Energy security in the Amazon

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1. Introduction

The provision of universalized and affordable energy services[1] in a secure and environmentally sound manner is essential to achieve sustainable development. Access to modern energy sources allow for higher mobility, increased productivity, greater access to information and education, poverty alleviation, increased leisure time, among other benefits. Energy is thus a central element in fostering development and in increasing quality of life. In fact, the large progress observed in the last century is intimately related to the unprecedented rise in energy use, particularly electricity and hydrocarbons. Such progress came along with technological innovation in energy extraction, transport and transformation, as well as increased capacity, flexibility and efficiency of the conversion of final energy sources into energy services. This, in turn, improved production processes and satisfied various needs of the population.

The welfare gained with the availability of various energy services goes beyond that of merely improving quality of life, going up to the point in which modern society is now dependent on such services. Energy is not only key for development, but is also a maintainer of a series of benefits which are now essential for its very functioning. Not only greater use of modern energy carriers leads to general improvements in quality of life, but the lifestyle of modern society is supported by the direct and indirect benefits of energy use. As such, great concern arises in terms of securing the provision of modern energy carriers and, as a consequence, of modern energy services.

Energy security usually refers to minimizing the risk of disrupting the supply of energy services, including, in this context, issues related to the affordability of these services. Therefore, it is defined in this chapter as guaranteeing the supply of modern energy services at affordable prices. According to Moreira and Esparta (2006), energy security relies on several factors, including supply constraints, transport or transmission constraints, cost and financial limitations, natural disasters, poor planning and logistics, poor management or maintenance, market shifts, technological changes, acts of nature, sabotage or international market fluctuations. Energy security is thus intimately related to the vulnerability of an energy system to any combination of these factors and vulnerability is usually associated with – but not limited to, as will be discussed below – the non-diversification of energy sources and suppliers.

Analyses of energy security often emphasize the dependence on energy imports, especially oil[2]. In general, the dependence of oil-importing countries is a main

[1] Energy services are the actual services obtained from the use (conversion) of final energy sources. Energy services are 'heat', 'lighting', 'mobility', etc., rather than energy carriers, like electricity, gasoline, firewood and so on.

[2] Several studies have used different approaches for empirically and systematically analyzing the vulnerability of oil-importing countries (e.g., Kendell, 1998; Bielecki, 2002; Vivoda, 2009). Bhattacharyya and Blake (2010), conversely, analyzed the vulnerability of oil-exporting countries.

subject of analysis in the geopolitics of oil from the perspective of political science (Babusiaux and Bauquis, 2007). Other studies consider the difficulties to obtain cheap energy and the dependence on oil from OPEC countries (Du et al., 2010), estimates of military costs in the Persian Gulf (Dellucchi and Murphi, 2008), and possible ways to reduce the dependence on oil imports (Greene, 2010, Vivoda, 2009).

However, according to Percebois (2007), vulnerability is not limited to dependence, since a system may be vulnerable but not dependent on foreign imports and *vice-versa*. Importing energy from a diversified range of suppliers using state- of-the art final end use technologies may be less vulnerable than relying on a concentrated mix of inefficiently and domestically produced energy. In fact, a country or region may be vulnerable for having an economy that is over-dependent on the exports of energy sources, for example oil (Bhattacharyya and Blake, 2010).

Energy security, thus, is associated with physical, technical and economic aspects. The first, for instance, refers to the energy endowments of a country or region, quantitatively, qualitatively and in terms of its diversification. On the technical side, energy security refers to the robustness of a system against disruptions in the supply of energy caused by failures in infrastructure (e.g. transmission networks, pipelines, power plants, refineries, etc.). It should be noted that this relates to the provision of energy services which can be obtained from a range of different final energy sources. Furthermore, the extent to which an economic structure depends on specific energy services to produce wealth is also a vulnerability, which leads to the third facet of energy security.

The economic aspect of energy security is linked with both physical and technical aspects, for it relates to the definition of energy reserves and the ability to recover them, costs, investment capacity, market conditions, price volatility, economic structure and to institutional and regulatory frameworks. Although some physical (e.g. natural availability of resources) and technical (e.g. accidents or natural disasters) features of energy security do not directly depend on economic conditions, the capacity to invest and maintain energy infrastructure is rooted in economics. This is specifically relevant for developing countries, in which, according to Moreira and Esparta (2006), economic aspects are the main risks to energy security (e.g. uneconomical pricing, lack of access to capital for investing in energy infrastructure, high share of energy imports bill on the balance of payments, etc.). Finally, political and institutional uncertainties can also be relevant risks to energy security in some regions.

In the quest for a sustainable global energy system, besides securing supply climate change is an essential element in energy planning and currently plays a central role in energy policy. The need to reduce emissions of greenhouse gases

(GHG) is a major driving force in the development of the global energy system. The transition to a low-carbon energy system could shift local energy vulnerabilities from issues related to, for example, import/export dependence on fossil fuels to vulnerabilities associated with the low level of predictability of the availability of renewable energy sources. Also, changes in local climate may cause impacts on energy systems which might, in turn, affect the security of supply (Schaeffer et al., 2012). Therefore, there are potential trade-offs and synergies between energy security and climate change policies which will depend both on local circumstances as well on the long-term strategies adopted (Turton and Barreto, 2006). This study will analyze the case for the Amazonian regions.

The objective of this chapter is to assess the scientific evidence base on the consequences of the impacts of a changing climate and of climate response policies on energy security in the Amazonian regions. More specifically, it aims at understanding how climate change exacerbates traditional threats and generates new risks to energy security in the region and beyond. Finally, this chapter will provide a set of policy recommendations aimed at multi-sectoral decision makers.

2. What are the interactions between Amazonian ecosystem services and security?

Energy security is closely related to provisioning and regulating ecosystem services, as defined by the Millennium Ecosystem Assessment (MEA, 2006). Energy resources concern the amount of primary energy available, which can be an existing fossil resources stock or a continuous flow of kinetic or biomass energy. Climate change can affect energy systems through changes in the provision of ecosystem services, as will be discussed in this section. Ecosystem services related to aesthetic, cultural, spiritual and religious values, especially in local indigenous communities, may be threatened by the increasing exploitation of energy sources in Amazonian regions. Also, there are some ways in which climate change may cause problems to energy security which are not associated with the ecosystem services provided by the local environment. This is the case, for example, of extreme weather events, which may become more frequent and intense as a result of global warming (IPCC, 2007).

According to the most recent climate projections, global climate change is expected to have considerable impacts on natural and human systems, especially on the reliability of the energy system. However, despite being one of the key systems for social and economic development, energy systems often do not incorporate the effects of future variations in climate in their planning and operation. An overview of Table 1 shows that many impacts/sectors have not, to our knowledge, been formally explored.

Table 1: Summary of Physical Climate Change Impacts on Energy Systems

Energy Sources	Climate Variables	Related Impacts	Vulnerable Countries in the Amazonian Region
Natural Gas (thermoelectric power generation)	air/water temperature	cooling water quantity and quality	Bolivia, Brazil and Peru
	air/water temperature, wind and humidity	cooling efficiency and turbine operational efficiency	
	extreme weather events	erosion in surface mining	
Petroleum	extreme weather events, air/water temperature, flooding	disruptions of on-shore extraction	Bolivia, Brazil, Colombia, Ecuador and Peru
	extreme weather events, flooding, air temperature	disruptions of production transfer and transport	
	extreme weather events	disruption of import operations	
	flooding, extreme weather events and air/water temperature	downing of refineries	
		cooling water quantity and quality in oil refineries	
Biomass	air temperature, precipitation, humidity	availability and distribution of land with suitable edaphoclimatic conditions (agricultural zoning)	Brazil, Ecuador and Peru
	Diffuse solar radiation	Increased diffuse solar radiation may favour some oilseeds, such as soybean and sunflower (Souza, 2009, 2010, 2011)	

	extreme weather events	desertification	
	carbon dioxide levels	bioenergy crop yield	
Hydropower	air temperature, precipitation, extreme weather events	total and seasonal water availability (inflow to plant's reservoirs)	Bolivia, Brazil, Colombia, Ecuador and Peru
		Increased erosion and accumulation of sediments in reservoirs.	
		dry spells	
		changes in hydropower system operation	
		evaporation from reservoirs	

Source: Based on Schaeffer et al (2012)

Fossil fuels endowments refer to a stock, which, once discovered, can be economically feasible to extract (reserves) or not (contingent resources). The endowments of a country/region are fundamental in the planning of the energy system's expansion and the security of energy supply. Fossil energy supply technologies, though relatively less susceptible to variations in environmental conditions, are not totally free from the eventual impacts from climate change. Although climate change does not impact the actual amount of existing oil and natural gas resources, it can affect our knowledge about these resources and the access to them. Furthermore, climate policy will have effects on the relative prices of energy, which will influence the optimal choice of resources and technologies. Environmental policies at the local and global level, thus, are a key driver in energy planning. As such, energy provisioning ecosystem service can be impacted by climate change through both physical and economic access to these resources.

Energy resources need to be converted into final energy sources in order to meet specific energy services. Energy conversion technologies that convert primary energy into final energy may be susceptible to changes in climate conditions. For example, changing climate may affect thermal electricity production by affecting the generation cycle efficiency and the availability and quality of cooling water for thermal power plants (CCSP, 2007). The thermal generation technologies that could be particularly affected in Amazonian Regions are natural gas and biomass residues.

Other energy related provisioning services relevant to the Amazon region is the supply of energy from biomass (i.e. firewood or biofuels). This ecosystem service relates to both an existing stock and a reproductive capacity. Indeed, in some Amazonian localities fuelwood is the only energy source for cooking services; besides, since it has no price,[3] it does not pose any challenge related to economic affordability (Ramirez, 2006). In addition, based on a case study for the Peruvian Amazon, Coomes and Burt (1999) found that peasant charcoal production - often cast as a rapacious, wasteful use of the forest - can provide significant cash income for forest peoples and high returns per hectare, particularly when integrated into swidden-fallow agroforestry systems, hence without causing notable forest destruction. This can also help in alleviating poverty.

As for the second, the reproductive capacity of biocrops depends on the edaphoclimatic conditions which can alter with climate change. As pointed out by Lucena et al. (2009b) and Schaeffer et al. (2012), changes in climate variables, like temperature, rainfall, as well as CO_2 levels directly affects many key factors of agriculture, like crop yield, agricultural distribution zones, incidence of pests and the availability of land suitable for growing some crops. The main impacts are losses in biocrops productivity or even eventual losses in suitable areas for growing energy crops due to alterations in local climate.

Other renewable energy endowments refer to a flux of energy which is closely related to climate conditions. In this case, the effects of climate change are given through changes in regulating services, such as climate and water regulation. The energy source most affected from changes in regulating services for Amazonian regions is electricity from hydropower. Hydropower generation depends directly on the availability of water resources and, therefore, on the hydrological cycle, which is affected by changes in the levels and seasonal variability of climate variables like temperature and precipitation, as well as the vegetation cover. Natural climate variability already has great influence on the planning and operations of hydropower systems. These systems are built based on historical records of climatic patterns, which determine the amount and variability of energy produced over daily or seasonal fluctuations. Changing climate conditions may affect the operation of the existing hydropower system and even compromise the viability of new entrepreneurships. In fact, global climate change can add a significant amount of uncertainty to the already uncertain operation of hydropower systems.

[3] It is worth mentioning that a fuel wood may have no price, but it still has a cost related to the time and effort for collecting it.

Although impacts on energy supply and demand[4] are the most evident, climate change can also affect other aspects of the energy sector, such as energy transportation. Increased frequency and intensity of extreme weather events caused by global warming creates and exacerbates risks to energy transport infrastructure and, consequently, to the continuous supply of energy. The transmission and transfer of energy extends for thousands of kilometers and can therefore be exposed to a series of weather and climate events, such as landslides and floods, causing disruptions. Impacts thus, also include issues related to energy infrastructure siting and their exposure to extreme weather events.

Lastly, impacts of climate change on energy systems may also have indirect effects on other economic/natural systems. Likewise, impacts on the latter can affect the supply and demand for energy. In the case of the Amazonia regions, some cross-sector security issues related to climate change are: competition for water resources (in electricity generation, oil refining and irrigation of energy crops), land competition (for biofuels production) and the provision of health services. It is important to stress that existing and correlated threats may be exacerbated by changes in climatic patterns, including frequency and severity of extreme weather events.

Water and energy security are deeply interlinked. Although hydropower production is the most intuitive connection between water and energy issues, water – both in terms of quantity and quality – is essential for many energy production, transport and conversion activities. For instance, thermal electricity generation, oil extraction and refining, and growing energy crops all require large amounts of water. Waterways are essential for energy transportation and for bringing fuels to isolated communities in Amazonian regions. To illustrate the connection between water and energy in Amazonia, according to projections made using the mean results of 20 GCMs[5] for the IPCC A2 emission scenario (Mulligan et al., 2012), runoff at two large hydropower plants in the Brazilian Amazonia (Belo Monte – 11,233MW, and Tucuruí – 8,370MW) may decrease from 8-10% in 2050. The same projections, on the other hand, point out an increase of 1% in the Paute Molino and Mazar hydropower plants in Ecuador (total of 1,260MW) and 8% in the Mantaro hydropower plant in Peru (798MW).

As for biofuels, there is little scientific evidence to state that liquid biofuels production is either a relevant cause for deforestation or a driving force behind land-use competition in the Amazon. For instance, in the case of deforestation, Walter et al. (2011) indicate that the expansion of sugarcane areas in Mato

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[4] Although not discussed here, as many studies point out, climate change can have significant effects on the demand for energy, especially for ambient cooling in the case of the tropical countries (Schaeffer et al., 2012). In Amazonia Region this is restricted to major cities; however, futures research should be done to carefully assess those impacts in Amazonia.

[5] GCM – General Circulation Models. These models are three dimension representations of the Earth's atmosphere and its interactions with the oceans, surface and biosphere. They are used to project the effects of changes in the chemical composition of the atmosphere on climate variables, such as temperature, precipitation, etc.

