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# The impact of $CO_2$ taxation on the configuration of new refineries: An application to Brazil

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This article evaluates the impact of pricing $CO_2$ emissions over the configuration of new refinery complexes in their conceptual phase. Two refineries' schemes were simulated through a linear programming optimization model in order to compare the optimum configuration obtained before and after the input of different $CO_2$ prices. The cases analyzed represent refining projects to be located in Brazil, a growing market for fuels and petrochemical feedstocks, as well as an oil producing country with rising crude exports. After 2012, emerging countries, such as Brazil, may adopt carbon emission reduction targets. Therefore, it is worth analyzing the impact of pricing $CO_2$ emissions in these countries, where the majority of new refining projects will be located. Our findings indicate that the initial refinery configurations proposed are quite rigid technologically for $CO_2$ prices up to US$ 100/t $CO_2$. For $CO_2$ prices higher than US$ 100/t $CO_2$, refineries reduced their emissions by increasing the consumption of natural gas used to produce hydrogen, and through changes in the original configurations towards less-energy consuming process units. Promising technological advances, such as carbon capture and storage (CCS), can also diminish the rigidity of the model and facilitate actions to curb carbon emissions.



## 1. Introduction

Part of the technological development of the oil refining industry worldwide is justified by the fact that this is an industrial activity with high fossil fuel consumption and, consequently, high $CO_2$ emissions. Oil refining processes are energy-intensive, requiring considerable amounts of direct or indirect heat. Between 7% and 15% of the crude oil input is used by the refinery processes (Worrell and Galitsky, 2005; Szklo and Schaeffer, 2007). Therefore, oil refining is a large $CO_2$ emitter. $CO_2$ emissions in oil refining derives from fossil fuel consumption for heat and/or power generation, and chemical reactions that occur in the refining units aiming at reducing the carbon content of molecules (Sigaud, 2008). In sum, the global refining industry is facing challenges as crude oil quality continues to decline and demand for medium and light refined products grows (Rogner, 2000; Bentley, 2002; Adelman, 2004), along with a heightened need to reduce the environmental impact of these products, mainly those related to greenhouse gas (GHG) emissions from producing and burning them (IPCC, 2007).

Faced with the rising global demand for high-quality products and the restricted supply of light and sweet crudes, refineries have been seeking technological solutions that make refining more complex. Various alternatives are being tested, particularly units for conversion of residues and hydrotreatment/hydrocracking, along with integration with refining of petrochemicals. The objective is conversion of heavier (and cheaper[1]) crude oils into good-quality fuels and other products with high value added (Williams, 2003; Johnson et al., 2002; Martino and van Wechem, 2002).

However, as refineries become more complex, their specific $CO_2$ emissions and environmental impacts increase (Szklo and Schaeffer, 2007; Johnson et al., 2002; Babusiaux, 2003). In this context, it is important to analyze the impact of GHG emission reduction policies on oil refining activities.

Various studies have sought to measure the energy efficiency of refineries and evaluate policies to mitigate their emissions (Worrell and Galitsky, 2005; Energetics Inc., 2007; Szklo and Schaeffer, 2007). These studies normally emphasize energy-efficiency actions and/or control of GHG emissions in processing units (heat integration, fouling control, new catalysts, etc.),[2] which seem to be explained by the fact that most countries or

[1] And more accessible, since the marginal supply of petroleum is increasingly of heavier and sour crudes (Kaufmann et al., 2008).

[2] For instance, in a recent study to the World Bank, Schaeffer et al. (2009) estimated the marginal $CO_2$ abatement costs for alternatives such as the use of pinch techniques, fouling mitigation and advanced control, to be implemented in the existing Brazilian refinery park.

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regions that currently target $CO_2$ emissions are not expanding their oil refining industry (this is the case, for example, of the European Union refinery park and even the Californian one—Worrell and Galitsky, 2005). Therefore, curbing $CO_2$ emissions of already installed plants by improving heat integration (or through other process options) is the basic technical answer to deal with carbon emission targets for existing refineries, which are quite rigid in terms of their conceptual designs (or configurations).

New refineries, on the contrary, can physically both improve their units (e.g., through heat integration) and/or choose their least-$CO_2$ emitter configuration. New refineries will typically operate for more than 35 years, and, as such, the choice of their configurations, which is made today, will affect their operations for a long period of time.

Some countries, such Brazil, China and India, which plan to expand their refinery parks (EPE, 2007), as of today are not constrained by carbon emission targets, although this situation may change in the near future. Very likely, these countries will face growing pressure to curb their carbon emissions (Diringer, 2008). Should the planned refineries in these countries consider, in their conceptual phase, a future need of curbing carbon emissions? What is the carbon price that would justify changing refinery designs in order to reduce refineries' emissions?

Therefore, the present study examines the impact of restrictions on $CO_2$ emissions on the configuration of new refinery complexes in their conceptual phase, when there is still a certain degree of flexibility in choosing processing units and alternative production routes. In this case, the most relevant result of the simulation is the choice of the refining scheme (or production routes) in light of a need to reduce GHG emissions.

