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Comprehensive energy analysis of natural gas transportation in molecules or in electricity

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Abstract. This paper's aim is to do a global evaluation (considering four dimensions: technical-economic, environmental, social and political) in the ways of natural gas transportation (gas pipelines, GNL and GTL) and electric transmission, in order to supply the energy demands of Mato Grosso do Sul, a brazilian state. The transport ways had been compared between itself using a software of decision taking (Decision Lens Suite), which determined a better way for transporting natural gas in this case. In a generalized manner the gas pipeline is the best way of transporting natural gas, therefore it takes advantage in the majority of the analyzed dimensions.

Keywords: energy; integrated energy resources planning; natural gas; electricity; full cost FCAount

1. Introduction

From a global view, natural gas for many years has become a great resource to complement the oil demand and even its replacement. Focusing in South America, there are few countries which have a mature natural gas market; the most advanced in this sector is Argentina. However, gradually other south-American countries realized that this energetic resource is necessary for their economy development, perhaps for it is cheaper, cleaner and generate greater added value in certain industrial products. It is exactly here where Brazil fits. The natural gas consumption in Brazil has been accelerating more and more each year, allowing this country to be now considered dependent of this resource.

Also in South America, there is a country with significant natural gas reserves (until then the second larger volume considering proven and probable reserves), Bolivia. On current estimates, the likely reserves come close to the Venezuelan ones, and some experts say that in five years these estimates will overcome Venezuela in terms of volume. Many countries see Bolivia as a potential supplier of natural gas, only the resource, without any added value. The Bolivian view is different in this matter; they current talk very much about the industrialization of this resource, so

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they can export it. Brazil, for now, depends on this Bolivian gas and imports about 30 million cubic meters of gas per day from Bolivia. Ergo, in order to have a natural gas supply without harming any of the mentioned countries, the question of supply / consumption has to be treated in such a way that, in an overview, consider the smaller impacts in four dimensions which must be analyzed. They are: technical-economic, social, environmental and political. Having caution in this analysis moment and considering these four dimensions with the same weight, it is possible to have an efficient negotiation and a sustainable natural gas supply (based in Integrated Resources Planning analysis).

2. Full cost accounting

Initially, it should be clarified that by full cost (in this case, energy resources) it is understood that it should not be viewed as simply monetary cost, but as the various costs for each and every one of the different attributes and each dimension relating to development. Thus, the Full Cost Accounting (FCA) needs the premise of the characterization of resources in all their potential, such as the potential for contamination, heating, energy, health effect, jobs etc., which allows definition of multi-criterion costs for the systemic assessment of energy resources. In the case of this study, the aim is to facilitate decision making in time and enable sustainable energy planning for sustainable development (UDAETA 2010).

In this sense, the IRP (UDAETA 2007), i.e., Integrated Resources Planning, places the sustainable development as its most diffuse goal. Thus, to use sustainable energy in general and for the IRP, in particular, it is necessary to compare energy resources on the supply side (ERSS) energy resources on the demand side (ERDS) in a way that a ranking is generated for suggestion of resources, ranging from the most indicated to the least indicated. Usually, this decision making is performed with technical and economical data, however, in the case of this study, they include with the same importance the negative and positive impacts of the adoption of resources, so that the final result reflects the greater number of points possible. Among these aspects are the environmental, social and political, it also evidence that the greatest difficulties of considering these types of impacts are subjectivity and difficulty in pricing.

2.1 Procedural insertion of FCA into IRP

In the current structure of IRP (UDAETA 2010), the FCA is used in two different ways for the same integration of resources: one into the deterministic FCA and another into the FCA holistically held (by the En-St). As a premise, both FCAs must have the same tree criteria, i.e., the same attributes, sub-attributes and the same alternatives.

The first use occurs in the deterministic FCA, in which all costs associated (not necessarily monetary or monetized) attributed to energy resources are deterministically estimated, there is no qualitative data to be considered, including the environmental, social and political, and such “costs” related are sometimes generically called notes. Thus, this type of use of FCA can be extremely complex because all aspects considered should be valued numerically from potential specific and predetermined, either in monetary form or another that proves useful. It can be said that all externalities must be internalized in order to be quantitatively considered.

Still on the deterministic FCA, unlike the “costs” relating to, or notes, resources that are calculated deterministically, the weights of the sub-attributes can be calculated by experts qualitatively. This procedure is used for the pairwise comparison (as evidenced later in this work), but based on a methodology for complex decisions known as AHP (Analytic Hierarchy Process) (SAATY 1991).

