CLIMATE CHANGE AND ENVIRONMENTAL POLICIES IN THE EUROPEAN ELECTRICITY SECTOR

Giulio Federico[1]

Abstract: One of the greatest challenges faced by the European electricity sector at present, and the foreseeable future, is the need to meet stringent environmental objectives designed to mitigate the risk of costly climate change. This article surveys the main elements of the economics of climate change, with specific attention on the European power sector. It also reviews current and announced European environmental policies in the electricity sector. In order to meet environmental objectives in the most-cost efficient way, this article suggests that greater emphasis should be placed on the carbon pricing and trading and on the technology-neutral promotion of low-carbon sources of power, and less on separate renewable electricity targets.

---

[1] Public-Private Sector Research Center, IESE Business School; and Charles River Associates. This article is based on an update of Chapters 7 and 8 of G. Federico (2010). I received helpful comments on the material in this article from Daniele Agostini, Juan José Alba Rios, Natalia Fabra, José Luis Moraga, Ignacio Pérez Arriaga, Xavier Vives and Nils-Henrik von der Fehr. I also thank Luisa Fernanda Gutiérrez for excellent research assistance. I am grateful for support from the Spanish Ministry of Science and Innovation under project ECO2008-05155 at the Public-Private Sector Research Center at IESE.

1. INTRODUCTION

The need to mitigate the risks associated with climate change is arguably the greatest policy challenge faced by the European energy sector at present. The European Union has committed to fairly ambitious environmental targets for 2020 (especially in terms of renewable deployment), which are expected to need to be even more stringent for the period beyond 2020. These targets are likely to require, over time, a profound transformation of the power sector in particular, with significant and continued growth of renewable energy and the need to consider and promote alternative sources of low-carbon generation (most notably, nuclear power and thermal plants based on carbon capture and storage (CCS)[2]).

Whilst over the past two decades the main imperative pursued by E.U. energy policy has been arguably the drive towards more competition in the wholesale and retail energy markets, the next decades are likely to be dominated instead by the need to design and implement effective policies to tackle climate change.

This article surveys the main environmental issues that are currently facing the European energy sector, with a particular focus on the power sector, and their policy implications. The emphasis on the electricity sector is justified by the fact that it accounts for a large share of total greenhouse gas (GHG) emissions at present and because it has significant decarbonisation potential due to the possibility of large-scale deployment of low-carbon technologies. The power industry is therefore set to acquire a critical role in the process of reducing GHG emissions in other sectors as well (e.g. transport and residential heating).

The article starts by reviewing the basic economics of climate change, both in terms of the potential costs and benefit of action to address global warming, and of the optimal design of policies aimed at limiting the stock of carbon emissions in the atmosphere. It then reviews the design and performance of E.U. environmental policy in the power sector to date. Finally, in the final section, the article discusses some of the key policy challenges associated with environmental policy in the European and energy sectors over the medium term, given the current policy objective of drastically curtailing carbon emissions by 2050.

---

[2] CCS technology allows thermal plants (both coal- and gas-fired) to capture, transport and store underground most of their CO_2 emissions, thus reducing their emission rate into the atmosphere by roughly 80%.

2. THE ECONOMICS OF CLIMATE CHANGE

The economics of climate change and related policies is complex. This is due to the interactions between the predictions of climate change science, the presence of multiple market failures associated with carbon emissions and low-carbon technologies, and the structural complexities of energy markets (most notably in the power sector).

The review of the fundamental economics of climate change presented in this first substantive section focuses in turn on:

i. The scientific evidence on global warming and the implications for the cost-benefit analysis of action towards climate change.
ii. The main market failures associated with climate change and the required policies to address such failures.
iii. The implications for the power sector of a greater share of low-carbon generation (most notably renewable).
iv. The interaction between environmental policies and other key energy policies pursued in Europe (i.e. energy security, and more effective regulation and competition).

2.1. Climate change and the timing of reductions in greenhouse gas emissions

There is currently a fairly widespread consensus among European policymakers on the need to decisively reduce GHG emissions[3] over the next couple of decades in order to prevent the risk of excessive global warming. This is reflected in current E.U. environmental policy (reviewed below). It is also testified more broadly by the outcome of the Copenhagen meeting on climate change of December 2009 (i.e. the Copenhagen Accord), where world leaders agreed on the need for deep cuts in global emissions so as to hold the increase in global temperature below 2 degrees Celsius (even though they failed to agree on precise commitments to reduce emissions).

The current scientific evidence, as summarised in the Intergovernmental Panel on Climate Change (IPCC) of 2007[4], is that the global stock of GHG needs to stabilise at roughly 445-490 parts per million (ppm) of CO_2-equivalent (CO_2-eq.) in order to contain the increase in global mean temperatures above pre-industrial levels to 2-2.4 degrees Celsius. The IPCC

---

[3] Given that most GHG emissions are due to CO_2 emissions, the terms GHG and CO_2 (or carbon) emissions are used interchangeably in this article.

[4] We consider the summarised analysis in the IPCC 2007 report to be the starting point of our review in terms of the factual evidence on climate change.

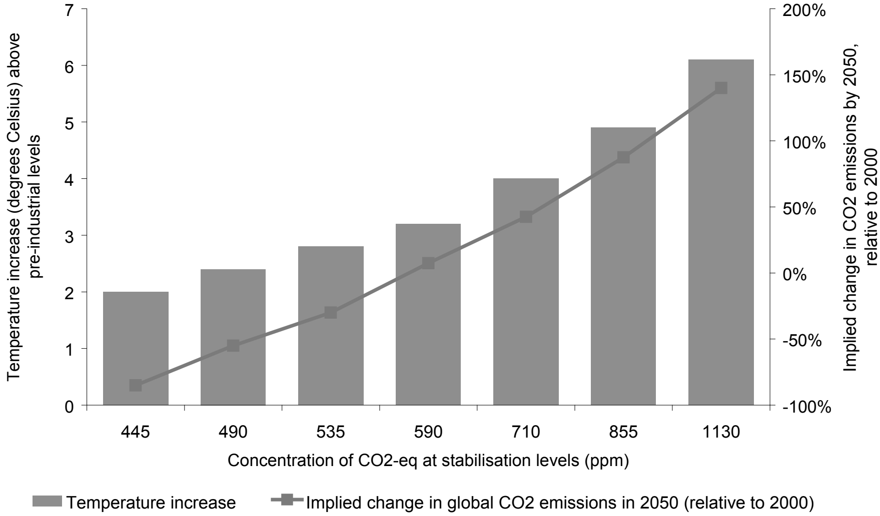
also reports that the global stock of CO_2-eq. stood at 375 ppm in 2005, well above pre-industrial levels as a result of human activities.

Temperature increases in excess of the 2-2.4 degrees Celsius range reported by the IPCC are likely to be associated with dangerous and costly global warming. Under a business-as-usual (BAU) scenario, the stock of emissions will reach a level of 1,000 ppm during the next century according to the IEA (2009), thus implying a global temperature rise of up to 6 degrees Celsius with potentially very damaging consequences for human activity.

2.1.1. *Implications for GHG Emission Profiles*

Stabilising the stock of emissions at 445-490 ppm of CO_2-eq. requires global emissions to peak by around 2015 and to be reduced by 50% to 85% by 2050, relative to 2000 levels, according to the estimates contained in IPCC, 2007. If emissions are stabilised at 450 ppm there is approximately a 50% chance that temperatures will not increase above the threshold of 2 degrees Celsius (DECC,2009a). Less incisive action on GHG emission would be associated with significantly higher temperature increases according to the IPCC estimates, as shown in Figure 1 below.

FIGURE 1: **Relationship between CO_2-eq. concentration levels, temperature increase and 2050 emission levels**



Source: IPCC (2007).

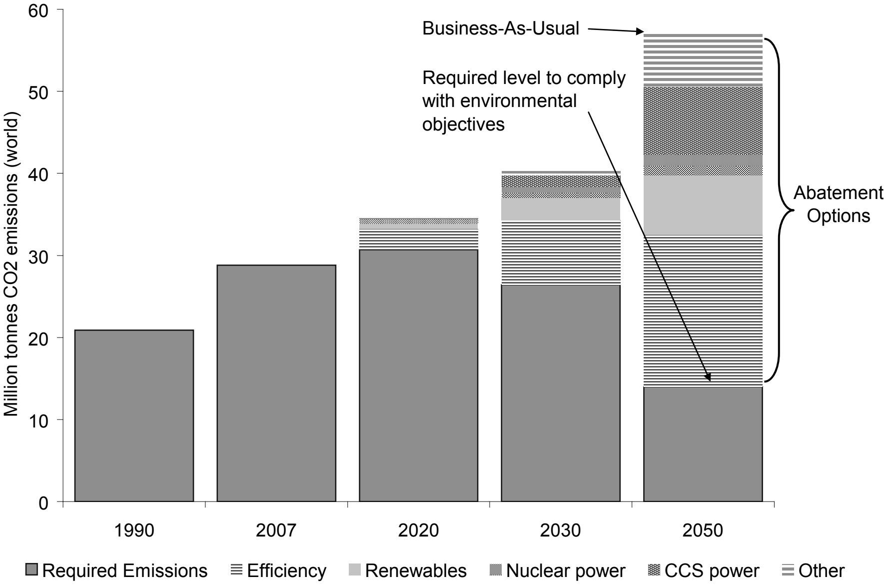
More recent calculations presented by McKinsey,2009 show that by 2030 global GHG emissions could fall by 35% compared to 1990 (if appropriate policies are implemented) and that this reduction could make it reasonably possible to contain the increase in temperature within the threshold of 2 degrees Celsius. McKinsey, 2009 also reports that a delay in taking abatement actions (e.g. until the next decade) would make it practically impossible to prevent global warming in excess of 2 degrees Celsius.

Similarly, the IEA,2010a argues that the decade between 2010 and 2020 is critical in order to achieve the required reduction of at least 50% of global emissions by 2050. For this to be feasible, global emissions need to peak by 2020 and decline steadily thereafter. Attempting this reduction later in time would need much sharper reductions in the flow of CO_2 emissions and significantly higher costs.

