LOOKING TO THE ANDES: LONG-TERM SCENARIOS OF OIL SUPPLY AND DEMAND FOR PERU, COLOMBIA AND ECUADOR

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Overview

In the last decade, the Andean countries (Peru, Colombia and Ecuador) have increased their petroleum production. In Colombia and Ecuador, oil production has increased significantly due to the exploration of new regions. Peruvian oil production grew from 115 kBPDC in 1990 to 150 kBPDC in 2012 due to the production growth of natural gas liquids of the Camisea project in the Amazon region. However, conventional oil production declined from 115 to 65 kBPDC. In the case of Colombia, for the same period oil production increased from 420 kBPDC to 935 kBPDC. This growth is mainly explained by the exploration of the region called “Llanos Orientales”. In the case of Ecuador, the production rose from 285 kBPDC to 505 kBPDC mainly due to the production in the northeastern Amazonia region.

Meanwhile, between 1990 and 2013 the GDP of these countries grew at rates between 4 to 7% p.a. (for Peru at 6.3% p.a., for Colombia, at 4.2% p.a., and for Ecuador, at 5.1% p.a.) (World Bank, 2013). This economic growth has led to an important increase in the gasoline (petrol) and diesel consumption, mostly associated with the vehicle fleet and thermal power generation.

Colombia and Ecuador crude oil and petroleum products’ exports represent 44% and 55% of their total exports, respectively. Net exports of these goods are estimated at US$ 27.3 and 11.1 billion, also respectively (Observatory of Economic Complexity, 2012). On the other hand, crude oil and petroleum products in Peru account for 14.5% of their imports. Net imports of these products are estimated at US$ 2.3 billion (MINEM, 2013a). In spite of the net trade position, these three countries are all implementing policies for replacing and, then lowering, petroleum products’ consumption, aiming at energy security, diversification and mitigation actions related to climate change.

This work aims at estimating the oil supply-demand balance of these countries up to 2030, according to many programs and policies that governments are implementing. The next sections present the policy measures that governments are implementing by sectors.

Residential Sector

Peru is implementing the “Natural Gas Massification Project”. This project comprises a liquified natural gas distribution system from the “Pampa Melchorita” plant to the cities to be supplied, regasification in each “measurement & regulation station”, and distribution to final users through gas pipelines. Eleven cities in the north and south of Peru are planned to be supplied (PROINVERSION, 2013a).

With regard to the households served with natural gas pipelines, the current administrations plan to increase them to 400 thousand until 2015 and 1.2 million until 2020. In addition, the Ministry of Energy and Mines is promoting the “Programa Nacional de Cocinas Familiares-Cocina Peru”. The goal is to distribute 1 million LPG cookers until 2016 in the framework of the National Plan for Universal Access to Energy 2013-2022 (R.M. No. 203-2013-MEM/DM). This substitution program offers, as main benefits, health care and environmental protection by replacing the use of firewood (MINEM, 2013c).
In Ecuador, the government is implementing the substitution of LPG cookers by electrical induction cook stoves. Nowadays, 92% of LPG is consumed by the residential sector (Ministerio Coordinador de Sectores Estratégicos, 2013). The introduction of 2.6 million electrical induction cook stoves are planned until 2017 to reduce the consumption of LPG in the residential sector (Ministerio de Electricidad y Energía Renovable, 2014).

**Services and Industrial Sector**

In Peru, the Referential Plan for Energy Use 2009-2018, approved by R.M. No. 469-2009-EM/DM, focuses on the optimization and modernization of 60% of the country’s industrial boilers by 2018. This has to be achieved by the implementation of good practices in operation (2%), air-fuel ratio control (3%), and purges’ automatization (1%).

In Colombia, the following initiatives will affect the industrial energy demand: a) electricity savings for mechanical drive, by providing useful tips for a better use of motors, as well as by replacing the current motors fleet with more efficient ones; b) boilers’ optimization, by promoting good operational practices; and c) efficient lighting, by replacing lamps in 500 industries. It is estimated that with the implementation of these actions the sector will save 11% of its final energy consumption (MINMINAS, 2010).

**Transport Sector**

In Peru, through Supreme Decree N° 059-2010-MTC of December 24, 2010, the Basic Network of Underground – Electric Massive Transport System of Lima and Callao was approved. Supreme Decree N° 009-2013-MTC modified the formed conforming six (06) referential lines. Currently, stretch 2 of the first line is in execution and the second line is in the bidding process. This underground line covers Lima’s East-West axis with a length of 27 km and a branch of 8 km. According to projections from the feasibility study (PROINVERSION, 2013b), line 2 will have 304 thousand users by 2018 (opening year), 662 thousand by 2020, and 1.16 million users by 2030. It is estimated a demand of 94 MW and 406 020 MWh by 2047.

