Energy Policy 38 (2010) 5388–5398

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Policies for the transition towards a hydrogen economy: The EU case

Raimund Bleischwitz [1], Nikolas Bader *

College of Europe, Department of European Economic Studies, Dijver 11, 8000 Bruges, Belgium

ARTICLE INFO

Article history:
Received 12 August 2008
Accepted 13 March 2009
Available online 1 May 2009

Keywords:
Energy policy
Innovation
Hydrogen

ABSTRACT

This paper reviews the current EU policy framework in view of its impact on hydrogen and fuel cell development. It screens EU energy policies, EU regulatory policies and EU spending policies. Key questions addressed are as follows: to what extent is the current policy framework conducive to hydrogen and fuel cell development? What barriers and inconsistencies can be identified? How can policies potentially promote hydrogen and fuel cells in Europe, taking into account the complex evolution of such a potentially disruptive technology? How should the EU policy framework be reformed in view of a strengthened and more coherent approach towards full deployment, taking into account recent technology-support activities?

This paper concludes that the current EU policy framework does not hinder hydrogen development. Yet it does not constitute a strong push factor either. EU energy policies have the strongest impact on hydrogen and fuel cell development even though their potential is still underexploited. Regulatory policies have a weak but positive impact on hydrogen. EU spending policies show some inconsistencies. However, the large-scale market development of hydrogen and fuel cells will require a new policy approach which comprises technology-specific support as well as a supportive policy framework with a special regional dimension.

1. Introduction

The introduction of hydrogen in Europe's energy system – as envisaged by the Hydrogen Deployment Strategy and the Implementation Plan (Hydrogen and Fuel Cell Technology Platform, 2007) – will constitute a major change. As hydrogen can be a carbon-neutral means to substitute fossil fuels, the European Commission – in line with governments worldwide – regards its further development and market introduction as desirable (EC, 2007a). However, hydrogen cannot compete yet with incumbent technologies, in particular not when it is derived from renewable energies, and is still in its early stage of market introduction.

The following paper takes on the well-established argument that in early phases of business development and market introduction innovations need a technology-specific support scheme. Without such a specific support scheme, lock-in effects of prevailing technologies (Arthur, 1989; David, 1985) provide incentives to incremental innovation only, along existing trajectories and, thus potentially disruptive technologies such as hydrogen cannot emerge. The dominance of prevailing technologies, the risk of being entrapped in a carbon lock-in (Unruh and Carrillo-Hermosilla, 2006) or other large technological system (Walker, 2000), potential diseconomies of scale (Isoard and Soria, 2001), and the necessity to reach at least a critical mass of production legitimize tailor-made support schemes for hydrogen. The European Union – in line with other governments worldwide – has introduced specific support schemes such as the joint technology initiative (JTI).

It is important to acknowledge, however, that due to its distinct characteristics hydrogen will need a more complex support scheme than renewables (Ros et al., 2007; Roads2HyCom, 2008). At least three elements constitute the distinct character of hydrogen and fuel cells from a policy-related point of view:

1. As hydrogen is an energy carrier (and not an energy source such as wind) it not only needs infrastructure for its production but also for its distribution.
2. Unlike biofuels that can be blended into conventional gasoline or diesel fuels or renewable energy which can be fed into the electricity grid, hydrogen needs to be made compatible with the existing energy infrastructure.
3. The overall performance of hydrogen and fuel cells relies on some weak links such as storage technology where technological progress is crucial.

For those reasons it is unlikely that support and incentive systems that have proven to be successful for renewable energies

* Corresponding author. Tel.: +32 50477315; fax: +32 50477300.
E-mail address: nbader@coleurop.be (N. Bader).
[1] Raimund Bleischwitz is also affiliated with the Wuppertal Institute and the Universities of Wuppertal and Kassel (all Germany).

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.03.041

will be sufficient for the mid-term to long-term deployment of hydrogen and fuel cells.

The paper proposes that hydrogen requires a comprehensive support scheme which bridges the gap between the three dimensions of (a) market requirements, (b) sustainability/climate requirements and (c) hydrogen technology development. Such a comprehensive support scheme will have to balance strategic deployment on the one hand and openness and flexibility on the other—a balance which has been discussed with regard to governance and economic policy by Bleischwitz (2007) and Metcalfe (2003).

With its recently launched joint technology initiative, the EU aims at establishing jointly with the European industry a tailor-made support system for hydrogen and fuel cells and plans to spend almost 1 billion € between 2008 and 2017 for these technologies (New Energy World IG and EC, 2008; Council of the European Union, 2008). However, neither the JTI nor previous EU research spending on hydrogen and fuel cells will be analyzed in this study. Going beyond the level of technology-specific support schemes our paper undertakes a screening of the existing EU policy framework with the aim of an impact analysis towards any mass market development of hydrogen and fuel cells. It seeks to identify barriers as well as inconsistencies and side-effects that hinder the envisaged uptake of a hydrogen economy in Europe. This is important because in European member states the policy framework depends to a large part upon the EU level with increasing importance of EU regulation (Pelkmans, 2006).

The EU sets targets for its Member States with regard to energy efficiency or the share of renewable energy in electricity production; it regulates the emission trading scheme (ETS) and partly also the European markets for gas and electricity; it sets minimum levels for energy taxation and subsidizes energy technologies through its regional funds and research projects. Shedding light on the impact of current EU policies is crucially important for future hydrogen and fuel cell development in Europe as well as in other regions. Our approach thus complements research on how policies shape technological change towards sustainable energy, which has been done as ex-post evaluation of US experiences (Norberg-Bohm, 2000), of renewable energy sources in Germany, Sweden and the Netherlands (Jacobsson and Bergek, 2004) and of energy-efficiency technologies (Grubb and Ulph, 2002).

The paper is organized as follows. Section 2 analyzes EU *energy* policies (ETS, energy efficiency, renewables) for they have a direct impact on hydrogen and fuel cells as well as on competing technologies. Section 3 deals with *regulatory* policies; those are not directly related to hydrogen and fuel cells but have the potential to hinder or promote the development of these technologies (energy taxation, liberalization of the internal market for gas and electricity). Section 4 analyzes EU *spending* policies asking whether they might constitute a push factor for hydrogen and fuel cell development. Finally, Section 5 draws *conclusions* and gives recommendations for an enhanced policy framework.

2. EU energy policies

Since its early beginning in postwar Europe energy has always played a prominent role in the European integration process. Two of the three founding treaties established organizations which dealt with energy supply: the European Coal and Steel Community (1951) and the European Atomic Energy Community (1957). In recent years, new policies have emerged as a response to climate change (Lechtenböhmer et al., 2005; Pelkmans, 2006). The EU now has substantive power in several fields which are of direct relevance for hydrogen and fuel cell development.

2.1. Energy efficiency policies

Energy efficiency (EE) regulations are normally designed to decrease the energy intensity of an economy, i.e. to minimize "the amount of energy used per unit GDP" (IEA, 1987). Fuel cells when used with hydrogen are relatively energy efficient (compared with traditional gasoline-powered internal combustion engines). Legislation on EE may therefore indirectly favour the development and market introduction of fuel cells.

Since 2000, the Community has adopted several measures in the field of EE. Many legal instruments concern specific sectors such as buildings and the labelling of precisely defined products such as household appliances or electric ovens. Two relatively recent directives are already rather encompassing in their scope and set a framework for nearly all sectors:

- The *directive on energy end-use efficiency and energy services* of 2005 sets the target that every member state must on average improve by 1% its EE every year. These targets are indicative. The Member States are relatively free to choose the instruments by which they want to reach these goals (EC, 2006a).
- In 2005, the EU also adopted a *directive on the ecodesign of energy-using products*. This directive applies in principle to any energy-using product and aims to improve EE in the whole life cycle of the product. The text provides for EE standards and requirements for every stage of the production beginning with the early design phase. The text itself does not set any binding targets (EC, 2005a); this is done via processes at an administrative level.