Grosso has mostly displaced pasturelands and other crops (mostly soybean), and that the hypothesis of sugarcane directly causing deforestation is highly improbable. Additionally, Gauder et al (2011) conclude based on future scenarios that competition for land between sugarcane production and major food crops is not evident. Nevertheless, for biodiesel, some authors indicate that the expansion of soybean and cattle pasture has resulted in large-scale deforestation of the Amazon rainforest (Barona et al., 2009, Fearnside, 2009, Morton et al., 2006). However, as of today, there is not enough evidence to indicate that biodiesel production was a significant driver for this deforestation, or a driver for land use competition, since only 7% of the soybean production in Brazil was used to produce biodiesel in 2010 (Miyaki et al., 2012). However there are other effects that must be explored, such as Indirect Land Use Change (Nassar et al., 2010) and Indirect Land Cost Increases (Rathmann et al., 2010), which may pose some threats to forest areas in Amazonia through second-order effects.

Finally, energy security is closely related to health security, especially for Amazonian regions. Health services require reliable electricity supply, which as discussed in this chapter, may be an issue for isolated communities. Also, rural populations depend on fuel for accessing health facilities and services. Health care is one of the many co-benefits that modern energy services bring to development and poverty alleviation. It is worth stressing that traditional firewood stoves not only have low conversion efficiency, but also emit large amounts of toxic elements. There is overwhelming evidence that indoor air pollution is a major cause of acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD) and lung cancer (Sampson et al 2003; Smith et al 2000; Smith 1993). As an alternative to this traditional kind of cooking in developing countries today new designs of improved stoves and bio fuels are available (Legros et al., 2011; Maes and Verbist, 2012).

Figure 1 summarizes the interactions between ecosystem services in the Amazonian regions and energy security discussed in this section.

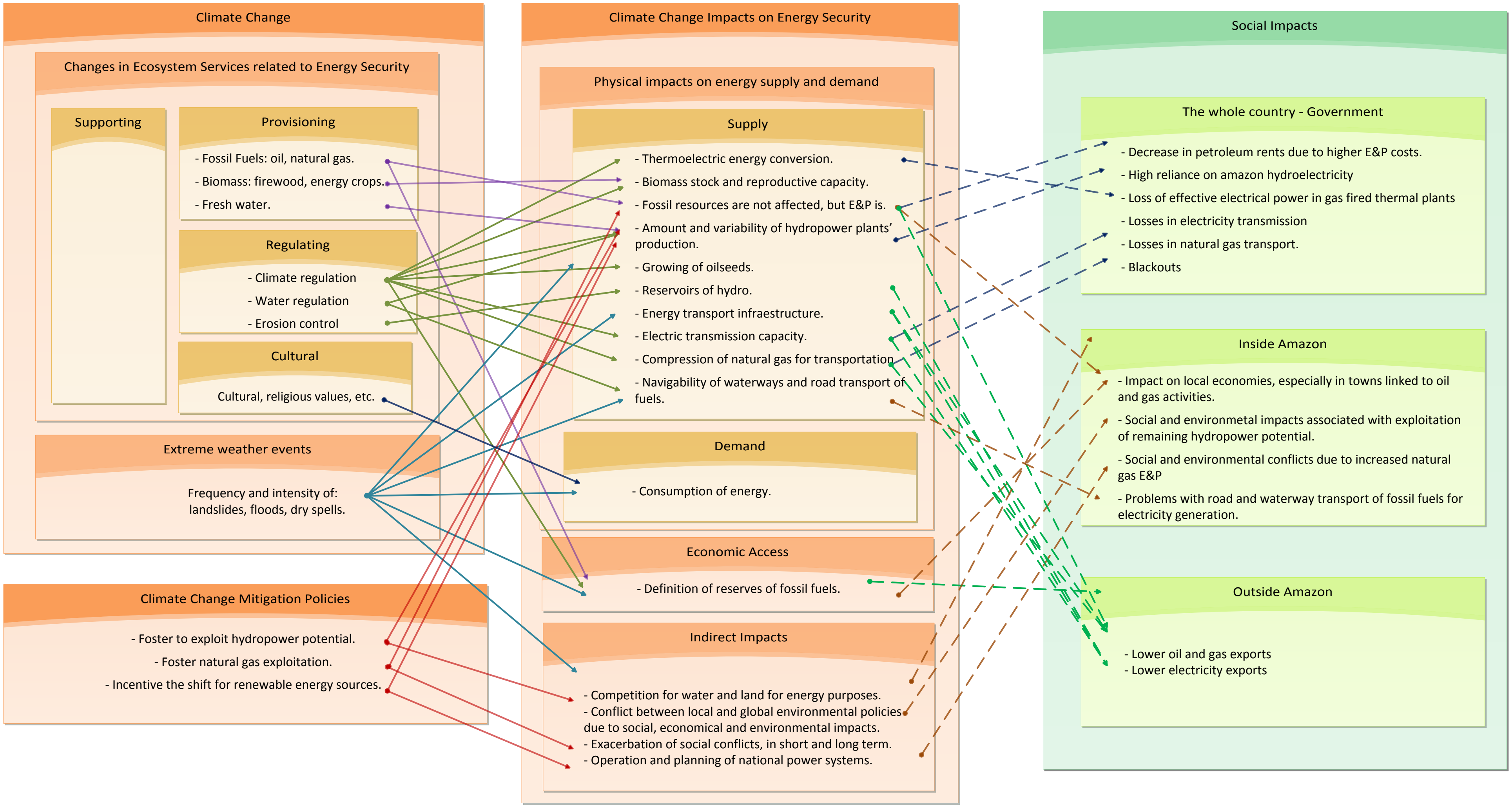

Figure 1: Summary of the interactions between ecosystem services in the Amazonian Regions and energy security

3. What are the existing security threats, through impacts on ecosystem services, to security?

In order to fulfil the objective of assessing the scientific evidence base on the impacts of climate change on energy security, firstly a characterization of the energy supply chains in Amazonian regions is conducted. This puts the potential threats into the context of existing energy resources and infrastructure in the region. It uses the Greater Amazonia political concept defined by Eva and Huber (2005) as the definition of the Amazonian regions. For this purpose energy information at the sub-national level[6] has been taken as the more disaggregated unit to compose the Amazonian region.

Bolivia

The Amazonia of Bolivia belongs to the physiographic region called *Región de los Llanos*. It is the second producer of hydrocarbons (mainly natural gas) in the country, after the Sub-Andean region. In this region are located the fields of Sabalo and San Alberto, that in 2010 represented 33.9% and 25.8% of total production of natural gas in the country (YPFB,2012) .

The Amazonian departments of Cochabamba and Santa Cruz produced around 24.4% (3.5 billion cubic meter of natural gas per year) of total natural gas in the country in 2010. In 2010, 70% of natural gas produced was exported to Brazil, 13% to Argentina and only 17% was traded domestically (MHE, 2010).

Primary liquid hydrocarbons production in Bolivia are strongly tied to liquids of natural gas production and consequently to the production of natural gas. Hence, Cochabamba and Santa Cruz accounted together for around 27% of liquid hydrocarbons production (4.2 million barrels of oil, condensates of natural gas and natural gasoline). Furthermore, the three major oil fields in Bolivia (Paloma, Surubí, Surubí Noroeste) are located in the Amazonian department of Cochabamba, resulting in a production of 1.1 million barrels of oil barrels in 2010.

Exploitation of hydropower in Bolivia is lower than in other Andean countries. Nevertheless, 96% of the energy produced in hydroelectric plants (2070 GWh in 2010 (CNDC, 2012), was located in the Amazonian Region of Bolivia, mainly in the departments of La Paz and Cochabamba.

Nearly 90% of electricity from thermal power generation of the national grid (3512 GWh in 2010) was produced by natural gas-fired thermal plants in the more developed departments of the Bolivian Amazonia (La Paz, Cochabamba and Santa Cruz). However, in the less developed departments, such as Pando and Beni, there are several isolated systems that use diesel for generation.

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[6] In Brazil is named “states”; in Peru “regions”; in Ecuador “provinces”, in Colombia and Bolivia “departments”.

All four refineries in Bolivia are located in the Amazonian departments (3 in Santa Cruz, 1 in Cochabamba). Gasoline is the most produced carburant (5.47 million barrels per day), followed by diesel oil (3.97 million barrels per day). Jet Fuel and Kerosene are also produced in both departments on a smaller scale. LGP production from refineries (82 kt in 2010) is lower than from natural gas processing plants (252 kt in 2010).

The Amazonian departments of Bolivia are responsible for the majority of energy consumption in Bolivia (in order of importance: Santa Cruz, La Paz, Cochabamba, Beni and Pando). Diesel is the most consumed fuel in Bolivian Amazonia, with 2.8 million liters per day (77% of the country), followed by gasoline, with 2.2 million liters per day (82% of the country). Amazonian departments are responsible for 0.78% of LGP consumption in the country and 80% of natural gas (exclusively in the main cities of La Paz, Santa Cruz and Cochabamba) (MHE, 2011) .

Brazil

Amazonas is the only state in the Brazilian Amazon that produces oil and natural gas. Crude oil production in this state barely represents 2% of Brazil's total crude oil production, while natural gas corresponds to 17% of the country's production. The main oil stream is called Urucu, which is a very light sweet crude oil (48.5° API) extracted from the Solimões sedimentary basin. In 2010 Urucu crude reached 2 million cubic meters, while Amazonas state also produced 3.8 billion cubic meters of associated natural gas and 49 million of cubic meters of non-associated gas.

The only installed refinery in the Brazilian Amazon – REMAN – is located in Manaus, the capital of the State of Amazonas. This refinery's utilization factor hovers around 96%, which is quite high but can be explained by the refinery's relatively simple scheme to process a single stream of high-quality crude. It is one of the oldest in the country (operating since 1956) with a current capacity of 46,000 barrels per day – thus, it is also one of the smallest refineries in Brazil. The products of REMAN are mainly used to supply demand for local oil products.

In 2010 diesel and heavy fuel oil represented 70% of oil products sales in the North region, while gasoline was only 19% (IBP, 2012). While total sales of diesel oil in Brazil were 49.2 million m^3, in Pará and Amazonas the sales were 1.6 and 1.2 million m^3 of diesel, respectively (ANP, 2011). Brazilian Amazonia relies heavily on diesel oil for transportation and electricity production in isolated places.

Close to Manaus, in the Municipality of Coari, there are three installed natural gas processing plants: Urucu I, II and III. These plants operate at an average utilization factor of 99% and have an accumulated capacity of 9.7 million cubic meters per day. In 2010, Urucu plants processed 3.5 billion cubic meters of natural gas, outputting 3.3 billion cubic meters of dry gas and 847 thousand cubic meters of LGP. This represented 20% of Brazilian total LPG production.

In terms of solar energy, Northern Amazonia presents the highest levels of diffuse radiation, mainly in the Amazonas river estuary. This is due to the large haziness in the region, deriving from the Intertropical Convergence Zone (ICZ) (Matos et al., 2011). The average daily global and tilt solar radiation in Brazilian Amazonia hovers between 4.55 – 4.90 kWh/m^2 and 4.60-5.60 kWh/m^2, respectively. Solar radiation directly influences biomass growth.

Three types of biomass are used for energy purposes in the Brazilian Amazon (Cunha da Costa, 2004): a) charcoal for the steel and pig iron industry and for power plants; b) liquid biofuels for transportation and electricity generation; c) biomass waste from biofuel production. The first is associated with the use of energy crops and the deforestation of native forest to produce charcoal for the iron and steel industries (De Abreu, 2004). The second is associated with the great potential for the cultivation of palm oil and soybeans, which are the raw materials with the greatest potential for biodiesel and *oil in natura* production. Biodiesel from palm oil in Pará represents 95% of national production (Queiroz et al., 2012). There are also extensive areas covered with native palm trees, notably *buriti* and *babacu* with a representative potential for biodiesel production (Andrade et al., 2011; van Els et al., 2012). There is a small production of ethanol (4% of national production) in the Brazilian Amazon, except in the states of Roraima and Amapá.

Until 2010 Brazilian Amazonia had 12.5 GW of operating hydroelectric capacity and 3.7 GW in construction. Actually, Brazilian Amazonia is a net exporter of electricity to the rest of the country. In 2010, using the interconnected Brazilian grid, the northern region exported a total of 4,369 GWh. This net amount comes from the difference between the exportation to Northeast region (12,054 GWh) and the importation from Southeast/Midwest regions (7,684 GWh). On the other hand, such large hydroelectric power plants in Brazilian Amazonian have been criticized for supplying electric intensive industries located within Amazonian limits as well as large consumption centers in regions far from Amazonian borders. The energy which is currently locally produced is restricted to big urban centers, neglecting thousands of people who live in remote rural communities.

Brazilian Amazonia is served by four types of electric power systems: the Brazilian interconnected power system (national grid), isolated systems, generation in individual decentralized systems, and decentralized mini grids generation in isolated communities. The latter are not registered by ANEEL[7] (van Els et al., 2012). The isolated systems, most of which are installed in the

[7] Brazilian power sector regulatory agency.

Amazonian region, consists of 300 electrically isolated distribution networks and supplies electricity to 4% of Brazilians. The electricity generation cost of the isolated systems is very high due to the high price of fossil fuels, which should also be added to fuel transportation and distribution logistics costs (Cunha da Costa, 2004). The service is also expensive due to the inefficient operation of Long hours Low load Generators.

Colombia

The Colombian Amazonia is the second largest oil producer region in the country after the Llanos, on the border with Venezuela, providing around 23% of the total oil produced in the country. Two areas concentrate E&P efforts in Colombian Amazonia: the Rubiales Fields, which is the largest producer field in Colombia (average of 123,582 barrels of heavy oil per day in 2010, representing around 16% of national production) which is located in the Meta department in the frontier of "Greater Amazonia"; and the Putumayo department, bordering with Ecuador, with several fields which produced on average 35,635 barrels per day in 2010 (around 5% of national production), mostly of medium oil.

Natural gas production in the Colombian Amazonia is insignificant. This resource is produced mainly in the Guajira and Casanare departments, which are in the Caribbean sea coastal region and the Llanos region, respectively. No sugar cane is produced for energy purposes in the Colombian Amazonian region and the sugar cane ethanol plants are located in Rio Cauca Valley in the Pacific sea coast region. Production of biodiesel also occurs outside of the Amazonian region.