For Europe, the required reductions in energy-related CO_2 emissions are even sharper than for the world as a whole. In the scenario developed by the IEA (2010c) to stabilise the concentration of GHG at 450 ppm of CO2-eq., Europe's energy CO_2 emissions are required to fall by just over 20% by 2020 (relative to 1990), and by 45-55% by 2030/2035. The corresponding reductions in the power sector are sharper still, with the share of the electricity industry in total energy emissions more than halving between 2007 (when it stood at 37%) and 2030/2035 (when the corresponding share is required to be cut to 13-18%). This implies that emissions in the European power sector would need to fall by over 70% by 2030, and more than 80% by 2035 (relative to 1990).

IEA projections indicate that a broad range of technologies will be needed to achieve the required reduction in emissions relative to a BAU scenario (see Figure 2). Over the next decade (by 2020), global abatement efforts can be fairly moderate and mainly focused on energy-efficiency measures (accounting for two thirds of required reductions), with a significant contribution also from renewable and nuclear power (30% of abatement in total). By 2030 and 2050 the role played by CCS generation is projected to have to increase considerably (accounting for almost 20% of abatement efforts by 2050, relative to 3% only by 2020), with renewable and nuclear power combined still playing a significant role (close to ¼ of the overall carbon reduction by 2050). By 2050 efficiency and end-use fuel switching measures are forecast to account for almost 60% of abatement measures. By that year, total emission-reduction efforts would need to cut emissions by three quarters relative to a BAU scenario. These projections also imply that the cost of meeting environmental targets would increase substantially if only some technologies are relied upon to cut emissions.[5]

FIGURE 2: **Global CO_2 emissions and distribution of abatement efforts by modality**



Source: IEA (2009) and IEA (2010a).

2.1.2. *The costs and benefits of action on climate change*

The Stern Review commissioned by the U.K. government in 2006 was tasked with reviewing the economics of climate change (Stern, 2007). The Review focused its analysis on scenarios where GHG stabilised in the range of 450-550 ppm of CO_2-eq. (slightly above those considered by the IPPC as compatible with an excessive increase in global warming).

The Stern Review estimated that the annual costs of stabilising emissions at 500-550 ppm would be around 1% of annual GDP by 2050 (on average),

---

[5] Macroeconomic simulations performed in the United Kingdom indicate that the total cost of achieving an 80% reduction in emissions by 2050 would almost double if only renewable generation were used to dercarbonise the power sector versus an alternative policy of using nuclear and CCS technologies as well (see DECC (2009b)).

and found this level to be significant but "fully consistent with continued growth and development, in contrast with unabated climate change, which will eventually pose significant threats to growth" (Executive Summary, p. 13).[6]

The European Commission's impact assessment of its climate change package of 2007 (which is described in the next section of this article) shows that investment in a low-carbon economy would cost 0.5% of total global GDP during the 2013-2030 period, thereby implying a reduction in global growth of roughly 0.2% per year up to 2020.[7] The IPCC 2007 report indicates a slightly lower reduction in annual growth rates by 2030 and 2050 (less than 0.12 percentage points) in order to stabilise GHG in the 445-535 ppm range. By contrast, the Stern Review computed that the cost of inaction on climate change would be on the order of 5%-20% of annual global GDP (on average in the future). These computations justified the Review's conclusion that the "benefits of strong early action [on climate change] considerably outweigh the costs".

Stern's conclusions for early action on climate change are partially based on a consumption smoothing argument: it is better to suffer a constant small loss in consumption, rather than delay action and incur a much larger loss in the future. As noted by some economists (e.g. Nordhaus, 2007 and Weitzman, 2007), this argument supports the conclusion in the Stern Review if one weighs future consumption almost the same as current consumption, by assuming a fairly low social discount rate. Using higher rates weakens the case for early action. On the other hand, both Stern and Weitzman note that there is a risk that the consequence of global warming will be much worse than expected, with potentially catastrophic consequences. Climate change policy arguably should also seek to reduce the likelihood of this risk by effectively representing insurance against the possibility of very significant consumption losses (see, in particular, Weitzman, 2010). The uncertainty associated with the costs of climate change can therefore actually strengthen the case for early action to curb GHG emissions and provide support to current E.U. policy on this issue (provided that other countries also reduce their emissions so as to meet global environmental objectives).

---

[6] More recent estimates contained in DECC, 2009b indicate a cost of 3% of global GDP by 2050 for a trajectory towards stabilisation at 450 ppm CO_2-eq.

[7] See European Commission, 2007.

2.2. Economic mechanisms for reducing carbon emissions

The scientific evidence and economic arguments reviewed above provide support for a policy aimed at curtailing carbon emissions rapidly over the 2020-2050 period in order to prevent an excessive increase in global temperatures. A separate policy question is *how* to optimally achieve the required reduction in GHG emissions. This question should be guided by the overall objective of minimising the cost of reducing carbon emissions. Cost-minimisation calls for the adoption of a set of policies that directly address the market failures associated with climate change and only intervene where market failures are present. It also suggests the need to design a technology- and sector-neutral approach to carbon abatement, implying that carbon reduction should take place in those sectors that have the lowest cost of reducing emissions, and that technologies should also be used that minimise abatement costs (over time).

2.2.1. *Carbon Pricing*

The fundamental market failure to be addressed by climate change policy is the externality associated with GHG emissions. This externality relates to the fact that emitters of GHG do not face the full social costs of emissions, which include their adverse impact on the environment (as measured by the risk of global warming associated with GHG emissions).

This market failure can be addressed by putting a price on GHG emissions to be borne by emitters or consumers. Standard economic theory indicates that this price should be set equal to the incremental cost of carbon abatement (so as to induce emitters to abate). The optimal amount of abatement to be targeted via carbon pricing is given by equalising the social marginal benefit of abatement (which is equivalent to the social damage from emissions) with its marginal cost.

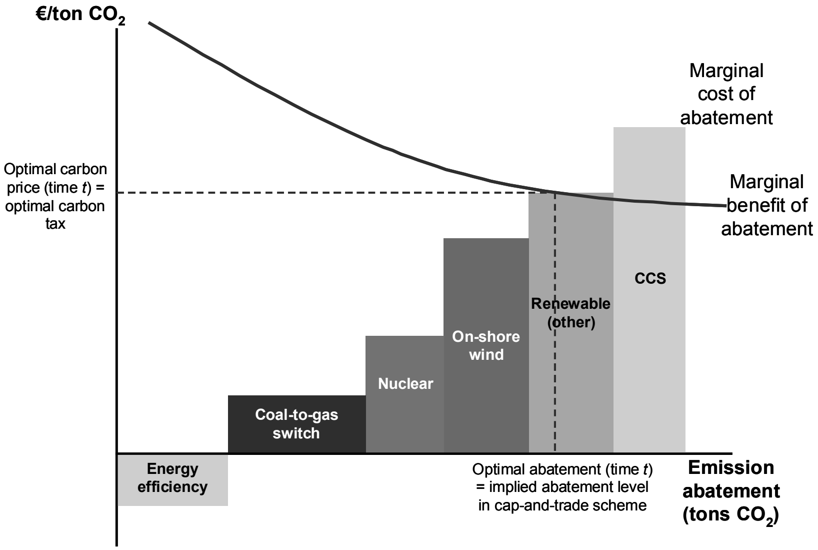
Figure 3 summarises the concept of optimal carbon pricing by showing a hypothetical "merit order" (or abatement cost curve) for emission abatement relative to a BAU counterfactual for the power sector only. This schedule stacks in increasing order each potential source of emission reductions starting from the lowest-cost options (in terms of € per tonne of avoided emission) to the more expensive ones. Abatement options are costed on the basis of their long-run incremental costs (which include the capital costs of deployment).

In the hypothetical example shown in Figure 3 (which is loosely based on McKinsey's review of carbon abatement economics for the power sector

(McKinsey,2009[8]), the cheapest forms of abatement are energy efficiency efforts (which would be privately profitable even in the absence of carbon pricing), followed by switching existing electricity output from coal plants to less polluting gas-fired plants, new nuclear capacity, on-shore wind capacity, other types of renewable energy and CCS.

In the hypothetical example, in a given time period *t*, it is optimal to invest in all carbon-abatement options except CCS in order to reduce carbon emissions. The optimal carbon price would be set at the cost of the most expensive abatement option required, which in the example considered here is represented by renewable sources other than on-shore wind. The corresponding optimal carbon price will be reflected in electricity prices during hours when thermal power stations are price-setting, thus increasing the profitability of carbon-free baseload generators (e.g. nuclear and renewable), making them more competitive and stimulating entry (assuming that the latter is feasible).

FIGURE 3: **Illustration of hypothetical abatement cost curve for the power sector and optimal carbon price**



---

[8] McKinsey,2009 shows that by 2030 the merit order of the main carbon-abatement options relative to BAU in the power sector will include (in increasing cost order): demand reduction, nuclear power, low-penetration wind, solar CPS and PV, and CCS (applied to both gas and coal).

Carbon pricing can be achieved using two basic mechanisms: a *cap-and-trade* (or quota) system; or a *carbon tax*.

- ***Cap-and-trade***. Under cap-and-trade, a binding cap on emissions is set in any given period (or across multiple periods) and emission permits are allocated to emitters (either through an auction or via alternative mechanisms such as grandfathering) that allow them to subsequently trade with each other. Trading of permits between emitters will establish a price for carbon emissions that will in equilibrium equal the marginal cost of abatement at the emission quota.

  Trading will also allow abatement to take place where it is most efficient, e.g. more emission-intensive producers (e.g. coal-generators) will face incentives to sell their permits to less emitting technologies (e.g. gas-fired generators), assuming that the emission cap binds. This is because less emitting generators are able to produce more electricity output for a given number of emission permits and a given level of relative fuel prices. They will therefore place a higher value on the permits than technologies with higher emission rates. This outcome can be achieved independently of whether permits are grandfathered or auctioned.[9]

  Trading of emission permits also allows for an optimal distribution of abatement efforts across sectors and countries, as long as the cap-and-trade scheme includes multiple sectors and countries.

- ***A carbon tax***. The alternative to a cap-and-trade system is a carbon tax, which directly sets the price of carbon. Emitters will take this tax into account in their pricing and output decisions. This will in turn discourage production from high carbon-emitters (e.g. coal plants) to the benefit of less emitting technologies and carbon-free sources. The abatement levels achieved with a carbon tax will equal the point where the tax crosses the marginal cost of abatement schedule, as illustrated in Figure 3.