Some legal texts refer explicitly to fuel cells. For instance, the EU directive on combined heat and power mentions them as a cogeneration technology (EC, 2004). However, even when fuel cells are not directly mentioned in EU directives, the latter can still have great impact on their market introduction. The before mentioned ecodesign directive sets a framework for *all* energy-using products (except for vehicles for transport) and therefore also concerns fuel cells. In fact, progress in fuel cell technology in some specific areas like small appliances has the potential to further the development of fuel cells in other areas too, such as transport. One should note, however, that standards need to be set with a mid-term perspective in order to go beyond incremental improvements and to attract financing for the fuel cell business which is yet to a large part SME based in Europe (Jacob et al., 2005; Patterson, 2008).

In the coming years the EU is very likely to adopt more ambitious legislation in the field of EE. At its summit of March 2007, the EU has agreed on the target to save "20% of its energy consumption compared to projections for 2020" (EC, 2007b). According to EU estimates already half of this energy savings target could be reached if the existing legislation was well implemented and the promotional and dissemination activities reached out to a high number of energy consumers. However, to reach the remaining 10%, the Community will need to adopt and implement new legislation (EC, 2005b)—which may facilitate the market introduction of fuel cells assuming that a long-term perspective beyond 2020 is taken into account.

With regard to further EE legislation it is interesting to see that energy consumption has grown between 1990 and 2004 mainly in two sectors and is expected to continue to grow in future: electricity consumption (households and services demand more electricity) and transport (freight and passenger transport). In the latter, there have so far been relatively little EE improvements (OECD/IEA, 2007).

Consequently, the European Commission proposed relatively ambitious targets for the reduction of future *transport emissions*. Its proposal stipulated that by 2012 the average emissions of new cars sold in the EU shall not exceed 120 g CO_2/km (EC, 2007c). The European Parliament endorsed in December 2008 not only this benchmark but furthermore introduced a long-term target of 95 g CO_2/km for 2020 (EC, 2008a). Given that in 2004 the average emissions of new sold cars amounted to 163 g CO_2/km, this legislation will force car producers to make drastic cuts in emissions and consequently substantial improvements in EE.

To conclude, the EU has been relatively active in the field of EE in recent years. However, the implementation of EE legislation by Member States has so far been insufficient (EC, 2008b). Moreover, new legislation will need to be adopted if the union is to reach its 20% goal by 2020 (Lechtenböhmer et al., 2005; Business Europe, 2007). The European Commission has therefore announced in its Second Strategic Energy Review that a more focused EE action plan will be prepared (EC, 2008c). This development can benefit hydrogen and fuel cells which can be important means for reaching higher EE standards especially if a perspective beyond 2020 is taken.

However, if any cost benefit analysis would focus on 'low hanging fruits' in the short term and not take into account possible positive alternatives after the year 2020, hydrogen and fuel cells may not be considered a priority. It is thus not only uncertain whether the EU rhetoric will be followed by new legislation and effective implementation at the national level but also what impact on hydrogen and fuel cells this may have. Looking ahead one may also conclude that EE policy may become a powerful tool for fostering hydrogen and fuel cells in areas where the potential for market penetration is huge (mobile applications, auxiliary power, see Fri, 2003, p. 70 on that aspect of any disruptive technology) and where the environmental pressure to act facilitates actions (e.g. public busses for urban areas).

2.2. Renewable energy policies

Hydrogen is only as green as its energy source. As long as it is produced via gas reforming or via electrolysis based on carbon-intensive electricity, it may offer some minor carbon reduction advantages, but will not significantly curb carbon emissions (Heiman and Solomon, 2007). The penetration of renewable energy sources in the European energy system is therefore a precondition for the sustainable use of hydrogen.

The EU set in 2001 the target of a 21% renewable energy share of total electricity consumption by 2010 (Directive 2001/77/EC). This follows a target set in 1997: increasing the share of renewable energy sources to 12% of gross energy consumption. The current status of renewable electricity production shows the following figure, demonstrating implementation deficits in some member states (Fig. 1).

Based on current predictions, it seems very unlikely that the 12% target of primary energy consumption or the target of a 21% share in electricity consumption can be reached by 2010 (EurObserv'Er, 2007, p. 73). However, at the EU Summit in March 2007, the EU leaders set the future threshold even higher agreeing to meet 20% of their overall energy needs by the use of renewable energy by 2020, a target which has been backed by the European Parliament in December 2008 (EC, 2008a).

This shows that the EU does not lack the ambition to increase the share of renewable energies. It has clearly stated its will to do so. However, it clearly shows deficits in the *implementation* of its goals. Thus, the EU will probably fail with regard to its targets for 2010. One of the essential conditions of 'green' hydrogen production is thus currently unlikely of being fulfilled. Yet, the example of Germany which is four years ahead of its schedule

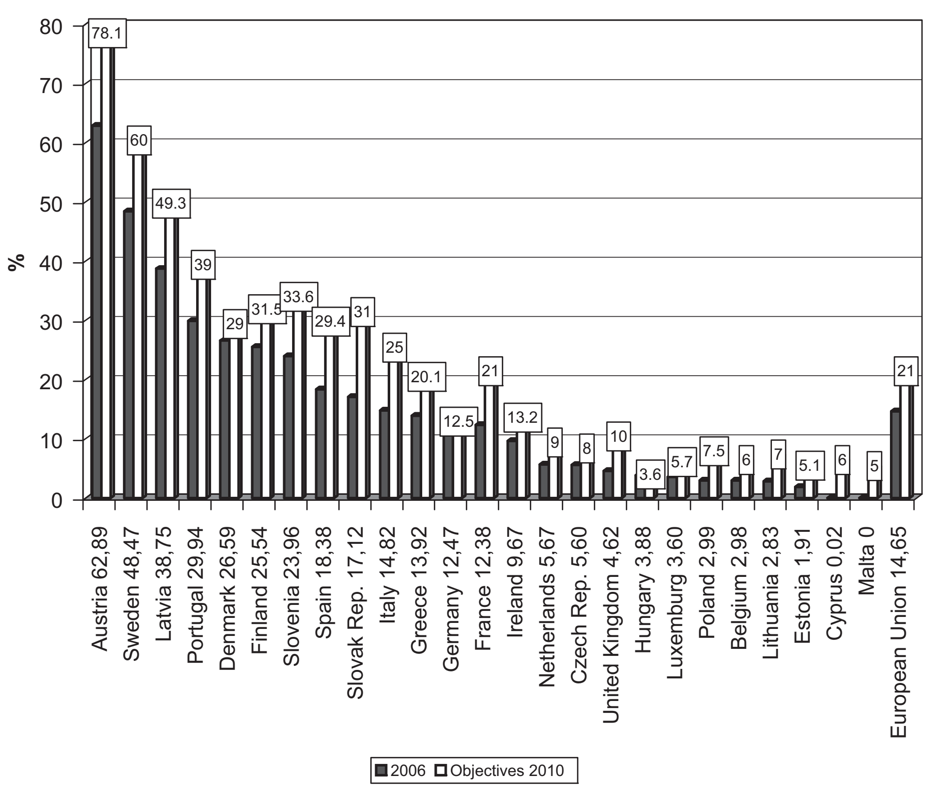

Fig. 1. Share of renewable energies in gross electricity consumption in EU member states in 2006. *Source*: EurObserv'Er (2007).

shows that with proper incentives – basically with remuneration fees providing certainty about production costs – the EU targets may be reached.