There are no hydropower plants operating in Colombian Amazonia. This energy resource is well exploited in the Andean Region, mostly in the Antioquía Department, which has an effective capacity of near 3.7 GW.

Secondary energy production in Colombian Amazonia is limited to the supply of local demand. However, in the case of hydrocarbons, oil products are imported from Barrancabermeja, the largest refinery in the country located in the Andean Region (MINMINAS, 2012) . There is only one refinery in the Amazonian Region of Colombia, which is located in the Putumayo department: the Orito Refinery, with a capacity of 2,800 barrels per day, producing mainly gasoline, kerosene, diesel and fuel oil. In 2010, this refinery operated with the small utilization factor of 62%.

The Colombian Amazon power system is located within the Not Interconnected Zones (NIZ)[8]. Energy services in these zones are characterized by low coverage,

[8] According to Law 143, 1994and Law 855, 2003, NIZ are defined as those that have no access to electricity services through the national interconnected electric system (SIN) whose interconnection is not generally financially viable, because of economies of scale.

reduced number of hours of service, poor service, high technical losses, high prices, defaults in payments and low income customers (ZAPATA, 2001). According to IPSE (2011), the NIZ comprises 66% of national territory, 91 municipalities, 118,000 users and 118 MW of installed capacity, mainly of diesel gensets. In 2008, the Colombian Amazonian Region had an installed capacity of 49 MW (SSPD, 2012) mostly of diesel gensets ranging from 6 kW to - 3,390 kW, many of them owned and operated by local municipalities. The city of Leticia, located in the frontiers of Colombia, Brazil and Peru, the so-called *Tres Fronteras*, has the highest installed capacity in the Colombian Amazonia (14.7 MW in 2008).

Therefore, diesel is the main fuel consumed in the Amazonian Region of Colombia, 77% of which is consumed in the Department of Meta. This fuel is used in medium weight road vehicles, tugboats (between 400 and 3,000 horsepower (SENA, 2007)) and in isolated electricity generation systems.

Without taking into account the department of Meta, gasoline consumption overcomes diesel consumption by at least a two-fold factor in the Colombian Amazonia. In addition to consumption in the vehicle fleet, there is the gasoline consumption in outboard motors boats for fluvial transport in Amazonian rivers.

There is no public information on fuel oil and LGP consumption by departments in Colombia. However, since there is no reported electricity generation in isolated systems based on fuel oil or relevant industry that could consume this fuel, its consumption in Colombian Amazonia is assumed to be insignificant. For LGP there is only one storage terminal in the Amazonian departments of Colombia, located in the Apiay municipality of the department of Meta (with a delivery of 8.2 million gallons in 2005, representing only 2.5% of the total delivery of LGP in the country (SSDP, 2006)). However, this municipality is located out of the Greater Amazonia frontier. According to the Quality of Life National Survey 0f 2008, 81% of the households of the Orinoquía-Amazonia region uses LGP for cooking purposes, while firewood represents just 3%.

Ecuador

About 99% of Ecuadorian oil production comes from the Amazonian Provinces of Sucumbios, Orellana and Pastaza. Currently Ecuador produces about 500,000 bpd of crude oil, from which about 164,000 bpd is produced by the State-owned Company Petroecuador. The main crude oil streams are “Oriente” oil (26° API) and “Napo” oil (19° API).

In the northern Ecuadorian Amazon are located the Amazonas Refinery and the Sushufindi Processing Unit of natural gas. The refinery has been operating since 1987 and as of today has a total processing capacity of 20,000 bpd. The final products are extra gasoline, diesel-1, jet fuel, diesel-2 and fuel oil residues for auto consumption. The gas processing plant has been operating since 1984 and as of today has a total processing capacity of 25 million cubic feet. The utilization factor of the refinery is very high, reaching on average 99%, while the natural gas processing unit has a very low utilization factor, reaching on average 46%.

Hydroelectric generation is also concentrated in the Ecuadorian Amazon. According to CONELEC (2012), 83% of current national hydroelectric capacity is mainly constituted by six big plants. Five of them are located in the Amazon watershed, with a total installed capacity of 1,720 MW. The largest hydroelectric plant in the Amazon watershed under operation is Paute Molino (1,100 MW). There are also some hydroelectric plants under construction: Coca-Codo Sinclair (1,500 MW), Del Sitanisagua (115 MW), Quijos (50 MW) and Sopladora (487 MW).

Ecuadorian Amazon Provinces have an electric power service coverage of 91% in urban areas and 71% in rural areas, which represents approximately 31,500 families without electric service. In urban areas the electricity supply comes from the national grid, except for Sucumbios and Orellana Provinces that have an isolated grid based in thermoelectric plants. In the Northern region of Ecuadorian Amazonia, a large number of medium size thermal power plants generate the electricity required by the petroleum production facilities. These are self-producer power plants.

Between 1997 and 2008 the fund for rural electrification (FERUM) installed a total capacity of 5.2 MW in the country. Approximately 70% of this power was installed in the Amazon Region using solar photovoltaic technology. This program contributes to reducing the lack of electricity supply in isolated areas of Amazonia, providing an alternative for electricity generation with renewable sources.

Peru

The Amazonia of Peru is the main producer region of hydrocarbons, providing around 73% of the total oil and liquids of natural gas and 96% of the natural gas produced in the country. The exploration and production (E&P) of oil and gas in the Peruvian Amazonian region is concentrated in two areas: the northern region of Loreto, which produced 11.14 million barrels of heavy oil in 2010 (42% of total production of oil in Peru) and the Camisea Project which is located in the Cusco region near the Urubamba River and is by far the country's largest natural gas producer. In 2010, Camisea's lote 56 and lote 88 produced 234,315 million cubic feet (92% of natural gas produced in the country). In the same year, 72% of natural gas was used for domestic consumption and 28% was exported as liquefied natural gas (LNG) to markets such as the United States, Spain, Brazil and Mexico.

Sugar cane fields are not significant and are used to produce ethylic alcohol for non-energetic uses. However, there are initiatives to promote the production of biofuels on 1,040,000 deforested hectares using low scale plants (SNV, 2007).

Secondary energy production in the Peruvian Amazonia is much lower than that of primary sources, since the main transformation centers are located near the coast. There are four refineries located in Peruvian Amazonia, all limited to primary distillation (two in Loreto and the others in Ucayali and Amazonas). There is only one natural gas processing plant that produces LPG from natural gas of Aguaytia wells. Natural gas from Camisea is processed at the coast of Peru, in Pisco.

Hydropower in the Amazon basin is not well exploited (less than 1% of its hydraulic potential[9]). Nevertheless, the largest hydro plant in Peru, "Central Hidroeléctrica del Mantaro", with an installed capacity of 798 MW is located in Huancavelica and uses water from the Mantaro river after being impounded in Tablachaca Dam. This project responds to 61% of the electricity produced in the Amazon of Peru and 15% of the total production of electricity in the country.

In the San Martin region, a high density forest area, is located the only plant that produces biodiesel from palm oil, with around 12,000 hectares and a production capacity of 200 tons of biodiesel per year.

In Peruvian Amazonia there are isolated systems that use fuel oil (those with higher capacities, mainly in cities) and diesel in small electricity generation sets (gensets). Diesel is also used intensively in transport. Biomass is an important energy source for Peruvian Amazonian communities, providing firewood for cooking and heating. The production and use of firewood in Peru is sensitive to LPG prices, this being used mainly in the residential sector. Local consumption of natural gas is for electricity generation in the Aguaytia thermal plant, as there is currently no natural gas distribution network in the Peruvian Amazon.

Energy integration among Amazonian regions

Energy trade between countries inside Amazonia is not relevant when compared to international-national trade among the analyzed countries (e.g. interconnection Colombia-Ecuador, Peru-Ecuador and the gas pipeline interconnection Bolivia-Brazil). For instance, at the Leticia-Colombia border, diesel, jet fuel and fuel oil are imported from Iquitos-Peru by aircraft (MINMINAS, 2012). Another interesting case is the city of Tabatinga at the

[9] It is related to the potential energy contained on water (theoretical potential) that could be used to produce electricity through the use of the gravitational force of water falling and/or water flowing driving water turbines and generator. Electricity production depends on the water flow and on the difference in height between the source and the water's outflow. Not all the hydraulic potential is available for electricity production, from this gross potential there is a quantity that could not be used because it belongs to protected areas for example.

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Brazilian border, where fuel is bought in the nearby city of Leticia across the Colombian border (Silva, 2006). For the case of electricity, the interconnection between Brazil-Venezuela through a 780 km transmission line of 230/400 kVa with a capacity of 200 MW allows the isolated city of Boa Vista to import power from the Venezuelan national grid. Furthermore, there are some initiatives of energy integration that involves the Amazonia Region such as the "Peru-Brazil Energy Agreement", aimed at developing studies to assess the potential of energy integration, evaluate hydropower projects for exporting electricity from Peru to Brazil, and assess the implementation of electric interconnections. Around 6,000 MW of hydropower capacity related to the Peru-Brazil Energy Agreement is planned in the Peruvian Amazon. However, there are significant environmental concerns about the impacts to ecosystems and indigenous communities which could be the main barrier for developing the projects related to this agreement (Gamboa and Cueto, 2012).

4. How does climate change exacerbate these threats and generate new threats to security?

Climate change impacts on energy security could affect energy systems in direct and indirect ways. Natural disasters caused by climate change could directly affect the production of primary energy and also the final energy supply infrastructure (oil pipelines, natural gas pipelines, electric transmission lines and distribution lines, etc.). Also extreme climatic events could affect the provision of final energy. This is the case for problems in waterway transportation, caused by dry periods, which affect diesel oil and gasoline supply. It is also the case for floods, caused by increased rain, which affects terrestrial transportation of oil products. A discussion of how the direct and indirect impacts of climate change can exacerbate energy security threats in the specific context of Amazonian regions is conducted below. Initially primary energy production (provisioning services) is analyzed; then, energy conversion and transport are investigated. Finally, an evaluation of the most important climate change induced threats to energy security is made.

Impacts on Energy Production

Strengthened and more frequent extreme weather events resulting from climate change could affect E&P in Amazonian Regions, increasing the difficulty of the exploration and exploitation of oil & gas resources. Hence, this can increase E&P costs of petroleum in the Amazonian regions, where concessions have been launched by the governments of Peru, Colombia, and Ecuador in order to increase the proven reserves and production of oil and gas of these countries.

For instance, the statistics of the Hydrocarbons National Agency of Peru (PeruPetro) indicate that up to this date there are 7 concessions for drilling and 42 for exploration, covering an area of 10,710 km^2 and 253,025 km^2, respectively, in the Amazonian region of Peru. In Colombia, in 2011, the basin of Caguan Putumayo was the third most explored basin (with 6 wells drilled). In the Brazilian Amazonia, while crude oil reserves (107 million barrels) represent only 0.8% of proven Brazilian crude oil reserves, those of natural gas are about 55 billion cubic meters, which is equivalent to 13.2% of the country's proven reserves. Therefore, natural gas can increasingly play a central role for energy security in the Brazilian Amazon, as well as for the whole country, since major cities in the Amazonian region have installed natural gas-fired power plants that will be connected to the country's power grid. Floods on onshore Amazonian wells could severely affect the petroleum supply for the above mentioned countries. These events, besides having strong impacts on local economies (especially in towns linked to oil and gas activities and states where petroleum rents are relevant for the government budget), would increase the imports of fossil fuels to Amazonian regions affecting energy security.

Power generation systems of the studied countries heavily rely on hydropower plants located in Amazonian regions (with the exception of Colombia). In Peru, Bolivia, Ecuador and Brazil, these plants represents 22%, 35%, 39% and 11% of total electricity supply, respectively. Since Amazonian regions are net exporters of hydroelectricity, impacts due to climate change can jeopardize the electricity supply in South American countries. To compensate these effects it will be necessary to invest in alternative energies with reliable firm power or fossil fuel thermal plants to increase the margin of reserve – see Box 1. It also raises the need for integrated planning of hydropower at the river basin scale, and not by individual dams, in order to reduce risks and optimize the exploitation of hydro resources.

Box 1
Least Cost Adaptation for Decreased Hydropower Reliability in Brazil

The Brazilian energy sector relies heavily on renewable energy sources, especially in the power sector. Hydroelectric power plants accounted for around 80% of Brazil's electric power generation in 2010 (MME, 2011). Given that the availability and reliability of these renewable sources depend on climate conditions which can vary in light of global climate changes, Lucena et al. (2010) applied an integrated resource planning approach to calculate least-cost adaptation measures to a set of projected climate impacts on the Brazilian power sector.

Despite the high uncertainty concerning future climate projections, the study showed that to compensate for a lower reliability of hydroelectric production, amongst other less relevant impacts, the Brazilian Interconnected System would need an increased installed capacity able to generate 150-160TWh per year, depending on the GHG emission scenario. The least cost generation capacity mix to attend this would be based mostly on natural gas, but also sugar-cane bagasse, wind power and coal/nuclear plants. Total investments required would total around 50 billion US dollars up until 2035.

The methodology used by Lucena et al. (2010) had the advantage of finding optimal solutions that take into consideration the whole energy chain and the interactions between energy supply and demand. The indirect effects found in the study were the displacement of natural gas from other consuming sectors, such as industry, in favor of its use for power generation.

As an illustration, Box 2 shows the case of vulnerability of Ecuadorian electric system associated with the hydrological variability in extreme low rainfall and dry periods.

BOX 2
Vulnerability of Ecuadorian electric power system due to hydrological variability in extreme low rainfall periods

By the end of 2010 the interconnected Ecuadorian electric power system capacity (SNI) comprised 2.24 GW of hydropower and 2.15 GW of thermal power fuelled mainly with oil products. Ecuadorian hydroelectric plants use river flows from both Amazon and Pacific watersheds, which have a "quasi-complementarity" energy production regime. As rainy seasons vary between both watersheds, there is some complementarity - between February to April in the Pacific watershed and between May to August in the Amazon watershed. But between October and January the occurrence of rain is scarce in both watersheds, illustrated by the low river flows in the main dams and hydropower plants. The vulnerability of the Ecuadorian hydroelectric system grows proportionally with the increased probability of these simultaneous critical hydrological scenarios on both watersheds, especially on the Amazon one where 77% of the national installed capacity and energy production is concentrated.

