particular, ensemble simulations with the 60-km resolution have been performed and compared with the 20-km version for this study.

Two extreme indices for precipitation are used to illustrate changes in precipitation extremes over Colombia, one for heavy precipitation and one for dryness. All over the country, RX5D is projected to increase in the future. Largest RX5D increases (rainfall intensification) are found over south eastern Colombia. At a higher resolution (20-km) the model projects even larger increases in RX5D.

Figure A2.1. Changes in Maximum Five-Day Precipitation Total (mm) between the Present and the End of the 21st Century for (a) 60-km and (b) 20-km, Respectively

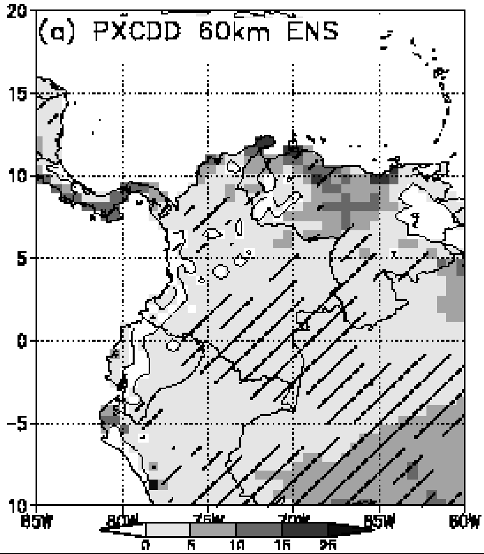
For 60-km model, areas with the highest projected consistency in sign are hatched. Zero lines are contoured.



Source: MRI of the JMA.

Likewise, Figure A2.2 shows the changes in maximum number of consecutive dry days. A "dry day" is defined as a day with precipitation less than 1 mm d^{-1}. Consecutive dry day periods are projected to increase, in particular over the northern coast.

Figure A2.2. The Same as In Figure A.2.1 Except for Consecutive Dry Days (day)



Source: MRI of the JMA.

Impact on River Steam Flow

Using the runoff data, derived from rainfall projections under the Earth Simulator, stream flow in large rivers can be calculated. The analysis used a "GRiveT" river model.[2] In the present-day simulation, large rivers are well represented by this model. Although the analysis has yet to be made for basins in Colombia with large hydropower potential, a similar assessment made for rivers in the Amazon Basin indicates that the changes in extremes and in particular the concentration of rainfall and the lengthening of dry periods will increase the amplitude of stream flows, which in turn would affect the mean firm capacity of hydropower installations.

Notes

[1] This model is an operational short-term numerical weather prediction model of JMA and part of the next generation climate models for long-term climate simulation at MRI.

[2] (GRiveT: Global Discharge model using TRIP, the 0.5 x 0.5 version with global data for discharge channels; Nohara et al. (2006). The river runoff assessed in the land surface model is horizontally interpolated as external input data into the TRIP grid so that the flow volume is saved.

Appendix 3. Pool Prices under Various Scenarios

Pool prices in the wholesale market are formed by adding other variable costs (CERE, FAZNI, environmental and Automatic Generati on Control AGC) to the pure marginal cost. The report presents this for the mean case scenario.

Other scenarios are defined in the Table A3.1:

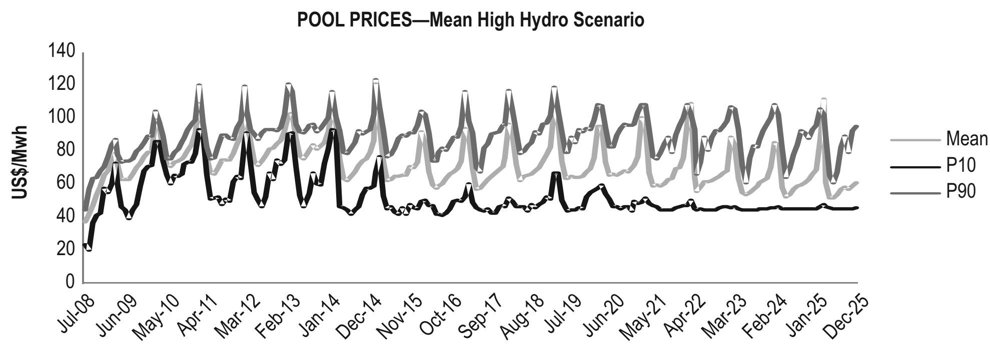
Table A3.1 MEM Scenarios

SCENARIO	DEMAND	FUEL PRICES	HYDRO
MEAN	BASE	BASE	REVISED
MEAN HIGH HYDRO	BASE	BASE	XM FACTORS
LOW	LOW	LOW	REVISED
HIGH	HIGH	HIGH	REVISED

Source: Authors' data.

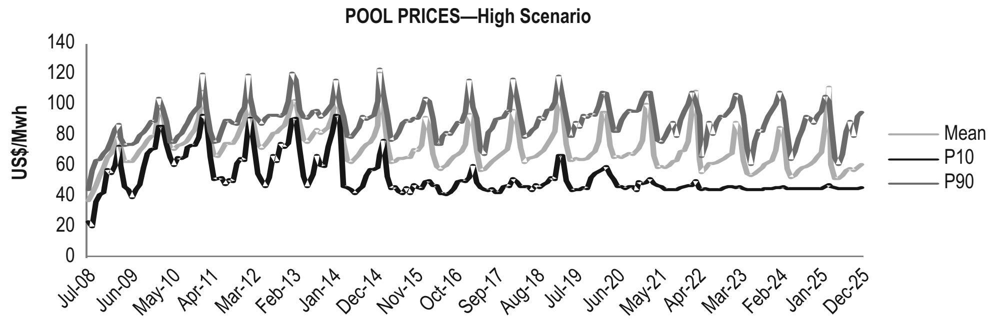
The following Figures (A3.1 and A3.2) present this for the mean high hydro and high scenario. Figure A3.3 compares the pool prices for base and base high hydro scenarios.

Figure A3.1 Pool Prices, Base High Hydro Scenario



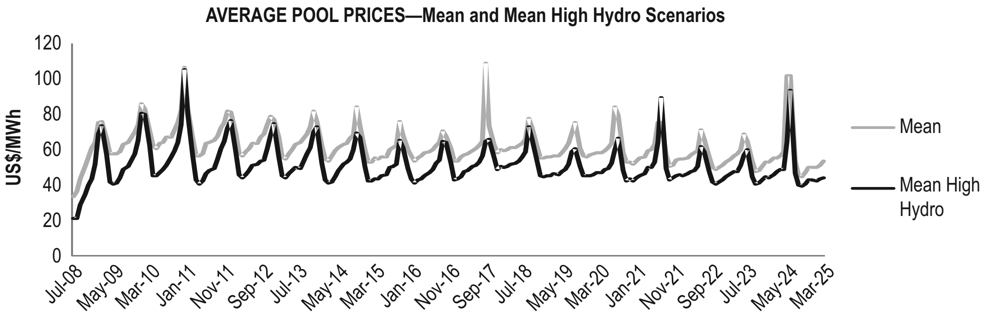
Source: Authors' data.

Figure A3.2. Pool Prices, High Scenario



Source: Authors' data.

Figure A3.3. Comparison of Pool Prices for Base and Base High Hydro Scenarios



Source: Authors' data.

As can be observed in Figure A3.3, the average pool prices for the mean scenario are regularly higher than the mean high hydro scenario.

Appendix 4. Results of the Expected Returns on Investments with the Individual Application of the Policy Instruments for Different Market Scenarios

Tables A4.1–A4.5 depict the expected returns on investments with the individual application of the selected policy instruments discussed in chapter VII of the report.

The analysis of the information contained in table A4.1 indicates:

- All policy instruments improve the financial outcome of the potential investment under consideration, as compared with the baseline condition. Individually, none attains the selected threshold of a return on equity of 14 percent before taxes.
- A generous access to concessionary financing (policy instrument C2) provides the greater inducement. This option requires clean technology concessionary funding for up to 50 percent of the total unit investment.
- Eliminating CERE payments (column F) is a very effective instrument.
- Adjusting the access to the reliability charge (or leveling the playing field for nonconventional renewable energy technologies) is also a very effective incentive, as indicated in column H, depending on the methodology used for selecting the reliability factor.
- Eliminating income taxes does not seem to be an effective instrument to attract investments to RET, given the criteria used to judge financial feasibility.
- As should be expected, the comparison of results presented in Table A4.1 indicates that a reduction in unit investment moves the expected returns closer to the defined threshold of 14 percent before taxes but falls short of reaching this target. The use of individual policy instruments is not sufficient incentive for potential investors. The following tables summarize the analysis conducted when assessing the likely impact on potential investors of the selected policy group options.
- This policy group option does not provide adequate incentives to potential investors if the investment costs are to remain high, at or above US$2,100/kW.
- However, this policy group offers interesting flexibility for low unit investment costs. In particular, if the reliability factor is estimated through the methodology indicated in section VII.3, this would be the only government intervention required to open the market to wind powered energy investments.[1]

Table A4.1. Effectiveness Analysis of Individual Policy Instruments

Results expressed as financial returns on capital for a 300 MW wind farm in northern Colombia

POLICY OPTIONS	A	B1	B2	C1	C2	D	E	F	G	H
TYPE I Financial Instruments										
Carbon CERs	18	0	0	0	0	0	0	0	0	0
Access CTCF loans	0	0	0	0.3	0.5	0	0	0	0	0
Access to soft loans	0	0.4	0.7	0	0	0	0	0	0	0
TYPE III Government Fees										
Income taxes	0.33	0.33	0.33	0.33	0.33	0	0.33	0.33	0.33	0.33
Generator charges	1	1	1	1	1	1	0	1	1	1
TYPE V Regulatory Instruments										
Sustainability charge	0	0	0	0	0	0	0	0	5	0
CERE payments	1	1	1	1	1	1	1	0	1	1
Reliability charge	0	0	0	0	0	0	0	0	0	0.36
Investments Costs	**1800**	**$/kW**								
Project before taxes	7.5%	5.8%	5.8%	5.8%	5.8%	5.8%	6.2%	9.4%	7.1%	9.5%
Project after taxes	6.1%	4.6%	4.6%	4.6%	4.6%	5.8%	5.0%	7.8%	5.8%	7.9%
Equity before taxes	7.3%	5.4%	5.9%	7.4%	10.2%	4.9%	5.6%	10.0%	6.8%	10.1%
Equity after taxes	5.6%	4.0%	4.4%	5.7%	8.3%	4.9%	4.1%	7.9%	5.1%	8.0%
Investments Costs	**2100**	**$/kW**								
Project before taxes	6.1%	4.4%	4.4%	4.4%	4.4%	4.4%	4.9%	7.8%	5.7%	7.9%
Project after taxes	4.9%	3.5%	3.5%	3.5%	3.5%	4.4%	3.9%	6.4%	4.6%	6.4%
Equity before taxes	5.4%	3.6%	3.9%	5.2%	7.3%	3.3%	3.8%	7.7%	4.9%	7.8%
Equity after taxes	3.9%	2.5%	2.8%	3.8%	5.7%	3.3%	2.6%	5.9%	3.5%	6.0%
Investments Costs	**2400**	**$/kW**								
Project before taxes	4.9%	3.4%	3.4%	3.4%	3.4%	3.4%	3.8%	6.5%	4.6%	6.6%
Project after taxes	3.9%	2.6%	2.6%	2.6%	2.6%	3.4%	3.0%	5.3%	3.6%	5.3%
Equity before taxes	3.9%	2.2%	2.4%	3.4%	5.2%	1.9%	2.5%	6.0%	3.5%	6.1%
Equity after taxes	2.7%	1.3%	1.5%	2.4%	3.9%	1.9%	1.5%	4.4%	2.3%	4.5%

Source: Authors' data.

Note: The policy instruments used are read in the upper half of the table, while the lower half indicates the expected financial returns. For example, policy instrument A corresponds to access to payments for the reduction of GHG at a price of US$18/ton CO_2. Policy instrument D shows that income taxes are waived.

Policy Groups

Tables A4.2, A4.3, and A4.4 present the results obtained from the analysis of the three policy groups under consideration. In each case the analysis seeks to find a combination of instruments that jointly create the conditions for potential investors to move their capital toward RET initiatives. The tables retain the same general design used to describe the results of individual policy instruments. Reading the table from left to right, the columns aggregate the instruments used to create the policy group of interest. For example, as shown in table A4.2 the Group Policy Options are built as follows: Baseline + Carbon CERs + Soft Loans (20, 40, and 70 percent) + access to clean technology concessionary financing (30 and 50 percent).

The use of financial instruments to build a policy option provides great flexibility. In the particular case under study the threshold, or target financial rate of return (FRR), is not achieved if the investment costs approach US$2,400/kW. For the low investment cost scenario, potential investors require access to clean technology concessionary resources for nearly 30 percent of the expected cost.

Table A4.2. Effectiveness Analysis of Policy Options: Use of Financial Instruments

Financial results for a 300 MW wind farm in northern Colombia

POLICY OPTIONS	A	B	C	D	E	F
TYPE I Financial Instruments						
Carbon CERs	0	18	18	18	18	18
Access CTCF loans	0	0	0	0	0.3	0.7
Access to soft loans	0	0	0.3	0.7	0.4	0
TYPE III Government Fees						
Income taxes	0.33	0.33	0.33	0.33	0.33	0.33
Generator charges	1	1	1	1	1	1
TYPE V Regulatory Instruments						
Sustainability charge	0	0	0	0	0	0
CERE payments	1	1	1	1	1	1
Reliability charge	0	0	0	0	0	0
Investments Costs	**1800**	**$/kW**				
Project before taxes	5.8%	7.5%	7.5%	7.5%	7.5%	7.5%
Project after taxes	4.6%	6.1%	6.1%	6.1%	6.1%	6.1%
Equity before taxes	4.9%	7.3%	7.9%	8.7%	12.1%	20.3%
Equity after taxes	3.5%	5.6%	6.0%	6.8%	9.9%	18.0%
Investments Costs	**2100**	**$/kW**				
Project before taxes	4.4%	6.1%	6.1%	6.1%	6.1%	6.1%
Project after taxes	3.5%	4.9%	4.9%	4.9%	4.9%	4.9%
Equity before taxes	3.3%	5.4%	5.8%	6.4%	9.0%	15.9%
Equity after taxes	2.2%	3.9%	4.2%	4.8%	7.1%	13.7%
Investments Costs	**2400**	**$/kW**				
Project before taxes	3.4%	4.9%	4.9%	4.9%	4.9%	4.9%
Project after taxes	2.6%	3.9%	3.9%	3.9%	3.9%	3.9%
Equity before taxes	1.9%	3.9%	4.2%	4.6%	6.7%	12.5%
Equity after taxes	1.1%	2.7%	2.9%	3.3%	5.2%	10.4%

Source: Authors' data.

The use of government fiscal mechanisms is explored in table A4.3 below. As indicated in the table, the group encompasses a wide range of fees and payments to the government. The following sequence was used, as indicated by reading the table from left to right: baseline + Carbon CERs + tax shelter + waiver of generator charges + elimination of the obligation to contribute to CERE. The results indicate that this policy group option alone cannot create the required incentives to attract potential investors to wind-power projects.

Table A4.3. Effectiveness Analysis of Policy Options: Use of Government Fees and Payments

POLICY OPTIONS	A	B	C	D	E	F
TYPE I Financial Instruments						
Carbon CERs	0	18	18	18	18	18
Access CTCF loans	0	0	0	0	0	0
Access to soft loans	0	0	0	0	0	0
TYPE III Government Fees						
Income taxes	33%	33%	0%	0%	0%	0%
Generator charges	1	1	1	0	1	0
TYPE V Regulatory Instruments						
Sustainability charge	0	0	0	0	0	0
CERE payments	1	1	1	1	0	0
Reliability charge	0	0	0	0	0	0
Investments Costs	**1800**	**$/kW**				
Project before taxes	5.8%	7.5%	7.5%	8.0%	10.9%	11.3%
Project after taxes	4.6%	6.1%	7.5%	8.0%	10.9%	11.3%
Equity before taxes	4.9%	7.3%	7.3%	8.0%	12.3%	12.9%
Equity after taxes	3.5%	5.6%	7.3%	8.0%	12.3%	12.9%
Investments Costs	**2100**	**$/kW**				
Project before taxes	4.4%	6.1%	6.1%	6.5%	9.1%	9.5%
Project after taxes	3.5%	4.9%	6.1%	6.5%	9.1%	9.5%
Equity before taxes	3.3%	5.4%	5.4%	5.9%	9.6%	10.2%
Equity after taxes	2.2%	3.9%	5.4%	5.9%	9.6%	10.2%
Investments Costs	**2400**	**$/kW**				
Project before taxes	3.4%	4.9%	4.9%	5.3%	7.8%	8.1%
Project after taxes	2.6%	3.9%	4.9%	5.3%	7.8%	8.1%
Equity before taxes	1.9%	3.9%	3.9%	4.4%	7.7%	8.1%
Equity after taxes	1.1%	2.7%	3.9%	4.4%	7.7%	8.1%

Source: Authors' data.

The use of regulatory instruments comprises the last group of policy options. Under this group the following sequence of instruments is used, as depicted in table A4.3 below: Baseline and Carbon CERs + reliability charge (reliability factors of 0.20, 0.30 and 0.36) +CERE waiver (50 percent, 100 percent). The results summarized in table A4.3 indicate:

Table A4.4. Effectiveness Analysis of Policy Options: Use of Regulatory Instruments

POLICY OPTIONS	A	B1	B2	B3	C1	C2	C3	D1	D2	D3
TYPE I Financial Instruments										
Carbon CERs	18	18	18	18	18	18	18	18	18	18
Access CTCF loans	0	0	0	0	0	0	0	0	0	0
Access to soft loans	0	0	0	0	0	0	0	0	0	0
TYPE III Government Fees										
Income taxes	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%
Generator charges	1	1	1	1	1	1	1	1	1	1
TYPE V Regulatory Instruments										
Sustainability charge	0	0	0	0	0	0	0	0	0	0
CERE payments	1	1	0.5	0	1	0.5	0	1	0.5	0
Reliability charge	0	0.2	0.2	0.2	0.3	0.3	0.3	0.36	0.36	0.36
Investments Costs	**1800**	**$/kW**								
Project before taxes	7.5%	9.5%	11.1%	12.6%	10.4%	12.0%	13.5%	10.9%	12.5%	13.9%
Project after taxes	6.1%	7.9%	9.3%	10.8%	8.7%	10.2%	11.5%	9.2%	10.6%	12.0%
Equity before taxes	7.3%	10.2%	12.6%	15.2%	11.6%	14.1%	16.6%	12.4%	14.9%	17.5%
Equity after taxes	5.6%	8.0%	10.2%	12.5%	9.2%	11.5%	13.8%	10.0%	12.3%	14.7%
Investments Costs	**2100**	**$/kW**								
Project before taxes	6.1%	7.9%	9.3%	10.7%	8.7%	10.1%	11.5%	9.2%	10.6%	11.9%
Project after taxes	4.9%	6.4%	7.7%	9.0%	7.2%	8.5%	9.7%	7.6%	8.9%	10.1%
Equity before taxes	5.4%	7.8%	9.9%	12.0%	9.0%	11.1%	13.2%	9.7%	11.8%	13.9%
Equity after taxes	3.9%	6.0%	7.8%	9.6%	7.0%	8.8%	10.7%	7.6%	9.5%	11.4%
Investments Costs	**2400**	**$/kW**								
Project before taxes	4.9%	6.6%	7.9%	9.2%	7.4%	8.7%	9.9%	7.8%	9.1%	10.3%
Project after taxes	3.9%	5.3%	6.5%	7.6%	6.0%	7.2%	8.3%	6.4%	7.5%	8.6%
Equity before taxes	3.9%	6.1%	7.9%	9.7%	7.1%	9.0%	10.8%	7.8%	9.6%	11.4%
Equity after taxes	2.7%	4.5%	6.1%	7.6%	5.4%	7.0%	8.5%	5.9%	7.5%	9.1%

Source: Authors' data.

Notes

[1] As explained in the document, estimates using the available information from Jepírachi, complemented by observational records from nearby wind measuring stations from 1985 to 2008, produce a reliability factor of 0.415. A standard deviation of 0.055 results in the reliability factor of 0.36 used in this analysis.

Appendix 5. Exempting CERE Payments by 50 or 100 Percent

In addition, the analysis also considered the option of exempting 100 percent or 50 percent of the CERE payment. The results show that clean technology concessionary financing is still required if CERE is considered only at 50 percent and above a unit price of US$2,100. Alternatively, this type of financing is not necessary if the unit investment is US$1,800 and the CERE payment is exempted, even at 50 percent. In short, eliminating the CERE payment alone is also an effective instrument. If CERE payment is eliminated, a unit investment cost of US$1,800/kW allows the IRR to reach the 14 percent target. The results are summarized in table A5.1 below.