The conclusions for our paper is that the EU will have to better monitor and enforce the implementation of the renewables objectives at Member State level in order to comply with its ambitious targets for 2010 and 2020. This will also require dissemination and harmonization of those support mechanisms that have proven to be successful (Jansen et al., 2005). It is difficult to imagine that the EU will be in excess of renewable energies by 2020 that can be utilized to produce hydrogen on a large scale. Overcapacities may emerge in some regions (e.g. electric hydropower, windmills in Denmark, on islands or offshore). This has two implications: Firstly, synergies between renewable energies, electricity systems and hydrogen shall be exploited and, secondly, at least for a transition period other options to produce hydrogen (such as by-production in chemical industry or gas reforming) seem more realistic (Steinberger-Wilckens and Trümper, 2007; Ros et al., 2007).

2.3. The emission trading scheme

Emission trading is one of the so-called Kyoto mechanisms to implement the reduction of green house gases (GHG). According to economic theory an ETS reduces the costs of reaching a specific emissions target by taking advantage of different marginal abatement costs of the participating actors. Cost savings are particularly big if mitigation costs differ significantly between sources covered by the scheme. The cost differences create an incentive to trade. Given that hydrogen production can be done via fossil fuels, the specific mechanisms of the EU ETS are of great importance for its future market price.

Reforming of natural gas for instance is a widely used hydrogen production process even though it cannot significantly curb GHG emissions. The widespread use of gas reforming is due to the fact that many fossil fuel-based hydrogen production processes are less costly than hydrogen production from renewable energies. Yet, a well functioning ETS will increase the cost of carbon-intensive production processes. Thus, potential low carbon alternatives such as carbon capture and sequestration (CCS) would become more competitive (Fischedick et al., 2007). CCS could decrease the well-to-tank CO_2 emissions of hydrogen production. Without a functioning ETS the related well-to-tank costs, however, are significantly higher than those of the carbon-intensive alternatives (Wietschel et al., 2006). By putting a price on carbon-intensive processes, an ETS could set incentives for low carbon emitting hydrogen production processes such as those derived from renewables or fossil fuel combustion combined with CCS.

In view of internalising negative externalities the European Union therefore designed a European Emissions Trading Scheme. It started on 1 January 2005 based on the Directive 2003/87/EC (Bleischwitz et al., 2007). The scheme specifies two periods, the first from 2005–2007 and the second corresponding to the first commitment period of the Kyoto Protocol from 2008–2012. It is a cap and trade system which initially only focuses on CO_2. Its implementation will, however, take place in different phases with reviews and possibilities for its extension to additional gases and sectors.

The ETS currently applies to combustion installations with a rated thermal input above 20 MW, mineral oil refineries, coke ovens, iron and steel production, cement production and pulp and paper production. Around 12,000 installations take part in the system which covers about 45% of total EU CO_2 emissions.

With regard to hydrogen the main question is to what extent the EU ETS encourages a shift of investments towards more sustainable energy supply systems, including potentially disruptive technologies such as hydrogen and fuel cells. Existing analysis reveals that the ETS partly encourages the uptake of climate-friendly technologies by rewarding businesses investing in energy efficiency and some green technologies turning their investments into quick, short-term profits. But given the uncertainties about the development of hydrogen and fuel cells as well as other more disruptive sustainable technologies, the ETS can hardly encourage investments into long-term solutions. The risk of sunk costs, as well as the coordination costs for many investors is still too high (Mc Kinsey and Ecofys, 2005; Endres and Ohl, 2005). This bias in favour of path-dependent and incremental innovation is aggravated by the limited playing field of the ETS: the automobile industry and oil industry are not covered by the EU ETS. Surrounded by those constraints, the EU ETS in its current form does not yet provide enough incentives to embark on radically new sustainable technologies such as hydrogen and fuel cells.

Instead of setting incentives for hydrogen development, the ETS might at some point even hinder its development. It is very likely that the ETS will in future also apply to hydrogen production. In its communication "2020 by 2020, Europe's climate change opportunity" of January 2008 the Commission proposed a major reform of the ETS (EC, 2008d):

- The ETS should apply to all important industrial emitters
- GHGs other than CO_2 should be included in the ETS
- From 2013 onwards the whole power sector should be part of the ETS
- EU-wide auctioning of allowances should increasingly replace the national allocation plans which are currently in place

The European Parliament has backed many points of this proposal in its resolution of December 2008. The reformed ETS will apply to almost all industrial emitters. The non-power sector will have to buy at least 20% of its allowances on the market from 2013; this share will rise to at least 70% in 2020 (EC, 2008e). Hydrogen production (e.g. in the chemical industry) would then most likely fall under it too. Without specific provisions for the advantages of hydrogen on a life-cycle basis, the ETS would thus hinder (GHG-intensive) hydrogen production.

In contrast, options to facilitate the market introduction of hydrogen and fuel cells are as follows: processes for hydrogen production could be exempted from the ETS whereas nearly all other industrial emitters may be included. However, GHG-intensive hydrogen production should only be exempted from the ETS for a certain time period needed to develop a market. Once a market for hydrogen and fuel cells exists, hydrogen production should be included in the ETS to promote less GHG-intensive production processes. The allocation mechanism may on the other hand be supportive to the hydrogen economy. A company producing hydrogen at certain standards may be entitled to additional free allowances ('grandfathering'), taking into account the GHG reduction via the application of hydrogen. As a complementary mechanism, the funds from auctioning allowances may also be used for the market introduction of hydrogen and fuel cells. Of course, those proposals suppose that the prices for CO_2 allowances rise, meet expectations to rise further and thus set incentives for long-term investment in new energy solutions.

To a certain extent the text adopted by the European Parilament already displays some of these features: power generated with CCS technologies will be exempted from the revised ETS. This would then also apply to hydrogen derived from

Table 1
Minimum rates applicable to motor fuels according to the EU energy taxation directive.

	Minimum excise rates before 2004	Minimum excise rates from 1.1.2004	Minimum excise rates from 1.1.2010
Petrol (per 1000 l)	337	421	421
Unleaded petrol (per 1000 l)	287	359	359
Diesel (per 1000 l)	245	302	330
Kerosene (per 1000 l)	245	302	330
LPG (per 1000 l)	100	125	125
Natural gas	100 (per 1.000 kg)	2.6 (per gigajoule)	2.6 (per gigajoule)

Source: EC (2007d).

Table 2
Minimum tax rates applicable to heating fuels and electricity.

	Minimum excise rates before 2004	Minimum excise rates from 1.1.2004 (business use)	Minimum excise rates from 1.1.2004 (non-business use)
Diesel (per 1000 l)	18	21	21
Heavy fuel oil (per 1000 kg)	13	15	15
Kerosene (per 1000 l)	0	0	0
LPG (per 1000 kg)	0	0	0
Natural gas (per gigajoule)	–	0.15	0.3
Coal and coke (per gigajoule)	–	0.15	0.3
Electricity (per MWh)	–	0.5	1.0

Source: EC (2007d).

CCS processes. Based on "best-in-class-technology" benchmarks, free allowances will furthermore be given to industries. Thus, the most advanced and greenest hydrogen production processes could be rewarded. In addition, 50% of the ETS revenues will be used for financing climate adaptation and mitigation measures. This includes also research and development as well as demonstration projects (EC, 2008e) and may thus also apply to hydrogen and fuel cell development.

3. EU regulatory policies

The EU level also impacts on some regulatory policies. Given that some of these policies may influence the price of hydrogen they can be seen as an essential part of the EU policy framework for hydrogen promotion. In the following our paper will thus analyze the EU policy in the field of energy taxation and the liberalization of the gas and electricity market.

