The Static and Dynamic Efficiency of Instruments of Promotion of Renewables

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Summary

This paper deals with a comparative analysis of the economic and social efficiency of the instruments used to promote renewable energy sources (RES), first from a static standpoint and then using dynamic criteria to assess their ability to stimulate technological progress and cost reduction. First, the instruments are analysed in relation to the classical discussion of environmental policy that opposes price-based instruments versus quantity-based instruments in an uncertain environment (feed-in tariffs as price based system on one hand, quotas + green certificates, competitive bidding as quantity-based instruments on the other hand). Next, the incentives to invest and innovate in the context of each framework are analysed in relation to the sharing of the surplus associated with each of them between producers/constructors and consumers or the public budget. Finally, the paper looks at the overall cost-efficiency of the policies on the basis of each instrument, by referring to factual evidence in European experiences. It concludes that if social preference is attached to climate change prevention and reflected in a high quantitative objective for renewables, sliding scale feed-in tariffs are a good compromise in order to promote technical progress and national RES industry also. The quota/certificate system also presents a number of advantages in terms of static efficiency, but its ability to stimulate innovation still has to be confirmed by experience.

1. Introduction

The general awareness that has been growing over the past 20 years of the threats to the environment, in particular the risk of climate change, has led to a significant reawakening of interest in renewable energy, because of the environmental advantages that it represents in comparison to conventional energy sources. This interest led to the voting-in, on October 27 2001, of the European Directive on the promotion of electricity from renewable sources (hereinafter abbreviated as RES-E)[1] with the aim of doubling the share of renewable energy in total energy consumption by 2010. Faced with the more specific deployment of green electricity production required by the European Commission (22% of gross electricity consumption by 2010 as against 13.9% in 1997), it will be a vital concern to achieve these goals at the lowest possible cost.

Public funding for research and development and subsidies to encourage investment were initiated 25 years ago and have long been the main measures used within the European Union to promote RES. They are still aimed at the least mature technological areas, but in the case of those that are nearly competitive, more specific instruments are now used with the aim of introducing RES into the

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[1] Directive 2001/77/CE of the European Parliament and Council dated 27 September 2001.

electricity market. Support schemes fall into three main categories that are either price-based or quantity-based in their approach:

- Feed-in tariffs, used in particular in Denmark, Germany, Spain, and France since 2001, which were the most widely used incentive system until 2003.
- Bidding processes such as those used in the United Kingdom, Ireland and France until 2000. This type of scheme is based on an overall objective for renewable energy to be generated nationally and reached in several successive rounds by development of projects framed by long-term contracts with guaranteed power purchase and price. Its principle allows differentiation between technologies on the basis of their differences of maturity.
- Quotas combined with tradable green certificates schemes, where electricity suppliers (or in some countries, producers or final consumers) are obliged to produce or buy a certain quota of renewable energy defined from a national objective. This type of scheme is already used in some countries in Europe (Italy, United Kingdom, Belgium), in the USA with some of the "renewables portfolio standards" (in particular Texas) and in Australia, but will be extended to most of the EU Member States (Austria, the Netherlands, Denmark, Sweden) in the near future.

To help clarify matters, we propose a comparative analysis of the relative efficiency of the instruments used to promote renewable electricity[2], first from a static point of view and then using dynamic criteria. The justification of policies supporting renewable energies is made on the basis of both internalisation of externalities in electricity production and their role in stimulating the learning process in relation to still commercially immature renewable technologies. First, we characterise the rationale of these policies in a cost-efficiency framework; then we analyse the instruments in relation to the classic discussion of environmental policy that opposes price-based approaches to quantity-based approaches; and finally, we examine the sharing of the surplus (rent) allowed by each policy instrument and its effects on the tendency of manufacturers and RES producers to innovate. We shall proceed by graphic analysis before checking the results with empirical observations.

2. Rationale of public policies supporting renewable energy

The obstacle facing renewable energies in the domestic electricity market is twofold. First of all, the wholesale price gives a very incomplete idea of the real cost of electricity production. As it does not take into account the cost of pollution control inherent in the use of fossil fuels, it prevents the environmental benefits of renewable energies from being considered at their true value, and thus removes any comparative advantage they may have. Secondly, as these technologies are not completely mature, they cannot enter into direct competition on the market with conventional technologies. Without the widespread dissemination needed for the technological learning process and the scale economies to occur properly, these technologies cannot aim to be competitive. Public intervention may therefore be justified in theory in two main ways: internalisation of environmental externalities and stimulation of technological change.