In addition, the monorail massive transport system for Arequipa’s metropolitan area is currently under evaluation. It is expected to have a length of 14 km and supply an approximate demand of 314 thousand passengers per day (MTC, 2013a). Finally, the government aims at the goal of 400 NGV stations by 2020 in the framework of the “natural gas massification” plan (MINEM, 2013b).

In Ecuador, the transport sector demands 49% of energy and mainly uses petrol and naphthas (44%) and diesel oil (43%) (Ministerio Coordinador de Sectores Estratégicos, 2013). Public transportation initiatives like Quito’s underground system or Cuenca’s tram system aim to use electricity from 2016 onwards, displacing the use of liquid fossil fuels that are currently used in the transport sector.

In Colombia, the main initiative involves the technological shift of the automotive fleet, which purpose is to modernize the fleet under the criteria of adequating the vehicles’ features to the operative requirements of companies, as well as the establishment of better driving techniques. By implementing this action, by 2015 a 1.29% reduction in the energy intensity (GJ/distance) is expected for all the technologies in the transport sector (MINMINAS, 2010).

Additionally, the CONPES 3510 document, which provides policy guidelines to promote sustainable production of biofuels in Colombia, proposes the incorporation of the expected developments in the biofuels market as a variable for the transport’s infrastructure planning (DNP, 2008). Accordingly, Decree 2629 of 2007 stipulates that from January 2012 onwards the new vehicle fleet that requires petrol would have to be adapted to work normally using interchangeably either basic petrol, or a mix composed by 80% fossil fuels and 20% ethanol (E-20) (MINMINAS, 2007). In the case of the vehicle fleet that uses diesel or ACPM, vehicles should be adapted to use B-20 as minimum (MINMINAS, 2007).

**Power Generation**

In Peru, the National Plan for Universal Access to Energy 2013-2022 considers a program to replace incandescent lamps by compact fluorescent lamps (CFLs). 1 500 000 lamps will be distributed/sold with subsidy to low income households by 2016; 500 000 lamps are planned for public buildings; and 100 000 high pressure sodium (HPS) lamps will be replaced with LED or induction for street lighting (R.M. No. 203-2013-MEM/DM). Further, a law proposal is being analyzed to progressively eliminate from 2015 the imports, distribution, production, retailing and use of incandescent lamps. The time frame for this initiative should not exceed 2020 (DGEE/MINEM, 2013).
For electricity supply, Peru’s Ministry of Energy and Mines has commissioned to PROINVERSION to tender 1100 MW of hydroelectric power plants that would start operation by 2018/2019 (MINEM, 2013b). As a long run strategy, and according to the results of the study “New Sustainable Energy Mix and Strategic Environmental Assessment as a Planning Tool” (MEF, 2011), by 2040 the structure of the electricity mix will be: 40% hydroelectricity, 40% natural gas, and 20% renewable energy resources.

In the case of Ecuador, the main policies and programs that will affect the hydrocarbons demand refer to altering the electric power generation mix. Currently, electricity accounts for 13% final energy use. The current electricity mix has the following structure: hydroelectricity (53%), thermal generation (45%), international interconnections (1%), non-conventional renewable energy (1%) (Ministerio Coordinador de Sectores Estratégicos, 2013).

Until 2017, large hydroelectricity facilities, known as Ecuador’s “emblematic” electricity generation projects, will be implemented. Hence, it is expected that hydroelectricity will raise its share in the electricity mix to above 90%, diminishing the thermal generation share and, thus, fossil fuel demand (mainly fuel oil, diesel, and natural gas). Currently, only the generation units of CELEC EP Termogas Machala (255 MW) use natural gas but the potential for using natural gas in other units with gas turbines (currently using diesel) remains. In this case, the diesel demand would decrease, while the demand for natural gas would increase.

In Colombia, the following initiatives from the residential sector are expected to affect electricity demand: Light bulbs replacement and efficient energy use in domestic fridges and air conditioners appliances. The objective of the first initiative is to replace 32 millions of incandescent light bulbs with compact fluorescent lamps in the strata 1, 2 and 3. The penetration of these efficient light bulbs will reach 20% of the light bulbs in the Colombian households. The objective of the second initiative is the replacement and scraping of two million fridges (MINMINAS, 2010). Interestingly, according to MINMINAS (2010), fridges account for 20% to 50% of the energy consumption of strata 1 and 2, and 26% of stratum 3.