The second use is carried out in FCA, processed in interaction with En-St. This assessment is entirely qualitative: the sub-attributes are compared as in the deterministic, FCA although with the option coming from all En-St, and resources are evaluated in relation to sub-attributes qualitatively. Therefore, verbal scale is used, which is also included in the methodology of decision making of AHP mentioned above.

Concerning the En-St, it is important to show the permanent contradiction between them. Even because the En-St are a wide range of entities that sometimes (depending on the timing and geography), have common and / or antagonistic interests, and the assessments on specific points on certain energy sources are different. Moreover, the contradictions between En-St can also be ideological or commercial source, leading to situations “said” competition among peers. Thus, the FCA indeed incorporates the ideas and positions of these and all En-St in contradiction or not (without discrimination), upon the suggestion of the ranking of energy.

As for the rankings of energy generated by the two FCAs, it is important to emphasize that the alternatives are not mutually exclusive, i.e., the FCA does not have a single energy resource as a response, but a full ranking so that all alternatives should be present there considered for implementation, however, guided by the priorities calculated. It should be noted that a ranking presented by the FCA does not include the temporal matter nor the question of restricted capacity (that on the energy source itself).

In the context of the IRP methodology (UDAETA 1997, 2010), after making up the two FCAs and the determination of rankings of energy resources the integration of resources is done procedurally (energy). Energy integration, ultimately, shows the consolidation of a single listed of energy resources (a ranking of specialized resources). This consolidation should be developed with the intervention from the team that develops the IRP so that the geographical reference and their temporal analyzes (geo-referencing analysis are very useful at this stage of IRP) are incorporated.

Finally, it is important to notice that the desired end state of the IRP is the preferred plan generation with the considered timeframe. However, this study focuses primarily on FCAs and the consolidation only related to the ranking in a given instant of time, with the conditions set forth therein. In full view of the IRP, several FCAs should be generated, providing many rankings and scenarios in time, thus enabling the full generation portfolios of resources and energy plans.

3. Analyzed dimensions

For this is a study which aims a sustainable system, based on the Integrated Resource Planning (IRP) and using the Full Cost Account (FCA), the analyzed dimensions were four: technical-economic, environmental, social and political. The technical-economic dimension has a scope facing physical and economic effectiveness of each project. The environmental and social dimensions analyze the impacts in the environment and society due to the construction and operation of transporting ways of energy. The political dimension aims to seek acceptability of the interested and involved ones for each form of energy transport analyzed. The following diagrams in the subsequent figures show the dimensions and the sub-criteria used in this study.

