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Qualitative Comparative Analysis of cities that introduced compressed natural gas to their urban bus fleet

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ABSTRACT

This paper compares 39 cities from all over the world that shifted fuel used in urban buses that serve public transport. The study seeks to find out which configurations (combination of conditions) lead to the choice of compressed natural gas (CNG). In order to archive the objective, a qualitative comparative analysis (QCA) was performed, modelling three main conditions (variables) associated with fuel shifting that produced the option for CNG (positive outcome) or other vehicle fuel (negative outcome). Results show that CNG is more attractive economically than other options, which by the methodology terms, it is considered a necessary condition. However, economic viability alone is not sufficient to cause the choice for CNG, it only happens when there is an absence of concern in being dependent on fossil fuels or the presence of an interest in promoting better public transportation services. These combinations of conditions, which are context sensitive, show the complex nature of choosing cleaner substitutes for diesel oil. The use of QCA permitted a comparison between all sample cases, reduced the complexity of the urban transportation planning, and allowed a better understanding of this problem.

1. Introduction

The concept of "Sustainable Transportation" has been widely discussed due to concerns about life-quality in cities. This concept has a broad definition which includes: providing reliability and accessibility to transportation; optimising the use of resources; reducing emissions of pollutants and greenhouse gases; promoting technological innovations; and encouraging public transportation [1].

From this multifaceted perspective, many cities are seeking to become examples of sustainable transport promoters [2]. Within the field of energy options associated with the transport system used, one of the strategies adopted is to replace fuels like diesel and gasoline with cleaner alternatives (mainly because of the emissions of gases produced by the fuel), such as biofuels, compressed natural gas (CNG) and electricity. Even in terms of the choice of energy options, decision makers need to consider an array of reasons that can motivate any changes, overcoming the unique concerns with the local air quality [3,4].

Other factors also influence the decision of the central administration of a city, which usually has the responsibility of the replacement choice [5]. The objective of this paper was to examine three of them: economic viability, dependence on diesel, and improvement of public transportation. This article investigated which configurations (combinations of these factors) lead to the choice of compressed natural gas. The questions that this research sought to answer are:

- When cities choose to replace the fuel used by their bus fleets with an alternative to diesel oil, which causes (conditions) drive this change?
- Is it possible to notice a pattern in this option, given the same conditions?
- Which combination of conditions leads to the CNG option specifically? And which ones do not?

Qualitative Comparative Analysis (QCA) is a methodology used in order to better understand these complex patterns of conditions that lead to a qualitative phenomenon. In social sciences, cases usually are intrinsically complex, multifaceted and often with blurred boundaries [6]. Former social scientists used to call this complexity a Plurality of Causes [7,8].

No study that specifically addresses fuel substitution using QCA methodology could be found in literature in order to compare the

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results obtained in this analysis. However, authors from many fields, such as environmental sciences, transport, public policies and urban planning have already used it for cross-case comparisons. A study by Sager [9] used this methodology to test two theoretical currents of urban transportation planning in 17 European cities and identified the neoprogresist theory as the most efficient model of management. But sometimes, a theme is so complex that not even QCA helps to simplify it, such as in Scouvart et al. [10].

A study by Yamasaki [11] sought to understand how antinuclear social movements are relevant to changes in policy. The results found out that the absence of intense antinuclear social mobilisation is a necessary condition for changes to occur, raising a debate on the strength of social movements and the importance of their "timing" in different contexts.

The methodology also has some variations that can be used according to a research problem. In Warren et al. [12], multi-value QCA [13] was used, not to reduce the complexity, but to prove the relevance of socioeconomic factors in the success of public health intervention policies. Hess and Mai [14] used fuzzy-set QCA [15] to study the factors affecting the transition from fossil fuels to renewable electricity generation (sustainability transitions) in 18 countries in Asia. They have discovered that the generation of renewable electricity in the richest and most democratic countries is lower than in poorer and authoritarian countries.

By using QCA, this paper contributes to the literature by extending an analysis of the causal relationship that involves a fossil fuel considered less aggressive in terms of green house gases (GHG) than oil and coal to the transportation sector.

