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Energy-mix Scenarios for Bolivia

Escenarios de la matriz energética para Bolivia

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Abstract

Nowadays the Bolivian energy-mix is misbalanced due to the primary production of energy, which is focused in gaseous hydrocarbons, whereas the consumption is intensive in liquid hydrocarbons. At the same time the Bolivian electric system is mainly thermo, while the country present high hydro potential. In this framework this document makes reference to the trending evolution of the Bolivian energy-mix and proposes a mitigation scenarios based on the a) reduction of liquid hydrocarbons consumption; b) and introduction of renewable energies an energy efficiency measures in the electric system. Methodologically, the construction of such scenarios is developed by a bottom-up simulation for the time span 2007-2025. We based our estimations on previous results we obtained in the project Renewable Energies Generation in South America (REGSA), founded by the European Union.

Keywords: LEAP, renewable energy, energy mix, hydrocarbons and electricity.

Resumen

En la actualidad, la matriz energética de Bolivia se encuentra desbalanceada debido a la producción primaria de energía, la cual se enfoca principalmente en la producción de hidrocarburos gaseosos. Sin embargo, el consumo es en cambio intensivo en hidrocarburos líquidos. Adicionalmente, el sistema eléctrico en Bolivia se caracteriza principalmente por la generación termoeléctrica, siendo que el país cuenta con un potencial para la generación

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hidroeléctrica. En este contexto, este trabajo referencia la evolución de la tendencia de la matriz energética de Bolivia y propone escenarios de mitigación basados en: a) la reducción del consumo de hidrocarburos líquidos; b) introducción de energías renovables y medidas de eficiencia energética en el sistema eléctrico nacional. La construcción de estos escenarios, se desarrolla metodológicamente mediante simulaciones tipo *bottom-up* para el periodo 2007-2025. Las estimaciones presentadas en este documento, se basan en resultados anteriores que los autores obtuvieron en el proyecto de Generación de Energías Renovables en América del Sur (REGSA), fundada por la Unión Europea.

Palabras clave: LEAP, energía renovable, matriz energética, hidrocarburos y electricidad.

Classification/Clasificación JEL: O14, Q2, Q3, Q32, Q42, Q43.

1. Introduction

The supply side of the Bolivian energy mix is composed by fossil fuels, while in the demand side is mainly fossil fuel derivatives, electricity and biomass. In the last years the hydrocarbon sector shows a constant reduction in oil production explained by a decline of the wells and low levels of investment. Aliaga (2012) calculate low levels of capital expenditures (CAPEX) since 2007 for this sector. As a consequence of the low investment rates, gas reserves started to decrease significantly since 2005. This situation opens a critical scenario; in which it is possible that Bolivia will present problems in order to match production and consumption. This scenario implies from one side a potential increase of diesel imports, and from the other side difficulties to fulfill export of natural gas to Brazil and Argentina (Aliaga and Mercado, 2009).

In the case of the electric sector, Bolivia is segmented vertically in three activities: generation, transmission and distribution. The companies are regulated due to its natural monopoly structure. Nowadays, the Bolivian electric system has a variety of gas-fired power plants with an effective capacity that reaches the 854 MW. Hydroelectric centrals by its side reach an effective capacity of 372 MW while the gross generation of the whole system is 3,972,911 MWh[1]. According to Aliaga (2012), this structure is biased towards thermo generation, because the sector does not reflect the real generation opportunity costs of the entire energy-mix. This situation obeys to the existence of a subsidized price of natural gas for thermo generation that distorts market signals.

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[1] Statistical Yearbook of the Electric Industry in Bolivia: Year 2011.

This background shows the necessity for a better formulation of governmental policies in the energy field. We require tools based on a systemic focus that takes into account the interrelations between the energy system, the economy, the society and the environment. In this framework, this research seeks to contribute to a better understanding of the energetic situation of the country and to provide elements for the construction of an energy policy. We plan to generate a base scenario that prospects the Bolivian energy system up to year 2025 and propose a mitigation scenario. To achieve these objectives, we will model with LEAP (Long Range Energy Alternatives Planning System).

The organization of the paper is as follows. In the next section we discuss the structure and characteristics of the energy mix in Bolivia and describe the main changes that has taken place in recent years. In Section II we present a methodological review about some approaches found in the economic and engineering literature about the topic. In Section III we present and detail the main characteristics of the model and subsequently in Sections IV and V, we present the main results and forecast based on the methodology. Finally, in Section VI, the concluding remarks are detailed.

2. The Bolivian Energy-Mix

Energy production in Bolivia is characterized by its high dependency of primary fossil energy resources. A review of the characteristics of the National Energy System (NES, hereafter) by analyzing the National Energy Balance[2] (NEB, hereafter) can describe the flow of the main energy aggregates of Bolivia.

