Expansion of the Brazilian refining industry and its local requirements: critical factors for siting a new refinery in Rio de Janeiro State, Brazil

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Abstract

The trade-off between welfare and environmental quality is clear in the refining industry. Economic development and well-being are still related to oil product demands in contemporary society. However, the refining industry is usually aggressive to the environment, bringing externalities out to localities where facilities are built. Therefore, there is a dilemma between meeting national oil product demands growth and preventing environmental damages in the locations eligible for a green field project. This paper shows that Brazil should expand its refining industry over the next twenty years by two to four new refineries. One of these refineries, focused on petrochemicals, might be located close to major consumption centers. In this case, Rio de Janeiro State is an interesting option. The analysis indicates the trade-offs between the positive and negative external effects of a new refinery in the Itaguai Municipality. The advantages of good logistics and infrastructure might be offset by the cumulative environmental problems related to air, water and solid wastes management in the region.
Keywords: refinery expansion, location, environmental pressure, Brazil.

1 Introduction

The trade-off between welfare and environmental quality is particularly clear in the refining industry. Economic development and well-being are still closely related to oil product demands in contemporary society, despite relevant efforts to substitute and/or to save oil products after the Oil Shocks in the 70's.

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However, the refining industry is usually very aggressive to the environment, bringing externalities out to localities where facilities are built. In this sense, there is a dilemma between meeting national oil product demands growth and preventing, or at least controlling, environmental damages in the locations eligible for a green field project (local communities might say “gray” field project). As a matter of fact, environmental requirements have become one of the major issues in refinery green field projects. For instance, new refinery capacity will probably not be installed in the USA in the next 30 years, mainly due to environmental requirements for green field projects (oil products supply increase will come mostly from imports and conversion capacity) – [1]. In the case of Brazil, evidences brought out by [2–7] suggest that Brazil might reach a bottleneck in its refining capacity for supplying the oil products market in the coming years, particularly for key fuels such as diesel, which has presented high levels of dependence during the past two decades.

Brazil's refining industry includes thirteen refineries with the operational processing capacity of 1.96 million barrels/calendar day [8]. The main refineries are located alongside or close to the consumer centers at the southeast region of the country, except for the RLAM refinery, which is located in Bahia State where crude oil production outputs paraffinic crude oil (KUOP of 12.6), allowing the production of lube oils. There are seven refineries in the Southeast, whose output meets some 50% of the demand for oil products in Brazil [8]. The total capacity of these refineries was equivalent to 62% of the operating capacity of Brazil's refining segment in 2003.

Brazil is a net importer of diesel. In 2003, 30% of total oil product imports consisted of diesel oil [8]. Although its thirteen refineries have been revamped in order to handle the average lower quality processed crude, while the oil products market has shifted towards medium cuts, they are nearing production capacity. Short and medium-term investments planned for conversion and treatment units at existing refineries might not be enough to meet the diesel market growth. In this case, total refinery capacity expansion might be required. However, while meeting oil products demand is a national need, identifying the location where the facility will be built requires the definition of who will hold the local environmental burdens. Refineries result in economic benefits for the regions where they are installed, but put environmental pressures, particularly due to intensive water use and atmospheric emissions. Developing countries such as Brazil must also deal with complex logistics and infrastructure difficulties when taking decisions on the best location for a new refinery.

2 Brazil’s refinery expansion through 2025

Oil products demand and supply forecasts are based on two studies: one performed to the Ministry of Mines and Energy [5]; and another jointly concluded with the International Atomic Energy Agency [9]. These studies used the following tools:

- The Model for Analyses of Energy Demands (MAED) developed by the International Atomic Energy Agency (IAEA) - for more details see [9].

- For the transportation sector, the forecast of the light vehicle fleet by type followed a scrapping curve. For the industrial sector, the Integrated Energy Planning Model (IEPM) was used – for more details see [10] and [11]. For the residential sector, logistics curves were sized to forecast the penetration and use of stoves in households, by income and location (rural and urban areas).

In addition, two technical and economic scenarios were drawn up – see Table 1:

1. Business as Usual Market Scenario. This scenario does not include qualitative changes in the development of Brazil's production segment other than those already delineated over the past few years. Shifts in the Brazilian economy – such as the incorporation of technical progress and alterations to the production structure – take place at a pace compatible with that of the past decade.
2. Alternative Scenario. This scenario includes qualitative changes to Brazil's production development, through upgrading exports and "dematerializing" the economy from 2010 onwards.

Table 1: Real GDP growth rate and sector added value assumptions for the Brazilian economy (% p.a.).