3.1. Taxation

Green taxation has received much academic attention in recent years. Several studies have shown the effectiveness of environmental taxes and emphasize that there still is potential for better and wider use of these instruments (Glomm et al., 2008; Görres and Cottrell, 2008; OECD, 2006). Energy taxation in particular can be an effective instrument of influencing demand if well applied and combined with other instruments (Berkhout et al., 2004). Consequently energy taxation has the potential to support or hinder the development and market introduction of hydrogen and fuel cell technologies.

The main EU instrument in the field of fuel taxation is the Council Directive 2003/96/EC aiming at "restructuring the Community framework for the taxation of energy products and electricity". Before the entry into force of this directive, EC minimum tax rates applied only to mineral oils. The rationale for this directive thus has been to apply minimum taxation also to electricity, coal and natural gas and to reduce distortions of the internal market due to different tax rates.

The directive sets out minimum levels of taxation for energy products. The tax is paid by whoever purchases the energy product in question and not by the producer. Electricity consumed in the production of electricity, so-called on-site consumption is exempted from the directive (EC, 2003a). The final shape of the Directive which entered into force on 1 January 2004 is characterised by Hasselknippe and Christiansen (2003) as follows:

- New minimum rates are to be set at the latest by 1 January 2012 for a new period from 2013
- The minimum rates are set at a relatively low level (see below)
- Some energy-intensive industries can benefit from exemptions; the tax rates for business and industry are generally lower than those for other economic actors
- A return of revenue to companies/industries is possible if they enter into energy efficiency agreements (100% return to energy-intensive industries with agreement, 50% return to other industries)

Tables 1 and 2The Directive on the minimum taxation of energy products does not explicitly refer to hydrogen. Thus, in absence of any European minimum taxation level, Member States have the freedom to opt for the tax rate which they deem most appropriate at national level. According to a study led by Bocconi University (Chernyavs'ka et al., 2006), hydrogen is not taxed in a specific way in 13 Member States (Belgium, Denmark, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Slovakia, Spain). Five Member States tax hydrogen when it is used as motor fuel (Austria, Czech Republic, Germany, the Netherlands, United Kingdom). Seven Member States are not included in the study for they did not reply to the research enquiry (Cyprus, Estonia, Finland, Lithuania, Poland, Slovenia, Sweden).

An optimal tax in environmental terms aims at internalising negative externalities. In this respect, it is important to calculate not only the environmental costs of a given fuel at the end-use stage but also at the production stage. Currently, hydrogen *production* – in cases when it is produced via fossil fuels – causes higher external costs than the production of competing fuels. Hydrogen *use*, on the other hand, produces little or no external costs (GHG emissions) and may substitute other environmentally more harmful fuels and energy carriers. From a systems perspective, there is no overall rationale for taxing hydrogen as long as it contributes to lowering overall environmental pressure of the energy system. However, this assessment depends upon the assumption that hydrogen is produced in a sustainable way, for instance through electrolysis based on renewable energy or gas reforming combined with carbon capture and storage (Chernyavs'ka et al., 2006).

European states which tax hydrogen impose only low rates. Given that currently hydrogen is produced in a conventional way using fossil fuels, the tax level for hydrogen is estimated to lie below a level which would be needed to internalise its total external costs (Chernyavs'ka et al., 2006). The current European tax systems thus put hydrogen in a favourable position. In view of the promotion of hydrogen in Europe, this situation is definitely positive and should be maintained in the coming years. Member States currently taxing hydrogen may also reflect and withdraw from their taxation of hydrogen.

Looking ahead to the envisaged deployment, however, the question of hydrogen taxation must be addressed. When hydrogen applications pass the threshold from early markets to mass markets, a comprehensive framework which promotes sustainable hydrogen production will be needed. It is likely that there will be a trade-off between cost-effective production of hydrogen at a large scale via gas reforming processes on the one hand and GHG reduction and the aim to promote clean energies on the other hand (Steinberger-Wilckens et al., 2008). Assuming that this situation occurs after 2010, the EU will be faced with the dilemma of having to implement its radical GHG commitments (20% by the year 2020 based upon 1990 levels, more if other nations follow) and large-scale production of hydrogen for which gas reforming is the most cost-effective option (Ros et al., 2007). Taxation thus needs to be put into the context of a long-term GHG reduction after 2020 as well as other energy-related goals such as competitiveness and energy security. If a priority in favour of hydrogen is made, an – at least limited – exemption of gas reforming from taxation (respectively the ETS) can be legitimate.

3.2. The liberalization of the internal market for gas and electricity

The liberalisation of the European market for electricity and gas is supposed to strengthen the competitiveness of European firms and improve the efficiency of the energy market (Pelkmans, 2006; Delgado et al., 2007). Consumers should have greater choice of energy suppliers and all energy suppliers should have access to the market, irrespective of their market power and the energy source. Thus, also small producers of sustainable energy technologies could better promote their products provided that the price mechanisms reflect the external costs too; such liberalization policy has e.g. proven to be effective in the promotion of cogeneration in the UK (Tichy, 2008, p. 27).

However, in its conclusions of 9 March 2007 the Presidency of the Council of the European Union stated that ''a truly competitive, interconnected and single Europe-wide internal energy market [...] has not yet been achieved'' (EC, 2007b). In view of reaching this goal, the Council sees the need to firstly fully implement existing directives. Secondly, further measures that go beyond existing legislation are to be discussed and implemented.

The implementation of existing legislation refers mainly to two directives of 2003, one on the internal market for natural gas, the other on the internal market for electricity:

- The directives stipulate that for non-household customers the markets for electricity and gas must be liberalised by 1 July 2004.
- The respective markets for the remaining customers, above all private households, must be liberalised by 1 July 2007 (EC, 2007e; EC 2007f).

Notwithstanding these already elapsed deadlines, the internal markets for electricity and gas have not yet been fully liberalised and actors still complain about the persistence of entry barriers to the market. Thus, the Commission stated in a sector inquiry of early 2007 that several problems need to be addressed and respective policy responses to be implemented if the liberalisation is to advance (EC, 2007g).

Among the proposed policy responses, unbundling (i.e. ''the effective separation of supply and production activities from network operations'') has caused particularly heated debate. The Commission furthermore proposes to establish a European ''Agency for the Cooperation of Energy Regulators'' which would set the framework in which national regulators operate, oversee the cooperation between transmission operators, take decisions concerning cross-border issues and advise the Commission (EC, 2007h). Currently (January 2009) European politicians are debating these proposals (also called ''the third energy package'') of the Commission.

From today's perspective, it is difficult to see which option may eventually be retained. However, the reform models under discussion are likely to increase competition on European markets for electricity and gas supply and thus lead on the medium term to lower prices—relative to a situation without policy change, not in absolute terms. The liberalization of the gas and electricity markets may thus have a certain even though not significant influence on the level of the price curve. The overall price level will also depend on other factors such as impacts from climate policy and international markets for energy fuels. In addition, any active competition policy favouring market entry is also likely to have positive impacts on hydrogen and fuel cell companies (for business development and financing of hydrogen and fuel cell companies see Mönter and Doran, 2007).

At the current price level, hydrogen is not competitive with most energy sources and energy carriers. One might therefore be tempted to conclude that rising energy prices favour hydrogen development as long as only prices of competing energy vectors and sources increase and not that of hydrogen.

However, electricity and gas are two major inputs for hydrogen production. If gas and electricity prices rise, the price for hydrogen rises too. The price for hydrogen is thus dependent upon the gas and electricity price. In absolute terms, hydrogen will always be more expensive than gas and electricity as long as it is mainly produced via electrolysis and gas reforming.

Yet, the price for gas and electricity may affect the way hydrogen is produced. High prices for gas and electricity can be an incentive for further research of alternative hydrogen production processes, such as biological production.