2.1. Evolution of Energy Aggregates

According to the NEB, there has been significant growth in the production of primary energy. This significant increase is evident in the increase of: 40782.19 Kboe produced in 2000, 105522.29 Kboe in 2006 and 139297.10 Kboe 2012. This increase in primary energy production has been followed by a sluggish increase in *per capita* consumption. In this sense, energy consumption *per capita* went from 0.26 Boe/hab. in 2000, 0.30 Boe/hab in 2007 and equal to 0.38 Boe/hab in 2012. The aggregate energy production and *per capita* consumption dynamics show that one of the features of this system is the slow growth in consumption of secondary energy, which is accompanied by an intensive use of fossil structure derivatives.

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[2] National Energy Balance (2000-2012) – Ministry of Energy and Hydrocarbons.

2.2. Production and Supply of Primary Energy

According to the NEB (2012), the Total Gross Domestic Supply (TGDS) of primary energy was equal in 2012 to 51464.77 Kboe, exceeding supply recorded in 2006 (47826.13 Kboe) and 2000 (26100.62 Kboe). The composition of the TGDS, can be summarized as: i) oil and derivatives: 39% in 2000, 34% in 2006 and 37% in 2012. ii) Natural Gas: 37% in 2000, 52% in 2006 and 47% in 2012. iii) 5% in 2000, 3% in 2006 and 3% in 2012. Finally, iv) Biomass: 20% in 2000, 12% in 2006 and 13% in 2012. Changes registered in the composition of the TGDS show us that, in 2012 83% of the total supply is generated from non renewable resources while the remaining 17% came from renewable resources. As reference, in 2000 75% was generated based on non-renewable sources while in 2006 this kind of energy represented the 86% of the gross supply. As mentioned above, this determines that the production and supply of primary energy in Bolivia is highly dependent of fossil derivatives.

The evolution of aggregate secondary power supply shows a slower growth compared to primary energy. This offer, passed from 16651.30 Kboe produced in 2000, in 2006 21211.11, and reached 23910.60 Kboe in 2012. For 2012, the production of secondary energy by energetic (in percent) represented: 22.7% on gas, electricity 22.7%, 19.2% diesel, 10.5% in LPG and 20.1% in other derivatives. Therefore, the picture of the composition of secondary and primary energy production to the country shows: a growing trend in primary energy production and a slight reduction in oil production since 2007, as can be seen in Table 1. This last could be explained by the fact that the country's proven oil reserves were depleted and no major discoveries of wells were recorded. Furthermore, we can determine that hydropower production has not grown significantly in recent years; this fact accompanies the increased production of primary energy from non-renewable sources.

Table 1
Evolution of Oil in kboe (2000-2012)

	Production	Exports	Changes in inventories
2000	11256,2	1293,22	172,8
2001	12624,7	940,75	-130,97
2002	12766,3	675,46	-225,52
2003	13985,7	990,95	674,77
2004	16480,1	1796,27	-297,11
2005	18093,3	1616,8	114,93
2006	17442,7	1525,55	102,32
2007	17710,4	1038,38	-37,57
2008	16914,3	-	162,1
2009	14718,6	-	162,1
2010	15355,8	-	-7,59
2011	15938,45	-	-1,16
2012	18875,43	-	6,85

Source: Own calculations based on data from the NEB 2012

2.3. Energy Consumption

According to the NEB, the consumption of primary energy is concentrated in Natural Gas and Biomass. The total primary energy consumption in 2012 reached 14992.11 Kboe, while 7229.9 Kboe were consumed in 2000. The composition of primary energy consumption between 2000 and 2012 can be summarized as: i) in 2000, 35% natural gas and 65% of biomass. ii) In 2006, 46% of natural gas and 54% of biomass. Finally, iii) in 2012, 59% of natural gas and 41% of biomass were consumed. Regarding the consumption of high energy consumption in Bolivia this consists of: electricity, LPG, Diesel, Petrol and other derivatives. Table 2 shows the composition of secondary energy consumption between 2000 and 2012.

Table 2
Evolution in secondary energy consumption (2000-2012)

ENERGETIC	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Electricity	10,76%	10,86%	10,95%	10,70%	10,51%	10,80%	10,74%	10,74%	11,13%	11,06%	10,95%	10,50%	10,40%
LPG	10,00%	10,45%	10,72%	10,65%	10,89%	10,83%	10,41%	9,94%	9,13%	8,84%	8,50%	8,00%	7,70%
Diesel Oil	22,80%	23,06%	23,12%	24,63%	25,70%	26,24%	26,74%	26,57%	25,41%	23,43%	24,23%	24,30%	24,70%
Gasoline	16,05%	15,31%	14,38%	13,75%	13,41%	12,06%	12,36%	13,63%	15,37%	16,14%	16,52%	16,70%	16,90%
Natural Gas	12,28%	12,27%	13,30%	13,75%	14,40%	15,45%	16,34%	17,60%	18,51%	20,59%	20,41%	21,60%	22,30%
Biomass	22,96%	23,38%	22,76%	21,92%	20,79%	20,14%	19,29%	18,20%	17,34%	16,95%	16,44%	15,90%	15,70%
Other	5,15%	4,66%	4,76%	4,62%	4,30%	4,48%	4,13%	3,32%	3,11%	2,98%	2,94%	3,00%	2,40%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: Own calculations based on data from the NEB 2012