These actions can save 25.5% of the electricity consumed by the residential sector (MINMINAS, 2010). Similarly, for the commercial sector a program of diffusion, promotion, technological application, and good practices in lightning systems, refrigeration, and air conditioning should be highlighted. This program aims to replace 294,000 commercial refrigeration appliances and to conduct energy efficiency projects in illumination of public buildings (hospitals and schools). This program can save 10% of the electricity consumed by the commercial sector (MINMINAS, 2010).

The following table summarizes the Policy actions considered for the countries assessed.
Table 1. Government Programs of Peru, Colombia and Ecuador to be modeled in the Policy Scenario.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Peru</th>
<th>Colombia</th>
<th>Ecuador</th>
</tr>
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<tbody>
<tr>
<td><strong>Industrial, Public and Services Sector</strong></td>
<td>- Operational improvements in 60% of industrial boilers by 2018.</td>
<td>- PROURE measures (an estimated reduction of 11% and 10% in the energy intensity for the industrial and services sector) (MINMINAS, 2010).</td>
<td></td>
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<tr>
<td><strong>Power Generation</strong></td>
<td>- Lighting Program (1.5 million and 0.5 million LCFs in households and public buildings by 2016; 100 000 LEDs in public lighting). - NUMES Plan for Power Generation (Aims an energy mix for Power Generation in 2040: 40% NG; 40% Hydro; 20% Renewable Energy)</td>
<td>- Replacement of 32 million incandescent lamps by LFC (MINMINAS, 2010). - Substitution of 2 million old refrigerators by efficient refrigerators (MINMINAS, 2010).</td>
<td>- Hydro Power Generation Expansion (more than 90% of electricity produced by hydro power plants in 2017).</td>
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**Methods**

**OIL SUPPLY**

For modeling the future supply of oil, this study updated the Multi-Hubbert modeling of Chavez-Rodriguez et al (2013) and Gonzalez et al (2013) for the cases of Peru and Colombia, respectively. These works adopted 2P reserves as the Ultimate Recoverable Resources (URR) for the conservative scenario, and higher URR for optimistic scenarios. In
addition, for Ecuador a new Multi-Hubbert was made based on global historical production taken from (OLADE, 2014), and reserves data taken from MRN (2014). Table 2 shows the URR for the Multi-Hubbert modeling.

Table 2. URR adopted for the Multi-Hubbert modeling by country. Source: (MINEM, 2013a), (MINEM, 2013), (OLADE, 2014), (MRN, 2014).

<table>
<thead>
<tr>
<th>Country</th>
<th>EUR-Conservative Scenario (MMBbls)</th>
<th>EUR-Optimistic Scenario (MMBbls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td>3,885</td>
<td>8,637</td>
</tr>
<tr>
<td>Colombia</td>
<td>16,718</td>
<td>49,765</td>
</tr>
<tr>
<td>Ecuador</td>
<td>6,776</td>
<td>10,247</td>
</tr>
</tbody>
</table>

DEMAND MODELLING: BASE YEAR

Residential Sector

For Peru, a bottom-up approach was used. The household/population index based on INEI (2007) results were used. Based on INEI (2013), the distribution of household by fuel used for cooking purposes and by urban and rural areas was estimated. To estimate the households supplied with natural gas, the statistics of residential connections published by OSINERGMIN (2013) were taken, assuming that there is natural gas distribution only in urban areas. The average value of 1.1 cylinder of LPG of 10kg per month per household for Peru reported by Vásquez et al.(2014) discounted by the estimated value for water heating purposes was used for the energy intensity for cooking. For cooking with firewood, the energy intensity reported in MINEM (2000) was used. We used the same energy intensity for cooking of firewood for coal and “other sources”.

The values reported by Vásquez et al. (2014) were used also to estimate the households that use different energy sources for water heating purposes. We adopted the energy intensity for water heating of EPE (2010), 17 m$^3$ of natural gas per month per household during 7 months per year. The energy equivalence of natural gas energy intensity was used for LPG. For firewood and other sources we applied a 56% higher energy intensity than the energy intensity of natural gas and LPG, in order to take account the efficiency penalties. LPG consumption in the residential sector resulted in 34 571 TJ, higher than 29 793 TJ estimated in MINEM (2014), in order to adjust total values, LPG consumptions of commercial, industrial and metallurgic-mining sectors were reduced proportionally to their consumptions.

The modeling of the residential sector for Colombia also divided the households by urban and rural population, assuming that in urban areas all household have access to electricity whereas in rural areas the population should be divided by connected to the grid and not connected to the grid. Household data for the base years and projections was obtained from DANE (2010).