Analysis is confronted with a different picture if one blanks out hydrogen for stationary use and looks at hydrogen for transport applications only. From an end user perspective hydrogen for transport applications competes mainly with oil. Thus, the price of hydrogen must be compared with the crude oil price. In a scenario where the medium term increase in crude oil prices is higher than the increase in prices for electricity and gas, hydrogen will become more competitive with regard to oil as a transport fuel (Martinot et al., 2007). Any development with a conducive policy framework that renders electricity and gas relatively cheaper with regard to crude oil can therefore be seen as an incentive benefitting the use

Table 3
Expenditure estimates for EU policies.

Expenditure estimates for EU policies (in billion €)	Budget 2008	Change from 2007 (%)
Sustainable growth	58	5.7
Competitiveness, including	11.1	18.4
Education and training	1.0	9.3
Research	6.1	11.0
Competitiveness and Innovation	0.4	6.8
Energy and transport networks	1.9	92.5
Social policy agenda	0.2	8.0
Cohesion, including	46.9	3.1
Convergence	37.0	5.2
Regional competitiveness and employment	8.6	−5.1
Territorial cooperation	1.2	2.6
Natural resources, including	55.0	−1.5
Environment	0.3	12.0
Agricultural expenditure and direct aid	40.9	−3.4
Rural development	12.9	4.5
Fisheries	0.9	2.2
Freedom, security and justice	0.7	16.7
Citizenship	0.6	14.7
EU as a global player	7.3	7.3
Administration	7.3	4.4
Total	129.1	2.2

Source: EC (2008f).

of hydrogen in transport. It is worth noting that competition for the market for clean cars and sustainable mobility will need to be aligned with those policies (Table 3).

4. EU spending policies

A glance at the EU budget may suffice to highlight the relative importance of spending policies. Out of the 129 billion € which the EU planned to spend in 2008, around 100 billion € were foreseen for the two biggest items on the budget sheet alone: cohesion and natural resources (the latter referring mainly to the Common Agricultural Policy).

In the following EU spending policies will be screened with regard to their possible positive or negative effects on hydrogen and fuel cells.

4.1. Regional policy

The treaty stipulates that the Community should aim for economic and social cohesion. The main policy destined to respond to this challenge is the Community's regional policy which aims to lessen regional disparities. The latter have drastically increased in recent years. The process of European integration and market liberalisation, however, cannot be blamed for social disparity as Pelkmans points out (Pelkmans, 2007). The gap in wealth between poorest and richest regions has mainly increased due to the enlargement of the Union which opened in 2004 its doors to new member states whose regions sometimes represent only 50% of the average EU wealth (expressed in GDP per capita in PPP).

Regional policy matters for the development of hydrogen and fuel cells inasmuch as it channels billions of euros to European regions. A great share of this money could potentially be used for clean energy technologies. The growing importance of regional policy is reflected in the fact that the share of regional spending will increase to 36% of total EU spending by 2013 and represent the amount of 308 billion € over the period 2007–2013. The major part of this amount goes to the poorest regions since only those regions that have a GDP per capita below 75% of the EU average are eligible for all of the three main objectives of regional funding (EC, 2007i). The ensuing spending policy will be of importance for infrastructure investments of the hydrogen and fuel cell economy in Europe (e.g. production and distribution).

In theory, a relatively big part of regional spending should be channelled towards innovation. In its aim to re-launch the Lisbon strategy and to mobilise all available resources, the Commission has announced to promote growth and employment also through regional policy instruments. In fact, the regional level of economic and political governance plays a crucial role in innovation processes (Rodríguez-Pose and Crescenzi, 2007). Thus, EU regional funding should be concentrated on innovation, research, knowledge and entrepreneurship (EC, 2007j) to be sure this enforces a shift from a merely socially oriented policy towards a more forward-looking approach. This shift can potentially benefit the hydrogen and fuel cell development in particular in regions with existing hydrogen by-production and other capacities (see Madsen and Andersen, 2009; Bader et al., 2008).

It is, however, very difficult to assess the exact amount of money that will be spent on hydrogen and fuel cells via the EU regional funds given that a category "hydrogen and fuel cells" does not exist in the respective EU documents. In the following, the planned spending on "innovation" will be analyzed since instruments supporting the development of hydrogen and fuel cells would most likely fall into this category. The Commission defines spending in innovation in the wider sense as spending that falls in one of the following four categories: research and technological development, entrepreneurship, innovative ICT and human capital. The spending for research and technological development (such as the promotion of "environmental-friendly products and processes") is "referred to as innovation in the narrow sense" (EC, 2007j). The investment in entrepreneurship (e.g. support for firms and start-ups), innovative ICT and human capital should establish an environment conducive for growth and help to reap the fruits of research activities. Innovative regions can therefore facilitate the adoption of a new, potentially disruptive, technology (Huber, 2004) such as hydrogen and fuel cells.

In the period 2000–2006, 11% of the EU cohesion spending was dedicated to innovation. For 2007–2013, 25% (85 billion €) of the envelope is planned to be channelled towards innovation. Given that national and private co-financing and additional investment are not yet included, the actual sum will be far greater (EC, 2007j). The role of innovation in the cohesion spending has thus clearly increased in the 2007–2013 financial framework compared with the previous one, albeit on a low level.

With regard to the three objectives of regional funding, the Convergence objective is allocated by far the greatest financial resources: 282.8 billion € will be available under this heading for the period 2007–2013. Around 61 billion € out of these 282.8 billion € are planned to be spent for innovation which represents nearly 22% of the total allocation. However, only those regions which have a GDP below 75% of the EU average are eligible for cohesion funding. The most prosperous regions which are in many cases also the most innovative regions are consequently not eligible. Currently 84 regions representing 154 million inhabitants can apply for cohesion funding (Fig. 2).

The increased spending for innovative measures can be seen as very positive with regard to hydrogen development. However, it is questionable whether the money is spent in the most effective way. In fact, hydrogen and fuel cells have so far been deployed in relatively innovative regions that dispose of the necessary capital, the political will and technical know-how (see the article of Madsen and Andersen, 2009). Yet, the Commission states itself that "Cohesion policy concentrates its financial support on the poorer regions that are usually included in the group of regions

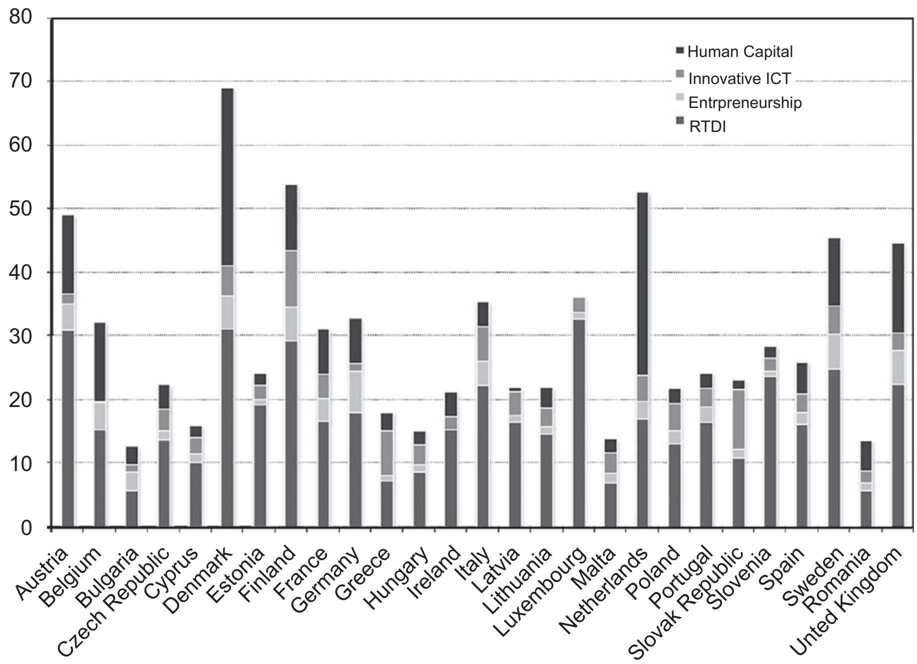

Fig. 2. Planned investment in innovation 2007–2013 by country (all objectives). *Source*: EC (2007j).

with lower levels of innovation" (EC, 2007j). Regions that have already gained some experience with hydrogen and fuel cells and are well placed to pursue their development are often not eligible for the major part of the spending—with a few notable exceptions (e.g. in Spain, Southern Italy or Wales). Regional policy as it has been pursued in the past might be an effective tool to bridge the social gap in Europe. In future, more efforts need to be undertaken to align regional policy with the deployment of hydrogen and fuel cells. The scoping exercises of projects such as Roads2HyCom provide tentative evidence on regions as well as tools that can be used for more in-depth research.

