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Policy Paper

What policy should be adopted to encourage deployment of hydrogen vehicles in France?

Guy Meunier[1] and Jean-Pierre Ponssard [2]

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[1] INRA Aliss and CREST, Ecole Polytechnique, Research Associate Chair Energy & Prosperity.

[2] CNRS and CREST, Ecole Polytechnique, Co-diretor Chair Energy & Prosperity.

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Key Messages

- The transition to clean mobility has two imperatives: at the global level the fight against climate change and at the regional level the fight against urban pollution, which results in premature death and numerous respiratory infections.
- Norway's experience with clean mobility, the most advanced country in this area, highlights several key factors for success: the importance of social awareness of the issues through a public policy involving large subsidies; the importance of public support for the deployment both of vehicles and of infrastructure; the risks of overly proactive national deployment in the absence of a strong technological and industrial base; and dependence on vehicle manufacturers' international strategies.
- The critical analysis of this experience lays the foundations for an optimal deployment economic model comprising three phases: take-off, powering up and cruising, with support policies adapted to each phase.
- The deployment of hydrogen vehicles worldwide and manifestly in France is currently in the take-off phase, while battery powered electric vehicles are in the powering up phase. Different policies need to be implemented.
- The plan for the deployment of hydrogen put forward by Nicolas Hulot in June 2018 can be interpreted in the light of this framework. Three recommendations emerge from this reading: (i) apart from light utility vehicles and taxi fleets, focus on buses, trucks, boats, and locomotives, where hydrogen now has a competitive advantage compared to battery use; (ii) consolidate the pilot projects and encourage their proliferation at a European level through coordination between major cities, since the interconnection between these areas can only be effective in the second stage; (iii) encourage R & D and investment for the production of carbon-free hydrogen, but using a CO_2 benchmark price in cost-benefit analysis that goes well beyond the proposed value of €20/tCO_2 so as to take advantage of experience and spread innovation.

1. The challenges of the transition towards clean mobility

CO_2 emissions from transport in the EU28 accounted for approximately 26% of total emissions in 2013. Since 1990, emissions from road transport have increased, while those from other sectors (energy, manufacturing industry, building, etc.) have been decreasing (I4CE, 2017). This growth stems from the increase in the demand for transport due to increasing urbanization and higher standards of living. 75% of the transport sector's emissions come from road transport. According to a report by the International Energy Agency, the number of vehicles will double by 2050 (IEA-International Energy Outlook report, February 2013).

The transport sector also has a local and regional impact. An OECD report estimates that more than three million people die prematurely because of excessive levels of fine particulate matter (PM 2.5) and ozone in major cities (OECD, 2014). These high levels are attributable mainly to transport.

Given this situation, the transition to clean mobility is a major challenge for the public authorities at regional, national and international level. The options available for the transition are: reduction in the demand for transport, transfer to less carbon-emitting forms of transport (rail, river, bicycle, etc.), and the deployment of electric vehicles (battery or hydrogen powered).

The purpose of this Policy Brief is to show how the work done in the framework of the Energy and Prosperity Chair can clarify thinking on the issue.[3] We are particularly interested in the role of hydrogen vehicles and the policy proposed by the Hulot plan.[4]

[3] This work is gathered together in the sustainable mobility research initiative and can be downloaded from the Chair's website http://www.chair-energy-prosperity.org/chercheurs-associes/initiative-de-recherche-mobilite-durable-2/

[4] Nicolas Hulot, Minister of State and Minister for Ecological Transition, announced a plan to deploy hydrogen for the energy transition on 1 June 2018. https://www.ecologique-solidaire.gouv.fr/plan-hydrogene-outil-davenir-transition-energetique

2. What Norway's experience teaches us

Norway's experience[5]

In 2016 the share of new vehicle registrations of BEVs and PHEVs (battery electric vehicles and hybrid vehicles) in Norway exceeded 50%. The transition to clean mobility, however, has been far from smooth. Launched in the late 1980s, it has really only taken shape from 2013.

