Analysis of emission data from electricity generation plants

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1. Introduction

The EPA has several responsibilities as a part of its mission to protect human health and the environment. The air quality division within the agency analyzes various emission sources to understand how the air quality is affected by this. One important emission source, is that associated with electric power generation. A good understanding of the factors affecting emissions from electric power plants can suggest pathways for focused future analysis and provide actionable insights for reducing emissions and improving air quality.

The purpose of this study is to explore the extent to which numerous factors such as fuel type and plant generation characteristics influence the quantity of emissions.

2. Dataset

The dataset that was used for this analysis contains emissions characteristics of electric power plants in the US for 2010. There are 5393 power plants with several factors that can be classified into three main categories:

- Plant emission information: Quantity of CO_2, SO_2 and NO_X emissions from each plant
- Plant generation characteristics: Plant's Nameplate Capacity, Heat Input, Net Generation & Capacity Factor
- Fuel type information: Primary and secondary fuel types for each plant & the proportion of generation from each fuel source

Three pre-processing steps were performed to prepare the data for the analysis:

- One concern in the dataset is the large variation in the plant generation characteristics and the presence of significant outliers for each fuel type. This is shown in Fig.1 where box plots of the Capacity and the Net Annual Generation are presented for each fuel type. On the scale of the axis, it is clear that the Coal and Gas plants are on an average higher capacity and have large variations with outliers taking a range of extreme values. Hence, the analysis of plant generation properties with emissions was performed with subsets of primary fuel types to get better insights.
- The generation plants in that dataset are composed of combustion plants (using conventional fossil fuel resources), non-combustion plants (using renewable sources for electricity generation) or partial combustion plants that use both fossil fuels and renewable sources. About 73% of the total electricity generation was through either combustion or partial combustion plants and since the non-combustion plants do not have any emissions, they were dropped from the dataset for analysis. Furthermore, within the plants that used combustion sources, only 3% of the annual generation was from partial combustion plants. Hence, for simplicity of analysis, these plants were also dropped from the dataset.

- For each primary fuel type, a large proportion of plants (> 80%) have at least 70% of their generation from the primary fuel, hence it is reasonable to study the data by groups of primary fuel category, keeping the small fraction of mixed fuel sources in mind.

3. Analysis

3.1 Analysis of emissions with fuel type

Since the combustion plants are powered by different primary fuel sources, one important question to ask would be how the quantity of emissions are affected by each fuel type. To compare power plants with a broad range of generation and emission properties, the Annual Emission Rate which gives an estimate of the quantity of emission per unit of electricity generated, was used. The box plots shown in Fig.2 show the variation in Annual Emission Rate (lbs/MWh) for each of the three emission gases: CO_2, SO_2 & NO_X.

From the plot for CO_2 emissions, we can observe that Coal power plants (on an average), emit the highest amount of CO_2 per quantity of electricity generated and the Biomass power plants emit the least. However, the Biomass plants show a large variation, with several plants producing close to or even more than certain Coal power plants, as can be inferred from the outliers in the box plot.

Similarly, the plots for SO_2 & NO_X emissions show that Coal and Gas are the highest emitters (on an average) respectively.

Using this understanding, it is easier to focus efforts on power plants of a specific fuel type to effectively reduce emissions in an area. However, to provide better suggestions on further investigation of those power plants, it is important to understand how the emissions are affected by their operating conditions.

3.2 Analysis of emissions with plant generation characteristics

To understand the how plant operation characteristics affect the emissions, one important quantity that was used in the analysis is the Nominal Heat Rate for each plant. This quantity, which is a measure of how efficiently the primary fuel is converted to electricity provided a good measure for studying emissions. The scatter plot of the emission gases with this quantity shown in Fig.3 show an approximately linear correlation, suggesting that more efficient plants (with lower Heat Rate) have lower emissions per unit of electricity produced.

