Energy-Water-Climate Planning for Development Without Carbon in Latin America and the Caribbean

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November 2011

SEI STOCKHOLM ENVIRONMENT INSTITUTE

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Cover art: Itaipú Dam on the Paraná River, Brazil / Flickr-Maite Elorza (txikita69)

Acknowledgments:

We thank SEI for funding this study, Liz Stanton as the leader of this initiative, Marion Davis for her helpful contributions to the manuscript, Ramón Bueno for his reviews, and internal reviewers.

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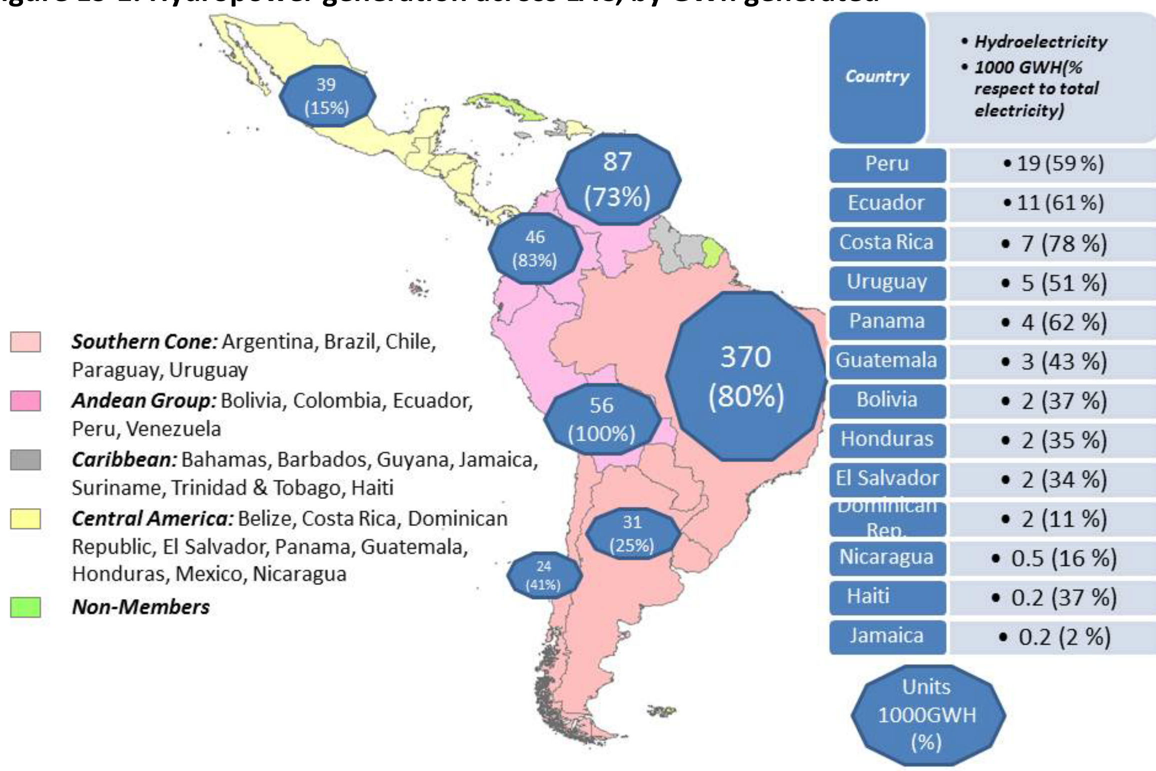
Executive summary

Energy is essential for development, but given the urgent need to mitigate climate change, developing nations are under pressure to keep their carbon emissions low. This leaves them with three options: abandon development; ignore climate concerns; or take a third path: finding energy sources that emit little or no carbon. This report focuses on the third option, which we call "development without carbon" (DWC), looking at the viability of hydroelectric power as a low-carbon energy source for Latin America and the Caribbean (LAC) in a changing climate.

We estimate that hydropower supplies 46 percent of electricity across the LAC region, a far larger share than the 16 percent global average – yet it has been estimated that only 21 to 38 percent of the region's hydroelectric potential has been realized (the higher number reflects "economically feasible" potential). LAC has already a considerable hydropower base to build on, but changes in the water supply due to climate change, competing uses, and population growth could thwart further development plans.

Energy portfolios, water availability, and hydropower production, however, vary significantly across LAC. To quantify these differences, we gathered data on water, energy, and hydropower for each country. Figure ES-1 shows hydropower generation across LAC, by country and organized into four regions to match the Inter-American Development Bank's classification of its 26 borrowing members: *Southern Cone:* Argentina, Brazil, Chile, Paraguay, and Uruguay; *Andean Group:* Bolivia, Colombia, Ecuador, Peru, and Venezuela; *Caribbean:* Bahamas, Barbados, Guyana, Jamaica, Suriname, Trinidad and Tobago, and Haiti; *Central America et al.:* Belize, Costa Rica, Dominican Republic, El Salvador, Panama Guatemala, Honduras, Mexico, and Nicaragua.

Figure ES-1. Hydropower generation across LAC, by GWh generated



Source: Electricity data from International Energy Agency, Data for 2008, (http://www.iea.org/country/index.asp); regional classifications from Inter-American Development Bank *(IDB 2011) .*

As shown in Figure ES-1, the Southern Cone produces the most hydroelectricity (484,458 GWh), or 68 percent of total electricity production. The Andean Group, meanwhile, produces 71 percent (165,859 GWh) of its electricity from hydropower. In Central America, Mexico produces the most hydropower, 39,178 GWh, representing 15 percent of national electricity generation (258, 913GWh), but all the other countries have a larger share of hydropower in their energy mix, topped by Costa Rica, at 78 percent. The Caribbean, however, with very limited surface water production, does not rely heavily on hydropower.

Climate trends

The Intergovernmental Panel on Climate Change (IPCC) found that the main water-related concerns for the LAC region in a changing climate will be rainfall reduction in arid regions, glacier shrinkage, and strains on the water supply for human consumption, agriculture and hydroelectricity in water-stressed areas, all while the population continues to grow. The LAC region is large and diverse with a climate that varies from cold, glaciated high mountains to temperate and tropical coastal zones. The IPCC's *Fourth Assessment Report* shows that during the 20th century, LAC precipitation was uneven, at times decreasing in the west of the Andean region, while increasing in the east in the Southern Cone and in Central America, and in some countries of the Andean Region. Mean temperatures over 10-year periods show an upward trend in the Southern Cone and Andean Region, as do minimum temperatures, while maximum temperatures show uneven trends.

The most important consequence of rising temperatures over the last 30 years has been critical glacial retreat in Bolivia, Peru, Colombia and Ecuador. Over this period, glacier shrinkage has contributed to total discharge at the expense of reducing and in some places exhausting the glacier reservoir. Studies indicate that during the next 15 years, small Andean glaciers are likely to disappear, affecting water availability and hydropower generation, while larger glaciers will continue to shrink. Changes in glacier water contributions will affect water supply for multiple upstream and downstream uses, including small and large-scale agriculture, urban water utilities, and hydropower.

Temperature projections for the LAC region over the next century show a continuation of the warming trend, ranging from 0.4°C to 1.8°C by 2020, and 1.0°C to 7.5°C by 2080 (from a 1961-1990 baseline), depending on the model and scenario considered. The greatest warming is projected to occur in the Andean Region and Southern Cone. Precipitation changes show a higher degree of uncertainty: for the Andean Region, they range from a reduction of 20 to 40 percent to an increase of 5 to 10 percent for 2080. Uncertainty regarding precipitation is even larger for the Southern Cone, for both winter and summer. In general, there is great variation among climate models when it comes to rainfall, with some showing increases and others showing decreases in the same period and region.

Planning for hydropower expansion in a changing climate

Still, given the great untapped potential, exploiting hydropower is seen as the best way to meet growing energy requirements for much of the LAC region (except the Caribbean), and since 1970, generation capacity has increased five-fold. Many major hydropower facilities across LAC, however, were designed based on climatic patterns that are now changing, reducing hydropower production reliability and increasing the vulnerability of the energy supply system. In the Southern Cone and the Andean Group, conventional hydropower is already vulnerable to rainfall anomalies due to the El Niño and La Niña weather patterns. Now glacier retreat is starting to affect hydropower generation in the areas of La Paz, Bolivia, and Lima, Peru. The projected glacier disappearance could also affect hydroelectricity generation in Colombia. In Ecuador, on the other hand, some scenarios project increases in precipitation that may expand the potential for hydropower generation.

Hydropower infrastructure will have to be planned within the ranges of uncertainty that climate trends impose, moving away from static planning and design. Plans will likely need to accommodate forecasts for targeted operations based on climate and demands, with flexible infrastructure. Pumped-storage hydropower and small hydro are options to overcome climatic variability. It is important to note that hydropower requires far more water than most energy sources, 17 liters per KWh, versus 1.9 for coal and 2.6 for nuclear (but 360 for biomass) – but hydropower also returns water into the system after generation. Still, hydropower variability due to changing water volumes means that energy planners should arrange to obtain base power from other energy sources during some periods. Robust analytical frameworks can help policymakers understand these tradeoffs and make informed choices.

Two powerful planning tools

One effective way to address these issues in LAC is to link two advanced water and energy decision support tools developed by SEI: Water Evaluation And Planning (WEAP) and the Long-range Energy Alternatives Planning system (LEAP), both of which are accessible to a large community of users, with licenses given at no cost to nongovernmental organizations, government agencies, and academic institutions in developing countries. WEAP is a robust, practical water resources planning tool that allows users to address freshwater management challenges and allocate limited water resources, with full integration of supply-demand questions, water quality, and ecological considerations. LEAP is an integrated modeling tool that is widely used for energy policy analysis and climate change mitigation assessment. It has a flexible structure that allows for local, regional, and global application of various modeling methodologies such as accounting, simulation and optimization. Both systems are now being integrated to further strengthen their capabilities.

WEAP, LEAP and the combined tool can help address many pressing concerns in conjunction with DWC and hydropower development in particular in the LAC region:

- *How can energy and water resources planning tools and infrastructure be designed to accommodate climate uncertainty?* Some possibilities include forecasting for targeted operations, building infrastructure designed for failure, and incorporating non-structural systems like communications or IT to enhance water management.
- *How can tradeoffs be assessed between competing energy demands for water, such as biofuels and hydropower? Which variables or indicators could be used to assess these tradeoffs?* The WEAP-LEAP software integration can be helpful as a framework for addressing the quantitative questions related to the linkages between energy and water. Current capacity in the region can serve as a baseline for exploring further capacity-building in the DWC context.
- *How should competing water demands be prioritized? Should they be evaluated based on their economic values, or are there other feasible ways to value the benefits of water use?* By incorporating economics and social consideration of into these decisions, it will be possible to have a clearer guide for water allocation priorities.
- *How can participatory processes support the promotion of low-carbon electricity within watersheds and help identify tradeoffs between water uses and energy sources?* Water benefit sharing and autonomous social processes can motivate involvement into decision making to achieve solutions that can improve the conditions to access water and energy for stakeholders.

SEI continues to formulate studies to answer those questions, and it is committed to working with researchers across the LAC region to develop their own studies to inform and support DWC planning.

1. Introduction

Energy is essential for development, and building a strong energy supply is a priority for any nation seeking to grow its economy and reduce poverty. Given the urgent need to mitigate climate change, however, developing nations are also under pressure to keep their carbon emissions low. This leaves them with three options: abandon development; ignore climate concerns; or take a third path: finding energy sources that emit little or no carbon.

This report focuses on the third option, which we call “development without carbon” (DWC). (An accompanying paper, *Development without Carbon: Climate and the Global Economy through the 21st Century* (Stanton 2011), examines the implications of including low-carbon, high economic growth scenarios in climate-economics models.) This report, looks specifically at the prospects for low-carbon energy development in Latin America and the Caribbean (LAC), focusing on hydroelectric power. This region has a record of low carbon emissions, and extensive use of hydropower has helped several countries grow their economies while holding down emissions. The question is, in a changing climate, can the LAC region continue to rely on hydropower on such a large scale?

We estimate that hydropower supplies 46 percent of electricity across the LAC region, a far larger share than the 16 percent global average (IEA 2010). This great reliance on hydropower means that LAC has already a considerable base of clean energy to build upon as it seeks for additional energy sources. But it is crucial to integrate water and energy planning in these countries, with close attention to climate change. Hydropower depends on a steady supply of water. Over the course of the 20th century, however, LAC precipitation levels rose and fell without a clear regional trend, while regional temperatures grew steadily, and climate projections for the next 100 years indicate inconsistent trends in precipitation and steady increases in temperature.

We organized our analysis into four regions, matching the Inter-American Development Bank’s classification of its 26 borrowing member countries (IDB 2011):[1]

- **Southern Cone:** Argentina, Brazil, Chile, Paraguay, Uruguay
- **Andean Group:** Bolivia, Colombia, Ecuador, Peru, Venezuela
- **Caribbean:** Bahamas, Barbados, Guyana, Jamaica, Suriname, Trinidad and Tobago, Haiti
- **Central America et al.:** Belize, Costa Rica, Dominican Republic, El Salvador, Panama Guatemala, Honduras, Mexico, Nicaragua.

In this paper, we examine historic climate patterns, future scenarios, and their potential impacts on water resources availability for hydropower production. We look at how energy portfolios could evolve under different scenarios, and discuss key considerations in LAC water and energy planning in the context of a changing climate, including adaptation and mitigation tradeoffs. We also describe how two tools developed by the Stockholm Environment Institute are being used to help planners in the LAC region address these issues: the Water Evaluation and Planning System (WEAP), and the Long-range Energy Alternatives Planning System (LEAP).

We describe both tools in detail, summarize existing applications of this software in LAC, and explain how LEAP and WEAP connect to create an integrated water and energy planning tool. We conclude with a discussion of key considerations of water and energy planning in the context of a changing climate, including adaptation and mitigation tradeoffs.

[1] The IDB classification does not include non-member countries: Cuba, Puerto Rico and the French Guyana.

2. Climate trends

The Intergovernmental Panel on Climate Change (IPCC) found that the main water-related concerns for the LAC region in a changing climate will be rainfall reduction in arid regions, glacier shrinkage, and strains on the water supply for human consumption, agriculture and hydroelectricity in water-stressed areas, all while the population continues to grow (Bates et al. 2008). Climate-energy-water planning requires understanding of these impacts. Below, we explore historical and future climate trends to elucidate the effects they might have on DWC prospects.

Historical climate by region

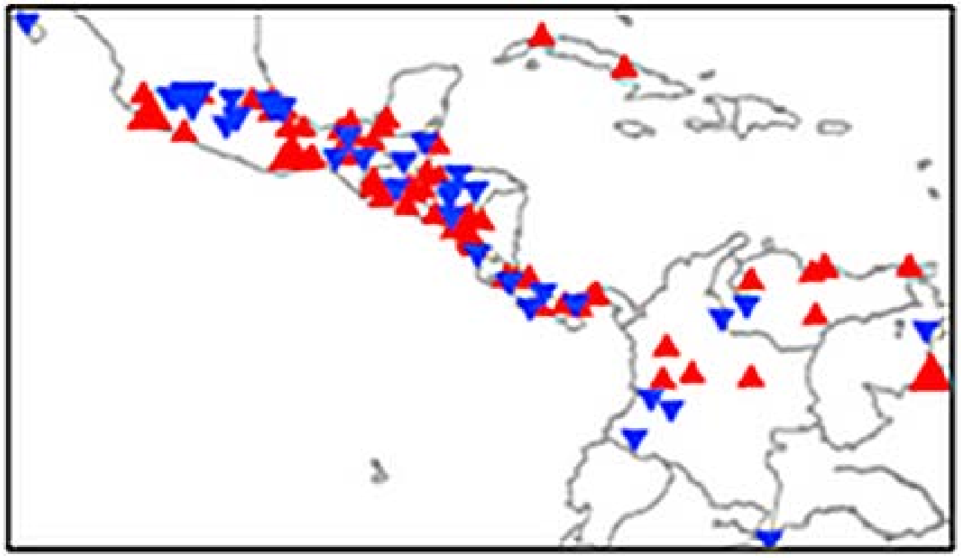
The LAC region ranges from middle latitudes to the tropical zone, and from sea level to high Andean elevations. The result is an enormous variation in climate from Tijuana to Tierra del Fuego. The region has large humid, arid, and semi-arid areas, and the climate varies from cold, glaciated high mountains to temperate and tropical coastal zones.

The IPCC's *Fourth Assessment Report* (IPCC 2007, Working Group II) shows that during the 20th century, LAC precipitation was uneven, at times decreasing in the west of the Andean region, while increasing in the east in the Southern Cone and in Central America and in some countries of the Andean Region. Mean temperatures over 10 year periods show an upward trend in the Southern Cone and Andean Region, as do minimum temperatures, while maximum temperatures show uneven trends. Figures 1 and 2 below illustrate some of the precipitation trends; see Table A-1 in Appendix 1 for detailed country-by-country data.

Figure 1: Trends in rainfall in Central America and northern South America (1961-2003)

Note: An increase is shown by a plus sign, a decrease by a circle. Bold values indicate significance at p<0.05. Source: IPCC (2007, Working Group II).

Figure 2: Trends in rainfall in Central America and northern South America (1961-2003)



Note: Large red triangles indicate positive significant trends at p<0.05, small red triangles indicate positive non-significant trends, large blue triangles indicate negative significant trends, and small blue triangles indicate negative non-significant trends. Source: IPCC (2007, Working Group II).

The IPCC report notes both positive and negative impacts from increased precipitation in the Southern Cone and the Andean Region: there has been increased flooding, but in the Argentinean Pampas, increases in precipitation have led to greater crop yields. Pasture productivity has also increased in Argentina and Uruguay (IPCC 2007, Working Group II).