	2005/10	2010/15	2015/20	2020/23
GDP	4.26	4.11	4.05	4.05
<u>Business as Usual Market Scenario</u>				
Agriculture	3.58	3.55	3.38	3.26
Industry	5.42	5.16	5.03	4.98
Services	3.60	3.45	3.42	3.46
<u>Alternative Scenario</u>				
Agriculture	4.19	4.13	4.88	4.93
Industry	4.00	3.00	1.86	1.80
Services	6.00	6.00	3.00	3.00

In terms of energy prices, the basic assumption was the convergence of oil and oil products prices in the Brazilian and the international markets. The scenarios took the oil, oil products and natural gas price forecasts drawn up by the US Department of Energy as the basis for the international prices [1]. Technical assumptions were made for potential inter-energy substitutions and crude oil production curves [12]. In terms of oil output quality, increasingly heavy acid oil production is expected. This affects the technological options for the development of Brazil's refining industry. Three options were assessed:

- Expansion of Brazil's current refineries in terms of processing capacity and conversion and treatment capacities. Modifications currently under way in Brazil's existing refineries are designed to boost the processing of domestic heavy crudes while reducing the supply of heavy oil products (fuel oil) and fostering higher and better supplies of medium and light oil products (diesel, jet fuel, and LPG). Investments are channeled to bottom-of-barrel units, such as delayed coking, vacuum residue catalytic cracking, and hydrocracking, and to hydrotreatment. These projects alter the oil products output profile of the existing refineries (see Table 2), but do not represent a significant expansion in the atmospheric distillation capacity as a whole.

- A new refinery optimized for diesel (see Table 3), processing mainly the Brazilian Marlim crude oil (API 19, sulfur content of 0.7% and TAN of 1.1), which is the main stream produced in Brazil [13]. The key bottom-of-barrel units of this refinery are delayed coking and hydrocracking. Due to its versatility, this refinery can also output higher yields of light cuts, and is flexible to step up its production of heavy oil products as well, if necessary.
- A new refinery focused on propylene (see Table 3), which is produced in a DCC unit, LPG and distillates (mainly diesel). This petrochemical integration is in line with technological innovation of the oil refining industry worldwide [14] and [15]. This venture would solve the diesel dependence issue, also guaranteeing petrochemical feedstock supplies.

Table 2: Estimated production profiles for Brazil's current refining segment (%).

Oil Product	2001	2010	2015-2020
LPG	8.1	8.9	9.1
Gasoline	19.5	21.9	23.8
Naphtha	10.5	11.3	9.6
Kerosene	2.6	5.4	5.9
Diesel	36.4	40.7	41.6
Residuals	22.9	11.9	10.1

Table 3: Production profiles for new refining schemes.

Production Focus	Diesel	Fuel-Propene
Capacity (10^3 barrel per day)	250	200
Yield (%)		
LPG	9.5	2.4
Gasoline	34.1	22.0
Naphtha	5.3	3.4
Propene	-	16.4
Kerosene	0.0	-
Diesel	44.6	21.0
Heavy oil products	11.6	14.0

Finally, the expansion refining criteria was based on reducing the vulnerability of Brazil's oil chain. In this case, a ceiling of 10% dependency was stressed for the key oil product on Brazil's fuel market: diesel. This figure corresponds to the average ceilings adopted in previous studies – [3, 5, 7].

Therefore, among the refinery options described above the modeling strives to select those whose versatility or industrial integration potential would justify investments in Brazil. The findings of the simulations indicated that the expansion of Brazil's refining sector between 2002 and 2025 should take place through four refineries in the Business as Usual Scenario, and two refineries in the Alternative Scenario – see Table 4.

Table 4: Forecast of entry schedules by refinery profile in Brazil.

	Business As Usual Scenario		Alternative Scenario	
Refinery type	Diesel	Petro-chemicals	Diesel	Petro-chemicals
2010	0	1	0	1
2015	1	0	1	0
2020	1	0	0	0
2025	1	0	0	0

3 Critical factors for sitting a new refinery in Brazil: Rio de Janeiro State Case Study

Both scenarios indicate that Brazil should expand its refining segment by two to four refineries over the next twenty years. Implying an additional 500 to 1,000 thousand barrels per day of refining capacity, this is fully compatible with our forecast increase in Brazil's crude oil production output (equal to 1,730 kbpd between 2002 and 2025) – see [12].