2.1. A response to the limitation on internalisation of environmental externalities

The main advantage of renewables over conventional energy is that they contribute to the preservation of public goods, namely clean air and climate stability. Because of the non-excludable and non-rival characteristics of these public goods, private actors are not prepared to invest in something that everyone can acquire freely. In such conditions, the diffusion of RES cannot be

[2] The thermal use of renewable energies will not be dealt with here even though they offer a potential for development that is at least as high as that for electricity. Pending a European directive similar to that for electricity production, the issue of heat production from renewable energy sources is distinctly different and would need to be discussed in a separate article.

assured spontaneously by the market. Deregulation of the electricity market, seen as the possibility offered to customers of expressing their preferences and thus their willingness to pay for this environmental good by the purchase of labelled green electricity, could be seen as a possible market solution. However, experience shows that it is a very partial response for two reasons: as can be seen from experience in Europe, the impacts of green programs are quite limited and the problem of free riding remains (Batley and al., 2001; Wiser and Pickle, 1997). Individual choices do not fully reflect the real value that the public may place on preserving the environment by purchasing green energy and therefore cannot replace public support.

The most satisfying solution from the point of view of economic rationality would be to internalise environmental impacts by taxing fossil fuel prices. The level of taxes should then be calculated so as to compensate for the costs that the negative externalities impose on society. The appropriate level of taxation is however difficult to assess because of uncertainty regarding the shape of the social damage cost function related to fossil fuel use[3]. So, as long as energy taxes (or its dual approach by quotas and exchanges of emissions permits) do not equalize the marginal cost of the damage caused by using fossil fuels, supporting RES through subsidies aims to re-establish balance in the conditions of competition between technologies to the benefit of the least polluting[4].

Given the problems that occur in observing certain parameters, it is impossible to refer to an optimum level of renewable energy production. Consequently, one is forced to adopt a strict cost/efficiency approach in which the target is defined exogenously by political decision-makers on the basis of available scientific information, but without strict economic rationalisation. The aims fixed by the European Union's directive – however indicative – that would represent a considerable advance in the development of RES-E if it were respected, proceed from this cost-efficiency approach. It is also in this perspective that we shall compare the efficiency of the instruments available to the public authorities for throwing light on discussions concerning the amount of resources allocated to deploying renewable energies.

1.1 2.2. Stimulating technological change

A real appreciation of the RES advantages by the market and the establishment of equitable conditions for competition between fossil fuels and renewable energy sources will still not guarantee the creation of a dynamic renewable energy diffusion process that is consistent with the collective objective of preserving the environment. Renewable energy sources, which like any new technology have to compete with established technologies, remain in an unfavourable position. They have not reached their optimum performance in terms of cost and reliability. Optimum performance will be achieved gradually as a result of the process of learning by doing and by using (Arrow, 1962; Dosi, 1988). In other words, as B. Arthur points out, it is not because a particular technology is efficient that it is adopted, but rather because it is adopted that it will become efficient (Arthur, 1989). Other barriers relative to the technical and economic characteristics of renewable energies stand in the way of their diffusion: the new actors in the liberalised electricity markets tend to favour the least capital-intensive generation technologies with non-random energy supply. Therefore, technological and organisational learning processes are necessary before the RES reach their optimum performance and are really integrated in energy markets.

For these reasons incentive systems are required, so that renewable energy technologies can be adopted beyond narrow market niches and progress on their learning curves. Public support for new

[3] Another caveat on this rationale by environmental externalities has to be issued because of the local character of green electricity production, with its eventual visual impacts and their social perception. So we have to balance their environmental advantages with these impacts which are reflected in their perceptions by the local populations in their geographic context. That means also that the reference to a collective preference function is not obvious in a cost-advantage approach given the conflictual nature of its genesis and its contingent value depending upon the specific local compromises.

[4] Subsidising RES production does not lead to over-consumption of electricity, which would be inefficient, as some critics argue, because the subsidies are re-funded by a tax on electricity paid by all the consumers.

energy technologies will stimulate a dynamic process that will reveal their ultimate performance (Foray, 1996) and at the same time help expand the range of techniques that can contribute to environment preservation.

3. "Price-based" versus "quantity-based" incentive instruments

An examination of the policies implemented in Europe over the past 20 years to stimulate the development of RES shows that the instruments used all show a strong similarity to the instruments of environmental policy to which they can be assimilated. In particular, they raise the same questions from the point of view of the classical debate between price-based and quantity-based in environmental policies (Weitzman, 1974, Cournede and Gastaldo, 2003).