The National Energy Balance of Colombia was used to describe the energy services in urban households by three categories: thermal uses, refrigeration, and other electricity uses. For the rural sector only final energy use per household and by fuel was modeled based on the National Energy Balance data and the study of the energy consumption in rural areas of Pinto (2004).

In Ecuador, the residential sector was not divided per areas. Total population for base year and projections were taken from INEC(2012). The residential sector energy uses was divided by two categories: thermal uses, electricity uses. The energy intensity and the fuel shares (for the case of thermal uses) were estimated based on energy consumption values for the residential sector of the National Energy Balance of Ecuador (MICSE, 2014). Same as the case of Ecuador and Colombia, we employed energy intensities on sectorial GDP basis.

Transport Sector

The ASI methodology (Schipper et al., 2000) was used to modelling the transport sector for the three countries. As our aim is not to calculate the emissions, we applied an ASI-based equation as follows:

$$E_i = \sum_{j=vehicle\ type}^{vehicle\ type} A_{i,j} S_{i,j} I_{i,j,k}$$
Where:

\( i = \text{Type of fuel.} \)

\( E_i = \text{Fuel consumption (gal, } m^3) \).

\( A = \text{Activity (use of the vehicle – km/vehicle-year)} \)

\( S = \text{Structure (number of vehicles by modal – vehicles)} \)

\( I = \text{Energy intensity (average efficiency by vehicle – gal/km, } m^3/km) \)

In the case of Peru, the statistics of MTC-OGPP (2014a) were used to quantify the number of vehicles per modal and type. To distribute them by fuel used, we used the distribution of the accumulated vehicles along 2007 to 2012 reported by MTC-OGPP (2014b). The expanded number of vehicles by type and by fuel does not fit with the numbers reported for NGV (natural gas vehicles) by Infogas (2014). In order to solve this problem, the same distribution by vehicle type of the accumulated from 2007-2012 was used, and then they were expanded by the NGV number from Infogas (2014). In addition, the number of natural gas buses was fixed using the values reported by PROTRANSPORTE (2012) for the “Metropolitano” transport. The differences from the initial calculation and the expansion to fit the NGV was distributed among the gasoline and diesel vehicles proportionally to the distribution of MTC-OGPP (2014b).

For the efficiencies of vehicles, Annex II of MICSE/ENERINTER (2013)’s efficiencies were adopted. The average distances travelled per month and the number of days of use per month reported by Palomino (2012) were taken as reference, however they were selected arbitrarily among the type of vehicle and type of fuel\(^1\), in order to meet the fuel demand reported in MINEM (2014) for transport and public sector.\(^2\)

The first estimates showed a lower consumption of LPG than the reported by MINEM (2014) for the transport sector. For this reason the LPG fleet was expanded in order to attend that value fixing the buses, trucks and tractor trucks that used LPG reported in the 2007-2012 period MTC-OGPP (2014b), considering that this is a technology recently introduced in Peru. The LPG vehicles added were extracted from the gasoline and diesel vehicles with the same methodology that was applied to NGV before.

For the consumptions of fuel oil and jet fuel for maritime and air transport, energy intensity on a GDP country basis (INEI, 2014) was adopted to meet the consumption of these fuels in the transport sector reported in MINEM (2014).

For Colombia, the characterization of the vehicle fleet was based on the data of MINTRANSPORTE (2011). The consumption by type of vehicle and by type of motor (Otto, Diesel) was taken from UPME (2012a). The average age of the vehicles was taken into account to have an approximated estimate of the specific fuel consumption. Distances travelled from UPME (2012a) by type of vehicle were taken into account as well.

For the air, rail, fluvial and maritime transport sectors the GDP by sectors reported by DANE were adopted as Activity level, while that for the fuel consumption was used the statistics of UPME (2014).

For Ecuador, the structure of the vehicle fleet was based on data of INEC (2014). For the efficiencies of vehicles and distances travelled, value from the Annex II of MICSE/ENERINTER (2013) was taken as a reference at the beginning. In order to meet the demand of fuels reported by MICSE (2014), distances travelled were adjusted. For the fuel oil and jet fuel for maritime and air transport, the same methodology as in the case of Peru was used for Ecuador.

**Industry, Public and Services Sectors**

In Peru, the mining-metallurgic, agriculture and livestock, fishing and industrial sectors were modelled according to the energy intensity by source, based on MINEM (2014)’s data and sectorial GDP (INEI, 2014). The LPG intensity consumption for the commercial, industrial and mining-metallurgical sectors was discounted in order to meet the total LPG consumption in the country due to the residential sector LPG consumption differences with MINEM (2014). For the public sector an energy intensity on a population basis was used.

\(^1\) According to Palomino(2012)’s results, there are higher distances travelled and days used per month when a vehicle uses LPG and natural gas than with gasoline and diesel.

