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Sustainable Development Opportunities at the Climate, Land, Energy and Water Nexus in Nicaragua

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Abstract

There are strong interconnections between the practices needed to sustainably manage land, energy, and water resources, which become even more pronounced when the many implications of climate change are taken into consideration. An exploration of these resource sectors in Nicaragua, a country at high risk from climate change, shows how their linkages directly impact the opportunities for development available to a rapidly growing economy. In particular, these linkages may shape solutions for sustainably managing agriculture, confronting water scarcity, and promoting local energy resources, which together can provide independence from global market volatility. Here we synthesize the state of climate, land, energy, and water issues in Nicaragua and highlight the potential for integrated resource planning in the country. We focus on three ongoing, sustainable development initiatives as case studies: rain-water harvesting in the Pacific Mountain Corridor, community-scale breadfruit processing in the Caribbean Coast region, and national bioenergy production using sugarcane bagasse.

Introduction

In the face of rapid economic growth, there is a need for all countries to think about how to sustainably manage natural resources and protect biodiversity, while promoting both energy and food security. In the case of small, developing countries like Nicaragua, there is a need to reduce high expenditures on fuel imports as well as to maintain and expand agricultural production in the face of a changing climate and increasing demand. From 1990 to 2010, gross domestic product (GDP) in Nicaragua grew 4.4% annually, while national electricity consumption grew 5.7% per year. Today, over 55% of Nicaragua's export revenue goes towards oil imports, dwarfing investments in education and healthcare (The World Bank 2013b). Protecting domestic food production and expanding domestic energy production can provide a

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critical hedge against global market price fluctuations. At the same time, these goals should be balanced with further engagement in global commerce, which can provide private employment opportunities and government revenue to fund strategic investments in education, job training, health, and infrastructure. Most importantly, in order to reach any of these goals, there is a need to think holistically about how to manage land, energy, and water resources in a way that respects their limitations, the interconnections between them, and the increased stresses on all of them from climate change.

Nicaragua, the largest and least populated country in Central America, makes an excellent case study for cross-sectoral research. It has substantial but threatened land resources, significant but largely untapped renewable energy resources and vast but unevenly distributed water resources. Nicaragua also faces significant projected climate change impacts and has a low adaptive capacity, i.e. a low ability to develop and implement adaptation measures (Harmeling and Eckstein 2013). Its substantial rural population and the continued prominence of agriculture, forestry, and fisheries in the national economy make the country particularly susceptible to climate change. At the same time, these factors also make it easy to perceive the connections between climate, natural resources, people, and economic activities. These clear connections in turn support the search for cross-sectoral solutions.

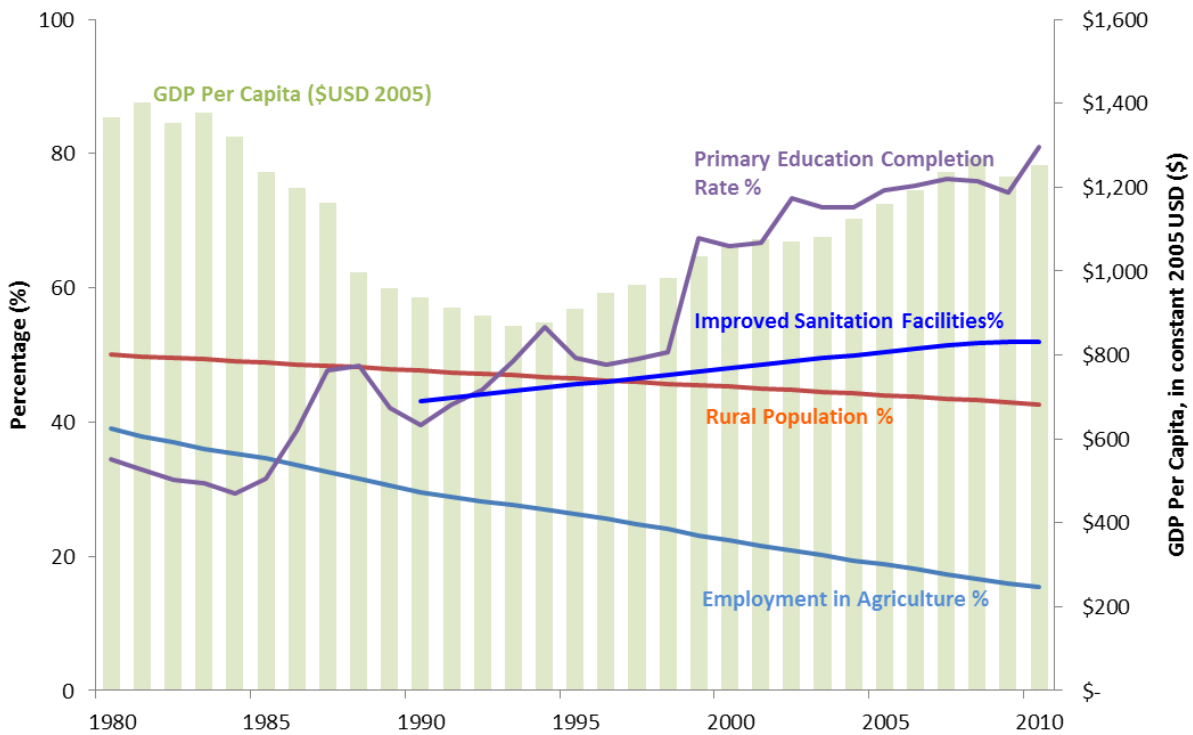
Nicaragua is the second poorest country in the Western Hemisphere, and despite its relatively large agricultural sector, more than 1 million people still suffer from malnutrition (OXFAM 2012). Although it has a challenging history of dictatorship, civil war, trade embargos, and natural disasters, the country's recent stability has encouraged significant investment in free trade, tourism, and renewable energy. Nicaragua is now cited as the second-most attractive country in the hemisphere for renewable energy investment (BID-FOMIN / Bloomberg 2012). Nicaragua has also made significant progress towards meeting Millennium Development Goals related to health, literacy, and access to education and energy (UN-ECLAC 2009). Nevertheless, significant political, governance, capacity, and planning challenges have prevented full maximization of the country's development potential in the context of a population that has more than tripled in the last 50 years (Figure 1).