However, the need for expanding refining industry in the country level raises the question of finding a proper location for the new facilities. At local-level, fuel and petrochemicals market and environmental requirements become major issues. As pointed out in the first section, the oil products market and the refinery capacity are concentrated in the Southeast region of Brazil. This region accounts for around 60% of Brazil’s GDP and Manufacturing Value Added [16]. It represents around 50% of the country’s oil products market [8], and presents fuel surpluses that are channeled to other Brazilian regions (Mid-West and Northeast, basically) and to other countries (Brazil’s fuel surpluses include, especially, gasoline and high-grade petcoke). Therefore, the analysis of the regional location of new refineries in Brazil usually suggests the Northeast region for a fuel-focused refinery and the Southeast region for a petrochemical-focused refinery. Actually, one of the new refineries simulated in both scenarios is integrated with petrochemicals (coming on-stream in 2010). In this particular case, the Southeast region is the most suitable location, concentrating the country’s petrochemicals market and an increasing demand for propene [17]. It is also heavily dependent on naphtha from domestic refinery production and from imports.

At the Southeast region, Rio de Janeiro State holds 92.0% of Brazil's proven offshore reserves [8], is located close to major oil product consumption centers, particularly for petrochemicals, and has an advantageous location for both oil products imports and exports. In addition, the Campos Basin at Rio de Janeiro holds around one-third of Brazil's total probable reserves (probability of 50%), and Rio de Janeiro accounts for 82.6% of Brazil's total production.

Therefore, Rio de Janeiro State is a good macro-location candidate for a new refinery focused on petrochemicals. However, this industrial complex imposes pressures on the environment and the infrastructure in the site where it is located. This refinery is complex (see Table 5). It requires 600 MJ per barrel of feed, and 5,000-13,000 m^3 per hour of water in open cycle. The project implementation schedule time is 4 years.

Table 5: Main refinery processing units.

Atmospheric Distillation Unit – ADU (1,000 bpd)	200.0
Vacuum Distillation Unit (%)	65.2
Delayed coking (%)	31.6
DCC unit (%)	65.6
Hydrocracking (%)	10.0

Note: downstream units' capacity is related to the ADU capacity.

Due to its available basic infrastructure and proximity to industrial market, Itaguai Municipality is frequently eligible for new industrial facilities in Rio de Janeiro State. This region comprehends utilities, roads and ports, and it is up to 500 km close to Sao Paulo, Minas Gerais and Rio de Janeiro industrial markets (see Figure 1). Still, it already has an area originally earmarked for the Rio de Janeiro Petrochemical Complex owned by PetroRio. This is the area that was assessed in the present study. In addition, Itaguai offers fiscal exemption from land duties, work levies and occupancy permits for ten years, to companies employing more than thirty people. Finally, the assessed site presents low-density urban areas (less than 0.1 inhabitant per km^2), despites the vicinity to the town of Itaguai.

Figure 1: Sepetiba Bay location in Rio de Janeiro and Brazil.

The following site factors were assessed in Table 6: energy, water, road, rail, port and pipeline infrastructure, labor-force, land, conservation units, air quality, water quality, solid wastes.

Table 6: Local Site Factors for Itaguai.

Site Factor	Facility Requirements (demand)	Site Availability (supply)	Comments
Energy	The refinery is self-sufficient. The CHP plant of 200 MW generates surplus power.	The site is also served by natural gas-fired thermo-power plants.(1)	The refinery does not impose a local pressure.
Water	Water requirement hovers between 5,000 and 13,000 m^3/h (1.17 – 3.60 m^3/s).	Gross water availability is 78.68 m^3/s. A saline wedge penetrates 5 km up the Guandu River that serves Itaguai and reduces water availability to 28.68 m^3/s.	There is water availability. However, there is also a problem of a saline wedge penetration in Guandu River.
Transportation Infrastructure	The location of the refinery should be as close as possible to ports, roads, railroads.	There are two ports: the Port of Sepetiba (83 millions of tones) and the TEBIG Terminal owned by Petrobras in Angra dos Reis. The assessed area is 2.5 km away from highways; the Mangaratiba rail spur runs through this area.	The region is well provided by road and rail infrastructure. The Port of Sepetiba has a large spare capacity, but a bulk liquids terminal needs to be built.
Labor-Force	The new Refinery will demand roughly 30,000 workers under temporary contracts (refinery construction), while some 1,200 workers under permanent contracts (refinery operation)	The labor force in the Rio de Janeiro Metropolitan Region in December 2003 was around 5 million people aged 18 to 49 years old	There might be migration from other Municipalities, with large number of workers brought in for the implementation phase. However, Itaguai has the advantage of lying close to the Metropolitan Area of Rio de Janeiro.

Table 6: Continued.

