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The competitiveness of alternative transport fuels for CO_2 emissions

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ABSTRACT

This paper examines the potential role of hydrogen and electricity in reducing CO_2 emissions from transport. First, we describe the main characteristics, costs and supporting policies of the two alternative fuels. Then we quantify and valuate economically the expected CO_2 savings, examining the Italian province of South Tyrol a case study. Through the analysis of three alternative scenarios, results reveal a potential reduction of the Tank-To-Wheel emissions up to 59% in comparison to the do-nothing option, which corresponds to an economic saving of about €543M. These results constitute an instance of the effectiveness of alternative fuels for limiting the effects of climate change deriving from mobility. In terms of transport policy, the integrative approach of hydrogen and electricity, often seen in competitive terms, can indeed be fruitful, especially in a first penetration phase, provided that policy-makers have a long-term vision about future mobility. This should include not only issues related to the technological improvement, but also thoughtful and balanced measures for an efficient carbon policy.

1. Introduction: CO_2 emissions and alternative fuels

At the European level, transport systems account for about 30% of the European production of greenhouse gases (GHGs) and this percentage has been steadily increasing in recent years (EU, 2014). Particularly, carbon dioxide (CO_2) constitutes more than 78% of total anthropogenic GHG emissions (IPCC, 2014), thus being the primary object of carbon policy measures. Since CO_2 transport efficiency has become an issue of the utmost relevance, several political measures have been proposed to face it adequately. In Nocera et al., 2011, we focused on the promotion of freight and passenger modal split, analysing financial instruments (e.g., taxes, charges and tolls), technical and regulatory constraints (e.g., orders and bans), as well as the improvement of the attractiveness of existing alternatives. The European guidelines for Sustainable Urban Mobility Plans (Wefering et al., 2013) suggest the importance of internalizing these measures in the evaluation: in Nocera et al., (2015a), we have defined a methodology to assess their CO_2 efficiency.

However, the reduction of CO_2 emissions can also be achieved through a complementary strategy aiming at improving the energy efficiency of vehicles by reducing the fuel consumption. Several solutions related to the engine efficiency have been developed. IEA (2012) indicates that market ready technology is expected to significantly reduce (up to 50%) CO_2 emissions per new car within 2030 thanks to the improvement in the engine, transmission, aerodynamics, tyres, heating and air conditioning. This estimate refers to existing technologies, dependent on petrol and fossil fuels. However, numerous alternatives can be considered, provided that they meet the requirements of technical feasibility, environmental acceptance, economic competitiveness and simple availability (Balat, 2008). Several fuels may correspond to these characteristics: natural gas, methanol, ethanol, liquefied petroleum gas (LPG), biodiesel, electricity both plug-in and fuel cell, hydrogen, boron, Fischer-Tropsch fuel, p-series, electricity and solar fuel (Johnston et al., 2005). The use of such fuels is not homogeneous. Some of them (e.g., methanol, natural gas, LPG) are already a partial alternative to fossil fuels, while others (e.g., boron, Fischer-Tropsch fuel, solar fuel) are more limited, due to a lack of infrastructures and high costs of production and distribution. This is also the case for electricity and hydrogen.

In this paper, we focus on the benefits in terms of reduction of CO_2 emissions deriving from the introduction of alternative vehicles under certain assumptions of cost, infrastructure deployment and technology standards (henceforth, "carbon reduction potential"). Section two describes the nature and the main characteristics of hydrogen and electricity as transport fuels, including their efficiency and costs. Section three presents the methodology adopted to quantify and economically valuate CO_2 emissions. Section four tests the efficiency of such alternative fuels on a concrete case study, also illustrating the real impact in different scenarios. Section five discusses the implications in terms of transport and energy policies. Some conclusions about the role of

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alternative fuels end the contribution.

2. Hydrogen and electricity in transport field

Differently from other primary energy sources (such as fossil energy, biomass, wind or solar power), hydrogen and electricity do not exist freely in nature. In fact, they are not an energy source, but a secondary form of energy that has to be manufactured through specific transformation processes of primary energy resources.

2.1. Hydrogen

At 122 Kj/g, hydrogen is the fuel with the highest specific energy content: it stores approximately 2.75 times more energy per unit mass than hydrocarbons. Furthermore, it is the most abundant element in the universe. Hydrogen production could be achieved by several processes, including reforming natural gas or biomass and electrolysis from large-scale renewable installations (Mazza et al., 2004; Korpas et al., 2008). Differently from electricity, once that hydrogen is produced it can be also stored; however, the volume required is approximately four times higher than gasoline, with relevant constraints (Demirbas, 2002). To overcome this problem, different storage methods can be adopted. Hydrogen can thus be stored as a compressed gas, as a liquid in cryogenic containers, or as a gas bound with certain metals in metal hydrides (Balat, 2008).

