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CASE STUDY

Dealing with petroleum surpluses in Brazil through optimization refining model

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ABSTRACT

This study develops a model for linear programming to identify the best option for the use of potential surplus oil in Brazil. The methodology is capable of identifying key international markets that could be served by oil exports and oil products from Brazil, in addition to providing investment in new refineries, in the national refinery installed base or in foreign markets. Through a case study application, it was found that the proposed modeling is capable of adequately representing the real problem of the different possibilities of utilization of surplus crude oil from Brazil. This is a relevant tool to design liquid fuels supply policies in petroleum producing countries. It also helps understanding the better strategy for valuing petroleum surpluses.

1. Introduction

According to official estimates, Brazil may have a significant increase in its oil production, reaching 874,400 m^3/d (5.5 million bpd) in 2022 [1]. The aggregate forecast demand for oil for domestic consumption of oil products is 524,700 m^3/d (3.3 million bpd), implying, thus, a surplus of 394,800 m^3/d (2.2 million bpd) in that year [1]. Thus, in the coming years, Brazil could become an exporter of crude oil and/or opt for the expansion of its refinery installed base and export oil products.

Meanwhile, the decision to choose the best option to take advantage of this potential is not trivial. It includes: i) export of crude oil by adding *ex-situ* value; ii) export of crude oil without adding *ex-situ* value; and iii) export of oil products.

Thus, this paper describes the development of a modeling technique to identify the best option for the valorization of surplus oil production in Brazil that can also serve as a basis for use in other countries with an oil exporting profile. Actually although in this work the proposed modeling is applied to Brazil, it has a universal application.

The modeling simulates the Brazilian refinery installed base, the supply of the domestic market (oil and products), the ability to export and import crude oil and/or oil products, in addition to forecast new refinery investments in Brazil and abroad. Thus, the modeling aims to ascertain whether the best option for Brazilian surplus oil is the exporting of crude oil or implementation, either in the country or internationally, of an export-oriented capability for oil products. This study also contributes to identify the major international oil and oil derivative markets which can be served by Brazilian exports, to determine the volumes involved in these logistic flows, to predict investments in the refining installed base in the country or abroad, and to meet these possible demands.

In this sense, this study also deepens other published articles that were written by the same research centre in order to assess the international placement of Brazilian oil surpluses [2] and plan the long-term refinery expansion [3–5].

Since the 1960s, an important application of operational research has been the development of models for refinery planning. Bodington and Baker [6] and Cooper and Charnes [7] report the first models using linear programming that appeared in several international companies in the oil sector. Notably, since the early 1980s the French Petroleum Institute (IFP) has developed and used models of refining based on linear programming to evaluate the evolution of the oil industry structure [8,9], such as the global refining model known as "*Oil is Used in Refineries to Supply Energy (OURSE).*"The U.S. Department of Energy's Energy Information Administration (EIA), has also developed a complex linear programming model for simulation of the global oil industry called "*World Oil Refining, Logistics and Demand Model* (World)" [10].

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In Brazil, as shown by Iachan [11], the first linear programming model for refining was developed in 1967 and had the objective of optimizing the types of oils to be processed at a refinery in order to meet a particular forecast demand for oil products. The mathematical modeling to optimize the allocation of oils continues to be studied by Petrobras [12]. From 1970 onwards, linear programming modeling was used by Petrobras in other applications [13,14].

To analyze the problem of the domestic supply of oil products and possible expansions to refining installed base, the Energy Research Company (EPE), under the Ministry of Mines and Energy (MME) of Brazil, developed the Oil Products Supply Planning Model (PLANDEPE) using linear programming [15]. The PLANDEPE optimizes the Brazilian system of oil derivative supply, minimizing the total costs involved in meeting existing demands.

It is a disaggregated model, presenting the current configuration of the national refining installed base, including details of existing refineries and of the major expansions underway, besides possible expansions being studied and of the logistical flows. Meanwhile, this model does not represent the diverse international oil and derivatives markets, nor does it allow the option of investing in overseas refineries to process the possible Brazilian oil surplus.

Thus, scientific literature shows the use of modeling to solve problems involving operational planning of refinery production [16], highlighting the complexity of this type of problem and the need to optimize, simultaneously, thousands of variables. It also shows that the linear programming model is suitable for solving real planning problems of the supply of oil and its derivatives.