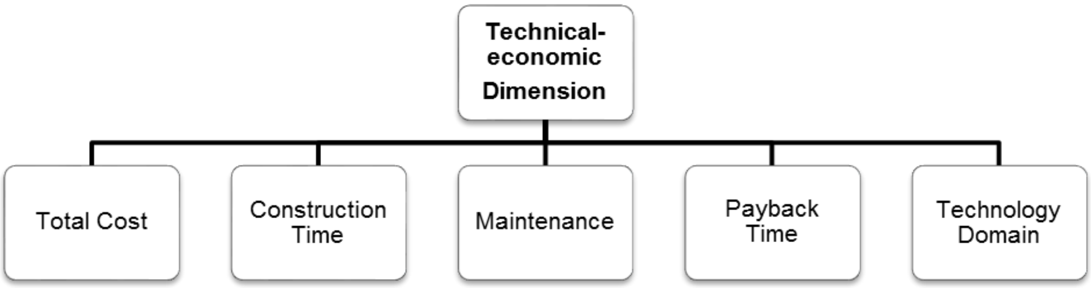

Fig. 1 Technical-economic dimension and its sub-criteria

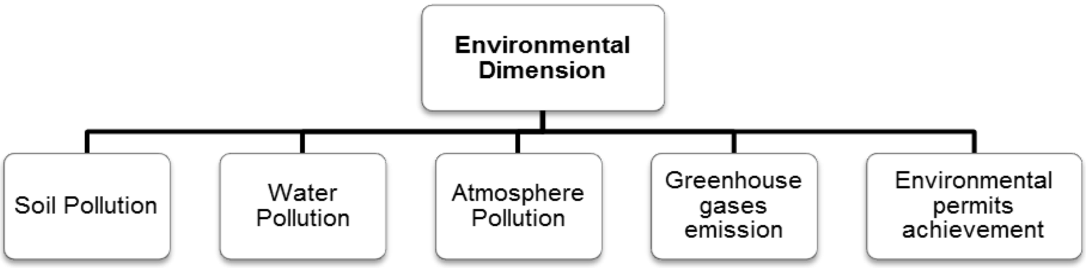

Fig. 2 Environmental dimension and sub-criteria

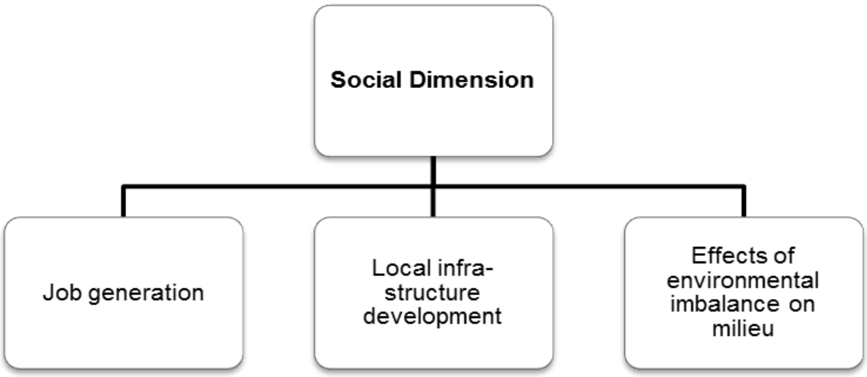

Fig. 3 Social dimension and sub-criteria

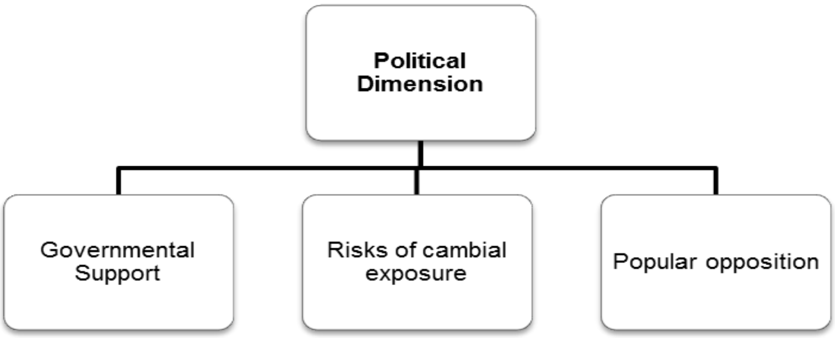

Fig. 4 Political dimension and sub-criteria

Fig. 5 Region of study identification

4. Region of study identification

The energy transport studied is comprehended between two regions: the producer fields of natural gas in Bolivia and the demanding region correspondent to the border between Bolivia and Brazil. The natural gas fields of this study are in southern Bolivia, more specifically in the administrative region of Tarija, which are illustrated by red dots in Fig. 5.

There are three fields of natural gas extraction which will be considered in the study, known as San Antonio Field, San Alberto Field and Margarita Field. The reserves corresponding to these fields has a natural gas volume, considering proven and probable reserves, of almost 25,23 TCF, which is equivalent to 51,8% of the 48,7 total TCF of Bolivian reserves (Ministry of Hydrocarbons and Energy of Bolivia 2005).

The natural gas volume to be delivered shall attend some Mato Grosso do Sul energetics demand, plus the natural gas demand of the mining and steel of “El Mutún” region. The energy transport will follow the path of other existing transport infrastructure installed in the region, and will have to travel a distance of approximately 897,9 km (340,8 km from Margarita to Rio Grande and 557 km from Rio Grande to the Brazilian border), as shown in blue dashed lines in Fig. 5.