In addition, the influence of the basic factors of Capacity, Net Generation & Heat Input on the emission rate were also studied. Out of these factors, the Net Generation had an interesting influence on SO_2 & NO_X emissions, as shown in Fig.4. The SO_2 emission rate shows a nearly linear decrease with increase in net generation for gas and oil power plants for lower values of net generation. At higher values however, the SO_2 emission rate was nearly constant. This effect is also visible in NO_X emissions, albeit much more weakly. The CO_2 emission rate did not show any such effects.

From this analysis, we can infer that the Heat Rate and Primary Fuel Type are the most crucial factors that affect emissions from combustion power plants. Suggestions for emission control measures at a power plant should begin with an investigation into these parameters.

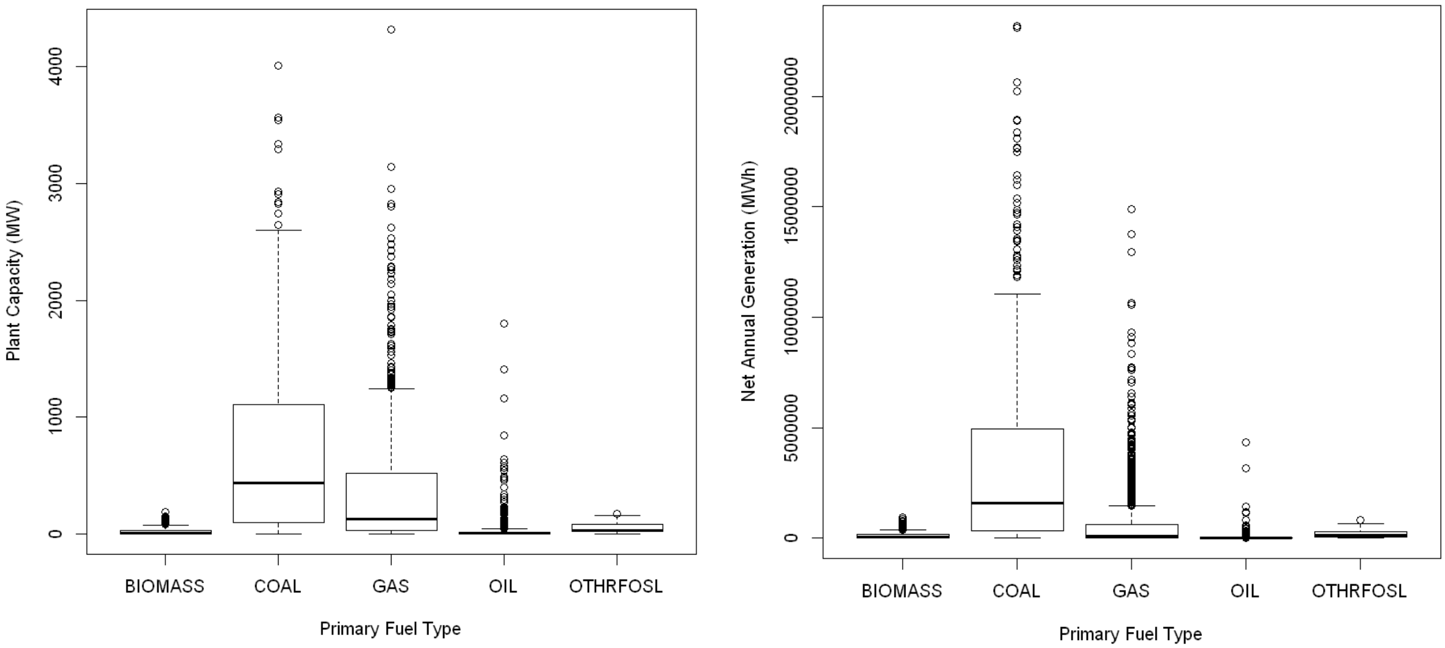
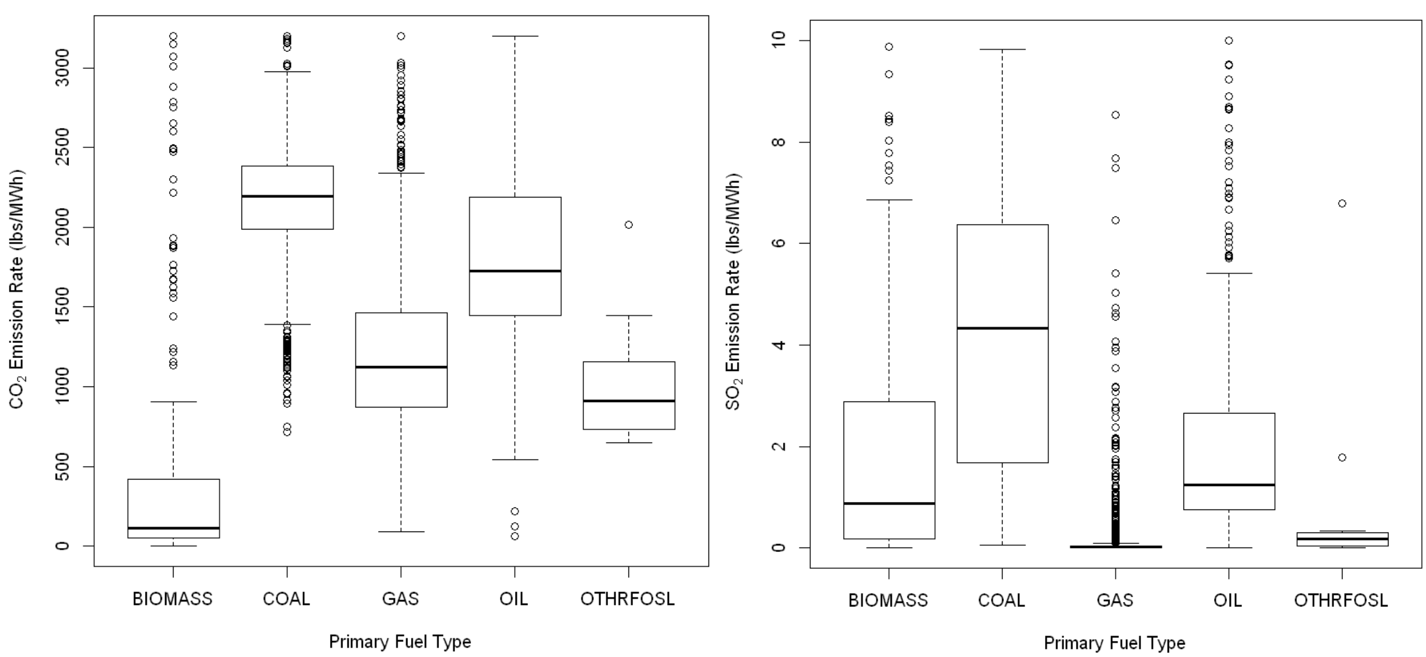