If the positions of the marginal cost and benefit schedule are certain, then a carbon tax is equivalent to a cap-and-trade system in that both can achieve the optimal abatement effort. If there is uncertainty on the positions of the

---

[9] In an auction-based system, emission-intensive producers will not be able to afford to purchase emission permits at the price established in the auction, given their higher emission rates relative to cleaner producers. This will generate the same outcome of a situation where permits are grandfathered and trading subsequently takes place.

schedules, then the two systems are no longer equivalent. Economic theory (e.g. Weitzman, 1974) suggests in this case that if the marginal benefit of abatement is steep (relative to the marginal cost schedule), then a cap-and-trade system is superior to a carbon tax. Alternatively, if the marginal benefit schedule is flat (relative to marginal cost), a carbon tax is preferable. This economic result derives from the fact that, under conditions of uncertainty, the socially optimal outcome is unlikely to be achieved. However, the efficiency loss resulting from deviating from the optimal carbon price will be reduced by using a carbon tax (rather than a cap-and-trade mechanism) if the marginal cost schedule is steeper than the marginal benefit schedule. The reverse result holds with a steep marginal benefit schedule relative to marginal costs.

Some economists (e.g. Green, 2008 and Newbery, 2010a) have argued that in any given time period the marginal benefit of abatement is fairly flat, since the flow of emissions in a time period has a limited effect on the stock of emissions (which in turn determines global warming). This would support the use of a carbon tax over a quota-based system.

On the other hand, a cap-and-trade system can target emission reductions directly with lower informational requirements (Tirole, 2010). It also has several political economy advantages over carbon taxes (e.g. the ability to compensate emitters if necessary and to publicly commit to a given medium-term emission target). Over a long period of time, the design of both a carbon tax and a cap-and-trade system can be adjusted as more information on the costs and benefits of abatement become available, meaning that in practice the difference between the two systems in terms of their final outcomes may not be that great.

The other potential disadvantage of a cap-and-trade system over a carbon tax is that it can lead to fluctuations in the carbon price, making investments in long-lived low-carbon assets riskier (Baldursson & von der Fehr, 2004). Because of this feature, policy makers in the UK are advocating for a floor to be established on carbon prices for some technologies.[10] The aim of this measure would be to reduce the risk associated with long-lived investments

---

[10] See in particular, the UK Treasury in its Energy Market Assessment of March 2010 (U.K. Treasury, 2010a), and in its consultation document on the carbon price floor (U.K. Treasury, 2010b); the Committee on Climate Change in its June 2010 report (CCC, 2010); and the consultation document of the Department of Energy and Climate Change, on Electricity Market Reform (DECC,2010).

in low-carbon generation (e.g. nuclear and CCS), whilst preserving some of the benefits of a cap-and-trade system.

Current prices under the European carbon trading scheme are well below €20/tonne CO_2, as reviewed below. The U.K.'s Committee for Climate Change estimated that the carbon price in 2020 will be between €25 and €40/tonne, given the current European emission targets (CCC (2010)). Whilst there is uncertainty on the levels of carbon prices necessary to stimulate low-carbon investment, both current carbon prices and the forecast for 2020 are likely to be below the required levels.

For example, the IEA projects that carbon prices in OECD countries would need to reach levels of USD 50/tonne CO_2 by 2020 and USD 110/tonne CO_2 by 2030 to allow for the required abatement efforts (including investment in new nuclear, renewables, and CCS); see IEA (2009). Carbon pricing at these levels would make onshore wind and nuclear more competitive than fossil-fuel generation (CCGTs and coal) by 2020, and would also make CCS more competitive by 2030. At lower carbon prices (e.g. USD 30/tonne CO_2), nuclear power is not commercially attractive relative to coal and gas-fired generation (using a return on capital of 10%) (IEA (2010b)).

Alternative modelling of cost-abatement options contained in McKinsey (2009) also indicates that carbon prices need to be significantly higher than current levels for new-build in coal CCS to be commercially feasible (in the range of €70 to €80/tonne CO_2 by 2015 and €30 to €45/tonne CO_2 by 2030, as a result of lower assumed capital costs for CCS plants due to assumed learning effects). To reach overall carbon-abatement targets (i.e. a worldwide reduction of 35% to 40% relative to 1990 by 2030), a global carbon price of just short of €60/tonne CO_2 would be necessary (also allowing for coal and gas CCS retrofit).

2.2.2. *Technology policy and renewable support*

If the only market failure associated with climate change were the fact that GHG emitters do not internalise the social cost of emissions, then establishing a single carbon price would be sufficient to achieve the socially optimal outcome (with no uncertainty on the costs and benefits of abatement, as noted above). In particular, no specific support for some types of low-carbon technologies such as renewable energy would be required. If renewable sources were needed to efficiently achieve a given abatement level, then the carbon price would increase sufficiently so as to make renewable generators competitive relative to fossil-fuel technologies (as in the cost of abatement curve shown in Figure 3).

Establishing a carbon price would in fact represent a technology-neutral form of achieving carbon abatement without favouring some options (e.g. renewable) at the expense of others (e.g. nuclear and CCS). Indeed, a specific support policy towards renewable energy (or any other form of low-carbon generation) damages the profitability of other forms of low-carbon investment by reducing the carbon price relative to a counterfactual with no support (assuming a fixed emissions target). The reduction in carbon prices is due to the fact that renewable support increases the supply of carbon-free energy for any given level of carbon prices (see Aldy & Pizer, 2009).

However, there may be additional market failures associated with immature forms of low-carbon technologies that warrant specific and complementary support measures. In particular, innovation in low-carbon sources by a given investor may generate spillover effects on other investors which imply that the original innovator cannot fully appropriate the return from the investment.[11] This spillover (or lack of full appropriability) would discourage the optimal level of R&D and/or deployment in the absence of government support (see, e.g., Hanemann, 2009). Moreover, some immature technologies (e.g. solar PV) display quite strong learning rates associated with R&D and/or deployment.[12] If investors cannot fully appropriate these learning effects, again, the optimal level of investment and deployment will not be achieved.

Technology policies in favour of renewable generation can therefore be used to complement the beneficial effects of carbon prices, thus providing an additional incentive for deployment. These policies can take the form of subsidies for R&D and/or deployment. Alternatively, forms of cooperation in renewable R&D between market operators could be encouraged (as long as the risk of collusion in the product market can be mitigated).

A dual environmental policy is required, given that there are two separate market failures to deal with: the direct environmental one and the innovation one. The optimal policy therefore requires a combination of both carbon

---

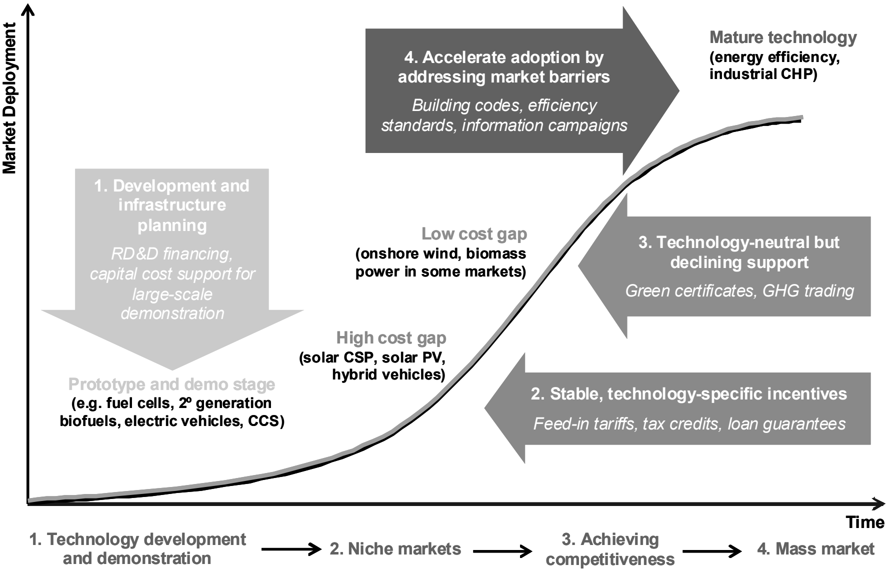
[11] As noted in the Stern Review, "the knowledge gained from R&D is a public good; companies may under-invest in projects with a big social payoff if they fear they will be unable to capture the full benefits. Thus there are good economic reasons to promote new technology directly" (Stern, 2007, Executive Summary).

[12] IEA, 2008 uses learning rates of 7% for onshore wind, 9% for offshore wind, 10% for concentrated solar power (CSP) and 18% for solar PV, based on input from technology experts. McKinsey, 2009 uses similar learning rates for renewable electricity.

pricing and technology policies. As formally shown by Acemoglu *et al.*, 2009 and discussed in Aghion *et al.*,2009, using carbon prices alone will not be efficient and will raise the cost of action on climate change.

The presence of technology spillovers can, in principle, justify the adoption of both 'push' (i.e. R&D support) and 'pull' (i.e. deployment subsidies) policies in favour of some types of low-carbon production, such as immature renewable generation and CCS. Ultimately, when low-carbon technologies are more mature, carbon pricing may be sufficient to encourage the entry of low-carbon sources and a more technology-neutral policy can be adopted. Figure 4, from IEA (2010a), summarises the type of policies for supporting low-carbon technologies as a function of the market deployment and maturity of each technology.

FIGURE 4: **Policies for supporting renewable technologies**



Source: IEA (2010a).

In the absence of a precise quantification of the size and sources of the spillover effects, it is, however, hard to establish the optimal split between push and pull policies, and the socially desirable target for renewable deployment overall.[13] The European Commission has committed to demanding renewable targets by 2020 (on top of a commitment to reduce carbon emissions). It is not clear, however, that technology spillover effects on their own can justify the level of these deployment targets (relative to the renewable deployment levels that would be achieved using carbon pricing alone).[14] As Newbery, 2010b argues, the required calculations for establishing the optimal level of renewable support are hard and the country-specific targets set by the Commission may be interpreted instead as a way of "avoiding the question, encouraging solidarity and ensuring fair and equitable burden sharing" (p. 3132).

The design of renewable support mechanisms

An additional question in the design of renewable electricity support schemes relates to the issue of which mechanism to adopt to provide effective deployment subsidies. The main dichotomy that has emerged in European practice on this issue is one between tradable quotas (or green certificates) and feed-in tariffs.

