SOCIAL COST-BENEFIT ANALYSIS OF HYDROGEN MOBILITY IN EUROPE

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Abstract

The deployment of hydrogen technologies in the energy mix and the use of hydrogen fuel cell vehicles (FCV) are expected to significantly reduce European greenhouse emissions. We present a social cost-benefit analysis to estimate the period of socio-economic conversion, period for which the replacement of gasoline internal combustion engine vehicles (ICEV) by FCV becomes socio-economically profitable. In this study, we considered a hydrogen production mix of five technologies: natural gas reforming processes with or without carbon capture and storage, electrolysis, biogas processes and decentralized production.

We estimate two external costs: the use of non-renewable resources in the manufacture of fuel cells by measuring platinum depletion, and the abatement cost of CO_2 through FCV. We forecast that carbon market could finance approximately 10% of the deployment cost of hydrogen-based transport and that an early economic conversion could be targeted for FCV: about 10 years could be saved by considering externalities.

Keywords: *Hydrogen economy, hydrogen fuel cell vehicles, social cost-benefit analysis, external costs, carbon abatement cost, platinum depletion.*

Overview

Several studies have explored the potential technological innovations, the associated economic conditions and prospective scenarios for the deployment of new power-trains in Europe. Hydrogen requires a comprehensive support scheme that bridges the gap between market requirements, sustainability and climate requirements, and hydrogen technology development. We present a social cost-benefit analysis (CBA) framework to assess the progressive replacement of gasoline ICEV by hydrogen FCV in the European market over the period 2015-2055. The social benefits are estimated in terms of carbon prices for three scenarios: optimistic, moderate and conservative. Regarding social costs, we included external costs related to the consumption of platinum. Even if platinum loading per FCV has significant reduction and platinum recycling rate increases, the demand for this mineral will continue rising. The social CBA framework is composed of three estimation steps: the total cost of ownership (TCO), the external cost estimation (carbon abatement cost and platinum depletion) and the social-economic comparision. The final results consist of two indicators that take into account external costs of carbon abatement and platinum depletion: the social net present value (SNPV) and the year of social conversion.

Methods

Hydrogen demand from FCV in Europe. We assume new registrations of passenger cars in Europe – 11 825 400 cars in 2013 – will be replaced by the FCV gradually following the Energy Technology Perspectives (ETP) 2014 tendencies that assumes actions to limit global warming to 2°C. Important assumptions are: (*i*) a vehicle efficiency of 0.95 kg H_2 per 100km in 2015 and of 0.7 kg H_2 per 100km in 2050; (*ii*) a driving range of approximately 600km per fill-up; (*iii*) a vehicle lifetime of 10 years. Demand scenarios are built according to the average daily driven distances: 80km in the optimistic scenario; 60km in the moderate scenario; and 40km in the conservative scenario. The trend is a slow introduction of FCV for the period 2015-2030, followed by an important market share starting around 2035, as predicted by the European project HyWays, POLES model and PROTEC H2 project.

Hydrogen supply and production mix in Europe. Five hydrogen production technologies are considered in our study. The production mix includes: steam methane reforming (SMR) process from natural gas; SMR with carbon capture and storage (CCS); SMR with biogas; SMR on-site type station; and electrolysis. The hydrogen supply scenario assumes long-term solutions will favor carbon-neutral processes with significant hydrogen production by electrolysis of water using renewable energy sources.The dominance of SMR process from natural gas will be partially replaced by cleaner alternatives. The deployment of hydrogen-based transport raises new challenges for production infrastructures that need to evolve to exible small scale on-site production facilities. In this study we consider that on-site production facilities at the fueling stations are designed for $50Nm^3/h$ of hydrogen, which corresponds to the refilling of 25 vehicles per day and have a daily storage capacity of 100 kg H_2. The capital cost per hydrogen refueling stations (HRS) with on-site production is expected to decrease from k€ 1500 in 2015 to k€ 700 in 2050. Moreover, annual operating and maintenance cost should decrease from 10% to 8% of the capital cost. Lastly, the number of HRS is estimated from the hydrogen demand determined for each of the three scenarios.