Table A5.1. Financing Necessary if CERE Is Returned 50 Percent or 100 Percent, Depending on Investment Costs

Investment cost/kW (US$)	% Returned CERE	In all cases it is assumed that there is 30% equity
$2,400	100%	Need 15% clean tech concessionary financing + 55% soft loans
	50%	Need 40% clean tech concessionary financing + 20% soft loans + 10% commercial credits
$2,100	100%	Need 45% soft loans + 25% commercial credits
	50%	Need 15% clean tech concessionary financing + 55% soft loans
$1,800	100%	No additional financing required
	50%	Need 35% soft loans + 35% commercial credits

Source: Authors' data.

The results of analyzing the possibility of excluding the hypothetical 300 MW wind-power project from paying CERE charges indicates that not paying for CERE charges results in a return of investment that is the same as if the reliability payment is recognized at 40 percent. Therefore, the policy maker has an option of either not charging the CERE payment to wind-power producers, or recognizing their project's firm capacity. In this case, it might be simpler and in the country's interest to recognize the firm capacity of each project.

Appendix 6. Complementarity between Wind Power and Hydroelectric Resources

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Estudios Energeticos Limitada

Chapter 1: Introduction

This report presents the results of the studies conducted to analyze the complementarities existing between hydroelectric resources and wind power in Colombia, including synergies that can occur during El Niño occurrences.

Colombia is a country with abundant natural resources for the production of renewable energy. Historically, power-sector development has been based on hydroelectric energy (approximately 80 percent of energy consumption). The country also has abundant coal resources, which are largely exported and which represent a considerable energy reserve of strategic interest for the country. At the moment there is only one wind power farm in the country (Jepírachi), located on the Caribbean coast, in the province of La Guajira, with 19.5 MW installed capacity.

Several wind-power advantages in the Colombian power system have been mentioned. Among these, the complementarities with hydroelectric resources are investigated in this study. Specifically, preliminary analyses indicate that during the dry hydrological period (December to April), wind velocities in the Caribbean are above the annual. Likewise, it has also been argued that wind velocities are above the mean when El Niño occurs.

- This study aims to find an answer to the following questions: Does complementarity exist between water resources and wind-power resources in Colombia (for example, in La Guajira)? What could be the contribution of wind resources to the reliability of the national electricity system? What is the natural variability of the wind resource (monthly and summer potential contribution)? What is the wind-power contribution during the period of "extreme" summer, associated with the El Niño phenomenon?

Chapter 2: Methodology

The main aspects of the methodology are to:

1. Use the Puerto Bolívar meteorological station as the basis of the analysis. Information beginning in 1986 is available.
2. Fill in abundant missing hourly data.
3. Conduct a statistical analysis of hourly wind velocity characteristics.
4. Convert hourly wind-velocity data in hourly power generation using conversion factors corresponding to a particular wind turbine and a given capacity installation.
5. Estimate monthly generation information.
6. Select four discharge measurement stations of the National Interconnected System for analysis of synergies of joint hydroelectric power and wind turbine operation.
7. Analyze river discharges and Jepírachi generation during El Niño occurrences.
8. Estimate the firm energy obtained from the individual operation of hydroelectric plants (with and without reservoirs) and wind-power plants, as well as their joint operation. Firm energy will be defined as the maximum energy that can be produced without deficits during the analysis period, which will include El Niño occurrences. The analysis will be conducted using a simulation model that will operate the plants to provide a given energy target, adjusting this target until no deficits are generated. The analysis will be conducted for each of the hydroelectric plants selected.
9. Measure synergetic gains due to the complementarity between hydroelectricity and wind power, as the difference between firm energy in a joint operation and the sum of firm energies in isolated operation.

Chapter 3: Data Base

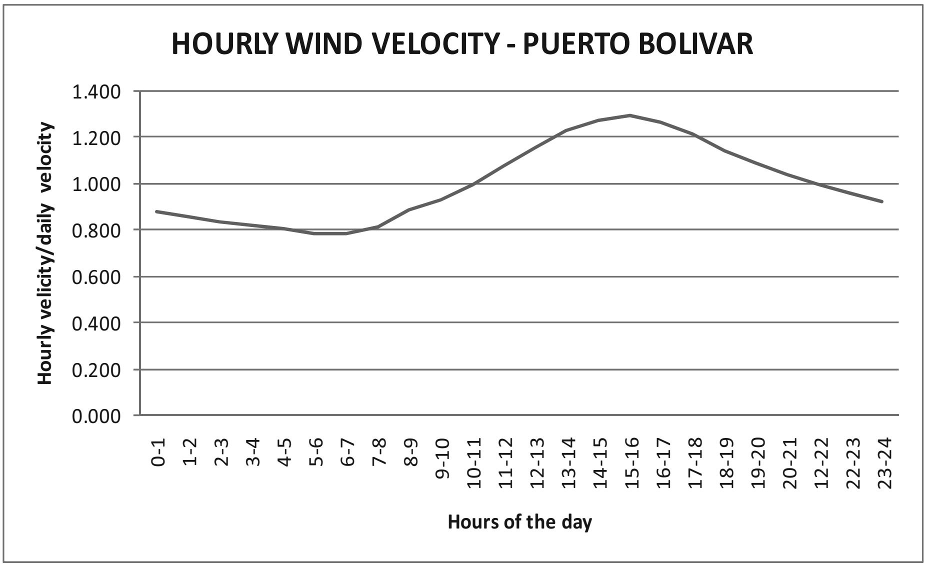
3.1 Wind Velocity Information

The World Bank obtained hourly data for two stations in the Colombian Caribbean from IDEAM.

The first station is located in Puerto Bolívar, in the vicinity of the Jepírachi power plant. It covers the period between October 1986 and December 2008, with several missing records. (There are 162,124 hourly records out of a total of 195,072, representing 83 percent.)

There is no clear behavior of the distribution of hourly velocities during the day for the different months of the year. The distribution of wind velocities in the different hours of the day is shown below.

Figure A6.1. Hourly Wind Velocity: Puerto Bolívar

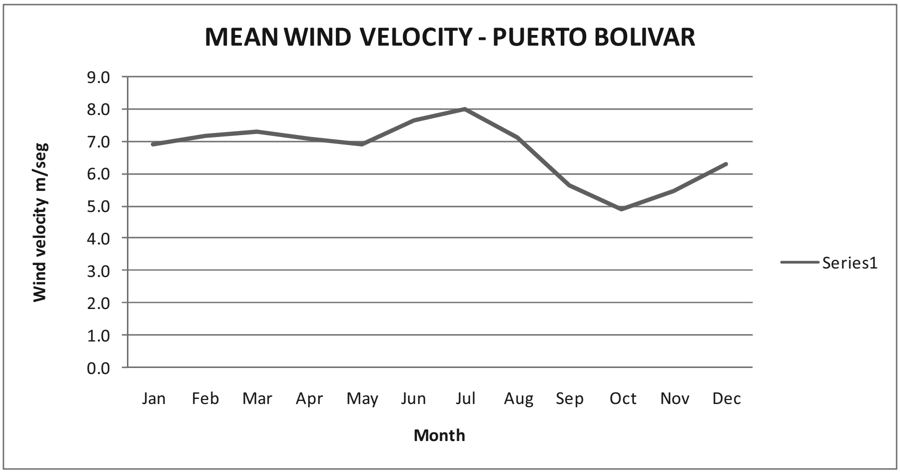


Source: IDEAM.

Figure A6.1 shows the trend of larger wind velocities during peak electricity load hours, while smaller wind velocities tend to be concentrated during early morning hours which are the minimum load hours. Therefore, there is a complementarity of wind velocities with electricity load, which is a clear advantage for wind power.

As seen in figure A6.2, large wind velocities occur from December to April, which are the months with lower river discharges. This represents a positive complementarity between wind power and hydroelectric power.

Figure A6.2. Seasonal Behavior of Mean Wind Velocity

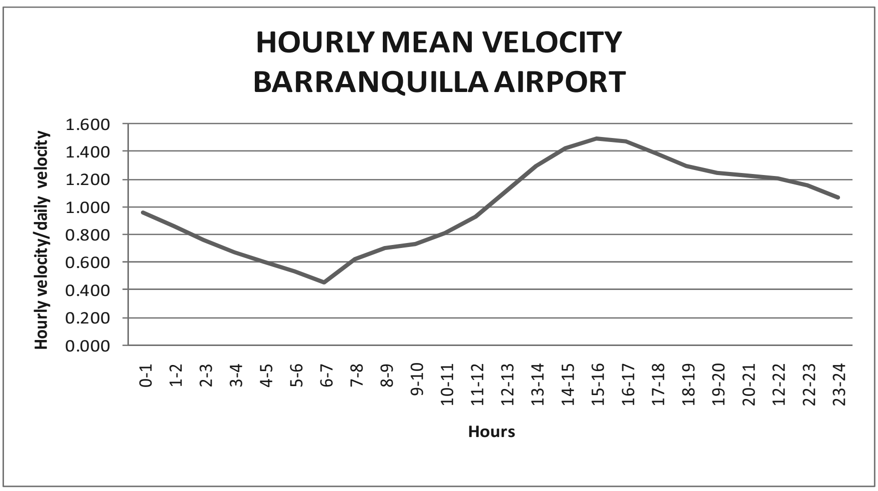


Source: IDEAM.

Figures A6.3 and A6.4 show similar results for the Barranquilla Airport where the second station is located. The results are similar for the Puerto Bolívar and Barranquilla Airports, although the difference between the minimum and maximum values is more accentuated for the Barranquilla Airport.

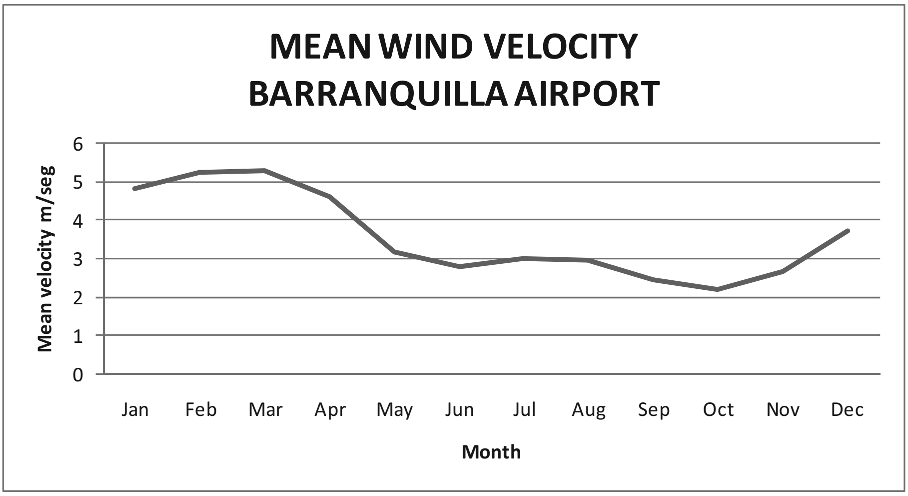
Mean velocities at the Barranquila Airport are substantially lower than those at Puerto Bolívar and do not have a good correlation with the Puerto Bolívar station, due to the fact of the shading effect of the Sierra Nevada de Santa Marta. Therefore, this station was not used.

Figure A6.3. Hourly Mean Velocity: Barranquilla Airport



Source: IDEAM.

Figure A6.4. Mean Wind Velocity: Barranquilla Airport



Source: IDEAM.

3.2 River Discharges

Monthly data for four rivers associated with hydroelectric power plants were used in this study. The information was obtained from databases for simulation of the interconnected hydrothermal power system.

Rivers considered were the Nare River at the Santa Rita Dam (1955–2009), the Guavio River at the Guavio Dam (1963–2009), the Cauca River at the Salvajina Dam (1946–2009), and the Magdalena River at the Betania Dam (1972–2009), representing a sample of geographical regions of the country. Table A6.1 shows mean monthly values for these rivers.

Table A6.1. Mean Monthly Values for the Guavio, Nare, Cauca, and Magdalena Rivers

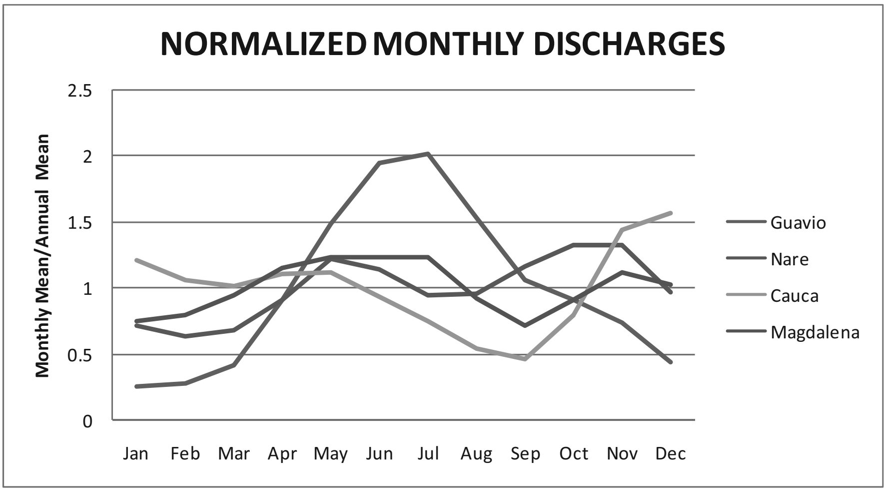
MEAN MONTHLY VALUES - m3/seg

	Guavio	Nare	Cauca	Magdalena
Jan	18.4	36.2	166.3	145.4
Feb	19.9	32.3	145.8	154.6
Mar	29.9	34.5	139.7	183.4
Apr	65.6	46.4	152.2	225.2
May	106.3	62.1	153.1	240.4
Jun	139.2	58.2	127.9	240.5
Jul	144.4	47.9	103.2	240.3
Aug	110.0	48.8	74.6	179.1
Sep	76.0	59.3	63.2	138.6
Oct	64.9	67.6	109.6	177.4
Nov	52.7	67.6	197.2	218.0
Dec	31.3	49.6	215.5	199.2

Source: Appendix authors' data.

Figure A6.5 illustrates the diversity of meteorological condition shown by the rivers chosen.

Figure A6.5. Normalized Monthly Discharges of the Four Rivers

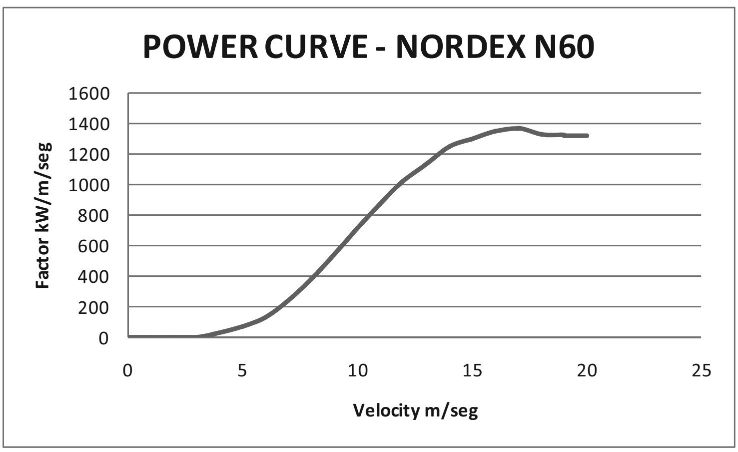


Source: Appendix authors' data.

3.3 Technical Information for the Jepírachi Power Plant

The Jepírachi wind-farm power plant is located in the northern part of Colombia, on the Guajira peninsula on the Caribbean Sea. It has been equipped with 15 Nordex N60 aerogenetors (1,300 kW each), with a total installed capacity of 19.5 MW. The power curve (relating wind velocity with power delivered by the generator) for each unit is shown in figure A6.6.

Figure A6.6. Power Curve for Each Unit



Source: Appendix authors' data.

The power curve is valid for standard air density (1.225 kg/m³). For a different air density a correction has to be made. Air density at Jepírachi is 1.165 kg/m³). Velocity is at tower altitude (60 meters). Therefore, a correction must be made, taking into account a roughness factor (0.15), and the air density in the power curve of the manufacturer and Puerto Bolivar, since velocity measurements are made at a 10-meter altitude.

3.4 Jepírachi Generation

Hourly Jepírachi generation was obtained from the Neon database operated by Xm, the system operator. The information was available between February 2004 and March 2009.

The following tables summarize the information at monthly hour level.

Table A6.2. Jepírachi Monthly Hour Generation kWh (1 to 12)

JEPIRACHI MONTHLY HOUR GENERATION KWH (1 to 12)												
	Hora											
	1	2	3	4	5	6	7	8	9	10	11	12
Feb-04	46409	44317	39107	35323	30761	31072	29592	30234	39381	45079	54153	39381
Mar-04	140936	125710	116189	113622	113044	109002	104041	115101	135418	137050	158091	135418
Apr-04	127838	121365	115335	108995	105044	105672	112597	131031	138595	154124	190674	138595
May-04	231996	233364	228772	225541	209674	192621	193550	209064	211206	206943	222462	211206
Jun-04	330876	312374	304223	298968	294805	300260	303424	313792	340632	377004	377463	340632
Jul-04	242488	227097	221345	203293	183794	170140	176278	190410	187934	202619	246582	187934
Aug-04	240662	220931	213009	213823	220730	197890	191253	229974	252703	263633	276345	252703
Sep-04	46563	37095	36999	36673	35451	21177	21253	24676	22056	27475	50192	22056
Oct-04	61729	55937	48722	49209	46999	38244	34866	53119	66744	77137	89306	66744
Nov-04	60176	50989	42348	57550	69987	64443	59364	64631	100781	108311	127689	100781
Dec-04	83709	82030	66083	66415	61500	60122	61066	73683	120077	141600	155051	120077
Jan-05	117439	112019	113308	107172	100759	93807	74290	90023	134068	173343	197178	134068
Feb-05	130617	121767	100697	88478	80324	79221	68862	91027	138653	171403	214050	138653
Mar-05	190359	162779	151840	131416	118121	108643	99305	123272	163227	182891	224965	163227
Apr-05	154972	150516	145551	132760	114786	114394	122887	146267	163255	173237	184477	163255
May-05	134648	127325	118908	107702	107549	107578	111381	134308	133262	135237	146744	133262
Jun-05	116432	93899	92139	90527	75461	77493	74215	94447	114563	130210	150332	114563
Jul-05	179538	181386	172213	143606	124863	122338	128007	137707	154542	162466	188642	154542
Aug-05	172650	150581	147546	135425	126542	119151	122975	133853	132222	146884	182514	132222
Sep-05	125927	128747	134390	127963	117870	103245	102499	122933	117671	119877	137928	117671
Oct-05	125927	128747	134390	127963	117870	103245	102499	122933	117671	119877	137928	117671
Nov-05	58513	46187	46865	45333	45406	50663	45348	58816	76657	83044	92404	76657
Dec-05	83773	69392	58543	56719	61611	59192	54709	61794	101314	147022	168341	101314
Jan-06	142530	143363	135094	137363	121598	106907	95523	100618	143210	193212	235846	143210
Feb-06	186891	176962	156182	146437	141071	134439	136036	174944	230149	268658	279571	230149
Mar-06	194406	192387	186007	167988	160020	162331	158345	196017	248324	279524	322582	248324
Apr-06	134752	125313	118589	117559	112926	107591	91856	127226	162933	178068	191372	162933
May-06	146913	152761	150091	134786	129561	127175	137489	160875	150092	168364	202209	150092
Jun-06	188191	181644	165323	153041	145705	142623	149388	158433	193370	216576	245133	193370
Jul-06	273952	264547	247057	231815	220277	225774	245223	277116	303914	328205	345305	303914
Aug-06	175006	161350	151769	162598	163303	152824	159408	190130	187454	212316	226024	187454
Sep-06	121836	112256	113384	115297	101732	93420	97781	122323	114837	110926	150603	114837
Oct-06	33764	33913	30844	28615	26543	36114	41069	72346	73642	72866	85308	73642
Nov-06	55494	46044	48843	44619	44781	42900	43367	59042	70262	78197	90236	70262
Dec-06	59470	51653	51913	44500	46813	39869	46792	66155	110377	157627	223358	110377
Jan-07	80766	76745	69222	62755	54673	59807	66482	103797	192493	264594	283181	192493
Feb-07	88263	83999	72931	65508	66247	66469	74406	108545	157399	193461	218661	157399
Mar-07	136785	117686	122976	113518	102743	94738	106547	177327	197942	207676	238591	197942
Apr-07	142636	137103	136786	130534	126182	125110	132306	144649	123012	119740	147654	123012
May-07	111543	107354	105961	106932	94222	90915	83770	91401	89206	75341	94698	89206
Jun-07	84322	64716	49950	44181	34957	36981	68150	105818	130863	169942	203073	130863
Jul-07	179391	156942	143594	155505	162125	168097	182542	217389	231059	226006	253728	231059
Aug-07	106610	101659	82770	78702	64441	58055	58989	62929	64588	73801	93390	64588
Sep-07	86064	76093	76628	77241	69730	58474	52812	66407	62516	56065	76632	62516
Oct-07	24349	17836	14402	12186	12462	13039	13080	21766	21746	20414	26371	21746
Nov-07	73889	66966	60180	55416	56802	62436	64525	92063	130866	135115	145750	130866
Dec-07	90271	78076	68034	69976	69645	71624	66075	77080	105941	136080	173809	105941
Jan-08	150988	139050	130543	137005	126762	108916	101454	118931	173812	220046	245562	173812
Feb-08	186657	185811	163518	148699	134753	134196	128160	160803	210344	232433	252266	210344
Mar-08	194511	183501	168074	160775	152081	139823	126657	158281	198509	207617	241720	198509
Apr-08	192195	174564	152676	149851	135665	127285	127594	147007	160517	152390	174664	160517
May-08	163070	154352	140156	139326	141993	135519	154812	179539	169203	163547	194966	169203
Jun-08	226274	200330	185411	178294	164696	166520	170894	196275	199596	207061	246916	199596
Jul-08	187039	172327	171895	160658	145228	135780	135324	165633	190247	219829	257446	190247
Aug-08	105591	89614	80009	76364	70617	65652	67979	82000	88168	94028	106812	88168
Sep-08	31755	27904	31262	29408	23547	23649	24996	30282	36672	43186	49006	36672
Oct-08	53756	53432	44587	50841	38415	38779	33396	38066	49877	60150	64042	49877
Nov-08	34799	34755	34418	32401	31708	38107	34486	38293	45255	60389	56459	45255
Dec-08	64346	62404	53736	54629	46539	53755	49296	56524	78246	116582	128353	78246