4.1 Study energetic demand

The case study area comprises the border between Bolivia and Brazil – in Brazilian territory the Mato Grosso do Sul (MS) state and in Bolivian territory the iron reserves of Mutún. Therefore, to estimate the energy needs of the region, nothing better than analyzing the flow of energy in the

Table 1 Study energetic demand

Energetic resource	Quantity in toe/year	NG Volume (m^3)
Electricity	298.420	1,33 MM/day (45% of income)
Imported NG	575.343	0,6 MM/day
Imported Diesel	863.462	6,27 MM/day
NG for Mutún		6 MM/day

Table 2 Technical-economic indices

Technical-economic \ Coefficient	10	7,5	5	2,5	0
Total Cost (US$)	< 80 millions	80 a 140 mi	140 a 200 mi	200 a 260 mi	> 260 mi
Maintenance	Low Frequency/ National pieces	Average frequency/ National pieces	Frequent Maintenance/ National pieces	Average frequency/ Imported pieces	Frequent Maintenance/ Imported pieces
Construction Time	< 1 year	-	1 a 3 years	-	> 3 years
Technology Domain	regional	-	national	-	Imported
Payback Time (years)	< 2	2 a 5	6 a 10	11 a 15	> 15

Table 3 Indices of environmental dimension

Environmental Impact \ Factor	10	5	0
Air Pollution	Does not Pollute	Affects air quality slightly	Cause environmental imbalance
Water Pollution	Does not Pollute	Minor changes in water temperature	Harmful waste in water, diversion of natural water flow
Soil Pollution	Does not Pollute	Afects soil quality slightly	Harmful waste in soil, Dejetos nocivos nos solos, land variation
Ease of obtaining environmental permits	No obstacles	Reasonable obstacles	Many obstacles
Emission of greenhouse gases	negligible	medium	High

state of MS to estimate quantities of natural gas and / or electricity for this service in the coming years. Table 1 shows the volumes of natural gas needed to meet the demand of the study area (data from MS energy balance of 2005).

4.2 Used indices

In a more complex analysis each sub-criterion would probably present a different weight, but it

Table 4 Indices of social dimension

Social \ Factor	10	5	0
Job generation	> 1400	Between 800 and 1400	< 800
Local infra-structure development	Contributes greatly	Contributes moderately	Does not affect
Effects of environmental imbalance on milieu	Does not Pollute	Average Discomfort	Harmful noises and impacted visual

Table 5 Indices of political dimension

Political \ Factor	10	5	0
Risks of cambial exposure	National technology, no risk	Mixes technology, partial risk	Imported technology
Governmental Support	Strong support	Indifferent	Opposite
Population Opposition	Full support	Low opposition	Population against

would only be possible to determine them from diverse opinions of decision makers, entrepreneurs, environmentalists, interested and involved etc., and from this make a calculation to get the actual importance of each of these. From each sub-criterion was established a system of notes which will be used for the comparison of transport ways can be done. This rating scale is shown in the following Tables 2 to 5.

5. Results

With all the necessary data, we used a software to aid in decision making (Decision Lens Suite) on which form of transport was the least expensive in all parameters. A computational tool was chosen because, once created the tree of criteria, the handling of weights is done quickly and efficiently, the calculation of average scores is accurate and shown in graphs that illustrate which dimension was the most significant for a way of energy transport to be better than another.

5.1 Ways of transport analyzed to meet the electricity demand

The first comparison between the energy transports was conducted to meet the electricity demand of the study area. We started from the premise that there were already thermoelectric generation plants in the study area and gas liquefaction plants. Or in its origin, for the case of electric transmission, or in its destination, for the case of natural gas transportation through pipelines or by using LNG trains. Therefore, the analysis in three (technical, economic, environmental and social) of the four dimensions was focused only on the transport itself. The political dimension had to be directed beyond the transport and see the regional importance of plants implementation of natural gas processing. The results obtained for this case may have a variety of explanations. The LNG was the way which had the best performance. The most loaded factors in his favor were the technical-economic, environmental and political. It showed