3. Methodological Approaches

The E-3 (energy, economic, environment) models represent the evolution of the energy, economic and environmental systems during a specified period of time. At a given instant, the structure of the economy can be considered fixed but with over time occurs gradual structural changes and allow the appearance of innovations. In the short run, the capital stock is fixed, while in the medium and long term technology changes, the capital stock is changed and the allocation of resources to productive sectors evolves.

The time horizon of a model defines the terms under which the system is represented by influencing the type of relationships that this holds. Also, this view influences the importance of the exogenous variables, depending on the variability of these inputs for the time horizon considered. Thus, we can define some temporal criteria such as:

- In the short term, it is considered that technology is fixed and that the population is constant or varies according to a known pattern.
- In the medium term, changes in: technology, capital stock and in demographic and economic patterns may be anticipated reasonably well from recent historical data.
- Based on the time horizon, the technologies that are already in use or those that are about to begin to be used, must be considered.
- In the long term, it is considered structural changes such as depletion of non-renewable energy resources, the development of alternative energies and the penetration of new technologies.

Second, the models also differ in their ability to analyze specific sectors and technologies. In the energy sector, some models with low detail allow the study of few sources of energy (such as oil or electricity), while models with a higher level of detail can handle hundreds of forms of energy. The same range of possibilities of disaggregation exists outside the energy sector. Some models distinguish between a few categories of energy demand, such as transportation or manufacturing, while others allow the consideration of hundreds of industrial processes or end uses.

Third, expectations about the evolution of prices in the E3 models are based on two competing hypotheses for calculating prices. On the one hand, the hypothesis of myopic forecast, which implies that economic agents expect prices to remain present or vary in a known manner. This assumption implies that agents do not know the model endogenous structural relationships or future values of the exogenous variables. On the other hand, the assumption of perfect foresight is also used, which considers that economic agents predict prices through the model. This implies that all agents adjust their consumption, production and investment according to expected change in prices.

Fourth, the models can do both, optimization and simulation. In the first, objective functions subject to a variety of restrictions trying to minimize energy costs and maximize consumer utility are used. The solution provided is optimal among all possible alternatives. Optimization models identify an optimal solution and allow us to set the stage to get to that point, so are suitable for the design of policies. Furthermore, simulation models variables evolve according to behavioral equations, trying to represent how the real system under given conditions represent works. These models are used to evaluate a given scenario.

Fifth, E3 models differ in the treatment of energy technologies. The assumptions on which the models are based are important for the description of technologies and projections of future developments, determining the conclusions that can be derived on technological options. All the models contain or refer to any information that describes a technology in a base or reference year, may even be described capital costs and operating fuel requirements, technical life time, the ability to production and environmental impacts of technology.

Most models attempt to predict which technologies are more likely to be incorporated and its insertion rate. These projections are often based on the evolution of the relative costs of technologies. Usually, described in terms of initial investment and annual costs of operation and maintenance. Some models go a little further and take into consideration the entire life cycle of the technology, *i.e.,* include the costs of dismantling and recycling. In other cases also take into account the costs of the externalities they cause.

In this framework, the constraints imposed to avoid absurd results inconsistent with reality are as important as the technology descriptions. Similarly, economic constraints may be limitations on the investment, while environmental restrictions may consist in establishment of production goals with renewable energy or emission limits.

The literature argues that long-term models have to consider the impact of the emergence of technologies that are still in their early development stages. Costs, yields and dates of occurrence of these technologies are in many cases just speculative. For this reason technology is usually treated in an aggregate manner, so that the model results represent very general technology improvements.

Models of long term take into account restrictions on the depletion of natural resources and environmental constraints and technologies backstop, *i.e.,* they are not restricted in the simulation period (*e.g.,* renewable energy), where its importance increases as you go up prices of exhaustible energy resources.

Sixth, the methods to model and/or future prospect attributes of technologies, ranging from the use of exogenous parameters to the use of behavioral equations that depend on other variables. Suppose the use of the learning curves (Isoard and Soria, 1999; Isoard and Soria, 2001; Kouvaritakis, Soria and Isoard 2000a; Kouvaritakis, Soria, Isoard and Thonet, 2000b), in which the lowering of costs of a technology is plotted over time as cumulative production increases. Lowering costs and increasing the efficiency and productivity of a technology can also be modeled as functions of R & D.