Total cost of ownership FCV vs. ICEV. The year of economic conversion is the moment at which the total cost of FCV is equal to the total cost of ICEV for the period analyzed including infrastructure cost and lifetime of vehicles and hydrogen production mix. To estimate this time, we choose the total cost of ownership (TCO) analysis. The TCO considers the costs over the lifetime of a vehicle, including purchase price (the sum of all costs to deliver the assembled vehicle to the customer) and running cost (infrastructure on HRS and fuel cost and maintenance cost per vehicle). We measure the difference between buying a FCV including the infrastructure needed and the conventional case of buying an ICEV. The total deployment cost of hydrogen-based transport is the variation of TCO multiplied by the number of cars.

External costs: FCV fleet as a carbon abatement option. The climate change impacts avoided by hydrogen-based transport are evaluated via the abatement cost of carbon. This includes the whole deployment as an investment, spread from 2015 to 2055, in a fleet of vehicles that abate emissions. Our aim is to estimate the carbon price needed to make hydrogen FCV profitable. We determine the threshold price at which the replacement between FCV and ICEV is launched if and only if the price of CO_2 is above the threshold. To evaluate carbon emissions, we use life cycle assessment (LCA) studies for the emissions of the hydrogen production mix and emissions of the ICEV. The abatement cost of CO_2 for the substitution of all cars is computed. The carbon price at the end of the period is actualized to 2015 at the social discount rate of 5%. Based on the moderate scenario, carbon abatement cost by using FCV is estimated to be approximately e 18 per ton eq. CO2 in 2015 and avoided greenhouse emissions are estimated at 2 millions tons CO2 in 2015. The net present value (NPV) of deployment cost is e 382 millions in 2015. The results show that a carbon market could finance approximately 10% of the hydrogen deployment cost.
Platinum depletion. We take into account the scarcity of minerals by measuring platinum depletion. Each FCV contains approximately from 30 to 40 g of platinum in 2015. We assume a progressive reduction of platinum use for FCV down to 10-15 g of platinum in 2050. As of today, ICEV consumes 5.6 g of platinum per vehicle; moreover given the maturity of the technology involved, we expect this quantity to remain stable during the analyzed period. Platinum depletion estimated by net price method is computed as the market price minus the marginal extraction cost of platinum. We use average estimates: USD 55.6 (2010 €41.94) as the market price and USD 31.7 (2010 €23.91) as the marginal cost of extraction of one gram of platinum. Then, the net price (platinum depletion) is valued to approximately 2010 €18 per gram of platinum extracted. Hence, each gram of platinum extracted is depleting at 2015 €19.44. Platinum depletion is considered constant over the studied period, and represents about 8% of the deployment cost in 2015.
We took into account the carbon abatement cost and the platinum depletion, and found that while the former usually gets much more attention than the latter, these two external costs are quantitatively close.

Results

The present social cost-bene_t analysis of FCV vs. ICEV provides two main results.
First, the economic comparison by TCO converges in 2049 (optimistic scenario) or in 2052 (moderate scenario) or in 2054 (conservative scenario). At this point the FCV and ICEV will have the same lifetime cost. This is the first step in the total deployment evaluation. Next, in each scenario the benefits of carbon abatement by hydrogen vehicles and costs by platinum depletion are integrated for each year. In conclusion, including external costs enable to save about 10 years in the full deployment of hydrogen-based transport FCV.
Second, under more ambitious carbon prices estimated by ETP 2015 from 2020 to 2050, we estimate a social cash flow. It includes low and high global marginal abatement costs for CO_2 as well as the platinum depletion estimated before. The social net present values are computed for each scenario and they are net savings resulting from the replacement of ICEV by FCV during the period analyzed.

Conclusions

We conclude that the deployment of FCV should promote a net social benefit. We could win about 10 years in the economic conversion. The social CBA includes dominant assumptions and key points that require further attention. Our results are quite sensitive to the hydrogen production mix; extended analysis of other hydrogen production configuration would improve robustness of our model. To extend the present social CBA of hydrogen-based transport, it would also be important to consider other aspects such as air quality and noise benefits and social acceptability of hydrogen risks.

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