Source: Neon database operated by Xm

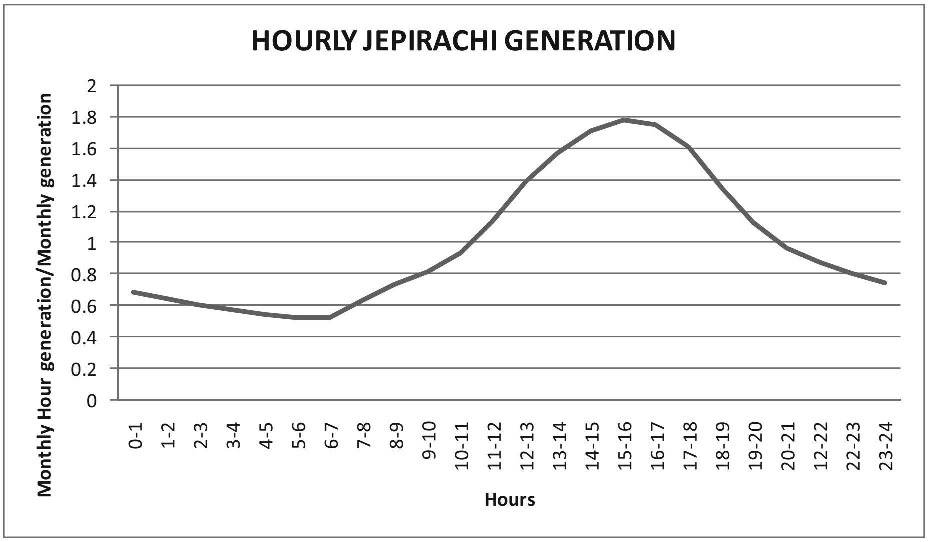
Table A6.3. Jepírachi Monthly Hour Generation kWh (13 to 24)

JEPIRACHI MONTHLY HOUR GENERATION KWH (13 to 24)												
	Hora											
	13	14	15	16	17	18	19	20	21	22	23	24
Feb-04	98832	116252	121112	116121	115746	109831	102702	88486	75112	71280	66288	54858
Mar-04	209915	222360	226980	228988	230264	225482	204557	191778	184204	175480	157655	144963
Apr-04	287841	308331	319624	322955	312303	290319	257954	217061	199895	180377	168059	143401
May-04	278974	309557	320782	339221	342712	317194	294642	278238	265014	267321	259511	248826
Jun-04	409552	425714	447946	471293	475756	464108	438164	412355	400403	399448	385357	361131
Jul-04	355699	422982	457067	451330	447171	422930	380081	323514	299569	282693	269326	254858
Aug-04	354570	419574	456167	471056	460154	439583	382403	339621	280883	266809	263923	249949
Sep-04	97805	137998	189027	204910	213888	183621	148821	138255	123365	98224	89071	70124
Oct-04	147251	194101	223123	226578	231010	204510	172888	144304	117469	85971	69242	64860
Nov-04	205158	205387	209871	229119	232997	216665	170954	136850	98301	76084	64232	66332
Dec-04	231460	276812	299321	321964	310293	266583	179038	126340	97680	90461	87406	84458
Jan-05	258325	301063	321480	319443	318790	294302	238770	209083	186783	161498	153155	135287
Feb-05	315201	331622	341827	365001	342725	324492	281304	224905	211600	201198	170405	143229
Mar-05	376594	427460	455243	469330	450999	418348	379968	329361	291567	258868	229836	211167
Apr-05	271492	285599	319247	329261	321717	306514	261862	223342	193847	169473	164377	153722
May-05	215529	232751	259749	274240	277104	252820	220982	201209	181340	173999	162739	151609
Jun-05	176273	209676	220576	246222	252478	254471	228805	199115	170318	144279	127117	126592
Jul-05	265501	308665	346186	355825	358698	316074	281342	258556	241290	221569	203399	194914
Aug-05	304565	352928	385470	410458	393774	359458	310473	257302	229357	212566	199387	187263
Sep-05	239844	289204	302050	321373	299517	265394	213934	171449	152194	140641	137612	138227
Oct-05	239844	289204	302050	321373	299517	265394	213934	171449	152194	140641	137612	138227
Nov-05	121430	144074	176884	181349	176428	156629	126755	99778	86610	85577	75391	66819
Dec-05	235340	278407	298848	317624	308204	251596	184531	140527	118467	107466	100216	93312
Jan-06	297591	312213	335222	350897	362125	335277	265013	220422	195749	186607	173772	166502
Feb-06	353252	373926	391412	411281	405491	391225	339936	286458	257249	230442	205121	197894
Mar-06	460954	482631	488260	486242	477543	441109	381590	339041	298122	264119	239649	209951
Apr-06	279775	329916	377467	401883	393763	359292	301963	224752	192494	171885	149502	143365
May-06	319630	357492	384891	409886	406684	373414	302349	240642	193930	167322	151309	147432
Jun-06	310895	332181	400086	431605	430180	424080	360362	285688	237219	211937	201652	199751
Jul-06	401830	422321	457354	464218	469127	426919	386932	329370	275202	273212	271802	264170
Aug-06	333779	366160	409564	453522	457085	416253	363068	302381	254522	221891	211144	200374
Sep-06	293854	338058	379687	397428	378110	351788	293816	240502	191294	156274	144871	135047
Oct-06	175005	209381	207484	225583	237867	203258	135133	86640	48166	36688	35897	34898
Nov-06	191568	235337	270363	286155	295931	260626	194329	148383	113079	94403	83464	75348
Dec-06	327977	373835	403263	413182	394487	350348	202481	130575	103574	84822	75342	57249
Jan-07	420510	455144	467110	466372	451484	416899	353725	252184	173892	134679	94213	83736
Feb-07	341224	390256	421898	428223	425323	391610	329281	261810	194782	147320	120428	106426
Mar-07	356405	414973	453991	470945	447771	408009	356324	269582	203153	168954	162023	143045
Apr-07	282406	310738	334771	350266	349246	312744	269336	241341	201140	178680	166082	153390
May-07	230448	283151	310982	340678	327283	300680	239819	202271	168300	148287	144181	123500
Jun-07	233700	257474	290373	324978	346464	336987	274039	169109	138581	134795	116039	102221
Jul-07	348952	383832	407687	401533	391359	368189	328132	282425	247193	223914	210796	190559
Aug-07	230393	290796	334389	325578	326678	305269	249026	182901	154951	140690	127179	112397
Sep-07	174368	203981	240120	289150	282957	259729	219883	171180	140650	117127	106259	93724
Oct-07	47037	63818	86835	100704	101463	95600	78947	62255	44651	34891	27253	22520
Nov-07	208529	230499	241063	246768	240535	220457	177799	140615	118235	114625	95984	86350
Dec-07	230459	241534	264572	278771	263945	234513	196068	156999	130672	118176	103910	98726
Jan-08	340054	378326	406077	406508	391829	333922	276244	244967	232306	209806	188271	154815
Feb-08	326300	363704	380896	396105	393385	368342	314384	277194	241242	217727	206113	205375
Mar-08	389435	437416	464872	473405	454508	409841	347882	294388	270853	251649	227481	208901
Apr-08	340106	390412	421859	440491	430585	390649	337703	301237	264715	236788	218018	205065
May-08	319964	367183	399320	433539	419788	388254	320916	276542	243471	216244	203152	180406
Jun-08	313496	357607	431142	443789	430007	392750	343404	313940	287019	262303	250843	246133
Jul-08	370006	394993	417817	435181	430535	375194	314522	269597	250177	239403	229782	204162
Aug-08	174777	209503	233851	252589	252856	237003	181824	159600	145402	117937	107903	109202
Sep-08	94118	133119	149249	163896	158904	144601	118924	91800	71418	58785	52261	44988
Oct-08	100118	117826	151023	151582	155406	141521	126389	111171	96806	84618	69173	64148
Nov-08	116445	143008	150568	167772	167080	146407	115897	94145	76043	63186	52745	43469
Dec-08	188203	211681	234862	234010	218937	197061	157795	124273	103599	96777	76449	73344

Source: Neon database operated by Xm.

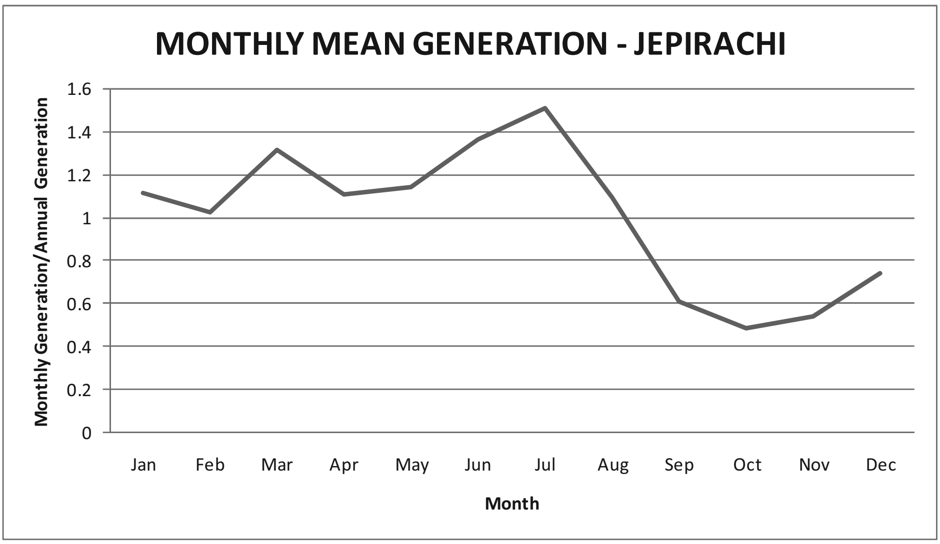
The distribution of wind velocities at different hours of the day is shown in figure A6.7. A favorable complementarity with daily electricity load fluctuations is observed. Differences between this curve and the corresponding curve for wind velocity are due to the nonlinear nature of the relationship between wind velocity and power.

Figure A6.7. Jepírachi: Hourly Generation



Source: Neon database operated by Xm.

Figure A6.8. Jepírachi: Monthly Mean Generation



Source: Neon database operated by Xm.

A favorable complementarity with river discharges is observed. Differences between this curve and the corresponding curve for wind velocity are due to the nonlinear nature of the relationship between wind velocity and power.

Chapter 4: Extension of Jepírachi Information

Limited generation information at the Jepírachi power plant due to its short operation period is an obstacle for an analysis of this plant's contribution to the firmness of the power system in a joint operation. Therefore, generation information was extended using the longer wind velocity records available at Puerto Bolívar. The procedure followed is described below:

- Power calculations using wind velocities data at Puerto Bolívar.
  - For each of the hours of existing data at Puerto Bolívar, power generation in a Nordex N60 turbine was calculated.
  - The calculation adjusted wind velocity to an altitude of 60 ms using an assumed roughness factor (ar).
  - Power corresponding to the adjusted velocity was calculated based on the power curve of the aerogenerator. It was adjusted to take into account differences between air densities at Jepírachi and the standard value.
- Regression between hourly estimated power at Puerto Bolívar and Jepírachi generation.
  - Common hourly data between Jepírachi generation reported by XM and Jepírachi generation computed using the methodology described in a. (above), were used to perform a regression analysis. This analysis was repeated using different values of the roughness coefficient, choosing the value giving the best fit.
- Missing hourly velocity information at Puerto Bolívar was filled in.
  - Initially, the correlation between wind velocities at the Puerto Bolívar and Barranquilla Airports was studied, but no significance was found. Therefore, missing data were filled in based on daily mean velocity, if available. Otherwise, monthly mean velocity was used and finally, multiannual monthly mean velocity was used. All these results were adjusted to consider the hourly seasonality observed in the data.

d. Extension of Jepírachi generation.
  - Jepírachi generation information was extended (1985–2008) using the regression equation found and applied to the filled-in Puerto Bolívar velocity records. Tables A6.4 and A6.5 show extended monthly generation values for Jepírachi.

Table A6.4. Extended Monthly Generation for Jepírachi (January to June)

EXTENDED MONTHLY GENERATION FOR JEPIRACHI (KWH)						
	Jan	Feb	Mar	Abr	May	Jun
1985	5834634	5682658	6515124	5886177	5767205	6914523
1986	5834634	5682658	6515124	5886177	5767205	6914523
1987	5834634	7887850	6889132	6483911	5767205	7236743
1988	7268860	7500189	8912351	6991765	7381501	6608671
1989	5834634	5682658	6515124	5930856	6758656	7576098
1990	9451220	5305019	4739058	6958182	6607606	7778632
1991	6888466	6044854	6438107	6649830	7122249	7487965
1992	6151827	6929893	8137434	7015526	6335503	7483811
1993	6475069	5620726	7363741	6390443	4092576	7248022
1994	6418401	7009124	7217540	7328519	7059915	8586733
1995	6697520	5836699	6443392	6231644	6491717	6627188
1996	5370648	6182659	6476131	5931191	5767205	6914523
1997	4676298	7837674	7564978	6823904	5922530	7007094
1998	5774991	5591419	7138039	6586111	5526878	7276299
1999	5773035	5364206	6468408	7050548	6026792	6759032
2000	5834634	5885611	6515124	5886177	6363170	7978651
2001	6235307	1399111	1603269	1734096	2497808	8361813
2002	6742444	6307064	7893469	6571283	7252543	7122733
2003	6213564	7372513	6822730	6040200	8540665	7014330
2004	4417189	1630762	3947270	4669053	6122227	9037782
2005	4431175	4802542	6244397	4828971	4138032	3619306
2006	5030369	6179175	7233905	5023244	5386714	6027382
2007	5426555	5031539	5762332	4826728	4020576	3947717
2008	5502418	5912375	6480628	5917684	5767061	6500230

Source: Appendix authors' data.

Table A6.5. Extended Monthly Generation for Jepírachi (July to December)

EXTENDED MONTHLY GENERATION FOR JEPIRACHI (KWH)						
	Jul	Aug	Sep	Oct	Nov	Dec
1985	7734911	6152792	3710858	2721909	3403509	4825251
1986	7734911	6152792	3710858	4571029	5907804	7209327
1987	9115923	8104222	5159465	2721909	4541764	6151577
1988	9115498	4376842	5177179	3453668	3353160	4825251
1989	7940524	6146705	4396355	6007866	5039010	5520377
1990	7449251	7981166	5372166	1751368	3965017	5536141
1991	8293163	7556200	6611484	4786059	3860408	4825251
1992	8855269	7881288	5345987	5580324	4515810	4825251
1993	8031142	7856364	3710858	6098720	4384973	6404446
1994	9710702	8014871	6137318	3802563	3901304	5442340
1995	6927623	3109042	3523425	2325658	4327140	4696092
1996	7207639	5736949	4090081	2721909	3403509	5121455
1997	8740789	8016731	5505666	2770995	3656170	6710743
1998	7066678	6175066	3769276	4174693	3401869	4825251
1999	7604889	5483666	2420295	2147343	2330244	4750685
2000	7497365	7177243	3394830	4059808	3775646	5349653
2001	7717748	8186006	5364343	4789924	4050187	4968515
2002	8186261	7731705	4112645	4967635	5747633	6888561
2003	8378413	6973755	4221191	2511494	3088666	4628588
2004	6911378	7201819	2131765	2623595	2895604	3527309
2005	5263834	5401123	4179454	4179454	2251921	3560560
2006	7761522	6197955	4783490	2289704	2992357	4075575
2007	6150271	3770902	3173954	1005641	3245168	3529592
2008	6204898	3252952	1699921	1974458	1863222	2842356

Source: Appendix authors' data.

Chapter 5: Case Studies for Complementarity Analysis

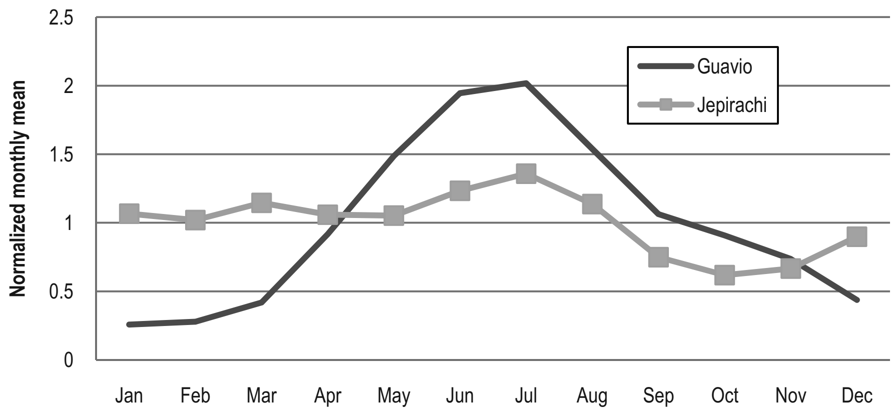
Complementarity between hydroelectric generation and wind generation at Jepírachi is due to two factors: noncoincidence in seasonal mean values of both variables, and synergy obtained on the lack of coincidence of extreme events for them.

5.1 Mean Monthly Discharges and Jepírachi Generation

The following figures show normalized values (monthly mean divided by the annual mean) for wind velocities and river discharges for the four rivers in which complementarity with wind power was analyzed.

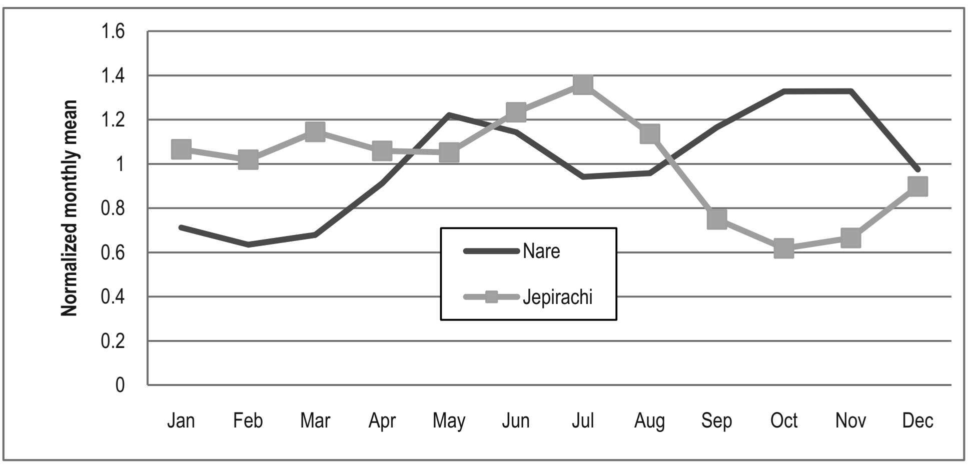
Figure A6.9 shows the complementarity between these resources, since low water discharges during the drier months (January to April) correspond to high wind power.