Fig.1 Representative box plots of the Capacity and Net Generation over Fuel Type to show the skew in the dataset and the presence of significant outlier values.



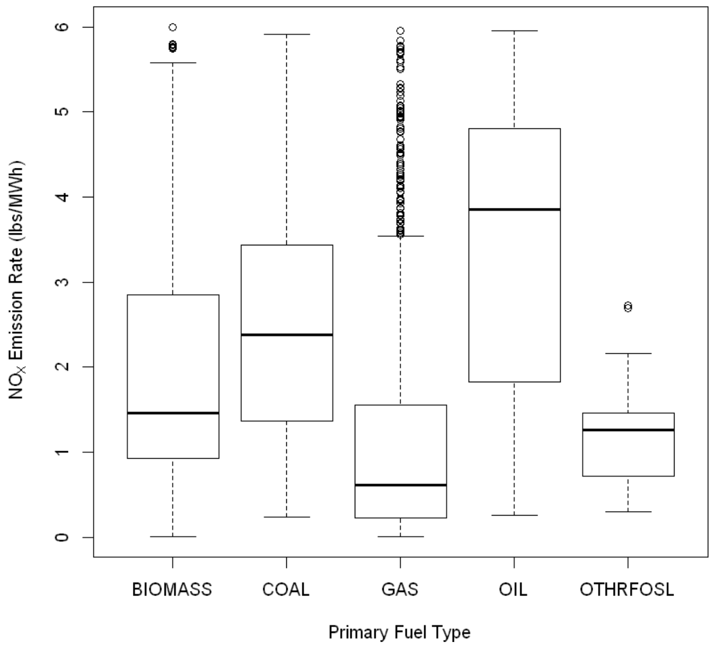
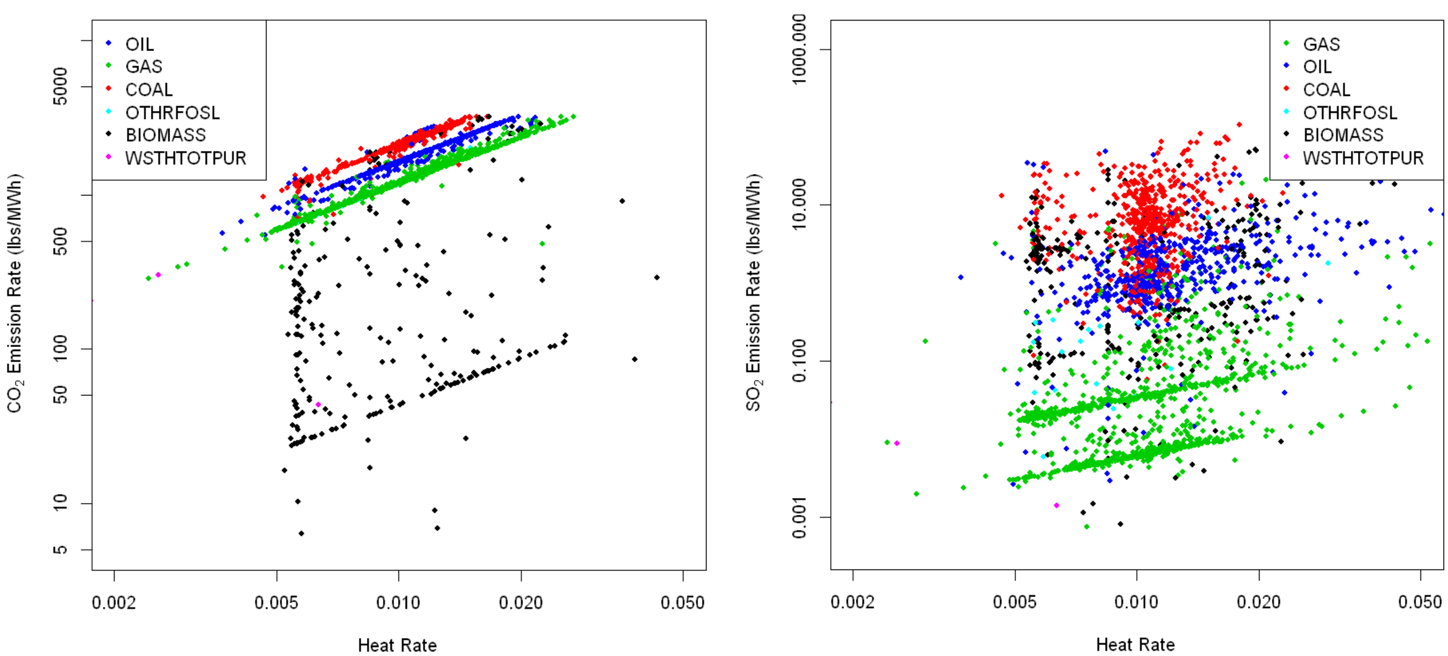


Fig.2 Box Plot showing the Emission Rate for each of the gases categorized by Fuel Type. Note that emission rates for CO_2 are on an average an order of magnitude higher than SO_2 and NO_X