Although current technology allows the adoption of hydrogen for naval, terrestrial and maritime transport modes, it has been mostly employed for terrestrial vehicles such as cars, buses, light trucks and heavy goods vehicles (HGVs). The last three categories have less technical implementation problems, because they have sufficient capacity for hydrogen storage tanks, while for cars the volume constraint is more critical. Nevertheless, car manufacturers are very active, so that several prototypes have been built and the first mass-produced cars are already on the market. For them, three different technologies can be adopted. First, the hydrogen internal combustion engine (HICE) is a modified version of the traditional gasoline-powered engine. Then, the hydrogen fuel-cell electric vehicle (HFCEV) uses hydrogen and oxygen to create electricity by an electro-chemical process. Finally, the hybrid hydrogen-fossil fuels engines is powered by hydrogen or diesel/petrol. Under specific assumptions (efficiency of hydropower plants at 90%, electricity transmission at 95%, electrolysis at 70% and fuel cell at 50%), the efficiency of the hydrogen vehicles is about 30%, that is to say it is twice that of vehicles powered by fossil fuels. The product deriving from the use of hydrogen as fuel consists mostly of water and a little amount of nitrogen oxides (NO_x), which is up to 1/200 lower than diesel engines.

Investment costs for HICE are one-third lower compared to HFCEV. However, its fuel consumption is twice as high and there are problems of storage and autonomy. Consequently, technological development is oriented on HFCEVs. The cost for this option is significantly higher than traditional fuels (IEA, 2015), mostly due to the fuel cells, which require expensive components (such as platinum catalysts), and thus bring a hydrogen vehicle to a final price of about $90,000 (Anandarajah et al., 2013). However, in the last decade such costs have been halved and the technological development over the next few years should grant a further significant reduction (DOE, 2014). In a long-term perspective and with mass production costs, hydrogen vehicles are likely to become competitive with vehicles powered by traditional fuels.

About 95% of the hydrogen production is based on natural gas reforming (Energy.gov, 2015). Barreto et al., 2003 considered fossil fuels the first step to obtain a real hydrogen economy, necessary to build an adequate infrastructure network, but not sustainable in the long term. In a broader phase, the implementation of a new hydrogen economy based on renewable energies should follow (Muradov et al., 2008; Rosen, 2015), even if high costs, initial investments, technological developments and scarce resources constitute relevant issues (Kleijn et al., 2010). Despite such issues, some countries consider hydrogen as a promising transport fuel. California presented a roadmap (CFCP, 2014) indicating that 6600 vehicles are expected to circulate by 2017 and 18,500 by 2020. At the European level, the Commission is expecting more than 16 million FCEVs by 2030, with a reduction of petrol by 40% by 2050. Coherently with this vision, Germany aims at reaching the circulation of 250,000 HFCEVs by 2023 and 1.8 million by 2030; other countries (such as Denmark and France) introduced ambitious targets as well (Brunet et al., 2015).

From a technological perspective, there are no barriers to create an efficient European hydrogen refuelling station network (Hyer, 2015). The real problem is the cost of infrastructure: with 2.8M€, the investment to build a new fuel station is still very high (Melaina et al., 2013) and the costs to start a new production centre are much higher. As a consequence, a real and widespread hydrogen infrastructure is missing and only few hydrogen refilling stations (about 120) in 13 EU Member States were operative in 2013 (Eubusiness, 2015). The Council Regulation 521/2008 (EC, 2008) created the Fuel Cells and Hydrogen Joint Undertaking, which is responsible of a program of research and technology development, as well as demonstration projects. However, hydrogen is still limited to a very marginal niche of the market.

2.2. Electricity

Electric Vehicles (EVs), which use the electric motor as primary source for traction, include two main classes: the Hybrid Electric Vehicles (HEVs) and the Battery Electric Vehicles (BEVs). HEVs also use a secondary heat engine system: depending on the technology adopted, Tie and Tan (2013) distinguish the extended range electric vehicles, the parallel hybrid electric vehicles, the series hybrid electric vehicles, the complex hybrid electric vehicles and the plug-in hybrid electric vehicles. BEVs operate purely electrically. They use an electric motor for traction and chemical batteries, fuel cells, ultra-capacitors and/or flywheels for their corresponding energy sources (Ehsani et al., 2005). Due to their high efficiency (up to 95%), lithium-ion batteries are the most adopted power source. They are more efficient than the internal combustion engine and fuel cells, converting about 60% of the electrical energy from the grid to power at the wheels. Furthermore, EVs allow for the conversion of the kinetic energy lost during braking into energy. On the other hand, the lower energy content of the batteries grants a reduced autonomy, the battery packs are heavy and occupy much vehicle space and recharging time is still a critical issue. The residential charging infrastructure is the standard domestic solution. Since the completed recharge lasts from four to twelve hours, it is ideal for nighttime charging, when it can take advantage of the low cost tariffs. Alternatively, public charging stations are located near facilities, services or shopping centres, thus allowing owners to recharge their car while they use the nearby facilities. The ultra-fast charging station is similar to a petrol station: it grants a partial charge of the battery in limited time and is ideal for longer distance trips. For safety reasons, it requires the presence of an operator during the recharge activity. Differently from hydrogen, infrastructural costs of recharging points are not so high, at least in countries with a well-developed electrical network. Besides, there is no need for specialized maintenance. However, BEV deployment needs a higher density network (mostly in urban areas), because of the reduced range.

Costs to produce EVs are rather high, over €12,000 more than an internal combustion engine car (Prud'homme and Koning,