Agriculture and natural resource extraction have historically formed the backbone of the Nicaraguan economy. Although growth in direct resource extraction and the manufacturing and services sectors has absorbed a large number of the workers who have exited agriculture in the last half-century, agriculture, forestry, and fisheries together still contribute about a third of annual GDP and roughly half of total export revenue (World Bank). According to the Food and Agriculture Organization of the United Nations (FAO), in 2010, direct agricultural production employed roughly 15% of the workforce (FAO-FAOSTAT 2013). It is important to note, however, that this statistic masks a larger number of workers who provide seasonal labor on farms as well as additional employment from timber production, fisheries, agricultural processing industries, and informal enterprises operating from farms. Unlike other Central American countries, Nicaragua still remains largely self-sufficient in staple crop production and has a history of support for small farms (FAO-FAOSTAT 2013; World Bank 2002).

Our study's framework emphasizes the conflicts and opportunities around the climate-land-energy-water (CLEW) nexus. We first describe the land, energy, and water sectors in Nicaragua, outlining key issues and emphasizing cross-sector and climate change impacts. We

then highlight three case studies: breadfruit-based flour production as a community-scale solution to poverty on the Atlantic Coast; rainwater harvesting in the Pacific Mountain Corridor as a means to reduce risk and increase the incomes of small farmers; and energy production from agricultural wastes at the national scale. The goal is to synthesize the state of CLEW issues in Nicaragua and highlight the potential for integrated resource planning.

Figure 1: Trends since 1980 in percentage of the population employed in agriculture (FAO-FAOSTAT 2013), living in rural areas (FAO-FAOSTAT 2013), completing primary education (The World Bank 2013b), and with access to improved sanitation facilities (The World Bank 2013b). Also shown is GDP per capita in 2005 US\$ (The World Bank 2013b).



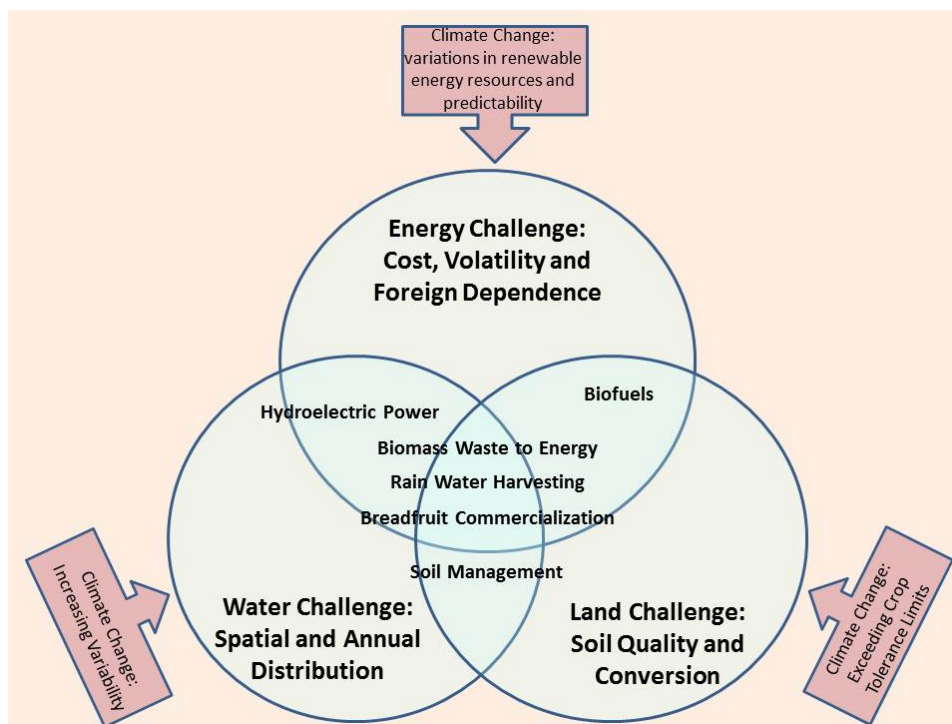
Climate–Land–Energy–Water Nexus

Water resources, energy, and the use of land for food production play a crucial role in societal well-being and are closely linked to all other economic sectors. These three areas pose potential security risks related to inadequacy or lack of access, environmental impacts (both local and global), and reliability of supply, particularly in developing countries (Bazilian et al. 2011). To a large extent, these security issues are related to climatic variables such as temperature, precipitation, wind speed, etc. They may consequently be influenced by impacts from global climate change. These combined pressures can undermine a country’s resilience in the face of shocks, serving to drive social–ecological systems beyond critical thresholds, hence the importance of an integrated analysis lens (Hoff 2011).

Due to the complexity of each individual sector, planning and management rarely takes into account the numerous interrelations between the three sectors. Even when considered, these relations are treated hierarchically, with one sector given priority. Thus, the analysis of the

relationships between water resources, agriculture and land use, and energy are usually carried out from the individual perspective of the policy-maker (Bazilian et al. 2011). In turn, the sectoral bias of the policymaker defines what is given priority in security policies related to climate change. In the presence of direct and indirect impacts across sectors, this can lead to suboptimal resource use and send misleading signals for future planning (Bazilian et al. 2011). Therefore, one of the challenges in assessing the impact of global climate change is to do it from an integrated perspective so as to consider the complex interrelations between different sectors (Lucena, Schaeffer, and Szklo 2010). There is now a growing body of literature that highlights these interdependencies and defines a framework for integrated analysis (Dale, Efroymsen, and Kline 2011; Hoff 2011; Skaggs et al. 2012). These interfaces, and the issues relevant in the Nicaraguan context, are displayed in Figure 2 below.

Figure 2: Schematic showing the interrelationships between the energy, water, and land sectors, along with cross-cutting climate change impacts. Also highlighted are interconnecting issues relevant in the Nicaraguan context.