\(^2\) It was assumed that the share of gasoline and diesel consumption reported in MINEM (2014) were for transport purposes.
The same methodology was applied to model the Colombian industry, public and service sectors, GDP sectorial data was obtained from DANE (2014), and the energy consumption by fuels in this sectors was taken from UPME (2014).

In Ecuador, the industry structure was modeled by activities of the Manufacture Survey of 2010 (INEC, 2012b). In this study, the consumption of fuels by activities is also reported; this structure was adopted to update the energy consumption according to the National Energy Balance values (MICSE, 2014).

**Power Generation**

To model the power generation sector in Peru, the installed and effective capacity, the energy production and the efficiency by technologies and by source were taken from COES (2013). The electricity demand and the load duration curve were also obtained from this source. For the case of auto-producers, the consumption of fuels published in MINEM (2014) was kept constant.

In the case of Ecuador, data of CONELEC (2014) were used for the capacities and the energy production by technology and source. The efficiency of the technologies of COES (2013) was used for Ecuador as well. The fuel consumption of auto-producers was obtained from MICSE (2014), and it was maintained constant as in the case of Peru.

In Colombia, the data for installed and effective capacity, energy production and efficiency by technologies and sources were taken from XM (2014). Auto-producers correspond to 3% of the electricity production and they were divided by technologies and by fuel sources.

**FORECASTING DEMAND: BUSINESS AS USUAL AND POLICY SCENARIO**

In this section we depict the methodology and assumptions used to model the business and usual and policy scenario by sectors for the three countries.

**Residential Sector**

The population forecast (INEI, 2009) by urban and rural areas was used for the household projections. For the baseline scenario the fuel share of the base-year was maintained for cooking and water heating services.

For the policy scenario, the “natural gas massification” policy of increasing natural gas connections for households until 2016 was modeled. Furthermore, in the household with new connections, the LPG consumption was displaced by natural gas.

Given this policy, the distribution of 1 million LPG cookers until 2016 was added considering a distribution of these kits proportionally to the firewood and other biomass users in the urban and rural areas. For water heating, the proportion of household users of water heating of the household that use the energy source for cooking estimated in 2012 (Vásquez et al., 2014) was maintained.

In Colombia, the household projections by urban and rural areas were taken from DANE (2010). For the baseline scenario, the energy intensity for all the energy services was maintained. The policy measures of lamps substitution will be depicted in the policy measures that impact fuel consumption in power generation.

In Ecuador, the population projection was taken from INEC(2012). The fuel shares and energy intensities were kept constant for the baseline scenario. In the policy scenario, the implementation of the substitution of 2.6 million LPG cookers by electrical induction cooks stoves was modeled interpolating until 2017. The values presented by MEER, (2014) were used for the energy consumption of LPG by household and the projected consumption of electrical induction cook stoves by household.

**Transport Sector**

For the baseline projections in Peru, the 4 last years increasing rates (2009-2012) by type of vehicle (MTC-OGPP, 2014a) were taken for projections until 2020. The addition of new vehicle were divided by fuel used in the vehicle with the proportion estimated in 2012 (MTC-OGPP, 2014b), excluding the NGV.

For the NGV the numbers of vehicles reported by Infogas (2014) for 2013 were adopted. In the baseline scenario the same NGV fleet is maintained without increasing after 2013.

For the 2020-2030 forecast, the lower value between the increasing average rate from 2000-2012 and the increasing average rate from 2009-2012 by vehicle type was adopted (MTC-OGPP, 2014a).
In the policy scenario, for the “natural gas massification” in transport policy, the goal of NGV stations of the government until 2020 was modeled using a value of 760 new vehicles/NGV station. This resulted of a linear least square fitting passing by 0, based in the data of Infogas(2014) for the period 2005-2013. The increases of the NGV vehicles is distributed according the distribution by type of vehicle that were licensed in 2012 (MTC-OGPP, 2014b), furthermore the number of new NGV vehicles discounted the vehicles projected in the baseline. The differences were distributed among the gasoline, diesel and LPG vehicles.

To estimate the impact of alternative modals as the subway projects, the passenger-km/vehicle-year based on the distances travelled and days used reported by Palomino (2012), load factors (passenger/vehicle) for “other Latin American countries” of the MoMo Lite model (Fulton and Kaneko, 2010) by type of vehicle aiming to estimate the passenger-km/year distribution by type of vehicle.