The most important consequence of rising temperatures over the last 30 years, meanwhile, has been critical glacial retreat in Bolivia, Peru, Colombia and Ecuador (Francou et al. 2003), as outlined in Table A-2 in Appendix 1. Over this period, glacier shrinkage has contributed to total discharge at the expense of exhausting the glacier reservoir. Studies indicate that during the next 15 years, small Andean glaciers are likely to disappear, affecting water availability and hydropower generation (Ramirez et al. 2001). We present more detail on this in the hydrologic trends and hydropower section below.

Depending on the location of the glaciers, not only temperature increases, but also uneven precipitation may have influenced their dynamics. Declines in rainfall may have contributed to rapid retreat of the glacier by decreasing the amount of water falling as snow and turning into ice. Such reduction in water inflow may affect watersheds by reducing the contribution to the glacier reservoir and reducing the inflow to non-glaciated areas. In regions with increasing rainfall, the potential positive impact on glacier volumes may have been counteracted by rising temperatures – it may not have gotten cold enough for the water to fall as snow and turn into ice. In these regions, increased temperatures may have also increased the potential for flooding. The exact dynamics of glacier retreat in specific areas, however, are difficult to pinpoint because along with temperature and precipitation, glaciers are affected by other climatic factors, such as cloud cover and relative humidity. Studies examining how these processes occurred over the last century are localized and scarce (Table A-2 in Appendix 1).

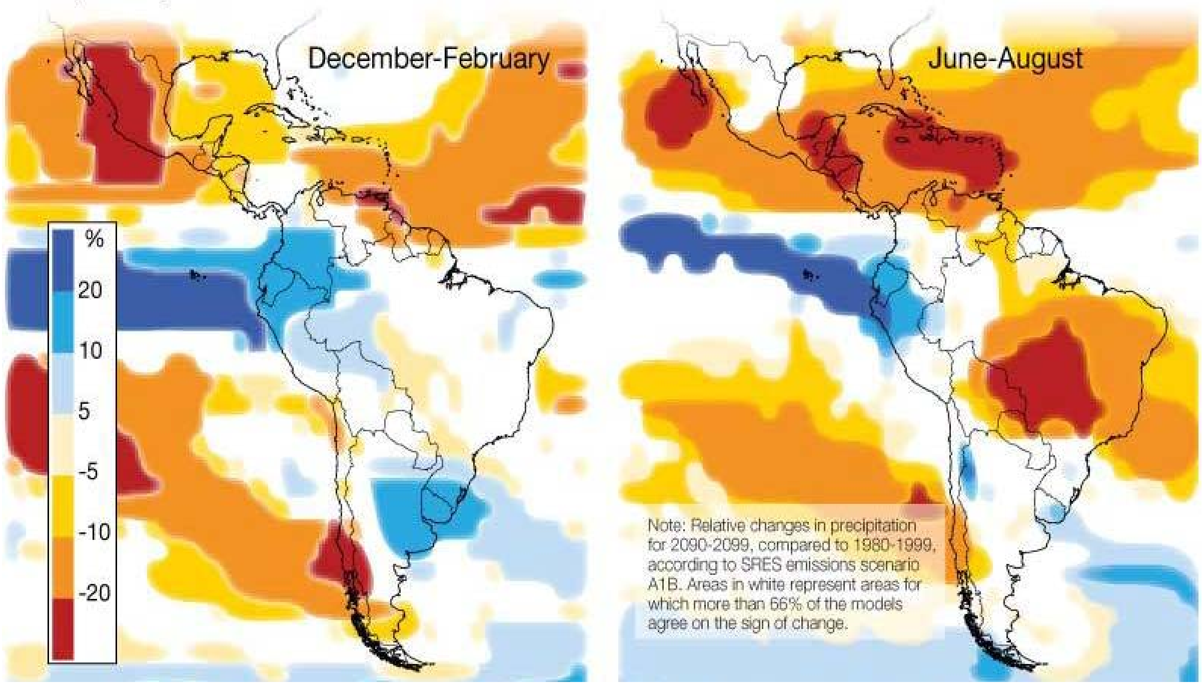
Future climatic trends in LAC

There is a fair amount of uncertainty in climate projections for LAC, especially when it comes to precipitation. For this study, we have drawn on projections of average temperature and rainfall throughout the current century derived from general circulation models (GCMs) available at the IPCC Data

Distribution Centre (IPCC n.d.), which are given at a resolution of 300 km and for two different emissions scenarios (IPCC's SRES A2 and B2).

Figure 3 shows changes in precipitation for the A1B scenario, from another analysis using IPCC data (López Izquierdo 2010). This indicates a 5- to 10-percent potential reduction in precipitation by the end of the century (2090-2099) in Central America, as compared to 1980-1999. For other countries, such as Mexico, southern Chile, and the northeastern portion of Venezuela, the decrease is projected to be between 10 and 20 percent. This projection also indicates a summertime increase in the rainfall regime of 5 to 10 percent in Ecuador, central and southern Colombia, eastern Argentina, and much of Peru. For the winter season, Central America, southern Mexico, the northern portion of Venezuela, and the eastern portion of Brazil, may show reductions of 10 to 20 percent.

Figure 1: Changes in precipitation, 2090-2099 versus 1980-1999, in percentages



Source: López Izquierdo (2010), drawing on IPCC (2007), Working Groups I, II and III.

Table A-3 in Appendix 1 reports temperature and precipitation changes for sub-regions of Latin America for three 30-year time slices centered at 2020, 2040, 2080, obtained from seven GCMs and the four main SRES emissions scenarios, A1FI, A2, B1 and B2. For 2020, temperature shows a warming trend on the order of 0.4°C to 1.8°C, and for 2080, of 1.0°C to 7.5°C as compared to the 1961-1990 baseline period. The greatest warming is projected to occur in the Andean Region and Southern Cone (referred to as Amazonia in Table A-3, Appendix 1). In this table, precipitation changes show a higher degree of uncertainty: for the Andean Region, they range from a reduction of 20 to 40 percent to an increase of 5 to 10 percent for 2080. Uncertainty regarding precipitation is even larger for the Southern Cone, for both winter and summer.

The main source of uncertainty for regional climate change scenarios is associated with projections from different GCMs. For rainfall changes, different climate models show different patterns; in some cases, one GCM shows increasing rainfall in a given time period and region while another shows decreasing rainfall. The uncertainty of projections of LAC precipitation remains high (Boulanger et al. 2006), which is a great limiting factor to the practical use of such forecasts for guiding active energy planning, adaptation, or mitigation policies.

Even if rainfall stays steady or increases, glaciers will recede as temperatures rise. In regions where rainfall (or winter precipitation) decreases, glaciers will recede even more quickly, magnifying water stresses. The prognosis for small glaciers is that they will disappear, while larger glaciers will shrink, diminishing the glacier reservoir of water (Ramirez et al. 2001; Zapata et al. 2008). The overall panorama of water-related impacts from climate change makes it critical to develop methodologies that can be used to improve capacity to predict and inform economic and energy planning (Vergara et al. 2011).

The IPCC's *Climate and Water* report (Bates et al. 2008) makes the following projections for LAC in terms of climate, water, and population trends:

- Reductions in rainfall occurring in arid and semi-arid regions of the Southern Cone could cause great water shortages.
- The population in water-stressed areas, where water supply and hydroelectricity generation can be affected by climate change, could grow to 66 million by 2020, according to SRES A2 projections.
- Reduction in base flows during the dry season coming from glacier melt in the Andean Group and the Southern Cone is expected to cause a decrease in hydropower production. In these regions, flood risk is expected to grow during the wet season.

It is important to stress that glacier shrinkage will affect only a portion of the LAC region, and it will have different impacts in different seasons and locations, with the greatest impacts in the dry and months upstream in the glaciated watershed. Smaller but still considerable accumulated impacts may be felt in the downstream floodplains, where the most intensive agriculture occurs. In general, glacier shrinkage is expected to affect dry-season water availability in Bolivia, Peru, Ecuador, and Colombia. The latter two countries have smaller glaciers that have melted rapidly (IPCC 2007, Working Group II). In Peru and Bolivia, water from glacier melt supplies densely populated cities, including Lima and La Paz, and hydropower facilities such as el Cañón del Pato – the third-largest in Peru. Glaciers in these countries have also undergone accelerated melt, with some regions losing up to 30 percent of their glacier area (Vergara et al. 2011). In Chile and Argentina, glaciers are in the central region, where most of the population is located. Changes in glacier water contributions will affect water supply for multiple upstream and downstream uses, including small and large-scale agriculture, urban water utilities, and hydropower.

3. Hydropower in LAC

Hydropower is a low-carbon energy source producing only 11 liters of CO_2 per kilowatt-hour (KWh), and it is third in terms of carbon emissions after wind (6.7 liters of CO_2 per KWh) and geothermal (8.4 liters CO_2 per KWh) (Cho 2010). Hydropower from rivers can be produced by conventional dams, pumped storage, and run-of-the-river. Conventional dams, also called impoundments or hydropower reservoirs, produce more than half of all electricity in eight Latin American countries. In a hydropower reservoir, water is initially stored in a reservoir above the dam to be released on demand, allowing immediate responses to electricity requirements. Large reservoirs are very controversial because they result in inundated areas that have caused ecological and social damage. The World Commission on Dams has called on project developers to take these concerns more seriously, consulting systematically with affected people and working to ensure that they benefit from dam building and that overall costs and benefits are shared equitably (WCD 2000).

In addition to conventional hydropower dams, pumped-storage hydroelectric power stations are used to pump water up to fill impoundments at off-peak (low demand) times, and then released again later to produce hydropower at periods of peak demand. As in many other parts of the world, the existing pumped-storage capacity in LAC could be increased, as many conventional dams could be converted into pumped storage (IEA 2010).

Run-of-river hydropower has smaller-scale infrastructure than conventional dams and produces less energy. Run-of-river systems require no big dams but, instead, take water from the river through a pipe or canal, called diversion, and a produce energy through a turbine. This type of hydropower, known as "small hydro," has a lower local ecological impact than conventional dams, and is usually included in renewable portfolio standards that exclude large hydroelectric plants.[2] As with pumped-storage hydro, there is potential for further small hydro development in LAC.

In the Andean Region and the Southern Cone, especially in Chile, both conventional hydropower dams and run-of-river installations are common. In the Caribbean region, where hydroelectricity is a very small portion of the total supply (see below), very little growth in hydropower production is projected over time, since there is no surface water runoff available for hydropower use.

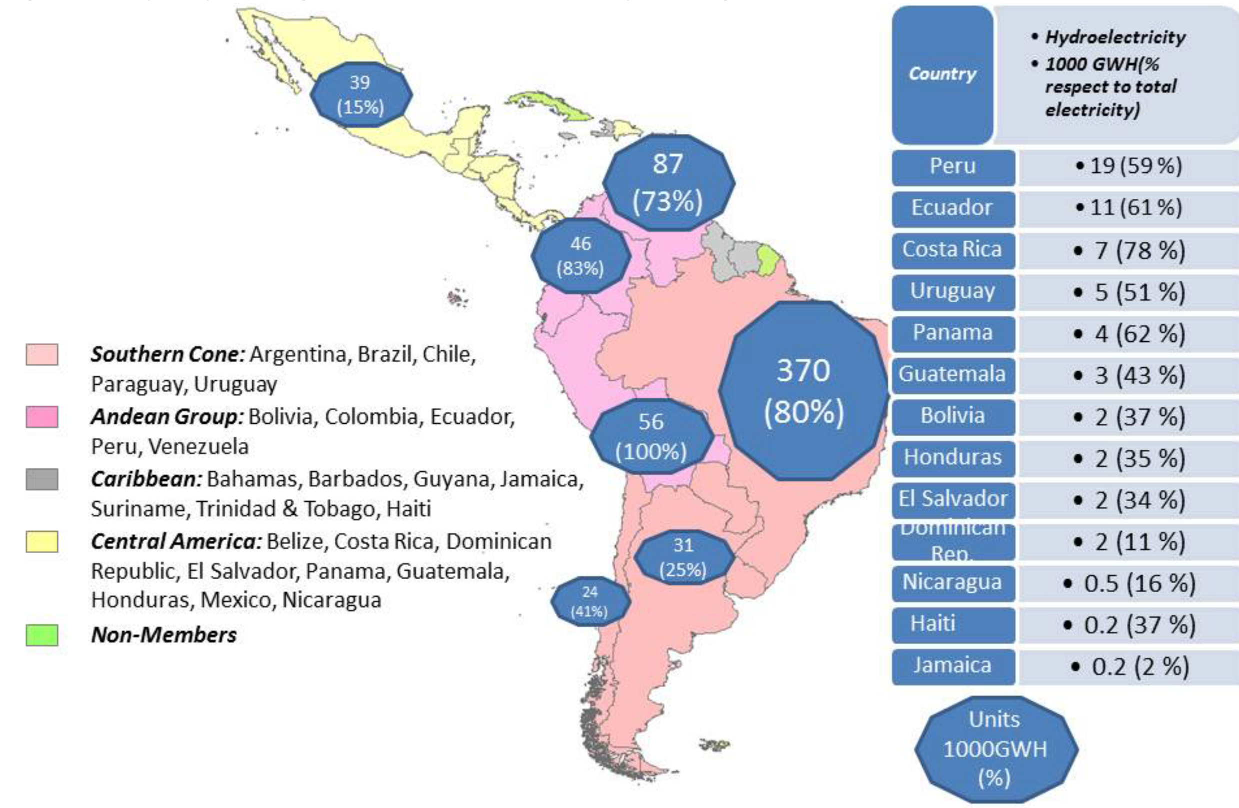
Different starting points

Energy portfolios, water availability, and hydropower production vary significantly across LAC. To quantify these differences, we gathered data on water, energy, and hydropower from the International Energy Agency (IEA), and from the Food and Agriculture Organization.

Our review includes hydropower generation in absolute numbers and as a share of total electricity, along with surface water runoff—since it is closely linked to hydropower potential – and an "electricity index" measuring gigawatt-hours[3] (GWh) generated per 1,000 residents. Figure 4 shows the first measure, amount of hydropower generation across LAC, in thousands of GWh generated.[4]

[2] See, for example, California's policies on hydropower: http://www.energy.ca.gov/hydroelectric/.
[3] A gigawatt-hour is one million kilowatt-hours (KWh).
[4] See Table A-4 in Appendix 2 for the underlying data, including total electricity and hydropower generation for 2008, as well as the resulting electricity index.

Figure 2: Hydropower generation across LAC, by GWh generated



*Source: Electricity data from International Energy Agency, Data for 2008, (http://www.iea.org/country/index.asp); regional classifications from Inter-American Developmen*t Bank *(IDB 2011) .*

Among these regions, the Southern Cone produces the most hydroelectricity (484,458 GWh), or 68 percent of total electricity production. Paraguay supplies 100 percent of its electricity from hydropower and exports another 46,300 GWh per year. The Southern Cone region also has the greatest surface runoff, 6,700 km^3/yr, 80 percent of which is produced in Brazil's Amazon forest. Brazil has the largest dam capacity in the region (513 km^3 out of a 574 km^3 regional total). And the Southern Cone has the best electricity coverage in LAC, with an electricity index[5] of 2.7 though with a wide variation among countries: Paraguay has the highest electricity index, 8.9, while Brazil's index is 2.4; all the other Southern Cone countries have indices close to that of Brazil.

The Andean Group produces 71 percent (165,859 GWh) of its electricity from hydropower. Colombia has the highest share of hydropower in its electricity supply, 83 percent, second only to Paraguay across LAC. In absolute terms, Venezuela leads, with 86,841 GWh of hydropower production, representing 73 percent of its total electricity requirements. The Andean Group produces a total of 5,100 km^3/yr of surface water, primarily from Colombia (2,100 km^3/yr) and Peru (1,600 km^3/yr). The region's electricity index is lower than in the Southern Cone, with 1.9. Venezuela rates highest, with a 4.2 index, while Bolivia has the lowest, 0.6.

The Caribbean – with only 16 km^3/yr in surface water production – depends less on hydroelectricity production than the other LAC regions, but it also generates less power overall, with an electricity index of 1.2. The electricity index indicates a lower availability than the Southern Cone and the Andean Group.

[5] Electricity index is given in GWh per 1000 inhabitants.

Trinidad and Tobago has a 5.9 electricity index, followed by Jamaica at 2.9; Haiti has the lowest index in all LAC, 0.05.

In Central America, Mexico produces the most hydropower, 39,178 GWh, representing 15 percent of its total electricity (258, 913GWh), but all the other countries have a larger share of hydropower in their energy mix. Costa Rica rates highest in this regard, generating 78 percent of its electricity from hydropower. The Central America region ranks third in surface water production (992 km^3/yr) after the Southern Cone and Andean Group, but it has a slightly higher electricity index than the Andean Group, 2.0. Mexico leads the region, with a 2.4 index, followed by Costa Rica, at 2.1. Guatemala and Nicaragua have the lowest electricity index, both at 0.6.

Expanding hydropower in a changing climate

As the preceding outline shows, hydropower is a significant electricity source in LAC, but not the only one. Even in some countries with substantial hydropower production, coal, petroleum products, and natural gas play major roles in energy production; the three combined account for roughly 50 percent of the combined electricity production of Argentina, Chile, Bolivia, Ecuador, the Dominican Republic, and Mexico. There are also other low-carbon options, such as wind and solar power and biofuels, which may be added to electricity portfolios. The main renewable sources beyond hydropower currently in use in LAC are small biomass installations in a few countries throughout LAC, and geothermal areas of Central America, such as Costa Rica and El Salvador where it accounts for about 10 and 20 percent of total energy production, respectively (see Appendix 3 for historical time-series graphs of electricity sources in LAC countries).