Agriculture and Land-Use in Nicaragua

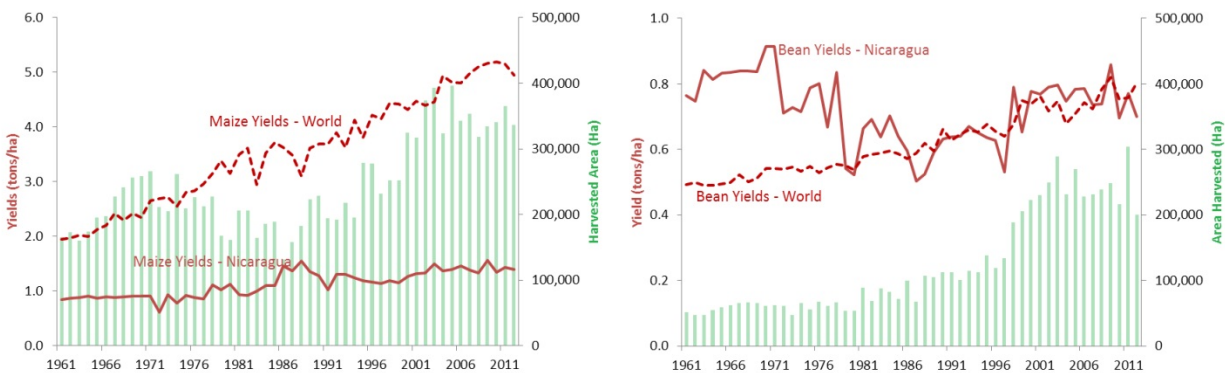
The agricultural economy in Nicaragua can be divided into two main sectors, with some overlap between them. The staple crop sector, which produces rice, maize, and beans, is mostly made up of small, family-run farms. Most staple crop farmers have minimal access to inputs and improved seeds, and their farms are often located in isolated and mountainous areas with poor soils, high depth to groundwater, and limited access to markets. The cash crop sector, on the other hand, produces high-value crops for export. These farms tend to be larger and to lie on flat land with easy access to groundwater for irrigation. Cash crop farmers also have better access to technology, credit, and agricultural extension services. Some of these distinctions have started to blur: 20% of bean production is now exported outside the country, for example. Still,

the cash crop sector continues to provide a large source of export earnings and typically occupies the country's prime farmland.

Nicaragua's key cash crops have historically been bananas, tobacco, sugarcane, and cotton. Today, however, livestock and coffee, produced throughout the country, are the two largest generators of export revenue followed by sugarcane and peanuts (FAO-FAOSTAT 2013). Cash crop production fell severely during the 1980s, when coffee trees and other farm infrastructure were targeted during the civil war. Since then, with the exception of cotton, which has faced global competition from synthetic fibers, most cash crop production has surpassed historic levels. At the same time, new industries, such as peanut production, have grown in importance. The area devoted to livestock has also more than tripled.

Most staple crops are rain-fed—indeed, less than 3% of the country's agricultural land is irrigated (FAO-FAOSTAT 2013)—heightening farmers' vulnerability to climate variability and long-term climate trends. Staple crops are primarily grown for home consumption, although there is some commercial production as well, especially of beans. Seasonal hunger in the country tends to occur in rural areas and follows the seasonal rains.

Figure 3: Nicaraguan maize and bean yields as compared to world averages (FAO-FAOSTAT 2013). Also shown is the growth in harvested area for each crop.



While yields in Nicaragua's cash crop sector have kept pace with world averages, yields for maize have only grown at half the global average rate from 1961 to the present. Bean yields have actually fallen slightly over this same period. Increases in maize and bean production of roughly 300% (in the context of a roughly 200% growth in population since 1960) have mainly been achieved by expanding the area of land under cultivation, as shown in Figure 3, above. In fact, since 1980, permanently cropped land has doubled, and a third of the forest cover has been lost (Figure 4).

Soil erosion and low fertility are major problems in the region, primarily due to deforestation, hill-slope farming, and intensive farming, which has continued for decades without sufficient fertilizer inputs to replace depleted nutrients. The topsoil also tends to be particularly thin and vulnerable to erosion in deforested areas on the Atlantic side of the country. Conservation agriculture strategies, like the quesungual system, which is based on traditional Central American practices (Ayarza et al. 2010), aim to stop slash-and-burn agriculture, prevent soil erosion, and preserve soil moisture and fertility. These strategies include mulching biomass,

maintaining shade trees, intercropping, and implementing other no-tillage and agroforestry practices. The quesungual system, promoted by NGOs and external research institutions, has been used successfully in recent years in some areas of Central America (New Agriculturalist 2009).

Figure 4: Change in forest cover in Nicaragua from 1983 to 2000, with projections to 2050.

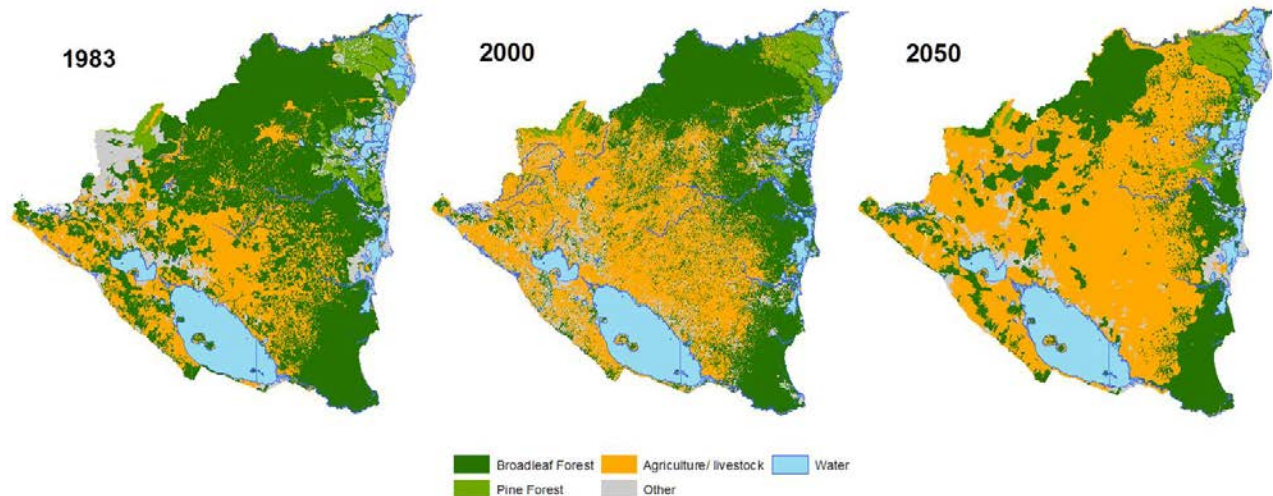


Image courtesy of the Ministerio del Ambiente y los Recursos Naturales, Nicaragua.