In order to estimate the impacts of the modal substitution, the passenger demand for the Line 2 was obtained from PROINVERSION (2013b), for the other 4 new Subway Lines we used the passenger demand estimated in JICA (2013), the length of the different Subway Lines were taken from Consorcio Subway de Lima(2013) assuming for the average travelled distances the half of the length of the Line respectively. For the Arequipa’s monorail, the information indicated by MTC (2013a) was taken for the passenger demand and the length of the projects.

For the start year of operation for the Line 2 this study adopted the data of PROINVERSION (2013b), for the other lines and the monorail, the start year of operation was estimated based on statements of civil servants in media about the auction and the implementation.

According to Doll and Balaban (2013) a common criticism leveled against all subways is that they have experienced ridership far lower than what was predicted. This hypothesis could be observed also in the passenger demand projected for the Line 1 in the studies of AATE (1998) and JICA (2013) and the real ridership observed in 2012 (MTC, 2013b), the month with higher ridership in that year actually corresponded to 47% of the demand estimated in (AATE, 1998).

To take account this hypothesis in consideration, we adopted a conservative factor of 60%.

The passenger-km of the subway projects was divided as follows: 80% public transport users, and 20% particular vehicle users. Additionally, we assume that since 2022, when the Lines 3 and 4 begin to operate, the shares for subway users will be: 70% public transport users and 30% particular vehicle users.

The distribution of the passenger-km shifted to the Subway system was removed from vehicles (excluding the NGV vehicles) according to their participation in the passenger-km by category: public transport and particular use. For the Quito Subway we applied the same approach by passenger-km. We obtained estimates of projected passenger users and average distances travelled. It was used a modal shift of 85% from public transport and 15% of particular vehicle users. For public transport it was considered just modal shift from buses, considering that all of them operate with diesel. For particular vehicles it was distributed among the consumption by fuel at 2011.

In Colombia, the projections of the vehicle fleet were made based on the trend used in the Cross Section model of (Di Sbroiavacc and Dubrovsky, 2011). In this study the authors used the expected evolution of the GDP per capita, population-vehicle relationships, commercial developing (Di Sbroiavacc and Dubrovsky, 2011). For the mass transit in Colombia, the Bogota systems (Transmilenio), Medellín (Metroplus), Pereira (Megabus), Cali (MIO) and Barranquilla (Transmetro) were considered. The projections of the lanes and the feeders took into account the expansion data reported by the reports of the companies and projections based on historic data.

In the case of Jet-fuel and Bunker oil consumption for air and maritime transport respectively, for all of the three countries a top-down methodology was used. For the case of Peru and Colombia, correlations between the Jet-fuel consumption and the GDP were used. In Colombia this was also performed for the bunker Consumption. For the case of bunker for Peru and Fuel Oil and Jet Fuel for Ecuador, intensities based on national energy balances (MICSE, 2014; MINEM, 2014) and GDP were used.

For the Policy Scenarios of Colombia, a 1.29% reduction of the energy intensity for all technologies in the transport sector was used according to MINMINAS (2010) for a period of 10 years. Additionally the mandatory ethanol and biodiesel mix stated in MINMINAS (2007) was modeled.

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3 The assumed modal shift from public transport is higher than the reported by (Vuk, 2005) for the Madrid subway (50%), the new subway in Athens (56%), the Crydon Tramlink (69%) and the Manchester Subwaylink (50%), however it is lower than the considered for the Copenhagen Subway (72%) and the Quito Subway (85%).
Industry, Public and Services Sectors

For all three countries the baseline scenario was projected under an energy intensity basis and the future evolution of GDP. For the Policy Scenario in Peru the improvement of the operation of 60% of the boilers in the country by 2016 was modeled. For that purpose, a reduction of the energy intensity of 3.6% \(^4\) was considered for the consumption of natural gas and fuel oil in the industrial sector. In the case of Colombia, for the Policy Scenario the actions depicted in MINMINAS (2010) for the industrial and commercial sectors were considered, meaning a reduction of 11% and 10% in the energy intensity respectively for all energy sources in a period of 10 years.

Power Generation

To model the expansion of power generation in the short term for both scenarios, the power generation projects planned for 2013-2016 from COES (2012) were considered. These are projects in construction or planned with high certainty to be developed, most of these projects have a contractual date for the commercial operation entrance based on auctions and concessions. For the long term baseline, the distribution of capacities by technology and by fuel planned at 2016 in COES (2012) was maintained to expand the generation until 2030. A reserve margin of 15% was adopted to expand the power generation. The electricity demand forecasted in COES (2012) was used for the baseline scenario. For the policy scenario, we used a structure for the expansion of capacity that would result in an electricity supply based in 40% Hydro, 40% Natural Gas and 20% Renewable Energy Resources in 2040.