✓ ***The different stages of deployment***

- 1990-2000. Launch of pilot projects at the national level

Several attempts to introduce BEVs into major cities (mainly Oslo and Stavanger) are jointly launched by foreign vehicle manufacturers (the Danish company Kewet, the French firms Peugeot and Citroën) and national producers or distributors of electricity. Government support takes the form of exemption from the registration tax (100% on imported vehicles) and of the use of ferries and city car parks free of charge.

Despite specific encouragement during the 1994 Olympic Winter Games, sales are disappointing, due to quality issues for vehicles, reliability issues for batteries, the lack of sales network, etc.

- 1999-2002. An unsuccessful attempt at expansion

Ford and Kewet create a joint subsidiary in Norway, and hope to count on captive fleets (municipalities, the postal service, company fleets, etc.). The government introduces a further exemption, this time in relation to VAT (24%).

Sales remain sluggish, Ford pulls out, and Peugeot stops producing BEVs.

- 2003-2009. Holding on despite difficulties

The government remains supportive of clean mobility. It allows BEVs to drive in bus lanes and increases toll rates for fossil fuel vehicles. Consumer lobbies are set up to maintain incentives for BEVs.

But demand still does not take off.

- 2010-2016. Take-off and expansion of the transition

Following the economic crisis of 2008/2009, a national recovery plan is set up. In particular, it offers subsidies for the installation of urban charging stations. This global recovery plan is followed in 2011 by a specific programme for the installation of rapid charging stations every 50 km on the main inter-regional routes. A number of retail companies (McDonald's, Ikea, etc.) set up their own terminals at their commercial outlets.

Growing social awareness of the issues leads to a national plan for clean mobility in 2012. Overall targets for CO_2 emissions from vehicles are posted. These objectives imply a penetration rate of BEVs and PHEVs of around 20-30%. The Norwegian authorities are committed to maintaining the support policy until 2017.

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[5] This analysis of the Norwegian case is mainly based on Figenbaum, 2017.

At the same time, the range of BEVs is growing with the arrival of new models: Renault Zoe, Nissan Leaf, VW E-Golf, Tesla Model S, etc. Private sales are finally rising, and extending from city centres to outlying areas. While the majority of sales so far have been for a second car for affluent households with home recharge, they are now reaching a larger proportion of the population for long distance journeys.

✓ ***Key factors***

The following factors appear to have played a decisive role in the success of the transition to clean mobility in Norway.

- A multi-instrument public policy that is adaptive but implemented with determination. The price of carbon is not a major factor in this policy (€31/t CO_2 in 2016 according to I4CE.[6]
- Growing social awareness ensuring the acceptability of change.
- The importance of public support for the deployment both of vehicles and of infrastructure.
- The risks associated with overly proactive national deployment in the absence of a strong technological and industrial base to support it.
- Conversely, dependence on the international situation, particularly with the arrival of new models and the resulting competition.

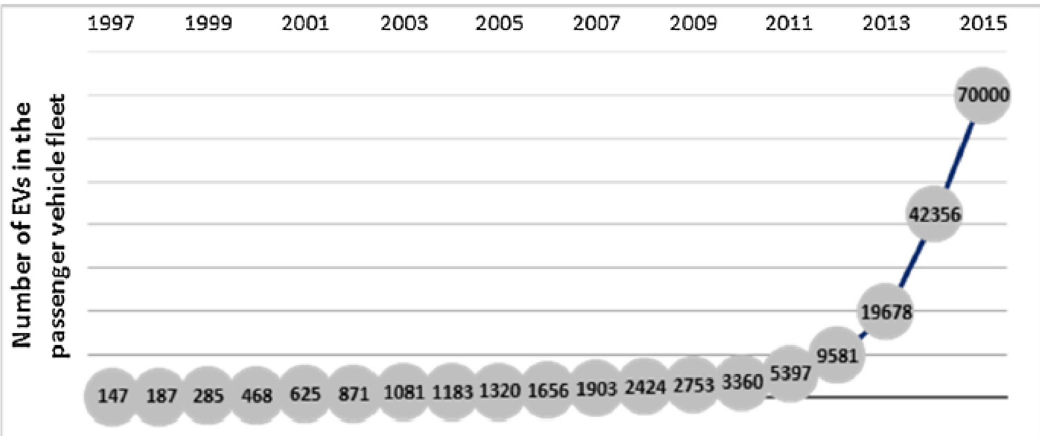

Fig. 4. Passenger BEV fleet in Norway, 2015 preliminary ±1%; source: Asphjell et al. (2013) and OFVAS (2016).