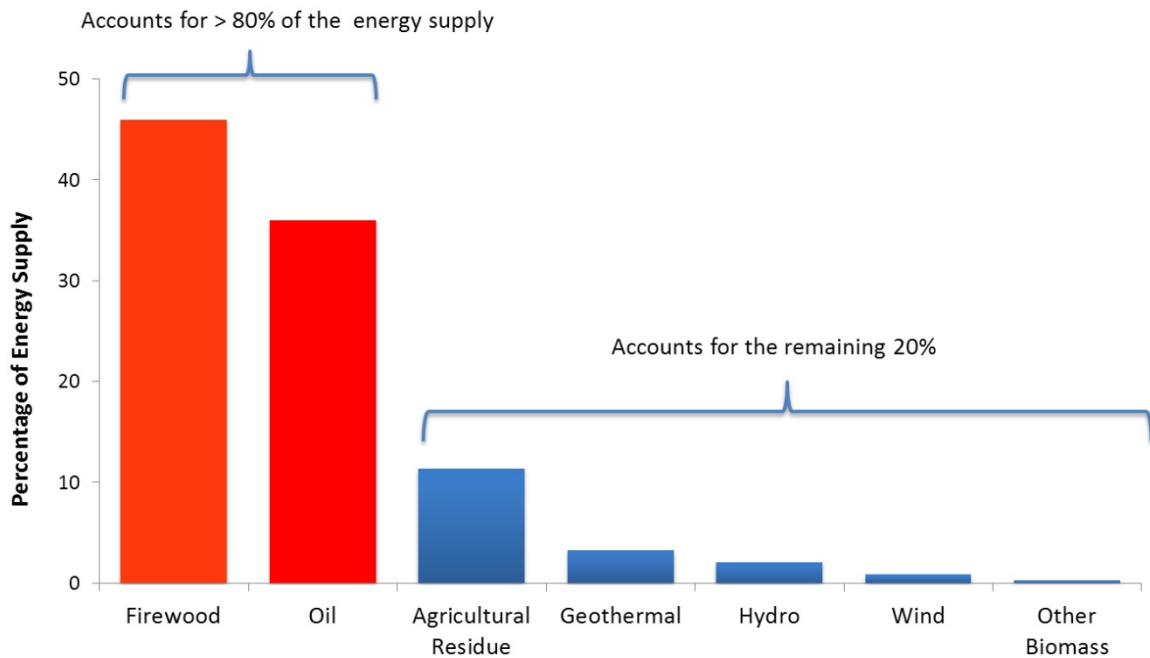
Government actions establishing biosphere reserves such as Bosawás and the autonomous region of the Rama-Kriol territory have helped to arrest deforestation. However, land-use conflicts between indigenous peoples and mestizos, who are expanding the agricultural frontier through farming and livestock production, are still a problem in many parts of the eastern half of the country. In addition, illegal logging has contributed to deforestation, and the national military has even become involved in efforts to halt it (Rogers 2013). Most importantly, in the long-run, efforts to improve agricultural yields for key staple crops can help to reduce pressures to clear new agricultural lands in order to increase production.

Energy in Nicaragua

Firewood and oil are the predominant sources of energy in Nicaragua. In 2011, over 80% of the country's energy came from these two sources (Figure 5), with agricultural residues supplying an additional 10% (MEM 2012c). That same year, residential energy consumption accounted for nearly half of the country's demand (47%), and almost all of that demand (~90%) was met by burning firewood. The remaining half of the demand was made up of transportation (26%); industry, agriculture, and fishing (15%); and commercial and public services and other (12%) (MEM 2012c).

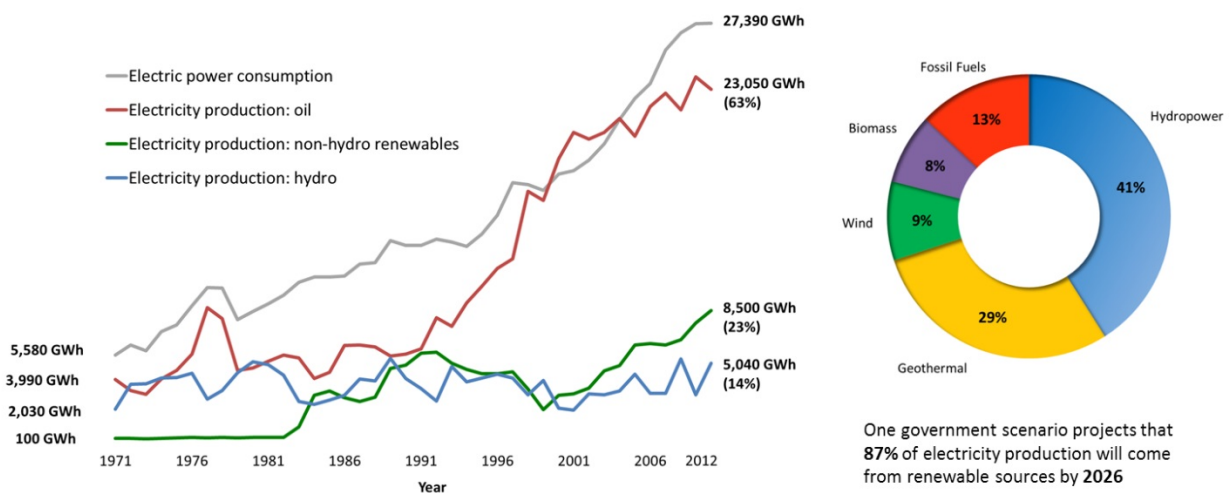
From 1990 to 2010, electricity consumption grew an average of 5.7% per year (The World Bank 2013b), with petroleum-based thermal power plants accounting for 66% of the electricity produced in 2011 (MEM 2012c). This heavily petroleum-based electricity matrix placed a significant burden on the economy, as national expenditures on petroleum represented 55% of total export revenue in 2011 and reached as high as 68% in 2007 (MEM 2012b). Hidden in these

Figure 5: Breakdown of total energy supply in Nicaragua in 2011 (MEM 2012c).



already high figures is the fact that nearly all of Nicaragua’s imported oil currently comes from Venezuela and is heavily subsidized, which represents another long-term strategic risk for the country (MEM 2012b). Rising electricity demand combined with the high cost (and risk) of meeting that demand with oil have led to concerted efforts to expand the role of renewable energy sources in the electricity and overall energy matrices (Figure 6).