The power expansion for Ecuador in the baseline scenario was modeled based on the same capacity structure reported in CONELCE (2014). For the policy scenario the expansion plan of MEER/CONELEC (2012) was considered, including the major hydro power plant Coca-Codo Sinclair (1500MW).

For power generation in Colombia, we used the expansion plan of UPME (2012b) for both scenarios.

Additionally, actions by the demand side that could impact the fuel consumption in power generation were modeled. For Peru, the substitution of 1,500,000 and 500,000 incandescent lamps by CFLs in households and public buildings respectively, and the distribution of 100,000 LEDs in public lighting were modeled interpolated from 2012 to 2016. For Colombia, we considered in the policy scenario the substitution of 32 million incandescent lamps for CFL with an interpolation until 2015 that was modeled decreasing the energy intensity in electricity. We adopted an energy consumption of 73 kWh/year and 26 kWh/year for incandescent lamps and CFLs respectively. For public lighting, we considered the values reported by NOWAXLED (2014) for HPS lamps (1179 kWh/year) and LEDs (242 kWh/year). In addition in Colombia, for the policy scenario, the replacement of 2 million old refrigerators by efficient refrigerators for a period of 10 years was modeled.

In Ecuador, the distribution of 2.6 million electrical induction cook stoves until 2017 was modeled using an electricity consumption of 100 kWh/month-household (MEER, 2014).

Results

The following figures shows the baseline scenario demand of oil products, biofuels and natural gas. We present the figures including biofuels and natural gas because they are direct competitors with the oil products.

\(^4\) 6% of the 60% of the boilers.
Figure 1. Oil Products, Biofuels and Natural Gas Consumptions in the Baseline Scenario for Peru

Figure 2. Oil Products, Biofuels and Natural Gas Consumptions in the Baseline Scenario for Colombia.
In the baseline scenario Diesel and Gasoline will increase significantly in the period assessed, mainly driven by the increasing demand of passenger and freight transport.

In Peru, the growth of trucks fleet for freight transport are the main driving force behind the increasing demand for diesel. Additionally, the growth of the SUV, which had an average growth rate of 15.4% in the the period of 2009-2012, will contribute significantly to the increase of gasoline consumption in this country.

The increased participation of natural gas in the transport for the baseline scenario of Colombia will mitigate the increasing demand of diesel and gasoline in urban transport for passenger and freight. The lower growth in Colombia compared with the other countries is explained by the model for forecasting which resulted in a lower growth rates of the transport fleet when compared to the other countries.

For the case of Ecuador in the baseline scenario (and in the policy scenario as well), no ethanol or biodiesel consumption are considered. The fuel oil consumption in the baseline scenario is explained by the power generation plants, as this country has no gas power plants such as Peru and Colombia, and in the baseline scenario the hydro power expansion is reduced.

Findings of the Policy Scenario for each country and the Baseline Scenario are showed in the following figures.
Figure 4. Differences in Energy Consumptions by Source between the Baseline and Policy Scenarios for Peru.

Figure 5. Differences in Energy Consumptions by Source between the Baseline and Policy Scenarios for Colombia.
As can be seen in Figure 4, in the Policy Scenario the implementation of the 5 Subway Lines in Lima and the Arequipa Monorail reduce diesel and gasoline consumption. We estimate that in 2030 these projects will substitute the equivalent to 136 thousand of particular vehicles and 41 thousand vehicles for public transport. These lasts have the highest consumptions of diesel.

The Natural Gas Masification Plan for the transport sector, when completed in 2020, will bring reduction in the order of 1.1 Mboe of gasoline, and 0.2 Mboe of diesel and LPG for each one.

There was also a net reduction of LPG consumption in residential sector, this means that reduction caused by the “Natural Gas Massification” program for the residential sector overcome the increase of LPG consumption caused by the “Cocina-Peru” program.

The contribution of the NUMES program for the reduction of fuel consumption of power generation was estimated in around 2 Mboe/year of diesel for the next decade compared to the baseline. However this program increased the consumption of natural gas and NCRE (non-conventional renewable energy) in detriment of hydro power plants. The Lighting Program resulted in marginal reductions of diesel (in the order of 50 kboe/per year).

The main reductions of oil products demanded in Colombia were achieved by the increase in the ethanol and biodiesel blends with gasoline and diesel respectively. The reductions resulted of the PROURE implementation program for the transport had impacts for the reduction of gasoline and diesel consumption in the order of 500 kboe in 2030 for each fuel. The PROURE program in industry and the efficiency lighting and refrigeration had reductions in the power generation consumption of around 400 kboe of fuel oil in 2030, however they had a greater impact in the consumption of hydro and coal for power generation. The PROURE program in the industry achieved reductions of 0.5 Mboe in the industry in 2030 and slightly reductions of fuel oil (40 kboe) and crude oil (170 kboe).