Figure A6.9. Mean Monthly Values at the Guavio River Dam Site



Source: Appendix authors' data.

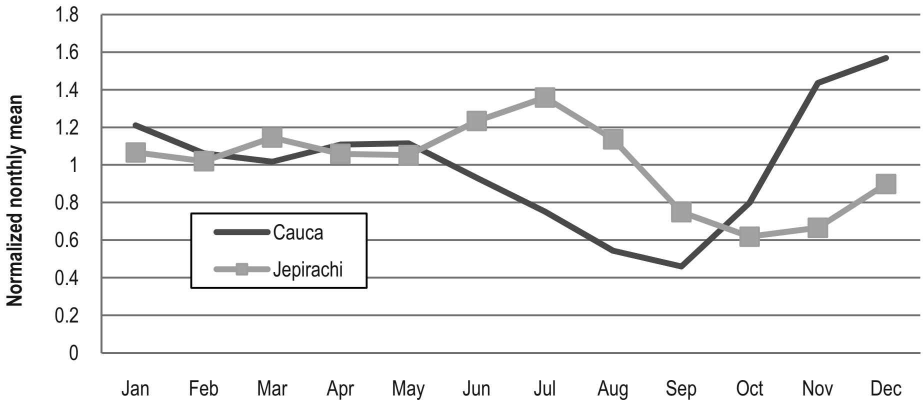
Figure A6.10. Mean Monthly Values at the Santa Rita Dam Site on the Nare River



Source: Appendix authors' data.

The graph shows very good complementarity between the Nare River and wind power at Jepírachi. Low discharges during the two dry seasons (December to March and July and August) correspond to high wind power; the opposite is also true.

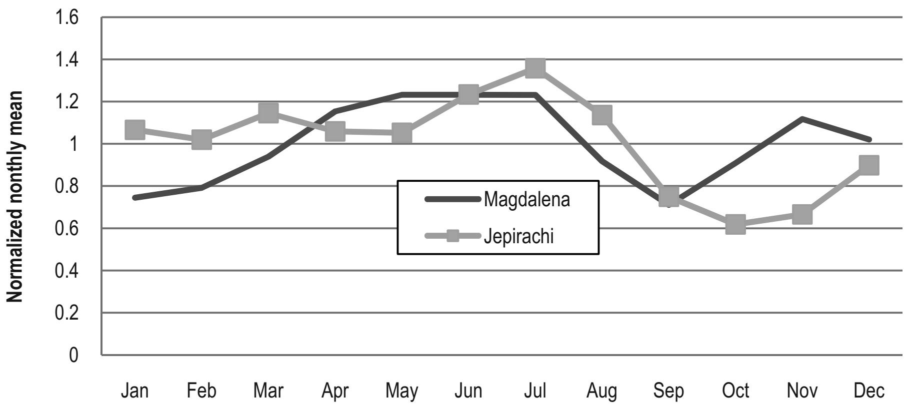
Figure A6.11. Mean Monthly Values at the Salvajina Dam Site on the Cauca River



Source: Appendix authors' data.

The Cauca River at the Salvajina Dam site presents a dry period from June to September which is complemented by high wind power at the Jepírachi site.

Figure A6.12. Mean Monthly Values at the Salvajina Dam Site on the Magdalena River



Source: Appendix authors' data.

Discharges of the Magdalena River at Betania follow a similar pattern to wind power at Jepírachi, although some complementarity is observed during the first dry season occurring at the beginning of the year.

5.2 El Niño occurrences

Colombia's interconnected power system is severely affected by severe droughts due to its very large hydroelectric component. Historically, during these periods electricity prices rise due to the supply shortage and, in extreme cases, electricity rationing may occur. An example is the rationing in 1992, with severe economic and political consequences in the country. Droughts in Colombia occur due to a global climatological event known as El Niño that affects nearly the entire country. Next Table identifies the El Niño periods that have occurred since 1950, according to IDEAM.

Table A6.6. El Niño Periods since 1950

"EL NIÑO" PERIODS Source: IDEAM		
Start	Finish	Months
Jul-51	Jan-52	6
Mar-57	Jul-58	14
Jun-63	Feb-64	8
May-65	May-66	13
Oct-68	Jun-69	8
Aug-69	Feb-70	6
Apr-72	Feb-73	10
Aug-76	Mar-77	7
Aug-77	Feb-78	6
Apr-82	Jul-83	15
Jul-86	Mar-88	20
Apr-91	Jul-92	15
Feb-93	Aug-93	6
Mar-94	Apr-95	13
Apr-97	May-98	13
Apr-02	Apr-03	12
Jun-04	Mar-05	8
Aug-06	Feb-07	6

Source: Appendix authors' data.

An analysis was conducted of the severity of El Niño occurrences in the four rivers selected (Nare, Guavio, Cauca and Magdalena) compared with energy delivered by the Jepírachi power plant. Initially, average historical values for river discharges and Jepírachi generation during El Niño periods were examined, as shown in following tables. An example will better illustrate better the analysis conducted. The first column of the first table analyzes the severity of the El Niño occurrence between July 1986 and March 1988. The series of mean discharge occurrences in all historical periods starting in July and finishing in March of the following year were analyzed (as shown in the table). The mean and standard deviation of these series were obtained (shown at the end of the table), and the departure from the mean value, expressed in terms of standard deviations, was obtained for the value corresponding to El Niño (July 1986 to March 1988) and is shown at the end of the table. The tables present the information for all El Niño occurrences from 1985 to December 2008 for the four rivers already mentioned, as well as historical and reconstructed generation at the Jepírachi power plant. El Niño occurrences are shown in gray in the tables.

Table A6.7. Analysis of El Niño Occurrences in Guavio River Discharges (1986–1995)

TABLE 1. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
GUAVIO RIVER

Jul. 86 Mar. 88			Abr. 91 Jul. 92			Feb. 93 Ago. 93			Mar. 94 Abr. 95		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Jul-63	Mar-65	60.06	Apr-63	Jul-64	69.92	Feb-63	Aug-63	75.70	Mar-63	Apr-64	56.94
Jul-64	Mar-66	67.40	Apr-64	Jul-65	79.97	Feb-64	Aug-64	75.27	Mar-64	Apr-65	64.99
Jul-65	Mar-67	57.03	Apr-65	Jul-66	68.81	Feb-65	Aug-65	85.40	Mar-65	Apr-66	67.11
Jul-66	Mar-68	63.08	Apr-66	Jul-67	65.89	Feb-66	Aug-66	52.44	Mar-66	Apr-67	51.86
Jul-67	Mar-69	67.73	Apr-67	Jul-68	84.14	Feb-67	Aug-67	87.93	Mar-67	Apr-68	67.57
Jul-68	Mar-70	65.23	Apr-68	Jul-69	77.97	Feb-68	Aug-68	94.44	Mar-68	Apr-69	70.26
Jul-69	Mar-71	75.13	Apr-69	Jul-70	80.53	Feb-69	Aug-69	69.10	Mar-69	Apr-70	64.65
Jul-70	Mar-72	80.60	Apr-70	Jul-71	97.58	Feb-70	Aug-70	99.61	Mar-70	Apr-71	82.70
Jul-71	Mar-73	77.06	Apr-71	Jul-72	100.64	Feb-71	Aug-71	107.96	Mar-71	Apr-72	84.30
Jul-72	Mar-74	67.00	Apr-72	Jul-73	83.92	Feb-72	Aug-72	109.86	Mar-72	Apr-73	72.37
Jul-73	Mar-75	67.47	Apr-73	Jul-74	82.51	Feb-73	Aug-73	75.46	Mar-73	Apr-74	68.41
Jul-74	Mar-76	66.10	Apr-74	Jul-75	78.49	Feb-74	Aug-74	90.61	Mar-74	Apr-75	64.09
Jul-75	Mar-77	74.10	Apr-75	Jul-76	95.67	Feb-75	Aug-75	85.99	Mar-75	Apr-76	70.86
Jul-76	Mar-78	62.94	Apr-76	Jul-77	88.67	Feb-76	Aug-76	117.47	Mar-76	Apr-77	78.69
Jul-77	Mar-79	60.09	Apr-77	Jul-78	72.44	Feb-77	Aug-77	75.00	Mar-77	Apr-78	58.91
Jul-78	Mar-80	59.04	Apr-78	Jul-79	69.74	Feb-78	Aug-78	76.63	Mar-78	Apr-79	59.27
Jul-79	Mar-81	60.88	Apr-79	Jul-80	75.49	Feb-79	Aug-79	69.96	Mar-79	Apr-80	63.13
Jul-80	Mar-82	59.11	Apr-80	Jul-81	72.39	Feb-80	Aug-80	75.44	Mar-80	Apr-81	59.43
Jul-81	Mar-83	70.60	Apr-81	Jul-82	79.08	Feb-81	Aug-81	74.60	Mar-81	Apr-82	66.71
Jul-82	Mar-84	78.63	Apr-82	Jul-83	91.63	Feb-82	Aug-82	90.24	Mar-82	Apr-83	79.66
Jul-83	Mar-85	73.62	Apr-83	Jul-84	92.31	Feb-83	Aug-83	102.13	Mar-83	Apr-84	77.71
Jul-84	Mar-86	67.12	Apr-84	Jul-85	82.16	Feb-84	Aug-84	106.16	Mar-84	Apr-85	69.06
Jul-85	Mar-87	75.89	Apr-85	Jul-86	89.86	Feb-85	Aug-85	78.79	Mar-85	Apr-86	67.44
Jul-86	Mar-88	73.60	Apr-86	Jul-87	89.63	Feb-86	Aug-86	110.30	Mar-86	Apr-87	78.78
Jul-87	Mar-89	70.86	Apr-87	Jul-88	75.53	Feb-87	Aug-87	91.97	Mar-87	Apr-88	64.30
Jul-88	Mar-90	72.71	Apr-88	Jul-89	84.73	Feb-88	Aug-88	66.87	Mar-88	Apr-89	65.18
Jul-89	Mar-91	66.91	Apr-89	Jul-90	89.78	Feb-89	Aug-89	98.09	Mar-89	Apr-90	73.62
Jul-90	Mar-92	65.10	Apr-90	Jul-91	85.34	Feb-90	Aug-90	104.51	Mar-90	Apr-91	70.64
Jul-91	Mar-93	65.02	Apr-91	Jul-92	77.94	Feb-91	Aug-91	100.49	Mar-91	Apr-92	69.94
Jul-92	Mar-94	69.79	Apr-92	Jul-93	77.95	Feb-92	Aug-92	69.31	Mar-92	Apr-93	59.21
Jul-93	Mar-95	77.55	Apr-93	Jul-94	94.88	Feb-93	Aug-93	97.86	Mar-93	Apr-94	73.01
Jul-94	Mar-96	60.63	Apr-94	Jul-95	85.68	Feb-94	Aug-94	111.73	Mar-94	Apr-95	80.13
Jul-95	Mar-97	57.14	Apr-95	Jul-96	67.70	Feb-95	Aug-95	60.00	Mar-95	Apr-96	50.44
Jul-96	Mar-98	60.42	Apr-96	Jul-97	81.59	Feb-96	Aug-96	89.71	Mar-96	Apr-97	64.29
Jul-97	Mar-99	68.01	Apr-97	Jul-98	83.38	Feb-97	Aug-97	91.19	Mar-97	Apr-98	58.79
Jul-98	Mar-00	70.75	Apr-98	Jul-99	89.81	Feb-98	Aug-98	102.20	Mar-98	Apr-99	78.68
Jul-99	Mar-01	66.49	Apr-99	Jul-00	84.11	Feb-99	Aug-99	89.73	Mar-99	Apr-00	69.36
Jul-00	Mar-02	67.04	Apr-00	Jul-01	80.88	Feb-00	Aug-00	89.37	Mar-00	Apr-01	68.45
Jul-01	Mar-03	70.74	Apr-01	Jul-02	86.79	Feb-01	Aug-01	80.96	Mar-01	Apr-02	68.21
Jul-02	Mar-04	64.52	Apr-02	Jul-03	82.16	Feb-02	Aug-02	106.01	Mar-02	Apr-03	73.84
Jul-03	Mar-05	73.75	Apr-03	Jul-04	89.32	Feb-03	Aug-03	76.74	Mar-03	Apr-04	65.69
Jul-04	Mar-06	64.77	Apr-04	Jul-05	87.01	Feb-04	Aug-04	116.03	Mar-04	Apr-05	81.73
Jul-05	Mar-07	63.68	Apr-05	Jul-06	82.15	Feb-05	Aug-05	74.21	Mar-05	Apr-06	68.79
Jul-06	Mar-08	56.29	Apr-06	Jul-07	75.35	Feb-06	Aug-06	91.33	Mar-06	Apr-07	67.05
Jul-07	Mar-09	59.08	Apr-07	Jul-08	72.14	Feb-07	Aug-07	72.53	Mar-07	Apr-08	56.25
Jul-08	Mar-10		Apr-08	Jul-09		Feb-08	Aug-08	75.53	Mar-08	Apr-09	64.01
Average		67.13	Average		82.30	Average		87.89	Average		68.18
St, Dev.		6.29	St, Dev.		8.25	St, Dev.		15.63	St, Dev.		7.99
Deviation from mean		1.03	Deviation from mean		-0.53	Deviation from mean		0.64	Deviation from mean		1.50

Source: Appendix authors' data.

Table A6.8. Analysis of El Niño Occurrences in Guavio River Discharges (1997–2007)

TABLE 2. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
GUAVIO RIVER

Abr. 97 May. 98			Abr. 02 Abr. 03			Jun. 04 Mar. 05			Ago. 06 Feb. 07		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Apr-63	May-64	63.31	Apr-63	Apr-64	60.12	Jun-63	Mar-64	55.07	Aug-63	Feb-64	44.83
Apr-64	May-65	72.89	Apr-64	Apr-65	68.37	Jun-64	Mar-65	65.95	Aug-64	Feb-65	26.30
Apr-65	May-66	68.76	Apr-65	Apr-66	71.16	Jun-65	Mar-66	68.78	Aug-65	Feb-66	17.20
Apr-66	May-67	55.79	Apr-66	Apr-67	52.96	Jun-66	Mar-67	54.88	Aug-66	Feb-67	30.40
Apr-67	May-68	71.22	Apr-67	Apr-68	71.11	Jun-67	Mar-68	66.63	Aug-67	Feb-68	13.75
Apr-68	May-69	74.78	Apr-68	Apr-69	73.92	Jun-68	Mar-69	72.64	Aug-68	Feb-69	17.00
Apr-69	May-70	70.75	Apr-69	Apr-70	68.19	Jun-69	Mar-70	63.99	Aug-69	Feb-70	27.25
Apr-70	May-71	88.02	Apr-70	Apr-71	85.55	Jun-70	Mar-71	82.06	Aug-70	Feb-71	27.10
Apr-71	May-72	91.50	Apr-71	Apr-72	86.42	Jun-71	Mar-72	82.82	Aug-71	Feb-72	41.45
Apr-72	May-73	76.71	Apr-72	Apr-73	75.02	Jun-72	Mar-73	69.98	Aug-72	Feb-73	12.25
Apr-73	May-74	76.01	Apr-73	Apr-74	72.72	Jun-73	Mar-74	73.57	Aug-73	Feb-74	18.95
Apr-74	May-75	68.72	Apr-74	Apr-75	66.57	Jun-74	Mar-75	61.98	Aug-74	Feb-75	10.55
Apr-75	May-76	79.56	Apr-75	Apr-76	73.17	Jun-75	Mar-76	73.55	Aug-75	Feb-76	18.90
Apr-76	May-77	80.13	Apr-76	Apr-77	81.25	Jun-76	Mar-77	78.28	Aug-76	Feb-77	13.60
Apr-77	May-78	63.75	Apr-77	Apr-78	61.97	Jun-77	Mar-78	63.85	Aug-77	Feb-78	12.15
Apr-78	May-79	63.44	Apr-78	Apr-79	62.76	Jun-78	Mar-79	59.79	Aug-78	Feb-79	9.75
Apr-79	May-80	66.56	Apr-79	Apr-80	66.22	Jun-79	Mar-80	65.09	Aug-79	Feb-80	15.85
Apr-80	May-81	65.73	Apr-80	Apr-81	62.51	Jun-80	Mar-81	61.18	Aug-80	Feb-81	13.45
Apr-81	May-82	72.69	Apr-81	Apr-82	70.11	Jun-81	Mar-82	63.00	Aug-81	Feb-82	17.40
Apr-82	May-83	85.02	Apr-82	Apr-83	83.65	Jun-82	Mar-83	76.36	Aug-82	Feb-83	38.75
Apr-83	May-84	79.00	Apr-83	Apr-84	78.18	Jun-83	Mar-84	76.96	Aug-83	Feb-84	46.05
Apr-84	May-85	74.46	Apr-84	Apr-85	71.91	Jun-84	Mar-85	76.24	Aug-84	Feb-85	11.05
Apr-85	May-86	72.19	Apr-85	Apr-86	71.53	Jun-85	Mar-86	72.91	Aug-85	Feb-86	21.30
Apr-86	May-87	81.07	Apr-86	Apr-87	81.78	Jun-86	Mar-87	89.00	Aug-86	Feb-87	22.45
Apr-87	May-88	67.74	Apr-87	Apr-88	67.54	Jun-87	Mar-88	72.91	Aug-87	Feb-88	13.05
Apr-88	May-89	74.24	Apr-88	Apr-89	69.38	Jun-88	Mar-89	73.11	Aug-88	Feb-89	26.65
Apr-89	May-90	81.60	Apr-89	Apr-90	74.98	Jun-89	Mar-90	69.63	Aug-89	Feb-90	22.10
Apr-90	May-91	72.36	Apr-90	Apr-91	70.81	Jun-90	Mar-91	62.57	Aug-90	Feb-91	16.25
Apr-91	May-92	71.50	Apr-91	Apr-92	73.25	Jun-91	Mar-92	76.71	Aug-91	Feb-92	12.90
Apr-92	May-93	65.30	Apr-92	Apr-93	62.74	Jun-92	Mar-93	63.53	Aug-92	Feb-93	14.95
Apr-93	May-94	81.11	Apr-93	Apr-94	75.67	Jun-93	Mar-94	72.74	Aug-93	Feb-94	14.15
Apr-94	May-95	84.00	Apr-94	Apr-95	83.85	Jun-94	Mar-95	83.13	Aug-94	Feb-95	13.55
Apr-95	May-96	57.55	Apr-95	Apr-96	52.17	Jun-95	Mar-96	49.24	Aug-95	Feb-96	25.75
Apr-96	May-97	71.45	Apr-96	Apr-97	66.82	Jun-96	Mar-97	62.65	Aug-96	Feb-97	23.90
Apr-97	May-98	66.70	Apr-97	Apr-98	61.93	Jun-97	Mar-98	56.73	Aug-97	Feb-98	11.35
Apr-98	May-99	85.03	Apr-98	Apr-99	83.49	Jun-98	Mar-99	77.69	Aug-98	Feb-99	28.25
Apr-99	May-00	77.70	Apr-99	Apr-00	72.42	Jun-99	Mar-00	66.67	Aug-99	Feb-00	23.75
Apr-00	May-01	74.14	Apr-00	Apr-01	71.73	Jun-00	Mar-01	70.02	Aug-00	Feb-01	15.95
Apr-01	May-02	76.74	Apr-01	Apr-02	71.95	Jun-01	Mar-02	69.77	Aug-01	Feb-02	16.20
Apr-02	May-03	80.08	Apr-02	Apr-03	76.43	Jun-02	Mar-03	70.08	Aug-02	Feb-03	10.20
Apr-03	May-04	75.61	Apr-03	Apr-04	68.75	Jun-03	Mar-04	62.41	Aug-03	Feb-04	16.10
Apr-04	May-05	86.50	Apr-04	Apr-05	84.02	Jun-04	Mar-05	76.66	Aug-04	Feb-05	20.45
Apr-05	May-06	76.09	Apr-05	Apr-06	72.65	Jun-05	Mar-06	62.54	Aug-05	Feb-06	16.35
Apr-06	May-07	69.01	Apr-06	Apr-07	67.68	Jun-06	Mar-07	57.59	Aug-06	Feb-07	10.80
Apr-07	May-08	60.02	Apr-07	Apr-08	58.74	Jun-07	Mar-08	58.73	Aug-07	Feb-08	17.30
Apr-08	May-09		Apr-08	Apr-09	67.76	Jun-08	Mar-09	71.00	Aug-08	Feb-09	19.95
Average		73.70	Average		71.13	Average		68.71	Average		19.95
St, Dev.		8.07	St, Dev.		8.06	St, Dev.		8.45	St, Dev.		9.00
Deviation from mean		-0.87	Deviation from mean		0.66	Deviation from mean		0.94	Deviation from mean		-1.02

Source: Appendix authors' data.