Figure 6: Nicaraguan electricity consumption and production from 1970 to 2012 (left) (The World Bank 2013b) and one government scenario for the electricity production mix in 2026 (right) (MEM 2012b). Investments in thermal plants caused bunker-fuel oil production to boom in the early 1990s, but high oil prices have recently encouraged investments in renewable energy.



The electricity sector underwent significant reform in 1998-1999, but the focus was on privatization with less effort directed towards promoting rural electrification or the development of Nicaragua's vast renewable energy potential. However, in the last 10 years, the country has made progress towards universal energy access, achieving a 72% electrification rate in 2011, with a peak electric power demand of 617 MW (MEM 2012a). Progress has also been made in the development of renewable electricity sources, which accounted for 34% of production in 2011 (MEM 2012c). However, structural factors, including a deeply entrenched culture of electricity theft and high system losses (both technical and non-technical) have slowed advances in the sector.

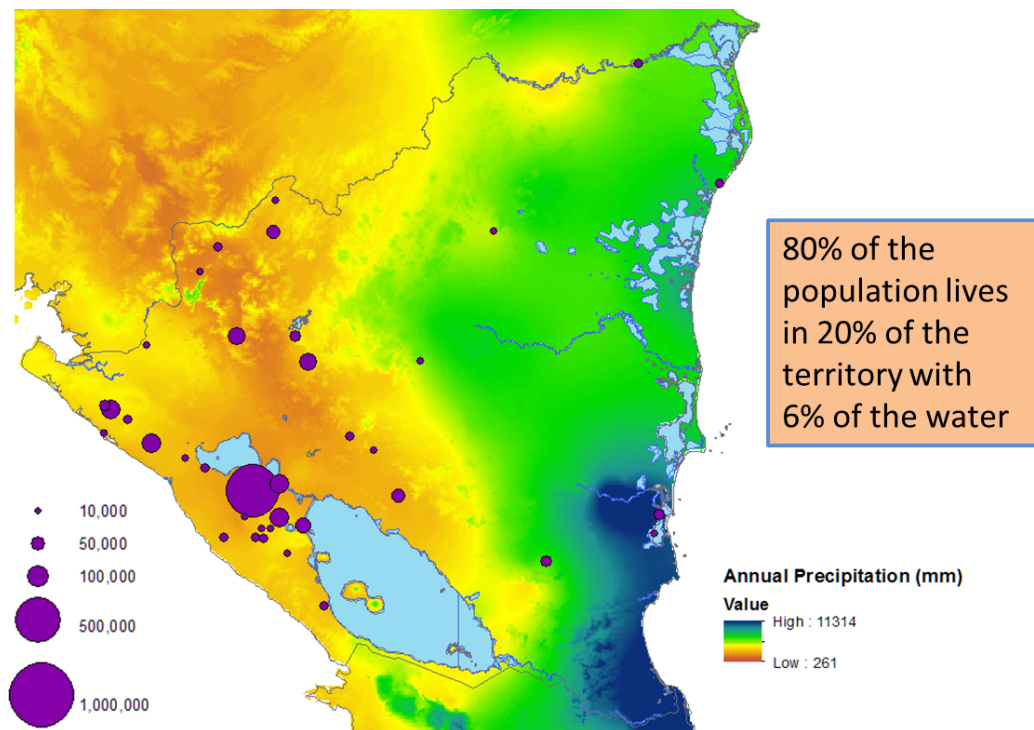
Nicaragua's economically viable renewable energy resource potential is conservatively estimated at 3,000 MW, composed of 1,700 MW hydropower, 1,000 MW geothermal energy, 200 MW wind energy, and 100 MW biomass-based power (Mostert 2007). Nicaragua has a vision of developing these resources to become a regional leader, with one proposed scenario calling for 93% of the electricity matrix to come from renewable sources by 2026 (MEM 2012b). Although promising, this vision does not include offshore wind development on the Pacific Coast or centralized or distributed solar development. Thus far, solar energy has gone largely underutilized except for off-grid energy access deployments. This may change, however, given recent trends towards lower prices in the solar industry.

Plans for integrating renewable energy into the country's economy have also not considered how climate change will affect energy generation. For example, although the Intergovernmental Panel on Climate Change (IPCC) projects that monsoon precipitation will decrease in the coming decades, resulting in increased competition for water resources, the government still plans to use hydropower to supply roughly 40% of all electricity during that same period. While Nicaragua has the potential to generate a large percentage of its energy from renewable sources and has been making progress towards that goal, it is vital that policy-makers take an integrated resources planning approach in order to make smart energy infrastructure investments that meet demand, are cost effective, support broad access, and are resilient to future climate change.

Water in Nicaragua

Nicaragua is one of the most water-rich countries in the world, but the resource is very unevenly distributed in both space and time. Most precipitation falls during a six-month rainy season that lasts from May to November, although the eastern half of the country gets some rainfall throughout the year. Even during the rainy season, many regions on the Pacific Coast and in the mountains (referred to as the Pacific dry corridor throughout Central America) suffer from periodic drought. Since the vast majority of the population lives on the Pacific side, Nicaragua faces a situation in which 80% of the population lives in 20% of the territory with only 6% of the water (Figure 7). Furthermore, existing water sources on the country's western side are under threat. Recent years have seen unsustainable rates of groundwater extraction for commercial agriculture, primarily on the Pacific Coast and in the capital city of Managua. Serious pollution of surface water bodies, primarily due to pesticide use and lack of sanitation facilities, also endangers water supplies.

Figure 7: Annual precipitation in Nicaragua. Also shown are population centers with more than 10,000 people, with the sizes of the dots scaled by total population.



Extreme weather events, principally hurricanes but also flooding and droughts, pose additional risks for Nicaragua. Beyond the impacts on private homes and national infrastructure, extreme events can further increase the risk to agricultural production. For example, in 2010, intense and sustained rainfall wiped out roughly 50% of the bean crop, prompting a ban on exports (MAGFOR 2013; UNAG, 2012). Then, in 2012, a sustained drought saw historic low rainfall in much of the Pacific dry corridor, resulting in massive crop losses, including the lowest bean production since 2001.

The incidence of extreme weather events is projected to increase with climate change, making it critical to plan proactively for agricultural adaptation and disaster management. Small-scale water storage and management solutions hold potential for mitigating drought-related losses by, for example, capturing runoff during the rainy season in mountainous areas (see case study below). More broadly, integrated watershed management (Gregersen, Ffolliott, and Brooks 2007) will be necessary throughout the country in order to maintain soil moisture and control flooding under extreme conditions.