3.1. Type of Energy Models

We can distinguish four groups of models according to their sectoral coverage, the configuration of the energy sector and/or its functional relationship with respect to the rest of the economy or specific sectors of the economy. In general, these categories are:

- The engineering models of energy or a specific, industry known as “bottom-up”.
- Hybrid models with a mixed economic-engineering approach, which couple a model of the energy sector or one part of the overall economy.

- Models of economic general equilibrium approach (top-down) representing all sectors of the economy.
- IAM: integrated assessment models of climate change, which associate an economic model to climate, ecological, and even social models.

3.2. Bottom-Up Models

The engineering models (bottom-up) represent an energy system in detail, considering it as a set of technologies for production, distribution and final energy demand, competing. Over time, technologies undergo changes in their use, efficiency, cost and power requirements. On one hand, the demand for energy and non-energy sectors of the population evolution is defined exogenously. On the other hand, energy prices are calculated in the model. This type of model allows a breakdown by region and energy sources.

The operation of this type of models is generated from exogenous inputs (such as GDP or population), of energy prices and supply. From this information, the activity levels in the sectors considered in the model (*i.e.,* the demand for transport, etc.) are determined. With these levels of activity, the demands of different forms of secondary energy (electricity, gasoline, diesel, etc.) are calculated.

Thus, the scheme allows the primary energy production be related to the high energy demand, energy production from renewable sources, and exogenous factors such as technological efficiency. Thus, both production and demand for energy, and sectorial activity levels are then influenced by the prices of the different forms of energy considered. Meanwhile, prices are calculated based on historical prices, and as a result of changes in supply and demand.

Operational research has been widely used for modeling energy systems from an engineering point of view (Kavrakoglu, 1982; Samouilidis, 1980; Samouilidis and Berahas, 1983). Some In the literature review and ratings of some models of energy systems appear in Boyd, Fox and Hanson (1990), Huntington, Weyant and Sweeney (1982), Rath-Nagel and Voss (1981), and some comparisons and review in Koreisha (1980) and Ulph (1980).

Most often, we find references to specific models of the electricity sector (Amagai, 1991; Baughman, Krafka and Sullivan, 1984; Frankel, 1971; Hillsman, Alvic and Church, 1988; Hoster, 1998; Neubauer, Westman and Ford, 1997; Parikh and Deshmukh, 1992;

Soloveitchik, Ben-Aderet, Grinman and Lotov, 2002; Thompson, Moore, Calloway, Young, Lievano and Nawalanic, 1976; Uri, 1976, Uri, 1977, Xie and Kuby, 1997). There are also references to models of industrial processes (McLaren, Parkinson and Jackson, 2000; Pilati and Sparrow, 1980), or specific industries such as manufacturing (Newton, 1985), steel (Ackerman and Almeida, 1990; Anandalingam and Bhattacharya, 1985; Hidalgo, Szabo, Ciscar and Soria, 2005; Polenske and McMichael, 2002).

There are also hybrid models, which can represent the interactions between the energy system and the rest of the economy. Economic growth is described by an aggregate production function in which the different forms of energy are added as a primary factor of production. The energy production activities cannot be described separately according to this formulation, therefore production aggregate function is coupled to a detailed engineering model that represents the energy system (Boyd *et al.*, 1990; Lakhani, 1980; Pandey, 2002; Samouilidis and Mitropoulos 1982; Viguier, Babiker and Reilly, 2003).

4. The Model

The Long Range Energy Alternatives Planning System (LEAP) is useful tool for modeling energy and environmental scenarios. These scenarios are based on complete energy-mix balances. The drivers of the model are the demographic growth, the sectorial economic development, specific energy technology, prices and other characteristics.

Demand: The technology in the model is a coupling of the macro-energy model and the structure of energy consumption of the economy. It is included a demand level in terms of different disaggregated final consumptions of energy in a way that converge to the macro-energy scheme. In this framework, the final energy consumptions of each economic sector evolve in a way that is convergent to the speed of adjustment of the economy and demographic growth.

With this structure it is possible to generate alternative scenarios by modifying the demographic profile or economic sectors in the economy. As a consequence, it is possible to examine the evolution of the total consumption and disaggregate it by sources through time in all sectors of the economy. All the computations are determined by the levels of final demand. In this research we include the following sector: households, industry, transport, commerce and agriculture.

At the beginning is defined a sector (i) an activity (j), such that it is obtained a pair (i, j) that configures all the economy in terms of an energy final demand. Here, energy consumption (EC) is calculated as the product of a level of activity and the annual energy intensity (EI) or energy use by unit of activity. The final *EI* is the final annual average *EC* of an energy branch, when the source is a pure energy form, like electricity, the units must be of energy – and when the *EI* is specified for a branch of aggregated *EI*, the intensity can only be taken into account in energy units.

$$EC = AL * EI(1)$$

EC = Energy Consumption
AL = Activity Level
EI = Energy Intensity

$$AL = \sum AL(i,j)$$

The AL is a measure of the energy consumption in each economic activity. The demand structure analysis involves the levels of activity in absolute terms (*e.g.*, household's quantity) in a level of hierarchy and in both, share of participation and percentage of saturation in all hierarchy levels. In this way, the total activity shows the result of multiplying each one of the AL branch chains, with an associated speed of economy adjustment for a final *EI*. This is the annual average of final energy consumption for a branch of technology, but also can be defined in the immediate superior level as aggregated *EI*.