Historically, in the years when the hydrological period was low in the Amazon watershed, Ecuador faced an electricity crisis between November and January (with electricity rationing at the end of 2005 and 2006). November 2009 saw the worst river flow in the last 46 years in the Amazon watershed (47% lower than the November average). This extreme drought coupled with some structural problems of the Ecuadorian electric power sector led the country to an electricity crisis that caused several blackouts until the beginning of 2010.

During this crisis the electricity demand was met through increasing both the number of thermoelectric units and the amount of electricity imports. To face this crisis the Government urgently installed seven new thermoelectric units (22 MW each) and rented a thermoelectric capacity of 205 MW that operated until February 2010. The volume of diesel imports increased 30% during October 2009 and February 2010 to supply the demand of the thermoelectric units in comparison to the average of the three past years in the same period. In that period the volume of diesel import for thermoelectric supply was 1.7 millions of barrels, and due to the subsidy for fuels in the domestic market, the cost for the country (difference between income from national sales and import cost) was around 92 million USD.

In response to this crisis, the Regulation CONELEC 001/05 (Operation of SIN in deficit of generation conditions) was improved and the Regulation

CONELEC 003/10 (Technical operation of emergency thermoelectric power plants in deficit periods and/or electricity rationing) was created, precisely to mitigate the impacts of extreme weather events. The National Plan for Electrification 2012 – 2021 made by CONELEC in partnership with CENACE considers as a premise the lesson learnt during the 2009 crisis. Thus, the electric power system should: 1) have a minimum monthly energy reserve of 10% to satisfy national consumption without imports; 2) not depend on the hydrologic regime (considering only firm energy of the system); and 3) not depend on electricity imports from neighbouring countries that should be only used to optimize national production.

Thus, the expansion plan considers in the short term the installation of some modern thermoelectric plants. In the medium- to long-term, some new hydropower plants, as well as renewable sources, have been considered.

This plan foresees until 2021 a total installed capacity of 7.5 GW, from which 67.4% would come from hydroelectric power plants. The under construction Coca-Codo Sinclair hydroelectric power plant (1,500 MW) is located in the Amazon watershed at the Pastaza River. This unit is a run-of-river plant with a relatively small regulation reservoir and will be the largest in the country. Despite the expected amount of energy generated to the national grid, the hydrologic vulnerability of the Ecuadorian electric power system will continue to exist in the period October-January, since the Pastaza river follows a similar pattern as the other Amazonian rivers and its reservoir cannot store water for seasonal regulation.

Climate change could increase the frequency and intensity of critical hydrologic periods, which would represent a high energy security risk for the country. Therefore, high dependence on thermoelectric power will continue to exist to guarantee the national supply of electricity, increasing the imports of oil products, and thus affecting energy security even further if the capacity of national refineries is not increased.

Impacts on Energy Conversion

Rises in ambient temperature due to climate change will negatively affect power output and efficiency of gas fired-turbines. This effect has a greater impact in tropical regions, where temperatures are much higher than ISO conditions for this equipment. This is especially critical for Bolivia that has 54% (682 MW) of its effective power based on natural gas thermal plants located in the Amazonian region. A correction factor of 0.975 in the gross power of this equipment resulting from a temperature rise of 4°C would lead to a loss of 2% of the effective power in the country's national grid. Compensating for these effects will require investments in new power plants or in gas turbines' air intake cooling systems, increasing electricity generation costs and reducing energy security. However, this is not an important impact relative to other climate change impacts on energy systems.

Impacts on Energy Transport

Energy transport may be the component in the energy supply chain most affected by climate change effects in Amazonian regions. Rising temperatures cause reductions in natural gas transmission capacity and in the efficiency of natural gas compression for pipeline transportation. However, the major impact of climate change would be from the effects of increased frequency, intensity and duration of extreme weather events, which could cause interruptions in the transport of energy, increasing risks for energy security.

Since Amazonian regions are a net exporter of oil and gas, importing non-Amazonian regions of Peru, Brazil, Ecuador and Bolivia could be affected by disruptions in the supply of energy. For instance, in Peru, the transport of natural gas is made by a pipeline in the Amazon region of Ayacucho, which is subdivided into two pipelines: one for the domestic market and the other for exports. A contingence, such as floods and landslides caused by deforestation processes and climate extremes could jeopardize the country's energy supply. Such contingencies have happened before for both gas pipelines (La República, 2004) and liquids of natural gas pipelines (BNAmericas, 2005) (Figure 2) from Camisea, which supplies thermal plants responsible for around 34% of the electricity generation in the National Interconnected System

In Brazil, extreme weather events could affect oil and gas pipelines, as well as fundamental electricity transmission lines. In Urucu there is a small unit of diesel production which supplies diesel to Coari-Solimões through an important polypipe. There is also an important gas pipeline that transports the natural gas from Urucu to the city of Manaus, the region's largest consuming centre. As extreme events can lead to disruptions in the supply of energy, climate change can exacerbate threats to energy security in those regions.

Figure 2
Left: Flood in Camisea pipeline caused by intense rains.
Right: Landslide affecting foundations of transmission lines.

As shown in Figure 3, transmission lines in the Amazonian region of Peru, Brazil, Bolivia and Ecuador have a radial configuration. This means that interruptions caused by atmospheric electrical discharge (ISA, 2010), storms and landslides (CONELEC, 2012) would lead to blackouts in cities supplied by these transmission lines. Standby generation would improve energy security but would increase power generation fixed costs. An even more costly solution is to construct new transmission lines based on the n-1 criterion[10]. However this would cause deforestation and major impacts to the Amazonian forest and biodiversity.

Figure 3. Transmission Grid in Peru(1), Brasil(2), Bolivia (3) and Ecuador (4)[11].

Climate change effects on the navigability of waterways could affect fossil fuels supply and consequently electricity generation in isolated systems. Transport of oil products in Amazonian regions is intensively dependent on fluvial transport. For instance, in 2006 the total cargo transported in the Amazonas river basin in Colombia was 87,721 tonnes, 10,072 of which were of hydrocarbons (69% diesel and 18% gasoline) (SENA, 2007) (See Figure 4). Isolated regions that depend on fuel supply for electricity generation are exposed to risks that can be exacerbated by climate change. For example, in Colombia, Putumayo and Meta are currently the only Amazonian departments interconnected to the National Grid. In the

[10] The N-1 criterion expresses the ability of the transmission system to lose a linkage without causing an overload failure elsewhere.

[11] The maps of the grid transmission of these countries could be found in the webpage of Osinergmin, Eletrobras, CNDC and Conelec respectively.

long term, there is no plan to connect other Amazonian departments in the Referential Expansion Plan of Generation and Transmission of Colombia 2010-2024. Consequently, isolated electricity generation in these Amazonian localities will continue to depend on the supply of fossil fuels.

Figure 4: Fluvial Transport of Fuels in the Putumayo River in Colombia

An alternative to compensate negative effects on the navigability of rivers, and increase the reliability of fossil fuels supply is to invest in the expansion of storage capacity in isolated localities. Another alternative is investment in road infrastructure, although this could lead to further deforestation and environmental impacts if not based on a strong planning process that involves the use of zoning processes and legal mechanisms. This topic should be better evaluated in future studies related to fuel logistics in Amazonia. For instance in relation to storage capacity, in the Brazilian State of Amazonas there is a strategic stock of oil, oil products, ethanol and GLP in the Coari Municipality with a total volume of 80.000 m^3 distributed in 13 tanks. This stock is managed by the Transpetro terminal, which is responsible for the fuel supply to the waterway transport. In the areas that are not connected by waterways, road transport combined with air transport is used to supply fuels to storage terminals in inner areas of Amazonian localities.

Finally, extreme events can also affect road transport of fuels. In the Brazilian State of Roraima, in June 2011, the Branco River registered its worst flood in history, which affected all 15 municipalities of the State. This extreme event caused problems in terrestrial transport, including interruptions along highway BR-174, which links Roraima and other Amazonas States, leading to fuel shortages.

Analysis of Potential Threats to Amazonian Energy Security

Energy security threats induced or exacerbated by climate change may result from changes in the trends of climate variables (such as temperature, precipitation, etc.) or by increasing frequency, intensity and duration of extreme weather events. It is difficult to assess the likelihood of the potential impacts of climate change without making use of specific climate scenarios, as different trends in climate variables have distinct effects on energy security in Amazonian regions. It is beyond the scope of this report to conduct such analysis, but future studies should produce a range of climate scenarios and analyze their implications for energy security.

However, the relative importance of climate change impacts depends not only on climate, but also on the existing and foreseen infrastructure in the region. Some characteristics of specific energy technologies may render them more susceptible to variations in climate variables or to extreme events. Based on the impacts discussed above and the characteristics of the Amazonian energy system described in the previous section, a preliminary analysis of the relative importance of ecosystem service for energy security indicates that hydropower and energy transport are most vulnerable to climate change.

In terms of changes in the trends for climate variables, hydropower could be more affected given its close dependence to hydrological variability. Since hydroelectricity depends directly on water flow through the turbines, a decrease in runoff diminishes hydropower production. However, an estimation of total economic costs of climate change on hydropower in the Amazon region is not straight forward and has a large amount of uncertainty involved. The relationship between runoff and hydropower production is not direct, but depends on: 1) storage capacity of the dam; 2) level of integration with other regions and energy sources; and, 3) the way the whole electric system is operated. If models indicate a decrease in runoff in the long term for some regions, negative impacts on energy production can also be expected in those areas. Nevertheless, more specific studies are required in order to calculate the economic cost of runoff variations on hydro electricity production[12].

Extreme weather events can affect energy transportation and, therefore energy access in isolated communities, reducing security of supply for these populations. Likewise, transportation of exported energy from Amazonian regions is vulnerable to such events, which may cause large economic costs. Aggregated energy data for Amazonia is presented in Table 2. The most important primary energy source in Amazonia is hydrocarbons (mainly petroleum), which is relevant in all five countries assessed. Hydraulic Energy production is relevant in the Amazonia region of Brazil and Peru.

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[12] According to medium term simulations for the Brazilian electric power system (Lucena et al., 2010; Schaeffer et al., 2011), every unit of missing electricity (MWh) could be compensated using natural gas thermoelectric generation. Assuming a levelized cost of electricity (LCOE) for natural gas-fired thermoelectricity (open cycle) in a range between 91.9 and 152.4 US$/MWh (DOE/EIA, 2010), it is possible to make a preliminary estimate of the potential costs for a given loss in hydropower generation.

Table 2: Primary Energy Production in Amazon Region by countries.

Energy Resource	**Primary Energy Production (103 toe)**						Structure
	Bolivia	**Brazil**	**Colombia**	**Ecuador**	**Peru**	**Total by Source**	
Oil and Liquids of Natural Gas	442	1,843	8,070	24,853	5,766	40,974	59,6%
Natural Gas	3,449	3,831	10	1,527	6,685	15,501	22,5%
Coal	-	0	0	0	38	38	0,1%
Hydraulic Energy	178	3,873	0	559	749	5,359	7,8%
Firewood	581	2,172	102	23	1,747	4,626	6,7%
Sugar Cane	0	2,215	0	0	32	2,248	3,3%
Total by Country	4,650	13,935	8,182	26,962	15,017	68,746	100%

Sources: Based on YPFB (2012); CNDC (2012); MHE (2011); EPE (2011b); ANP (2011); IBGE (2010); ACP, (2012); (BCE, 2012; CONELEC, 2012a, 2012b; INEC, 2010; MEER, 2008; PRIETO, 2007); MINEM (2011a,2011b,2011c,2011d); COES (2011).

On the other hand, fuels account for most of the final energy consumption in the Amazonian regions. As stated before, secondary energy production in Amazonia is small when compared to its primary production (20%), because petroleum refineries, gas processing plants, and thermal power plants are mainly located near the consumer centers outside Amazonia. Mineral diesel used for transport and on-site electricity generation is the most important fuel. Electricity consumption is also important given its inelastic demand. Therefore, the transport of these energy sources can be hampered by extreme weather events, reducing the security of supply to Amazonian communities.

Finally, actions to reduce GHG emissions, whether they are coordinated on a global scale or not, will change the conditions in which the energy system is operated and planned, giving rise to new energy security challenges. On one hand, increasing the share of renewable energy sources requires an integration effort given the inherent variability – or even intermittency – of some of these energy sources. Furthermore, renewable energy endowments refer to a flux of energy, which is closely related to climate conditions. For this reason, it can be expected that climate change may affect renewable sources more intensively than fossil ones. Therefore, given the probable higher vulnerability of renewable energy to changing climate conditions, mitigation policies based on increasing the share of renewable energy sources would entail additional challenges for energy security. As pointed out by Lucena et al., (2009a), there is a paradox here: renewable energy is most vulnerable to the very problem it seeks to avoid.

5. What are the impacts on human security across different populations within and outside Amazonia?

Having discussed the multi-faceted dimensions of energy security, it is clear how the current debate on energy-related environmental problems gives rise to a range of issues that might influence the vulnerability and affordability of energy supply. In the case of key threats related to climate change, land use change and climate policies, assessing eventual risks to energy security must encompass the different dimensions through which those problems interact. A definition based solely on individual aspects of energy security would not suffice to take into account all relevant issues related to climate change and energy security in the Amazonian regions. Also, analyzing the Amazonian regions as an isolated system does not capture the many facets through which climate change, land use change and climate policies may impose risks to energy security. Therefore, in this section a broad view of energy security is adopted, which attempts to capture the various ways in which identified key threats and energy security are related and the twofold role of the Amazonian regions as both an energy consumer and an exporter of energy carriers and primary resources.

This section identifies the impacts on populations outside and within Amazonia, in the latter case, making a distinction between indigenous groups and local communities, rural areas and urban areas. This preliminary assessment does not allow for a classification of the impacts of climate change on energy security by income or social class (poor and wealthy). In general terms, impacts on energy security related to climate change are associated to poorer segments of society where vulnerability is higher.