Concurrently, existing methodologies presented in literature do not specifically deal with the optimization of the refining installed base in the long term, with a possible focus on refining for export and the representation of different international markets. This is the main focus of this study. Developing and testing tools for designing the expansion of the petroleum refinery system by oil producing countries is an important part of their energy planning. For example, the Canadian Energy Outlook applies an integrated energy planning tool (TIMES) to assess different strategies for the country's refining system, including crude oil and petroleum products exportation [17]. TIMES is a well-known and widely applied tool for energy planning, but usually it does not deeply detail all refining processing units characteristics [17,18]. Actually, one of the major contributions of the model developed by us is the possibility of detail the quality of the major petroleum products and composes their pool by different intermediary products. Besides, being a specific model for refining and logistics, it allows evaluating investments by process unit for either existing or new refineries, also considering the logistic costs.

2. Methods

2.1. Model description

The modeling of the problem proposed here was based on PLANDEPE [15]. Its functionality, developed with linear programming using AIMMS (Advanced Integrated Multidimensional Modeling Software) was used, changing the modeling so that the new structure would be capable of identifying the best economic option for the surplus oil in Brazil in the coming years, the main international markets to be served by oil and oil derivative exports, and the investments in new refineries, within the domestic installed base or in external markets.

The domestic refining installed base is represented by region, representing the current configuration of the Brazilian refinery industry, with the major expansions underway, in addition to possible expansions, both in new refineries and/or new processing units in existing refineries.

The model also contemplates international oil and derivative markets in various regions worldwide, with the possibility of investment in refineries abroad for processing surplus Brazilian oil. It also represents the flow of oil and derivatives between different points of supply and demand, national or international, allowing both import and export of crude oil as well as its derivatives.

For the storage of input and output data as well as for the elaboration of modeling, Microsoft Access software was used.

After receiving the AIMMS execution command it saves a file containing the detailed description of the mathematical programming problem and calls an optimizer (solver). In this study, the programming code used was that of PLANDEPE [15].

In this programming code, the model's objective function (FO) seeks to maximize the current value of profit or to meet certain demand at a minimal cost, over a given period of time. The main variables are those related with the refining and logistical decisions. The main constraints are related to the stock of materials (oil, intermediate products, and final products), which determine the conversion efficiencies of each process in refineries; equations regarding the quality of the intermediate and final products; equations for final product demand; equations of capacity of process units, and equations of availability of oil.

The optimization program (solver) used was CPLEX. Optimization results are exported to Microsoft Excel spreadsheets.

2.2. Main characteristics of the modeling structure

2.2.1. Number of periods

The proposed modeling methodology contemplates five periods, with each period corresponding to a five year time frame. For instance, in the context of the application, this study's first year corresponds to 2015 and the last to 2035.

2.2.2. National centers of consumption (bases)

The national centers of consumption are the regions of the country where internal demand for oil products is located. In the case study, centers of consumption aggregated by areas of demand are considered. For the application of this specific case, referring to Brazil, there are five consumption centers: Center, North/Northeast, Southeast, São Paulo, and South.

To meet the national demand for petroleum products, the model aggregates the marine and terrestrial terminals in the same regions of the country where the national centers of consumption were aggregated.

Thus, in the case of Brazil, the modeling covers four marine terminals (MT) and five regional terrestrial terminals (TT), namely MT North/Northeast; MT Southeast; MT São Paulo; MT South; TT Centre; TT North/Northeast; TT Southeast; TT São Paulo; and TT South.

2.2.3. International centers of consumption

The international centers of consumption are the external markets where the demand for oil and its derivatives are located. These international centers of consumption are aggregated by the world geographic regions.

Therefore, the international markets for oil and derivatives, represented in the model are: Africa; North America; South and Central America; Asia and Oceania; Eurasia; Europe; and the Middle East.

2.2.4. Raw materials (oils)

The modeling proposed in this study aggregates the Brazilian oil production according to density (light, medium, and heavy) and sulfur content (sweet or sour), forming five groups: light oil, sweet medium oil, sour medium oil, sweet heavy oil, and sour heavy oil.

As an import possibility, three representative groups of international oil were considered: African light oil, Arab light oil, and South American heavy oil.

2.2.5. Composition of the national refinery installed base

The Brazilian refinery installed base currently consists of 15 refineries within stalled operating oil processing capacity of