In the case of Ecuador, it is remarked the significant impacts in the reduction of fuel oil consumption for power generation that will be achieved by the Hydro Power Generation Expansion, this expansion plan also would reduce the natural gas consumption in power generation. The “Cocción Eficiente” program when completed in 2017 will bring savings estimated in 3.8 Mboe of LPG, the increase in the electricity demand caused by the entrance of 2.6 million electrical induction cookers caused slightly increases in fuel oil consumption in power generation, however the operation of Coca-Codo Sinclair power plant will cope this effect. The Quito Subway also will bring considerable reductions, in 2030 the diesel and gasoline consumption will be reduced in 1.1 Mboe and 0.4 Mboe respectively.

The following curves shows the Supply Oil Scenarios (Conservative-Optimistic) and the Baseline and Policy Scenarios for oil products demand. For the case of Peru the supply scenarios only consider crude oil production, they do not include the natural gas liquids.
Figure 7. Supply-Demand Curve for the Baseline and Policy Scenario for Peru.

Figure 8. Supply-Demand Curve for the Baseline and Policy Scenario for Colombia.
It seems that Ecuador has already reached peak oil, and its oil supply curve tends to decline both in the optimistic and conservative scenarios. On the other hand, even in the policy scenario, its oil demand will exceed the supply as early as in 2020 (conservative oil supply) or as late as in 2028 (optimistic oil supply). This highlights the importance of Ecuador’s strategy to diversify their energy mix from the supply side, and its efforts to shift their production and consumption matrix according to energy scenarios that include renewable sources.

In the case of Colombia, the conservative oil supply curve suggests that it will reach peak oil as soon as in 2015. However, and in contrast to Ecuador’s case, Colombia has more years on their advantage before its demand surpasses the oil supply (late 2020s in a conservative scenario). This represents opportunities for Colombia to plan and implement a progressive set of policies to diversify their energy mix from the supply side, and promote energy efficiency from the demand side.

Finally, in the case of Peru its demand exceeds its oil supply curves in all scenarios. This highlights the importance for a policy portfolio with effective demand side measures and the necessity of an international strategy to secure energy imports. According to this study, Colombia and Ecuador have the theoretical capability of contributing to fill Peru’s gap at least during the next decade. Overall, the three Andean countries could learn from each other from the implementation of their energy policies, especially from the demand side where more similarities can be found in the idiosyncrasy of the consumers in terms of behavioral patterns, a key aspect to be considered when designing demand side energy policies.

**Conclusions**

The Governments of the assessed Andean countries are implementing actions, such as the “Natural Gas Massification” plan of Peru, the “Cocción Eficiente” Program of Ecuador or the increasing of biofuels in Colombia, the Subway Lines in Peru and Ecuador, the Hydro Power expansion plan in Ecuador, or the efficient lighting and refrigeration program in Colombia- that will result in reductions of oil products consumption. These actions will also contribute to the energy security, the diversification of the energy mix and climate change change mitigation.

Our baseline projections shows that the demand of oil products in 2030 will be nearly twofold the demand of 2012. The diesel and gasoline are the main fuels required driven by the transport sector demand. In Ecuador, in the baseline scenario there is a significant growth of fuel oil consumption for power generation if the major hydro power plants are not constructed.

Should the governmental programs are implemented, there would be accumulated savings of 121 Mboe, 142 Mboe, and 214 Mboe of oil products for Peru, Colombia and Ecuador, respectively. Remarkably are the reductions achieved by the Subway Lines program in Peru, the increasing of biofuels blends in Colombia and the Hydro Power expansion plan in Ecuador.
The simulated supply-demand scenarios show that Ecuador and Colombia could change the net exporter position to a net oil importer position before 2030. This highlights the importance of implementing the current policy programs and also addressing more aggressive actions to cope with the increasing oil products demand. Furthermore, it suggests the need of making investments to promote the diversification of the energy supply with other energy resources such as natural gas or biofuels.

Further studies are needed to assess the economic impact of these scenarios for these countries. Economic policies have to take into consideration that oil and oil products are the main exporting goods of Colombia and Ecuador, and there are probable scenarios that these net exports could be offset by the increasing demand. In addition, in the case of Peru the negative oil trade balance will increase and this could decelerate the expected economic growth.

Finally, it is necessary to recognize the limitation of this work, as the fact that it is not considered the infrastructure and the current processes in the refineries of these countries that could explain the current importation and exportation, as well as the crude oil consumed in the transformation processes.

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