Under the first mechanism, a quota is set on renewable energy as a percentage of electricity supplied. Suppliers are obliged to meet this quota by purchasing green certificates from renewable electricity generators. Renewable producers therefore receive the price of the green certificate in addition to the wholesale electricity price, thus encouraging their deployment. "Banding" (i.e. the allocation of higher amounts of green certificates for any unit of output by a specific technology) can be used to encourage the deployment of more expensive sources of renewable generation (e.g. solar PV). A positive feature of a tradable green certificate scheme is that it is market-based, and can avoid over-compensating renewable generation. A drawback is that it may lead to volatile prices for green certificates over time (as the cost of competing renewable technologies evolves). It may not also favour the adoption of immature technologies unless appropriate banding is implemented.

Under an alternative feed-in-tariff mechanism, a fixed price is set administratively for each renewable technology for a given time period. This price lies above the expected electricity wholesale price in order to encourage

---

[13] Frontier Economics, 2009 finds that well-designed supply-push policies (e.g. R&D support) can lead to greater marginal impact on innovation than demand-pull policies.

[14] For a general discussion of this issue, see Tirole, 2008.

of entry of renewable generators. The feed-in tariff can be established irrespective of the price of electricity or be set as a premium on top of the electricity price. In the case of a feed-in premium, minimum and maximum levels for the overall compensation received can also be established, as is the case in Spain at present for some renewable technologies. The main benefit of feed-in tariffs over market-based mechanism is that they can provide greater investor certainty during the life of the investment. However, they carry the risk of over-compensating producers of renewable electricity if there is significant uncertainty on the cost of renewable generation and on learning effects over time (as the Spanish experience with solar subsidies discussed in Federico, 2010 demonstrates).

A hybrid mechanism between green certificates and feed-in tariffs is represented by renewable capacity tenders. Under this system, periodic tenders for renewable generation (potentially differentiating between technologies) can be organised in order to set the level of the fixed tariff (or market premium above wholesale prices) that is required to meet a particular renewable generation target for that period. The fixed tariff could apply for a long time period (e.g. 25 years). If a premium over the market price is established, this could be indexed to the carbon and/or electricity price in order to reduce market risk and the possibility of under- or over-compensating renewable generators. There is, however, limited international experience of successful auctions for renewable capacity. Rules would need to be carefully designed to ensure that investors deliver on the renewable capacity commitments agreed upon as part of these auctions and that participation costs are not too burdensome for smaller investors.

Table 1 summarises the advantages and disadvantages associated with green certificates and feed-in tariffs according to a December 2008 review by the Council of European Energy Regulators (CEER, 2008). An additional high-level difference between the two systems (not included in the CEER table) is that a green certificate system can provide more certainty that a given renewable objective will be met (provided that prices are allowed to reach their equilibrium levels), whilst a feed-in mechanism gives more certainty on the cost of a renewable support scheme (as long as adequate quantity limits are in place).

TABLE 1: **Advantages and disadvantages of renewable support schemes according to CEER analysis**

	Advantage	Disadvantage
Quota obligation with tradeable green certificate	• Flexible and market-oriented; • Initiate technological developments and innovation; • Often more political acceptance; and • Easy to enlarge to other countries.	• Higher insecurity for investors; • Volatile certificate prices; and • High transaction; and monitoring costs.
Feed-in tariff	• Very effective in increasing renewable energy; • Few regulatory and administrative costs; • Stable basic conditions; and • High investor certainty and planning reliability.	• Non-cost efficient; • Difficult to set correct fixed price or premium; and • Non-market oriented. However premiums are more so compared to fixed tariffs.

Source: CEER (2008).

Additional potential reasons to support renewable generation

There are other potential market imperfections associated with investment in renewable generation that may justify deployment support policies. These include security of supply issues and capital market imperfections.[15]

The first relates partially to the fact that renewable energy is a domestic source of energy and can therefore reduce dependence on foreign (and potentially unstable) sources of supply.[16] Given the public good features of security of supply, this consideration may provide further justification for

---

[15] Additional considerations which do not relate to energy-related market failures include the potential benefits associated with industrial policy and employment generation. These benefits should also be assessed in comparison with other competing uses of public funds.

[16] Additional security of supply considerations (relative to alternative forms of low-carbon generation, like CCS and nuclear) are that renewable sources can represent a long-term solution of energy consumption needs (unlike CCS, which requires sufficient carbon storage capacity over the medium to long term) and do not pose the type of safety and waste-management concerns associated with nuclear power.

a renewable support scheme (as an indirect way of limiting imports from potentially unstable suppliers).

On the other hand, the incremental security of supply benefit of renewable resources needs to be properly assessed relative to other forms of low-carbon generation which renewable energy may be crowding out over time (by lowering the carbon price). In particular, given that nuclear generation and coal-based CCS do not raise significant issues of external dependence (as both uranium and coal are easily available from a range of politically stable countries), the incremental security of supply benefits associated with renewable generation may be limited. In the short-term, however, renewable deployment may reduce dependence on foreign gas suppliers, which may improve external security of supply (especially if sufficient levels of domestic gas and electricity flexibility are available to mitigate the impact of the intermittency of renewable generation).

The second type of market imperfection relates to the riskiness of investment in low-carbon generation in the absence of a specific support scheme. Investments in low-carbon sources are particularly risky, since they are typically projects with high fixed costs and low variable costs, and whose market revenues are volatile due to fluctuations in input prices for thermal generators (i.e. oil, gas, coal and carbon). These investments lack the 'natural hedge' associated with thermal generators, whose marginal costs are correlated with electricity prices. Capital markets may therefore be unwilling to finance investments in low-carbon generation and prefer instead to fund more conventional generation projects. This may not represent a market failure as such, but it suggests that, in the short-term, markets may fail to deliver the levels of investments in low-carbon generation that are needed to achieve large reductions in emissions over the medium to long term. These considerations support the case for a floor on carbon prices (to apply to all investments in low-carbon technologies) or for long-term contracts (e.g. feed-in tariffs).

2.2.3. *International public good considerations*

A third aspect of the market failures associated with climate change relates to the fact that GHG emission abatement is also an international public good. This means that if a country reduces its emissions, this benefits other countries too by reducing the risk of global warming. This can create standard free-riding incentives between countries in the absence of an international decision-making mechanism and the risk of the under-provision of global abatement efforts relative to the optimal level. Similar issues can arise in relation to technology policy, since spillovers from renewable R&D and deployment are likely to arise across borders.

A way to solve these market failures is via international coordination and agreement on both emissions and renewable targets. At European level, this process of target setting and burden sharing by country has been relatively effective in the recent past and has allowed Europe to adopt a relatively stringent set of policies on climate change (reviewed below).

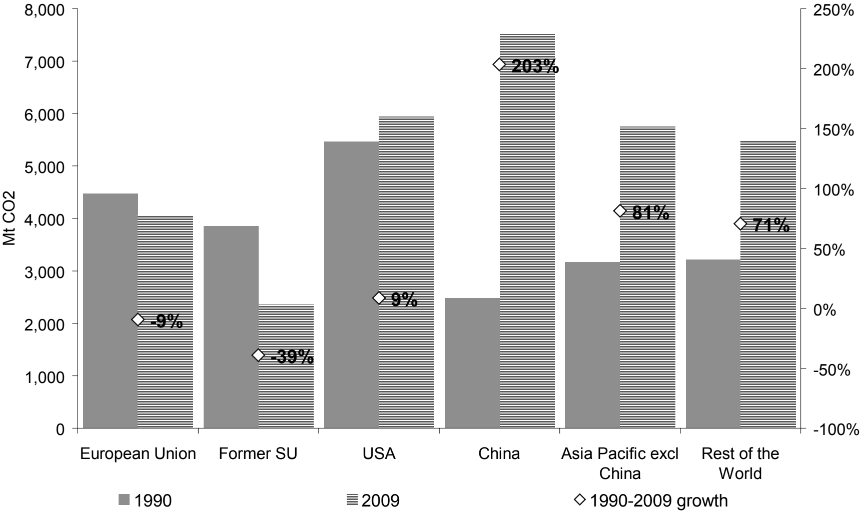
At the broader international level, the process of agreeing on emission cuts has been much more difficult, as shown (for example) by the failure to agree on binding targets at the United Nations summit in late 2009 in Copenhagen. This is partially due to the fact that the fastest growth in carbon emissions has been observed in developing and newly industrialised countries, which face a sharper trade-off between economic growth and decarbonisation than more developed economies.

Figure 5 summarises the overall levels of energy-related CO_2 emissions across the world in 1990 and 2009 and illustrates the fact the China is currently the world largest emitter and that the fastest increase in emissions was observed in developing countries over the 1990-2009 period (with only a moderate increase in the United States and a reduction in Europe). The data also show that the European Union only accounted for a modest share of total GHG emission in 2009 (13%). In the absence of an effective and binding global agreement on GHG reductions, current European efforts in this area will only have a limited impact on climate change and will therefore prove largely ineffective.[17]

---

[17] If the global supply of fossil fuels is sufficiently inelastic, environmental policies in only some "green" countries may also not contribute significantly to reduce total GHG emissions due to price effects on fossil fuels and the resulting higher level of emissions in "non-green" countries (see CESifo, 2008: chapter 5).

FIGURE 5: **International CO_2 emissions**



Note: Emission data include only coal-, oil- and gas-related emissions, and are not comparable to national emission data.

Source: BP Statistical Review of World Energy, 2010.

2.3. The economics of electricity markets in the presence of large amounts of low-carbon generation

Electricity markets have a particularly prominent role in the implementation of environmental policy in the energy sector as a whole. This is partially because power generation is a particularly large emitter of CO_2 in that it accounts for over 40% of global energy-related CO_2 emissions, which is well in excess of any other sector (such as transport and industry). It is also because power generation has greater decarbonisation potential than other sectors, thanks to the potential large-scale deployment of renewable and CCS generation, and the presence of carbon-free sources such as nuclear. The power sector can therefore help decarbonise other industries, most notably transport (e.g. via the adoption of electric cars) and residential heating. The demand for electricity generation is therefore likely to rise as other sectors decarbonise by becoming more electricity-intensive, thereby increasing the importance of environmental policies adopted in the power sector.

Because of these considerations, it is projected that the power sector will need to decarbonise rapidly over the next few decades if climate change goals are to be met. IEA (2010c) projects that, at E.U. level, the carbon intensity of generation needs to fall by more than 70%, from the current level of roughly 410 g CO_2/kWh to less than 110 g CO_2/kWh by 2030.