Climate Trends and Projected Changes

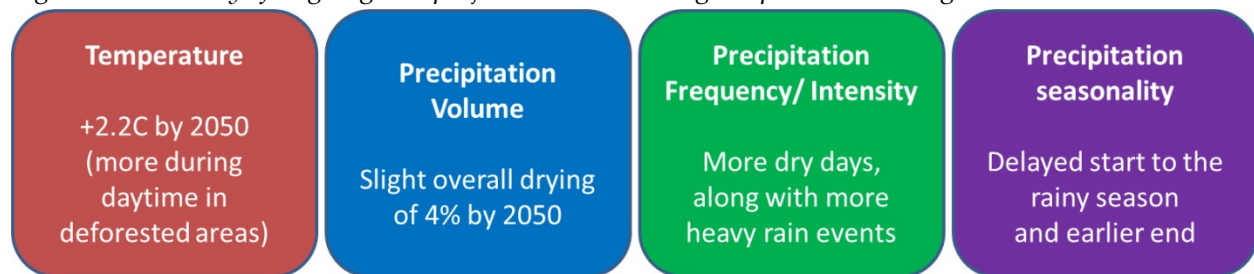
A number of studies of historical climate trends in Nicaragua and Central America have found consistent and significant changes, principally warmer temperatures along with more intense but less frequent rain events (Aguilar et al. 2005; Gourджи et al. in review; The World Bank 2013a). The total volume of annual and seasonal precipitation has also been changing, although trends are difficult to discern given Nicaragua's high interannual climate variability associated with the El Niño Southern Oscillation.

On average, temperatures in Nicaragua have increased by 0.90°C since 1960 according to a United Nations Development Program analysis (McSweeney, New, and Lizcano 2010). However, a more recent analysis with more weather stations shows an increase of up to 1.5°C over the same period in areas along the agricultural frontier (Gourdji et al. in review). That rate is much higher than the global tropical average and is undoubtedly influenced by deforestation.

Warmer temperatures, longer gaps between rain events, and an increased proportion of runoff due to heavy rainfall and reduced forest cover have all contributed to increased reports of agricultural drought in the country. Farmers have also noted changes in the timing and length of the rainy season, which make it more difficult to forecast the optimal times to plant and harvest (which is partly supported by observational evidence (Gourdji et al. in review).). Finally, increased rainfall intensity can worsen erosion, damage crops, and cause flooding, damaging ecosystems and infrastructure. In fact, the increasing intensity of extreme weather events is among the most critical climate risks in the region, according to a World Bank study, and Nicaragua and Honduras are the two countries in Central America most affected by these weather events (The World Bank 2013a).

Climate projections based on a suite of global climate models (Schmidt et al. 2012) indicate that through to 2050 Nicaragua will experience a slight decrease in annual rainfall (about 4%) and continued temperature increases (average increase of 2.2°C across models relative to the 1960–1990 baseline). These projections indicate that the annual maximum temperature will increase from 31.7°C to 34.1°C, and the minimum yearly temperature will increase from 18.9°C to 20.8°C. There will also be slightly less precipitation during the rainy season, principally in June and July during the *primera*, or the first agricultural production season. Even if the changes in total volume of precipitation are relatively minor, rainfall will continue to increase in intensity, and the risk of hurricanes is also likely to increase (Grinsted, Moore, and Jevrejeva 2013).

Figure 8: Summary of ongoing and projected climate change impacts in Nicaragua.



Climate Change Impacts and CLEW Nexus in Nicaragua

The Global Climate Risk Index 2013 (Harmeling and Eckstein, 2013), an analysis of the extent to which countries have been affected by the impacts of weather-related events (storms, floods, heat waves etc.), confirms that less-developed countries are generally more affected than industrialized countries, both in terms of being exposed to increased risks and being less resilient to climate hazards. According to this analysis, Central America is particularly vulnerable to the negative impacts of extreme climatic events, with Honduras and Nicaragua both in the top three most vulnerable countries in the world for the period 1992–2011.

Climate change exerts much of its impact through the water cycle. In addition to extreme storm events, much of the impact on Nicaragua will be felt through shifts in the timing and distribution (both in terms of geography and volume) of rainfall throughout the country. Increasing rainfall intensity and longer drought periods, combined with temperature increases, may reduce suitable growing areas and put downward pressure on yields for some of Nicaragua's key staple and cash crops (Gourdji et al. in prep.; Laderach et al. 2011). More intense flooding and drought episodes may also lead to more frequent and heavy crop losses. In particular, Nicaragua's staple crops (beans and maize), as well as key cash crops like coffee (the number one export commodity by market value from 2009 to 2011 (FAO-FAOSTAT 2013), are likely to see reductions in suitability and increased climatic stresses on yields due to soil moisture deficits and heat impacts. In addition, the incidence of plant diseases may increase with warming temperatures, especially when accompanied by wet conditions. A recent example is the current epidemic of rust affecting up to half of all coffee trees in Central America (Bregaglio, Donatelli, and Confalonieri 2013; Palencia and Cota 2013).

The low and stagnant yields for Nicaragua's staple crops, due in part to climate trends in the region but also due to declining soil fertility, have increased pressures to expand land area under cultivation in order to increase production. Inadequate yield and increased livestock production are the primary drivers of the expansion of the agricultural frontier and the resultant loss of forest cover. Deforestation itself has a number of negative feedback effects on climate and natural resources. First, a deforested landscape reduces soil infiltration, thereby increasing runoff and the risk of flooding and reducing soil moisture. Higher runoff and lack of tree cover in turn increases the rate of soil erosion, contributing to problems of low soil fertility in the region. Finally, deforestation influences regional climate change, principally through higher daytime temperatures due to reduced latent and increased sensible heating as well as reduced cloudiness and local drying during parts of the rainy season (Ray 2013).

The ability to store and manage water is critical in reducing farmers' exposure to climate variability and drought risk (see rainwater harvesting case study below). Poor soil management, along with deforestation, has reduced the soil's natural capacity for water retention, increasing the need for soil conservation and moisture retention practices along with small-scale water capture, retention, and distribution systems. Altogether, there is a need for soil restoration, watershed management, and proactive planning for projected climate impacts in the agricultural sector.