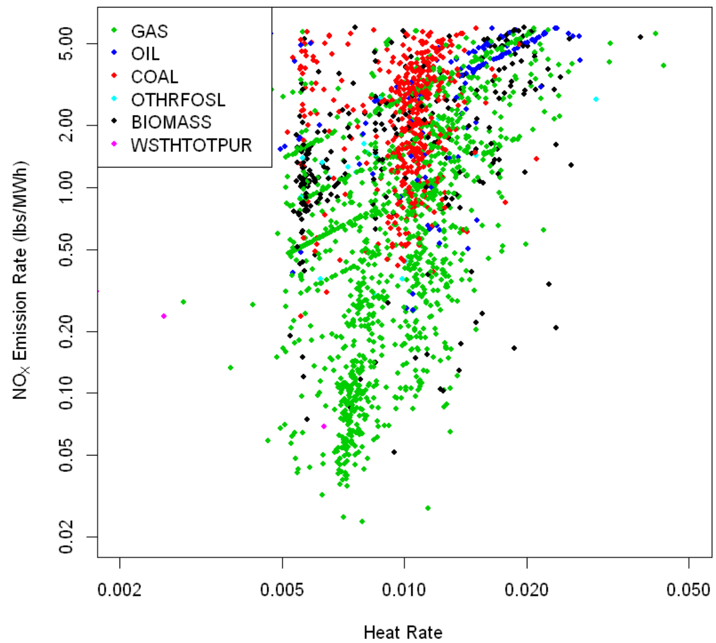
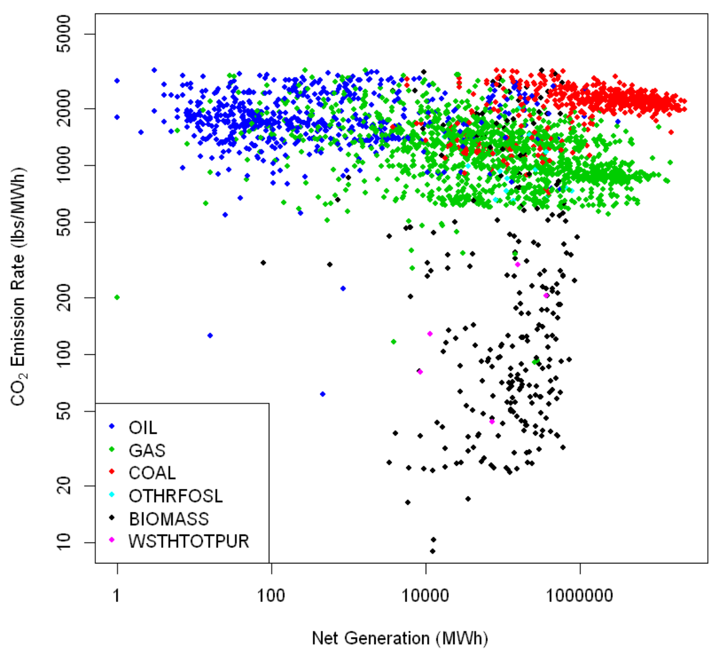
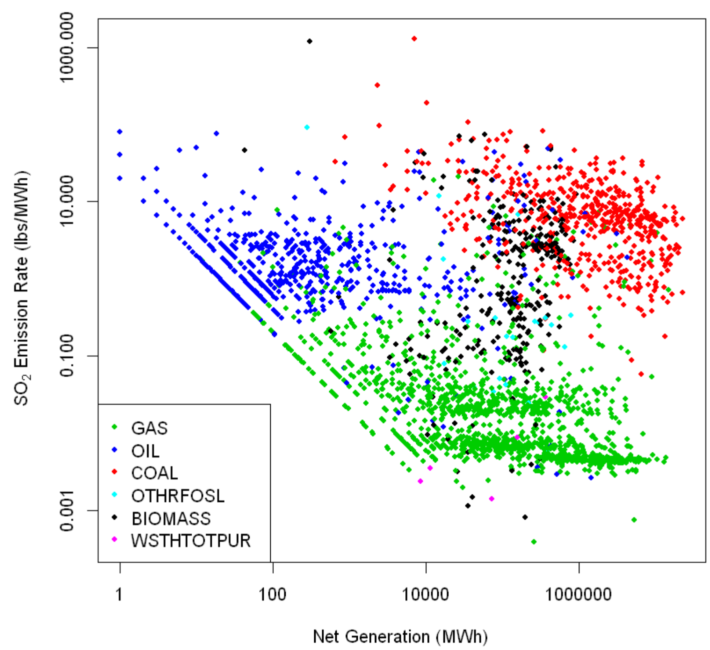