[6] See https://www.i4ce.org/wp-core/wp-content/uploads/2017/10/Global-panorama-carbon-prices-2017_5p_Final-version.pdf

3. Towards an analysis grid for formulating policies to support clean mobility[7]

Examining the Norwegian example, complemented by other case studies,[8] helps to organize thinking for formulating the bases of a support policy for the transition towards clean mobility. The recommendations are presented in the form of a typical trajectory, broken down into three phases: take-off, powering up and cruising. For each configuration we identify the corresponding structural characteristics and the most appropriate support policy.

Phase of deployment	Take-off	Powering up	Cruising
Structural characteristics	Major technological and commercial risks that do not allow sufficient profitability for the few companies likely to commit themselves. Non-existent private demand in the face of too high prices and a fragmented product offering.	Technological risks are under control, but business risks remain. Several development poles thanks to pilot projects that need to be consolidated. Private demand is starting to emerge.	Many companies in the market, based on different technologies (BEV, PHEV, FCEV, etc.) and offering complementary modes of transport (private vehicles, public transport, shared vehicles, etc.) Competition allows (will allow?) the social optimum to be achieved within a regulated framework.
Support policies	Encouraging R & D, subsidizing pilot projects involving captive fleets, builders and energy providers in order to initiate learning effects. Substantially subsidizing infrastructure in the corresponding areas. Helping to raise social awareness: plans at national level and in large cities on clean mobility, setting up the corresponding means (financing, green taxation, traffic restrictions). Encouraging coordination between deployment areas so as to maximize the effects of experience and the spread of innovations.	Maintenance of the financial support policy through infra-structure subsidies and rebates on vehicle purchase. Use of repayable advances to limit the cost of these subsidies. Opening up the pilot projects to competition, in particular to facilitate the entry of new manufacturers. Active support for infrastructure between deployment areas. Identifying the cost of externalities associated with the different modes of transport and development of green taxation aimed at internalizing these costs in private decisions.	Contributing to the emergence of technologies and modes of transport through differentiated policies. Progressive roll-out of financial support policies. Introduction of overall regulation of transport for use in public areas and the exploitation of the corresponding data.

[7] This section draws on the theoretical advances developed in Meunier-Ponssard (2018a). The underlying economic model is summarized in Box 1.

[8] See Brunet et al. 2015.

4. The Hulot hydrogen plan revisited

In June 2018 Nicolas Hulot introduced a hydrogen deployment plan for the energy transition. This offers an opportunity to judge the relevance of our analysis grid.

- What are the current structural characteristics of this sector in France?
- How far does the Hulot plan match the recommendations made in our theoretical analysis?

France is currently in the take-off phase

There are still few hydrogen fuel cell vehicle models on the market and prices are high. The few manufacturers selling these vehicles are mainly Japanese and Korean (Toyota, Hyundai and Honda).[9] To achieve a competitive cost level, technical advances are still needed regarding the performance and durability of the battery itself, production of a high-pressure hydrogen tank, and production and storage of carbon-free hydrogen in large quantities.

In fact, the penetration level of FCEVs worldwide is still very low. In 2017, there were 3000 FCEVs in Japan and 5000 in California.[10] In France private demand is almost non-existent. There are, however, three pilot projects: (i) the Paris taxi company Hype, which in 2017 had a fleet of 70 Hyundai vehicles (supplemented in 2018 by Toyota vehicles) and aims to increase the fleet to 600 vehicles by 2020, (ii) the project launched in 2015 by the Normandy Region, optimistically aiming for the deployment of 250 vehicles and 15 refuelling stations by 2018, mainly from captive fleets of the electric Renault Kangoo with a range extender, and (iii) a similar project launched in 2017 by the Auvergne-Rhône-Alpes Region, aiming for 20 stations and 1000 vehicles by 2019-2021.