4.2. Biofuels policy

Like hydrogen and fuel cell technologies biofuels are often referred to as 'sustainable' or 'green' alternatives to gasoline-fuelled transport. Biofuels and hydrogen are therefore competing for green credentials and future market shares in Europe. In this respect, the promotion of biofuels can have repercussions on the development of hydrogen and fuel cells.

Biofuels are also part of EU energy policies. The reason why they are dealt within the context of spending policies is the fact that the EU not only sets common targets but also sets financial incentives for biofuels production via the common agricultural policy (CAP) and its regional policy.

In 2003, the EU set the indicativetarget to increase the share of biofuels in transport to at least 5.75% by 2010. The rationale underlying this target is the assumption that CO_2 emissions in the transport sector might decrease if biofuels partly substitute petrol and diesel (EC, 2003b). According to the Green Paper "Towards a European strategy for the security of energy supply" which was published in 2000, the Commission aimed to increase the share of alternative fuels in transport to 20% by 2020 (EC, 2000). The term "alternative fuels" also includes gas and hydrogen but biofuels will have the main role to play if the Community is to reach this goal. At the EU summit of March 2007, the Council set the specific biofuels target even higher and proclaimed that it aims to reach a 10% share of biofuels in transport by 2020.

In late 2007, the Community was still far away from reaching this objective and it seemed unlikely that the goal of increasing the share of biofuels to 5.75% by 2010 could be reached. A progress report of 2007 shows that for 2010 a share of 4.2% seems more likely. In fact, the EU 25 reached a biofuels share of only 1% in 2005. Yet, other studies, notably the EurObserv'Er (2007), estimate that the EU member states may come close to their targets (EC, 2007k; EurObserv'Er, 2007).

In recent months, the 10% target has been substantially revised. Thus, the European Parliament refers in its resolution of 17 December 2008 to a 10% share in transport which "is to be achieved from renewable sources, not from biofuels alone". This could include also hydrogen and green electricity. Moreover, the Parliament calls for the development of "sustainability criteria for biofuels and the development of second and third generation biofuels in the European Union and worldwide" (EC, 2008e). These changes reflect growing concerns about the sustainability of biofuels. However, they do not fundamentally reverse the promotion of biofuels in Europe.

Many Member States promote biofuels via reduced excise duty rates on the ground of the 2003 directive on energy taxation (Bringezu et al., 2007). In addition to the promotion of biofuels by the means of common targets and tax exemptions, the EU also supports its production through the CAP. The 1992 reform of the CAP introduced the obligation for farmers to set aside a certain surface of their farmland. Normally, this land must not be cultivated. Yet, if a farmer produces crops for non-food use he is allowed to resort to the set-aside area. Already in 2005, 0.85 million hectares of set-aside land served for growing oilseeds for biofuel production. Since 2005, also sugar beet for biofuel can be planted on set-aside land (EC, 2006b).

Since 2004 farmers can furthermore benefit from a specific EU premium for energy crops of up to 45 euros per hectare. This incentive has worked so well that the area where energy crops eligible for this funding were grown increased from 0.31 million hectares in 2004 to 2.84 million hectares in 2007. The funding per hectare has since then been decreased because the budget ceiling for this instrument (90 million euros per year) was reached (EC, 2007l). The EU furthermore supports investment and training in biofuels via its Regional Development Fund and its Rural Development policy (EC, 2006b).

With regard to its effect on hydrogen and fuel cells the promotion of biofuels may facilitate the shift away from oil. Biofuels are a relatively rapid answer to the growing concern about security of supply, can be blended up to a certain degree with traditional fossil fuels, are easily to introduce (no special infrastructure needed) and might compensate for relative shortages of oil.

Exactly because of these advantages, biofuels can become a rival for hydrogen, at least in the mid term until 2020. However, it is questionable whether biofuels can be a sustainable response to the global energy challenges. First, they will not be able to fully substitute for fossil fuels since the global production capacities are limited by the land available and by shortages in other production factors. Second, it is questionable whether biofuels have such a good environmental footprint as its supporters claim—there is increasing evidence of negative environmental impacts (Bringezu et al., 2007; Patzek, 2007; House of Commons, 2008). Second-generation biofuels may have a better environmental footprint than the first generation. However, they are expected to represent only a small share of biofuels produced in 2030 and still face considerable technical and economic challenges (OECD/IEA, 2008)

With regard to the carbon footprint hydrogen performs clearly better when produced from renewable energy sources. Aligning biofuels policy with concerns about sustainable energy, the deployment of hydrogen and fuel cells and attempts to promote rural development thus will become a major challenge for the next years.

5. Conclusions and proposals for further policy research

The analysis of EU policy impacts on the development of hydrogen and fuel cells has yielded different results.

(1) EU energy policies have developed strong push factors towards more sustainable technologies. The ETS, energy efficiency or renewables promotion—all these policy instruments also have some positive impact on hydrogen and fuel cells since they constitute a framework for sustainable energy production and use. However, these push factors are too weak to lead to the deployment of hydrogen and fuel cells because of, firstly, lacking incentives towards long-term investments in sustainable technologies and, secondly, inconsistencies and negative side-effects within existing instruments that lead to distortions in hydrogen and fuel cell markets across Europe.
(2) Current regulatory policies tend to have a weak but positive impact on hydrogen. In most EU member states hydrogen is exempted from any taxation or taxed at relatively low rates. Thus taxation currently favours hydrogen over competing technologies. Yet, the EU cannot be credited with this situation since hydrogen is not explicitly mentioned in the directive on minimum taxation nor has the EU strong competence in the field of taxation. The effects of the liberalization of the market for gas and electricity seem to be relatively weak. Nonetheless, they are positive and may in general favour the market entry of hydrogen and fuel cells and in particular the use of hydrogen in transport.
(3) EU spending policies are a potentially powerful policy instrument for the regional promotion of sustainable technologies and infrastructure since they can channel funds towards them. However, this potential is currently not fully exploited. The analysis of regional policy yields a mixed result. On the one hand more regional funding has recently been directed towards innovation, a field closely related to hydrogen and fuel cells. On the other hand, cohesion funding normally does not apply to those regions which are the most innovative and the most advanced in the field of hydrogen and fuel cells. The CAP as the second big EU spending policy does not favour hydrogen or fuel cells. On the contrary it promotes biofuels which may on the long term compete with hydrogen and thus indirectly hinder its development.