IEA (2010a) also forecasts that, by 2050, the electricity sector in OECD Europe will need to be almost decarbonised, with more than 50% of generation coming from renewable and most the remainder being sourced by nuclear and CCS. Over the next decade (i.e. by 2020), it is projected that the share of renewable in the European Union will need to increase to between 33% and 40% of total electricity consumption in order to meet the current E.U. target of overall renewable energy (which is set at 20% of final energy consumption).

The significant increase in low-carbon generation required over the short to medium term poses significant challenges for the power sector. This is so for two basic reasons. The first is that some types of low-carbon generation (in particular wind, solar PV and nuclear) have low variable costs and relatively high fixed costs.

An increase in the level of low-carbon and low variable cost capacity will therefore increase the number of hours in the year when this capacity is marginal (or price-setting). As a result, market prices will be very low (e.g. close to 0 and possibly below 0 if, for example, renewable generators actually face a positive opportunity cost from not producing due to the presence of output subsidies).

Thermal generators with positive variable costs will therefore need to recover their fixed investment and operational costs in a lower number of hours, thereby requiring higher prices in these hours. For this to be possible in a competitive market, the effective reserve margin at peak times (i.e. the difference between demand and available supply) will need to become lower over time, thus allowing peak generators to obtain higher margins when they produce. Alternatively, a separate capacity payment mechanism would be required to compensate thermal generators for at least part of their fixed costs.

In the absence of a sufficient capacity payment arrangement[18] (which would stimulate entry), the price duration curves[19] will therefore need to

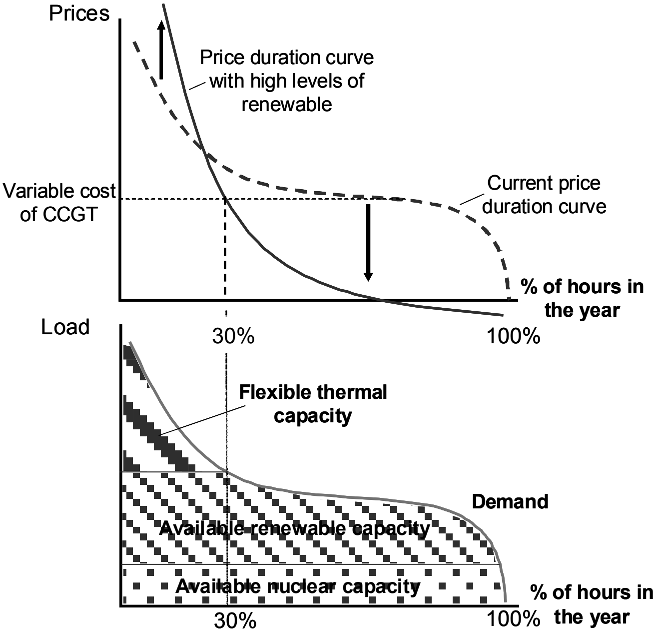
---

[18] This could include direct capacity payments made to generators or long-term reserve contracts procured by the transmission system operator.

[19] Price and load duration curves rank values from the highest (0% duration) to the lowest (100% duration) to describe the hourly profiles of prices/load over a given period (typically one year).

flip relative to current levels and become substantially peakier. As a result, thermal plants with positive variable costs will operate for a lower number of hours of the year. This process is illustrated in Figure 6, which plots a hypothetical price duration curve with higher levels of renewable generation in the top panel (compared to a price duration curve with less renewable capacity) and the corresponding load duration curve in the bottom panel. For simplicity, the figure assumes that flexible thermal generation is provided only by CCGT plants.

FIGURE 6: **Implications of greater amount of renewable generation on electricity prices and load duration curves**



The second reason why higher levels of low-carbon generation put pressure on electricity markets is that the most important and, at present, the most cost-effective component of renewable generation is on-shore wind. Wind is by its nature an intermittent source of generation, meaning that its output is not guaranteed and fluctuates with weather conditions. High levels of wind generation therefore require corresponding amounts of flexible thermal capacity (typically, CCGTs) as back-up generation in order to maintain system security. A system with significant levels of back-up generation may, however, not allow prices to rise sufficiently during peak times, thus reducing the ability of investors in thermal generation to recover their fixed costs and in turn limiting their incentives to enter the market.[20]

Both of these issues are illustrated in simulations performed for the U.K. electricity market. These simulations indicate that in scenarios with significantly higher levels of wind capacity, peak prices in the United Kingdom would more than double by 2020 compared to current levels and could increase more than ten-fold by 2030 (see DECC, 2009b). Newbery, 2010b summarises the findings of a similar simulation for 2020, which indicates that, in order to meet the European renewable target, 56 GW of renewable capacity will be needed in the United Kingdom, as well as a similar amount of non-renewable capacity. The latter would largely operate in back-up mode and achieve a load factor of just over 30% (given a peak demand level of 63 GW). Ofgem, the U.K. regulator, also projects that CCGT load factors will have to fall below 30% by 2025 if renewable targets are to be met, compared to current levels in excess of 60% (Ofgem, 2009).

The overall challenge posed by integrating significantly higher amounts of low-carbon generation into electricity markets is therefore one of guaranteeing system security at the same time as providing the adequate incentives for entry by flexible generation. Investors in flexible thermal generation will need to have sufficient confidence that peak prices will be able to rise significantly during times when renewable output is low and/or demand is high. Given the likely uncertainty over whether future peak prices will be able to reach the required levels and the volatility associated with electricity prices due to the presence of intermittent generation, market forces alone might not be able to deliver the required levels of entry by thermal generation. These considerations exacerbate the 'missing money' problem that has been associated with electricity markets (especially in the presence of binding caps on spot prices) and provide further support for separate arrangements to remunerate capacity to supplement revenues from energy markets.

---

[20] This challenge can be partially addressed by improving the forecasting of intermittent renewable generation, and by more effective interconnection of electricity markets (which can diversify the volume risk associated with renewable power).

Given the complexities involved in determining the required level of incentives for entry by thermal generation, it is, however, unlikely that an administratively set capacity payment would be able to achieve a desirable generation mix and deliver the correct level of back-up flexible generation. A system of capacity tenders or long-term reserve contracts established by the transmission system operator is likely to be a superior system to attract investment in additional thermal capacity when required. Capacity tenders could also be used to encourage entry by low-carbon capacity (including renewable, nuclear and CCS).[21] Demand-side flexibility could also be procured using similar mechanisms.

The difficulty posed by an extensive use of capacity tenders is that the policy makers would be partially pre-determining the 'right' energy mix by specifying the levels of capacity of each technology being procured. This calls for adopting technology-neutral capacity payment mechanisms as far as possible. Moreover, to avoid over- or under-compensating generators (in particular those whose costs are not correlated to electricity prices, such as renewables and nuclear), indexation provisions could be introduced in the capacity payments established through the auctions. For example, these payments could be indexed to the carbon price so that, if the carbon price were to rise in the future, the additional payment from the tender would be reduced (reducing the incidence of windfall profits). Similarly, if the price were to drop, the capacity payment established would increase, thereby insulating the producer from price volatility.

Capacity mechanisms of the type described above would not address the issue of fixed-cost recovery for existing installed capacity. In a context where there is over-capacity of thermal plants, separate arrangements may need to be put in place to allow for the recovery of fixed (but not sunk) operational costs (e.g. fixed gas access charges and O&M costs) to avoid the risk of a premature exit of plants. This could mitigate the need to introduce higher capacity payments for new plants by preserving a sufficient reserve margin.

---

[21] The adoption of capacity tenders for all generation capacity (including low-carbon generation and conventional thermal capacity) is one of the policy options considered by Ofgem, the U.K. regulator, in its review of options for delivering secure and sustainable energy supplies (Ofgem, 2010).

2.4. Interactions with other elements of energy policy

The final element of the economics of climate change reviewed in this section is the relationship between environmental policies in the energy sector and the other two core components of E.U. energy policy: security of supply and competition and liberalisation. The three policies interact in various ways: they are complementary in some respects, and create tradeoffs that need to be resolved in others.[22]

In the recent past, environmental policies and external security of supply have not been entirely mutually compatible due to the fact that gas was the most easily available source of relatively low-carbon generation (compared to coal), but it was largely sourced from external suppliers (e.g. Russia and Algeria). This potential conflict between the two policy objectives is set to diminish over time, given that, in order to meet increasingly ambitious emission targets, gas-fired generation will play a smaller role (at least in terms of overall output) and domestic resources (renewable, and to some extent nuclear) should become more prominent. Moreover, coal-based CCS would help mitigate external security of supply issues, since coal supply is more easily and widely available internationally than gas.

However (as discussed above), gas-fired generation will still be needed as a source of back-up generation, at least in the transition to an entirely decarbonised market. This means that gas contracts with foreign suppliers will need to become more flexible and that additional investments in domestic gas storage capacity will be needed.

Moreover, internal security of supply may be negatively affected by the higher share of renewable generation required to meet environmental objectives due to the intermittent nature of most renewable energy. This creates some tension between the two policy objectives that may need to be mitigated by devising appropriate capacity payment mechanisms and investing more in domestic flexibility (again, gas storage infrastructure, but also electricity-pumped storage capacity) and interconnection across Europe.

Competition policy and environmental policy should broadly be seen as complementary in many circumstances. This is because competition policy (and more effective regulation in general) aims to render energy markets more efficient and reduce the overall cost of the system. It therefore plays

---

[22] For a review of the interrelation between the various pillars of EU energy policy see Federico & Vives, 2010.

an important role in ensuring that the transformation towards a low-carbon market is achieved at the lowest possible cost. This is particularly so given that it is likely that pursuing the current European environmental objectives will increase total electricity costs significantly by increasing reliance on more expensive sources of generation. In a context of rising overall costs, keeping prices as close to variable cost as possible (which is one of the basic aims of competition policy) becomes even more important in order to reduce the impact of environmental policies on consumers. However, to the extent that environmental policies will lead to subsidies being paid out to specific technologies in addition to the wholesale market price, a wedge will be created between wholesale prices and actual wholesale costs. This wedge will tend to make competition policy in wholesale markets less effective in delivering beneficial outcomes for final consumers.

A separate consideration is that it will also be increasingly important not to necessarily conflate instances of high energy prices (e.g. during times of system stress) with the exercise of market power by energy firms. Energy prices will need to be able to respond to peak market conditions in order to provide the correct signals of economic scarcity and reward investment in infrastructure (e.g. new thermal generation capacity), which may only or primarily be required during peak periods. Competition policy and/or regulation will need to be applied carefully so as not to distort these market mechanisms. This consideration is actually likely to make it all the more important to have competitive markets in place (both in terms of vertical and horizontal structure) to give policy makers and consumers the confidence that the internal energy market is not distorted by the presence of operators with significant market power.