Land	The refinery requires 7-10 km^2 of area	The area under analysis covers 10.76 km^2. However, 2.79 km^2 can be flooded. The available area options are: 5.95 km^2 (without drainage project) and 8.74 km^2 (with drainage project)	Itaguai has already a site that could be devoted to a new refinery. However, a drainage system should still be implemented.
Conservation Units	The refinery cannot be installed in the conservation units.	The area has a large space of grazing land and meadows, in addition to rainforest and secondary vegetation. To the Northeast, it has a tract of floodlands. The refinery should respect the mangrove swamp, forest and secondary vegetation lands.	The site does not lie in conservation units. However, the mangrove swamp, forest and secondary vegetation should be preserved
Air Quality	The main pollutants from the refinery operation are: Sox, Nox, Volatile Organic Compounds, CO and Particulate Matters (PM).	The atmospheric pollutants concentration monitored in the region are below the ceiling amounts stipulated by Brazilian law [(2)]; however, close attention should be paid to the sharp increase over the past few years, due to industrial expansion in this region	The carrying capacity of Itaguai will be affected by a new refinery, mostly due to region cumulative effects (impacts of other industrial facilities located or planned in the area).

Table 6: Continued.

Water Quality	The new refinery generates 1-2 million m^3 per month of wastewater with high BOD, COD and contaminants concentration (phenol, sulfides, ammonia, toxic metals).	Two rivers are important. The Guandu River complies with the specification stipulated by Brazilian law. The Guarda River does not meet these specifications, with strong indications of degradation.	Due to heavier industrial concentration, Itaguai is few resilient to water pollution.
Industrial Wastes	The new refinery generates 500-750 kg of dangerous residues (spent catalysts, moods, waxes, heat exchangers fouling etc.)	The area lies alongside the Santa Cruz Industrial District, consisting of fourteen widely diversified industrial firms.	The refinery might interact with companies in the Santa Cruz Industrial District for treating and/or recycling their industrial liquid wastes, and for treating and disposing their solid wastes

(1) Santa Cruz Power plant (766 MW) and Eletrobolt (379 MW). (2) PM_{10} 44 $\mu g/m^3$, SO_2 2 $\mu g/m^3$, NO_2 12 $\mu g/m^3$ and O_3 25 $\mu g/m^3$.

In sum, from the logistical and infrastructure standpoints, Itaguai offers several advantages, including transportation infrastructure, skilled labor force and logistical synergies with neighboring industrial districts. However, from the environmental and urban planning point of view, Itaguai faces environmental issues such as polluted water-bodies, slums (*favelas*) and improper land use and occupancy. Itaguai presents:

- High vulnerability to contamination by heavy metals
- High water vulnerability (pollution of the Guarda River and the saline wedge in the Sao Francisco Channel)
- High possibility of saturation of the air basin due to the emission of atmospheric pollutants from the operation of the refinery;
- High level of urbanization and nearby townships with dense populations.

Interestingly enough, the case presented here shows a quite common situation of urban areas in developing countries, where sites with good infrastructure (especially transportation infrastructure) also face environmental vulnerabilities. It is worth noting that industrial projects seek for areas with developed public infrastructure, but those projects create additional local environmental pressures. In this sense, there is always an environmental opportunity cost to take in consideration: a project "X" might excludes a project "Y" due to their relevant cumulative effects over the local carrying capacity. Furthermore, such environmental opportunity cost also implies in socio-economic opportunity costs: the environmental pressures might bring more (less) socio-economic benefits for the region (income, jobs, and local taxies).

This might be the case for Itaguai Municipality, since its regional neighborhood places other large industrial facilities (such as the Santa Cruz thermo-power plant, and the Industrial District of Santa Cruz) and is eligible for other large industrial projects besides the petrochemical refinery.

4 Conclusions

Brazil might be called to expand its refining industry over the next twenty years by two to four new refineries, in addition to modifying its current facilities. One of these new refineries is focused on petrochemical products and might be located close to major consumption centers. In this case, Rio de Janeiro State is a good option. However, the decision on where to locate a refinery within Rio de Janeiro State is no trivial. It opposes the country's requirement for a green field project to the local perception of a "gray field" project. The analysis of a possible site in Rio de Janeiro State shows the trade-offs between positive and negative external effects of a new refinery. In the Itaguai Municipality, the advantage of good logistic and infrastructure are offset by the cumulative environmental problems related to air, water and solid wastes management. Moreover, there are other large industrial projects for the region. The refinery will have to compete with other projects for the "right" to pollute, such as new steel mills under consideration for the area analyzed here.

Finally, this paper shows the need for improving the site-location study. This will request detailed information about regional economies and environments, which is a great challenge for developing countries. Building a detailed regional database has to become a top priority in countries such as Brazil.

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