Still, hydropower remains a particularly attractive resource for many LAC countries. Estimates of the total potential hydropower capacity in the region vary, with considerably higher quantities deemed technically feasible than economically feasible. The estimated share of that potential currently being exploited varies accordingly; the IEA has put it at 21 percent (IEA 2010), while the World Bank has estimated 38 percent. (World Bank 2009). Given the great potential, exploiting hydropower in LAC, with the exception of the Caribbean, is considered the best way to meet growing energy requirements.[6] Since 1970, generation capacity has increased five-fold, with an accompanying growth in regional expertise and specialized manufacturing and services around the hydropower industry in most countries, with the exception of the Caribbean. The focus is primarily on exploiting the existing hydropower potential rather than on adapting existing conventional dams into pumped storage (Ray 2010). Small hydro is also considered as an alternative, but its viability is limited by the lower generation capacity. Moreover, though at a smaller scale than large hydropower sources, small hydro may also have negative ecological impacts such as the in-stream habitat impairment downstream of run-of river hydropower plants.

Many major hydropower facilities across LAC were designed based on climatic patterns that are now changing, reducing hydropower production reliability and increasing the vulnerability of the energy supply system. In addition, hydropower reservoirs often serve additional purposes, such as irrigation, flood control, water supply, and recreation. These competing demands could further threaten the energy supply system in the face of climate change and population growth, as demand for water for urban use and for irrigation and water supply are likely to increase even as supplies dwindle. Meanwhile, in regions with precipitation increases, the risk of flooding may be exacerbated where dams are not designed to accommodate extreme flood flows. Managing these reservoirs for hydropower production under such conditions can be challenging.

[6] Other readily available sources such as natural gas are also considered, but the latter is only available in large quantities in Argentina, Bolivia, Mexico and Venezuela, and in smaller amounts in Colombia, Ecuador, Peru and Dominican Republic (see Appendix 3).

Temperature increases and precipitation changes will affect runoff amounts, glacier meltwater, and reservoir storage (due to higher evaporation in warmer climate), all of which would affect hydropower production, particularly large-scale conventional hydropower (Maurer et al. 2009). In addition, potential increased flooding and sediments from landslides can affect hydropower production capacity.

In the Southern Cone and the Andean Group, conventional hydropower is already vulnerable to rainfall anomalies due to the El Niño and La Niña weather patterns (Bates et al. 2008). Now glacier retreat is starting to affect hydropower generation in the areas of La Paz, Bolivia, and Lima (Bates et al. 2008), a significant concern since multiple hydroelectric plants on the Mantaro River alone generate 40 percent of Peru's electricity, including all of Lima's supply.[7] The projected glacier disappearance could also affect hydroelectricity generation in Colombia (IPCC 2007, Working Group II). In Ecuador, on the other hand, some scenarios project increases in precipitation that may expand the potential for hydropower generation (Cáceres-Silva 2000).

In addition to logistical challenges in the context of an uncertain climate, expanding hydroelectric production in the region may face strong opposition because large impoundments and diversions can have ecological and social impacts, such as affecting fish habitats, flooding natural areas, and displacing rural communities. In Brazil, construction of the massive Belo Monte dam, which will be the third-largest hydropower plant in the world, has sparked major protests from affected indigenous peoples.[8] In Chile, plans to produce up to 30 percent of the domestic electricity supply from new hydropower are creating environmental concerns due to the potential impoundment of pristine rivers.

The social context of development determines how water resources will be shared. In watersheds with competing water uses, daily prioritization may be required. Upstream and downstream users need to interact and define processes to agree over the use of their resources. With the appropriate legal context, stakeholders can negotiate effective ways to share water resources. Agreements may include payments for "environmental services", which involve economic valuations for the use of natural resources and non-monetary benefits, such as granting water rights or provision of unrelated goods and services (Sadoff and Grey 2002).

Hydropower infrastructure will have to be planned within the ranges of uncertainty that climate trends impose, moving away from static planning and design. Plans will likely need to accommodate forecasts for targeted operations based on climate and demands, with flexible infrastructure, and will need to incorporate non-structural systems such as communications or information technology to enhance water management (Brown 2010). Pumped-storage hydropower and small hydro are options to overcome this climatic variability. The former has an additional infrastructure that allows for operations that can be more flexible based on weather forecasts. And the latter causes lower local environmental impacts and facilitates low-cost infrastructure investments that can be incorporated into climate adaptation plans.

It is important to note that almost any type of energy production implemented in LAC will require water: an estimated 1.9 liters per KWh for coal, 2.5 liters for geothermal, 2.6 liters per KWh for nuclear, 17 for hydropower, and 360 liters per KWh for biomass (Cho, 2010). Water and energy tradeoffs need to be assessed in the context of electricity supply planning because low-carbon sources consume water at different stages. Indeed, hydropower returns water into the system after generation, while biomass

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[7] J. Montoro Asencios, "En el Perú: Calor intenso y largas sequías." *Especiales UNMSM,* April 12, 2004. Universidad Nacional Mayor de San Marcos. Available at http://www.unmsm.edu.pe/Destacados/contenido.php?mver=11.
[8] On the Brazil protests, see K. Rapoza, "In Brazil, Protesters Shut Down World's Largest Hydro Dam Project." *Forbes*, Oct. 27, 2011. Available at http://www.forbes.com/sites/kenrapoza/2011/10/27/in-brazil-protestors-shut-down-worlds-largest-hydro-dam-project/. On Chile, see "Energy in Chile: Dancing in the dark", *The Economist*, Oct. 1, 2011. Available at http://www.economist.com/node/21531034.

consumes water that is lost from the system through evapotranspiration and incorporation into the crops. In addition to the availability of water, economic considerations in terms of willingness to pay for water will also shape energy choices and optimal water allocation. Hydropower variability due to changing water volumes means that energy planners should arrange to obtain base power from other energy sources during some periods. Competing water demands for energy production need to be addressed, and the energy required for pumping, treating, and moving water must also be considered. Robust analytical frameworks can help policymakers understand these tradeoffs and make informed choices.

4. WEAP and LEAP in LAC

One effective way to address these issues in LAC is to link two advanced water and energy decision support tools developed by SEI: Water Evaluation And Planning (WEAP) and the Long-range Energy Alternatives Planning system (LEAP), both of which are accessible to a large community of users, with licenses given at no cost to nongovernmental organizations, government agencies, and academic institutions in developing countries.

WEAP is a robust, practical water resources planning tool that allows users to address freshwater management challenges and allocate limited water resources, with full integration of supply-demand questions, water quality, and ecological considerations. WEAP can produce information about water demand for different uses, including energy production, and compare them with estimates of available runoff based on climate variables such as precipitation and temperature. Glacier dynamics and runoff contributions can also be estimated in WEAP by linking existing glacier algorithms to the WEAP supply and demand routines (for an example of such a methodology, see Vergara et al. 2011).

LEAP is an integrated modeling tool that is widely used for energy policy analysis and climate change mitigation assessment. It has a flexible structure that allows for local, regional, and global application of various modeling methodologies such as accounting, simulation and optimization. LEAP can be used to track energy consumption, production, and resource extraction in all sectors of the economy, while accounting for GHG emissions, costs, and local air pollutants.

WEAP and LEAP were developed by SEI researchers to support integrated sustainability planning, and they can also address climate change considerations. WEAP is useful to test adaptation measures for water systems, and LEAP is useful to test mitigation measures in the energy system. But these tools have individual limitations: WEAP lacks information about energy requirements for water movement, and LEAP lacks information about water availability for hydropower and for other energy requirements. By integrating the two systems, we can produce better estimates of hydropower variability, water demands for other energy sources besides hydropower, and energy requirements. An integrated tool could also be used to build scenarios for low-carbon and low-water energy sources, and test their feasibility – a valuable option for LAC water and energy planners at the regional and national levels.

WEAP and LEAP integration

This report describes the first steps in creating a DWC tool, building, in part, on WEAP and LEAP. Separately, our SEI colleagues are working on a WEAP-LEAP integration, which we describe below, starting with the computational aspects and applying the integrated system to two projects: a regional water resource planning model to explore the water-energy nexus in the U.S. Southwest and Southeast, and an integrated analytical framework for energy-water and climate planning model for the State of California.

The first project aims to guide energy policy and decision-making to achieve emission reductions and avoid unintended consequences related to water management in the context of power plant expansion to meet future electricity requirements. It is recognized that different energy management strategies will have different water management implications that extend to the local, regional, and national scale. For this project, a WEAP application has been developed to represent the implications for water resources of different energy and water management strategies and development pathways under current and future conditions. In addition to different energy development strategies and their associated water requirements, other development pathways can be explored with this platform, such as changes in municipal water demand use and patterns, and/or changes in irrigation demand.

The second project explores the water-energy nexus in California, where nearly 20 percent of all energy is associated with moving, lifting, treating, and using water (California Energy Commission 2005). This study brings together three key organizations to explore the water-energy nexus: the California State Department of Water Resources, which is responsible for California's management and regulation of water usage; the California Energy Commission, which also oversees climate mitigation efforts; and Pacific Gas and Electric Co., which provides natural gas and electricity to millions of customers in northern and central California. The focus of this project is to link water management options – such as reuse, reservoir re-operation, demand-side management, land use changes, and so forth – as represented in WEAP, to models of energy use for water utilities, as represented in LEAP.

The WEAP-LEAP integration is still under development, but a first draft of the combined tool is expected in early 2012. In addition to the specific applications of the WEAP-LEAP integration listed above, the model-linking functionality developed for those applications will be available to all users of WEAP and LEAP. In the following sections, we describe potential applications of this integrated framework, with a particular focus on regional planning. We also provide an overview of existing advanced WEAP and LEAP applications in the LAC region developed by advanced users that have worked in collaboration with SEI staff, and the water and energy considerations for development planning that can be derived from these applications.

Existing WEAP and LEAP models in LAC

As of August 2011, there were approximately 1,300 WEAP and 1,900 LEAP potential users in LAC (see Table 1). In order to gather information about existing LAC applications and their connections to DWC, we asked regular users – including SEI staff working on water and climate and energy programs – about models they have implemented. We reviewed reports to identify which part of the model could be used as an indicator for DWC. We tabulated the information about watershed location and contact information, focus of study, and highlights relevant for climate-water-energy planning, such as existing water demands and water uses for energy production. We then analyzed and commented on how water and energy considerations – such as the presence of hydropower as a clean energy source – provide insights into DWC. The WEAP and LEAP models studied are summarized in Appendix 4 Tables A-6 and A-7, and described in detail in Appendix 5.

Table 1: Estimated potential users for WEAP and LEAP in LAC

WEAP - LEAP Users in LAC based on the IADB Regionalization			
IADB Region	Country	WEAP Num of Users	LEAP Num of Users
Southern Cone		254	766
	Argentina	55	158
	Brazil	62	434
	Chile	115	132
	Paraguay	10	17
	Uruguay	12	25
Andean Group		638	566
	Bolivia	87	53
	Colombia	165	187
	Ecuador	80	93
	Peru	271	184
	Venezuela	35	49
Caribbean		10	83
	Bahamas	0	16
	Barbados	1	6
	Guyana	0	4
	Haiti	2	7
	Jamaica	2	12
	Suriname	4	28
	Trinidad & Tobago	1	10
Central America et al.		398	444
	Belize	3	5
	Costa Rica	16	21
	Dominican Republic	20	40
	El Salvador	9	36
	Guatemala	24	33
	Honduras	9	17
	Mexico	288	233
	Nicaragua	15	31
	Panama	14	28

Note: User numbers are as of Aug. 12, 2011. Source: WEAP and LEAP user databases.

The survey results indicate that the WEAP models implemented in different LAC regions were developed to respond to specific objectives, without expressly considering DWC. However, many are still quite relevant, especially as they relate to large-scale agriculture and hydropower production. Indeed, the agriculture studies reflect, at least in part, a major push around the world to grow biofuels in response to increased energy demand. Our analysis indicates that in Central America and Caribbean, agricultural areas devoted to biofuel crops will compete with other agricultural areas and other water users under likely future growth and climate change scenarios.

Most of the hydropower production models that we analyzed, meanwhile, were developed in the Southern Cone and Andean regions. A key result from these models is that in glaciated areas, hydropower production depends on base flow contributions from glaciers. Increased temperatures may accelerate melting until the glacier reservoir is exhausted. The consequent temporary increase in available base flows is likely to affect current reservoirs and their associated hydropower infrastructure. This will increase hydropower production and create an opportunity to use this extra volume for hydropower production by increasing infrastructure capacity. But the models also indicate negatives impacts when the increased flow ends and lower base flows than normal levels start to occur. Water volumes would drop, and less hydroelectricity could then be produced. In this context, the WEAP platform provides a good environment to test adaptation measures under climate change at a local/watershed scale.

For LEAP users, SEI has developed a series of national-level "starter" data sets to be used by developing-country energy planners as a starting point for their analyses (see Appendix 3 for graphs of data sets). One data set has been created for each country for which energy data is available from the IEA, including 20 in LAC: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela.

Each data set includes a comprehensive picture of historical energy demand and supply from 1970 to 2007, based on the IEA's World Energy Balances database (IEA 2008). The energy data includes information on fuel energy use in each major demand sector (e.g., households, industry, transport, agriculture). On the supply side, the data set include information on distribution losses, own use,[9] heat, electricity, combined heat and power production, and information on gas works, refineries and liquefaction. This embedded IEA data on historical electricity generation is broken down by fuel source, which highlights the generation mix of each national grid. This can inform historical contexts for hydroelectric power in LAC, show trends in power plant expansion, and help identify areas for potential fuel switching. Table 2 in Appendix 4 includes a summary of LAC-related projects in the LEAP database. Many of the applications are focused on mitigation options at the country level.

Integrating DWC in water and energy planning

A review of WEAP and LEAP applications in different LAC regions suggests that, beyond the original purpose of the studies, the results could be used to understand water and energy requirements for DWC, but we found no integrated energy-water assessments of the type that will be possible with the combined WEAP-LEAP software. Our review identified several issues that should be addressed when integrating DWC considerations in development planning (examples referred to below are from Appendix 4):

- Population growth in LAC will add constraints on water availability for clean energy uses due to competing demands, even as the water supply is diminished by changing climate. This may require designing infrastructure that is adaptable to climate variability and focus on low-carbon, low-water solutions. For instance, in Lima, a system of lakes and dams provides water and energy for the city. But this combined use may not be viable if water levels drop and demand for water in the city rises. This means that Lima may need to generate additional energy from other sources, a potential one being natural gas, which is available in the area.
- Maintaining and/or increasing hydropower production will be an attractive measure to mitigate emissions in several countries, but planners will have to consider the challenges that climate change presents in terms of variability in runoff patterns. The Paute River basin in Ecuador may be a case in which increased precipitation will increase the potential for increased hydropower production. The infrastructure may need adaptation to use this hydropower potential while improving emissions mitigation.

[9] Many power plants consume a small amount of electricity for internal processes in the form of "own use" requirements.

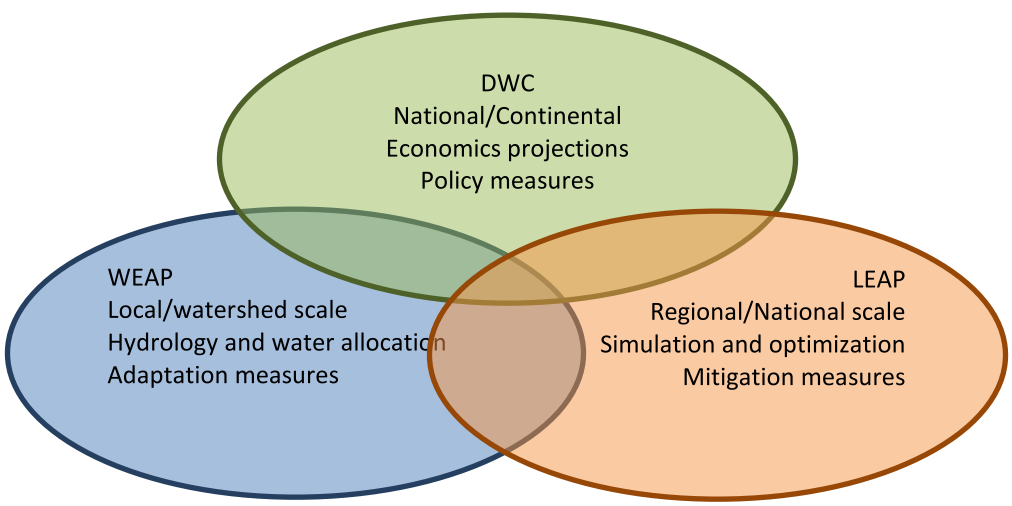
- Policies designed to foster economic growth by boosting energy production (low-carbon or not) may place new demands on the water supply. For instance, policies to increase small hydro in Mexico will need to consider changes in runoff and how these changes could impact overall hydropower production.
- Biofuels production as a viable low-carbon energy source may add to the water stress in some regions. The choice of low-water crops for biofuels may need to come into consideration in regions where current expansion of agriculture for biomass is being planned, such as Yaque del Sur in Dominican Republic and the Rio Chiura-Piura in Peru.
- Use of water for energy needs such as hydropower and biofuels could conflict with urban and agricultural uses. These challenges will need to be addressed by incorporating social components into decision-making, with stakeholders at the table such as the considerations observed in the Rio Grande/Rio Bravo study where stakeholders needs where represented within the scenarios considered.

The combined WEAP-LEAP platform can help planners test the degree to which policies can promote mitigation and the degree to which adaptation measures are required to provide enough water for all users. The current status of development and capacity building through the delivery of WEAP and LEAP trainings and collaborations between SEI and stakeholders in the region are an excellent base for developing additional capacity to incorporate a DWC planning platform that highlights adaptation and mitigation challenges.

5. Discussion

DWC is an important part of climate and development policies. Climate mitigation needs to be part of energy growth planning in LAC. Also, to the extent that energy production requires water – as it does with hydropower –adaptation measures in the water sector may need to be incorporated in the plans. Thus planning to support development in LAC needs to integrate climate-energy-water models with DWC climate economics, in as illustrated in Figure 5.

Figure 3: WEAP, LEAP and DWC focus and utility for climate-water-energy planning to support development



This multifaceted approach may be particularly important in considering hydroelectricity as an energy source and mitigation measure, which has great potential for DWC in LAC. Hydropower reliability is threatened by climate change, so developers will have to take climate projections into account in their planning. The implications for hydropower may be complex. Loss of glaciers may result in increased flows, but even if they do not affect flows initially, once glacier reservoirs are depleted, the loss of glacier contributions in the dry season could hurt hydropower production as well as livelihoods.