3. ENVIRONMENTAL POLICIES IN THE E.U. ENERGY SECTOR: DESIGN AND PERFORMANCE

This section of the article reviews the fundamental elements of E.U. environmental policy and its performance to date (with a specific focus on Spain where appropriate). It does so by distinguishing between two basic periods: the one from 1990 to 2010, which corresponds roughly to the reference period of the Kyoto Protocol; and the period between 2010 and 2020, which represents the main reference period for the current environmental targets set at E.U. level.

3.1. Phase I of E.U. environmental policy: 1990-2010

During the 1990-2010 period, E.U. environmental policy was characterised by three main elements, which are reviewed below:

i. A commitment under the Kyoto protocol to reduce GHG emissions by 8% during the 2008-2012 period relative to 1990.
ii. The establishment of Europe-wide carbon pricing through a cap-and-trade mechanism known as the Emission Trading System (ETS) to facilitate the reduction in carbon emissions and encourage the entry and production of low-carbon technologies.
iii. The adoption of a 12% target on the share of renewable energy in gross primary energy consumption by 2010, coupled with country-specific targets on the share of renewable generation in total electricity consumption by the same year.

3.1.1. *The Kyoto targets on GHG emission reductions*

Under the Kyoto Protocol (initially adopted in 1997 and ratified by the European Union in 2002), the E.U.-15 countries committed to reduce their overall GHG emissions by 8% during the 5-year period between 2008 and 2012 relative to the 1990 base year. This commitment was met by a combination of a reduction in emissions and other mechanisms available under the Protocol.[23]

By the end of 2009, GHG emissions in the E.U.-15 were roughly 13% below the base level established under the Kyoto protocol and therefore well on track to meet the commitment (see Figure 7, left-hand panel). This performance was partially due to the economic crisis of 2009, which lowered E.U.-15 GHG emissions by almost 7% relative to 2008 (ETC/ACC, 2010). For the E.U.-27 as a whole, GHG emissions in 2009 were 17.3% lower than in 1990, largely due to the economic transformation of Eastern Europe over the period, the switch to gas-fired generation in some markets (most notably the United Kingdom) and the recent economic downturn.

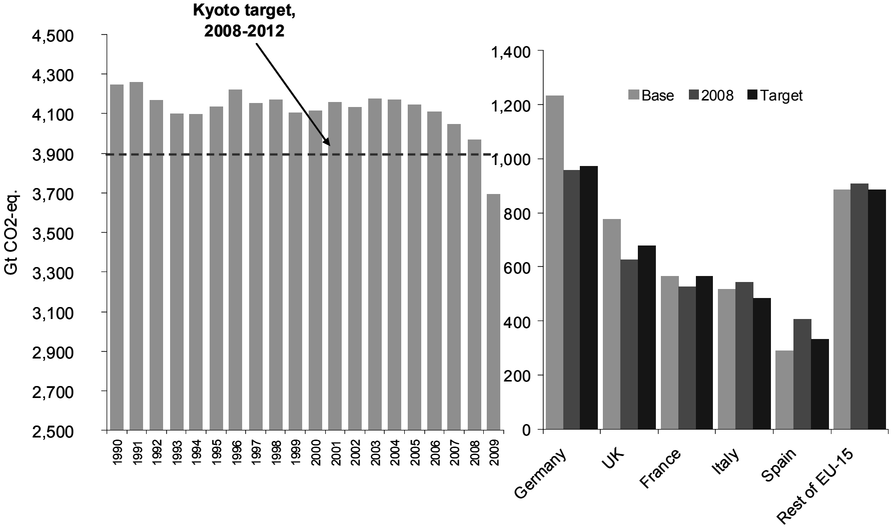
The overall reduction in E.U.-15 emissions masks the difference in performance across Member States. During the 1990-2008 period (for which complete country-specific data are available from the European

---

[23] These include the use of flexible mechanisms (e.g. acquisition of emission allowances from other parties to the Protocol, and project-based credits under the Clean Development Mechanism) and 'carbon sink removals' (e.g. through improved forest management).

Environment Agency), emission reductions in Germany and the United Kingdom alone (approximately 430 million tonnes (Gt) of CO_2-eq.) more than explained the overall reduction experienced at E.U.-15 level (-295 Gt), and compensated for the increases observed in Spain (116 Gt), Italy (25 Gt) and the rest of the E.U.-15 (24 Gt) (EEA, 2010). These figures are shown in the right-hand panel of Figure 7.

FIGURE 7: **European performance under the Kyoto targets, EU-15, 1990-2009 (million tonnes of CO_2-eq.)**



Source: EEA; ETC/ACC; Ministerio de Medio Ambiente.

The European Environment Agency projected during 2009 that E.U.-15 could outperform the Kyoto target by between 0.5% and 5% of base year emissions, depending on the mix of policies and the use of the Kyoto mechanisms being adopted (EEA (2009)). These projections were significantly affected by the economic crisis and the close to 7% reduction in E.U.-15 emissions experienced in 2009. This reduction will allow the E.U.-15 to meet its Kyoto Protocol targets more easily, but is likely to represent a largely one-off decrease that cannot be easily extrapolated into the future.

3.1.2. *The Emission Trading System (ETS)*

The ETS established in Europe in 2005 represents one of the fundamental elements of European environmental policy. The ETS is a cap-and-trade scheme which establishes a price for CO_2 emissions within the European Union. It currently includes roughly 40% of total GHG emissions in Europe and close to 50% of its CO_2 emissions.

The ETS has so far included two phases: Phase I from 2005 until 2007; and Phase II, which is scheduled to run from 2008 until 2012 (inclusive). A third phase is scheduled for the 2013-2020 period. Under both of these initial phases, allowances have been allocated to the CO_2 emitters included in the scheme mostly for free, thus allowing them to trade these permits among themselves with the purpose of establishing a transparent and unique price for carbon (in line with the economic theory of carbon pricing reviewed above).

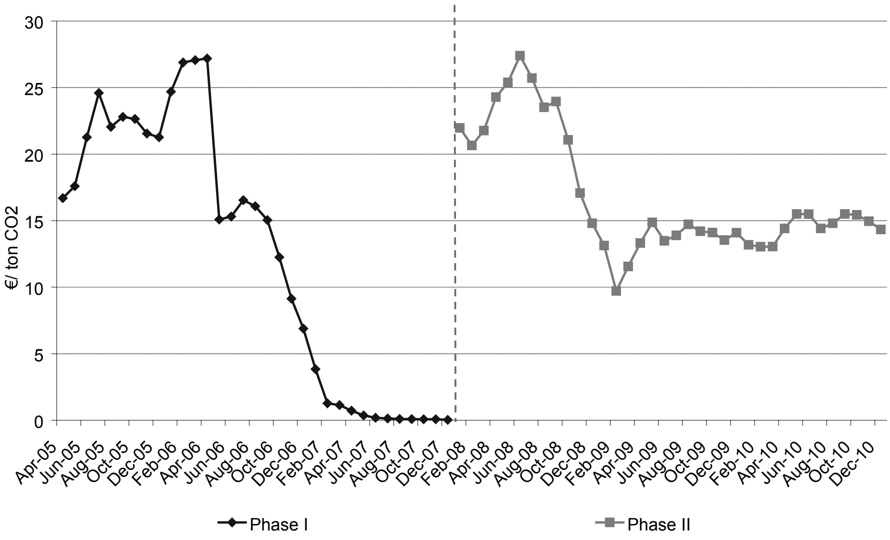
The emission target contained in Phase I of the ETS was in excess of actual emissions in 2005-2007 and therefore did not represent a constraint from an economic perspective (even though it was legally binding). This excess in allocations was due to difficulties in collecting adequate data on historical emissions, resulting in an over-estimate of past emissions and, therefore, an emissions target that was too high (relative to a business-as-usual benchmark). The over-allocation of permits, coupled with the lack of banking in Phases I and II, led to a collapse in the price of E.U. CO_2 allowances at the end of Phase I (see Figure 8). For Phase II, the target has been set at roughly 6.5% below 2005 levels to facilitate compliance with the Kyoto Protocol (European Commission,2008a).

CO_2 prices under Phase I of the ETS fluctuated between maximum monthly levels of over €25/tonne CO_2 in early 2006 and effectively 0 for most of 2007. During Phase II, prices initially recovered to €20-€25/tonne CO_2, but fell subsequently due to the impact of the economic downturn, and have stabilised at around €15/tonne CO_2 since mid-2009.

The creation of the ETS has established a transparent price for carbon across Europe and allowed for efficient carbon trading to take place. As such, it will be a key mechanism to facilitate efficient compliance with the European Union's current environmental targets during the 2010-2020 period.

However, the initial design of the ETS was flawed in some important respects. Most notably, over-allocation of permits in Phase I undermined the validity of the scheme in that phase and the price signal that it was able to deliver. Moreover, the free allocation of allowances to electricity generators and other large emitters during the first two phases directly created large windfall profits during periods when CO_2 prices were positive. These profits arose from the fact the wholesale electricity price reflected the opportunity cost of the permits (as it should in a competitive market), but thermal generators did not actually bear the cost of purchasing the permits. This over-compensated producers for the introduction of carbon pricing and increased the effective costs faced by consumers due to the introduction of carbon pricing. The shift to full auctioning of permits in the power sector in most E.U. countries from 2013 onwards (reviewed below) will reverse this effect (for thermal generators) and will imply that some emitters (coal plants in particular) will become net losers from the existence of the ETS.

FIGURE 8: **CO_2 prices under the ETS, April 2005-December 2010**



Source: ECX/SENDECO$_2$.
Note: Prices shown are monthly forward prices for delivery in December of each year.

3.1.3. *E.U. renewable targets for 2010*

In addition to the introduction of carbon pricing in 2005, the European Union also pursued a specific policy in favour of renewable sources of energy. This was initiated in 1997 with the publication of the White Paper on Renewable Sources of Energy (European Commission (1997)). In this paper, the European Commission established a strategy aimed at achieving a share of renewable energy sources in gross inland consumption of 12% by 2010 for the European Union as a whole. Gross inland energy consumption includes the consumption of all energy sources, including oil, solid fuels (such as coal), natural gas, nuclear and renewable sources. It is therefore a broader measure than just electricity consumption (which in turn relies on the primary energy sources that form part of overall energy consumption). The 12% target implied more than doubling the contribution of renewable energy relative to 1995 (when the E.U. share stood at 5.3%, as reported in the 1997 White Paper).