1.1. Background

In the last few years, climate change issues are usually a theme around the public policy energy debate as well as between academic researchers [16–18]. The concern of the earth's temperature increasing and its consequences are key subjects encouraging and facilitating the adoption of renewable energy sources around the globe. In order to reduce the carbon dioxide emissions or keep the total amount of emissions at some level is negotiated among interested parties, like those which were established in the Kyoto Protocol and the carbon trade tax [19].

On GHG issues, carbon dioxide is considered a main cause of global warming [20,21]. Studies have made policy contributions and suggestions in order to mitigate these emissions (see [22–45]). One straightforward option to reduce GHG is through the reduction of energy consumption [38]. However, other measures have been discussed, such as the adoption of renewable energy sources, and the use of natural gas as an energy transition source [46].

In Paris, during the annual Conference of Parties (COP) - COP21, in December of 2015, natural gas was described as a transition energy source that could replace more carbon-intensive fuels such as oil and coal, as well as support the expansion of renewable energy sources [46]. So, natural gas use is increasing worldwide and its role as an energy source promotes the concept of sustainable transportation [5].

1.2. Compressed natural gas as vehicle fuel

Literature points to three main reasons for using CNG as a fuel for buses: environmental and human health benefits, economic impact, and energy security [47–57].

There is a considerable increase in pollutants emission in vehicles around the world, especially in developing countries [58] where fleets are growing [59]. Such pollution is responsible for the increase in hospitalisations, respiratory diseases and lung cancer, which causes decreased life expectancy and economic costs to the public health system. A deep review on diesel emissions' effects on human health (but not limited to only these) is presented in the references [60–68].

Natural gas vehicles produce less toxic pollutants (except to NO_x[2]) and greenhouse gases (especially CO_2) than vehicles running on diesel oil [69,70]. However, these emissions are highly influenced by the its quality [51]. Also, CNG is less dangerous since it is lighter than air, which allows it to rapidly disperse, and has an ignition temperature higher than the other fuel, which reduces the risk of explosions and fires [71].

The availability of natural gas supply is increasing worldwide, but this requires a good distribution infrastructure [59]. Its price is, on average, cheaper than diesel oil, but still faces regulatory barriers in some countries, like Brazil [2,47].

Therefore, CNG can be seen as a transition fuel to renewable and cleaner sources [52], such as hydrogen [49] and biogas [72] because its infrastructure can be adapted to these sources in the future when they become more competitive [56].

2. Methodology

In the social sciences, there is a long struggle between researchers of quantitative orientation and qualitative guidance; herein defined as case-oriented and variable-oriented, respectively. In the world of comparative social sciences, this debate is even clearer. Ragin [8] describes that all empirical social research involves comparison of some form.

Case-oriented researchers have a holistic view of the cases and therefore compare whole cases among themselves in order to explain and interpret social units. Variable-oriented researchers, on the other hand, are radically analytical. Their works involve more testing of theories and considering statements prepared by their predecessors than revealing historical causes [73].

Traditionally, the critique to a positivist approach in the social sciences has led researchers to reject quantitative methods [74]. They consider that this form of analysis does not cover events, structures, and processes out of context by mixing them in an unrealistic statistical homogeneity [74]. However, it is undeniable that the use of these techniques provided greater legitimacy to comparative social sciences, or set the strong ideological positions that inevitably pervade this branch of knowledge [8].

Currently, many supporters of statistical methods recognise that it is necessary for researchers to actually know his or her studied cases. In addition, there is a relative consensus that the statistical methods work best; where one can have control over the experiment, isolating variables, as in the natural sciences [74].

In order to build a bridge between these two universes, Ragin [8] developed the tool known as Qualitative Comparative Analysis (QCA). This author expressed his concern about the incapacity of the traditional statistical techniques to incorporate historical and cultural elements, while purely qualitative methods have difficulty simplifying their conclusions [8].

2.1. Qualitative Comparative Analysis (QCA)

QCA recognises the complexity of qualitative analysis, but aims to simplify it through a comparative approach by means of Boolean algebra. Results are given in formulas that demonstrate parsimonious settings of causal combinations of different cases that produce similar results [6].

The minimisation technique reduces complexity and at the same time finds necessary and sufficient conditions for the outcome. Therefore, it is a good model to transcend the debate between qualitative and quantitative [74].

2.2. Boolean algebra

Published works already describe in detail the methodological processes of QCA development and how to apply its techniques [8–