Roll-out of hydrogen fueling stations in Spain through a procedure based on data envelopment analysis

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ABSTRACT

Several automakers have expressed their intention to start commercializing hydrogen vehicles on a larger scale by 2015. This commercialization requires efficient roll-out of hydrogen fueling stations, with prior identification of the areas most suitable for their establishment. Suitability of the different areas will be determined by several supply and demand and environmental criteria. In this article, in the case of Spain, we apply a methodology based on Data Envelopment Analysis to select the appropriate municipalities for the establishment of hydrogen fueling stations in the early stages of the deployment process. This methodology has the advantage of reducing subjectivity in the criteria aggregation process for the selection of municipalities.

1. Introduction

On September 8, 2009, several of the world's leading automakers (Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, the Alliance Renault/Nissan, and Toyota) signed a letter of understanding on the development and market introduction of fuel cell vehicles [1], in which they stated that: "Based on current knowledge and subject to a variety of prerequisites and conditions, the signing OEMs strongly anticipate that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialized". In this same document, the signatories also stated that: "In order to ensure a successful market introduction of fuel cell vehicles, this market introduction has to be aligned with the build-up of the necessary hydrogen infrastructure", and indicated that a key criterion

for the establishment of hydrogen fueling stations is that: "All hydrogen fueling stations are located smartly to enable customer access".

To plan this deployment of hydrogen fueling stations efficiently, some concept of suitability that enables identification of the most suitable areas for their establishment must be used. For us, there are two key features to this concept of suitability: it is not static, in the sense that it depends on the roll-out stage under consideration, and it is determined by several criteria.

The non-static nature means that it will depend greatly on the deployment process stage. Thus, areas deemed suitable for the establishment of hydrogen fueling stations during advanced stages of the roll-out process may not be considered as such in the early stages.

Even though the ideal areas can be selected based on a single criterion (mono-criterion), assimilating them, for example, to the number of actual vehicles in the different areas, the concept of suitability, from our viewpoint, must be defined more broadly by employing several criteria.

In general, these criteria can be classified into three main sets:

- *Demand criteria*: this set includes all the factors that influence the demand for hydrogen in a certain area. This demand will be determined both by the number of hydrogen vehicles owned in the area in question and by the number of hydrogen vehicles from other areas that transit in that area. In turn, the number of hydrogen vehicles owned in a certain area will depend on both the number of inhabitants and their willingness to use hydrogen vehicles. This willingness will in turn be influenced by the characteristics of these inhabitants (use of vehicle, age, income, level of education, level of environment awareness, etc.) [2–4]. Consideration of these criteria means that the degree of penetration of hydrogen vehicles in a city is not necessarily or exclusively proportional to the number of inhabitants.
- *Supply criteria*: this set of criteria refers to the potential impact of the technology used to produce hydrogen on the locating of hydrogen fueling stations. The production technology can determine the location of fueling stations in one area over another. For example, in a first stage, the hydrogen could be produced from natural gas. In this case, the absence of a natural gas network in the area could lead to the stations being located in another area with lower values in other criteria (such as demand), given the high cost of transport of hydrogen if the distance is far enough. Something similar occurs in the case of hydrogen production from renewable sources. The absence of renewable energy in an area means renewable hydrogen has to be transported from another area.
- *Environmental criteria*: one of the advantages of the Hydrogen Economy is the reduction in polluting gases caused by the use of fossil fuels in the transportation sector. This characteristic of hydrogen as an energy vector could lead the public sector, as a stakeholder in the deployment process, to value positively (and support) the location of hydrogen fueling stations in areas where there is too high a level of contamination, with the aim of promoting the use of a clean fuel in these areas.

These environmental criteria could also be included within the demand criteria. A higher level of contamination in one area could result in its inhabitants being more aware of environmental issues and, therefore, that there would be a higher demand for hydrogen vehicles in that area [2–4].

1.1. Multi-criteria approaches

The multi-criteria approach to the study of suitability has been applied in various studies. In Ref. [2], the authors study the geographical distribution of the demand for hydrogen vehicles to determine the location of hydrogen fueling stations in certain regions. These authors believe that the adoption by consumers of hydrogen vehicles is determined by

several factors: household income, households with two or more vehicles, air quality, clean cities coalitions, commute distance, education, hybrid vehicle registrations, state incentives and Zero-Emission Vehicle Sales Mandate. These authors point out that not all attributes have the same influence on the demand for hydrogen vehicles. In this paper, the weighing of the different criteria was performed by experts, and the values of the different attributes were divided into 5 categories arranged in order from the lowest (level 1) to the highest (level 5) influence on the demand for hydrogen vehicles. These considerations and weights were aggregated finally to estimate the demand for hydrogen in different areas within the regions studied.

HyWays [5] determines a series of early user centers and early hydrogen corridors for the ten European countries participating in the project. In each participating country, 3 to 6 early user centers were identified from a qualitative evaluation of a list of regional indicators: local pollution, cars per household, size of cars, possibility for stationary use, availability of experts, existing demo-projects, favorable hydrogen production portfolio (renewable energy sources, by-product hydrogen), customer base, regional political commitment and stakeholder consensus.

Similarly, HyRREG [6] identifies a number of early user centers for Portugal, Spain and part of France. In the case of Spain, these were identified from a list of objective indicators developed and evaluated by the Capabilities Analysis Group of the Spanish Hydrogen and Fuel Cells Technology Platform (GAC PTEHPC), although the list of indicators is not provided in the reference. In the case of Portugal, 18 indicators (including those of HyWays) were used to assess six regions of Portugal; these indicators were evaluated by stakeholders on a 0 to 5 scale. Finally, in the case of France, no criterion for the selection of the early user centers is provided.

In Brey et al. [7], the authors used different criteria to determine the most suitable areas for the establishment of hydrogen fueling stations in Andalusia, a region of southern Spain. This region was divided into areas (770 municipalities) and each area was characterized in terms of five criteria. The criteria used were: number of vehicles registered, kilometers of national and regional roads, income per capita declared in each area, supply of renewable energies, and environmental pollution. Finally, based on interviews with experts and the use of the Analytical Hierarchical process, the aforesaid authors obtained a score for each municipality reflecting its suitability for the establishment of hydrogen fueling stations.

1.2. Aim of the study

The aim of this article is to plan the deployment of hydrogen fueling stations in Spain in an early stage. To this end, we characterize each of the 7959 municipalities of mainland Spain in 2011 taking a series of criteria, presented in Section 2 hereof, into account. The purpose of these criteria is to reflect the suitability of each of the municipalities for the establishment of a hydrogen fueling station in an early stage. Finally, we use a procedure based on Data Envelopment Analysis to compare the different municipalities and select the suitable ones. The advantage of this technique is that it allows assessment of the suitability of municipalities without