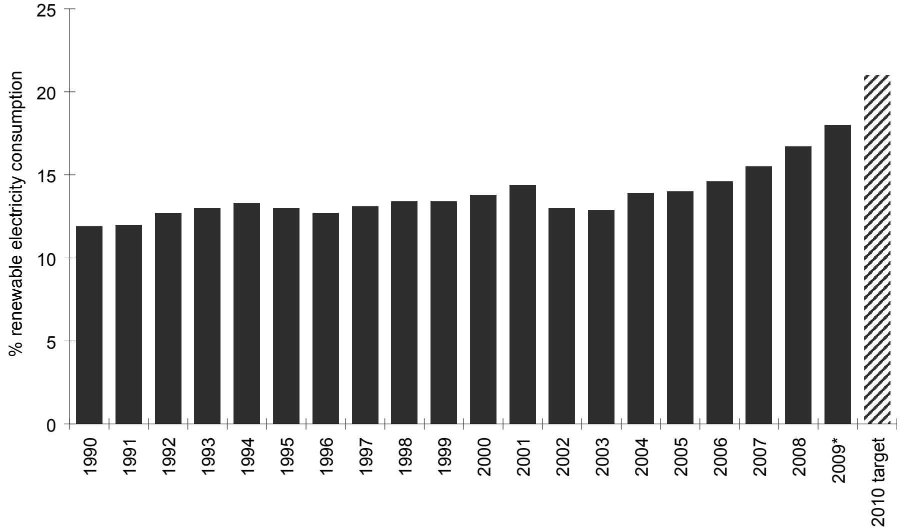
In September 2001 the European Commission established further renewable targets specific only to electricity in a directive on the promotion of electricity produced from renewable energy sources in the internal electricity (Directive 2001/77/EC). This directive contained indicative targets for each Member State on the proportion of gross national electricity consumption to be sourced from renewable sources by 2010. These electricity targets were set in order to comply with the overall target of 12% of energy consumption contained in the White Paper, thereby implying the need for over 20% of renewable electricity consumption across the E.U.-27 by 2010.

The targets contained in the 2001 Directive varied across countries to take into account differences in the starting levels of renewable electricity in each Member State, ranging from a share of 10% or less in Belgium, Hungary, the Netherlands and the United Kingdom, to roughly 30% or more in Austria, Finland, Spain and Sweden.

The performance of the European Union as a whole with respect to the overall renewable electricity targets is summarised in Figure 9.

The European Union as a whole achieved a 16.7% share of renewable generation in 2008 (up from 12% in 1990). Preliminary estimates for 2009 (based on Eurostat data) indicate that the corresponding share for 2009 increased to over 18%, which, however, remained short of the target of 21% for 2010. Based on the European Commission review of January 2011 (European Commission, 2011), countries that performed well relative to their renewable electricity targets include Germany and Hungary (which have already met their 2010 target), and also Belgium, Denmark, Ireland, the Netherlands and Sweden. Spain too appears to have met its renewable electricity target during 2010. Based on its January 2011 review, the European Commission does not expect its overall 2010 target to be met.

FIGURE 9: **Share of total renewable generation and wind generation in gross electricity consumption, 1990-2009**



* 2009 data estimated on a preliminary basis using Eurostat's provisional electricity statistics for 2009.
Source: Eurostat.

Different renewable support schemes have been employed across the European Union to subsidise renewable generation and encourage the achievement of E.U. targets. As reviewed by Lorenzoni, 2010, the majority of E.U.-15 countries (11 out of 15) have adopted either a feed-in tariff mechanism and/or a premium tariff system (whereby the renewable subsidy is paid on top of market prices). Only four E.U.-15 countries (Belgium, Finland, Sweden and the United Kingdom) have relied primarily on alternative systems such as green certificates and fiscal incentives to promote renewable generation. The European Commission reviewed the relative performance of different renewable support schemes in 2008 (European Commission, 2008b). It found that feed-in tariffs had been more successful than green certificates in promoting deployment of renewable generation and did so at a lower cost in the year that was analysed (2006).

3.2. Phase II of E.U. environmental policy: 2010-2020

European climate change policy has been substantially revised and made more stringent for the period after 2010. The overarching principles for this revision were contained in the Commission's climate and energy package approved by the European Union in 2008. This package includes three key targets:

i. Reducing total E.U.-27 GHG emissions by 20% by 2020 (relative to 1990 levels) with a further commitment to implement a 30% reduction in the context of a successful international negotiation on global emission cuts.
ii. Reaching a 20% level in the use of renewable sources in gross final energy consumption by 2020 (up from a level of just over 10% in 2008). This target implies achieving a percentage of renewable electricity of between roughly 33% and 40%, depending on the country.
iii. Reducing primary energy consumption by 20% of projected 2020 levels by improving efficiency.

The climate and energy package was followed by two specific directives in April 2009 aimed at implementing the Commission's targets:

- **The ETS Directive (2009/29/EC).** This directive establishes that emission allowances set in the ETS will be reduced by 21% below their 2005 levels by 2020 (in excess of the required reduction in overall GHG emissions during the same period). This change will be implemented from 2013 onwards (Phase III) with full auctioning of permits for the power sector in most Member States and a gradual phasing out of free allowances for other sectors under the ETS. The ETS is also set to be expanded in 2013 to also include the aviation sector.
- **The Renewable Energy Directive (2009/28/EC).** Under this directive, the 20% target of renewable energy sources by 2010 contained in the climate and energy package was translated into specific binding targets for each Member State. The target for Spain was set at 20%, which is therefore in line with the average level to be achieved across the European Union.

The new climate package broadly follows the same architecture of previous E.U. environmental policies, but with more stringent targets and a substantial revision to the ETS. The 20% reduction in emissions by 2020 implies an acceleration of carbon-cutting efforts relative to those observed during the 1990-2008 period (when E.U.-27 emissions fell by 11% over a longer time period and in part due to the one-off economic restructuring of Central and Eastern Europe). On the other hand, the economic downturn of 2009 contributed to a situation where current GHG emission are already 17% below 1990 levels, thus implying that the 20% reduction is likely to be easier to achieve than was originally anticipated.

The 21% reduction in CO_2 allowances under the ETS by 2020 (relative to 2005) also represents a significantly faster reduction than the 6.5% cut implemented in the first two phases of the scheme (between 2005 and 2012). However, the mechanics of the ETS (coupled with the economic downturn of 2009) is likely to soften the impact of the reduction in emission permits. In particular, as shown by the IEA (2009), the surplus of CO_2 allowances that is likely to arise during Phase II of the ETS due to the recession can be 'banked' into Phase III, thereby allowing countries to emit more than the Phase III cap would suggest. The IEA estimates that, by the end of Phase III of the ETS in 2020, emission levels may actually be at levels similar to 2008, mainly due to reliance on the banking of credits. The absence of a reduction in emissions by 2020 would make it harder (and costlier) for the European Union to achieve the required cuts in carbon emissions for subsequent periods (e.g. by 2030). This mechanism also risks depressing carbon pricing up to 2020 and discouraging investment in low-carbon technologies.

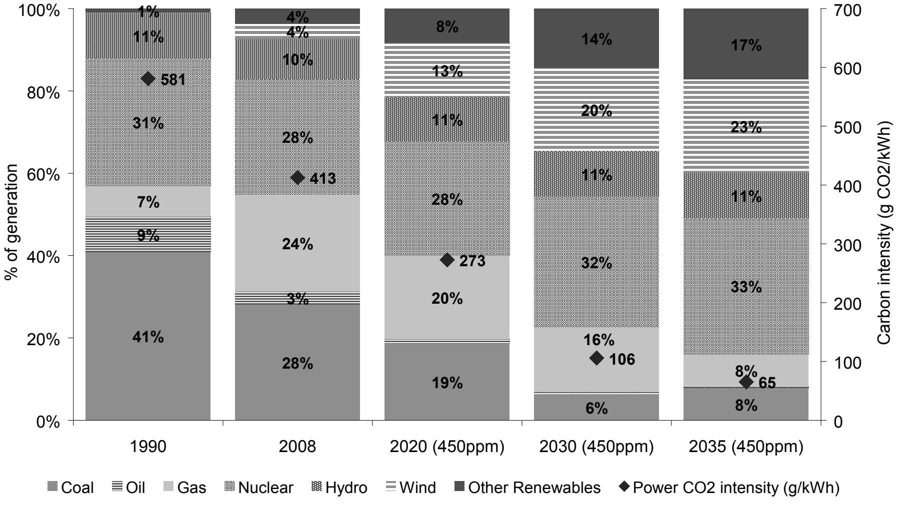
Because of these potential concerns, in May 2010 the Commission analysed a unilateral move to increase its commitment to reduce GHG emissions to 30% by 2020, up from the current targeted reduction of 20% (European Commission, 2010b). According to the Commission's analysis, the economic crisis of 2009 lowered the cost of achieving the original 20% target and also rendered that target less incisive in driving forward the required structural changes.

A more stringent 2020 target would also be in line with the IEA analysis for Europe in its "450 ppm scenario", which is compatible with objectives on climate change mitigation (see IEA,2010c). This scenario suggests the need for an overall reduction in CO_2 emissions in excess of 20% by 2020, relative to 1990 (without however allowing for banking of excess allowances across phases of the ETS). These projections also indicate the need for a reduction of 33% in emissions from the power sector relative to 2007 (well in excess of the reduction in ETS allowances of 21% over roughly the same period).

In terms of the required electricity mix (see Figure 10), the IEA suggests that by 2020 over 30% of electricity should come from renewable sources, roughly in line with the target in the 2009 Renewable Energy Directive. This analysis indicates that, if the European emission targets for 2020 are to be tightened, this probably should not be implemented by further increasing the share of renewable energy.

The IEA projections for 2020 also indicate the need for a stable share of nuclear output by 2020 (relative to 2008) and an increase by 2030-2035. Given the expected increase in electricity demand (13% in 2035 relative to 2008), this will require new nuclear plants to replace decommissioned plants and allow for some net growth in nuclear generation (roughly 33% relative to current levels, by 2035). By contrast, the share of coal- and gas-fired generation needs to reduce drastically by 2030-2035, relative to current levels. The share of coal is projected to start picking up from 2035, as CCS technology is introduced.