The share of each source represents the total final energy consumed, while the activity share reflects the quantity of "activities". The percentages of efficiency are used to calculate the useful general intensity for final consumption and base year participations. As a result the branches of energy intensity are the measures of the energy service provided by a unit of activity as following:

$$Efficiency = 100*(useful\ distributed\ energy\ /\ final\ energy\ consumed)$$

With this framework, the energy demand is calculated for the base year and for a future year in each scenario in the following way:

$$D(b,s,t) = TA(b,s,t) * EI(b,s,t)$$

Where:

D = is Energy Demand
TA = is Total Activity
EI = is Energy Intensity
b = is the Branch
s = is the Scenario
t = Year (since year 0 until final year)

All the scenarios evolve from the base year, where each technology branch is identified with a particular source. The model added all technology branches and calculates the final energy demand for each source as following:

$$D(b,0) = TA(B,0) * EI(b,0)$$

The total activity level for each technology is the product of the activity levels in all branches:

$$TA = (b,s,t) = A(b_1,s,t) * A(b_2,s,t) * A(b3,s,t) * \ldots * A(bn,s,t)$$

Where:

A (b) = is the Activity Level in a Branch (b)
b_1 = is the branch b of origin
b_2 = is the branch that depends on the previous one

Analysis of Existences: The energy consumption for a device that consumes energy is base on the current and forecasted existences of it, and the annual *EI* of such device. In the model we consider the vehicle park by a wide range of motorized vehicles. In the base year we specified the current existence, *e.g.,* of vehicles and the average of *EI* of those existences. The model admits the addition of new artifacts through the application of an exogenous growth rate. Then, it is calculated the average *EI* from the existences and for instance the general level of *CE.*

$$CE = Device\ existences * artifact\ EI$$

Transformation Analysis: This module simulated all the conversion and transportation stages of energy, from the primary energy extraction and imported energy until their consumption. These are the results of the primary energy requirements and import in each area.

Load Factor: The load curve of the system is the following average:

$$Load\ Factor = \frac{Total\ Production(MWh/year)}{Max\ Load\ of\ the\ System(MW) * 8760(^{h}/_{year})}$$

The Reserve Margin: The planned reserve margin let us to decide the adequate moment to include additional endogenous capacity. This means enough capacity to maintain the planned reserve margin to some specific technical value or above it.

$$Planned\ Reserve\ Margin(\%) = 100 * \frac{(Module\ Capacity - Max\ Load)}{Max\ Load}$$

$$Capacity = \sum Capacity * Value\ of\ Capacity$$

For all the module processes, the max load was calculated over the base of electricity requirements and the load factor of the module. Furthermore, the requirements of capacity are calculated over the base of the analysis of energy demand and all electricity losses in the modules of superior levels (transmission and distribution). When each process is included endogenously, it reaches its specified useful life and it's retired automatically.

The Dispatch Process: First, we calculate the share of energy outcomes in each process. The rule is that each dispatch is proportional to the production of base year. Then we have:

$$Process\ Share(i) = \frac{Base\ Year\ Outcome(t)}{\sum_{i-1}^{x} Base\ Year\ Outcome}$$

Also the dispatch norm is proportional to the available capacity (full)

$$Process\ Share(i) = \frac{Capacity(i) * MCF(i)}{\sum_{i-1}^{x} Capacity(i) * MCF}$$

The Dispatch Processes of a Load Curve: The merit dispatch order is the increasing order of the variable costs.

$$CVT = CVOM(i) + \frac{CT\ of\ the\ source(i)}{Efficiency(i)}$$

$$Max\ Power\ Requierement\ of\ the\ System(MW) = \frac{Energy\ Requierement(MWh)}{Load\ Factor * 8760}$$

First, we build a list of the processes in order of merit in order to calculate the available capacity of each group with the same order of merit. Then, it is made a discrete approximation to the load curve.

5. The Scenarios

Socio-Economic Scenario: This research will work with a socioeconomic scenario and two energy scenarios (trending or business as usual and mitigation). The formulation of a socioeconomic scenario responds to the need of having a vision about the evolution of the most important socioeconomic aggregates which at the same time affect the energy use, the future energy consumptions and the inherent greenhouse gas (GHG) emissions. At the end, we plan to obtain the evolution of explanatory variables that affect energy consumptions by sector of demand.