Table A6.9. Analysis of El Niño Occurrences in Nare River Discharges (1986–1995)

TABLE 1. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
NARE RIVER

Jul. 86 Mar. 88			Abr. 91 Jul. 92			Feb. 93 Ago. 93			Mar. 94 Abr. 95		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Jul-55	Mar-57		Apr-55	Jul-56		Feb-55	Aug-55		Mar-55	Apr-56	
Jul-56	Mar-58	46.34	Apr-56	Jul-57	56.21	Feb-56	Aug-56	61.69	Mar-56	Apr-57	57.79
Jul-57	Mar-59	32.95	Apr-57	Jul-58	37.60	Feb-57	Aug-57	40.71	Mar-57	Apr-58	37.63
Jul-58	Mar-60	33.64	Apr-58	Jul-59	31.68	Feb-58	Aug-58	31.56	Mar-58	Apr-59	30.28
Jul-59	Mar-61	40.42	Apr-59	Jul-60	38.61	Feb-59	Aug-59	30.00	Mar-59	Apr-60	35.31
Jul-60	Mar-62	42.88	Apr-60	Jul-61	41.01	Feb-60	Aug-60	37.51	Mar-60	Apr-61	40.84
Jul-61	Mar-63	52.44	Apr-61	Jul-62	48.93	Feb-61	Aug-61	33.60	Mar-61	Apr-62	41.99
Jul-62	Mar-64	49.32	Apr-62	Jul-63	56.69	Feb-62	Aug-62	55.69	Mar-62	Apr-63	56.65
Jul-63	Mar-65	44.83	Apr-63	Jul-64	46.53	Feb-63	Aug-63	49.24	Mar-63	Apr-64	45.92
Jul-64	Mar-66	45.08	Apr-64	Jul-65	43.83	Feb-64	Aug-64	40.91	Mar-64	Apr-65	43.26
Jul-65	Mar-67	46.64	Apr-65	Jul-66	43.56	Feb-65	Aug-65	35.59	Mar-65	Apr-66	41.83
Jul-66	Mar-68	47.91	Apr-66	Jul-67	50.76	Feb-66	Aug-66	39.31	Mar-66	Apr-67	46.55
Jul-67	Mar-69	46.77	Apr-67	Jul-68	48.89	Feb-67	Aug-67	50.07	Mar-67	Apr-68	45.64
Jul-68	Mar-70	48.86	Apr-68	Jul-69	49.41	Feb-68	Aug-68	46.21	Mar-68	Apr-69	49.92
Jul-69	Mar-71	54.32	Apr-69	Jul-70	48.59	Feb-69	Aug-69	38.64	Mar-69	Apr-70	44.57
Jul-70	Mar-72	66.16	Apr-70	Jul-71	65.99	Feb-70	Aug-70	43.51	Mar-70	Apr-71	58.11
Jul-71	Mar-73	55.01	Apr-71	Jul-72	67.64	Feb-71	Aug-71	76.86	Mar-71	Apr-72	66.13
Jul-72	Mar-74	48.54	Apr-72	Jul-73	45.06	Feb-72	Aug-72	52.69	Mar-72	Apr-73	45.02
Jul-73	Mar-75	60.69	Apr-73	Jul-74	56.09	Feb-73	Aug-73	36.21	Mar-73	Apr-74	52.97
Jul-74	Mar-76	61.30	Apr-74	Jul-75	59.13	Feb-74	Aug-74	55.84	Mar-74	Apr-75	57.80
Jul-75	Mar-77	53.27	Apr-75	Jul-76	61.31	Feb-75	Aug-75	50.69	Mar-75	Apr-76	60.09
Jul-76	Mar-78	39.04	Apr-76	Jul-77	41.66	Feb-76	Aug-76	49.01	Mar-76	Apr-77	41.51
Jul-77	Mar-79	49.93	Apr-77	Jul-78	50.83	Feb-77	Aug-77	35.10	Mar-77	Apr-78	44.46
Jul-78	Mar-80	48.50	Apr-78	Jul-79	53.37	Feb-78	Aug-78	60.59	Mar-78	Apr-79	52.84
Jul-79	Mar-81	42.76	Apr-79	Jul-80	46.91	Feb-79	Aug-79	44.39	Mar-79	Apr-80	48.06
Jul-80	Mar-82	51.01	Apr-80	Jul-81	46.15	Feb-80	Aug-80	33.06	Mar-80	Apr-81	37.21
Jul-81	Mar-83	49.59	Apr-81	Jul-82	60.96	Feb-81	Aug-81	53.56	Mar-81	Apr-82	58.96
Jul-82	Mar-84	39.28	Apr-82	Jul-83	44.58	Feb-82	Aug-82	52.61	Mar-82	Apr-83	44.44
Jul-83	Mar-85	49.38	Apr-83	Jul-84	46.66	Feb-83	Aug-83	38.23	Mar-83	Apr-84	40.25
Jul-84	Mar-86	53.20	Apr-84	Jul-85	54.26	Feb-84	Aug-84	51.06	Mar-84	Apr-85	52.94
Jul-85	Mar-87	46.37	Apr-85	Jul-86	50.79	Feb-85	Aug-85	48.39	Mar-85	Apr-86	50.66
Jul-86	Mar-88	43.10	Apr-86	Jul-87	42.14	Feb-86	Aug-86	44.23	Mar-86	Apr-87	42.37
Jul-87	Mar-89	57.32	Apr-87	Jul-88	46.19	Feb-87	Aug-87	36.36	Mar-87	Apr-88	42.99
Jul-88	Mar-90	61.80	Apr-88	Jul-89	62.64	Feb-88	Aug-88	48.97	Mar-88	Apr-89	61.71
Jul-89	Mar-91	48.79	Apr-89	Jul-90	52.78	Feb-89	Aug-89	50.71	Mar-89	Apr-90	52.76
Jul-90	Mar-92	41.68	Apr-90	Jul-91	46.19	Feb-90	Aug-90	41.71	Mar-90	Apr-91	44.55
Jul-91	Mar-93	35.89	Apr-91	Jul-92	37.53	Feb-91	Aug-91	40.36	Mar-91	Apr-92	37.89
Jul-92	Mar-94	42.95	Apr-92	Jul-93	37.80	Feb-92	Aug-92	30.19	Mar-92	Apr-93	35.01
Jul-93	Mar-95	46.40	Apr-93	Jul-94	48.09	Feb-93	Aug-93	38.97	Mar-93	Apr-94	46.84
Jul-94	Mar-96	49.49	Apr-94	Jul-95	46.95	Feb-94	Aug-94	41.31	Mar-94	Apr-95	42.69
Jul-95	Mar-97	57.65	Apr-95	Jul-96	60.15	Feb-95	Aug-95	52.27	Mar-95	Apr-96	53.49
Jul-96	Mar-98	41.42	Apr-96	Jul-97	55.28	Feb-96	Aug-96	64.27	Mar-96	Apr-97	57.90
Jul-97	Mar-99	43.61	Apr-97	Jul-98	34.03	Feb-97	Aug-97	40.31	Mar-97	Apr-98	31.94
Jul-98	Mar-00	68.16	Apr-98	Jul-99	60.18	Feb-98	Aug-98	35.40	Mar-98	Apr-99	55.04
Jul-99	Mar-01	70.02	Apr-99	Jul-00	75.00	Feb-99	Aug-99	67.37	Mar-99	Apr-00	71.34
Jul-00	Mar-02	49.22	Apr-00	Jul-01	62.89	Feb-00	Aug-00	74.29	Mar-00	Apr-01	66.10
Jul-01	Mar-03	38.28	Apr-01	Jul-02	41.34	Feb-01	Aug-01	37.43	Mar-01	Apr-02	38.95
Jul-02	Mar-04	40.88	Apr-02	Jul-03	43.82	Feb-02	Aug-02	42.76	Mar-02	Apr-03	40.02
Jul-03	Mar-05	51.20	Apr-03	Jul-04	48.73	Feb-03	Aug-03	43.21	Mar-03	Apr-04	45.25
Jul-04	Mar-06	57.63	Apr-04	Jul-05	60.48	Feb-04	Aug-04	47.91	Mar-04	Apr-05	55.87
Jul-05	Mar-07	54.55	Apr-05	Jul-06	60.24	Feb-05	Aug-05	53.67	Mar-05	Apr-06	56.35
Jul-06	Mar-08	61.07	Apr-06	Jul-07	59.86	Feb-06	Aug-06	57.03	Mar-06	Apr-07	55.89
Jul-07	Mar-09	73.96	Apr-07	Jul-08	73.12	Feb-07	Aug-07	56.59	Mar-07	Apr-08	67.00
Jul-08	Mar-10		Apr-08	Jul-09		Feb-08	Aug-08	76.61	Mar-08	Apr-09	75.74
Average		49.64	Average		50.94	Average		47.07	Average		49.19
St, Dev.		9.01	St, Dev.		9.68	St, Dev.		11.42	St, Dev.		10.14
Deviation from mean		-0.73	Deviation from mean		-1.39	Deviation from mean		-0.71	Deviation from mean		-0.64

Source: Appendix authors' data.

Table A6.10. Analysis of El Niño Occurrences in Nare River Discharges (1997–2007)

TABLE 2. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
NARE RIVER

Abr. 97 May. 98			Abr. 02 Abr. 03			Jun. 04 Mar. 05			Ago. 06 Feb. 07		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Apr-55	May-56		Apr-55	Apr-56		Jun-55	Mar-56		Aug-55	Feb-56	66.50
Apr-56	May-57	58.19	Apr-56	Apr-57	58.20	Jun-56	Mar-57	57.47	Aug-56	Feb-57	60.37
Apr-57	May-58	39.24	Apr-57	Apr-58	38.62	Jun-57	Mar-58	36.82	Aug-57	Feb-58	36.59
Apr-58	May-59	31.06	Apr-58	Apr-59	30.50	Jun-58	Mar-59	29.33	Aug-58	Feb-59	31.67
Apr-59	May-60	37.24	Apr-59	Apr-60	36.53	Jun-59	Mar-60	37.77	Aug-59	Feb-60	39.74
Apr-60	May-61	41.25	Apr-60	Apr-61	41.87	Jun-60	Mar-61	43.10	Aug-60	Feb-61	43.77
Apr-61	May-62	46.09	Apr-61	Apr-62	43.05	Jun-61	Mar-62	44.62	Aug-61	Feb-62	47.13
Apr-62	May-63	58.41	Apr-62	Apr-63	58.12	Jun-62	Mar-63	56.45	Aug-62	Feb-63	54.54
Apr-63	May-64	45.33	Apr-63	Apr-64	45.98	Jun-63	Mar-64	43.47	Aug-63	Feb-64	46.24
Apr-64	May-65	45.34	Apr-64	Apr-65	44.93	Jun-64	Mar-65	47.14	Aug-64	Feb-65	48.01
Apr-65	May-66	42.59	Apr-65	Apr-66	43.08	Jun-65	Mar-66	44.48	Aug-65	Feb-66	50.44
Apr-66	May-67	49.43	Apr-66	Apr-67	48.19	Jun-66	Mar-67	50.35	Aug-66	Feb-67	52.87
Apr-67	May-68	46.44	Apr-67	Apr-68	46.63	Jun-67	Mar-68	43.60	Aug-67	Feb-68	41.09
Apr-68	May-69	51.84	Apr-68	Apr-69	51.59	Jun-68	Mar-69	52.47	Aug-68	Feb-69	52.79
Apr-69	May-70	48.34	Apr-69	Apr-70	46.22	Jun-69	Mar-70	45.80	Aug-69	Feb-70	52.41
Apr-70	May-71	63.16	Apr-70	Apr-71	60.55	Jun-70	Mar-71	61.57	Aug-70	Feb-71	65.66
Apr-71	May-72	69.01	Apr-71	Apr-72	66.95	Jun-71	Mar-72	66.69	Aug-71	Feb-72	65.93
Apr-72	May-73	45.12	Apr-72	Apr-73	45.88	Jun-72	Mar-73	42.84	Aug-72	Feb-73	41.16
Apr-73	May-74	55.62	Apr-73	Apr-74	55.19	Jun-73	Mar-74	59.64	Aug-73	Feb-74	66.56
Apr-74	May-75	58.40	Apr-74	Apr-75	59.08	Jun-74	Mar-75	61.15	Aug-74	Feb-75	65.34
Apr-75	May-76	62.91	Apr-75	Apr-76	61.99	Jun-75	Mar-76	65.32	Aug-75	Feb-76	70.23
Apr-76	May-77	41.68	Apr-76	Apr-77	42.15	Jun-76	Mar-77	37.97	Aug-76	Feb-77	36.80
Apr-77	May-78	48.39	Apr-77	Apr-78	46.21	Jun-77	Mar-78	44.24	Aug-77	Feb-78	45.09
Apr-78	May-79	53.94	Apr-78	Apr-79	53.53	Jun-78	Mar-79	47.93	Aug-78	Feb-79	44.30
Apr-79	May-80	48.26	Apr-79	Apr-80	49.18	Jun-79	Mar-80	50.44	Aug-79	Feb-80	54.31
Apr-80	May-81	41.59	Apr-80	Apr-81	38.12	Jun-80	Mar-81	38.67	Aug-80	Feb-81	40.77
Apr-81	May-82	63.91	Apr-81	Apr-82	61.46	Jun-81	Mar-82	59.95	Aug-81	Feb-82	57.50
Apr-82	May-83	45.21	Apr-82	Apr-83	44.71	Jun-82	Mar-83	36.47	Aug-82	Feb-83	36.90
Apr-83	May-84	42.62	Apr-83	Apr-84	41.35	Jun-83	Mar-84	40.70	Aug-83	Feb-84	42.60
Apr-84	May-85	56.36	Apr-84	Apr-85	54.82	Jun-84	Mar-85	58.02	Aug-84	Feb-85	56.33
Apr-85	May-86	51.51	Apr-85	Apr-86	51.78	Jun-85	Mar-86	50.03	Aug-85	Feb-86	54.21
Apr-86	May-87	43.39	Apr-86	Apr-87	42.43	Jun-86	Mar-87	41.73	Aug-86	Feb-87	43.03
Apr-87	May-88	44.26	Apr-87	Apr-88	44.40	Jun-87	Mar-88	45.13	Aug-87	Feb-88	50.60
Apr-88	May-89	63.98	Apr-88	Apr-89	64.13	Jun-88	Mar-89	70.50	Aug-88	Feb-89	77.30
Apr-89	May-90	53.56	Apr-89	Apr-90	53.39	Jun-89	Mar-90	53.93	Aug-89	Feb-90	57.53
Apr-90	May-91	46.35	Apr-90	Apr-91	45.66	Jun-90	Mar-91	45.21	Aug-90	Feb-91	46.77
Apr-91	May-92	38.59	Apr-91	Apr-92	38.48	Jun-91	Mar-92	37.52	Aug-91	Feb-92	37.30
Apr-92	May-93	37.71	Apr-92	Apr-93	35.86	Jun-92	Mar-93	36.12	Aug-92	Feb-93	38.96
Apr-93	May-94	48.81	Apr-93	Apr-94	48.27	Jun-93	Mar-94	47.68	Aug-93	Feb-94	52.66
Apr-94	May-95	44.73	Apr-94	Apr-95	43.57	Jun-94	Mar-95	42.36	Aug-94	Feb-95	43.43
Apr-95	May-96	57.36	Apr-95	Apr-96	55.02	Jun-95	Mar-96	56.77	Aug-95	Feb-96	55.47
Apr-96	May-97	56.57	Apr-96	Apr-97	58.17	Jun-96	Mar-97	56.75	Aug-96	Feb-97	52.54
Apr-97	May-98	32.26	Apr-97	Apr-98	31.30	Jun-97	Mar-98	29.76	Aug-97	Feb-98	26.61
Apr-98	May-99	59.91	Apr-98	Apr-99	57.82	Jun-98	Mar-99	61.07	Aug-98	Feb-99	62.09
Apr-99	May-00	71.74	Apr-99	Apr-00	70.42	Jun-99	Mar-00	70.61	Aug-99	Feb-00	75.60
Apr-00	May-01	65.63	Apr-00	Apr-01	67.12	Jun-00	Mar-01	69.88	Aug-00	Feb-01	66.61
Apr-01	May-02	40.43	Apr-01	Apr-02	39.11	Jun-01	Mar-02	36.28	Aug-01	Feb-02	35.47
Apr-02	May-03	41.56	Apr-02	Apr-03	41.02	Jun-02	Mar-03	36.45	Aug-02	Feb-03	33.94
Apr-03	May-04	47.94	Apr-03	Apr-04	46.32	Jun-03	Mar-04	45.68	Aug-03	Feb-04	43.21
Apr-04	May-05	59.60	Apr-04	Apr-05	57.47	Jun-04	Mar-05	57.78	Aug-04	Feb-05	61.81
Apr-05	May-06	61.15	Apr-05	Apr-06	57.87	Jun-05	Mar-06	54.53	Aug-05	Feb-06	53.16
Apr-06	May-07	59.99	Apr-06	Apr-07	57.12	Jun-06	Mar-07	50.64	Aug-06	Feb-07	52.66
Apr-07	May-08	71.09	Apr-07	Apr-08	69.84	Jun-07	Mar-08	68.54	Aug-07	Feb-08	72.04
Apr-08	May-09		Apr-08	Apr-09	76.71	Jun-08	Mar-09	78.85	Aug-08	Feb-09	81.06
Average		50.68	Average		50.34	Average		49.97	Average		51.62
St, Dev.		9.93	St, Dev.		10.39	St, Dev.		11.42	St, Dev.		12.43
Deviation from mean		-1.86	Deviation from mean		-0.90	Deviation from mean		0.68	Deviation from mean		0.08

Source: Appendix authors' data.

Table A6.11. Analysis of El Niño Occurrences in Cauca River Discharges (1986–1995)