FIGURE 10: **Electricity generation mix, IEA scenarios for 2020, 2030 and 2035 (E.U.)**



Source: IEA,2010c.

Finally, in terms of revised ETS design in Phase III, the move to full auctioning for the power sector and an increase in auctioning overall is a positive adjustment to the scheme. It will prevent windfall gains being generated for carbon emitters (but not for non-emitters) at the same time as it creates a pool of resources that can be used to finance emission-reducing activities (e.g. CCS demonstration projects, as is the case under the ETS Directive, and renewable technology policy). The introduction of banking across Phase II and Phase III will also improve the efficiency of the price signal provided by the ETS.

4. CONCLUSIONS: POLICY CHALLENGES FOR THE EUROPEAN ELECTRICITY MARKET

Meeting the environmental objectives set by international policy makers, as embodied in the Copenhagen Accord of late 2009, will require a paradigm shift in energy markets over the next 20 to 40 years (assuming that an effective international agreement can be reached on these issues). Over this time horizon, developed countries will need to achieve deep cuts in GHG emissions to comply with the environmental targets and reach a reduction of at least 80% by 2050 relative to 1990 (European Commission,2010b). The power sector in particular will also have to virtually decarbonise over this period, given the greater potential for the use of low- or zero-carbon technologies in this sector (renewables, nuclear and CCS), and the ability of the electricity industry to reduce emissions in other sectors (e.g. transport and heating). Projections indicate that carbon emissions in the European power sector will need to be reduced by roughly 75% by 2030 (relative to 1990) with the industry being almost completely de-carbonised by 2050. More than half of electricity will need to come from renewable sources by 2050, with the rest split between nuclear and CCS (IEA,2010a).

The required changes in the European energy industry are likely to increase costs significantly as more environmentally friendly but also more costly technologies are used. Carbon prices are likely to increase over the future (thus raising the cost of fossil-fuel technologies) and so will the cost associated with renewable subsidies as targets become more ambitious. The overarching policy challenge should be one of achieving the required transformation towards a low-carbon economy at the lowest possible cost for society. For this to be possible, government interventions in the sector should be aimed at directly addressing the main sources of market failures.

In particular, this means that carbon pricing should represent the main economic instrument used to contain carbon emissions and achieve the required targets in a socially optimal way. This would ensure that a technology-neutral approach is adopted and that the most cost-efficient low-carbon technologies are utilised to reduce emissions. However, political and distributional considerations indicate that it is unlikely that carbon prices will reach the levels required to induce efficient abatement efforts, which implies that second-best solutions may have to be accepted.

The presence of additional market failures, such as technology spillovers, can justify the adoption of supplementary policies, like R&D and possibly also deployment support to renewables. However, when such policies are designed and reviewed, it needs to be clear which specific market failure is being corrected through government intervention. In particular, renewable support policies should *not* be justified in terms of the environmental externality associated with climate change, since this externality should be mainly addressed via carbon pricing for the reasons discussed above. Moreover, deployment support to renewable generation may actually reduce the effectiveness of carbon pricing in stimulating the entry of other forms of low-carbon generation by reducing the market price of CO_2. Careful thought should be given to these issues when revising and updating the current European renewable targets.

Once the main market failures are internalised via public policies (e.g. carbon pricing and renewable support), market tools should be relied upon to maximise the efficiency of the energy sector in the transition to decarbonisation. This calls for such measures as the introduction of carefully designed auction-based procedures to set renewable subsidies and a gradual move away from administratively determined feed-in tariffs. Capacity tenders could also be used to attract the required levels of flexible thermal generation if price signals from the energy market are perceived to be too unreliable to guarantee security of supply.

Given the complexity of the required structural changes, it will be difficult to design policies to achieve maximum efficiency. It is very possible that the relative contribution of competing low-carbon technologies (renewables, CCS and nuclear) and their respective deployment path over time will not be optimised. In particular, in the medium term there is a risk of over-reliance on renewable generation in Europe, given the ambitious European targets set for 2020. Whilst renewable generation may eventually have to reach a high share of total consumption (e.g. 50% according to IEA projections for 2050), a 35%-40% target in 2020 represents an excessively steep deployment trajectory (based on the IEA's modelling of the timing and composition of efficient abatement efforts).

On the other hand, partially due to the economic crisis of 2009-2010, the European carbon emission targets for 2020 do not appear to be sufficiently ambitious (with 85% of the required reduction in GHG emissions having already been achieved in 2009). If the target is ratcheted up to a 30% reduction relative to 1990, it will be socially desirable to achieve the incremental reduction in emissions primarily by lowering the emission cap under the ETS (thus achieving a higher carbon price), rather than by further increasing the renewable target. This will encourage energy efficiency and also investment in alternative forms of low-carbon generation (nuclear and CCS). A significantly higher carbon price may, however, raise distributional issues that will need to be addressed, since it will increase the market price received by all energy sources (and not just the incremental low-carbon investments required to meet the more stringent environmental objectives).

BIBLIOGRAPHY

Acemoglu, D., Aghion P., Burztyn, L. & D. Hemous
2009 "The environment and directed technical change", NBER Working Paper 15451.
Aghion, P., Hemous, D. & Veugelers, R.
2009 "No Green growth without innovation", Bruegel policy brief, Issue 2009/07, November.
Aldy, J. & Pizer, W.
2009 "Issues in designing US Climate Change Policy", *The Energy Journal*, 30(3).
Baldursson, F. & von der Fehr, N.-H.
2004 "Price volatility and risk exposure: on market-based environmental policy instruments", *Journal of Environmental Economics and Management*, 48(1).
CESifo
2008 *The EEAG Report on the European Economy 2008*.
Committee on Climate Change (CCC)
2010 *Meeting carbon budgets – ensuring a low-carbon recovery*, June.
Council of European Energy Regulators (CEER)
2008 *Status review of renewable and energy efficiency support schemes in the EU*, December.
Department of Energy and Climate (DECC)
2009a *Carbon valuation in UK Policy appraisal: a revised approach*, July.

2009b *Analytical Annex: the UK Low Carbon Transition Plan.*

2009c *Draft National Policy Statement for Nuclear Power Generation*, November.

2010 *Electricity Market Reform. Consultation Document*, December.

European Commission

1997 *Energy for the future: renewable sources of energy. White paper for a Community Strategy and Action Plan*, November.

2007 *Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond*, January.

2008a *Questions and Answers on the Revised EU Emission Trading System, Memo/08/796*, December.

2008b *The support of electricity from renewable energy sources*, January.

2008c *Energy sources, production costs and performance of technologies for power generation, heating and transport*, November.

2010a *Technical Annex to the Communication from the Commission to the Council and the European Parliament. Report on progress in creating the internal gas and electricity market*, March.

2010b *Analysis of Options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage*, May.

2011 *Recent progress in developing renewable energy sources and technical evaluation of the use of biofuels and other renewable fuels in transport in accordance with Article 3 of Directive 2001/77/EC and Article 4(2) of Directive 2003/30/EC*, January.

European Environment Agency (EEA)

2009 *Greenhouse gas emission trends and projections in Europe 2009. Tracking progress towards Kyoto targets.*

2010 *Annual European Union greenhouse gas inventory 1990-2008 and inventory report 2010*, EEA Technical report, 6/2010.

European Topic Centre on Air and Climate Change (ETC/AAC)

2010 *Approximated EU GHG Inventory for the year 2009*, Technical Paper 2010/4, September.

Eurostat

2010 *Statistical Aspects of the energy economy in 2009*, Statistics in focus, 43/2010

Federico, G. & Vives, X.

2010 "Políticas energéticas en la UE: seguridad de suministro, medio ambiente y competencia, *Cuadernos Económicos*, ICE, 79, June.

Federico, G.

2010 *The Spanish Gas and Electricity Sector: Regulation, Markets and Environmental Policies*, Reports of the Public-Private Sector Research Center, 5, IESE Business School.

Frontier Economics

2009 Alternative policies for promoting low carbon innovation, Report for the Department of Energy and Climate Change, July.

Green, R.,

2008 "Carbon tax or carbon permits: the impact on generators' risk", *The Energy Journal*, 29 (3), 2008.

Hanemann, M.

2009 "The role of emissions trading in domestic climate change policy", *Energy Journal*, 2009, 30 (Special Issue 2).

IEA

2008 *Energy Technology Perspectives 2008.*

2009 *World Energy Outlook 2009.*

2010a *Energy Technology Perspectives 2010: scenarios and strategies to 2050. Executive Summary.*

2010b *Projected costs of generating electricity, Executive Summary.*

2010c *World Energy Outlook 2010.*

Intergovernmental Panel on Climate Change (IPCC)

2007 *Climate Change 2007: Synthesis Report.*

Lorenzoni, A.

2010 "The support schemes for the growth of renewable energy", IEFE Working Paper No. 33, May.

McKinsey and Co.

2009 *Pathways to a Low-Carbon Economy. Version 2 of the Global Greenhouse Gas Abatement Cost Curve.*

Newbery, D.

2010a "Memorandum submitted to Environmental Audit Committee", in Environmental Audit Committee, House of Commons, *The role of carbon markets in preventing dangerous climate change.*

2010b "Market design for a large share of wind power: Editorial", *Energy Policy*, 38.

Nordhaus, W.

2007 "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, XLV (September), 686-702.

Ofgem

2009 *Project Discovery, Energy Market Scenarios*, October.

2010 *Project Discovery, Options for delivering secure and sustainable energy supplies*, February.

Stern, N.

2007 *The Economics of climate change: The Stern Review*, Cambridge and New York: Cambridge University Press.

Tirole. J.

2008 "Some Economics of Global Warming", *Rivista di Politica Economica*, November-December.

2010 "Climate Change Policy: A New International Architecture", presentation to The Economics of Energy Markets, conference held at the Toulouse School of Economics, January.

UK Treasury

2010a *Energy Market Assessment*, March.

2010b *Carbon price floor: support and certainty for low-carbon investment*, December.

Weitzman, M.

1974 "Prices vs Quantities", *Review of Economic Studies*, 41(4).

2007 "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, XLV (September), 703-724.

2010 "GHG Targets as Insurance Against Catastrophic Climate Damages", working paper, Harvard University.