The WEAP-LEAP applications studied also help highlight the challenges and opportunities to support development processes in low-water, low-carbon scenarios in general. The main challenges identified are:

- *How can energy and water resources planning tools and infrastructure be designed to accommodate climate uncertainty?* Some possibilities include forecasting for targeted operations, building infrastructure designed for failure, and incorporating non-structural systems like communications or IT to enhance water management, as Brown (2010) suggests.
- *How can tradeoffs be assessed between competing energy demands for water, such as biofuels and hydropower? Which variables or indicators could be used to assess these tradeoffs?* The WEAP-LEAP software integration can be helpful as a framework for addressing the quantitative questions related to the linkages between energy and water. Using these tools to assess competing demands for water required both for agricultural irrigation and hydroelectricity can be used to compare different climate and development scenarios. This integrated quantification can inform the design of infrastructure and planning tools discussed above. Current capacity in the region can serve as a baseline for exploring further capacity-building in the DWC context.
- *How should competing water demands be prioritized? Should they be evaluated based on their economic values, or are there other feasible ways to value the benefits of water use?* By incorporating economics and social consideration of into these decisions, it will be possible to have a clearer guide for water allocation priorities.
- *How can participatory processes support the promotion of low-carbon electricity within watersheds and help identify tradeoffs between water uses and energy sources?* Water benefit sharing and autonomous social processes can motivate involvement into decision making to achieve solutions that can improve the conditions to access water and energy for stakeholders.

Further articulation of these challenges could help identify areas for potential future research. Within SEI we are committed to seek opportunities to formulate studies that contribute in answering the questions above. Studies along those lines could also assist researchers in finding niches that could support the creation and implementation of case studies to introduce tools for energy-water and DWC climate planning in LAC.

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Appendix 1: Precipitation and temperature trends

Table A-1: Current climatic trends

Precipitation (change shown in % unless otherwise indicated)	**Period**	**Change**
Amazonia – northern/southern (Marengo, 2004)	1949-1999	-11 to -17/-23 to +18
Bolivian Amazonia (Ronchail et al., 2005)	since 1970	+15
Argentina – central and north-east (Penalba and Vargas, 2004)	1900-2000	+1 STD to +2 STD
Uruguay (Bidegain et al., 2005)	1961-2002	+ 20
Chile – central (Camilloni, 2005a)	last 50 years	-50
Colombia (Pabón, 2003a)	1961-1990	-4 to +6
Mean temperature (°C/10 years)		
Amazonia (Marengo, 2003)	1901-2001	+0.08
Uruguay, Montevideo (Bidegain et al., 2005)	1900-2000	+0.08
Ecuador (NC-Ecuador, 2000)	1930-1990	+0.08 to +0.27
Colombia (Pabón, 2003a)	1961-1990	+0.1 to +0.2
Maximum temperature (°C/10 years)		
Brazil – south (Marengo and Camargo, 2007)	1960-2000	+0.39 to +0.62
Argentina – central (Rusticucci and Barrucand, 2004)	1959-1998	-0.2 to -0.8 (DJF)
Argentina – Patagonia (Rusticucci and Barrucand, 2004)	1959-1998	+0.2 to +0.4 (DJF)
Minimum temperature (ºC/10 years)		
Brazil – south (Marengo and Camargo, 2007)	1960-2000	+0.51 to +0.82
Brazil – Campinas and Sete Lagoas (Pinto et al., 2002)	1890-2000	+0.2
Brazil – Pelotas (Pinto et al., 2002)	1890-2000	+0.08
Argentina (Rusticucci and Barrucand, 2004)	1959-1998	+0.2 to +0.8 (DJF/JJA)

STD= standard deviation, DJF= December/January/February, JJA= June/July/August. Source: IPCC (2007).

Table A-2: Glacier retreat trends in LAC

Glaciers/Period	**Changes/Impacts**
Peru Last 35 years	22% reduction in glacier total area; reduction of 12% in freshwater in the coastal zone (where 60% of the country's population live). Estimated water loss almost 7,000 Mm^3
Peru Last 30 years	Reduction up to 80% of glacier surface from small ranges; loss of 188 Mm^3 in water reserves during the last 50 years.
Colombia 1990-2000	82% reduction in glaciers, showing a linear withdrawal of the ice of 10-15 m/yr; under the current climate trends, Colombia's glaciers will disappear completely within the next 100 years.
Ecuador 1956-1998	There has been a gradual decline glacier length; reduction of water supply for irrigation, clean water supply for the city of Quito, and hydropower generation for the cities of La Paz and Lima.
Bolivia Since mid-1990s	Chacaltaya glacier has lost half of its surface and two-thirds of its volume and could disappear by 2010. Total loss of tourism and skiing.
Bolivia Since 1991	Zongo glacier has lost 9.4% of its surface area and could disappear by 2045-2050; serious problems in agriculture, sustainability of 'bofedales'[1] and impacts in terms of socio-economics for the rural populations.
Bolivia Since 1940	Charquini glacier has lost 47.4% of its surface area.

Source: IPCC (2007).

Table A-3: Projected temperature (°C) and precipitation (%) changes for broad sub-regions of Central and South America

Region	Condition	2020	2050	2080
Changes in temperature (°C)				
Central America	Dry season Wet season	+0.4 to +1.1 +0.5 to +1.7	+1.0 to +3.0 +1.0 to +4.0	+1.0 to +5.0 +1.3 to +6.6
Amazonia	Dry season Wet season	+0.7 to +1.8 +0.5 to +1.5	+1.0 to +4.0 +1.0 to +4.0	+1.8 to +7.5 +1.6 to +6.0
Southern South America	Winter (JJA) Summer (DJF)	+0.6 to +1.1 +0.8 to +1.2	+1.0 to +2.9 +1.0 to +3.0	+1.8 to +4.5 +1.8 to +4.5
Change in precipitation (%)				
Central America	Dry season Wet season	-7 to +7 -10 to +4	-12 to +5 -15 to +3	-20 to +8 -30 to +5
Amazonia	Dry season Wet season	-10 to +4 -3 to +6	-20 to +10 -5 to +10	-40 to +10 -10 to +10
Southern South America	Winter (JJA) Summer (DJF)	-5 to +3 -3 to +5	-12 to +10 -5 to +10	-12 to +12 -10 to +10

DJF= December/January/February, JJA= June/July/August. Ranges of values encompass estimates from seven GCMs and the four main SRES scenarios. Source: IPCC (2007).

Appendix 2: Electricity statistics

Table A-4: Electricity statistics for 2008

Electricity Production 2008									
Production from:	Total hydropower production *,#		Total Production of Electricity #	Electricity Imports#		Electricity Exports#		Domestic Supply (Req=Prod+Imp+Exp)	Electricity per 1000 inhab Index
	GWh	%		GWh	%	GWh	%	GWh	(GWh/1000 hab)
Southern Cone									
Argentina	30,740	25	121,906	8,458	7	(2,975)	-2	127,389	3.1
Brazil	369,556	80	463,369	42,901	9	(689)	-0.1	505,581	2.4
Chile	24,193	41	59,704	1,154	2	-	-	60,858	3.6
Paraguay	55,464	100	55,464	-	-	(46,300)	-83	9,164	8.9
Uruguay	4,505	51	8,769	963	11	(28)	-0.3	9,704	2.6
Southern Cone Total	484,458	68	709,212	53,476		(49,992)		712,696	2.7
Andean Group								-	
Bolivia	2,281	37	6,240	-	-	-	-	6,240	0.6
Colombia	46,403	83	56,024	77	0.1	(1,473)	-3	54,628	1.2
Ecuador	11,294	61	18,609	500	3	-	-	19,109	1.4
Peru	19,040	59	32,430	-	-	-	-	32,430	1.1
Venezuela	86,841	73	119,297	102	0.1	(569)	-0.5	118,830	4.2
Andean Group Total	165,859	71	232,600	679		(2,042)		231,237	1.9
Caribbean								-	
Jamaica	158	2	7,781	-	-	-	-	7,781	2.9
Trinidad & Tobago	-	-	7,892	-	-	-	-	7,892	5.9
Haiti	181	37	486	-	-	-	-	486	0.0
Caribbean Total	339	2	16,159					16,159	1.2
Central America et al.								-	
Costa Rica	7,387	78	9,475	96	1	(166)	-2	9,405	2.1
Dominican Republic	1,728	11	15,414	-	-	-	-	15,414	1.5
El Salvador	2,038	34	5,960	83	1	(89)	-1	5,954	1.0
Guatemala	3,712	43	8,717	5	0.1	(76)	-1	8,646	0.6
Honduras	2,291	35	6,537	-	-	(12)	-0.2	6,525	0.9
Mexico	39,178	15	258,913	351	0.1	(1,452)	-1	257,812	2.4
Nicaragua	534	16	3,361	28	1	-	-	3,389	0.6
Panama	3,973	62	6,430	105	2	(32)	0	6,503	1.9
Central America Total	60,841	19	314,807	668		(1,827)		313,648	2.0
LAC Totals	711,497	161	1,272,778	54,823		(53,861)		1,273,740	7.7
LAC Average	33,881	47	60,608	2,611		(2,565)		60,654	2.3

** Includes production from pumped storage plants. Sources: items marked #, IEA country energy statistics (http://www.iea.org/country/); items marked ##: FAO Aquastat database (http://www.fao.org/nr/water/aquastat/dbase/index.stm).*

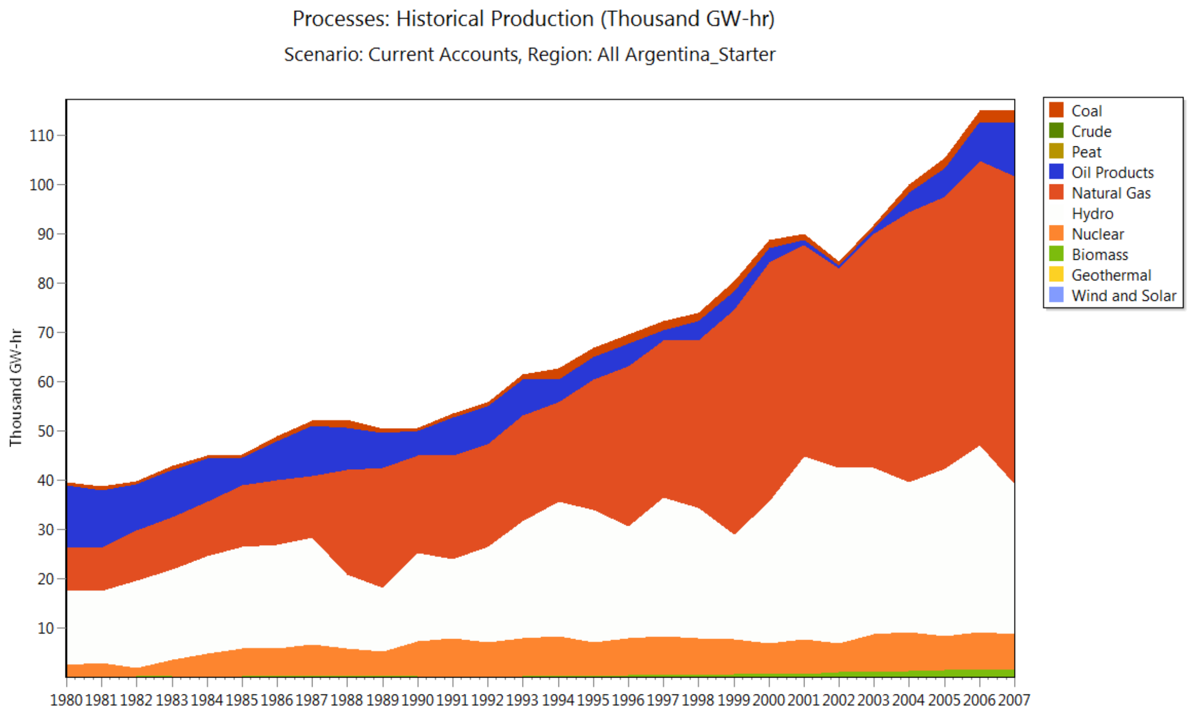
Table A-5: Water Statistics for 2008

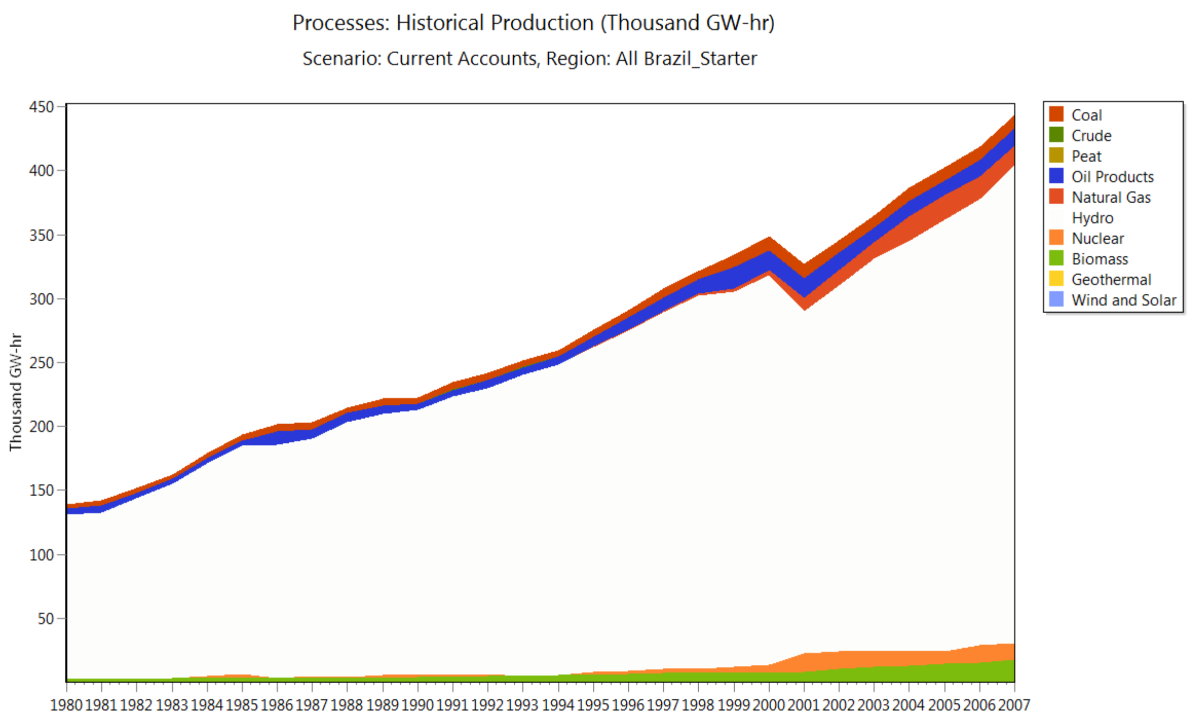
Water Statistics 2008				
Production from:	Average precipitation in depth##	Surface water: produced internally##	Total dam capacity##	Total population##
	(mm/yr)	(km3/yr)	(km3)	(1000 inhab)
Southern Cone				
Argentina	591	276	na	39,883
Brazil	1,782	5,418	513	191,972
Chile	1,522	884	5	16,804
Paraguay	1,130	94	38	6,238
Uruguay	1,265	59	19	3,349
Southern Cone Total	na	6,731	574	258,246
Andean Group				
Bolivia	1,146	277	0.3	9,694
Colombia	2,612	2,112	na	45,012
Ecuador	2,087	432	na	13,481
Peru	1,738	1,616	4	28,837
Venezuela	1,875	700	164	28,121
Andean Group Total	na	5,138	168	125,145
Caribbean				
Jamaica	2,051	6	na	2,708
Trinidad & Tobago	2,200		na	1,333
Haiti	1,440	11	na	9,876
Caribbean Total	na	16	na	13,917
Central America et al.				
Costa Rica	2,926	75	na	4,519
Dominican Republic	1,410	21	3	9,953
El Salvador	1,724	18	na	6,134
Guatemala	1,996	101	na	13,686
Honduras	1,976	87	9	7,319
Mexico	752	361	na	108,555
Nicaragua	2,391	186	0.4	5,667
Panama	2,692	144	na	3,399
Central America Total	na	992	12	159,232
LAC Totals	na	12,877	na	556,540
LAC Average	1,776	1,073	116	44,523

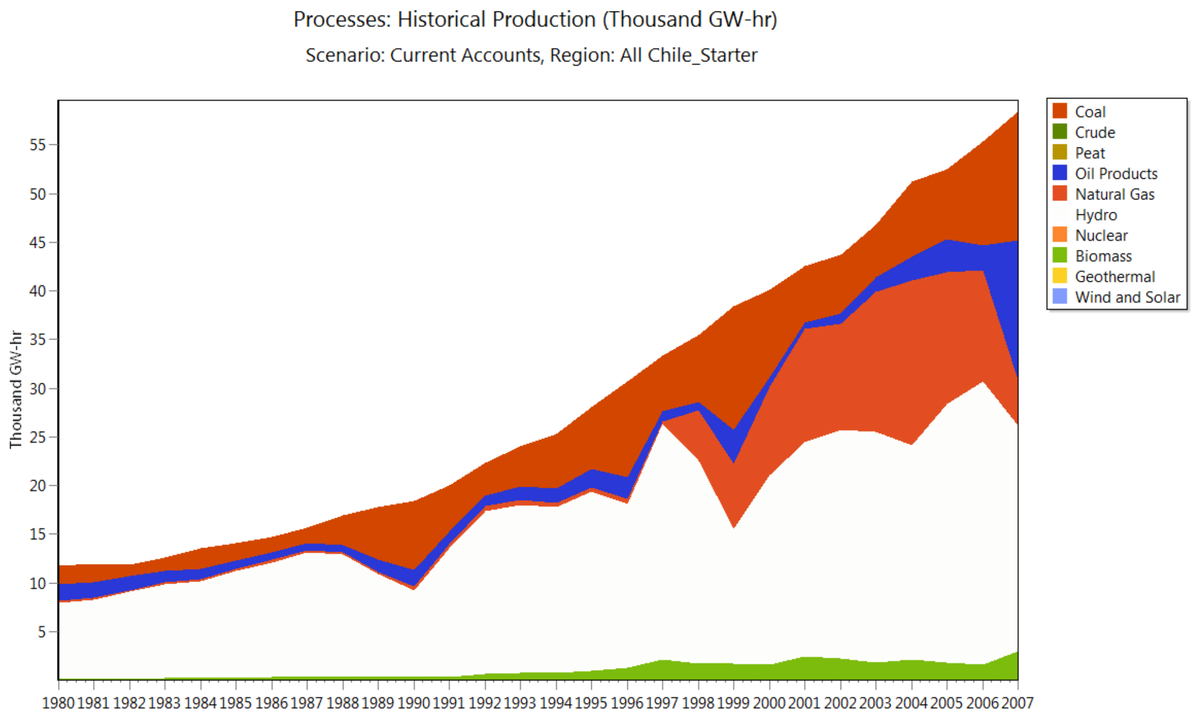
Source: FAO Aquastat database (http://www.fao.org/nr/water/aquastat/dbase/index.stm).