We assume the Bolivian GDP will grow in a rate of 4% annually[3] during the period 2007-2025. Aliaga and Rubin de Celis (2011) considered that the economic growth will be below the 4% from 2015 and will converge to its steady growth of 3.45%. This assumption is made taken into account that the most dynamic sectors of the economy will be the manufacture industry, transport and commerce and services and they will grow at 4.3%, 4.2% and 15% respectively. Instead, sectors like agro, fishing, mining and other will grow at 3.5% and 3.38%, respectively.

Energy Business as Usual (BAU) Scenario: The Business as Usual Scenario is a consistent description about how the Bolivian energy system will develop in the future in the absence of new and explicit energy policies and mitigation measures. This scenario incorporates

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[3] Source: "Energy Development Plan-Scenario Analysis 2008-2027", Ministry of Hydrocarbons and Energy.

technologic innovations (as a market process), but also production improvements or process substitution that will be verified even in the absence of explicit policies.

Residential Sector:

- Urban household's electrification will change from 87% nowadays to 97% in 2025. In the case of the rural electrification, we expect to change from 33% nowadays to 97%, (Espinoza and Jimenez, 2012).
- The energy intensities (Kboe/household), measured in terms of useful energy, will grow according to the evolution of GDP/household, with an elasticity of 0.83 for the urban households and 0.96 for rural households (Aliaga and Capriles, 2011).
- We expect a higher *per capita* incomes, with a moderate growth in the use of electric devices in urban households.
- We expect a marginal improvement in the efficiency of electric devices-energy intensities, measured in net energy, will reduce until reaching a 3% less in 2025 compared to 2007 in urban and rural households.

Commercial and Services Sector:

- It is considered a reduction of the energy intensity (Boe/US$ of aggregated value), measured in net energy, in a 3% during all period as a consequence of the increase in energy productivity of the sector.
- We expect a moderated penetration of natural gas substituting LPG, according to the elasticities calculated in Aliaga and Capriles (2011).

Industrial Sector:

- The natural gas will substitute diesel, according to the elasticities calculated in Aliaga and Capriles (2011),
- The consumption growth will be 7% following the sector trend of the last five years.
- The share of electricity will increase 6% each year following the trend of the last ten years.

Transport Sector:

- We expect a moderate trend of the substitution of gasoline and diesel by compressed natural gas (CNG) (Aliaga and Torrez, 2011).

- We expect an important improvement in the average age of the vehicle park, as since 2012 it is only possible to import vehicles of a maximum antiquity of 3 years.

Other Consumption Sectors:

- We expect that technology improvements will reduce in 3% the net energy intensities.

In the case of the energy supply, we based our assumptions in the Bolivian Plan of Energy Development 2008-2027, made by the Ministry of Hydrocarbons and Energy:

- The share between thermo and hydro generation (60/40) will remain constant during the whole exercise, since the subsidy of natural gas for thermo generation is still operative.
- The of growth of biomass will follow historic rates and the new thermo power plants will work with combined cycles using natural gas (it is not predicted the elimination of natural gas subsidy).
- The share of diesel generation for isolated systems it is assumed to be constant.
- It is assumed that refineries production follows the one considered in the "Bolivian Strategy of Hydrocarbon 2005-2025".
- It is assumed for this exercise that Bolivia has no hydrocarbon production problems until year 2016.

The Mitigation Scenario: This scenario introduces measures that promote energy efficiency during the period of simulation. As a result we expect a reduction in energy consumption, less intensity of oil derivatives consumption, higher energy efficiency impact and higher share of renewable energies in the energy-mix.

Residential Sector:

- We considered the substitution of incandescent lamps for low consumption lamps (LFC). In 2025, the 3% of the lamps will be of low consumption.
- It is considered a gradual substitution of inefficient refrigerators with more than 10 years of use. In 2025, it is expected that the 45% of the refrigerators will be efficient.
- It is assumed that the 35% of the households that use wood for cooking will do it with efficient wood-burning stoves in 2025.

- It is considered an increase in the use of natural gas as substitute of LPG in relation to the BAU scenario, reaching up to 35% of the useful consumption in the urban households.
- In the rural households it is not considered the use of natural gas, but it is considered a substitution of wood by LPG assuming that a 15% of rural population until 2025 will introduce decentralized systems of renewable energies.

Commercial and Services Sector:

- It is considered improvements in illumination, air conditioning and efficient refrigeration, with associated savings of 10% in electricity consumption until 2025.
- Energy efficiency measure modifies consumption patterns, with associated savings up to 3% until 2025.

Industrial Sector

- It is considered an improvement of 10% in the use of natural gas in comparison to the BAU scenario.

Transport Sector

- It is considered an increase of 10% in comparison to the scenario BAU depending on the type of vehicle.

6. The Energy-Mix Forecast

Energy Demand Forecasts: The total net consumption of energy[4] will grow in the BAU scenario, from 31,872 Kboe in year 2006 to 57,908 Kboe in year 2025, with an annual growth rate of 3.4%; while in the mitigation scenario, the growth of energy consumption will be smaller than in BAU due to energy efficiency measures and the substitution of wood in the residential sector, reaching in 2025 53,210 Kboe, with an average growth rate of 2.9%. Considering that GDP evolution will have an annual average growth of 4% in both scenarios (BAU and mitigation).