Changes in climatic conditions may also impact energy production and consumption. Although all energy sources are subject to climate influences to a greater or lesser extent, renewable sources are especially vulnerable to climate change, as their supply is directly linked to the climate (Schaeffer et al. 2012). For example, changes in rainfall patterns may compromise hydroelectric generation and the production of energy crops and biofuels. These energy sources can also be impacted by higher temperatures through greater evaporation in reservoirs and variations in climatic suitability for energy crops. Other renewable sources may also be impacted by changes in climate. Changes in cloud cover, ocean temperature, and land temperature may cause significant impacts on wind patterns and hence wind power potential, especially given that wind power is proportional to the cube of wind speed (so a doubling of the wind speed produces eight times the power). Similarly, increased cloudiness can impact both biomass production of energy crops and reduce solar radiation for thermal and

photovoltaic energy capture, although the trend is currently towards fewer rainy days and more radiation in the country. Although renewable sources are important tools in the effort to mitigate global climate change, they may become more vulnerable to the impacts of the very phenomenon they seek to avoid due to their heavy dependence on weather conditions (Schaeffer et al. 2013).

However, non-renewable energy may also be impacted by climate change. As pointed out by Schaeffer et al. (2012), climate change can exacerbate risks of extreme events—such as hurricanes, flooding, etc.—which can damage energy distribution infrastructure. Also, energy conversion technologies such as thermal power plants may have their efficiency and other operational parameters influenced by ambient temperature and water availability (Sathaye et al. 2013; Schaeffer et al. 2012).

It is expected that projected changes in water supply will have strong effects on hydropower production in some regions of Nicaragua and Central America (Parry et al. 2007). Most micro-hydro projects in Nicaragua are run-of-the-river and depend on precipitation that can vary from 200 cm per meter squared to zero. Because of the six-month dry season, most projects yield a yearly capacity factor of about 50% (Marandin et al. 2013). While hydropower represented 11.6% of total electricity production in 2011 (MEM 2012c), the government is planning for it to make up a 40% share by 2026 (MEM 2012b). Climate change poses risks to this production by changing runoff patterns in watersheds with hydro plants. For run-of-the-river micro-hydro plants with no water storage capacity, shifts in the timing and intensity of rainfall will drive changes in the amount and timing of electricity delivery, which may be suboptimal for grid demand or local consumption patterns. This holds even if total rainfall does not change significantly. For larger hydro plants with reservoirs, geographic shifts in total rainfall could have a significant impact on power production at critical times, as well as on total energy production throughout the year.

Finally, sea-level rise in coastal areas may have broad intersectoral implications for fresh water access, energy infrastructure, and agriculture.

Current Integrated and Sustainable Development Efforts

In the following discussion, we highlight three integrated, sustainable development initiatives underway in Nicaragua that are strategically positioned at the heart of the CLEW nexus. Each represents an opportunity (along with challenges) for broad-based development that respects the interrelationships between land, energy, water resources, and climate.

Rainwater Harvesting Systems for Agricultural Resilience

Efforts to arrest deforestation and improve farmers' incomes primarily focus on increasing intensification of existing farms through higher input use, the expansion of irrigation systems, technical extension services, weather insurance, and low-cost access to credit. Key to many of these initiatives is the ability to store and manage water, which is critical in reducing farmers' exposure to climate variability and drought risk. Many small subsistence farmers experience high interannual variability in rainfall, while suffering from high rates of rural poverty and seasonal hunger. Either too much or too little rainfall throughout the growing season can

destroy crops or severely reduce final yields. In some regions, crop loss in a given year can be up to 50% of the sown area (MAGFOR 2013).

Small-scale water capture and storage systems can supply supplemental irrigation to reduce losses during the traditional growing seasons while also helping farmers to increase their incomes by growing a third crop in the dry season. In addition, sufficient soil moisture helps crops to cope with higher air temperatures through transpirational cooling (Lobell et al. 2011). Depth to groundwater is high in many of the mountainous regions under cultivation in Nicaragua, and no cost-effective groundwater irrigation methods have been developed for these areas. Instead, rainwater harvesting systems provide the potential to capture runoff during the rainy season and store it in naturally occurring depressions in the land's surface.

The implementation of rainwater harvesting systems requires technical analysis of reservoir location, water transport and distribution, system maintenance and operation, economic considerations, and government support. In addition, well-functioning input markets are required for reservoir construction and maintenance, which can potentially help to generate employment in rural areas. A well-designed system would need no additional energy inputs, although these systems may hold the potential for small-scale energy generation in more advanced versions of the projects. The Latin American Fund for Irrigated Rice (FLAR) and the International Center for Tropical Agriculture (CIAT) have a successful 14 micro-dam pilot project in Nicaragua and are making ongoing efforts to demonstrate success, train farmers, and build demand (Figure 9).

Figure 9: Victor Beltrán, a small commercial farmer in the department of Madriz, and his rainwater harvesting reservoir built with the technical and financial assistance of the Fondo Latinoamericano del Arroz de Riego (FLAR), the town of Somoto, and other institutional partners.



Photo by Neil Palmer, International Center for Tropical Agriculture (CIAT).

Breadfruit Flour for Economic Development and Food Security

One solution to food security, local trade, and economic development on the relatively isolated Caribbean side of Nicaragua may lie in the overlooked subsistence crop, breadfruit. A common household tree in the region, the breadfruit tree can produce 200 fruit per year or six tons per hectare per year, a higher yield rate than corn, wheat, or rice. High in energy, fiber, and vitamins, it can supplement imported rice and potatoes, be processed to partially substitute for imported wheat flour, or be ground and dried for poultry and pig feed (Ragone, 2011). Its peak harvest takes place from June to September, which overlaps with the normal “lean” season for basic grains in the country. Currently, however, much of the fruit is lost, as it spoils within 48 hours of harvest if untreated (George 2007). The key barriers to capitalizing on the breadfruit opportunity in this region are aggregation, processing, and distribution, which must all be done in a timely, cost-effective manner. The general lack of civil infrastructure in the region combined with the rapid spoilage time make these challenges significant.