The Amazon is a heterogeneous region that ranges from isolated communities to large cities based on intensive industrial activity. Local energy needs and the means through which energy services are supplied greatly vary across the region. However, the largest share of the production of energy in the Amazonian regions is exported to consuming centres elsewhere, which highlights its importance as an energy exporter.

Climate change, land use change and climate policies can exacerbate energy security threats mainly in two ways. Firstly, climate change may cause direct impacts on energy systems through alterations in the climate patterns or increased frequency and intensity of extreme weather events. This has been discussed in the previous sections, including its repercussions for local populations, as well as neighbouring regions.

More frequent extreme weather events resulting from climate change could increase the difficulty of the exploration and exploitation of oil and natural gas resources in Amazonia, compromising the economy of local communities linked to this activity, and reducing funds available for investment in infrastructure projects and social programs, which derive from oil and gas royalties received by local governments (GPC, 2009). This could also affect the economy of the whole countries (especially those with economies that are highly dependent on oil exports, as is the case of Ecuador, Peru and Bolivia).

Direct climate change impacts on hydropower would reduce electricity generation, affecting not only local populations within Amazonia (urban and rural) that receive their electricity from national grids but also to the energy importer regions outside Amazonia. In this way, the whole country could experience both a decline in economic activity and increase in electricity production costs due to the use of more expensive energy sources.

Direct impacts of climate change on natural gas-fired power plants are not expected in the medium term, but in the long term those plants could provide less electricity to the national systems. Bolivia would be the country with the highest impact associated with an efficiency drop in natural gas power plants, given its large natural gas fired power plant installed capacity within Amazonia. However, even in the long term this is not a major impact compared to other climate change impacts on energy systems.

Due to the transportation sector structure within Amazonia, the major impact of climate change should be from the effects of increased frequency, intensity and duration of extreme weather events, which could cause interruptions in the transport and supply of fossil fuels (specially of diesel by waterway), increasing risks for energy security to local communities and indigenous groups within rural Amazon Regions that depend on diesel for electricity generation in gensets. Standby generation would improve energy security but would increase power generation fixed costs. Regions outside of Amazonian regions of Peru, Brazil, Ecuador and Bolivia that are net importers of oil and gas could also be affected by disruptions in the supply of energy within Amazonia.

Interruptions caused by extreme weather events would lead to blackouts in rural and urban areas within Amazonia supplied by these transmission lines. These interruptions, depending on the case, could affect to a wider region or even to the whole country.

Woody biomass used for cooking and heating in low-income households could be impacted by eventual desertification or savanization of local biomes caused by a changing climate. This would restrict access to traditional energy in communities that depends on them[13] and these communities would not only face a lower availability of energy, but also an increase in time and effort needed for fuel wood collection. Particularly, this could affect indigenous groups that rely

[13] Improved access to modern energy sources should be regarded as a possible way of reducing this impact and increasing low income community’s well-being.

on agroforestry, where firewood results from spontaneous harvest activities (Denevat et al.,1984).

Secondly, climate change impacts are not, however, limited to the physical effects on energy production and consumption. The other way in which energy security threats may arise from climate change relates to the direct and indirect economic effects of climate policy on established or future energy infrastructure and markets. It is not clear how future climate policies would generate incentives or disincentives to the exploitation of the natural energy endowments of the Amazonian regions. For example, on one hand there is a risk that mitigation policies will reduce recoverable fossil fuel resources and cause a premature retirement of fossil energy infrastructures. On the other hand, relatively low-carbon-intensive fossil fuels – such as natural gas – might become a viable short-term solution to reduce emissions.

Also, as a consumer of oil products, carbon-restrictive policies might introduce new risks for the continuous availability of energy services that are currently provided by these fuels in remote areas of Amazonia. This may imply higher energy prices for local isolated rural communities that depend on imports of oil products, such as diesel oil, to fuel electricity generation sets as well as their means of transportation. This may result in a loss of welfare given higher prices for related energy services if climate policies do not take into account the affordability of fossil fuels in remote areas.

It is expected that climate change GHG mitigation policies in Amazonian countries can foster the exploration of the vast hydropower resource, as it is one of the cheapest renewable options for electricity generation. However, there are several local social and environmental impacts associated with the exploitation of hydropower. Since Amazonia concentrates most of the remaining hydropower potential of these countries, it will also bear most of local environmental costs associated with future hydropower expansion. Therefore, local populations – most of those being indigenous groups or small rural communities – would be the ones more affected by this eventual higher future exploitation of hydropower production. For instance, the total hydropower potential[14] of the Brazilian Amazonia is estimated at 116 GW, which represents almost 50% of total Brazilian hydropower potential (EPE, 2006). As of today, 100 GW of this potential remains unexploited, 25% of which would affect indigenous areas and 16% is inside conservation areas (EPE, 2007). In the Peruvian Amazon, there are currently 19,564 MW of hydropower under planning. The Colombian Amazon also has a significant potential for hydropower plant with a potential of 12 GW. In Ecuadorian Amazonia is located approximately 80% of the country's total remnant hydroelectric potential, concentrated in Napo and Morona Santiago

[14] This is technical and economical hydropower potential. This number could be reduced when protected areas and indigenous lands are considered.

Provinces (there are 15 places identified with a total hydroelectric potential of 9.55 GW).

Large uncertainties surround the real possibility of fully exploiting this unexplored potential. There still remains important environmental concerns (Magno, 2006; Ravena, 2009) and social-politic conflicts associated with the construction of dams and the consequent flooding of large areas (Valdez Pizarro, 2004; Pimentel, 2012; Bermann Célio, 2012) that could exacerbate threats to local rural communities and indigenous groups. Environmental concerns include potential impacts derived from the deforestation for the impoundment area and transmissions lines, interruption of fluvial systems, changes in water quality, changes of the ecosystems, proliferation of vectors and diseases, displacement of local population and land-owners and threats to the rights of native populations, their identity and culture (Valdez Pizarro, 2004; Magno, 2006; Ravena, 2009; Pimentel, 2012; Gamboa and Cueto, 2012).

There are two main consequences of these environmental restrictions to hydropower. Firstly, the social and environmental impediments imply that not all the remaining hydro potential will be exploited. Secondly, the projects of hydropower plants that will eventually be built should be adapted so as to flood a smaller area and minimize social-environmental impacts[15]. However, hydro plants with smaller reservoirs operate as run-of-river, offering little flexibility. These plants are most vulnerable to climatic variations as natural river flow can be highly variable, especially across seasons. Reservoir storage capacity can compensate for seasonal (or even annual) variations in river flow, enabling electricity generation throughout the year and matching varying power demand. Reservoirs act as buffers by “storing energy”, which can help hydropower plants to cope with climate changes.

Therefore, there is a conflict between global and local environmental policies related to hydropower that is relevant for energy security. On the one hand there is the need to increase renewable electricity generation to meet increasing domestic demands for modern energy services and foster economic growth without increasing GHG emissions. On the other hand, one of the cheapest and most abundant renewable sources creates vast local social and environmental impacts on local communities and indigenous groups settled within large regions of Amazonia. On top of that, there is the paradox: reducing local impacts renders hydropower more vulnerable to the very problem it helps to avoid (i.e. by reducing GHG emissions).

In a similar way, climate change mitigation policies can induce the switch to natural gas due to its relatively low carbon emission factor in comparison to

[15] This has been the case, for example, of the Belo Monte hydropower plant in the Brazilian Amazonia (whose reservoir is two third the size of the original project) and the Coca-Codo Sinclair in the Ecuadorian Amazonia.

other fossil fuels. This can also be an energy security strategy to reduce the dependence on foreign oil. An increase in the demand of natural gas can lead to more effort of E&P of natural gas in the Amazonian regions, such as the Camisea Project in Peru (See Box 3) and Urucu in Brazil, possibly exacerbating existing threats to local communities that are settled in areas near the natural gas fields (see, for example, Box 3). According to Haselip (2011), western Amazon is likely to become an important source of non-Middle East and Venezuela oil and gas for importing nations. However there are several registered social conflicts related to these investments. The indigenous communities are the most active in opposing the development of oil and gas in light of the industry's poor records on consultation and transparency, as well as the historical failure to demonstrate the benefits of petroleum activities to these communities in the short and long term. The pressure for exploiting natural gas resources created by internationally adopted climate policies could, thus, exacerbate these conflicts.

Box 3
The Camisea Project as a Mitigation Instrument of Climate Change and its Impacts

At the end of December 2011, the area denominated "Great Camisea", in the South of Peruvian Amazonia, has two blocks of Production (Blocks 88, 56), and two Blocks contracted for Exploration (Blocks 57 and 58). These four blocks represent a jungle area of 10 279 km^2. The blocks of productions account for proven reserves of 10.7 TCF. In Selva region there are remains additional 0.8 TCF of proven reserves, 8.1 TCF of probable reserves and 5.2 TCF of possible reserves (MINEM, 2012e).

The exploitation and use of the Camisea Gas have had positive impacts in the economy of Peru (Apoyo,2007). It has also brought environmental benefits from fuel switching (from fuel oil/diesel/gasoline/LPG towards natural gas). Based on these benefits, Peru's climate change public policy, such as the "National Strategy on Climate Change", "Action Plan for Adaptation and Mitigation Against Climate Change", and "Second National Communication on Climate Change to the UNFCCC" promotes the use of natural gas as an instrument of mitigation of climate change. The only two CDM project registered of Peru in the Manufacturing industries Sectoral Scope are related to switching fuel oil to natural gas.

Paradoxically, these climate change policies could have a rebound effect related to the environmental impacts of the upstream and midstream activities, natural gas E&P and transport, in the Peruvian Amazonia such as deforestation and soil erosion, water and soil pollution, waste generation and noise (ICF, 2007; Ross, 2008; Chabaneix 2010), and social impacts, such as social conflicts through local grievance (Haselip, 2011), and especially social impacts related to the contact of isolated indigenous communities that could be irreparable (Napolitano et Ryan, 2007).

On the other hand, there are some climate change policies, such as those related to energy efficiency, that bring positive effects on local populations. For instance, programs for incentivizing the installation and use of modern stoves have been promoted through instruments like CDM and the voluntary carbon market[16]. Nationally Appropriate Mitigation Actions could be constructed scaling such programs up to a regional level, resulting in improvements on health conditions, and economic benefits to population when firewood is bought.

6. What are the potential policy options to mitigate or exacerbate the impacts of security threats on energy security?

As stressed by Moreira and Esparta (2006), the traditional approach to energy security is based on the diversification of energy supplies. This can be done internally, by maximizing the use of domestic resources and technologies, and/or externally, by selecting a greater variety of products from a diversity of supplies from different geographical regions.

In the case of Amazonian regions, this approach, although useful, is limited, as these regions are both net exporters of natural resources (primary energy resources or even primary energy embodied in low-value industrial goods) and net importers of liquid fuels (mostly diesel for remote gensets and road and water transport). Besides, resources are much larger than local demand and their prices are much higher than what most of the local population can afford. This is a structural feature of Amazonian regions, which poses three levels of security issues, as described below.

The first level is related to guaranteeing modern energy services supply to local communities at affordable prices; this is a permanent issue and includes, in the short term, the improvement of diesel supply system, in order to deal with unexpected shortages as identified in this report (for instance, better planning of diesel storage and logistics). In the long term, there are alternatives to diesel that should be incentivized. For instance, in some regions, the availability of oil seeds of low to medium viscosity allows for their use in gensets. Interestingly, this has been tested in some isolated systems of Brazilian Amazonia (Rosa, 2007). Brazil, Ecuador, Bolivia, Colombia and Peru have also promoted PV systems for local communities, which can be expanded to small villages and communities at suitable sites (Figure 5). There is also the possibility of using hydrokinetics devices (Figure 6) as micro scale hydropower systems, for converting the kinetic energy of rivers into mechanic and/or electricity. For example, as pointed out by Fleming (2012) and Anderson (2006), river flow near the Estuary of the Amazon River can reach 2.5 m/s. In other regions, especially in major cities, such as Manaus in Brazil, natural gas fired generators can also

[16] See the Voluntary Programme Activity : Qori Q'oncha – Improved Cookstove Diffusion Programme in Peru.

offer a lower carbon and cheaper alternative to diesel. A major technological challenge is how to deal and/or replace diesel supply in water passenger and freight transport. Improving logistic and planning can mitigate part of this challenge, but will not solve it.

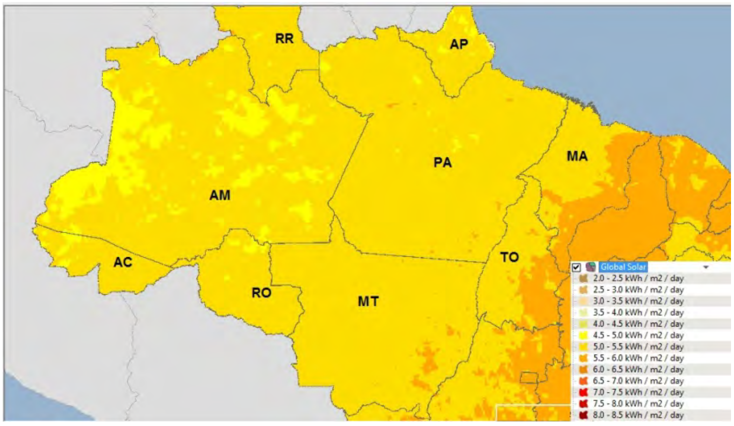

Figure 5: Global Solar Radiation in Brazilian Amazonia.
Projected using the Geospatial Toolkit developed by SWERA Program.

Figure 6: Golov Turbine in Amazonian Estuary (FOZ)
Source: Anderson, 2006

For this first level, policies should rely on two approaches: one is promoting the technological development of local energy converters and diversifying the electric power supply of remote communities; the other is giving economic incentives (financing, fiscal incentives and subsidies) for local utilities to provide modern energy services at affordable prices, especially those based on renewable energy sources. For instance, Brazil has an electricity tax applied to all consumers in the country, which is used to finance the provision of electricity to remote villages.

