Estimating the Marginal Emissions Factors for the Brazilian Power Market

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Overview

A key feature in the power market is the order of how each energy source is employed. This feature is called the Merit Order. This concept is related to the costs and flexibility of each technology, and consequently, the pollution of each one of these sources.

The Merit Order concept is simple. Given some quantity of energy demanded, or system load, the system operator decides which plants will be producing the energy needed to clear the market. The first plants dispatched will be those with the least costs of operation ("cheapest runs first"). The first plants to supply the current demand are usually renewable and nuclear sources. If the system load is increased but the cheapest energy sources are at full capacity, the next cheapest plant will be called to supply this additional load.

This energy-providing decision, however, does not only have cost implications. The higher-order plants not only cost more to produce energy but also are more pollutant. This design, ultimately, gives the system a dynamic characteristic regarding pollution. Depending on the load, and more importantly, the time of the day this load is supplied, the emissions will be different. The last plant dispatched is the so-called marginal plant.

One way to calculate a given system's emissions is simply to take the "ratio between the emissions of a given power system and the corresponding power generation in a given period" (Beltrami *et al.* 2022). This calculation is what is called Average Emissions Factors. This method, however, tends to smooth out the dynamic dimension of energy consumption and emission and, therefore, could result in a downward-biased estimation, since it does not account for the merit-order feature. To overcome this limitation, the Marginal Emissions Factor (MEF) was proposed by Hawkes (2010). Here, what is taken into account is which power generation technology is being dispatched on an hourly basis (what technology serves as the marginal plant), as Beltrami *et al.* (2022) put it, "a proper measure of the sensitivity of carbon emissions to the change of the load would be given by the average emissions of the marginal plants, i.e., the plants that produce at the margin". More detail on how the MEF is estimated in the Methods section.

In summary, the main advantage of estimating the MEF is to report a pollution figure that takes into account the composition of technologies of a given power system (the power sources mix), while also accounting for the order and time of dispatching. With that, this study intends to provide a novel and accurate characterization of the Brazilian Power Market regarding its pollution. The outcomes of this work will serve as a useful policy-guiding measure regarding the evaluation of greenhouse gases emission at a national level. Additionally, if a policy shifts the merit-order curve, the MEF analysis is able to capture this impact and can produce counterfactuals concerning the possible emissions scenarios.

Methods

To construct the marginal emissions factors, two main data sets are required. The first comes from the Brazilian National System Operator (ONS). From their data portal is possible to retrieve hourly data on the generation of each plant connected to the grid, the instant load, and transmission among each zone. Also from ONS comes the information about each power plant, such as their technology and the fuel used to produce the energy. The second set of data is the hourly emission of the power system. This data set is not readily available and will be calculated through the methodology based on Ferreira *et. al.* (2022) and Fontana *et. al.* (2021).

Having those two data sets in hand the following equation will be estimated:

$$\Delta E_{h,z} = \beta \Delta G_{h,z} + \varepsilon_{h,z}$$

Where *G* is the generation in hour *h* at zone *z*, *E* is the emission factor at hour *h* and zone *z* and finally Δ is the first difference between the generation at hour *t* and hour *t-1*. The outcome of this regression is the coefficient β being the Marginal Emission Factor of each zone of the national power system. The seminal paper using this methodology was done by Hawkes (2010). In addition to this model, a second one will be estimated. The regression is the following:

$$E_{h,z} = \beta_h G_{h,z} + \alpha_h + \varepsilon_{h,z}$$

This second functional form is known as the fixed effects model. As the name suggests the approach here is to employ the fixed effects framework to estimate the parameter β which was employed both by Holland and Mansur (2008) and by Callaway and Fowlie (2009).

In the same fashion as Beltrami *et. al.* (2022) the time frame considered for this study will be, at first, one single year. According to the authors, the year selected must be a "representative year as it reflects the key features and patterns of electricity generation and consumption which are relevant for a detailed short-run analysis of MEFs." For that, I will perform a series of statistical tests based on a few variables such as total generation, generation mix, total load, load shape, and technology of the marginal plant and then select what would be a typical year for the Brazilian power system.

Results

Even though the groundwork has been laid theoretically, and methodological approaches have been outlined, at present, the major efforts done so far are regarding the data. Given that this framework requires the use of hourly information and also the fact that Brazil counts with multiple power plants, the cleaning and treatment stages take a considerable amount of time. Therefore, the empirical component of the paper is yet to be executed. This, however, is no drawback. After having all the data sets ready, the empirical part of the paper is straightforward and must not bring any major issues.

Conclusions

This work aims to provide a new and more accurate characterization of the Brazilian power system regarding its pollution potential. The expected results of this paper have a series of policy implications. Firstly, it will serve as a subsidy for the effectiveness of public efficiency programs; will give a general frame of how "dirty" is the national energy matrix; have the possibility to be a source of inputs for new smart energy devices, giving information on which hours are the cleanest to consume energy; and finally, given the geographic heterogeneity of Brazilian power generation assets, will serve as a guide of how each zone will be more benefited of new sources of energy production.

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