We can note the relative backwardness of European manufacturers regarding FCEV technology. In France it seems that Renault if concentrating on BEVs, whereas Peugeot is trying to catch up. Germany has introduced a national plan for the installation of 400 refuelling stations by 2023, but Mercedes and BMW have been slow to enter the market. [11]

This situation on the part of European vehicle manufacturers contrasts with the stated commitment of some large French companies for hydrogen – such as Air Liquide, Engie, Michelin, and Safran – and the existence of start-ups, such as Safra for buses and Symbio for the Kangoo.

Support policy must be adapted to this take-off phase

While the deployment of BEVs in many countries can rightly be considered as being in the powering-up phase (or cruise phase in Norway), the greatest risk for FCEVs would probably be to trying to take a short cut by advocating the same policy as for BEVs. For this technology, encouraging competition between manufacturers is the best lever; infrastructure support for charging stations and especially for the purchase of vehicles should be gradually reduced despite pressures to maintain them.

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[9] General Motors and Daimler had developed prototypes in the 1990s but encountered difficulties in marketing them .

[10] Fargère, 2018.

[11] Mercedes is launching a hydrogen vehicle in September 2018: the GCL FCell.

The current stage of FCEVs suggests on the contrary that the pilot projects should be consolidated through specific actions. For this reason, the progressive proliferation of these projects in various geographical areas is the best way to develop learning effects and economies of scale. Here there are two problems to be surmounted.

- To obtain a significant volume of hydrogen, which is essential for the development of a green hydrogen production sector, it seems sensible, apart from light commercial vehicles, also to count on other uses such as buses, trucks,[12] or even boats and trains rather than individual vehicles, which will remain at a high price affordable only to a segment of the population for which handing out subsidies is socially unfair.[13] This is a necessary condition for the realization of axis 1 of the Hulot plan.
- The proliferation of deployment zones should be done at the European level so as to attain a sufficient volume to generate economies of scale for manufacturers. The Hulot plan focuses on the interconnection of large cities in France, by setting up refuelling stations throughout the main road network. This goal is clearly premature at this stage. It would be more appropriate to focus on the major European cities and to think how a national initiative such as the Hulot plan could contribute to the coordination effort at an international level. For example, this would involve developing common approaches to decarbonise public transport (including taxis) and the commercial transport of goods by introducing more restrictive policies in different cities.
- The use of repayable advances might be appropriate for promoting infrastructure deployment, ensuring income for the operator during the powering-up phase of hydrogen sales, with a refund on profits made subsequently.[14]

There are currently three pilot projects in France. The EasHyMob project in Normandy, the Zero Emission Valley project in Auvergne-Rhône-Alpes and the Hype project in the Paris region (see Box 2).

The Hulot plan also focuses on encouraging R & D (axis 1). This would be a particularly welcome measure given the technological risks still to be overcome. Here too, the use of repayable advances could be encouraged as an initial lever for triggering private financing when uncertainties are cleared up. The inability of banking institutions to deal with such uncertainty explains the absence of an efficient financial market in important sectors of the energy transition.

For example, it is surprising that a maximum CO_2 price of €20/t (which corresponds to the present value of the CO_2 shadow price) is proposed for cost-benefit analyses intended to justify support for the investments required for the production of carbon-free hydrogen (mainly by decentralized

[12] For example, we could draw on Ademe's approach to the deployment of trucks powered by natural gas (Lelarge, 2018).

[13] See the debate in California https://www.greencarreports.com/news/1098988_california-ends-electric-car-rebates-for-wealthiest-buyers-boosts-them-for-poorest

[14] This type of financing has the advantage of encouraging manufacturers to launch risky unprofitable programmes on equity while limiting windfall effects, i.e. awarding subsidies to projects that are inherently profitable. The inevitable asymmetry of information between firms and the operator on the prospects for success and the commercial benefits of a project strongly favours the use of such a contractual mechanism rather than simply the use of subsidies. The economic analysis of repayable advances has been published in the Revue de l'Energie (Meunier-Ponssard, 2018b). Thinking on the topic continues through Master’s courses jointly run with Ademe.

electrolysis).[15] If the objective is to induce a significant decrease in costs through economies of scales one could start instead on the basis of the following reasoning.[16]