Fig.3 Scatter plot showing the influence of Heat Rate on the emission rate. A strong linear dependency is observed in the case of CO_2 & weaker relationships in SO_2 & NO_X





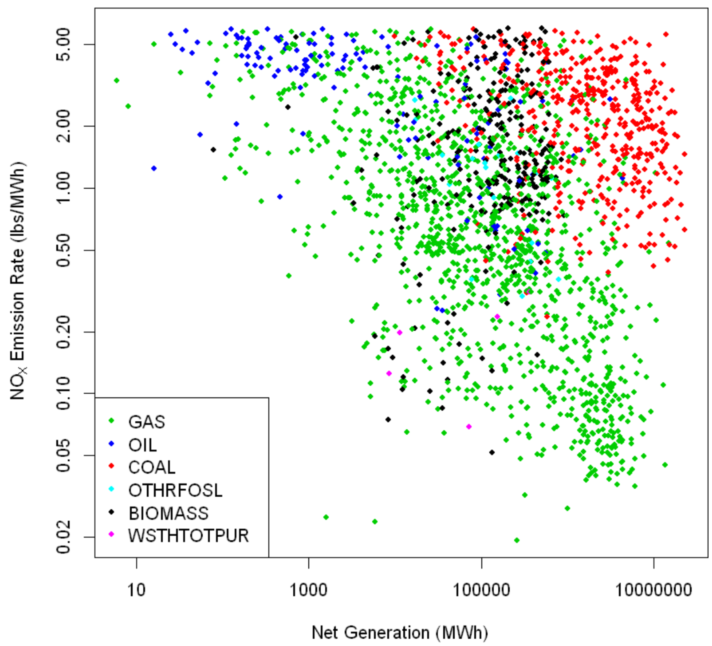


Fig.4 Scatter plot showing the influence of Net Generation on the emission rate. A strong linear dependency is observed in the case of SO_2 & weak relationship in NO_X

4. Conclusions

The analysis provided insights into the key factors that influence the emission rate of combustion power plants. The inferences can be summed up as:

- Each emission gas has a primary fuel type that, on average has emits higher than other fuel types. Further understanding of the nature of the processes that these power plants use for generating electricity from these fuels could inform reasons why one fuel type emits more than the other.
- Emission rates are also influenced by the operating conditions of the power plants, with the most important factor being the Heat Rate, which is a measure of efficiency of electricity conversion. The intuition that more efficient plants emit less, holds but the linear relationship between these quantities is interesting and could be explored further.
- The linear dependency of the SO_2 emission rate (and to some extent the NO_X rate) with the net generation is an interesting trend and suggests considering low generation plants for reducing SO_2 emissions. The two cluster of values raises questions about whether there is some other effect which is not captured in the dataset.

5. Appendix

The analysis done above revealed several interesting trends, but I omitted the inclusion of several expected trends in the main report and have discussed them here.