3.1. The instruments for promoting green electricity development

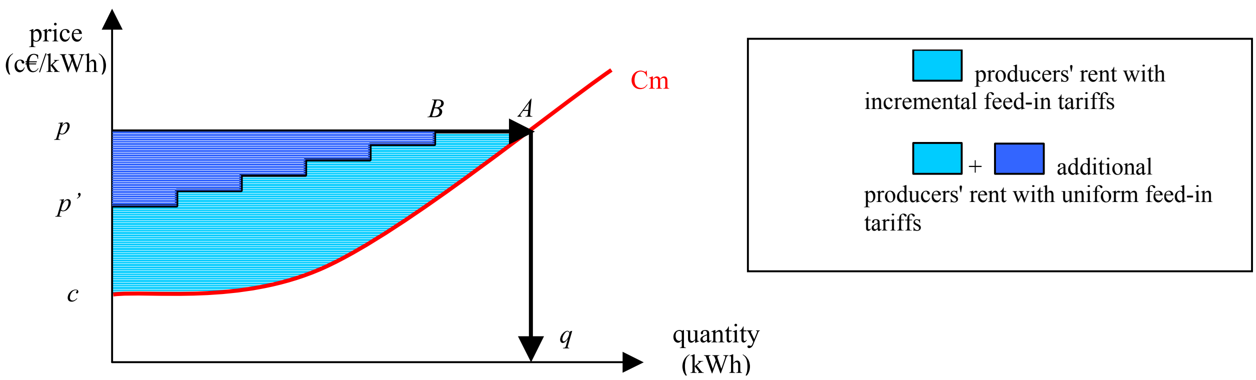
The different instruments are characterised by the type of subsidisation of the RES kWh, the type of obligation (agents to be mandated, obligation to buy or RES quotas) and the mode of financing the subsidy and the sharing of the surplus created by them, given that in the specific RES case, this surplus has mainly the nature of a differential rent.

- ***Feed-in tariffs***

The feed-in tariff scheme involves an obligation on the part of electric utilities to purchase electricity produced by renewable energy producers in their service area at a tariff determined by the public authorities and guaranteed for a specified period of time (generally about 15 years). Different tariffs can be defined for different technologies. As the feed-in tariff is higher than the average electricity price on the wholesale market, the system operates as a subsidy allocated to renewable electricity producers. It thus works in the same way as a subsidy does for firms that pollute. In practice, producers and developers are encouraged to exploit all available generating sites until the marginal cost of producing RES-E equals the proposed feed-in tariff p (cf. figure 1). The amount generated then corresponds to q.

The overcost is generally paid by cross-subsidies if incumbents legally retain an important captive market that allowed cost pass-through on the tariffs, or by a special fund fed by a tax on each kWh.

Figure 1: Incentives and rents by fixed feed-in tariffs



In the simplest case of a uniform feed-in tariff, all producers in a given technology band whose marginal cost is lower than the fixed feed-in tariff benefit from the same tariff p. In a static approach it is a differential rent that is thus granted to producers who have lower production costs (windy sites, easier access, abundant resources (biomass), etc) than the marginal producer: the rent is represented by the area (*cAp*) between the marginal cost curve (Cm) and the feed-in tariff *p*.

Carefully defined instruments can arbitrate between social preferences for preserving amenities by avoiding a concentration of installations at the most profitable sites (in particular in the case of wind power and small-hydropower units) and economic efficiency, which requires the most productive investments to be realised first. Indeed, the magnitude of differential rent will concentrate investment in very profitable sites where it could be disputed by social perception of the inconveniences associated with RES projects. Consequently it may be socially profitable to ensure a minimum profitability to producers at lower-quality generating sites while at the same time controlling the rent allowed to producers who benefit from more favourable conditions. This is possible with a tariff that decreases incrementally and in inverse relation to site productivity. This helps to limit the differential rent on the most favourable sites: the rent with a differential tariff is the area (*p'BAc*) situated between the marginal cost curve and the increments resulting from the tariff[5].

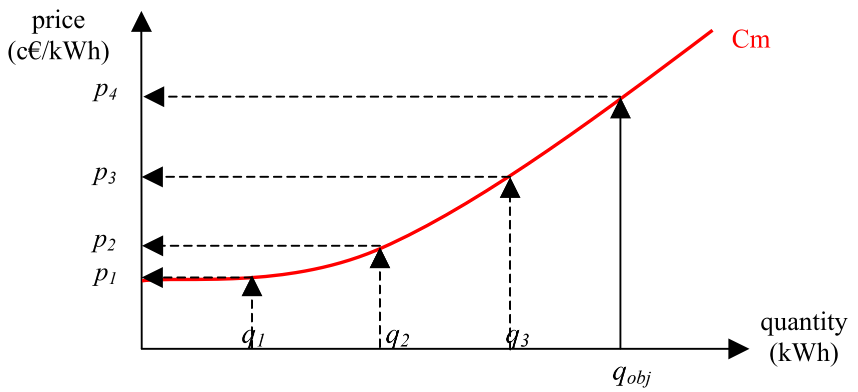
It is the same rent limitation logic that leads to differentiation of tariffs between various technologies in order to avoid promoting only the ones nearest to economic competitiveness. The possibility of a moral hazard from the promoter should not be ignored in this situation (as in the design of energy efficiency policies based on voluntary agreements, for example) with the possibility of the regulator being captured by the developers in a context of asymmetric information.