TABLE 1. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
CAUCA RIVER

Jul. 86 Mar. 88			Abr. 91 Jul. 92			Feb. 93 Ago. 93			Mar. 94 Abr. 95		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Jul-46	Mar-48		Apr-46	Jul-47		Feb-46	Aug-46		Mar-46	Apr-47	
Jul-47	Mar-49	122.05	Apr-47	Jul-48	120.06	Feb-47	Aug-47	83.00	Mar-47	Apr-48	119.43
Jul-48	Mar-50	152.67	Apr-48	Jul-49	118.81	Feb-48	Aug-48	115.14	Mar-48	Apr-49	119.00
Jul-49	Mar-51	219.10	Apr-49	Jul-50	215.75	Feb-49	Aug-49	122.29	Mar-49	Apr-50	192.93
Jul-50	Mar-52	160.95	Apr-50	Jul-51	205.88	Feb-50	Aug-50	295.57	Mar-50	Apr-51	232.36
Jul-51	Mar-53	125.95	Apr-51	Jul-52	132.94	Feb-51	Aug-51	144.86	Mar-51	Apr-52	137.86
Jul-52	Mar-54	133.10	Apr-52	Jul-53	118.63	Feb-52	Aug-52	123.14	Mar-52	Apr-53	121.86
Jul-53	Mar-55	167.52	Apr-53	Jul-54	148.56	Feb-53	Aug-53	104.00	Mar-53	Apr-54	148.14
Jul-54	Mar-56	190.62	Apr-54	Jul-55	177.75	Feb-54	Aug-54	144.14	Mar-54	Apr-55	176.00
Jul-55	Mar-57	170.10	Apr-55	Jul-56	184.56	Feb-55	Aug-55	163.57	Mar-55	Apr-56	192.64
Jul-56	Mar-58	124.86	Apr-56	Jul-57	147.88	Feb-56	Aug-56	152.00	Mar-56	Apr-57	149.07
Jul-57	Mar-59	92.10	Apr-57	Jul-58	105.13	Feb-57	Aug-57	125.43	Mar-57	Apr-58	109.86
Jul-58	Mar-60	110.38	Apr-58	Jul-59	97.00	Feb-58	Aug-58	84.71	Mar-58	Apr-59	90.29
Jul-59	Mar-61	117.76	Apr-59	Jul-60	119.94	Feb-59	Aug-59	91.43	Mar-59	Apr-60	120.50
Jul-60	Mar-62	111.62	Apr-60	Jul-61	109.75	Feb-60	Aug-60	114.86	Mar-60	Apr-61	112.00
Jul-61	Mar-63	127.29	Apr-61	Jul-62	117.63	Feb-61	Aug-61	98.86	Mar-61	Apr-62	111.64
Jul-62	Mar-64	130.52	Apr-62	Jul-63	144.38	Feb-62	Aug-62	122.29	Mar-62	Apr-63	144.36
Jul-63	Mar-65	123.86	Apr-63	Jul-64	131.25	Feb-63	Aug-63	159.29	Mar-63	Apr-64	129.00
Jul-64	Mar-66	120.67	Apr-64	Jul-65	129.81	Feb-64	Aug-64	121.14	Mar-64	Apr-65	132.43
Jul-65	Mar-67	149.76	Apr-65	Jul-66	111.06	Feb-65	Aug-65	94.00	Mar-65	Apr-66	108.14
Jul-66	Mar-68	161.86	Apr-66	Jul-67	168.13	Feb-66	Aug-66	94.86	Mar-66	Apr-67	168.07
Jul-67	Mar-69	130.33	Apr-67	Jul-68	134.88	Feb-67	Aug-67	147.00	Mar-67	Apr-68	139.36
Jul-68	Mar-70	137.00	Apr-68	Jul-69	136.63	Feb-68	Aug-68	133.86	Mar-68	Apr-69	137.29
Jul-69	Mar-71	161.86	Apr-69	Jul-70	137.31	Feb-69	Aug-69	128.14	Mar-69	Apr-70	137.50
Jul-70	Mar-72	179.00	Apr-70	Jul-71	180.69	Feb-70	Aug-70	131.57	Mar-70	Apr-71	186.93
Jul-71	Mar-73	123.00	Apr-71	Jul-72	156.75	Feb-71	Aug-71	179.57	Mar-71	Apr-72	167.00
Jul-72	Mar-74	143.10	Apr-72	Jul-73	100.56	Feb-72	Aug-72	133.43	Mar-72	Apr-73	102.21
Jul-73	Mar-75	178.90	Apr-73	Jul-74	171.50	Feb-73	Aug-73	89.71	Mar-73	Apr-74	173.36
Jul-74	Mar-76	174.43	Apr-74	Jul-75	151.69	Feb-74	Aug-74	159.86	Mar-74	Apr-75	157.21
Jul-75	Mar-77	145.24	Apr-75	Jul-76	178.94	Feb-75	Aug-75	155.29	Mar-75	Apr-76	187.86
Jul-76	Mar-78	97.76	Apr-76	Jul-77	102.69	Feb-76	Aug-76	152.14	Mar-76	Apr-77	110.29
Jul-77	Mar-79	111.86	Apr-77	Jul-78	108.19	Feb-77	Aug-77	77.14	Mar-77	Apr-78	104.71
Jul-78	Mar-80	123.76	Apr-78	Jul-79	119.25	Feb-78	Aug-78	92.00	Mar-78	Apr-79	112.71
Jul-79	Mar-81	118.10	Apr-79	Jul-80	124.44	Feb-79	Aug-79	118.00	Mar-79	Apr-80	132.64
Jul-80	Mar-82	142.24	Apr-80	Jul-81	128.19	Feb-80	Aug-80	105.14	Mar-80	Apr-81	119.00
Jul-81	Mar-83	144.95	Apr-81	Jul-82	167.63	Feb-81	Aug-81	151.71	Mar-81	Apr-82	168.86
Jul-82	Mar-84	132.19	Apr-82	Jul-83	141.88	Feb-82	Aug-82	171.29	Mar-82	Apr-83	153.00
Jul-83	Mar-85	155.00	Apr-83	Jul-84	148.25	Feb-83	Aug-83	128.57	Mar-83	Apr-84	141.64
Jul-84	Mar-86	157.14	Apr-84	Jul-85	163.19	Feb-84	Aug-84	158.29	Mar-84	Apr-85	169.21
Jul-85	Mar-87	130.90	Apr-85	Jul-86	147.00	Feb-85	Aug-85	117.14	Mar-85	Apr-86	144.50
Jul-86	Mar-88	96.57	Apr-86	Jul-87	110.50	Feb-86	Aug-86	148.14	Mar-86	Apr-87	120.00
Jul-87	Mar-89	139.76	Apr-87	Jul-88	98.63	Feb-87	Aug-87	80.29	Mar-87	Apr-88	89.14
Jul-88	Mar-90	158.19	Apr-88	Jul-89	167.38	Feb-88	Aug-88	101.86	Mar-88	Apr-89	167.71
Jul-89	Mar-91	117.14	Apr-89	Jul-90	127.88	Feb-89	Aug-89	147.57	Mar-89	Apr-90	135.07
Jul-90	Mar-92	107.52	Apr-90	Jul-91	116.38	Feb-90	Aug-90	129.00	Mar-90	Apr-91	118.36
Jul-91	Mar-93	101.48	Apr-91	Jul-92	103.06	Feb-91	Aug-91	111.86	Mar-91	Apr-92	110.07
Jul-92	Mar-94	122.95	Apr-92	Jul-93	105.63	Feb-92	Aug-92	78.71	Mar-92	Apr-93	99.86
Jul-93	Mar-95	125.52	Apr-93	Jul-94	136.75	Feb-93	Aug-93	121.86	Mar-93	Apr-94	140.43
Jul-94	Mar-96	129.10	Apr-94	Jul-95	120.63	Feb-94	Aug-94	134.57	Mar-94	Apr-95	123.86
Jul-95	Mar-97	149.90	Apr-95	Jul-96	144.25	Feb-95	Aug-95	106.29	Mar-95	Apr-96	141.50
Jul-96	Mar-98	115.71	Apr-96	Jul-97	146.75	Feb-96	Aug-96	152.00	Mar-96	Apr-97	154.50
Jul-97	Mar-99	124.76	Apr-97	Jul-98	94.31	Feb-97	Aug-97	131.86	Mar-97	Apr-98	92.43
Jul-98	Mar-00	192.90	Apr-98	Jul-99	161.88	Feb-98	Aug-98	91.57	Mar-98	Apr-99	162.07
Jul-99	Mar-01	166.79	Apr-99	Jul-00	196.44	Feb-99	Aug-99	177.14	Mar-99	Apr-00	207.86
Jul-00	Mar-02	103.21	Apr-00	Jul-01	119.82	Feb-00	Aug-00	186.86	Mar-00	Apr-01	136.77
Jul-01	Mar-03	92.33	Apr-01	Jul-02	102.17	Feb-01	Aug-01	88.36	Mar-01	Apr-02	103.56
Jul-02	Mar-04	92.67	Apr-02	Jul-03	94.24	Feb-02	Aug-02	97.04	Mar-02	Apr-03	90.42
Jul-03	Mar-05	118.19	Apr-03	Jul-04	105.12	Feb-03	Aug-03	91.73	Mar-03	Apr-04	106.50
Jul-04	Mar-06	136.31	Apr-04	Jul-05	122.75	Feb-04	Aug-04	88.13	Mar-04	Apr-05	125.39
Jul-05	Mar-07	131.57	Apr-05	Jul-06	141.19	Feb-05	Aug-05	119.00	Mar-05	Apr-06	144.29
Jul-06	Mar-08	144.85	Apr-06	Jul-07	132.30	Feb-06	Aug-06	148.51	Mar-06	Apr-07	133.14
Jul-07	Mar-09	176.39	Apr-07	Jul-08	176.43	Feb-07	Aug-07	130.51	Mar-07	Apr-08	172.94
Jul-08	Mar-10		Apr-08	Jul-09		Feb-08	Aug-08	179.73	Mar-08	Apr-09	182.54
Average		136.78	Average		136.54	Average		127.86	Average		139.02
St, Dev.		27.21	St, Dev.		29.27	St, Dev.		36.02	St, Dev.		31.37
Deviation from mean		-1.48	Deviation from mean		-1.14	Deviation from mean		-0.17	Deviation from mean		-0.48

Source: Appendix authors' data.

Table A6.12. Analysis of El Niño" Occurrences in Cauca River Flows (1997–2007)

TABLE 2. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
CAUCA RIVER

Abr. 97 May. 98			Abr. 02 Abr. 03			Jun. 04 Mar. 05			Ago. 06 Feb. 07		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Apr-46	May-47		Apr-46	Apr-47		Jun-46	Mar-47		Aug-46	Feb-47	
Apr-47	May-48	123.71	Apr-47	Apr-48	122.85	Jun-47	Mar-48	126.30	Aug-47	Feb-48	132.86
Apr-48	May-49	120.14	Apr-48	Apr-49	117.08	Jun-48	Mar-49	105.90	Aug-48	Feb-49	107.14
Apr-49	May-50	211.14	Apr-49	Apr-50	198.54	Jun-49	Mar-50	197.70	Aug-49	Feb-50	197.86
Apr-50	May-51	217.86	Apr-50	Apr-51	221.54	Jun-50	Mar-51	205.30	Aug-50	Feb-51	196.14
Apr-51	May-52	137.07	Apr-51	Apr-52	134.31	Jun-51	Mar-52	131.60	Aug-51	Feb-52	135.29
Apr-52	May-53	122.07	Apr-52	Apr-53	121.62	Jun-52	Mar-53	115.60	Aug-52	Feb-53	121.14
Apr-53	May-54	151.29	Apr-53	Apr-54	151.85	Jun-53	Mar-54	150.00	Aug-53	Feb-54	169.43
Apr-54	May-55	180.86	Apr-54	Apr-55	179.92	Jun-54	Mar-55	176.20	Aug-54	Feb-55	184.71
Apr-55	May-56	188.21	Apr-55	Apr-56	191.31	Jun-55	Mar-56	195.80	Aug-55	Feb-56	210.57
Apr-56	May-57	150.79	Apr-56	Apr-57	147.31	Jun-56	Mar-57	150.90	Aug-56	Feb-57	151.43
Apr-57	May-58	108.29	Apr-57	Apr-58	108.23	Jun-57	Mar-58	98.10	Aug-57	Feb-58	94.00
Apr-58	May-59	94.00	Apr-58	Apr-59	92.00	Jun-58	Mar-59	91.50	Aug-58	Feb-59	98.00
Apr-59	May-60	124.57	Apr-59	Apr-60	124.92	Jun-59	Mar-60	129.60	Aug-59	Feb-60	134.14
Apr-60	May-61	109.71	Apr-60	Apr-61	111.31	Jun-60	Mar-61	105.50	Aug-60	Feb-61	114.57
Apr-61	May-62	116.57	Apr-61	Apr-62	114.23	Jun-61	Mar-62	114.50	Aug-61	Feb-62	111.29
Apr-62	May-63	148.86	Apr-62	Apr-63	144.23	Jun-62	Mar-63	139.10	Aug-62	Feb-63	141.29
Apr-63	May-64	128.21	Apr-63	Apr-64	127.23	Jun-63	Mar-64	107.50	Aug-63	Feb-64	111.29
Apr-64	May-65	137.57	Apr-64	Apr-65	137.23	Jun-64	Mar-65	137.50	Aug-64	Feb-65	141.71
Apr-65	May-66	111.86	Apr-65	Apr-66	110.46	Jun-65	Mar-66	107.90	Aug-65	Feb-66	121.00
Apr-66	May-67	172.07	Apr-66	Apr-67	174.77	Jun-66	Mar-67	192.10	Aug-66	Feb-67	217.43
Apr-67	May-68	134.86	Apr-67	Apr-68	135.62	Jun-67	Mar-68	131.70	Aug-67	Feb-68	128.71
Apr-68	May-69	140.50	Apr-68	Apr-69	137.46	Jun-68	Mar-69	127.80	Aug-68	Feb-69	131.43
Apr-69	May-70	141.64	Apr-69	Apr-70	141.31	Jun-69	Mar-70	134.50	Aug-69	Feb-70	132.57
Apr-70	May-71	187.93	Apr-70	Apr-71	186.08	Jun-70	Mar-71	193.00	Aug-70	Feb-71	212.43
Apr-71	May-72	161.07	Apr-71	Apr-72	162.23	Jun-71	Mar-72	151.40	Aug-71	Feb-72	158.57
Apr-72	May-73	99.36	Apr-72	Apr-73	99.00	Jun-72	Mar-73	91.50	Aug-72	Feb-73	87.00
Apr-73	May-74	180.07	Apr-73	Apr-74	182.62	Jun-73	Mar-74	204.30	Aug-73	Feb-74	225.71
Apr-74	May-75	152.93	Apr-74	Apr-75	150.46	Jun-74	Mar-75	153.20	Aug-74	Feb-75	160.14
Apr-75	May-76	186.21	Apr-75	Apr-76	187.85	Jun-75	Mar-76	192.40	Aug-75	Feb-76	206.71
Apr-76	May-77	104.93	Apr-76	Apr-77	104.08	Jun-76	Mar-77	90.40	Aug-76	Feb-77	85.14
Apr-77	May-78	110.93	Apr-77	Apr-78	108.77	Jun-77	Mar-78	107.50	Aug-77	Feb-78	119.86
Apr-78	May-79	118.86	Apr-78	Apr-79	116.62	Jun-78	Mar-79	109.40	Aug-78	Feb-79	110.14
Apr-79	May-80	129.79	Apr-79	Apr-80	131.69	Jun-79	Mar-80	131.90	Aug-79	Feb-80	135.29
Apr-80	May-81	127.14	Apr-80	Apr-81	118.31	Jun-80	Mar-81	111.40	Aug-80	Feb-81	112.29
Apr-81	May-82	174.21	Apr-81	Apr-82	170.00	Jun-81	Mar-82	151.80	Aug-81	Feb-82	144.57
Apr-82	May-83	148.79	Apr-82	Apr-83	146.69	Jun-82	Mar-83	121.20	Aug-82	Feb-83	121.71
Apr-83	May-84	148.50	Apr-83	Apr-84	143.54	Jun-83	Mar-84	128.50	Aug-83	Feb-84	135.14
Apr-84	May-85	170.00	Apr-84	Apr-85	170.54	Jun-84	Mar-85	170.00	Aug-84	Feb-85	188.43
Apr-85	May-86	148.50	Apr-85	Apr-86	148.85	Jun-85	Mar-86	148.00	Aug-85	Feb-86	150.14
Apr-86	May-87	115.14	Apr-86	Apr-87	114.00	Jun-86	Mar-87	109.30	Aug-86	Feb-87	108.57
Apr-87	May-88	92.07	Apr-87	Apr-88	91.38	Jun-87	Mar-88	86.80	Aug-87	Feb-88	91.57
Apr-88	May-89	174.93	Apr-88	Apr-89	175.15	Jun-88	Mar-89	194.20	Aug-88	Feb-89	204.29
Apr-89	May-90	132.36	Apr-89	Apr-90	128.31	Jun-89	Mar-90	120.10	Aug-89	Feb-90	120.00
Apr-90	May-91	117.93	Apr-90	Apr-91	117.31	Jun-90	Mar-91	102.90	Aug-90	Feb-91	101.57
Apr-91	May-92	106.43	Apr-91	Apr-92	108.92	Jun-91	Mar-92	106.40	Aug-91	Feb-92	112.00
Apr-92	May-93	106.79	Apr-92	Apr-93	102.23	Jun-92	Mar-93	100.80	Aug-92	Feb-93	101.43
Apr-93	May-94	141.14	Apr-93	Apr-94	140.54	Jun-93	Mar-94	131.00	Aug-93	Feb-94	137.43
Apr-94	May-95	123.50	Apr-94	Apr-95	121.62	Jun-94	Mar-95	110.00	Aug-94	Feb-95	114.14
Apr-95	May-96	145.43	Apr-95	Apr-96	145.54	Jun-95	Mar-96	143.40	Aug-95	Feb-96	146.71
Apr-96	May-97	148.71	Apr-96	Apr-97	150.54	Jun-96	Mar-97	151.30	Aug-96	Feb-97	157.71
Apr-97	May-98	91.86	Apr-97	Apr-98	89.00	Jun-97	Mar-98	78.30	Aug-97	Feb-98	66.00
Apr-98	May-99	169.57	Apr-98	Apr-99	170.31	Jun-98	Mar-99	172.00	Aug-98	Feb-99	180.43
Apr-99	May-00	205.29	Apr-99	Apr-00	205.85	Jun-99	Mar-00	205.30	Aug-99	Feb-00	225.14
Apr-00	May-01	124.74	Apr-00	Apr-01	127.22	Jun-00	Mar-01	115.95	Aug-00	Feb-01	109.57
Apr-01	May-02	103.11	Apr-01	Apr-02	102.03	Jun-01	Mar-02	98.72	Aug-01	Feb-02	105.20
Apr-02	May-03	92.83	Apr-02	Apr-03	91.22	Jun-02	Mar-03	77.57	Aug-02	Feb-03	71.90
Apr-03	May-04	108.64	Apr-03	Apr-04	108.44	Jun-03	Mar-04	104.03	Aug-03	Feb-04	108.37
Apr-04	May-05	129.41	Apr-04	Apr-05	129.38	Jun-04	Mar-05	132.23	Aug-04	Feb-05	139.90
Apr-05	May-06	144.29	Apr-05	Apr-06	141.38	Jun-05	Mar-06	137.94	Aug-05	Feb-06	147.89
Apr-06	May-07	133.75	Apr-06	Apr-07	128.62	Jun-06	Mar-07	108.26	Aug-06	Feb-07	103.66
Apr-07	May-08	179.88	Apr-07	Apr-08	177.17	Jun-07	Mar-08	170.51	Aug-07	Feb-08	178.63
Apr-08	May-09		Apr-08	Apr-09	180.40	Jun-08	Mar-09	175.81	Aug-08	Feb-09	181.46
Average		139.49	Average		139.02	Average		134.86	Average		139.53
St, Dev.		31.07	St, Dev.		31.54	St, Dev.		35.09	St, Dev.		39.82
Deviation from mean		-1.53	Deviation from mean		-1.52	Deviation from mean		-0.07	Deviation from mean		-0.90

Source: Appendix authors' data.

Table A6.13. Analysis of El Niño occurrences in Magdalena River discharges (1986–1995)

TABLE 1. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG MAGDALENA RIVER											
Jul. 86 Mar. 88			Abr. 91 Jul. 92			Feb. 93 Ago. 93			Mar. 94 Abr. 95		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Jul-72	Mar-74	198.51	Apr-72	Jul-73	161.18	Feb-72	Aug-72	215.87	Mar-72	Apr-73	158.22
Jul-73	Mar-75	256.77	Apr-73	Jul-74	261.46	Feb-73	Aug-73	152.23	Mar-73	Apr-74	248.98
Jul-74	Mar-76	247.04	Apr-74	Jul-75	236.34	Feb-74	Aug-74	297.01	Mar-74	Apr-75	236.84
Jul-75	Mar-77	253.34	Apr-75	Jul-76	285.58	Feb-75	Aug-75	234.67	Mar-75	Apr-76	273.19
Jul-76	Mar-78	193.41	Apr-76	Jul-77	232.01	Feb-76	Aug-76	304.99	Mar-76	Apr-77	238.92
Jul-77	Mar-79	168.98	Apr-77	Jul-78	190.93	Feb-77	Aug-77	176.37	Mar-77	Apr-78	183.85
Jul-78	Mar-80	183.66	Apr-78	Jul-79	193.09	Feb-78	Aug-78	178.44	Mar-78	Apr-79	174.26
Jul-79	Mar-81	181.18	Apr-79	Jul-80	215.63	Feb-79	Aug-79	218.23	Mar-79	Apr-80	214.96
Jul-80	Mar-82	208.41	Apr-80	Jul-81	202.89	Feb-80	Aug-80	204.24	Mar-80	Apr-81	179.19
Jul-81	Mar-83	224.60	Apr-81	Jul-82	261.77	Feb-81	Aug-81	223.89	Mar-81	Apr-82	247.41
Jul-82	Mar-84	191.81	Apr-82	Jul-83	215.84	Feb-82	Aug-82	283.74	Mar-82	Apr-83	229.51
Jul-83	Mar-85	209.93	Apr-83	Jul-84	207.09	Feb-83	Aug-83	182.39	Mar-83	Apr-84	193.59
Jul-84	Mar-86	226.24	Apr-84	Jul-85	235.73	Feb-84	Aug-84	226.76	Mar-84	Apr-85	220.95
Jul-85	Mar-87	220.01	Apr-85	Jul-86	245.43	Feb-85	Aug-85	208.51	Mar-85	Apr-86	219.66
Jul-86	Mar-88	171.06	Apr-86	Jul-87	208.83	Feb-86	Aug-86	285.93	Mar-86	Apr-87	225.78
Jul-87	Mar-89	177.14	Apr-87	Jul-88	167.64	Feb-87	Aug-87	156.34	Mar-87	Apr-88	141.64
Jul-88	Mar-90	187.12	Apr-88	Jul-89	208.44	Feb-88	Aug-88	173.71	Mar-88	Apr-89	194.78
Jul-89	Mar-91	165.73	Apr-89	Jul-90	186.99	Feb-89	Aug-89	194.80	Mar-89	Apr-90	172.93
Jul-90	Mar-92	159.59	Apr-90	Jul-91	182.13	Feb-90	Aug-90	211.97	Mar-90	Apr-91	172.99
Jul-91	Mar-93	153.53	Apr-91	Jul-92	165.45	Feb-91	Aug-91	184.37	Mar-91	Apr-92	162.81
Jul-92	Mar-94	186.16	Apr-92	Jul-93	169.35	Feb-92	Aug-92	140.97	Mar-92	Apr-93	147.02
Jul-93	Mar-95	211.82	Apr-93	Jul-94	244.79	Feb-93	Aug-93	207.71	Mar-93	Apr-94	220.15
Jul-94	Mar-96	179.88	Apr-94	Jul-95	218.29	Feb-94	Aug-94	296.24	Mar-94	Apr-95	226.53
Jul-95	Mar-97	186.36	Apr-95	Jul-96	199.99	Feb-95	Aug-95	158.97	Mar-95	Apr-96	180.45
Jul-96	Mar-98	151.98	Apr-96	Jul-97	202.57	Feb-96	Aug-96	248.69	Mar-96	Apr-97	200.88
Jul-97	Mar-99	161.50	Apr-97	Jul-98	150.57	Feb-97	Aug-97	186.06	Mar-97	Apr-98	128.23
Jul-98	Mar-00	209.02	Apr-98	Jul-99	210.25	Feb-98	Aug-98	157.86	Mar-98	Apr-99	199.95
Jul-99	Mar-01	177.97	Apr-99	Jul-00	220.76	Feb-99	Aug-99	237.87	Mar-99	Apr-00	220.04
Jul-00	Mar-02	130.18	Apr-00	Jul-01	159.87	Feb-00	Aug-00	233.33	Mar-00	Apr-01	164.61
Jul-01	Mar-03	138.89	Apr-01	Jul-02	160.18	Feb-01	Aug-01	157.27	Mar-01	Apr-02	139.78
Jul-02	Mar-04	133.77	Apr-02	Jul-03	160.73	Feb-02	Aug-02	192.90	Mar-02	Apr-03	153.91
Jul-03	Mar-05	143.48	Apr-03	Jul-04	148.24	Feb-03	Aug-03	145.21	Mar-03	Apr-04	141.28
Jul-04	Mar-06	157.62	Apr-04	Jul-05	155.63	Feb-04	Aug-04	145.46	Mar-04	Apr-05	151.70
Jul-05	Mar-07	176.31	Apr-05	Jul-06	190.83	Feb-05	Aug-05	158.74	Mar-05	Apr-06	175.89
Jul-06	Mar-08	205.89	Apr-06	Jul-07	209.21	Feb-06	Aug-06	233.24	Mar-06	Apr-07	196.84
Jul-07	Mar-09	253.50	Apr-07	Jul-08	255.37	Feb-07	Aug-07	212.16	Mar-07	Apr-08	229.54
Jul-08	Mar-10		Apr-08	Jul-09		Feb-08	Aug-08	261.97	Mar-08	Apr-09	274.84
Average		188.40	Average		203.36	Average		207.81	Average		195.73
St, Dev.		33.89	St, Dev.		35.52	St, Dev.		46.66	St, Dev.		38.70
Deviation from mean		-0.51	Deviation from mean		-1.07	Deviation from mean		0.00	Deviation from mean		0.80

Source: Appendix authors' data.