Initially, my analysis looked at the variation of the actual quantity (in tons) of CO_2, SO_2 and NO_X with the operating parameters. This, I realized was not a very good metric because higher generation plants would naturally have higher quantity of emissions simply because they consume more fuel. Their linear dependence is shown in Fig.5 for the example of CO_2

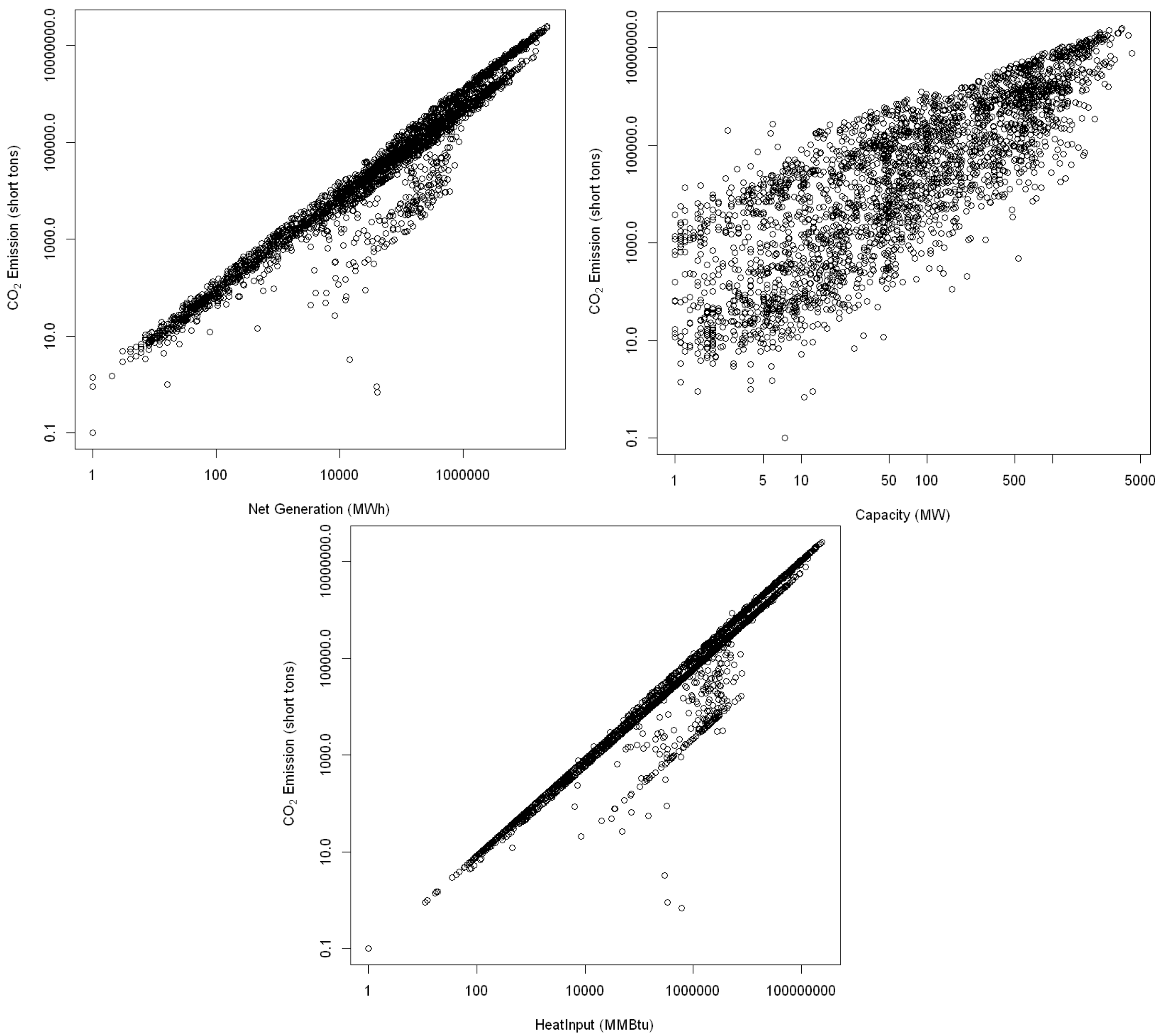


Fig.5 Effect of operating parameters in CO_2 emission quantity.