The Nicaraguan government is working in partnership with the UN Food and Agriculture Organization to support family farms. On the Caribbean Coast their Nicaribe program includes delivering 6,000 breadfruit trees to nearly 300 families in the Southern Atlantic Autonomous Region. The trees are being cultivated by the Foundation for the Autonomy and Development of the Atlantic Coast of Nicaragua (FADCANIC), a nonprofit agro-forestry and education organization in the region (Figure 10). FADCANIC is further investigating the processing and market potential of the breadfruit harvest. While breadfruit is currently present as a backyard tree, planted orchards may be required to ensure a consistent, high quality supply of fruit for

Figure 10: Breadfruit tree at the Wawashang Agroforestry Center, Nicaragua.



Photo by Mathias Craig.

processing. This represents a long-term investment as the trees take three to five years to start producing meaningfully, but then produce for decades with minimal labor, fertilizer, or other inputs. Orchards will require irrigation systems to keep young trees moist during their vulnerable first two years. Renewable energy sources such as solar can provide the power to run the irrigation systems. Finally, while the Caribbean Coast climate is currently very suitable for breadfruit growth, given the long-term nature of the tree production cycle, future climate conditions need to be considered. For example, if dry periods increase in duration, the need for irrigation may also increase.

Bioenergy Production Using Sugarcane Bagasse

Bioenergy production from sugarcane has the potential to dramatically influence both the liquid fuel and electricity markets in Nicaragua. Sugarcane is one of the country's main export crops, with an annual production of 6 million metric tons, a figure that is expected to increase in the future (GAIN 2012) (Figure 11). The Nicaraguan government recently signed a regional agreement that set out goals for the blending of biofuels with fossil fuels by 2020 (Latin American Energy Organization and United Nations Industrial Development Organization 2011), opening the door for sugarcane-based fuel to offset oil imports. To date, however, local ethanol production remains low. Thus far, Ingenio San Antonio (ISA), the country's main sugarcane mill, is the only Nicaraguan company that has ventured into ethanol production.

Figure 11: Nicaraguan sugarcane is used to produce sugar, rum, and biofuels.



Photo by Lâl Marandin.

Rather than using sugarcane directly for ethanol blending, it may make more sense to use bagasse, a waste product generated during sugarcane processing. Bagasse has great potential as a feedstock for electric power generation given its high calorific content (17.9 MJ/kg) and yield (0.3:1 wet bagasse to crushed sugarcane). Another key benefit of using bagasse as a biofuel energy feedstock is that it is a waste product and does not require additional resources such as land or fertilizer.

Sugarcane is principally grown on the Pacific Coast and is processed at four main mills close to population centers: ISA, Monte Rosa, Benjamín Zeledón, and Montelimar. In fact, in 1999, ISA established a 60 MW bagasse cogeneration unit, which meets mill demand and sells the remaining 24 MW to the national grid. In 2002, Monte Rosa established another plant with a 60 MW capacity, operating at 74% efficiency and producing 357 kWh per ton of bagasse (Latin American Energy Organization and United Nations Industrial Development Organization 2011). Thus, the use of biomass waste products displaces internal thermal and electric demand on-site and can be a net contributor to the national electricity grid.

Furthermore, sugarcane has a six-month growing cycle from November to May, so that bagasse availability is highest at the time when rainfall, and thus hydropower production, is low and electricity demand is high. During sugarcane off-peak season, other biomass waste sources such as timber waste can be used to continue to supply electricity to the grid.

While sugarcane bagasse can provide net energy and economic benefits, there are major concerns over water contamination from pesticide use on sugarcane plantations and high incidence of kidney disease in farm workers (Torres et al. 2010), perhaps due to dehydration and heat stress, although the causes have not yet been conclusively identified. These issues remain to be resolved within the sugarcane industry.

Conclusions

Nicaragua is the second-poorest country in the Western Hemisphere and has recently emerged from a challenging history of revolutions, wars, and natural disasters to a more peaceful and stable position, poised for growth. Rich in natural resources, Nicaragua has the largest standing primary forests and renewable energy potential in Central America and one of the highest total and per capita water resources in the world. Given that the country remains highly agricultural, with the livestock, coffee, and sugarcane industries playing a key role in the economy, it is imperative that Nicaragua maintain its natural resource base when planning for future economic growth. If the government, private sector, and NGOs manage the CLEW interrelationships well, they will preserve and enhance natural capital, leading to more private investment, especially in agriculture and tourism-related ventures. Prudent management of natural resources could also open the door for a transition away from agriculture and natural resource extraction in future economic growth strategies, if the country so chooses.

Recent decades have seen substantial environmental degradation due to deforestation, soil erosion, unsustainable groundwater withdrawals, and pesticide pollution. However, integrated resource planning, which takes into account the interrelationship of climate, land, energy, and water may offer a different way forward. Climate change heightens the imperative to manage these natural resource sectors holistically, given that impacts cut across them. Projected changes

in storm intensity, temperatures, and rainfall patterns should be taken into account for any long-term planning and infrastructure development in the country.

Nicaragua has already experienced significant climate trends in recent decades, especially warmer daytime temperatures, more intense rainfall, longer gaps between rain events, and declining soil moisture. Many of these trends have been exacerbated by high rates of deforestation, which can affect regional climate. In fact, the rate of daytime temperature rise in Nicaragua is roughly double the global average in the tropics, which can in large part be attributed to the loss of forest cover. Climate change projections for the coming decades show continuing temperature increases, slight decreases in total precipitation, a more intense hydrological cycle, a higher risk of flooding and droughts, and a rise in the intensity and frequency of extreme storm events such as hurricanes. Climate change may also impact renewable energy generation and water supplies due to reduced groundwater recharge from more intense storms with a higher proportion of runoff.

A changing climate will affect the suitability of traditional crops as well as increase risks to rain-fed agriculture from longer droughts and more intense storms. Pressures from climate change may also hasten the exit of small farmers from agriculture. The farmers who remain will require climate adaptation support, while those who leave the farm will need re-training and a social safety net. Efforts to improve agricultural yields on existing land may also reduce pressure to clear additional land to increase production.

In conclusion, Nicaragua is a country with a large natural resource base that has made impressive economic progress after many decades of instability. Continued growth that could lift large segments of the population out of poverty needs to protect and preserve the natural resource base upon which future growth and stability depends. Policy-makers should increasingly see the climate, land, energy, and water sectors as interrelated, and proactively plan with these interconnections in mind. In particular, it is critical that they consider the likely impacts of climate change before locking in place infrastructure that could take many decades to change.

Nicaragua's opportunities for sustainable development within a CLEW nexus framework are sufficiently large that the country could well become an example of wise natural resource use for Latin America and the world.

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