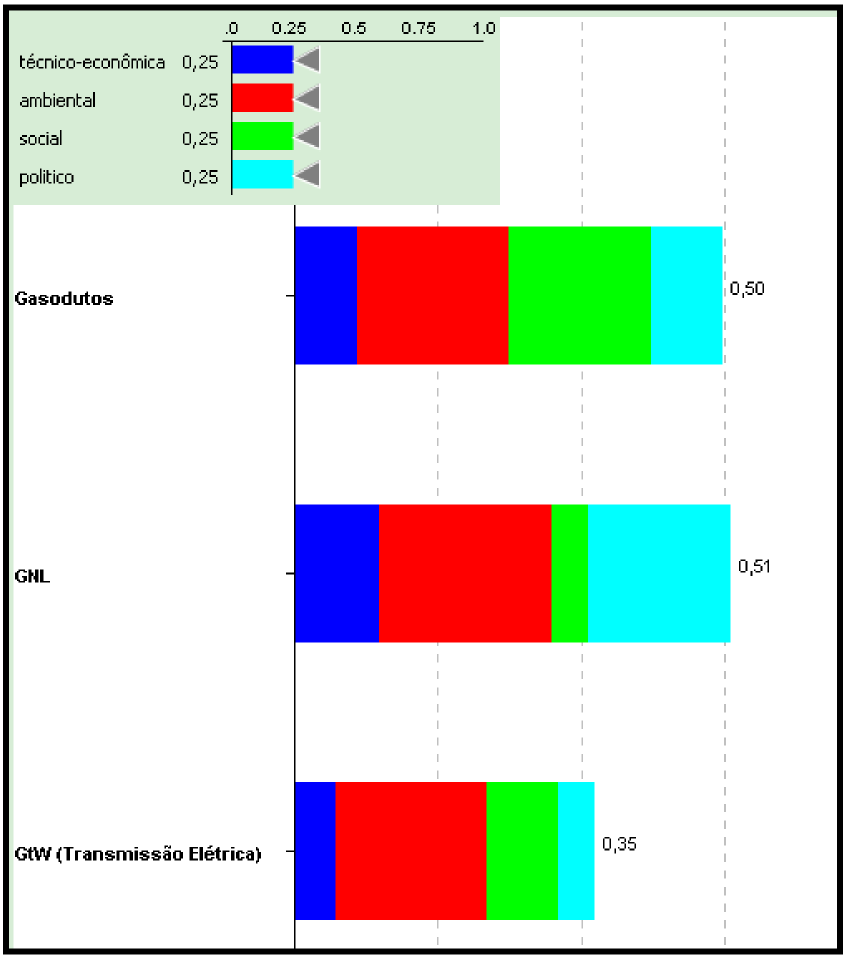

Fig. 6 Comparative graph for the supply of the electrical demand of this study

considerable advantage in technical-economic and environmental dimensions because, as previously explained, the implementation cost and the environmental damage caused by the implantation of the liquefaction plant were not considered, and due to the already existence of railways which would meet the trains of LNG transport. In the political dimension, the advantage of LNG was due to the fact that there is an interest by the Bolivian government in the implementation of a liquefaction plant for natural gas in its territory. The results are shown in Fig. 6.

5.2 Ways of transport analyzed to meet the natural gas demand

The second comparison was between the transportation of natural gas to meet the demand of the gas itself to the study areas. Due to the large volumes demanded, CNG was discarded as impractical in its transportation through trains or trucks. So the comparison was between LNG and the pipeline. In this situation, the pipeline reached a very superior performance in social analysis. The sub-criteria that weighed more in this dimension was the creation of jobs, greater than those