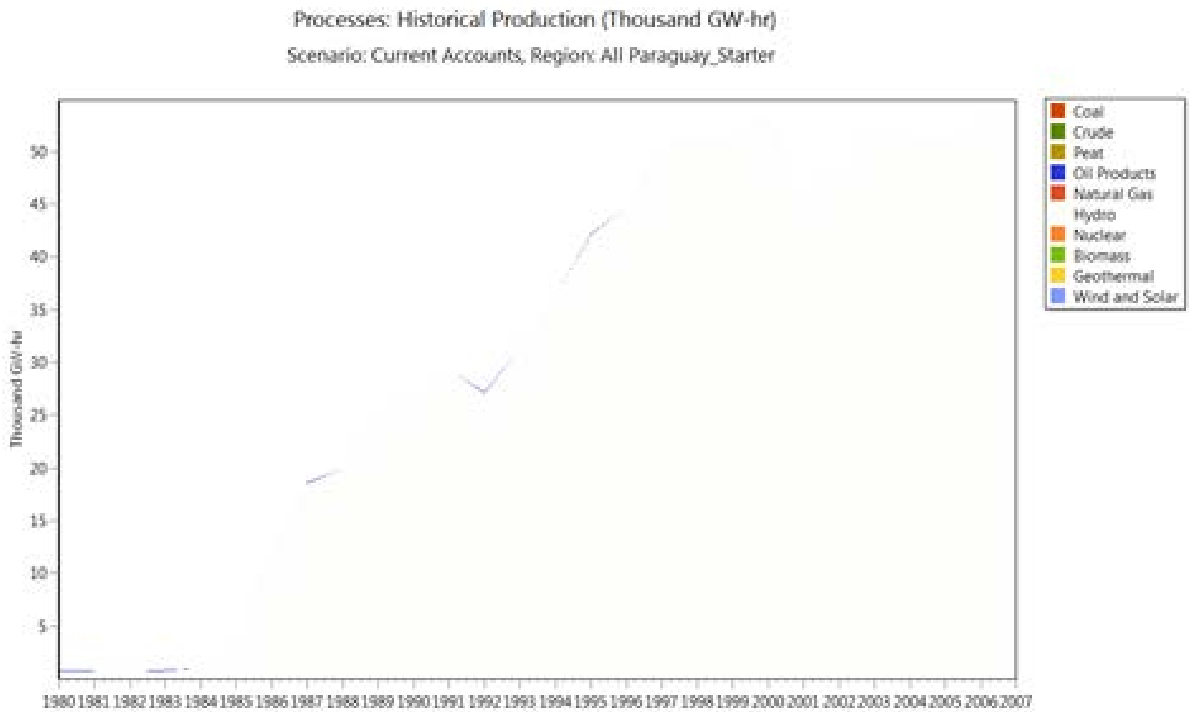
Appendix 3. LEAP Energy dataset starters

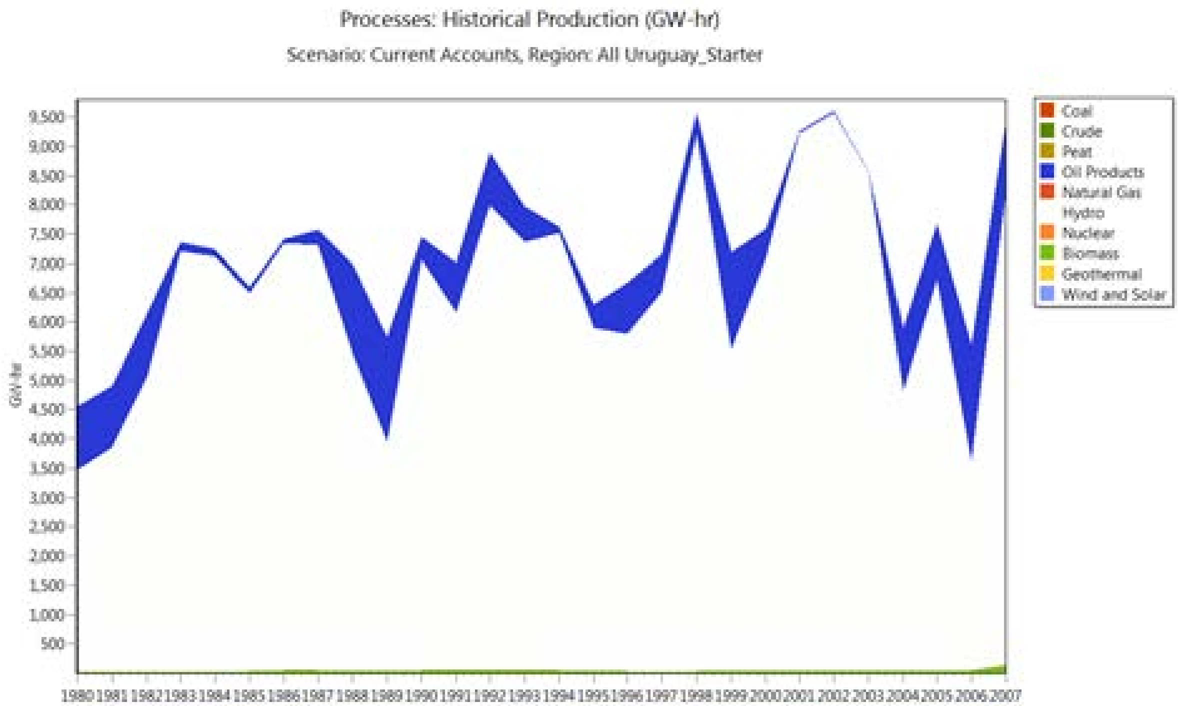
Southern Cone



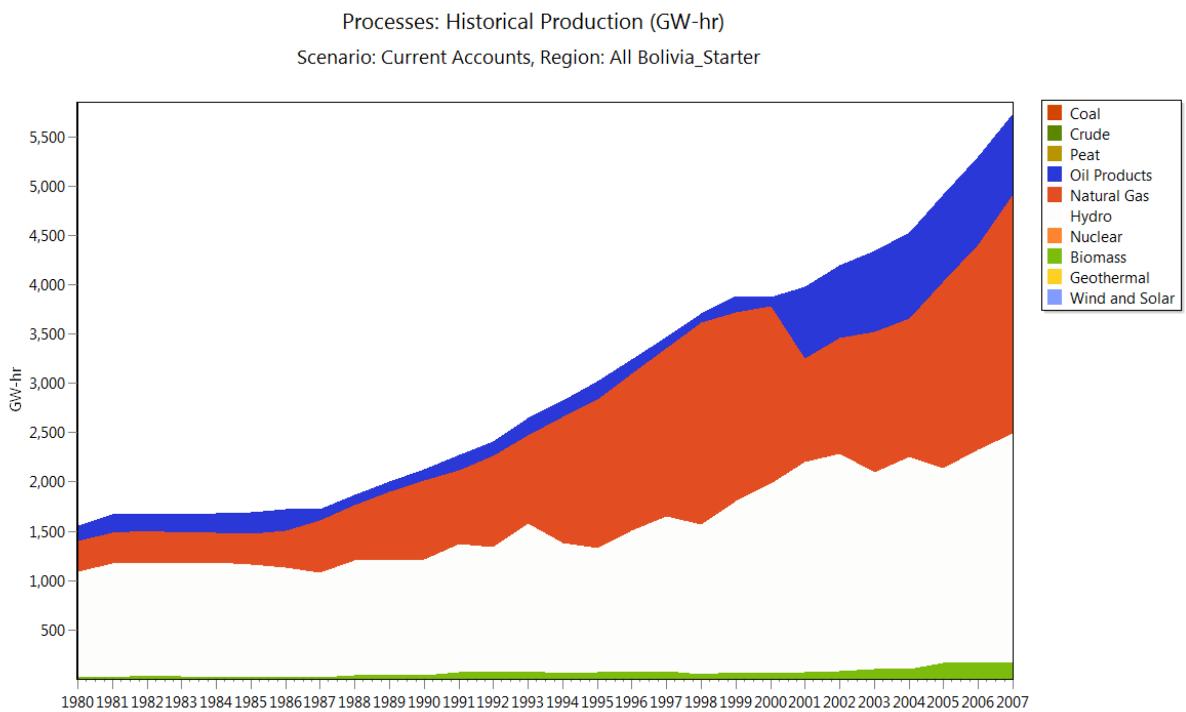


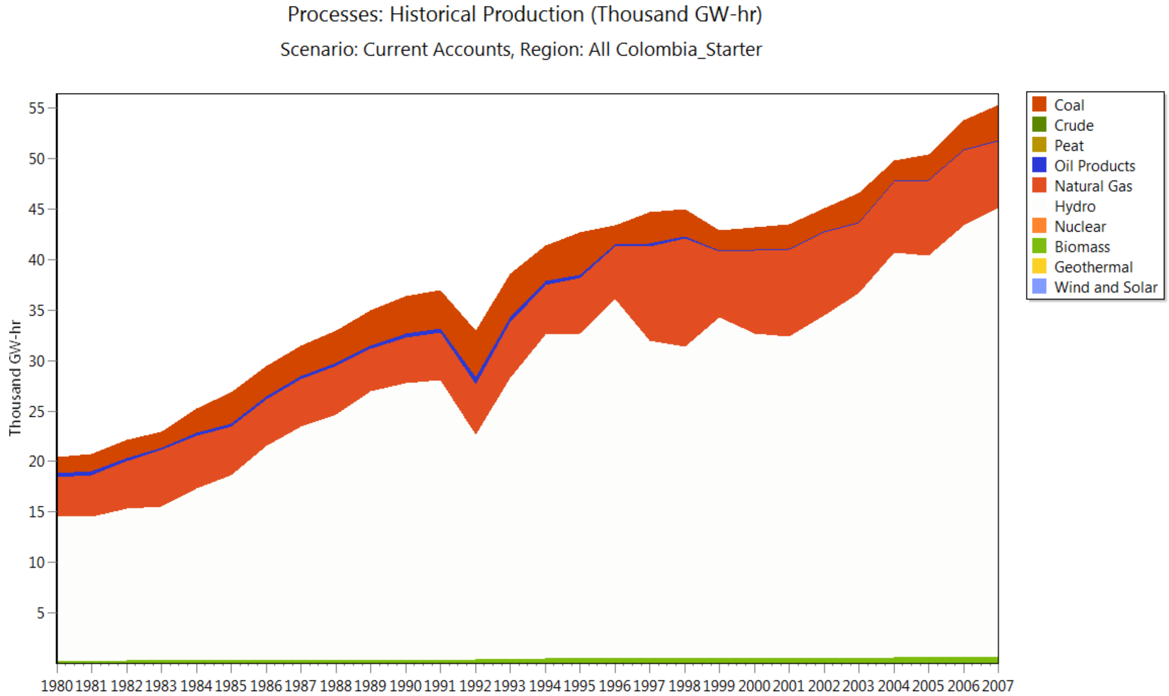

Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Chile_Starter
Thousand GW-hr
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

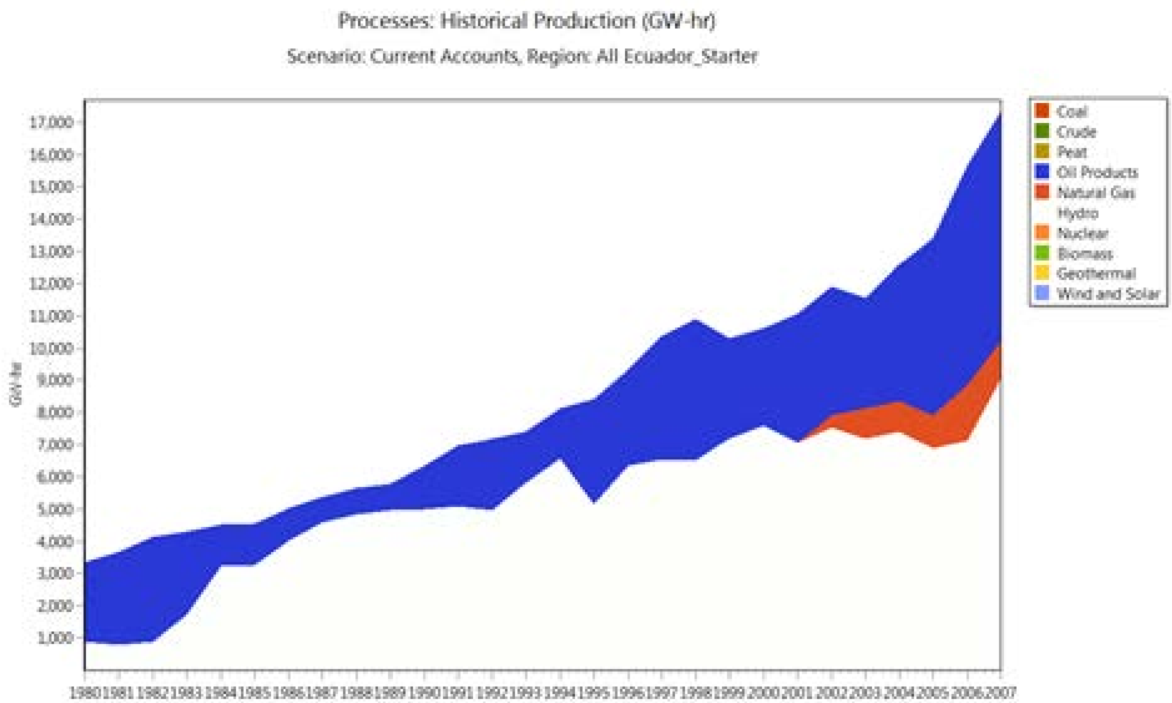

Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Paraguay_Starter
Thousand GW-hr
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar



Andean Group




Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Colombia_Starter
Thousand GW-hr
55
50
45
40
35
30
25
20
15
10
5
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar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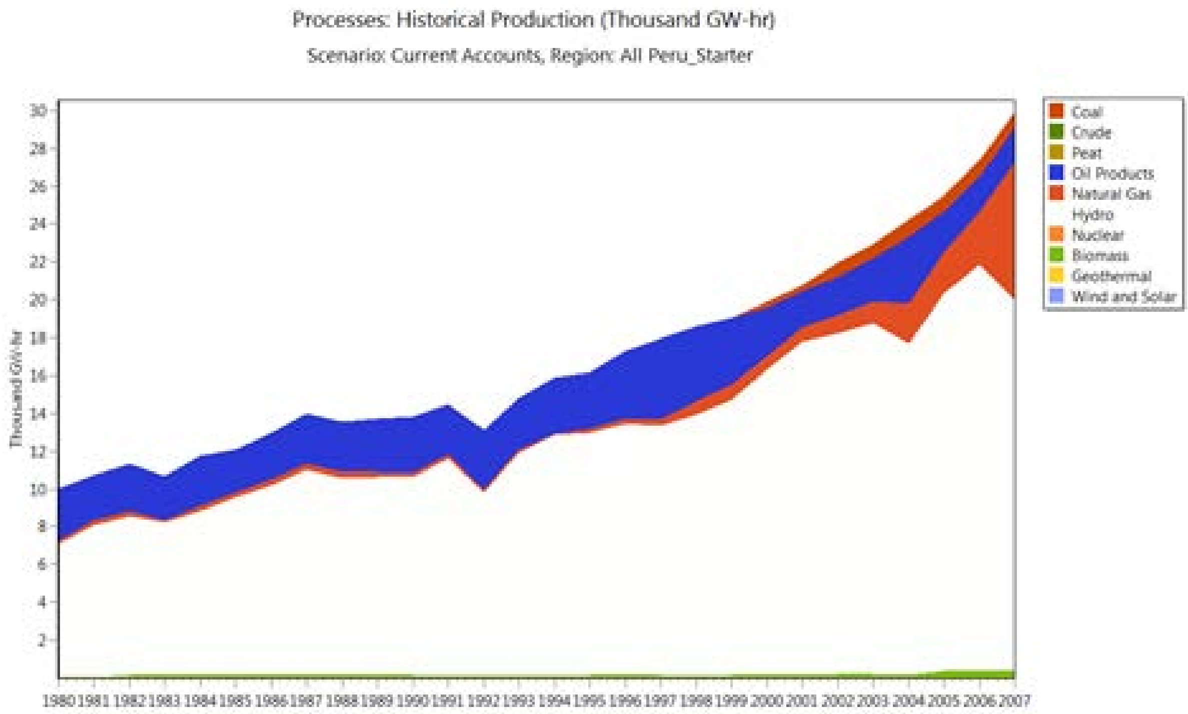
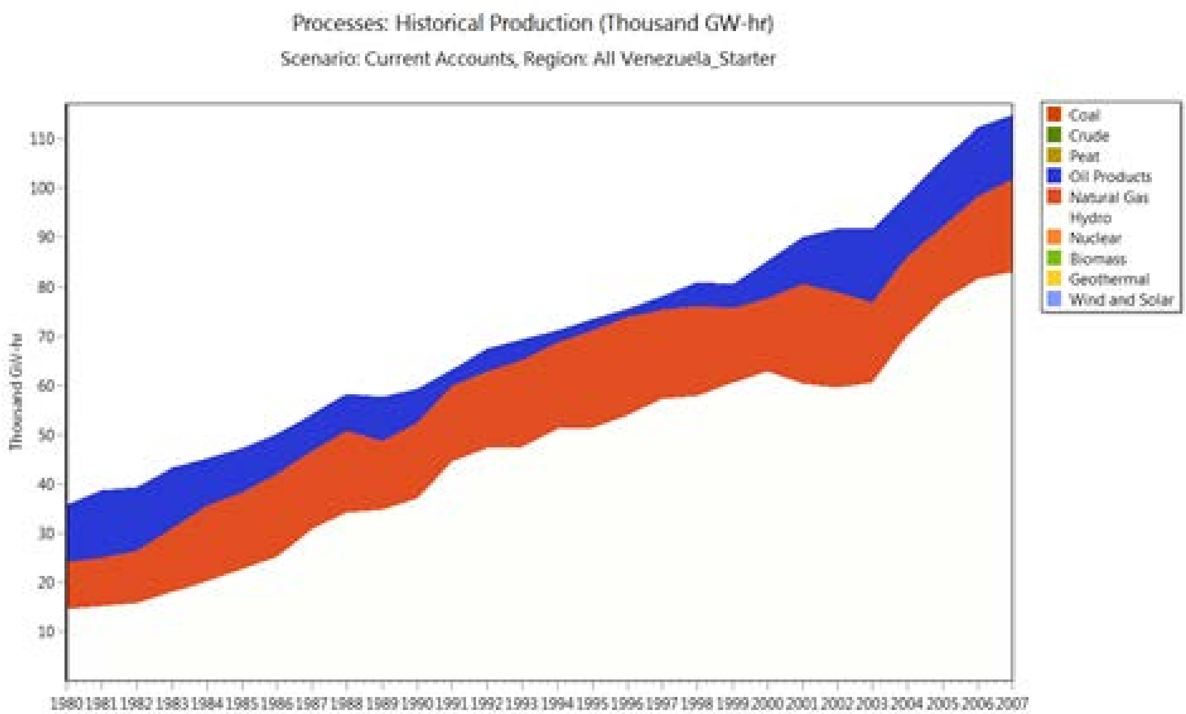
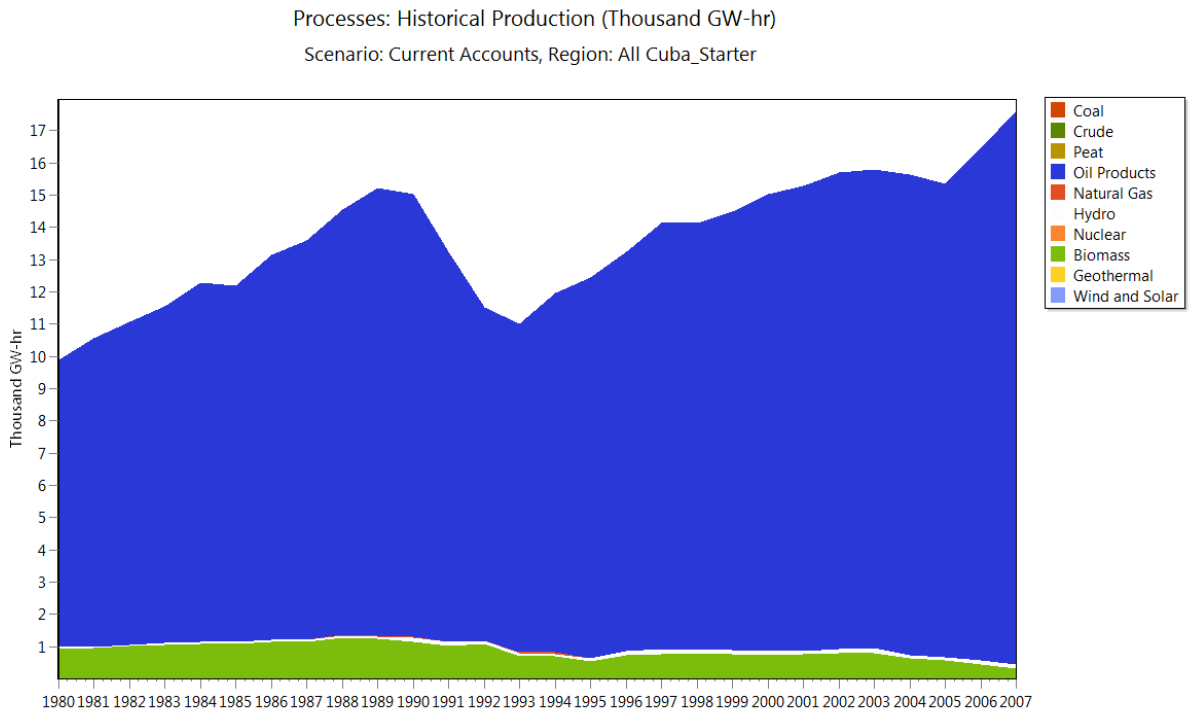
Scenario: Current Accounts, Region: All Ecuador_Starter
GW-hr
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

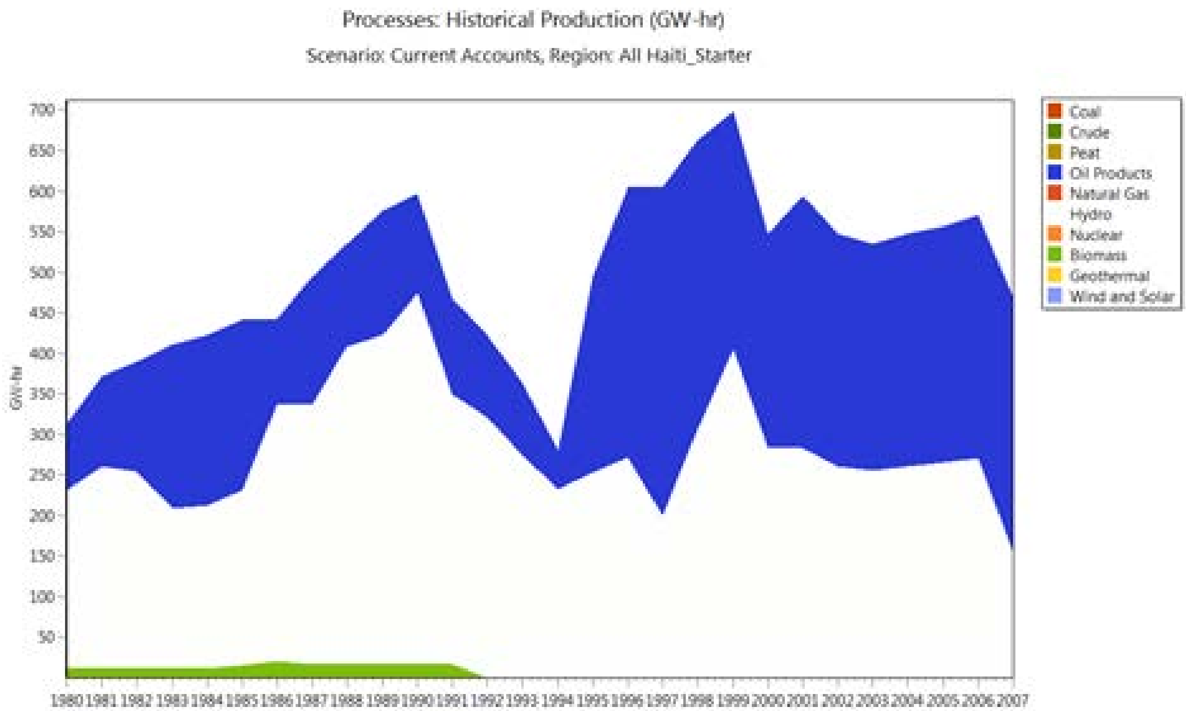

Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Peru_Starter
Thousand GW-hr
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Venezuela_Starter
Thousand GW-hr
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

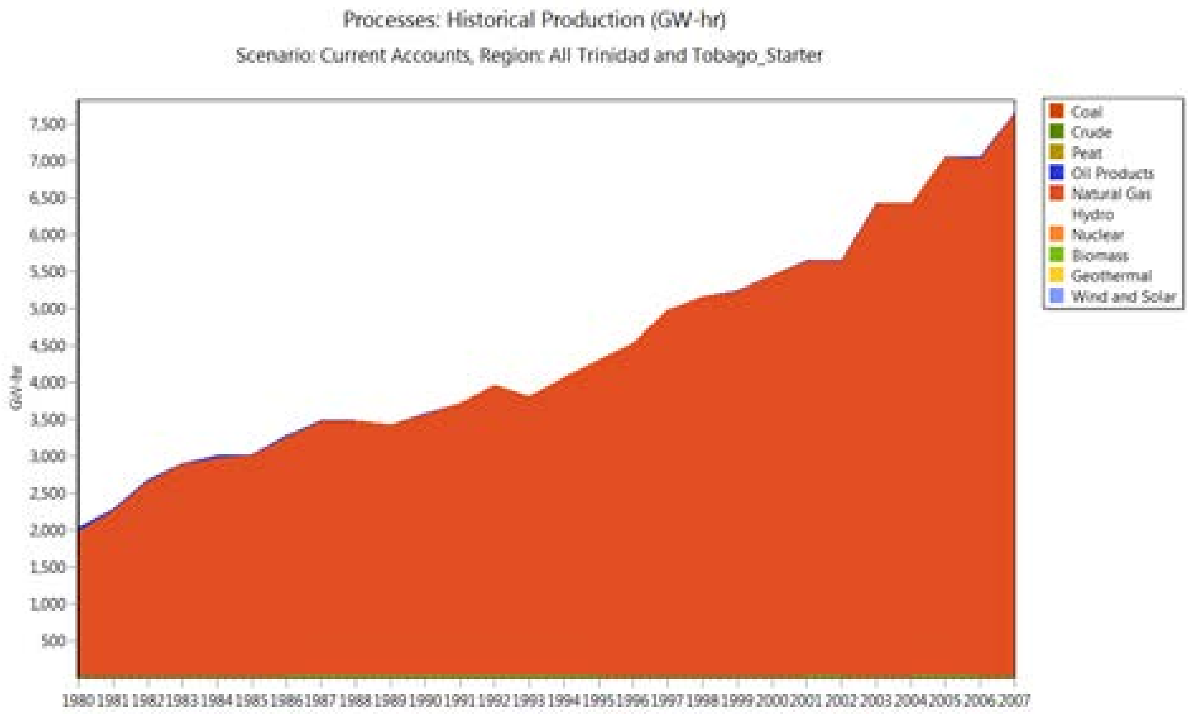
Caribbean



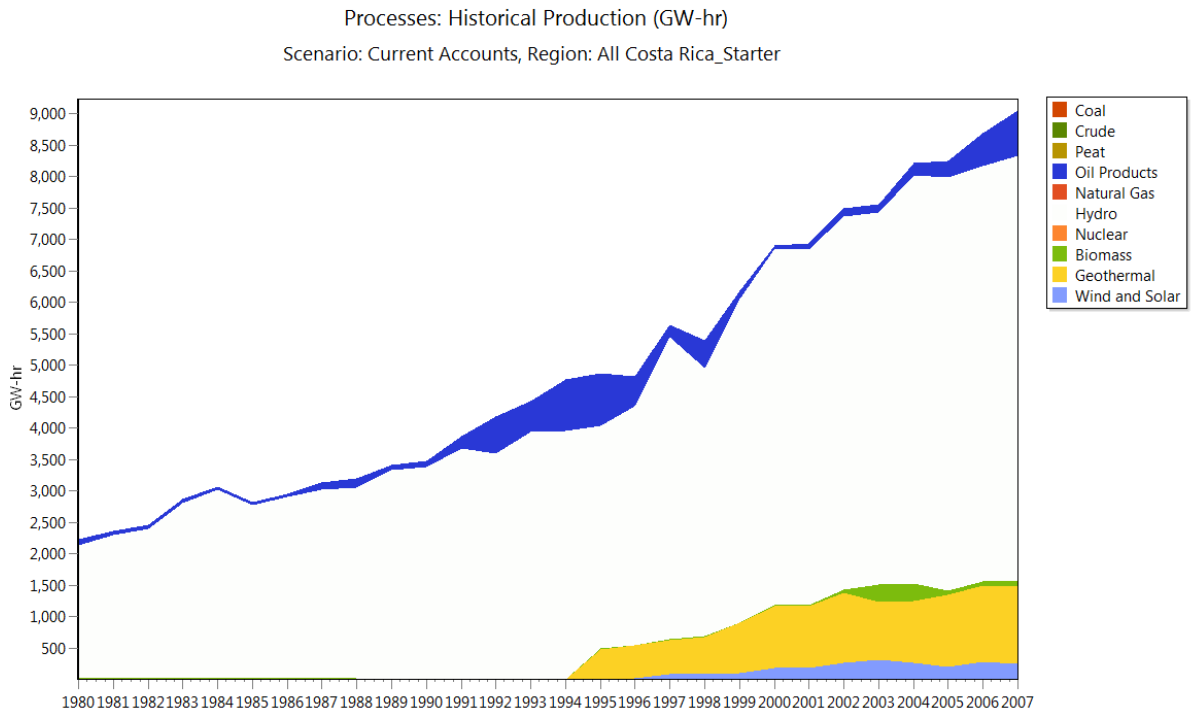
Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Cuba_Starter
Thousand GW-hr
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

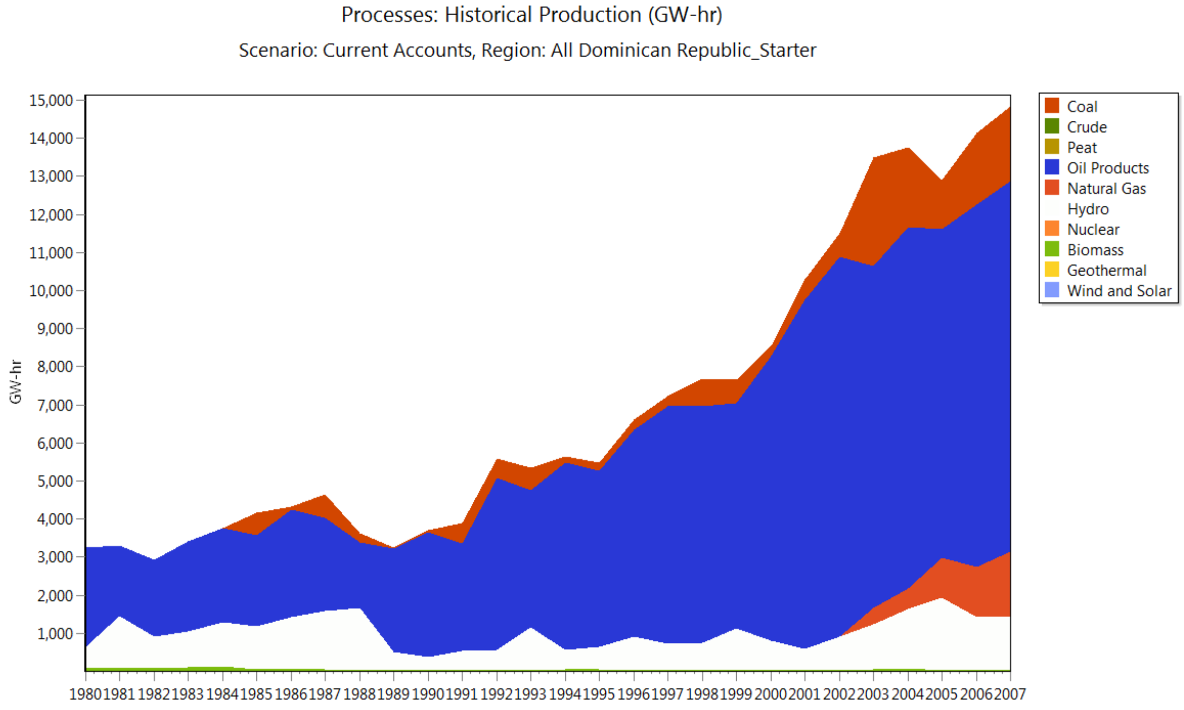


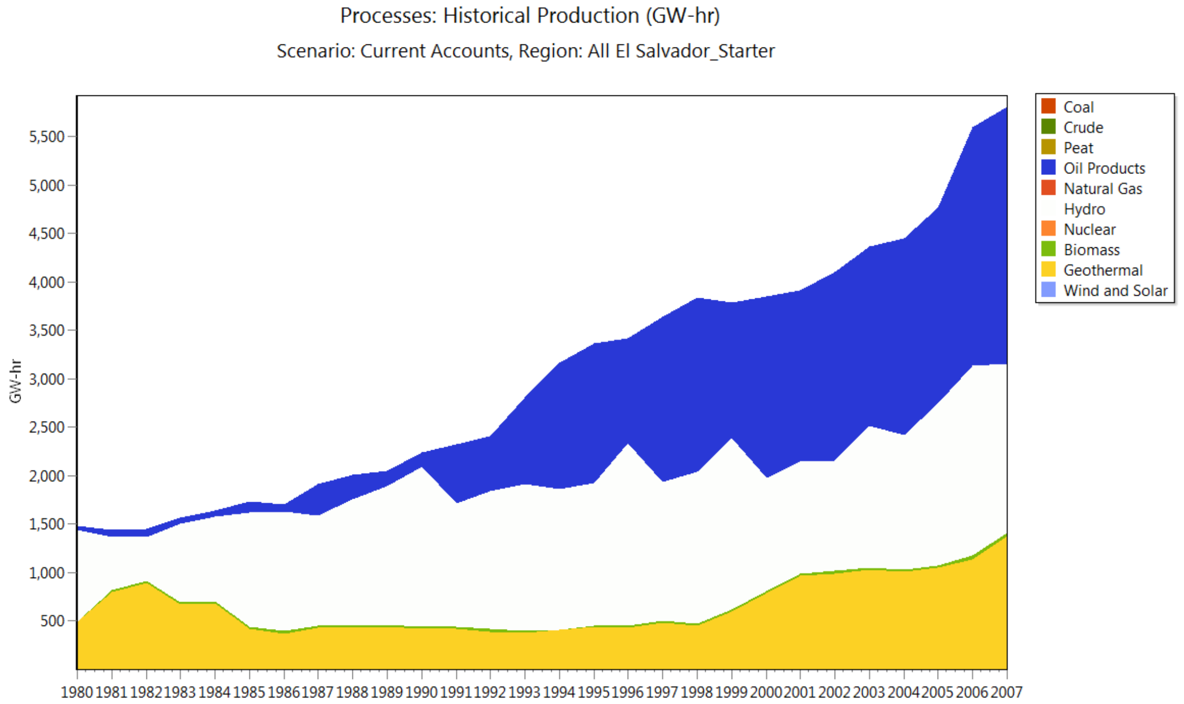
Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All Haiti_Starter
GW-hr
700
650
600
550
500
450
400
350
300
250
200
150
100
50
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