Table A6.14. Analysis of El Niño Occurrences in Magdalena River Discharges (1997–2007)

TABLE 2. ANALYSIS OF "EL NIÑO" OCCURRENCES - RIVER DISCHARGES IN M3/SEG
MAGDALENA RIVER

Abr. 97 May. 98			Abr. 02 Abr. 03			Jun. 04 Mar. 05			Ago. 06 Feb. 07		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Apr-72	May-73	155.96	Apr-72	Apr-73	154.37	Jun-72	Mar-73	131.63	Aug-72	Feb-73	110.30
Apr-73	May-74	263.41	Apr-73	Apr-74	262.03	Jun-73	Mar-74	279.30	Aug-73	Feb-74	288.46
Apr-74	May-75	231.73	Apr-74	Apr-75	225.95	Jun-74	Mar-75	219.19	Aug-74	Feb-75	209.10
Apr-75	May-76	280.36	Apr-75	Apr-76	276.30	Jun-75	Mar-76	275.74	Aug-75	Feb-76	277.21
Apr-76	May-77	234.94	Apr-76	Apr-77	235.78	Jun-76	Mar-77	215.10	Aug-76	Feb-77	199.49
Apr-77	May-78	190.36	Apr-77	Apr-78	189.50	Jun-77	Mar-78	175.23	Aug-77	Feb-78	174.39
Apr-78	May-79	183.64	Apr-78	Apr-79	179.32	Jun-78	Mar-79	155.50	Aug-78	Feb-79	131.64
Apr-79	May-80	211.74	Apr-79	Apr-80	212.75	Jun-79	Mar-80	198.14	Aug-79	Feb-80	187.31
Apr-80	May-81	198.64	Apr-80	Apr-81	181.30	Jun-80	Mar-81	169.86	Aug-80	Feb-81	150.37
Apr-81	May-82	261.22	Apr-81	Apr-82	254.11	Jun-81	Mar-82	232.97	Aug-81	Feb-82	227.03
Apr-82	May-83	227.59	Apr-82	Apr-83	225.99	Jun-82	Mar-83	193.28	Aug-82	Feb-83	178.54
Apr-83	May-84	201.66	Apr-83	Apr-84	196.80	Jun-83	Mar-84	176.30	Aug-83	Feb-84	192.64
Apr-84	May-85	225.25	Apr-84	Apr-85	226.62	Jun-84	Mar-85	227.59	Aug-84	Feb-85	240.34
Apr-85	May-86	225.78	Apr-85	Apr-86	228.61	Jun-85	Mar-86	232.66	Aug-85	Feb-86	193.00
Apr-86	May-87	216.29	Apr-86	Apr-87	215.65	Jun-86	Mar-87	215.15	Aug-86	Feb-87	185.46
Apr-87	May-88	146.08	Apr-87	Apr-88	145.81	Jun-87	Mar-88	134.43	Aug-87	Feb-88	138.06
Apr-88	May-89	209.62	Apr-88	Apr-89	204.78	Jun-88	Mar-89	223.75	Aug-88	Feb-89	189.40
Apr-89	May-90	176.95	Apr-89	Apr-90	165.11	Jun-89	Mar-90	154.06	Aug-89	Feb-90	145.20
Apr-90	May-91	178.29	Apr-90	Apr-91	176.77	Jun-90	Mar-91	160.47	Aug-90	Feb-91	133.59
Apr-91	May-92	158.67	Apr-91	Apr-92	163.41	Jun-91	Mar-92	162.55	Aug-91	Feb-92	164.14
Apr-92	May-93	160.81	Apr-92	Apr-93	153.82	Jun-92	Mar-93	152.84	Aug-92	Feb-93	125.54
Apr-93	May-94	229.96	Apr-93	Apr-94	219.87	Jun-93	Mar-94	203.01	Aug-93	Feb-94	187.73
Apr-94	May-95	221.67	Apr-94	Apr-95	224.13	Jun-94	Mar-95	197.61	Aug-94	Feb-95	164.83
Apr-95	May-96	187.24	Apr-95	Apr-96	184.72	Jun-95	Mar-96	175.37	Aug-95	Feb-96	148.77
Apr-96	May-97	194.89	Apr-96	Apr-97	191.48	Jun-96	Mar-97	190.73	Aug-96	Feb-97	173.97
Apr-97	May-98	134.79	Apr-97	Apr-98	129.55	Jun-97	Mar-98	112.84	Aug-97	Feb-98	79.47
Apr-98	May-99	214.17	Apr-98	Apr-99	210.75	Jun-98	Mar-99	203.99	Aug-98	Feb-99	186.63
Apr-99	May-00	232.73	Apr-99	Apr-00	220.71	Jun-99	Mar-00	205.14	Aug-99	Feb-00	200.50
Apr-00	May-01	157.36	Apr-00	Apr-01	155.56	Jun-00	Mar-01	127.80	Aug-00	Feb-01	121.43
Apr-01	May-02	141.89	Apr-01	Apr-02	138.68	Jun-01	Mar-02	131.14	Aug-01	Feb-02	116.09
Apr-02	May-03	158.58	Apr-02	Apr-03	154.68	Jun-02	Mar-03	148.39	Aug-02	Feb-03	114.97
Apr-03	May-04	145.56	Apr-03	Apr-04	144.25	Jun-03	Mar-04	132.23	Aug-03	Feb-04	129.37
Apr-04	May-05	158.50	Apr-04	Apr-05	158.36	Jun-04	Mar-05	151.66	Aug-04	Feb-05	144.40
Apr-05	May-06	177.11	Apr-05	Apr-06	176.20	Jun-05	Mar-06	163.69	Aug-05	Feb-06	155.50
Apr-06	May-07	194.76	Apr-06	Apr-07	190.65	Jun-06	Mar-07	171.75	Aug-06	Feb-07	148.36
Apr-07	May-08	241.32	Apr-07	Apr-08	239.09	Jun-07	Mar-08	238.13	Aug-07	Feb-08	214.46
Apr-08	May-09		Apr-08	Apr-09	276.02	Jun-08	Mar-09	289.07	Aug-08	Feb-09	263.03
Average		198.04	Average		197.01	Average		187.25	Average		172.72
St, Dev.		37.52	St, Dev.		39.22	St, Dev.		44.13	St, Dev.		47.26
Deviation from mean		-1.69	Deviation from mean		-1.08	Deviation from mean		-0.81	Deviation from mean		-0.52

Source: Appendix authors' data.

Table A6.15. Analysis of El Niño Occurrences at Jepírachi Power Plant (1986–1995)

TABLE 1. ANALYSIS OF "EL NIÑO" OCCURRENCES - ENERGY IN KWH
JEPIRACHI POWERPLANT

Jul. 86 Mar. 88			**Abr. 91 Jul. 92**			**Feb. 93 Ago. 93**			**Mar. 94 Abr. 95**		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Jul-85	Mar-87	5764185	Apr-85	Jul-86	5715773	Feb-85	Aug-85	6379056	Mar-85	Apr-86	5539347
Jul-86	Mar-88	6422022	Apr-86	Jul-87	6441876	Feb-86	Aug-86	6379056	Mar-86	Apr-87	6247520
Jul-87	Mar-89	6132963	Apr-87	Jul-88	6816347	Feb-87	Aug-87	7354998	Mar-87	Apr-88	6631787
Jul-88	Mar-90	5864084	Apr-88	Jul-89	6095130	Feb-88	Aug-88	7269545	Mar-88	Apr-89	6011369
Jul-89	Mar-91	6062719	Apr-89	Jul-90	6475338	Feb-89	Aug-89	6650089	Mar-89	Apr-90	6306075
Jul-90	Mar-92	6182776	Apr-90	Jul-91	6395260	Feb-90	Aug-90	6688416	Mar-90	Apr-91	6011417
Jul-91	Mar-93	6402382	Apr-91	Jul-92	6756367	Feb-91	Aug-91	7084624	Mar-91	Apr-92	6561814
Jul-92	Mar-94	6253623	Apr-92	Jul-93	6441281	Feb-92	Aug-92	7519818	Mar-92	Apr-93	6559013
Jul-93	Mar-95	6480640	Apr-93	Jul-94	6721780	Feb-93	Aug-93	6657573	Mar-93	Apr-94	6396776
Jul-94	Mar-96	5632175	Apr-94	Jul-95	6577503	Feb-94	Aug-94	7846772	Mar-94	Apr-95	6600790
Jul-95	Mar-97	5233897	Apr-95	Jul-96	5506845	Feb-95	Aug-95	5952472	Mar-95	Apr-96	5333111
Jul-96	Mar-98	5810455	Apr-96	Jul-97	5966733	Feb-96	Aug-96	6316614	Mar-96	Apr-97	5733818
Jul-97	Mar-99	5729205	Apr-97	Jul-98	6257190	Feb-97	Aug-97	7416243	Mar-97	Apr-98	6272154
Jul-98	Mar-00	5229874	Apr-98	Jul-99	5865564	Feb-98	Aug-98	6480070	Mar-98	Apr-99	5756883
Jul-99	Mar-01	4937749	Apr-99	Jul-00	5658389	Feb-99	Aug-99	6393935	Mar-99	Apr-00	5368818
Jul-00	Mar-02	5195507	Apr-00	Jul-01	5064481	Feb-00	Aug-00	6757620	Mar-00	Apr-01	4926389
Jul-01	Mar-03	6429024	Apr-01	Jul-02	6109140	Feb-01	Aug-01	4499979	Mar-01	Apr-02	5484855
Jul-02	Mar-04	5687418	Apr-02	Jul-03	6810213	Feb-02	Aug-02	7295008	Mar-02	Apr-03	6637391
Jul-03	Mar-05	4780761	Apr-03	Jul-04	5508310	Feb-03	Aug-03	7306087	Mar-03	Apr-04	5206022
Jul-04	Mar-06	4601699	Apr-04	Jul-05	4903049	Feb-04	Aug-04	5645756	Mar-04	Apr-05	4955349
Jul-05	Mar-07	4954198	Apr-05	Jul-06	5004060	Feb-05	Aug-05	4899743	Mar-05	Apr-06	4795268
Jul-06	Mar-08	4566048	Apr-06	Jul-07	4981479	Feb-06	Aug-06	6258557	Mar-06	Apr-07	5201357
Jul-07	Mar-09		Apr-07	Jul-08	4747240	Feb-07	Aug-07	4787152	Mar-07	Apr-08	4517570
Jul-08	Mar-10		Apr-08	Jul-09		Feb-08	Aug-08	5719404	Mar-08	Apr-09	
Average		5652427.35	Average		5948667	Average		6481608	Average		5784995.29
St, Dev.		624131.16	St, Dev.		671731	St, Dev.		885823	St, Dev.		665029.00
Deviation from mean		1.23	Deviation from mean		1.20	Deviation from mean		0.20	Deviation from mean		1.23

Source: Appendix authors' data.

Table A6.16. Analysis of El Niño Occurrences at Jepírachi Power Plant (1997–2007)

TABLE 2. ANALYSIS OF "EL NIÑO" OCCURRENCES - ENERGY IN KWH
JEPIRACHI POWERPLANT

Abr. 97 May. 98			**Abr. 02 Abr. 03**			**Jun. 04 Mar. 05**			**Ago. 06 Feb. 07**		
Start	Finish	Average	Start	Finish	Average	Start	Finish	Average	Start	Finish	Average
Apr-85	May-86	5485924	Apr-85	Apr-86	5464287	Jun-85	Mar-86	5349617	Aug-85	Feb-86	4618802
Apr-86	May-87	6194097	Apr-86	Apr-87	6226935	Jun-86	Mar-87	6281286	Aug-86	Feb-87	5896328
Apr-87	May-88	6666956	Apr-87	Apr-88	6611991	Jun-87	Mar-88	6671300	Aug-87	Feb-88	5921141
Apr-88	May-89	5857533	Apr-88	Apr-89	5788216	Jun-88	Mar-89	5494269	Aug-88	Feb-89	4671913
Apr-89	May-90	6312681	Apr-89	Apr-90	6289994	Jun-89	Mar-90	6212223	Aug-89	Feb-90	5980936
Apr-90	May-91	6181645	Apr-90	Apr-91	6109291	Jun-90	Mar-91	5920517	Aug-90	Feb-91	5362740
Apr-91	May-92	6554485	Apr-91	Apr-92	6571330	Jun-91	Mar-92	6463968	Aug-91	Feb-92	5817303
Apr-92	May-93	6270095	Apr-92	Apr-93	6437596	Jun-92	Mar-93	6394728	Aug-92	Feb-93	5749208
Apr-93	May-94	6375075	Apr-93	Apr-94	6322395	Jun-93	Mar-94	6437959	Aug-93	Feb-94	5983270
Apr-94	May-95	6548945	Apr-94	Apr-95	6553348	Jun-94	Mar-95	6457344	Aug-94	Feb-95	5690374
Apr-95	May-96	5284812	Apr-95	Apr-96	5247704	Jun-95	Mar-96	4956561	Aug-95	Feb-96	4219238
Apr-96	May-97	5694275	Apr-96	Apr-97	5676717	Jun-96	Mar-97	5527502	Aug-96	Feb-97	4798268
Apr-97	May-98	6126576	Apr-97	Apr-98	6172706	Jun-97	Mar-98	6091264	Aug-97	Feb-98	5432388
Apr-98	May-99	5677508	Apr-98	Apr-99	5650640	Jun-98	Mar-99	5429478	Aug-98	Feb-99	4783342
Apr-99	May-00	5361301	Apr-99	Apr-00	5284234	Jun-99	Mar-00	4973152	Aug-99	Feb-00	4121783
Apr-00	May-01	4639438	Apr-00	Apr-01	4804179	Jun-00	Mar-01	4847088	Aug-00	Feb-01	4484514
Apr-01	May-02	5888374	Apr-01	Apr-02	5783438	Jun-01	Mar-02	6438151	Aug-01	Feb-02	5772640
Apr-02	May-03	6683619	Apr-02	Apr-03	6540770	Jun-02	Mar-03	6516598	Aug-02	Feb-03	6147751
Apr-03	May-04	5155986	Apr-03	Apr-04	5081660	Jun-03	Mar-04	4681166	Aug-03	Feb-04	3924521
Apr-04	May-05	4968975	Apr-04	Apr-05	5032894	Jun-04	Mar-05	4980736	Aug-04	Feb-05	3944830
Apr-05	May-06	4734004	Apr-05	Apr-06	4683796	Jun-05	Mar-06	4689910	Aug-05	Feb-06	4397437
Apr-06	May-07	4971834	Apr-06	Apr-07	5045007	Jun-06	Mar-07	5034841	Aug-06	Feb-07	4399596
Apr-07	May-08	4517908	Apr-07	Apr-08	4421820	Jun-07	Mar-08	4271867	Aug-07	Feb-08	3734293
Apr-08	May-09		Apr-08	Apr-09		Jun-08	Mar-09		Aug-08	Feb-09	
Average		5745741	Average		5730476	Average		5657458	Average		5037070
St, Dev.		685203	St, Dev.		678529	St, Dev.		745717	St, Dev.		799741
Deviation from mean		0.56	Deviation from mean		1.19	Deviation from mean		-0.91	Deviation from mean		-0.80

Source: Appendix authors' data.

The following table summarizes the results. One can see that the four rivers show negative values for most El Niño occurrences, while Jepírachi generation is positive in most of them. The most severe occurrences for the rivers analyzed are April 1991–July 1992 (when a severe rationing occurred in the country) and April 1997–May 1998 (when pool prices rose significantly, forcing regulatory changes in the market). During these periods Jepírachi generation is well above the mean value, complementing hydroelectric generation.

Table A6.17. Summary of El Niño occurrences, 1986–2007

ANALYSIS OF "EL NIÑO" OCCURRENCES
Departure from mean value expressed as number of standard deviations

	"EL NIÑO" OCCURRENCES							
	Jul. 86 Mar. 88	Abr. 91 Jul. 92	Feb. 93 Ago. 93	Mar. 94 Abr. 95	Abr. 97 May. 98	Abr. 02 Abr. 03	Jun. 04 Mar. 05	Ago. 06 Feb. 07
Guavio River	1.03	-0.53	0.64	1.50	-0.87	0.66	0.94	-1.02
Nare River	-0.73	-1.39	-0.71	-0.64	-1.86	-0.90	0.68	0.08
Cauca River	-1.48	-1.14	-0.17	-0.48	-1.53	-1.52	-0.07	-0.90
Magdalena River	-0.51	-1.07	0.00	0.80	-1.69	-1.08	-0.81	-0.52
Jepirachi Powerplant	1.23	1.20	0.20	1.23	0.56	1.19	-0.91	-0.80

Source: Appendix authors' data.

5.3 Firm Energy

An analysis of firm energy was obtained from hydroelectric plants (with and without reservoirs) and the Jepírachi power plant in isolated operation, and compared with joint operation of hydro and wind power plants. Firm energy is defined as the maximum monthly energy that can be produced without deficits during the analysis period, which will include El Niño occurrences. The same results were obtained for the total energy obtained from the joint operation of the hydroelectric power plants and the Jepírachi plant.

The analysis was conducted using a simulation model that operates the plants and the reservoirs to provide a given energy target, adjusting this target until no deficits are generated. The analysis was conducted for each of the selected hydroelectric plants.

Hypothetical hydroelectric plants of similar capacity to that of wind power plants were analyzed. Mean multiannual inflow to the hydroelectric power plants (expressed in energy) at the plant sites is equal to the same value for the Jepírachi generation. This was done by multiplying river discharges by a factor to convert them to energy so that mean inflows are equal to Jepírachi's mean generation. In order to avoid confusion with existing hydroelectric plants, the hypothetical plants analyzed will be named Guavio River, Nare River, Cauca River, and Magdalena River.

Several reservoir sizes were analyzed; reservoir size (expressed as a fraction of mean annual inflow to the reservoir in energy) varies between 0 (run-of-river plant) to 1 (substantial regulation capacity). Results are shown in the following chapters.