The second level of security issues is related to the fact that Amazonian regions are net exporters of primary and final energy resources, basically petroleum resources and electricity, whose revenue is not fully perceived by local communities. In the case of petroleum, as stressed in this report, rents usually did not compensate social and environmental impacts and threats related with petroleum industrial activities. This is also an ethical issue, since, even if the petroleum rents are well perceived and the environmental impacts are better controlled, petroleum activities may affect native populations for which damages cannot be financially compensated. For electricity, usually local populations do not benefit from the generation itself because this is produced at large scale (and at high voltage) to be transmitted to other load centres. Therefore, in the second level, challenges include, in the case of petroleum, deciding whether or not s petroleum resources should be developed in some sites and, if so, how to divert benefits to local populations. In the case of electricity, interconnection and diversification are the main options for increasing the security of supply for regions outside Amazonia. Interestingly enough, some of these regions could benefit from the development of renewable energy sources, which is the case of wind in Northeastern, Brazil, and solar thermal power plant in Atacama, Chile.

It is also worth noting that global climate policies might have different impacts on the different energy resources provided by the Amazon to other regions. The effort to mitigate GHG emissions may encourage the exploration of renewables, such as hydro, and even low carbon fossil fuels such as natural gas, causing local impacts at the expense of global environmental improvements. On the other hand, some climate scenarios indicate that hydropower reliability can be reduced in the long term, resulting in lower energy security to consumer centres supplied by Amazonian electricity. The most usual option to deal with this loss of reliability is to invest in back-up power plants with fast ramp-up, such as natural gas-fired open cycle turbines.

The third level of security issues is associated with the economic specialization of Amazonian regions and its implication for energy-intensity. Indeed, industrial activities in those regions are mainly concentrated in basic mineral or industrial commodities, such as ores, aluminium, pulp, which embody high energy content for a low economic value. Conversely, Amazonia has a large potential, but yet almost unknown, for natural resources to be developed, which can be expressed as genetic diversity, allowing the construction of different bio platforms. Although it is not easy to economically value this diversity, clearly its exploitation is less energy intensive than the current activities of the regions. Hence, research centres, the development of local human capital, improvement of national patent systems, etc. are a part of a broad range of policy options that should be considered for the Amazonian regions, which will certainly reduce their energy vulnerability in economic terms.

These initiatives could even collaborate with supplying renewable energy. For example, incentives to produce bio-fuels on degraded lands in the Amazon could help to recover those lands and would also add value to local production. Cunha da Costa (2004) proposed a similar idea for the region close to the Carajas Iron Ore Program in the South-Eastern Brazilian Amazonia, where most of the deforestation has taken place in the last few decades. For this specific context, palm oil is highlighted as an interesting technological energy alternative due to its advantages at the socio-economic level, since it can be produced in a small-scale system managed in a cooperative way and is highly productive.

In sum, historically Amazonia was only seen by actors located outside this region as a space that should be occupied and exploited. As of today, its major perspective is to become one of the last frontiers for hydrocarbon and hydropower resources (Ravena, 2009). The configuration of Amazonia as a net exporter of energy and a reserve of natural resources (primary energy and minerals) (Valdez Pizarro, 2004; Magno, 2006; Bermann Célio, 2012), raises questions regarding equity and equality between local and external people. Energy security and well-being should be considered in this discussion.

Finally, improving our knowledge of how climate change may affect energy security in Amazonian regions is crucial. Vulnerability assessments of energy systems lie at the end of a chain of cumulative uncertainties. The major uncertainties of such studies reside in their starting point: greenhouse gas emissions scenarios and long-term climate projections[17]. Further in the assessment, the modelling tools used in energy analyses have their own level of uncertainty depending on how well the model used represents the affected system and how good the available database is. Therefore, it is important that such studies be conducted as scenario analysis (rather than predictions).

[17] Long-term climate projections are produced by General Circulation Models (GCM), which relate chemical variations in the atmosphere to climate variables such as temperature and precipitation (Frederick and Major, 1997). Despite their limitations, they are the only credible tools to simulate the physical processes that govern the global climate (Carter et al., 1994).

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Annex 1
Literature compilation

Acronyms

AE	Energy Authority of Bolivia
ANEEL	National Agency of Electric Energy of Brazil
ANH	National Agency of Hydrocarbons of Bolivia
ANP	National Agency of Petroleum, Gas and Biofuels of Brazil.
BCE	Central Bank of Ecuador
BP	British Petroleum
CNDC	National Committee for Load Dispatch
CONELEC	National Council of Electricity of Ecuador
COES	System Economic Operation Committees
DANE	The National Administrative Department of Statistics of Colombia
EPE	Company of Energy Research of Brazil
E&P	Exploration and Production
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
IBGE	Brazilian Institute of Geography and Statistics
IBP	Brazilian Institute of Petroleum and Gas
INE	National Institute of Statistics of Bolivia
INEC	National Institute of Statistics and Survey of Ecuador
INEI	National Institute of Statistics and Informatics of Peru
INPA	National Institute of Amazonia Research
MAE	Ministry of Environment of Ecuador
MEER	Ministry of Electricity and Renewable Energy of Ecuador
MME	Ministry of Mines and Energy of Brazil
MINEM	Ministry of Energy and Mines of Peru

OLADE	Latin-American Organization of Energy
ONS	National Operator of Electric System of Brazil
OPEC	Organization of Petroleum Exporters Countries
OSINERGMIN	The Energy and Mining Investment Supervisory Body
SIGAPRO	Ministry of Agriculture of Ecuador
SSPD	Superintendency of Residential Public Services of Colombia
UFRJ	Federal University of Rio de Janeiro
UnB	Federal University of Brasilia
UNFCC	United Nation Framework to Climate Change
UPME	Mining and Energy Planning Unit of Colombia
USP	University of São Paulo
YPFB	National Oil Endowments of Bolivia

Introduction

The analysis of energy security in Amazonia was conducted on the basis of scientific evidence from published data, papers and reports on climate change and energy security. The project focused on the following countries: Bolivia, Brazil Colombia, Ecuador and Peru. In some cases the availability of data was limited or non-existent. Despite the poor availability of data, a quantitative energy balance (primary energy production, secondary energy production and energy consumption) of the Amazonia Regions, by country, is presented. This compilation was made based on energy balances of Amazonian departments (or states) for the year 2010. This report identifies the sources used and knowledge gaps for each country. In addition, a brief discussion about the quantity and quality of information available as well as existing research gaps is presented.

2. Literature compilation

The sources of information used to write the energy security report are official national reports and statistics from governmental institutions, papers from international journals and technical production of universities. Below, a detailed description of the literature compilation by country is presented. This information was used to characterize the energy sector and their interrelations with climate change.

Bolivia

Socio-economic data was taken from the Insituto Nacional de Estadística de Bolivia (INE). The production of oil, condensates and natural gasoline by departments are published by *YPFB* in the "*Boletín Estadístico Gestión 2011*" (YPFB, 2012). The production of natural gas is also found in this study. Since there are no isolated hydroelectric power plants reported, the energy production of hydropower plants connected to the national grid reported by *CNDC* was used. Firewood consumption by departments (which was considered equal to production) was modelled using national firewood consumption, population and the data for type of fuel consumed by households by departments in the National Census of 2001 (INE,2012).

Table 1: Primary energy production in Bolivian Amazonia

Energy Resource	**Primary Energy Production (10^3 toe)**	**Share (%)**
Oil and Liquids of Natural Gas	442	9.5
Natural Gas	3 449	74.2
Coal	0	0.0
Hydraulic Energy	178	3.8
Firewood	581	12.5
Sugar Cane	0	0
Total	**4 651**	**100**

Source: YPFB (2012); CNDC (2012); MHE (2011)

Fuel production by department was calculated based on the fuel production by refinery and by natural gas processing plant (YPFB ,2012). In terms of electricity production for the grid connected power plants information of CNDC was considered while for isolated systems information by concessionaries and power plants was obtained from the AE.

Table 2: Secondary energy production in Bolivian Amazonia

Energy Carrier	**Secondary Energy Production (10^3 toe)**	**Share (%)**
Diesel Oil	548	24.9
Fuel Oil	0	0
Gasoline	670	30.5
LPG	320	14.5
Kerosene	163	7.4
Electricity	501	22.7
Non Energy Oil Products	0	0
Biodiesel	0	0
Total	**2 202**	**100**

Source: YPFB, (2012); AE, (2012); CNDC (2012)

Liquid fuel and natural gas consumption by departments in Bolivia was obtained from YPFB (2012). Electricity consumption was estimated based on the concessionary demand reported by CNDC, free consumer COBOCE (the only one in the Amazon region) and consumption in isolated areas based on isolated generation data from AE corrected for distribution losses.

Table 3: Energy Consumption in Bolivian Amazonia

Energy Carrier	**Energy Consumption (10^3 toe)**	**Share (%)**
Diesel Oil	892	22.9
Fuel Oil	0	0
Gasoline	639	16.4
LPG	331	8.5
Kerosene-Jet Fuel	143	3.7
ELECTRICITY	402	10.3
Firewood	581	14.9
Natural Gas	903	23.2
Total	**3 892**	**100**

Source: Based on YPFB (2011), CNDC (2012), AE (2012)

The following table was constructed based on data from CNDC for the power plants interconnected to the grid and isolated power units obtained from AE. There are also "co-operative" isolated generation summed up in AE, however it cannot be distinguished by departments (It is possible that Pando´s power unit generation could be included among this "co-operative" isolated generation).

Table 4: Electric Installed Capacity in the Bolivian Amazon

Boundaries by Country´s Amazon Region	**Electric Installed Capacity (MW)**	
Provinces/States	**Hydroelectric**	**Thermoelectric**
Pando		
El Beni		15
La Paz	289	32
Cochabamba	145	369
Santa Cruz		339

Source: CNDC (2012), AE (2012)

Brazil

The energy sector in the Brazilian Amazonia was characterized using data from 2010. Socio-economic data was taken from the Instituto Brasileiro de Geografia e Estatística (IBGE). Some publications (BERMANN CÉLIO, 2012; CARVAJAL, 2012; CUNHA DA COSTA, 2004; ELS, VAN et al., 2012; LASCIO, DI; BARRETO, 2009; REDCLIFT, 1994) were also used to adequately characterize the energy sector in the region, especially in rural areas where isolated fossil fuels based generation dominates.

Oil, natural gas and hydrocarbon data was obtained from Empresa de Pesquisa Energética (EPE), Instituto Brasileiro de Petróleo, Gás e Biocombustíveis (IBP), Agência Nacional do Petróleo, Gás Natural e Bicombustíveis (ANP) and IBGE. These sources provided important information about production, processing, transport and consumption of oil products for the Amazonian States. The most relevant information is compiled in the following tables. **Error! Reference source not found.** shows the primary energy production and **Error! Reference source not found.** shows the secondary energy production in Brazilian Amazonia.

Table 5: Primary energy production in Brazilian Amazonia

Energy Resource	**Primary Energy Production (10³ toe)**	**Share (%)**
Oil	1 843	13
Natural gas (wet)	3 831	27
Coal	0	0
Hydraulic energy	3 873	28
Firewood	2 172	16
Sugar cane products	2 215	16
Other primary sources	n.a.	
Total	**13 935**	**100**

Source: EPE, (2011b); ANP, (2011); IBGE, (2010)

Table 6: Secondary energy production in Brazilian Amazonia

Energetic Product	**Secondary Energy Production (10³ toe)**	**Share (%)**
Diesel Oil	646	6.7
Fuel Oil	269	2.8
Gasoline	301	3.1
LPG	575	6.0
Kerosene	129	1.3
Other energetics from oil	96	1.0

Non energy oil products	659	6.9
Dry natural gas	42	0.4
Electricity	6 089	63.6
Etanol	564	5.9
Biodiesel	201	2.1
Total	**9 570**	**100**

Source: EPE, (2011b); ANP, (2011); IBGE, (2010)

The **Error! Reference source not found.** shows the proven reserves of oil and natural gas and also presents the remaining hydraulic potential in Brazilian Amazonia by state.

Table 7: Proven Reserves of oil and natural gas and hydraulic potential in Brazilian Amazonia

	Proven Reserves		**Hydraulic Potential**	
Brazilian Amazonian States	**Oil (106 bbl)**	**Natural Gas (106 m3)**	**Total (MW)**	**Remaining (MW)**
Rondônia	0	0	12 891	12 597
Acre	0	0	1 121	1 121
Amazonas	107	55 878	19 898	19 623
Roraima	0	0	5 262	2 000
Pará	0	0	49 400	40 939
Amapá	0	0	2 006	1 929
Tocantins	0	0	6 674	4 880
Mato Grosso	0	0	16 807	14 951
Maranhão	0	0	2 191	2 072
Total Amazon Region	**107**	**55 878**	**116 249**	**100 110**
Total Brazil	**14 234**	**423 003**	**243 362**	**157 054**

The electric sector in Brazilian Amazonia was characterized using information from Agência Nacional de Energia Elétrica (ANEEL), Operador Nacional do Sistema Elétrico (ONS) and Eletrobras. **Error! Reference source not found.**8 presents the electric installed capacity for each state of the Brazilian Amazonia by energy source (hydroelectric and thermoelectric). Information regarding tariffs and electrification was taken from Ministério de Minas e Energia (MME) and EPE.

Table 8: Electric Installed Capacity in Brazilian Amazonia

Brazilian Amazonian States	**Hydroelectric (MW)**		**Thermoelectric (MW)**
	Operating	**Under Construction**	
Rondônia	294	0	613
Acre	0	0	136
Amazonas	275	0	1 900
Roraima	5	3 257.50	118
Pará	8 461	0	406
Amapá	77	0	219
Tocantins	1 783	11.4	1
Mato Grosso	1 440	415.94	713
Maranhão	119	0	435
Total Amazon Region	**12 454**	**3 685**	**4 541**
Total Brazil	**80 701**	**5 606**	**29 689**

Source: EPE, (2011b)

The literature presents an extensive number of scientific publications about the impacts (positive or negative) of the construction of hydroelectric plants in Brazilian Amazonia. Some groups of researchers criticize these projects and reject the Brazilian electric sector expansion strategy based on large hydropower plants. Within such groups there is the Instituto Nacional de Pesquisa Amazonica (INPA), which has published several articles explaining the different impacts (environmental, socio- economic, political, etc.) caused by hydropower plants in Amazonia. On the other hand, EPE and MME, which represent the government's point of view, argue that there are benefits for the rest of the country and propose minimizing the impacts in Amazon Region by not expanding hydropower capacity in populated areas or areas rich in biodiversity and indigenous native culture. The academic production of universities like Universidade Federal do Rio de Janeiro (COPPE/UFRJ), Universidade Federal de Brasilia (UnB), the George Washington University, Institute of Electronics USP, etc., often provides a more balanced analysis of this strategy of expansion.