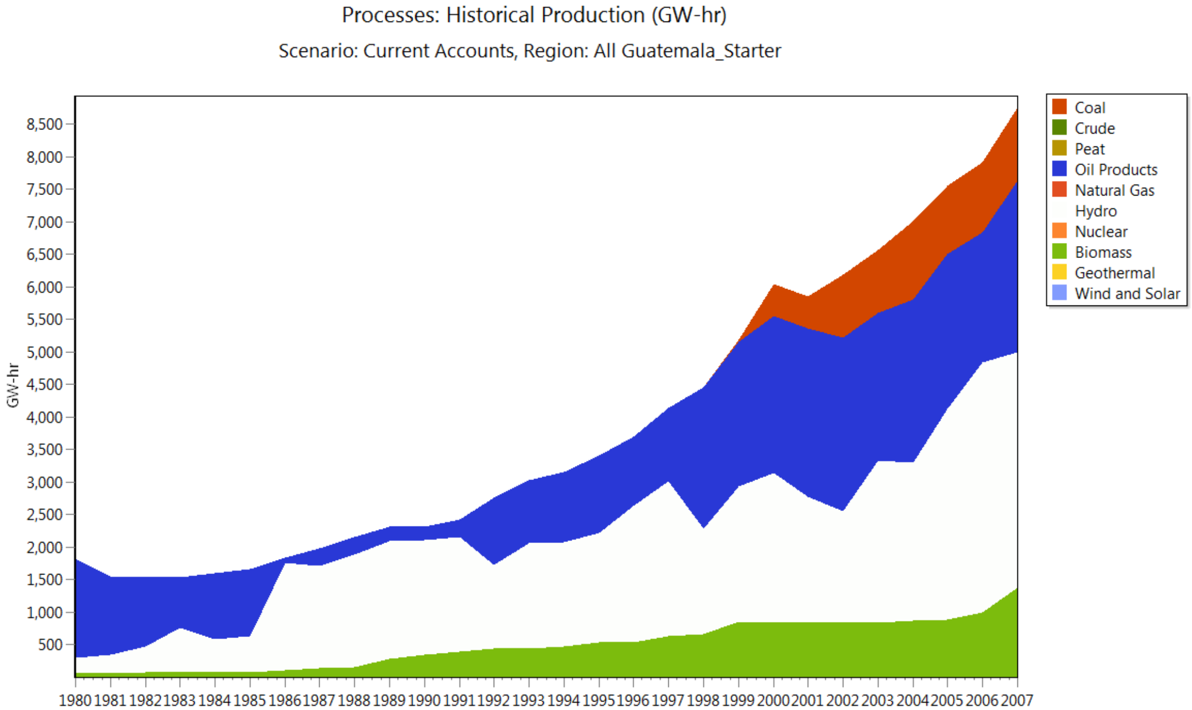


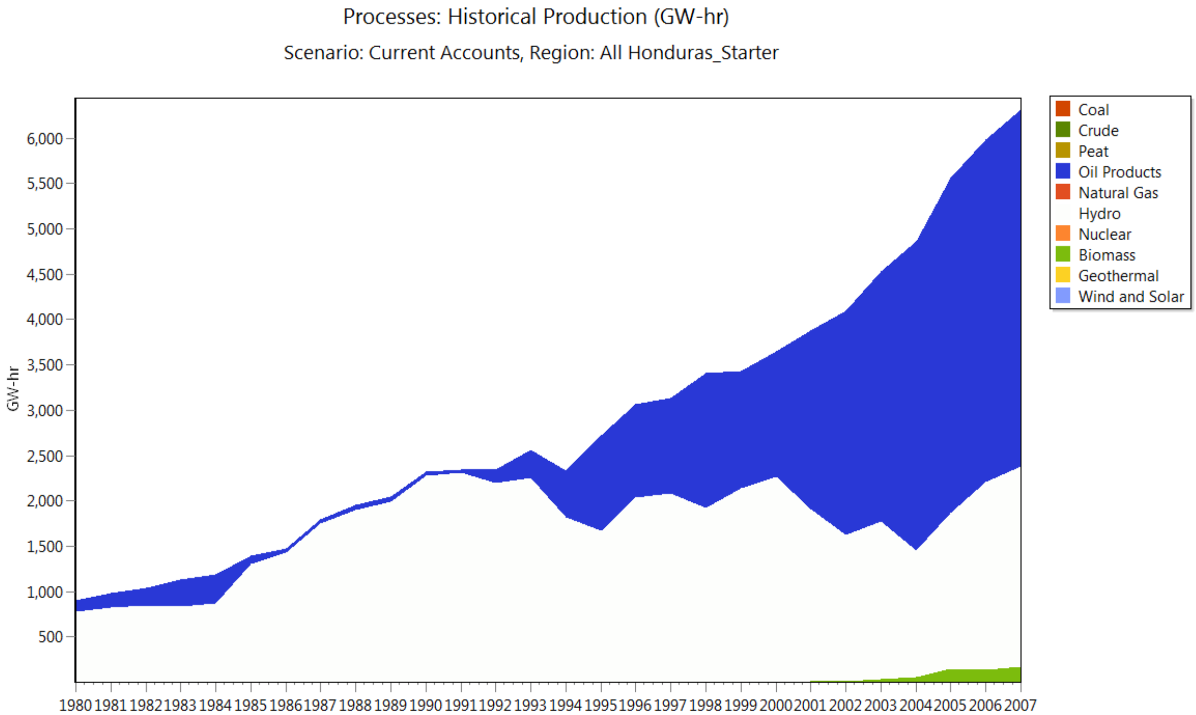
Central America et al.

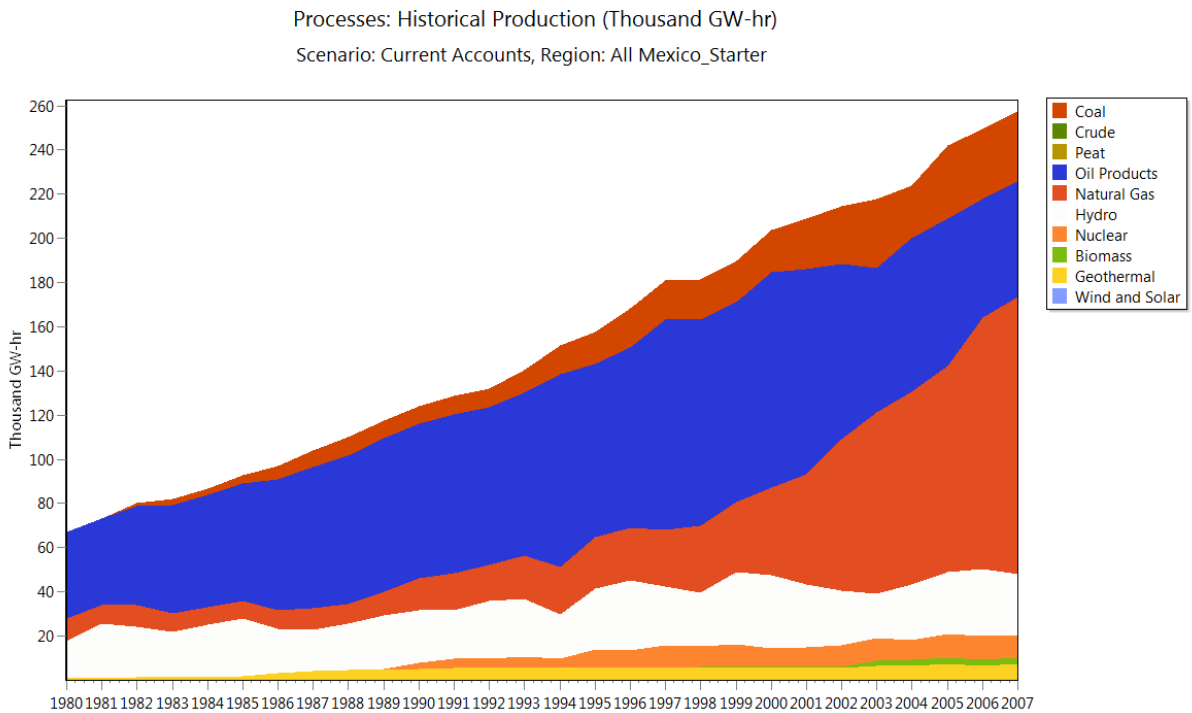


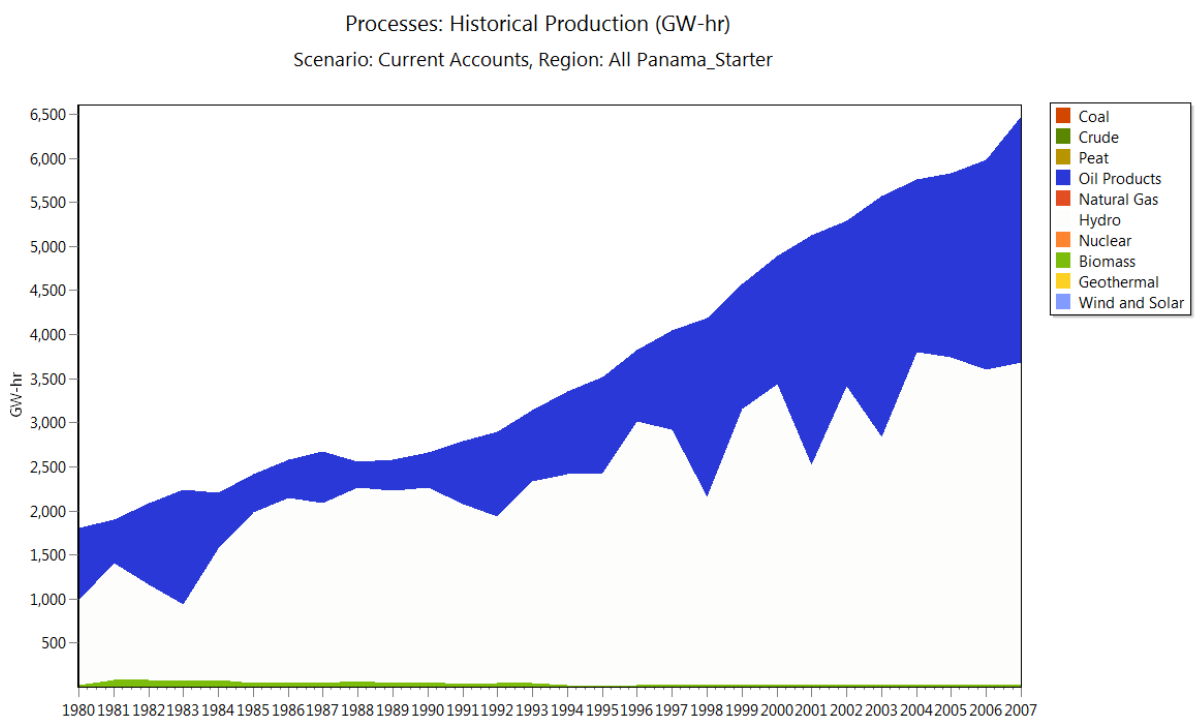

Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All Dominican Republic_Starter
GW-hr
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All El Salvador_Starter
GW-hr
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All Guatemala_Starter
GW-hr
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All Honduras_Starter
GW-hr
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (Thousand GW-hr)
Scenario: Current Accounts, Region: All Mexico_Starter
Thousand GW-hr
260
240
220
200
180
160
140
120
100
80
60
40
20
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar


Processes: Historical Production (GW-hr)
Scenario: Current Accounts, Region: All Panama_Starter
GW-hr
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Coal
Crude
Peat
Oil Products
Natural Gas
Hydro
Nuclear
Biomass
Geothermal
Wind and Solar

Appendix 4: WEAP and LEAP applications in LAC

Table A-6: WEAP Applications Database Summary

Focus of study	Highlights relevant for DWC in WEAP applications	Relation to DWC
Southern Cone-Brazil-Sao Francisco River, SEI (CPWF - Small reservoirs)-Eric Kempt-Benedict		
Management of small multi-purpose reservoir	Considerations for irrigation of some biofuels and pricing of energy in economic scenarios	Small reservoirs don't have high hydropower production potential. However, small hydro is a clean energy source. Being used for irrigation, small reservoirs can have potential for biofuel crops irrigation.
Andean Group-Ecuador-Rio Paute, CCG - Sebastián Vicuna		
Climate impact assessment on watershed that provides 50% of countries' electricity	Climate scenarios indicate increase in hydropower production on the order of 5-40%	If runoff increases with CC, and current infrastructure is sufficient at some specific locations, reservoirs with high hydroelectric production capacity may i) have the potential to increase hydropower production, and ii) have the potential to be operated optimizing extra volume and infrastructure capacity for higher production.
Andean Group-Perú-Rio Santa, SEI-Marisa Escobar		
Model glacier evolution within a CC context	Representation of the 3rd largest hydropower plant in the country. Assessment of potential changes on hydrology, including glacier contributions on water availability for hydropower production.	Baseflow contributed during the dry hemispheric winter season by glaciers can be affected by climate change
Andean Group-Perú-Metropolitan Area of Lima, Universidad Nacional Agraria de La Molina-Cayo Ramos		
Integrated management of water resources for drinking water of Metropolitan Lima	Includes modeling of hydropower systems associated to the water management for the metropolitan area	Hydropower is a main source of electricity for Peru. Changes in hydrology with climate change will affect this source. In recent years natural gas sources have increased, so potentially there may be a trend of increasing natural gas to replace any hydropower production loss.
Andean Group-Perú-Rio Chira-Piura, Universidad Nacional Agraria de La Molina-Cayo Ramos		
Water resources for the expansion of farming (agricultural water demand) due to the incorporation of energy crops for biofuel production (bioethanol).	Under current conditions of water provision, there was not found water to support a projected additional 23,976 ha for sugarcane for bioethanol production. The current supply of water would only be adequate to support an additional 10,000 ha for sugarcane production.	Based on statistics of IEA, biomass energy sources are low with respect to other sources in Peru. However, the trend indicates an increase of this source. Regarding this study, it can be seen that water sources may be limiting for increasing biomass production.
Andean Group-Perú-Colca Siguas, Universidad Nacional Agraria de La Molina-Cayo Ramos		

Focus of study	Highlights relevant for DWC in WEAP applications	Relation to DWC
Availability of water to support water reservoir management for agriculture and energy.	Hydrological balance considering agricultural demand (23,000 ha) and energy demand (400 MW) of the Tarucani, Lluta, and Lluclla hydroelectric plants. Consideration of additional agriculture demands (38,000 ha) and additional energy demands (200 MW).	Applications of WEAP for hydroelectric generation considerations most likely will have to include consideration of other users, such as agriculture.
Andean Group-Perú-Lambayeque, NCAR-David Yates		
Creating a framework for CC adaptation within water resources management.	One of the demans is hydropower and it is represented in the model.	This application of WEAP emphasizes the idea that hydropower demands needs to be considered within the context of other water demands, and that adaptation measures need to be considered across all these demands.
Andean Group-Colombia-Chinchina, Corpocaldas-Carlos Andres Sabas		
Defines from the point of view of integrated water resource management the indices of scarcity using the definition of water supply and demand	This WEAP application focuses only on municipal water demand and supply.	This region is potentially going to be developed for hydropower consequently any energy development consideration have to relate to the existing municipal demands.
Andean Group-Colombia-La Vieja (Rio Barbas, Cestillal, y Consota), Corpocaldas-Carlos Andres Sabas		
Assemble a model to provide a comprehensive framework, for planning and aimed policy analysis for an efficient water resources management	This WEAP application focuses only on municipal water demand and supply.	This region is potentially going to be developed for hydropower consequently any energy development consideration have to relate to the existing municipal demands.
Central America -Dominican Republic-Yaque del Sur, WeGroup-Sebastian Vicuna		
Availability of water resources under a potential scenario (incorporation of energy crops for biofuel production)	Under current conditions of water provision, there is potential for incrementing the energy crops for biofuel production. The implementation of a new reservoir may lead to increase agricultural areas as well as hydroelectricity production.	Based on statistics from IEA there is not hydroelectricity production in Dominican republic and the implementation of a new hydrolectricity facility may be of importance in the context of new energy sources without carbon.
Central America -Mexico-San Juan, SEI-Brian Joyce		
Identification of alternative water development strategies and their environmental implications. Estimated the true cost of water, reflecting opportunity costs, marginal costs, and scarcity costs	This region has great potential for biofuels crops since there is a large irrigation district. However water shortages imply that the biofuel crops chosen will have to be those with low water requirement.	In addition to constrains imposed by other agriculture uses, water shortages will define the type of biofuel crops that can come into the energy portfolio.