In Table 3, are shown the results of energy consumption forecasts for each socioeconomic sector incorporating non energy consumption and internal consumption. From final

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[4] Total Net Consumption = Final Consumption + Own Consumption.

consumption sectors, the sector with higher growth under BAU scenario will be the industrial sector since it's the most dynamic sector. The energy consumption growth rate in this scenario will be 4%. In the mitigation scenario, the socioeconomic sector with the higher growth will be agro, fishing and mining, with a rate of 3.5%; while industry will grow in 3.1%. This implies a smaller growth rate of the industry due to energy efficiency measures.

Table 3
Forecast of Net Energy Consumption by Sectors 2007-2025 (Kboe)

Sector	2007	2025		Tasa 2007-2025	
		Trending	Mitigation	Trending	Mitigation
Residential	5,586	9,283	7,069	2.9%	1.3%
Commercial and Services	839	1,658	1,396	3.9%	2.9%
Industrial	8,093	16,404	14,084	4.0%	3.1%
Transport	11,225	17,853	17,951	2.6%	2.6%
Agro Fishing and Mining	2,651	4,924	4,924	3.5%	3.5%
Non Energy	631	1,279	1,279	4.0%	4.0%
Own Consumption	2,846	6,507	6,507	4.7%	4.7%
Total	31,872	57,908	53,210	3.4%	2.9%

Source: Results from Simulation

The residential sector will have an energy consumption growth of 2.9% under BAU scenario and of 1.3% under mitigation scenario. The total number of households (rural and urban) will grow by a rate of 1.65%; by its side, GDP per household (GDP/households) will grow in a 2.3%. Considering income-energy consumption elasticity of 0.85 for urban households and 1 for rural households; the intensities of useful energy (boe/household) will grow in 1.7% and 2% respectively, which implies growth rates between 2007 and 2025 of 36% and 34% respectively for both scenarios.

In Table 4, we present the energy savings that will occur in the mitigation scenario in comparison to BAU scenario. In 2025, in the mitigation scenario will be consumed 4,688 Kboe less than in BAU scenario. This means a consumption reduction of 23.9%. In the industrial, commercial and services sectors, there will be a purples of 14.1% and 15.8% of energy in each sector respectively. At the same time, there will be a small increase (0.5% in 2025) in the energy consumption within transport sector under mitigation scenario, in comparison to BAU scenario as a consequence of a bigger participation of CNG with minor efficiency than gasoline.

In the whole forecasted period under the mitigation scenario it will be a surplus of 38,431 Kboe. This is equivalent to 1.2 times the total net consumption of the country in the base year 2007. These savings are a result of a 51% reduction in the residential sector; a 45.9% in the industrial sector, a 5.2% in the commercial and services sector and a -2.2% in the consumption growth in transport sector.

Table 4
Energy Savings in Mitigation Scenario Compared to Trending Scenario

Sector	2005		2025	Accumulated 2007-2025	
	Kboe	% s/Tend.	%	Kboe	%
Residential	2,215	23.9%	47.1%	19,610	51.0%
Commercial and Services	262	15.8%	5.6%	2,006	5.2%
Industrial	2,320	14.1%	49.4%	17,645	45.9%
Transport	-98	-0.5%	-2.1%	-830	-2.2%
Agro Fishing y Mining	0	0.0%	0.0%	0	0.0%
Non Energy	0	0.0%	0.0%	0	0.0%
Own Consumption	0	0.0%	0.0%	0	0.0%
Total	4,699	8.1%	100.0%	38,431	100.0%

Source: Results from Simulation

The evolution of the total net consumption by sources is presented in Table 5, where natural gas shows higher improvements; changing from 21.11% in the base year to 25.9% in 2025 in the BAU scenario and 35.8% in the mitigation scenario. This means annual average growth rates of 4.6% and 6%, respectively. In the opposite way, the main sources of consumption regression will be LPG, biomass and gasoline. Finally, the electricity will change from 9.8% of total net consumption in the base year to 11.9% in year 2025 for the BAU scenario. Meanwhile, in the mitigation scenario, the total net consumption of electricity will be 10.4% in 2025 due to the use of artifacts and efficient electric components (lamps, refrigerators and engines).