For this purpose, we ran simulations of two complex refinery configurations through a linear programming (LP) optimization model. Previous studies have used this method to analyze the allocation of $CO_2$ output among refined products (Babusiaux and Pierru, 2007; Tehrani, 2007) and also to analyze the impact of changes in product specifications and environmental pressures on the refining industry and systems of co-products in general (Tehrani and Saint-Antonin, 2007). This study stands apart from the others mentioned, however, in that it evaluates the possibility of changing the design of the refining scheme as a function of the GHG emissions estimated for the lifetime of the complexes during their design stage.[3]

The model applied here has two possible configurations for a new complex refinery to be built in Brazil. The two proposed configurations are:

- a refinery that maximizes the output of high-quality diesel; and
- a refinery that integrates the production of fuels and petrochemicals.[4]

The choice of Brazil as the setting to study the problem is appropriate because construction has been announced for six new refineries in the country intended to produce high-quality diesel and petrochemical products, to meet growing demand in the domestic market and for exports, over a time horizon until 2030 (EPE, 2007). Besides this, the perspectives for growing crude oil output in Brazil are promising, mainly from the new "pre-salt" deepwater exploration areas.[5]

Finally, besides the new refinery projects, the existing refineries in Brazil are being modified to meet the objectives of reducing the sulfur content of the oil derivatives produced and of increasing the conversion of heavy crudes into high-quality medium and light products, as is occurring in most other countries as well.[6] Through heavy outlays,[7] the Brazilian refineries have been significantly expanding their capacity to use the heavy acid domestic crude oil and to adapt to produce more medium distillates (diesel and kerosene) with lower sulfur contents. The main investments made so far have been to adapt existing units and to install deep conversion (delayed coking) and hydrotreatment units.

The Brazilian case is thus emblematic, as it involves new complex refining projects, conceived to satisfy a growing market for medium derivatives and petrochemical feedstocks, typical of developing countries, and to absorb the forecast increase in domestic crude output, typical of oil producing countries.

On top of these factors, Brazil may assume carbon emission reduction targets after 2012, along with the other BRICs[8] (Diringer, 2008). In this context, it is important to analyze the impact of pricing carbon emissions on new refinery projects, as these new refineries are designed to have a useful life of over 35 years (EPE, 2007).

Analyzing the impact of $CO_2$ emission costs on new projects in their design phase is very different from evaluating emission reduction alternatives to adapt or retrofit existing facilities. The reason is that, in a new refinery project, the entire concept can be altered, while in an existing refinery there are obviously more technical and economic restrictions that come into play. In this context, this article examines the changes in processing in new refineries in Brazil, considering price scenarios for carbon emissions. This is done by using an optimization model to evaluate the impacts of charging for $CO_2$ emissions on the configuration to two types of complex refineries, to be built to meet growing demand for derivatives and petrochemicals in Brazil.

The next section presents the methodology employed. Section 3 discusses the two refining configurations proposed and some premises of the optimization model. Section 4 examines the impacts of $CO_2$ taxation on refinery configurations in various scenarios. Section 5 reports the results of the sensitivity analysis of two special cases of capturing carbon and the restriction on the supply of natural gas. Finally, Section 6 presents some final considerations.

## 2. Modeling refining in linear programming

Optimization in LP is a suitable tool to analyze problems of allocation of complex resources. The principal use of optimization models in the oil industry is for periodic scheduling of production

[3] Interestingly, the previous study mentioned above referred mainly to existing European refineries, with already defined process designs.

[4] Clearly other configurations could also be proposed. Nevertheless, the analysis of expansion of refining capacity in the world currently indicates both expansion with the indicated focus and rising demand for diesel as a replacement for gasoline (Caruso and Clyde, 2008).

[5] Starting in May 2006, Petrobras, the Brazilian national oil company, announced the discovery of various areas in a new deepwater exploratory frontier, at water depths between 1500 and 3000 m and a further 3000–4000 m under the seabed, beneath a salt layer, along the southeastern coast of Brazil. The volume of these reserves has yet to be determined, but initial estimates are that just the area called Tupi contains a potentially recoverable volume of 5–8 billion barrels of light crude, with 28° API (Petrobras, 2006, 2008).

[6] The worldwide conversion index, which measures the installed conversion capacity in relation to the distillation capacity utilized, rose from 42% to 51% between 1993 and 2005. This indicates a need for greater investment in conversion than in additional distillation capacity (Pieterse and Correljé, 2008).

[7] Petrobras' 2008–2012 Business Plan calls for investments in the downstream area of around US$ 29.6 billion, of which US$ 8.6 billion will go to improve fuel quality, US$ 3.9 billion for conversion and US$ 5.5 billion for refinery expansion (Barbassa, 2008).

[8] BRICs—Brazil, Russia, India and China.