Energy demand in Brazilian Amazonia was described using information from EPE, MME, ANP and IBP. EPE published good references for electric installed capacity of self-producers by sector for every Brazilian State.

Publications describing electrification in rural areas of Brazilian Amazonia were also taken into account. Some articles highlight the importance of renewable energy sources as an alternative to electricity supply in remote areas and also as way of reducing fossil fuel consumption (ABREU, DE, 2004; ANDRADE et al., 2011; CARVAJAL, 2012; MATOS et al., 2011; QUEIROZ et al., 2012; REDCLIFT, 1994; SILVA, V. DA, 2007; etc.). Some projects and policies have been developed to foster the rural electrification in Brazilian Amazonia, the most relevant is universalization program Luz para Todos (ANDRADE et al., 2011; HOFFMAN, 2012).

Another important fact in Brazilian Amazonia is both the use of wood from deforestation and energy crops for industrial purposes, especially for iron and steel production (ABREU, DE, 2004; CUNHA DA COSTA, 2004).

Colombia

Socio-economic data from Colombia was obtained from DANE. Liquid hydrocarbons and natural gas production data by departments was found in the "Informe Estadístico Petrolero" (ACP, 2012). Consumption of firewood was calculated on a national basis by UPME. The estimate of the consumption of firewood in Colombian Amazon was modelled correlating population and the "unsatisfied living" component of the basic needs of the Colombia General Census 2005 by departments. Even though these results could have a high margin of error, they are adequate to estimate the values of firewood consumption by department.

Table 9: Primary energy production in Colombian Amazonia

Energy Resource	Primary Energy Production (103 toe)	Share (%)
Oil	8 070	98.6
Natural Gas	10	0.1
Coal	0	0
Hydraulic Energy	0	0
Firewood	102	1.2
Sugar Cane	0	0
Total	8 181	100

Source: ACP, (2012)

A published public source for fossil fuels by refinery per year in Colombia was not found. However, there was information about the intake of oil by refineries per year in UPME's website. Based on this and on the average structure of production of the Orito refinery found in Ecopetrol (2012), it was possible to estimate the fuel production in the Colombian Amazon, since the Orito refinery is the only refinery in the region.

Electricity production in Non-Interconnected Zones per departments was found in the SSPD (2012). However, the most up to date data was from 2008.

Table 10: Secondary energy production in Colombian Amazonia

Energy Carrier	**Secondary Energy Production (10^3 toe)**	**Share (%)**
Diesel Oil	28	35.6
Fuel Oil	22	28.4
Gasoline	23	29.5
LPG	-	-
Kerosene	-	-
Electricity	5	6.5
Non Energy Oil Products	0	0
Biodiesel	0	0
Total	**79**	**100**

Source: UPME, (20112); SSPD, (2012)

Gasoline and diesel consumption by departments were obtained from UPME (2012), however there was no information related to fuel oil, LPG, or kerosene consumption by departments. In order to estimate electricity consumption by departments, since the region was not interconnected, the electricity generated by the power units penalized with energy losses of 11% (arbitrary) was used.

Table 11: Energy Consumption in Colombian Amazonia

Energy Carrier	Energy Consumption (10^3 toe)	Share (%)
Diesel Oil	211	43.0
Fuel Oil	-	0
Gasoline	174	35.4
LPG	-	0
Kerosene	-	0
Electricity	5	0.9
Firewood	102	20.7
Natural Gas	0	0
Total	491	100

Source: Based on UPME (2012)

Based on the electricity capacity of power units found in SSPD (2012) the installed capacity by departments in the Colombian Amazon was calculated.

Table 12: Electric Installed Capacity

Boundaries by Country's Amazon Region	Electric Installed Capacity (MW)	
Provinces/ States	**Hydroelectric**	**Thermoelectric**
Amazonas		19.7
Vaupés		2.8
Guainía		9.5
Vichada		2.6
Guaviare		1.3
Caquetá		8.1
Putumayo		2.9
Meta		2.3

Source: SSPD (2012)

Data related to proven reserves was obtained from the shapefile "Mapa de Tierras Agosto 22 de 2012" available at the website of the ANH. The Hydraulic

Potential was obtained from the "Estudio del Sector de Energía Eléctrica –ESEE-1979".

Table 13: Proven Reserves of oil and natural gas and hydraulic potential in Colombian Amazonia. Source: ANH (2012), ESEE (1979)

Proven Reserves		**Hydraulic Potential**	
Oil (106 bbl)	**Natural Gas (106 m^3)**	**Total (MW)**	**Remaining (MW)**
57	-	12 018	12 018

Ecuador

Due to the importance of oil production in Ecuadorian Amazonia on the local economy there are continuous publications from the *Banco Central del Ecuador* (BCE, 2012) and the state oil company Petroecuador (PETROECUADOR, 2012).

Although Ecuador does not have a tradition as a natural gas producing country, there is a large quantity of associated natural gas that is not being used (around 47% of the total production is burned, vented or re-injected). Some running projects in the Amazonian Region attempt to collect a larger volume of this energy source in order to produce more LPG that could contribute to meeting the internal demand, lowering the imports from foreign countries. The lack of information regarding associated natural gas production and use is described in the next section.

Error! Reference source not found. shows a balance of primary energy production in Ecuadorian Amazonia. The Ecuadorian Amazon region does not produce coal or relevant quantities of energy crops such as sugar cane or soy palm. To estimate the firewood production a combination of econometric projections based on national energy balances (MEER, 2008) and a factor of firewood consumption per capita (100 kg of wood per year) (OLADE, 2009) was used. Until 1992 around 35% of firewood consumption in Ecuador had energy uses, while 40% was used for furniture industry and 25% was wasted (FAO, 1992). Since then, the use of firewood for cooking has fallen substantially due to the higher penetration of LPG and other oil products (MEER, 2008; OLADE, 2009).

Table 14: Primary energy production in Ecuadorian Amazonia

Energy Resource	Primary Energy Production (10^3 toe)	Share (%)
Oil	24 853	92.2
Natural gas (wet)	1 527	5.7
Coal	-	0
Hydraulic energy[18]	59.3	2.1
Firewood	23.0	0.1
Sugar cane products	-	0
Other primary sources	-	0
Total	**6 962**	**100**

The oil state companies, Petroecuador and Petroproducción, publish periodic reports about the operation of both the oil refinery and natural gas processing unit (UNGP) located inside the Amazon Region. The Shushufindi refinery has a capacity of 20.000 bpd and a current use factor of 99%. On the other hand, the UNGP is working with a low use factor of 45% due to the lack of associated gas uptake from oil wells. The small volume of LPG produced in the refinery is added to the UNPG production. In the same way, the small volume of gasoline from UNGP is added to the poly-pipe that transports gasoline from Amazonian refinery to the Highlands Region. Electricity includes hydroelectric and thermal production from the national interconnected system and self-producers.

[18] Hydraulic energy was calculated using the physical content of energy method.

Table 15. Secondary energy production in Ecuadorian Amazonia

Energetic Product	Secondary Energy Production (10^3 toe)	Share (%)
Diesel Oil	222.4	12.0
Fuel Oil	50.1	2.7
Gasoline	254.4	13.7
LPG	14.3	0.8
Kerosene	43.1	2.3
Other energetics from oil	551.2	29.7
Non energy oil products	-	0
Dry natural gas	-	0
Electricity	722.3	38.9
Etanol	-	0
Biodiesel	-	0
Total	**1 858**	**100**

Source: (CONELEC, 2012a, 2012b; PETROECUADOR, 2000, 2012)

Error! Reference source not found. shows the proven reserves of oil and natural gas as well as hydraulic potential in the Ecuadorian Amazon. These amounts were estimated taking into account data from British Petroleum Statistics (BP, 2011), Organization of Oil Producers Countries (OPEC, 2011) and from CONELEC (CONELEC, 2012b). There is a difference between the estimation of proven oil reserves from OPEC (7.2 Gb) and BP (6.2Gb).

Table 16: Proven Reserves of oil and natural gas and hydraulic potential in Ecuadorian Amazonia.

	Proven Reserves		Hydraulic Potential	
	Oil (106 bbl)	Natural Gas (106 m^3)	Total (MW)	Remaining (MW)
Ecuadorian Amazon Region	7 206	226.56	10 265	7 316

Source: (BP, 2011; CONELEC, 2012c; OPEC, 2011)

The electric sector in the Ecuadorian Amazon is well characterized due to the vast quantity of information provided by the regulator agency of the electric sector (CONELEC). This agency keeps track of hydroelectric plant's operation, the progress of the construction of new plants and also provides data to estimate the hydroelectric remaining potential in the Amazon Region (CONELEC, 2012a, 2012b, 2012c). Self-producing thermoelectric plants in the Amazon Region are important to supply electricity to oil companies for production activities (CONELEC, 2012b). The hydroelectric and thermoelectric installed capacity in this region is presented in **Error! Reference source not found.**.

Table 17: Electric Installed Capacity in the Ecuadorian Amazon

	Hydroelectric (MW)		**Thermoelectric (MW)**
	Operating	**Under Construction**	
Ecuadorian Amazon Region	777	2 172	540

Source: (CONELEC, 2012b, 2012c)

Peru

Socio-economic data for Peru was obtained from Instituto Nacional de Estadística e Informática de Peu (INEI). Liquid hydrocarbons and natural gas production data by departments are found in the "*Anuario Estadístico de Hidrocarburos 2010*" (MINEM, 2011a). Hydraulic energy and electricity production by departments were calculated based on the data from energy production by power plants from COES (2011) and the data for isolated systems energy production from the "*Anuario Estadístico de Electricidad 2010*" (MINEM, 2011b). Data about the production of coal by companies and departments were collected from the "*Anuario Minero 2010*" (MINEM, 2011c). It was assumed that the production of firewood by departments is equivalent to firewood consumption and the former was obtained from the firewood consumption model used for the estimates of the National Energy Balance of Peru (MINEM, 2011d). Sugar Cane data was calculated from SNV (2007) that reports an estimate of land dedicated to this crop in some Amazonian departments.

Fossil fuel and non-energy oil production in the Amazon was obtained from the production data by refinery in MINEM (2011a). Biodiesel production was obtained in MINEM (2011d).

Fuel Consumption by departments was obtained from the SCOP system of OSINERGMIN. Since consumption of natural gas in the Peruvian Amazon is mostly related to the consumption in thermal power plants, this consumption, as well as the electricity consumption, was taken from (MINEM, 2011a).

Table 28. Primary energy production in Peruvian Amazonia

Energy Resource	**Primary Energy Production (10^3 toe)**	**Share (%)**
Oil	1 559	10.4
Liquids of Natural Gas	4 206	28.0
Natural Gas	6 685	44.5
Coal	38	0.3
Hydraulic Energy	749	5.0
Firewood	1 747	11.6
Sugar Cane	32	0.2
Total	**15 017**	**100**

Source: MINEM (2011a,2011b,2011c,2011d); COES (2011)

Table 19: Secondary energy production in Peruvian Amazonia

Energy Carrier	**Secondary Energy Production (10^3 toe)**	**Share (%)**
Diesel Oil	130	9.7
Fuel Oil	114	8.6
Gasoline and Naphta	160	12.0
LPG	32	2.4
Kerosene	31	2.3
Electricity	828	62.1
Non Energy Oil Products	33	2.4
Biodiesel	6	0.4
Total	**1 332**	**100**

Source: MINEM, (2011a, 2011c); COES, (2011);

Table 20: Energy Consumption in Peruvian Amazonia

Energy Carrier	**Energy Consumption (10^3 toe)**	**Share (%)**
Diesel Oil	943	24.2
Fuel Oil	83	2.1
Gasoline and Naphta	352	9.0
LPG	96	2.5
Kerosene	46	1.2
Electricity	358	9.2
Firewood	1 747	44.8
Natural Gas	272	7.0
Total	**3 896**	**100.0**

Source: OSINERGMIN (2012); MINEM (2011 b)

According to the power plants localization and their capacity the installed capacity for each department of Peruvian Amazon was calculated using data from COES and MINEM.

Table 21: Electric Installed Capacity in the Peruvian Amazon.

Boundaries by Country´s Amazon Region	**Electric Installed Capacity (MW)**	
Provinces/ States	**Hydroelectric**	**Thermoelectric**
Loreto		54
Ucayali		217
Madre de Dios		9
Cuzco	92	14
Apurimac	9	
Junin	366	5
Pasco	130	
Huanuco		
San Martin		21
Amazonas	6	4
Cajamarca	5	
Huancavelica	798	
Ayacucho	3	
Total	**1 409**	**323**

Source: COES (2011), MINEM (2011b)

Data for proven reserves of oil and natural gas for regions in Peru was obtained from the "Informe Anual de Reserva de Hidrocarburos 2010" (MINEM, 2011e). The hydraulic potential by basins in Peru was taken from the "Atlas del Potencial Hidroeléctrico del Perú" (MINEM, 2011f).

Table 22: Proven reserves of oil and natural gas and hydraulic potential in Peruvian Amazonia

Proven Reserves		**Hydraulic Potential**	
Oil and Liquids of NG (106 bbl)	**Natural Gas (106 m^3)**	**Total (MW)**	**Remaining (MW)**
885	337 856	197 222	195 813

Source: MINEM(2011e,2011f)

3. Research gaps for energy sector characterization

Bolivia

Bolivia has good information to characterize the energy sector in the Amazon. Nevertheless, sometimes it is not well disaggregated. For instance, "*Boletín Estadístico de Gestión 2011*" presents data related to oil, condensates and natural gasoline all aggregated by fields or by departments.