Looking ahead the current policy framework at EU level does not set clear long-term signals and lacks incentives that are strong enough to facilitate high investment in and deployment of sustainable energy technologies. The likely overall effect thus seems to be too weak to enable the EU hydrogen and fuel cell deployment strategy. According to our analysis an enhanced EU policy framework pushing for sustainability in general and the development of hydrogen and fuel cells in particular should meet the following key requirements:

(1) A strong EU energy policy with credible long-term targets: The European governments have given their commitments for a strong reduction in GHG. However, the implementation must be improved and requires additional action. This implies for example higher carbon prices that set clear investment signals, higher energy efficiency requirements and a more ambitious implementation of renewable energy targets at national level. In addition, targets for the years 2030–2040–2050 need to be formulated and aligned with the hydrogen and fuel cell deployment strategy (see also Jacobsson and Bergek, 2004, p. 840 on the importance of long time scales to transform the energy sector).
(2) Better coordination of EU policies: Europe needs a common understanding of key taxation concepts (green taxation, internalization of externalities) and a common approach for the market introduction of new energy technologies. This requires more harmonization of tax systems, codes and standards. To promote its development hydrogen and its production sources could be exempted from any taxation for a certain period of time. In the mid to long run when mass markets for hydrogen are forming, it will however become rational to include hydrogen in any minimum taxation Directive or to reform this system taking into account the total external costs of the life cycle of respective energy products. However, policy consistency is of great importance in this respect. Liberalization of the gas and electricity markets should be pursued in line with putting a price on carbon and improving market access for small producers of renewable energy sources. Entrepreneurs and SMEs in hydrogen and fuel cell sector should get better access to financing, for example through a European trust fund. The sustainability impact of spending policies furthermore needs to be increased: setting up a distribution infrastructure for hydrogen and fuel cells will be facilitated if active regions in the field of hydrogen and fuel cells promote large-scale demonstration projects and become eligible for the main regional funds.
(3) Regions that dispose of strong clusters in hydrogen and fuel cell-related areas can further advance the market introduction and establish a first hydrogen infrastructure. Later on the first emerging hydrogen communities could be interconnected to create a wider hydrogen infrastructure in Europe. The EU can support these efforts and play a coordinating role (for the regional perspective see Madsen and Andersen, 2009).

Long-term policies need to be adaptive and open to technological change. Alternative developments e.g. battery technology are crucial for the patterns of a hydrogen inclusive economy (Larsen and Höjer, 2007; Macario, 2007). In the short and medium term other technologies may well be more promising than hydrogen and fuel cells. Plug-in hybrid cars are for instance already commercialized in Europe and North America and are expected to highly increase their market share in the coming decade (Wyman, 2008)—it is far from being clear how hydrogen and fuel cells will perform in comparison to these technologies. In the end, this clearly points out the need for a more in-depth research on a comprehensive long-term policy framework that induces and enables sustainable energy systems and other eco-innovations.

References

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-in by historical events. Economic Journal 394, 116–131.

Bader, N., Bleischwitz, R., Fuhrmann, K., Dannemand, P., Nygaard Madsen, A., 2008. Policies and socioeconomic aspects towards further dissemination of hydrogen communities in the EU, Deliverable 7.4 of Roads2HyCom.

Berkhout, P.H.G., Ferrer-i-Carbonell, A., Muskens, J.C., 2004. The ex post impact of an energy tax on household energy demand. Energy Economics 26, 297–317.

Bleischwitz, R., Fuhrmann, K., Huchler, E., 2007. The sustainability impact of the EU emissions trading scheme on the European industry. Bruges European Economic Policy Briefings 17.

Bleischwitz, R., 2007. Corporate Governance of Sustainability: A Co-Evolutionary View on Resource Management. Edward Elgar, Cheltenham.

Bringezu, S., Ramesohl, S., Arnold, K., 2007. What we know and what we should know. Towards a sustainable biomass strategy. A Discussion Paper of the Wuppertal Institute, 163, Wuppertal.

Business Europe, 2007. Energy Efficiency—Reconciling Economic Growth and Climate Protection, Brussels.

Chernyavs'ka, L., Gullí, F., Lanfranconi, C., 2006. Energy taxation policy in the European Union: the hydrogen case. Economia delle Fonti di Energia e dell'Ambiente 2, 5–28.

Council of the European Union, 2008. Council regulation setting up the fuel cells and hydrogen joint undertaking, Interinstitutional File 2007/0211 (CNS), Brussels 20 May 2008.

David, P., 1985. Clio and the economics of QWERTY. American Economic Review 2, 332–337.

Delgado, J., Friederiszick, H., Röller, L., 2007. Energy: Choices for Europe, Bruegel Blueprint Series, Brussels.

EC, 2000. Green Paper "Towards a European strategy for the security of energy supply," COM(2000), 769.

EC, 2003a. Council directive 'restructuring the Community framework for the taxation of energy products and electricity', 2003/96/EC, Official Journal, L283/51–L283/70.

EC, 2003b. Directive of the Parliament and the Council on the promotion of the use of biofuels or other renewable fuels for transport, 2003/30/EC, Official Journal, L123/42–L123-46.

EC, 2004. Directive of the Council and the European Parliament on the promotion of cogeneration based on a useful heat demand in the internal energy market, 2004/8/EC, Official Journal L52/50–L52/60.

EC, 2005a. Directive of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-using products, 2005/32/EC, Official Journal, L191/29–L191/58.

EC, 2005b. Green Paper on energy efficiency. Doing more with less, COM (2005) 265 final, Brussels.

EC, 2006a. Directive of the European Parliament and the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, Official Journal, L114/64.

EC, 2006b. Fact Sheet Biofuels in the European Union: An Agricultural Perspective. Office for Official Publications of the European Union, Luxembourg.

EC, 2007a. Communication from the Commission: a European strategic energy technology plan (SET-Plan)—'Towards a low carbon future', Brussels, 22 November 2007, COM(2007) 723 final.

EC, 2007b. Presidency Conclusions, Brussels European Council of 8/9 March 2007, 2 May 2007, 7224/1/07 REV 1.

EC, 2007c. Proposal for a regulation of the European Parliament and of the European Council setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light duty vehicles, COM(2007) 856 final.

EC, 2007d. Community framework for the taxation of energy products and electricity, available at 〈http://europa.eu/scadplus/leg/en/lvb/l27019.htm〉 last update 20 February 2007.

EC, 2007e. Directive of the European Parliament and the Council concerning common rules for the internal market in electricity, 2003/54/EC, Official Journal, L176/37–L176/55.

EC, 2007f. Directive of the European Parliament and the Council concerning common rules for the internal market in natural gas, 2003/55/EC, Official Journal, L16/74.

EC, 2007g. Communication from the Commission: inquiry pursuant to article 17 of regulation (EC) no. 1/2003 into the European gas and electricity sectors (final report), COM 2006(851) final.

EC, 2007h. Explanatory memorandum of the 3rd energy package, COM(2007)-DRAFT.

EC, 2007i. Overviews of the European Union activities: regional policy, last updated in September 2007, available at 〈http://europa.eu/pol/reg/overview_en.htm〉 accessed on 21 January 2008.

EC, 2007j. Commission staff working document: regions delivering innovation through cohesion policy, SEC(2007) 1547.

EC, 2007k. Report from the Commission—biofuels progress report. Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union, COM(2006) 845 final.

EC, 2007l. Biofuels: aid per hectare of energy crops reduced as the area exceeds 2 million hectares, EU Press release, 17 October 2007, IP/07/1528, Brussels.

EC, 2008a. European Parliament press release: European Parliament seals climate change package, REF.: 20081216IPR44857, 17 December 2008.

EC, 2008b. Energy Efficiency: delivering the 20% target, MEMO08/699, Brussels, 13 November 2008.

EC, 2008c. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Second strategic energy review. An EU energy security and solidarity action plan, SEC(2008) 2794 and SEC(2008) 2795, Brussels, unofficial version.

EC, 2008d. Communication from the Commission to the European Parliament and the Council, the European Economic and Social Committee and the Committee of the Regions, 20 20 by 2020, Europe's climate change opportunity, COM 2008 (30) final.