Table 5
Total Net Consumption by Sources

Sectores	2007		2025		2025	
			Trending	Mitigation	Trending	Mitigation
Avgas	27	0.1%	55	55	0.1%	0.1%
Biomass	5,037	15.8%	7,436	4,175	12.8%	7.8%
Diesel	7,588	23.8%	13,299	12,911	23.0%	24.3%
Electricity	3,135	9.8%	6,905	5,516	11.9%	10.4%
Gasoline	3,863	12.1%	4,820	3,497	8.3%	6.6%
Jet Kerosene	879	2.8%	1,780	1,780	3.1%	3.3%
Kerosene	119	0.4%	227	223	0.4%	0.4%
LPG	2,839	8.9%	4,733	2,346	8.2%	4.4%
Natural Gas	6,717	21.1%	15,004	19,059	25.9%	35.8%
Non Energy	631	2.0%	1,279	1,279	2.2%	2.4%
Refinery Gas	1,036	3.3%	2,370	2,370	4.1%	4.5%
Total	31,872	100.0%	57,908	53,210	100.0%	100.0%

Source: Results from Simulation

Electricity Supply: Neither of both scenarios considered the exchange of electricity with other countries. The gross total consumption of electricity will grow in 4.5% a.a. (annually accumulated) during the whole period in the BAU scenario, and in 3.2% a.a. in the mitigation scenario. The smaller growth in the mitigation scenario compared to BAU is explained by energy efficiency in the residential, commercial and services and industrial sectors. In 2025 the mitigation scenario will generate 2,609 GWh less than in trending scenario; this means the equivalent to 45% of base year (2007) generation. In accumulative terms, in the whole period 2007-2025, the mitigation scenario will generate 20,900 GWh less, 3.6 times the base year generation (See Table 6).

Table 6
Gross Generation of 2007-2025, GWh

Sectors	2007	2015	2020	2025	Tasa
Trending Scenario					
Auto producers	321	440	535	651	4.0%
Power Plants (SP)	5,514	7,926	9,863	12,211	4.5%
Total	5,835	8,366	10,398	12,862	4.5%
Mitigation Scenario					
Auto producers	321	440	535	651	4.0%
Power Plants (SP)	5,514	7,083	8,256	9,602	3.1%
Total	5,835	7,523	8,791	10,253	3.2%

Source: Results from Simulation

The self producers will continue generating from bagazze since it's a residual production, which it was 5.5% of the total gross generation in 2007. We expect that in 2025 will represent 5.1% in the BAU scenario and 6.3% in the mitigation scenario. Finally, the generation by type of power plant, it was simulated in LEAP by processes participation. The new hydroelectric centrals will start to operate in full capacity since year 2021 y and the geothermic will start working in 2016. The unsatisfied requirements of generation will be covered by new plants of combined cycle using natural gas.

Natural Gas Supply: In year 2025, under mitigation scenario, the total net consumption of natural gas will be 4,0055 Kboe more than in BAU scenario for the same year due to the higher penetration of natural gas in the final consumption sectors. In the case of the electricity generation in 2025, in the mitigation scenario there be a 4,698 Kboe less of natural gas than in BAU scenario due to the incorporation of geothermic generation and the measures of energy efficiency proposed that reduce electricity requirements. Both effects practically compensate each other, the increase of natural gas in final consumption and the reduction of intermediate consumption in thermo power plants. Only it is noticed a small increment in the exports of natural gas, from 666 Kboe in the mitigation scenario for 2025.

7. Conclusions and Recommendations

The reserves of natural gas provide an interesting flexibility to the energy-mix in order to support economic growth, given the assumption that Bolivia will invest the adequate amounts in the sector to produce enough gaseous hydrocarbons and promote focalized energy polices.

Under these assumptions, the mitigation scenario shows savings of 38,430 Kboe, 1.2 times the country total net consumption in the base year.

The electricity sector, due to energy efficiency tools, shows savings near 20,900 GWh, 3.6 times the current total gross generation. These savings and the expected geothermal generation will reduce the consumption of natural gas toward 4,700 Kboe in the year 2025. Nevertheless, these savings does not take into account potential reduction of natural gas consumption for thermoelectricity, as a result of the removal of the subsidy price of natural gas for thermo generation. The effect of this measure will be huge, but difficult to implement (Aliaga nd Tapia, 2012).

The transport sector is the main consumer of energy and also causes a huge misbalance in the energy-mix, for two reasons. First, the country is intense in gaseous hydrocarbons, while the sector is relative intense in liquid hydrocarbons. It is necessary to design and implement energy policies destined to change rapidly the transport consumption toward natural gas. Second, because the gasoline price is subsided, this causes several relative prices distortion in the economy, repressing inflation and produce fiscal deficit. It is very difficult to remove this subsidy, but also necessary in the long term - focalized policies must be design for this purpose.

The country does not have full energy autarky and security, because the energy-mix structure is disorganize. In order to match the energy-mix behavior with sustained economic growth it is necessary to remove or focalize the energy subsidizes prices. Without this measure the current misbalanced will highly increase in the next years. This structure reflects also small reductions of GHG emissions, near 1,920 Gg of CO2 equivalents in the year 2015. In the current energy structure, the energy efficiency measure and the renewable energies penetration, only explained 16% of lower GHG emissions, bring the main explanation the natural gas penetration instead of oil consumption (Aliaga and Paredes, 2010).

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