Focus of study	Highlights relevant for DWC in WEAP applications	Relation to DWC
Central America -Mexico-Rio Grande/Rio Bravo, UT at Austin-Daene McKinney		
Planning model to enable stakeholders to identify improvements in the management of the system that is feasible and beneficial to stakeholders	Potential increase irrigation is high in both sides of the border. The production of biofuel crops may play an important role as well due to large irrigated areas located through the basin.	Interplay between existing and planned irrigation and hydropower demands
Central America -Guatemala-Rio Naranjo, CCG-Sebastian Vicuna		
Study of climate change with emphasis in adaptation	This region includes a large agriculture area with large areas with biofuel crops	Biofuels production competes with other agriculture crops

Table A-7: LEAP applications database summary

Focus of study	Highlights relevant for DWC in LEAP applications	Relation to DWC	Report
Central America - Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Belice. ECLAC-Julie Lennox, coordinator			
Technical Report on Climate Change Economics	42% of installed electic capacity in central america is from hydro plants, future scenarios consider meeting 50% of identified hydro potential by 2100	Hydropower identified as a key option in mitigation scenarios. However, possible reduction in water availability may alter potential for hydropower development in the order of 33-50% (Maurer et al. 2009)	http://www.eclac.cl/cgi-bin/getProd.asp?xml=%20/publicaciones/xml/5/43925/P43925.xml&xsl=/mexico/tpl/p9f.xsl%20&base=/tpl/top-bottom.xslt, http://www.eclac.cl/publicaciones/xml/5/43925/2011-29-CambioClimatico-RT-L1016web_Cap_8.pdf
Central America -Honduras. Ministry of Natural Resources of Honduras-Mr. Wilfredo César Flores (dgeper@yahoo.com)			
Energy Policy for Honduras: 2008 - 2030	Honduras expects a 50% increase in hydro generation between 2008 and 2030.		http://www.energycommunity.org/documents/Aplicacion%20de%20LEAP%20en%20Honduras,%202010.pdf
Central America -Mexico. World Bank-			
Low Carbon Development for Mexico: scenarios for 2009 - 2030	19% of current electric capacity is from hydro	Includes costs of investment and operation for different technologies in addition to potential emission reductions. Small hydro power is calculated to have a net cost of 9.4 $/ t CO_2e. Includes risks of investing in hydro due to water concession licenses and water availability	English: http://siteresources.worldbank.org/INTLAC/Resources/Medec_final_Oct15_2009_Eng.pdf, Spanish: http://siteresources.worldbank.org/INTLACINSPANISH/Resources/WB_MX_MEDEC_Spanish_Final_Nov_09.pdf
Central America -Dominica. Commonwealth of Dominica- Collin Guiste (collincg@gmail.com) and Claude Davis (claudedavis@gmail.com)			

Focus of study	Highlights relevant for DWC in LEAP applications	Relation to DWC	Report
GHG Mitigation Assessment: 2000 - 2030	Dominica has ~8MW of hydroelectric power stations in operation (p. 2-5). In the future Dominica hopes to further capitalize on hydro resources.	Includes hydroelectric power in GHG mitigation modeling, but future emission-reducing mitigation scenarios do not include hydro-specific mitigation measures.	http://www.energycommunity.org/documents/Dominica2010.pdf
Caribbean-Jamaica, National Meteorological Service of Jamaica-Claude Davis (claudedavis@gmail.com)			
GHG Mitigation Assessment: 2009 - 2035	Hydro was 0.4% of Jamaica's energy supply in 2008, equating to 23.1 MW of installed capacity. Future scenarios include the addition of 47.1 MW of new hydro capacity	Likely a small impact - hydro in Jamaica will continue to be a very small portion of supply.	http://www.energycommunity.org/documents/JamaicaExecSum2010.pdf, http://www.energycommunity.org/documents/JaimaicaFinal2010.pdf, http://www.metservice.gov.jm/ClimateChange-2.asp
Souther Cone-Chile. Program of Environmental Management and Economics, University of Chile-Manuel Díaz R. (mdiazprogea@gmail.com)			
GHG Mitigation Assessment: 2007 - 2030	Both conventional hydro dams and run-of-river installations are prominent in Chile. Future proposed mitigation measures include 1000 MW of installed capacity by 2025		http://www.energycommunity.org/documents/Aplicacion%20de%20LEAP%20en%20Chile,%202010.pdf
Latin America-20 Countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela). SEI-Tory Clark (victoria.clark@sei-us.org)			
Starter National Data Sets	Includes historical hydroelectricity generation and capacity data where relevant	Includes baseline scenarios based on broad regional assumptions. Intended to be used as a starting point for country teams doing national mitigation analyses.	

Appendix 5: Current WEAP Models and LEAP models in LAC

WEAP

Southern Cone:

Brazil: Saõ Francisco River Basin. 2004-2008
Planning and evaluating ensembles of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security: tools and procedures: This project involved working in the Sao Francisco River Basin (Brazil), the Volta River Basin (Ghana), and the Limpopo River Basin (Southern Africa) on planning and evaluation of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security. Tens of thousands of rural communities in Africa and Latin America rely upon water from small multi-purpose reservoirs for their households, livestock, and irrigation schemes. In collaboration with local and regional stakeholders, we are in the process of developing tools for small reservoir analysis and design, improving methods for institutional, financial, and economic analysis, and building confidence in a science-based approach to planning reservoir systems. Building upon this foundation, decision-makers at the basin and national scale, together with local communities, will collaborate to ensure the long-term sustainability of local water supplies and adequate downstream flows. Well-sited, multi-purpose reservoirs making water available to smallholders are vital, allowing smallholders to realize the ultimate goals of increasing the production of food, reducing poverty, ensuring human health, and improving rural livelihoods.

Chile 2008-2009
Limari Basin, Chile: Model developed to estimate climate change impacts on a semi-arid snowmelt dominated basin.

Andean Group:

Ecuador 2009
Paute Basin, Ecuador: Model developed for a basin generating 50% of electricity in the country. Used for climate change impact assessment.

Peru 2008-2009
Water Management Adaptation to the Loss of Glaciers in the Andes of Peru: This project focuses on assessing potential changes in the watersheds of the Andes Mountains in Peru associated with the loss of glaciers due to climate change. An effort is underway to develop a module within WEAP that represents the evolution of glaciers under different future climate scenarios. This module will be used to developed WEAP applications of three Peruvian watersheds: the Santa; the Rimac; and the Mantaro. These applications will be run using climate scenarios developed for the region to investigate the water management implications of the loss of glaciers and possible water management adaptations.

Peru Rimac River
Integrated management of water resources for drinking water of Metropolitan Lima: This study corresponds to the modeling of complex water system, including the basin of the Rimac river, the upper Mantaro, the Chillon river, and the Lurin river and the infrastructure of collection, storage and distribution available. The purpose is to analyze and evaluate the performance of current and future water system with the incorporation of new water sources for water supply that meets the requirement of drinking water for metropolitan Lima, in the short, medium and long term.

Peru Chicama River Basin
Study of surface water resources in the Chicama river basin: This study has been developed to cover the

following objectives 1) simulate the hydrological basin as a whole, 2) define storage locations in the watershed to determine the availability of water in reservoirs and the likely volumes that could be dammed, 3) to implement a water balance model and hydrological simulation that allows to update management purposes, 4) to implement a simulation model which considers transferred volumes from the Santa river that are used for the special projects CHAVIMOCHIC y CHINECAS, and 5) to quantitatively assess the availability and water demand, setting the water balance of the water potential in the basin. The future has been quantified and evaluated considering the availability of water in the basin for four scenarios: a) current scenario, b) present scenario plus groundwater, c) current scenario plus groundwater and the Chavimochic volumes (Transferred volumes from the Santa river), and e) current scenario, groundwater and reservoirs in the watershed.

Peru Chira-Piura System

Assessing the impact of introducing bioenergy crops on the availability of water resources in the Chira-Piura system, Peru: A study evaluated the sustainability of water resources for the expansion of farming (agricultural water demand) due to the incorporation of energy crops for biofuel production (bioethanol) in the Chira Valley. The evaluation was based on four scenarios, which fundamentally varied demand and water availability in the valley of the Chira River. These scenarios were described and assessed with respect to impacts from the standpoint of system reliability, coverage of the application, and system vulnerability. They were: Scenario 1 – with reference to the current situation; Scenario 2 – with increasing areas of sugarcane; Scenario 3 – with increasing areas of sorghum; and Scenario 4 – with increasing areas of sugarcane and of farmers' crops. System simulation and reliability assessment were conducted using the WEAP (Water Evaluation and Planning System) model. The analysis used an integrated approach, looking at both supply of and demand for water. It provided a basis for evaluating the allocation of limited water resources among agricultural, municipal, industrial and environmental uses. Under current conditions of water provision, there was not found to be enough water available to support the introduction of a projected additional 23 976 ha for sugarcane production in the Chira Valley for bioethanol production. The current supply of water would only be adequate to support an additional 10 000 ha for sugarcane production in the valley. The results demonstrated the urgent need for land and water resources management for the Chira and Piura Valleys. In addition, improvement in water productivity (0.7 kg of rice per m3 of water, current situation, and 1.34 per kg of all crops in the valley) would be possible, enabling an increase in food production with the same volume of water and the same cultivated area.

Peru Colca Siguas System

Update study of the Colca Siguas system's water balance for renewal and other: This study evaluates the availability of water in Colca system with the purpose of supporting the water reservoir management. The assessment is based on the hydrological balance of the Colca system considering the agricultural demand of Pampa de Majes (23,000 ha) and Pampas de Siguas (38,000 ha) and the energy demand (400 MW) of the Tarucani, Lluta, and Lluclla hydroelectric plants. The balance is evaluated with the reliability of the system, the coverage of demand and vulnerability of the system. The results indicate that we can serve up to 1.070 Hm3 of agricultural demand, with a reliability of 75 percent. The availability of the Majes Siguas system is 1101.36 Hm3 (107.68 Hm3 Siguas basin, 698.76 Hm3 of the Colca and and 294.92 Hm3 of the Apurimac basin), for agricultural uses and municipal demands. For energy use in the Lluta and Lluclla power plants an annual volume of up to 993.7 Hm3 is available.

Colombia: Cuenca Alta del Rio Chinchina, 2010

A WEAP application was developed to define the indices of scarcity from the definition of water supply and demand, linking this information from implementing the integrated water resource management application in the Chinchina upper river basin. The specific objectives that were achieved were a) establish the water supply and demand, b) analysis of the water balance at the defined control points, c) elaborate a streamflow distribution proposal and actions to take, d) built and run the model, and e) define the management scenarios from population growth and expansion scenarios providing water public services in the study area. The model results are that the system cannot guarantee either the availability of water to meet the municipal growing demand or environmental flows in streams during the different drought periods which is a typical behavior characteristic of the Andean region.

Colombia: Cuenca de los Rios Barbas, Cestillal y Consota. 2010.
A WEAP application was developed to define the integrated water resource management for the Barbas, Cestillal, and Consota river basins. The objective of this application was to assemble a model to provide a comprehensive framework, flexible and easy to use for planning and aimed policy analysis for an efficient water resources management. The model forecasts that the whole system is under pressure and is not able to secure the municipal water demand neither the ecological flows most of the time.

Caribbean:

No applications are available for this region.

Central America et al.:

Dominican Republic, 2007
Haina Basin, Dominican Republic: Model developed for WEAP training workshop session.

Dominican Republic, 2007
Yaque del Sur, Dominican Republic: A WEAP application was developed for the Yaque del Sur River Basin in Dominican Republic to support the Plan Hidrologico Nacional. This application is an integrated assessment for representing the main water demand sites in the basin including agriculture and urban users. Among the infrastructure modeled there is a reservoir for agriculture use and a series of canals that delivered water to the demands sites inside and outside the watershed. A couple of scenarios were modeled, one representing an increment on agriculture water demand due to the increase in irrigation areas, and one representing the implementation of a new reservoir in the basin.

Guatemala, 2007
San Jose and El Naranjo basins, Guatemala: Models developed to estimate climate change vulnerability as part of the NCAP funded project.

Mexico, 2004
Water Planning in Mexico: WEAP was translated into Spanish and used for integrated water resources planning in several river basins in Mexico.

Mexico San Juan River Basin, 1993-1994
Water and Environment in the Rio San Juan: WEAP was used in an integrated water resources assessment of the Rio San Juan basin in Mexico, including the industrial center of Monterey. The study included the development of a supply and demand balance for the watershed, and the identification of alternative water development strategies and their environmental implications. The analysis also estimated the true cost of water in the region, reflecting opportunity costs, marginal costs, and scarcity costs.

Mexico - United States, Rio Grande/Bravo Basin
Physical Assessment Project: The “Physical Assessment” project comprises a consortium of U.S. and Mexican universities, NGOs and governmental agencies to explore water management options for the Rio Grande/Bravo system that respond to the growing pressure on this important resource. The project is creating and utilizing a “whole basin” hydrologic planning model of the shared river system to enable both the public and private water managers and stakeholders to identify the range of improvements in the management of the system that are hydrologically feasible and mutually beneficial to the affected stakeholders throughout the basin. Alternatives that pass this test will be subjected to economic, legal and institutional feasibility analysis in subsequent phases of the project. Alternatives that emerge will represent clear “winners” for future implementation http://www.riogrande.org

LEAP

Southern Cone:

Greenhouse Gases in Chile: Forecasts and Mitigation Options for 2007-2030, 2010
The Program of Environmental Management and Economics at the University of Chile has completed a study "Greenhouse Gas (GHG) Emissions in Chile: Background for the Development of a Regulatory Framework and Evaluation of Reduction Strategies". The study included projections of GHG emissions in Chile from 2007-2030 and evaluations of alternative policy options. The study used LEAP to examine fossil fuel emissions in the transport and energy sectors, and also included an exploration of emissions from industrial processes, land-use change and forestry.

Fundacion Bariloche: Capacity Building, Energy Planning and GHG Mitigation Assessment in Latin America and the Caribbean, 2009
Since the mid 1990s the Fundacion Bariloche (FB) has been helping organizations to apply LEAP as a tool for energy planning and GHG mitigation assessment throughout Latin America and the Caribbean. FB has organized numerous capacity building workshops and conducted many energy and climate mitigation studies for Government agencies in the region. A highlight of these efforts has been the annual workshops held in the city of Bariloche, Argentina, which to date have trained almost 300 professionals from Latin America and the Caribbean about energy planning using LEAP. Some examples of LEAP-related studies conducted by FB include:
• Demand and supply projection for Peru (2001), the Dominican Republic (2003 and 2008), Argentina (2007), Colombia (2007).
• Projections for Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay conducted for OLADE (2005).
• Climate change mitigation assessments for Argentina (2008), for the Electric Utility ENDESA (2008), El Salvador (2009), Nicaragua (2009) and Uruguay (2009).

Prospectiva Energética de América Latina y el Caribe, 2005
This scenario study is a biennial publication of OLADE (the Latin American Energy Agency). It provides a forward-looking overview of energy supply and demand prospects in Latin America and the Caribbean to the year 2018. It includes data on the 26 member countries of OLADE. The study was conducted by OLADE in conjunction with the Bariloche Foundation, Argentina and the Independent University of Mexico and with financial support from the European Commission. LEAP was used as the main modeling framework for the study.

Andean Group:

No applications are available for this region.

Caribbean:

Greenhouse Gas Mitigation Assessment in Jamaica, 2010
The National Meteorological Service of Jamaica presents a greenhouse gas mitigation assessment covering projections of selected GHGs over the period of 2009 to 2035. Guided by Jamaica's National Development plan, Vision 2030, and the National Energy Policy: 2009 - 2030, the team used LEAP to model 3 scenarios: a reference scenario and two mitigation policy scenarios. Vision 2030 includes 4 national goals, 15 national outcomes and over 50 national strategies aimed at putting Jamaica in position to achieve developed country status by the year 2030

Central America et al.:

Energy Policy for Honduras, 2010
The Ministry of Natural Resources and Environment of Honduras has designed an energy policy extending to 2030 which was modeled using LEAP. The analysis included two scenarios, one baseline and one "desired." The main objectives included a reduction in the the use of firewood, decreasing consumption from 42 percent in 2008 to 21 percent in 2030. The "desired" scenario also proposes the introduction of hybrid and electric cars, with the aim of having a more energy efficient transport sector.

MEDEC: México: Estudio sobre la Disminución de Emisiones de Carbono, 2009
Mexico's Special Climate Change Program—the Programa Especial de Cambio Climático (PECC), published in August 2009—sets Mexico's long-term climate change agenda, together with medium-term goals for adaptation and mitigation.

The World Bank recently used LEAP to help create a new study called México: Estudio sobre la Disminución de Emisiones de Carbono (MEDEC). The study is intended to contribute to the implementation of Mexico's long-term climate change agenda. The study, which was conducted by researchers based at the Centro de Investigación en Energía, evaluates the potential for reducing greenhouse gas emissions in Mexico over the next 20 years. It evaluates low-carbon interventions across key emission sectors in Mexico using a common methodology. Based on the interventions evaluated, it develops a low-carbon scenario through 2030.

ECLAC: The Economics of Climate Change For Central American Countries, 2009
The Economic Commission for Latin America and the Caribbean (ECLAC) in Mexico is preparing a study on the economics of climate change for Central American countries. These countries (Panama , Costa Rica , Nicaragua , Honduras , El Salvador , Belize and Guatemala produce less than 0.5 percent of global anthropogenic CO2 emissions. However, they are also especially vulnerable regions to the impacts of climate change. Temperature change, sea level rise, changing rain-fall patterns and other impacts will have an increasingly negative impact on the economies, populations and ecosystems of the region. ECLAC is using LEAP to estimate baseline emissions from Central America's energy sector, and to calculate the benefits of GHG mitigation actions as part of this study.

Costa Rica: Evaluating National Energy Policy Options, 1993
The Latin American Energy Organization (OLADE) and local agencies collaborated with SEI to evaluate the economic and environmental consequences of selected national energy policy options (1993).