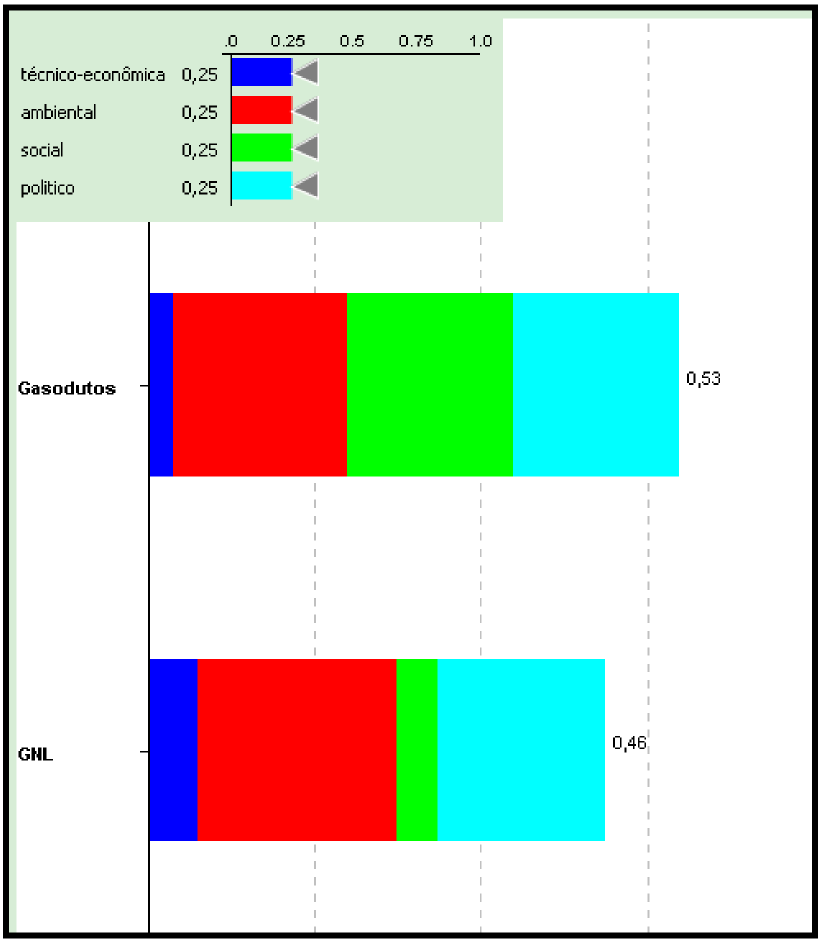

Fig. 7 Comparative graph for the supply of natural gas demand of this study

generated by the transport of LNG. The simulation graph of Fig. 7 shows these results.

5.3 Ways of transports analyzes to meet the diesel demand

The third and final comparative aims to meet the diesel demand in the state of Mato Grosso do Sul, Brazil. Here it was considered that the GTL plant already existed in Bolivia, or in the border region with Brazil, depending on the transport way in question. The focus on three of the four dimensions, again, was only in the energy transport. Looking at the obtained results, we note that there is a huge advantage of the GTL when compared to the LNG and to the pipelines. Firstly, the technical-economic advantage is due to the fact that the railway construction was not necessary (they already existed), the cost of wagons carrying GTL being less expensive than LNG, and also to the reduction of transported volume when the gas is in the form of liquid derivatives. In the political dimension, this way of transport also received immense advantage. That is because the Bolivian government has an interest in implanting a GTL plant so that it can meet its internal needs of diesel. These results can be seen in Fig. 8.

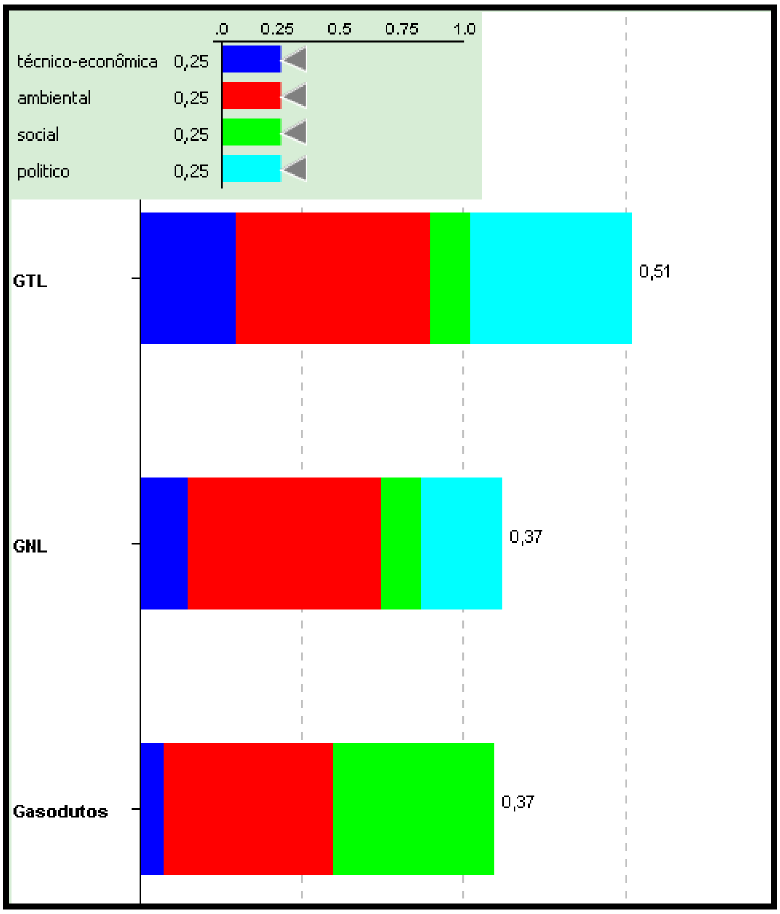

Fig. 8 Comparative graph to the supply of diesel demand of this study

6. Conclusions

Transport is the main link of any energy project. Without this step, one can simply say nothing happens. For this reason, there must be a special care in the evaluations within this link, for an inefficient transportation system, very costly, environmentally damaging, which has popular opposition or governmental, would become impractical.