5.3.1 Guavio River

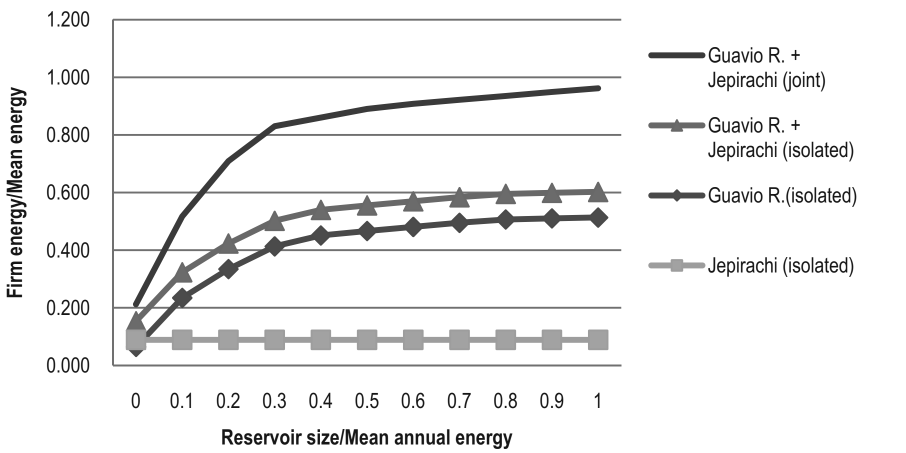
Table A6.18 and figure A6.13 show results for the Guavio River. Firm energy has been normalized dividing actual firm energy by the sum of mean energy for the Guavio River and Jepírachi.

Table A6.18. Firm Energy for Guavio and Jepírachi in Isolated and Joint Operation

FIRM ENERGY FOR GUAVIO AND JEPIRACHI IN ISOLATED AND JOINT OPERATION Firm Energy/Mean Energy						
	Reservoir volume expressed as a fraction of mean energy inflow to Guavio					
	0	0.2	0.4	0.6	0.8	1
Guavio River (isolated)	0.064	0.334	0.451	0.481	0.507	0.514
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Guavio River + Jepirachi in isolated operation	0.153	0.423	0.540	0.570	0.596	0.602
Guavio River + Jepirachi in joint operation	0.212	0.709	0.860	0.908	0.935	0.962

Source: Appendix authors' data.

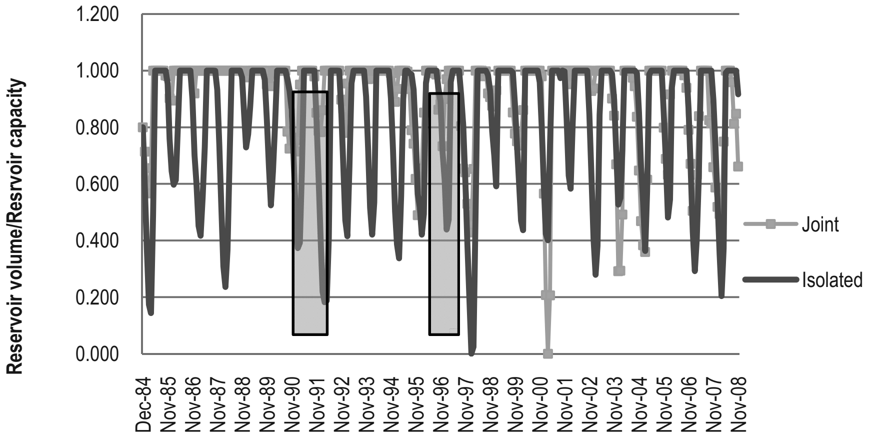
Figure A6.13. Firm Energy for Guavio and Jepírachi in Isolated and Joint Operation



Source: Appendix authors' data.

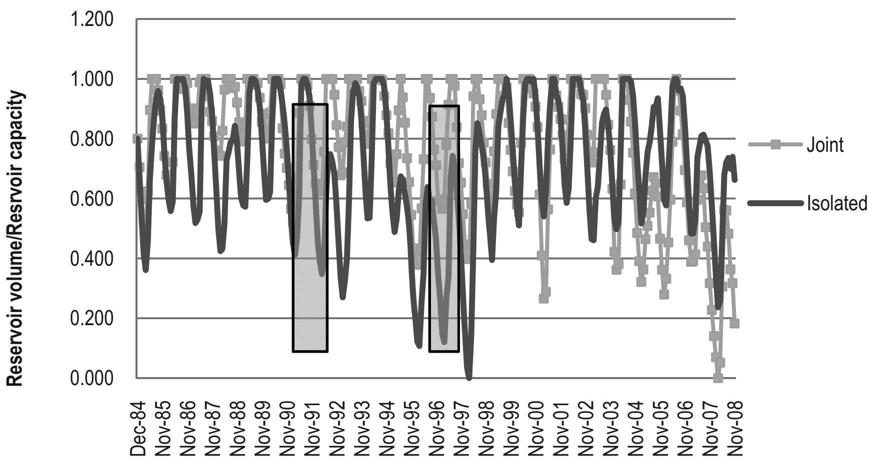
The substantial increase in firm energy when joint operation is considered can be seen both in the table and the figure. This is because critical periods for the Guavio River do not coincide with Jepírachi generation during the same period. The following figures, showing reservoir operation both in isolated and joint operation, illustrate this fact. Figure A6.14, corresponding to a reservoir size of 0.2, shows that in isolated operation the reservoir is emptied during the El Niño occurrence of April 1997–May 1998, while in joint operation the reservoir is emptied in April 2001. The El Niño occurrence of April 1997–April 1998 is balanced by large-scale generation in the Jepírachi power plant, showing the complementarity of river discharges in the Guavio River and wind generation in the Jepírachi power plant. Figure A6.15, corresponding to a reservoir size of 0.5, illustrates the same effect.

Figure A6.14. Guavio River Reservoir Operation with Reservoir Size 0.2



Source: Appendix authors' data.

Figure A6.15. Guavio River Reservoir Operation with Reservoir Size 0.5



Source: Appendix authors' data.

5.3.2 Nare River

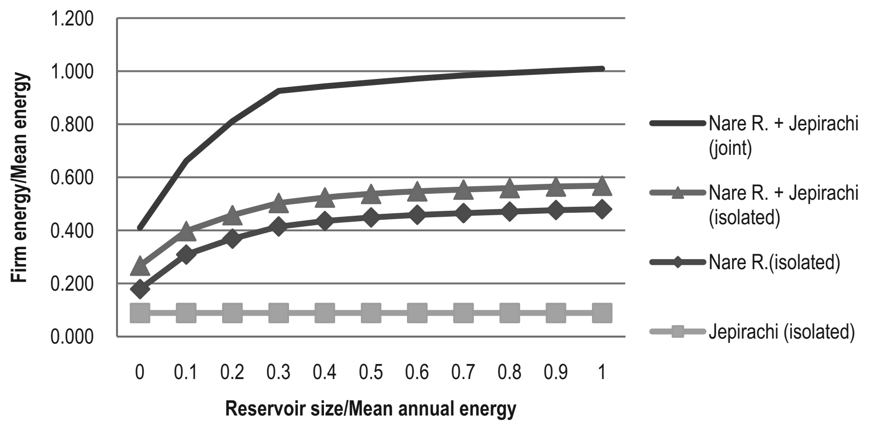
The following tables and graphs show the same results for the Nare River as those shown for the Guavio River. One can see the similarity of results with those for the Guavio River.

Table A6.19. Firm Energy for Nare and Jepírachi in Isolated and Joint Operation

FIRM ENERGY FOR NARE AND JEPIRACHI IN ISOLATED AND JOINT OPERATION Firm Energy/Mean Energy						
	Reservoir volume expressed as a fraction of mean energy inflow to Nare					
	0	0.2	0.4	0.6	0.8	1
Nare River(isolated)	0.179	0.369	0.435	0.459	0.471	0.480
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Nare River + Jepirachi in isolated operation	0.268	0.458	0.524	0.548	0.560	0.569
Nare River + Jepirachi in joint operation	0.410	0.811	0.943	0.972	0.994	1.009

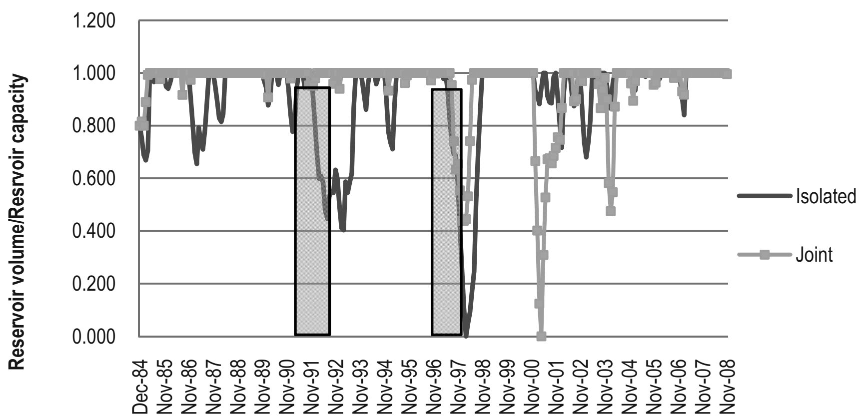
Source: Appendix authors' data.

Figure A6.16. Firm Energy for Nare and Jepírachi in Isolated and Joint Operation



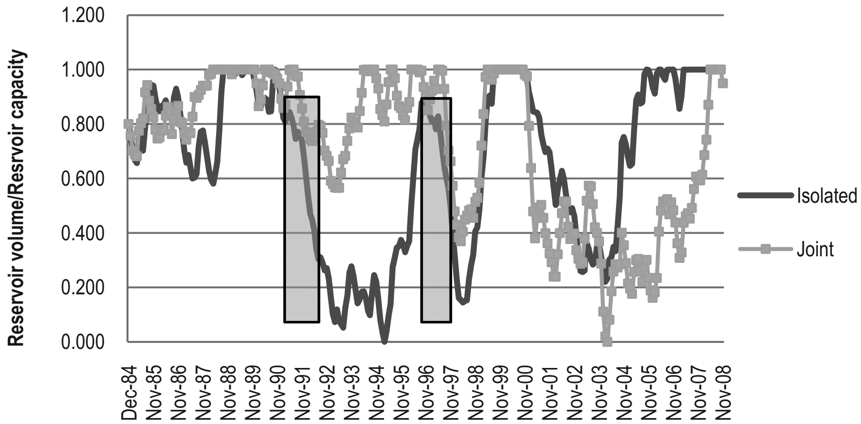
Source: Appendix authors' data.

Figure A6.17. Nare River Reservoir Operation with Reservoir Size 0.2



Source: Appendix authors' data.

Figure A6.18. Nare River Reservoir Operation with Reservoir Size 0.5



Source: Appendix authors' data.

5.3.3 Cauca River

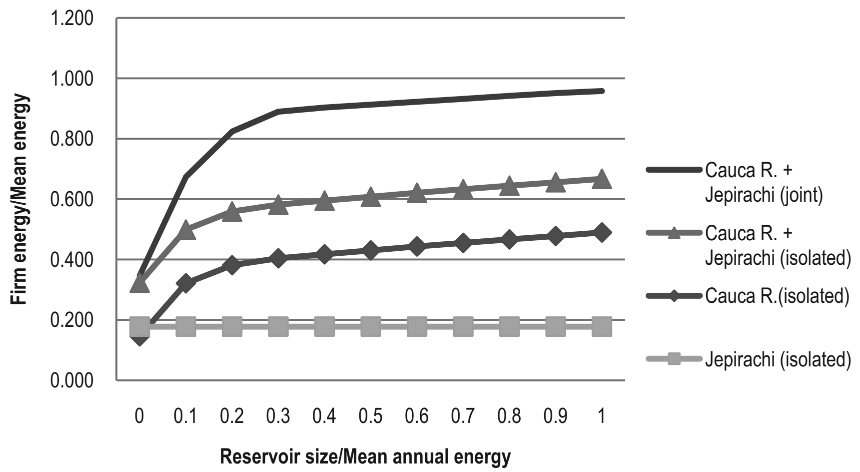
The following tables and figures show the same results for the Cauca River as those shown for the Guavio and Nare Rivers. Once again, one can easily see the similarity of results with those for the Guavio and Nare Rivers.

Table A6.20. Firm Energy for Cauca and Jepírachi in Isolated and Joint Operation

FIRM ENERGY FOR CAUCA AND JEPIRACHI IN ISOLATED AND JOINT OPERATION Firm Energy/Mean Energy						
	Reservoir volume expressed as a fraction of mean energy inflow to Cauca					
	0	0.2	0.4	0.6	0.8	1
Cauca River (isolated)	0.146	0.381	0.417	0.443	0.466	0.489
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Cauca River + Jepirachi in isolated operation	0.234	0.470	0.506	0.532	0.555	0.578
Cauca River + Jepirachi in joint operation	0.346	0.824	0.903	0.922	0.941	0.957

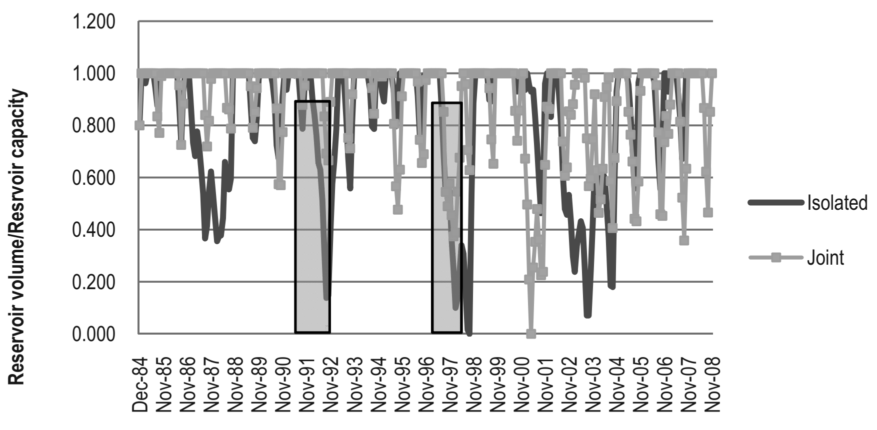
Source: Appendix authors' data.

Figure A6.19. Firm Energy for Cauca and Jepírachi in Isolated and Joint Operation



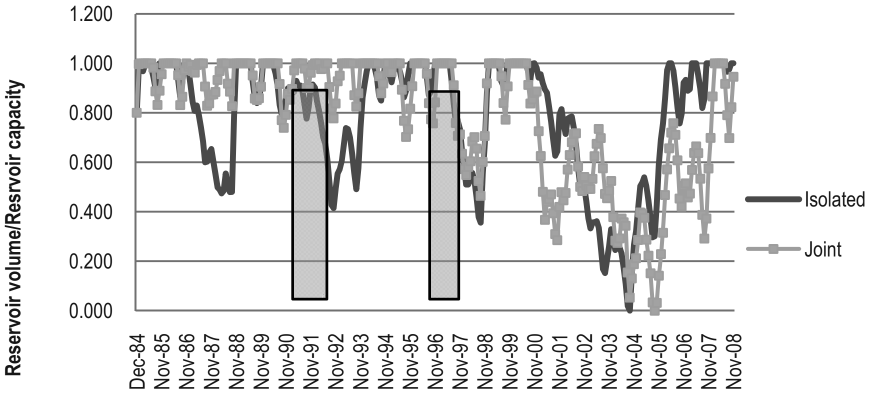
Source: Appendix authors' data.

Figure A6.20. Cauca River Reservoir Operation with Reservoir Size 0.2



Source: Appendix authors' data.

Figure A6.21. Cauca River Reservoir Operation with the Reservoir Size 0.5



Source: Appendix authors' data.

5.3.4 Magdalena River

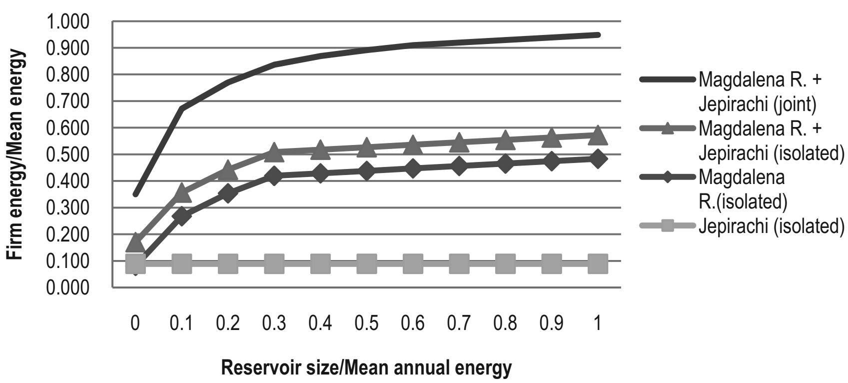
The following tables and figures show the same results for the Magdalena River as those shown for the Guavio River. One can see the similarity of results with those for the Guavio River.

Table A6.21. Firm Energy for Magdalena and Jepírachi in Isolated and Joint Operation

FIRM ENERGY FOR MAGDALENA AND JEPIRACHI IN ISOLATED AND JOINT OPERATION Firm Energy/Mean Energy						
	Reservoir volume expressed as a fraction of mean energy inflow to Magdalena					
	0	0.2	0.4	0.6	0.8	1
Magdalena River (isolated)	0.082	0.354	0.429	0.447	0.465	0.484
Jepirachi (isolated)	0.089	0.089	0.089	0.089	0.089	0.089
Magdalena River + Jepirachi in isolated operation	0.170	0.442	0.518	0.536	0.554	0.572
Magdalena River + Jepirachi in joint operation	0.350	0.770	0.869	0.910	0.929	0.948

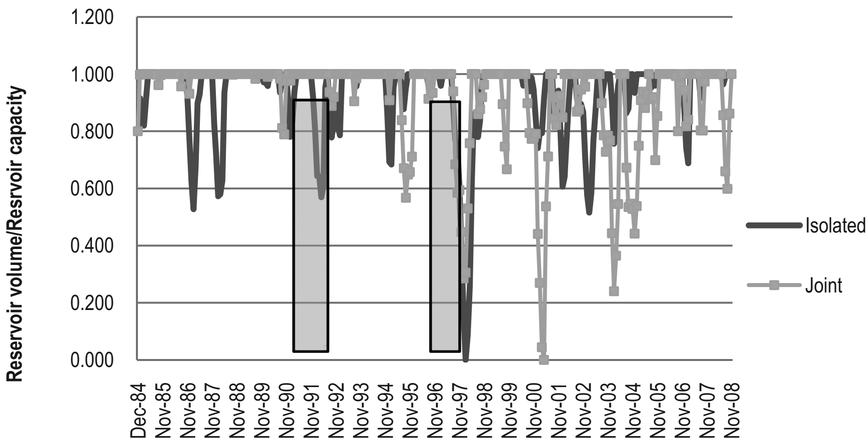
Source: Appendix authors' data.

Figure A6.22. Firm Energy for Magdalena and Jepírachi in Isolated and Joint Operation



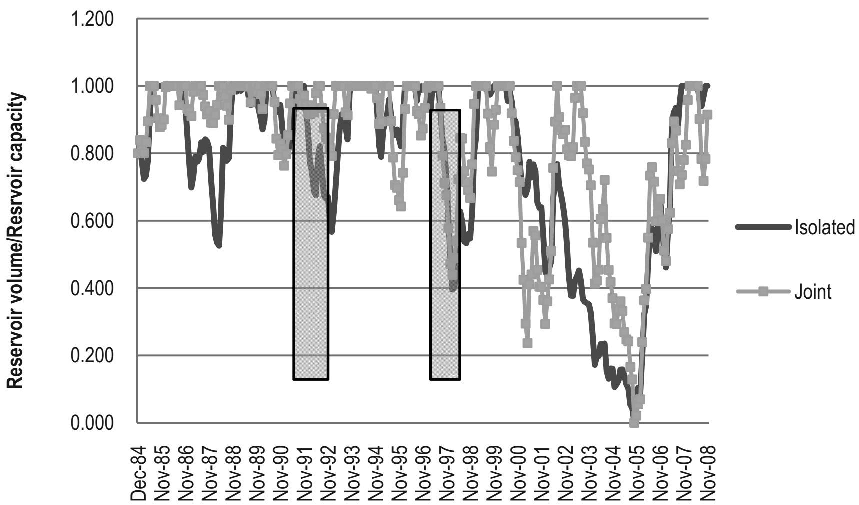
Source: Appendix authors' data.

Figure A6.23. Magdalena River Reservoir Operation with Reservoir Size 0.2



Source: Appendix authors' data.

Figure A6.24. Magdalena River Reservoir Operation with Reservoir Size 0.5



Source: Appendix authors' data.

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