Information related to electricity generation is divided by interconnected power plants and isolated power plants. It is recommended to indicate the localization of each power plant in statistics in order to avoid searching for individual plants. In addition, statistics related to isolated systems are provided by plant and by companies, However there is aggregated information for "other co-operatives" and "other self-producers" which is significant, especially for a region such as Amazonia (for instance, neither the generation nor electricity consumption in the Pando Department could be identified). For electricity consumption, it is recommended to elaborate the data by departments.

Fuel consumption by departments is well indicated by the reports of YPFB. However, there is a lack of information related to fuel oil. Firewood consumption by departments could not be found. A simple model using data from National Census of 2001 had to be constructed to estimate this information.

There is not an official study on the hydropower potential of Bolivia, only isolated initiatives to make an inventory of hydropower projects by ENDE, among others. It is necessary to assess the hydraulic potential of the Bolivian Amazon. The report about gas reserves in Bolivia made by Ryder Scott (HB, 2010) is no longer available. This could be a temporary situation, since the government is expecting to launch a new study in 2013[19]. It is also recommended elaborating and making available geo-referenced information (shapefile format) about electricity and oil and gas chain infrastructure.

[19] http://www.hidrocarburosbolivia.com/bolivia-mainmenu-117/upstream/55785-bolivia-triplicara-reservas-de-gas-natural-en-tres-anos.html

It must be highlighted that the government is making efforts to elaborate departmental energy balances. According to the Ministry of Hydrocarbons and Energy of Bolivia, this study is expected to be published in 2012[20].

Brazil

Brazil has important up-to-date databases about activities in the oil and gas, electric and biofuels sectors. There was enough information to characterize appropriately the energy sector in Brazilian Amazonia at the level of detail used to compare different Amazonian Regions. However, a more detailed analysis would require information at a level of detail which is not available. More demand data is required to make a better characterization by sector and state. It´s also important to develop a geo-referenced system (GIS) covering not only the electric sector but also oil and gas infrastructure, as well as biomass use (firewood and energy crops).

Colombia

Several improvements could be made related to energy information in Colombia, especially in the Amazonia region. Coal production by department in Colombia is not found in a public document. A model had to be elaborated to estimate firewood consumption by department. UPME has relevant energy information at the national level. However there is a lack of public information related to fuel production by departments or by refineries. Also there is a lack of information about fuel oil, kerosene, jet fuel, LPG consumption by departments.

It should be highlighted that for isolated generation systems, the last information available by SSPD is from 2008. It is necessary to update this information (including the kind of fuel that is being used in these power units). It is recommended also for all countries assessed, but especially for Colombia, to inventory the storage fuel capacity of these systems in order to assess the autonomy before interruptions in the fuel supply, since Amazonia is predominantly supplied by non-connected small systems.

The hydraulic potential of Colombia was assessed in a study of 1979, it is recommended to update this study.

ANH made available the shapefiles related to oil E&P activities, which were useful for this study. Despite UPME and Ecopetrol having online maps with

[20] http://www.hidrocarburosbolivia.com/bolivia-mainmenu-117/energia/56087-balance-energetico-departamental-de-bolivia-2010-sera-presentado-en-las-proximas-semanas.html

electricity and oil & gas infrastructure, shapefiles could not be downloaded. Therefore, making this information publicly available for research purposes is recommended.

Finally, it is also recommended to elaborate information regarding energy consumption for each economic activity by departments.

Ecuador

The energy sector in Ecuadorian Amazonia was characterized using data from different years due to the lack of updated information for 2010. Actually there is no updated official information available about associated natural gas production and its use in the Ecuadorian Amazonia. There are only theses and presentations made by Petroecuador authorities showing mass balances of associated natural gas produced in operative Amazon oil fields (PAZOS, 2008; PRIETO, 2007). Available information about oil production is enough to make a balance of primary energy in Ecuadorian Amazonia, but this is not the case for associated natural gas. Although firewood consumption is important in the Amazonian Region there is no updated information about the amount of consumption by year and by province.

The Ecuadorian database for the energy sector is still limited to the national territory and there are no details for each province. Fundamental information, such as national energy balances, input–output matrix and annual reports of oil and gas sector are not updated periodically and do not provide details. For example, there is no report about associated natural gas production, use, venting, re-injection and processing for all the oil blocks in production.

Peru

The availability of information about the energy sector in Peru was above the average of the countries studied. However, it is recommended to separate energy production by departments to avoid the work of localizing each power plant by departments and summing up their energy production. It is also recommended to elaborate departmental energy balances annually in order to monitor the evolution of energy consumption and supply in the Amazonia Region.

Distribution among economic sectors of energy consumption by departments (excluding electricity) could not be found. The last publication that contains information about this is the “Balance Nacional de Energía Útil” of 1998 so an updated version is necessary. Finally, it is recommended that the government make publicly available the geo-referenced information ("shapefiles") of energy infrastructure in order to provide more tools to researchers and academic institutions assessing energy security in the country.

4. Research gaps regarded to climate change and vulnerabilities

The objective of this section is to provide research topics and information gaps needed for helping policy-makers make better decisions regarding improvements in energy security in Amazonia, when facing climate change direct and indirect effects. These are summarized by countries, as follows:

Bolivia

Bolivia is especially vulnerable to climate change since more than half of the country is within the Amazonia region and its low income population is more exposed to climate change effects.

Unlike the other countries assessed, the main cities of Bolivia such as La Paz, Cochabamba and Santa Cruz de la Sierra are located in the Amazonia region. Consequently these cities and their energy systems are more affected by extreme weather conditions such as landslides, intense rains, floods and higher temperatures.

It is strongly recommended for Bolivia to complete a risk assessment of the electricity transmission and gas pipelines for disasters caused by climate change effects.

It is important for Bolivia to evaluate the consequences of the melting of the Andes glaciers and its impact on hydropower plants. It is also important to collect more information regarding energy supply chains in less developed Amazonian departments, such as Pando and Beni, and to assess how climate change could affect the supply of fuels.

Since gas power plants based on natural gas are responsible for nearly 90% of electricity in the national grid, an assessment of the performance of gas turbines under higher temperatures is recommended in order to identify power losses and the capacity needed and cost incurred to compensate these effects.

Brazil

There is some information regarding the impacts caused by climate change in the Brazilian Amazonia. It still seems premature to conclude that the recent extreme weather events that happened in Amazonia occurred due to climate change. ANA, (2011) reported extreme floods in the Roraima State and unusual dry periods in the Acre State. Those events caused problems for electricity selfgeneration due to river transport problems that jeopardized the transportation of fuels from big cities to distant villages in the country side. There is high vulnerability to energy security at the local level due to the intensive dependence on river transport for bringing diesel for power generation aimed at rural electrification (BERMANN CÉLIO, 2012; CUNHA DA COSTA, 2004; IBP, 2012; REDCLIFT, 1994). There are also some impacts on the energy sector infrastructure that could be associated with the extreme weather events. For example, oil and natural gas pipelines in Amazonas State could be affected by floods or electricity transmission lines might be impacted by landslides.

Regarding climate change vulnerabilities, there are also some studies that analyse the interaction between climate change and impacts on energy security. For example, SOITO; FREITAS, (2011) published the paper "Amazon and the expansion of hydropower in Brazil: Vulnerability, impacts and possibilities for adaptation to global climate change" , LUCENA, et al., (2009) published the paper "The vulnerability of renewable energy to climate change in Brazil" and MAGNO, (2006) indirectly sets some questions about the relation between hydroelectric plants development in Amazon Region and their vulnerabilities to climate change.

Colombia

Colombia is vulnerable to climate change, especially because of the localization of its population in floodable zones in the coast and unstable terrains in the highlands. It also has a high recurrence and magnitude of disasters related to climate (PNUD 2010). Since the Colombian Amazon is within the Not Interconnected Zones (NIZ), climate change effects on energy supply could be critical.

Assessment of the logistics of fossil fuels supply chains in NIZ in Amazonia should be done in order to identify critical spots that could jeopardize the supply chain. Special attention should be paid with regards to the navigability of rivers and how climate change could affect it.

Risk studies considering the interruption of transportation ways (such as roads and waterways) should be done, in order to identify alternatives of supply, its costs and the necessary infrastructure.

It is recommended to evaluate the diversification of the energy matrix in the Colombian Amazon within the framework of climate change effects on fuel supply chain, since it is very dependent on diesel for electricity generation. For instance, the implementation of hybrid systems – photovoltaics -thermal – could be analyzed in order to reduce the imports of diesel from other departments and increase the use of "local" resources. Assessments of the production of biodiesel in the deforested areas of the Colombian Amazon for dedicated biodiesel generators in NIZ systems is also recommended in order to increase autonomy.

Ecuador

The first and the second Ecuadorian National Communications to the UNFCCC not only present a GHG emissions inventory but also analyse two issues related to climate change: vulnerability and adaptation and mitigation of GHG emissions (MAE, 2011, 2001). These publications give more importance to the effects of climate change in Highlands and Coastal Regions due to their higher concentration of population. Ecuador pays special attention to glacier retreat and sea level rise.

Regarding vulnerabilities and adaptation in the energy sector, according to the First National Communication, the watersheds most affected by exacerbation of dry seasons in the Ecuadorian Amazon Region are the Pastaza River and Napo River. In the first is located the Agoyan Hydroelectric plant (170 MW) and in the worst case scenario21 the Agoyan plant could be affected by a reduction of river flow of 23% during the dry season (MAE, 2001). According to the Second National Communication, the river flow variation trend for rivers in the Amazonian Province of Napo is a decreasing one. For example, hydroelectric plants placed in Amazon Region like El Carmen (8,2 MW), Loreto (2,1 MW) and Quijos (50 MW) would face a decrease in their river flow around 23,5% and 33% (MAE, 2011)

Although the Paute Hydroelectric Project (1.170 MW) is outside the Amazon Region, due to its fundamental importance in the country, the analysis of climate change impacts on it should be taken into consideration. In the First National Communication, the most severe scenarios showed a river flow deficit (up to 55%) between November and February, while the optimistic scenarios showed no deficit along the year (MAE, 2001). The reduction in river flow in this hydroelectric plant implies the higher use of thermoelectric plants based on oil products, increasing fuel imports and GHG emissions. On the other hand, the Second National Communication showed different scenarios where in all cases river flow increases between 14% to 36% in the Paute hydropower plant (MAE, 2011).

In 2008 the CONELEC and Minister of Agriculture (SIGAPRO) published a zoning study of electric infrastructure in Ecuador in areas vulnerable to natural disasters (CONELEC - SIGAPRO, 2008). This study indicates that Ecuador is highly vulnerable to climate change events, especially to natural disasters

[21] The first publication considered four scenarios of climate change (temperature rises between 1°C and 2°C and varying precipitation regimes between -15% and +20%).

exacerbated by climate change. The risk associated with these events is calculated as the product of gravity and vulnerability. Three maps of susceptibility (erosion, floods and landslides) were produced for phenomena linked to climate change. The conclusions show that in the Amazon Region (the riverbanks of Coca and Pastaza Rivers) are areas prone to flood due to river overflow and high precipitation. On the riverbank of Coca River there are several thermoelectric plants of self-producers that could be strongly affected by floods. Most of Ecuadorian Amazonia is slightly susceptible to landslide events.

Figure 1: Map of susceptibility to floods in Ecuador.
Source: (CONELEC - SIGAPRO, 2008)

The National Strategy to Climate Change (2012) indicates that some regions of Ecuadorian Amazonia (Morona Santiago Province) are prone to river overflow and that in rest of the Amazon region there are no regions prone to low precipitation (MAE, 2012).

Ecuador has developed some research projects whose preliminary findings indicate the relationship between climate change and energy security. These studies evaluated the regulation of ecosystem services (hydroelectric plants) and extreme events (floods) that could affect energy infrastructure in the oil and electric sector. Nevertheless, there is still a high level of uncertainty about the interrelation between climate change variables in Ecuador. Further studies and new simulations of climate change scenarios for each watershed are required.

Regarding the energy sector, the first and second National Communication presented some measures to mitigate GHG. There are three measures directly related to the Amazon Region: a) improving the uptake and use of associated natural gas from the oil industry, avoiding venting and flare; b)increasing natural gas use in thermoelectric plants; and, c) using natural gas as vehicle fuel (MAE, 2011, 2001).

Peru

As stated by the Second National Communication to UNFCCC, Peru is highly vulnerable to climate change, not only due to structural factors such as poverty and inequity, but also due to the expected impacts on ecosystems of global importance such as Amazonia and the Glaciers.

In terms of impacts in energy systems, the effects of extreme weather conditions and the melting of glaciers seem to be the most relevant and their consequences have to be assessed.

Peru intends to expand its oil frontier in the Amazon. Assessments of the increases in costs of E&P activities in light of more frequent and intense extreme weather events and assessing whether E&P infrastructure is well prepared for these effects are necessary.

Since mitigation policies might indirectly foster the use of relatively lower emission fuels such as natural gas, E&P in sensitive Amazonian biomes could be incentivized. Therefore, the elaboration of geo-referenced maps of exploration and production wells is recommended in order to contrast with conservation areas and indigenous communities.

Research to simulate the impacts of extreme weather events on energy transport infrastructure in Peru should be done, especially for the Camisea pipelines. Since the electricity generation of the country is strongly dependent on this pipeline, risk studies evaluating alternatives such as switching dual gas turbines for other technologies are strongly recommended. It is also recommended to conduct technical-economic analyses of transmission lines that supply Amazonian systems considering contingences due to weather events, evaluating alternatives such a standby generation or constructing new lines to increase reliability.

Regarding the glaciers, studies such as Barnett et al (2005) and Bradley et al (2006) state that climate change is affecting the glaciers and this could negatively impact hydropower. However the results of Baraer et al (2012) suggests that the melting of the glaciers could result in an increase in river flows on average over the next 100 years, with consequently positive impacts on hydropower. Therefore further studies on the impact of the melting of Peruvian glaciers and its effects on hydropower are needed.

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