Any study which involves an agreement between countries has a high complexity evaluation degree. In most cases, especially when dealing with shared natural and energy resources, some part of it would feel impaired. From this observation, if the study is well done, seeking not to prioritize any specific side, it will then be able to develop the desired project.

The first dimension was analyzed is the technical and economic. It was clear that there may be several other sub-criteria of those used in this dimension, but for the purpose of study were chosen those that have greater relevance to this case. Similarly, in environmental dimension, were used sub-criteria that may be significantly affected when exist energy transport. The social dimension emphasizes factors that may benefit or not a population impacted by infrastructure located on their land. The political dimension aimed to factors related to currency conversion, popular opposition to a project and especially the local government support for this project exists.

Even in the case study , the comparative is not restricted only to compare the transport of natural gas to electric transmission, then, to chosen region, energy consumption is not only electrical, then the analysis of the transport of energy also prioritized cases where natural gas could enter as a substitute energy.

The first comparison between transport energy was conducted to meet the electricity demand of the study area. Starting from a premise that already exist thermoelectric generation plants in the study area and gas liquefaction plants. Or in starting point, in the case of electric transmission, or in destination for the case of transportation of natural gas through pipelines or by using LNG trains. Therefore, the analysis in three (technical-economic, environmental and social) of the four dimensions was focused only on the transportation. The political dimension had to be directed beyond the transportation and see the importance of regional deployment processing plants for natural gas. The results obtained for this case can have a variety of explanations. The LNG had the best performance. The most important factors weighed in his favor were the technical-economic, environmental and political. Had much advantage in technical-economic and environmental dimension because, as previously explained, the implementation cost and the environmental damage caused by the implantation of the liquefaction plant and were not considered due to the existence of previously railways that would meet the trains transport LNG. In the political sphere, the advantage of LNG was due to the fact that there was interest from the Bolivian government in implementation of a liquefaction plant for natural gas in your territory.

The second comparison was between the transport of natural gas to meet the demand of the gas itself to those areas of study. Due to large demanded volumes, CNG was discarded as impractical is its transportation via trains or trucks. So the comparison was between LNG and pipeline. In this situation, the pipeline reached the far superior performance in social analysis. The sub-criteria that more weighed in this dimension was the creation of jobs, much higher than those generated by the transport of LNG.

The third and final comparative aims to meet the demand for diesel in the state of Mato Grosso do Sul in Brazil. Here it was considered that the GTL plant already exists in Bolivia, or in the border region with Brazil, depending on the form of transport concerned. The focus on three of the four dimensions, again, it was only in the transport of energy. Observing the results, there is huge advantage when compared to the GTL and LNG pipelines. First, the technical and economic advantage is not given the need for railroad construction (because already exist), the cost of transporting GTL cars are cheaper than LNG, and also the reduction of the volume transported when gas is in the form of liquid derivatives. In the political sphere, this form of transport also received immense advantage. That's because the Bolivian government has an interest in deploying a GTL plant that can meet their domestic needs diesel.

Can finish saying that for the case considered there is no single way of transporting energy that is favorable if the objective is a balance between the four dimensions mentioned. Therefore, for the study in question (when the analysis of the demands is taken separately), the ideal place to meet the total energy demand would be combination: LNG trains to supply electrical demands to the Mato Grosso do Sul (MS - Brazil), with generating plants in Brazil, transport natural gas through pipelines to meet the demand of natural gas (to be consumed in MS and Mutún), and finally transporting liquid products extracted from natural gas (GTL) via trains equipped with tank cars. Taking into account that a pipeline and transportation of natural gas via LNG unlikely to be installed in the same passage, it can be stated, considering the advantages in all dimensions analyzed, the pipeline would be the best option for meeting the demand for electricity and natural gas the region under study, keeping the transport through GTL trains.

Resuming: when the analysis of demands is made separately, one obtain the results in the best forms of energetic transport of natural gas presented above. But, as these are two well-defined regions, separated between supplier (Bolivia) and plaintiffs (MS and Mutún), the analysis can and should be done in such a way that there will be no competition between ways of transporting natural gas. Thus, the pipelines take huge advantage over other ways of transport when it wants to meet the electricity demand and of NG in the MS and the demand of NG in Mutún. Together, and mainly due to political interests, the transportation via trains with GTL plant in Bolivia territory would be the best way of transportation to meet the diesel demand of this study .

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