- Pre-examine the path that would achieve parity given the cumulative level of production and an estimate of the effect of experience; the cost of a kg of hydrogen produced by electrolysis is today estimated at €4-6, whereas by SMR it is estimated at €2-3.[17]
- Assuming that the trajectory to achieve parity takes 10 years, its cost-benefit analysis allows a CO_2 price – say €50/tCO_2 – to be derived that justifies the launch of the trajectory in 2018. This price is the dynamic cost of abatement as opposed to the static cost of abatement obtained for a single piece of equipment produced in 2015. The static cost is evidently higher because it does not take into account the effects of reducing future costs. A rough calculation for an electrolyser shows that the static cost would be in the order of €200-300/tCO2.[18]
- The Hulot plan sets a parity target in 2028 at a cost of €2-3/H_2 but, at the same time, sets a ceiling price for valuing CO_2 economies at €20/tCO_2.
- Under these conditions there is an inconsistency. Either the price of CO_2 in cost-benefit analysis is revised upward, to €50/tCO2 in our calculation, or the 10-year goal to achieve parity is unrealistic.

In summary, cost benefit analysis should not be carried out on every individual investment. The analysis should be conducted on an entire investment programme, introducing the effects of learning-by-doing. Eventually the effects of experience will be reduced and it may be assumed that green taxation will be internalized in the price of a kilo of carbon-containing hydrogen (produced by reforming from hydrocarbons). Over this time frame, the need for government support will have disappeared.

The Hulot plan envisages setting up a working group to promote coordination between public and private funding, and in particular to ensure that public funding acts as a lever for private financing. As this brief shows, some initial feedback would no doubt be welcome.

[15] See the Hulot plan page 11.

[16] This reasoning is based on the article published in *Environmental and Resource Economics* (Creti et al., 2017).

[17] See the Hulot plan for the deployment of hydrogen, op. cit. page 5.

[18] The carbon intensity of a kg of hydrogen produced by SMR is 9.78 kgCO_2 /kgH_2 a production cost difference of €2/kg that corresponds to an abatement cost of 2/9.78 = €.200/kg or about €200/tCO_2, or €300 for a production cost difference of €3/kgH_2.

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Box 1: The economic model

General framework

- The model formulated in terms of static partial equilibrium with consumers, vehicle manufacturers in imperfect competition as specified by Cournot (each manufacturer produces X_i vehicles, no product differentiation, total offer X), station operators (only one per operator) in perfect competition with free entry (K total number of stations).

-The energy market is competitive. Each consumer buys a vehicle and uses it, refuelling at existing stations. The consumer pays the price of energy plus a margin covering the costs of the station.

-Externalities:

- related to the effect on the global and local environment (CO_2, fine particles, etc.), designated α
- network (complementarity between vehicles and infrastructure network), designated β
- vehicle production (experience effects and knowledge transfer), designated g
- market power of manufacturers, designated m

-Questions addressed:

- Comparing market equilibrium with the social optimum
- Defining public policies for achieving social optimal as a market equilibrium

NB: Units are redefined so that a vehicle consumes one unit of energy per unit of time; X vehicles therefore consume X amounts of energy, the direct cost corresponding to the energy consumed is not included in the model but the margin taken by the operators is included. Clean vehicles are assumed to replace emitting vehicles (not explicitly modelled here), which creates a positive external gain of *α* per vehicle.

Hypotheses

-Gross surplus of consumer $S(X,K) = (a-bX/2)X-\beta X/K$

- a represents the propensity to pay
- b represents price elasticity

Cost function of a vehicle $C_V(X_i) = (c°-gX)X_i$

- The marginal cost decreases according to the total quantity produced

-Cost function of a station $C_K(x) = f + c_F x^2/2$

- x is the quantity delivered by the station ($=X/K$),
- f is a fixed cost
- the optimal size of a station minimizes the average cost $x_m = (2f/c_F)^{1/2}$

-Social surplus function $W(X,K) = S(X,K) - C_V(X_i) - C_K(x) + \alpha X$

Results

-Depending on the value of the parameters on a

- A single market equilibrium in $(0,0)$
- Three market equilibria in $(0,0)$, (X^E_-, K^E_-), (X^E_+, K^E_+)
- Equilibrium (X^E_-, K^E_-) is unstable, it is a tipping point toward $(0,0)$ or (X^E_+, K^E_+)