EC, 2008e. European Parliament: texts adopted at the sitting of Wednesday 17 December 2008, P6_TA-PROV(2008)12–17, provisional edition.

EC, 2008f. EU budget 2008, Office for official publications of the European Communities, Luxembourg.

Endres, A., Ohl, C., 2005. Kyoto, Europe?—an economic evaluation of the European emission trading directive. European Journal of Law and Economics 19, 17–39.

EurObserv'Er, 2007. 7th report state of renewable energies in Europe.

European Hydrogen and Fuel Cell Technology Platform, 2007. Implementation Plan—Status 2006.

Fischedick, M., Esken, A., Luhmann, H.-J., Schüwer, D., Supersberger, N., 2007. CO_2-capture and geological storage as a climate policy option—technologies, concepts, perspectives. Wuppertal Spezial, 35e.

Fri, R.W., 2003. The role of knowledge: technological innovation in the energy system. Energy Journal 24 (4), 51–74.

Glomm, G., Kawaguchi, D., Sepulveda, F., 2008. Green taxes and double dividend in a dynamic economy. Journal of Policy Modeling 30, 19–32.

Görres, A., Cottrell, J., 2008. The tragic paradox: Germany's very successful but not very popular green budget reform: lessons from seven years of courageous turnaround (1999–2005). In: Chalifour, N.J., Milne, J.E., Ashiabor, H., Deketelaere, K., Kreiser, L. (Eds.), Critical Issues in Environmental Taxation: International and Comparative Perspectives. Oxford University Press, Oxford, pp. 701–722.

Grubb, M., Ulph, D., 2002. Energy, the environment, and innovation. Oxford Review of Economic Policy 18 (1), 92–106.

Hasselknippe, H., Christiansen, A., 2003. Energy taxation in Europe, current status – drivers and barriers – future prospects, Fridtjof Nansens Institute, Lysaker.

Heiman, M., Solomon, B., 2007. Fueling US transport. The hydrogen economy and its alternatives. Environment 49, 155–166.

House of Commons, Environmental Audit Committee, 2008. Are biofuels sustainable? First Report of Session 2007–08, Vol. I, London.

Huber, J., 2004. New Technologies and Environmental Innovation. Edward Elgar, Cheltenham.

IEA, 1987. Energy Conservation in IEA Countries. OECD/IEA, Paris.

Isoard, S., Soria, A., 2001. Technical change dynamics: evidence from the emerging renewable energy technologies. Energy Economics 23 (6), 619–636.

Jacob, K., Beise, M., Blazejczak, J., 2005. Lead Markets for Environmental Innovations, Zentrum für Europäische Wirtschaftsforschung Mannheim. Physica-Verlag, Mannheim.

Jacobsson, S., Bergek, A., 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. Industrial and Corporate Change 13 (5), 815–849.

Jansen, J., Gialoglou, K., Egenhofer, C., 2005. Market stimulation of renewable electricity in the EU—what degree of harmonization of support mechanisms is required? CEPS Task Force Report no. 56, Brussels.

Larsen, K., Höjer, M., 2007. Technological innovation and transformation perspectives in environmental futures studies for transport and mobility. International Journal of Foresight and Innovation Policy 3, 95–115.

Lechtenböhmer, S., Grimm, V., Mitze, D., Thomas, S., Wissner, M, 2005. Target 2020—policies and measures to reduce greenhouse gas emissions in the EU, Wuppertal Institute Report.

Macario, R., 2007. Energy transitions in transportation: is it a technology or a policy-driven process. In: Sheffield, J.W., Sheffield, C. (Eds.), Assessment of Hydrogen Energy for Sustainable Development. Springer, Dordrecht, pp. 83–96.

Madsen, A.N., Andersen, P.D., 2009. Innovative regions and industrial clusters in hydrogen and fuel cell technology. Energy Policy, this issue, doi:10.1016/j.enpol.2009.03.040.

Martinot, E., Carmen, D., Weiland, L., Qimin, C., 2007. Renewable energy futures: targets, scenarios, and pathways, Annual Review of Environment and Resources, 32, 169–203.
Mc Kinsey, Ecofys, 2005. Review of EU emissions trading scheme, Survey Highlights, 2005.
Metcalfe, J.S., 2003. Equilibrium and evolutionary foundations of competition and technology policy: new perspective on the division of labour and the innovation process. In: Pelikan, P., Wegner, G. (Eds.), The Evolutionary Analysis of Economic Policy. Edward Elgar, Cheltenham/Northampton, pp. 162–190.
Mönter, M., Doran, P., 2007. Financing and business development for hydrogen communities, Deliverable D7.2 of Roads2HyCom.
New Energy World IG, EC, 2008. Press communication: Developing New Energy for the Future: Europe Launches a 1 Billion Euro Project to get into Pole Position for the Fuel cells and Hydrogen Race, Brussels, 14 October 2008.
Norberg-Bohm, V., 2000. Creating incentives for environmentally enhancing technological change: lessons from 30 years of US energy technology policy. Technological Forecasting and Social Change 65 (2), 125–148.
OECD, 2006. The Political Economy of Environmentally Related Taxes, Paris.
OECD/IEA, 2007. Energy Use in the New Millenium—Trends in IEA Countries, Paris.
OECD/IEA, 2008. World Energy Outlook 2008, Paris.
Patterson, J., 2008. A map of hydrogen and fuel cell research and technology development activity in Europe. Deliverable 1.1 of Roads2HyCom.
Patzek, T.W., 2007. A first thermodynamic analysis of the corn ethanol cycle. Natural Resources Research 4, 255–270.
Pelkmans, J., 2006. European Integration: Methods and Economic Analysis, Third ed. Pearson Education, Harlow.
Pelkmans, J., 2007. How social is European integration? Bruges European Economic Policy Briefings, 18.
Roads2HyCom, 2008. State of the Art analysis of hydrogen and fuel cell technology, infrastructure and communities, Roads2HyCom Hydrogen and Fuel Cell WIKI, available at 〈http://www.ika.rwth-aachen.de/r2h/index.php/Main_Page〉 last accessed on 16 July 2008.
Rodríguez-Pose, A., Crescenzi, R., 2007. R&D, Spillovers, Innovation Systems and the Genesis of Regional Growth in Europe, Bruges European Economic Research Papers, 5.
Ros, M.E., Weeda, M., Jeeninga, H., 2007. Snapshots of hydrogen uptake in the future—a comparison study, Roads2HyCom.
Steinberger-Wilckens, R., Trümper, S., 2007. Hydrogen infrastructure atlas a nd industrial excess hydrogen analysis, Deliverable 2.1 and 2.1a of Roads2HyCom.
Steinberger-Wilckens, R., Trümper, S., Nygaard Madsen, A., Nøgaard, P., 2008. Potential of emerging and future CO_2-neutral hydrogen sources on the European scale, Deliverable 2.2 of Roads2HyCom.
Tichy, G., 2008. Politik, organisation und diffusion statt illusionen. Technologiesprünge als Lösung des energieproblems? Wissenschaft & Umwelt Interdisziplinär 11, 22–30.
Unruh, Gregory C., Carrillo-Hermosilla, Javier, 2006. Globalizing carbon lock-in. Energy Policy 34, 1185–1197.
Walker, W., 2000. Entrapment in large technological systems. Institutional commitment and power relations. Research Policy 29, 833–846.
Wietschel, M., Hasenauer, U., de Groot, A., 2006. Development of European hydrogen infrastructure scenarios—CO_2 reduction potential and infrastructure investment. Energy Policy 34, 1284–1298.
Wyman, O., 2008. 2015 car innovation. Innovationsmanagement in der Automobilindustrie, MMC.