-When the social optimum (X^*, K^*) is positive and sufficiently high it is possible to achieve it in the form of a market equilibrium with the following policy

- Subsidy provided for the purchase of a vehicle: $s_V = \alpha + bX^*/m + gX^*(m-1)/m$
- Subsidy given to each station operator: $s_K = \beta X^*/K^{*2}$

-When the social optimum (X^*, K^*) is positive but low, it is better to reach it by creating a joint venture between a vehicle manufacturer and station operators and only offering vehicle purchase subsidies.

- Subsidy provided for the purchase of a vehicle: $s_V = \alpha X^* + bX^*$

Box 2: Three projects for deployment in France

The EasHyMob project stems from a call for projects from the European Union (European Innovation and Networks Executive Agency) dating back to 2014 for a start-up in January 2016. The plan for 2016 included 15 stations and 250 vehicles by the end of 2018. The subsidy amounted to 50% of a €5 million budget intended to finance the deployment of stations (vehicles benefitting from the general subsidy granted at the time, i.e. €6,000). As well as this European subsidy, there was in addition a regional subsidy of 20% on the infrastructure and €7000 on hydrogen vehicles. A cost-benefit analysis of this plan carried out in 2016 revealed two major weaknesses[19]. First, deployment focuses on light commercial vehicles, mainly the electric Kangoo with hydrogen range extender. This increases the range from 180 to 300 km, which is well suited to captive fleets. On the other hand, without deployment of other vehicles, the volume of hydrogen demanded is low and the distribution network will be very expensive. Second, the subsidy is for a public or predominantly public entity, which poses several problems: the difficult financial situation of municipalities, their administrative slowness and the fact that their long-term business vision is more limited than that of a company. Thus the objective has been to reduce the price of the deployed infrastructure as much as possible and to move towards low capacity stations (20-50 kg/day) at 350 bar. These stations, while enabling an initial extended distribution network to be installed, will not be profitable because of their small size and their inability to refuel passenger vehicles, for which the standard pressure is 700 bar. This project highlights the fact that the subsidy should instead be used to "call on" private investment to balance an economic model in which there is a return on investment compatible with the financial sector. The EasHyMob project is expected to be completed a year late and has served as a model for the Zero Emission Valley project explained below

The Zero Emission Valley project was launched in 2017. Like the EasHyMob project, it also places the emphasis on the deployment of captive fleets in order to ensure its take-off. Three distinctive features are notable. It benefits from the direct support of manufacturers such as Engie and Michelin, which will cover investment in and operation of the stations. The refuelling stations concerned are double-pressure (350 and 700 bar) and compatible with heavy vehicles such as buses or trucks. It is thus possible that high consumption of hydrogen will quickly result in a return on investment compatible with the financial sector. To minimize the risk taken by manufacturers that invest on the stations, a model with an advance repayable by a public or private group is currently under study. Such model makes it possible to call on significant industrial financing while presenting balanced risk sharing.

[19] See Brunet and Ponssard, 2017.

The Hype project was launched in December 2015 by the Paris electric taxi company (STEP)[20]. This company exclusively uses hydrogen vehicles. The technology used offers the same advantages as battery-powered electric vehicles (no CO2 emissions and reduced fine particle emissions through braking) with a refuelling time of a few minutes and a substantial range of about 500-600 km, which is essential for heavy use vehicles such as taxis. In 2017 the operator had 70 vehicles supplied from two stations operated by Air Liquide, located at Pont de l'Alma and near Orly airport.

Today there are a 100 vehicles, that are able to recharge at four stations (Pont de l'Alma, Orly, Roissy and Versailles). Caisse des Dépôts et Consignations has taken a stake in Hype’s equity, as has Air Liquide. The project benefits from European subsidies.

The target is 600 vehicles (Hyundai and Toyota) by 2020, refuelling from several stations located in Paris and the Paris region.

A Renault Kangoo Z.E.-H2 connected to the hydrogen refuelling station of the General Council of La Manche, in Saint

[20] See Alena Fargère, 2018.