- ***Competitive bidding processes***

In the case of competitive bidding processes, the regulating authority defines a reserved market for a given amount of RES-E [1]. For example, the stated objective of the NFFO in the UK was to develop 1500 MW of new generating capacity from renewable sources by 2000 (DTI, 1995). There were also a quantitative objective in the French Eole 2005 to increase wind production capacity to a level between 250 to 500 MW by 2005. Competition between developers affects the awarding of long-term contracts with constant prices. Selection operates mainly on the basis of the price per kWh proposed during the bidding process established under the rule of the pay-as-bid price auction. Proposals are classified in increasing order of price until the amount of capacity to be contracted is reached. Each renewable energy generator selected is awarded a long-term contract to supply electricity. Regional electric utilities with captive markets (generally the incumbents) are then obliged to purchase the electricity from the selected RES producers located in their area. Bidding systems were used in the United Kingdom under the Non-Fossil Fuel Obligation (NFFO), in force from 1990 to 1998, which concerned different renewable energy technologies, and in France with the Eole 2005 programme set up in 1996 and abandoned in 2000, which concerned only wind energy.
The overcost for the mandated buyers is financed by the same ways as those implementing in the feed-in tariffs systems, in particular a fund financed by a tax on every kWh marketed.

[5] For a detailed discussion of the mechanism of incremental guaranteed feed-in tariffs, cf. El Green, 2001.

Figure 2: Incentives and rents with competitive bidding



This device with pay-as-bid price has the advantage of eliminating the differential rent as producers are paid at their bid price (p_1, p_2, p_3 corresponding respectively to q_1, q_2, q_3, which is supposed to be very near their marginal production costs because of competition. It is also noteworthy that bidding procedures requires differentiation of technology bands, as in the feed-in tariff system, in order to avoid competition between technologies at the premature stage.

Competitive bidding must not be considered a pure quantity-driven mechanism. The reason is that no quantitative objectives of renewable electricity production are set to electricity suppliers, as with the exchangeable quotas approach (see below). The objective here is defined on a national basis, a given capacity of RES to be reached in the year t; the producers are in competition with each other to be awarded a contract and benefit from the subsidies. We consider anyway that it belongs to the quantity-driven approach as, unlike the feed-in tariffs, it allows control of quantities produced (see below). It can be interpreted as a process of allocation of rights to receive a subsidy to produce by renewables under a long-term contract, these rights being interpretable as property rights on environmental goods.

- ***Quotas and green certificates***

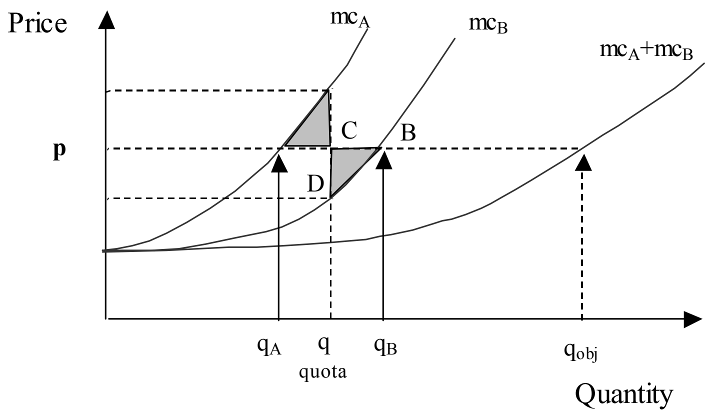
In this type of scheme, a fixed quota of electricity sold by suppliers on the market (it could be another type of agent, either electricity generators or consumers) must be generated from RES[6]. Operators then have the possibility of generating the required amount of electricity themselves, purchasing it under a long-term contract from a specialised renewable energy generator, or purchasing certificates from other operators with RES capacity beyond their quota or specialised entrants (Voogt et al., 2000). Certificates are issued by renewable electricity generators who benefit from generating renewable electricity in two different ways: by selling kWh on the electricity grid at the market price, and by selling certificates on the green certificates market.

The amount of green electricity to be generated is decided for the whole country for different time horizons, as in the case of bidding schemes, but it is allocated among each of the suppliers (generally defined in terms of supply share). Since operators do not all benefit from the same opportunities to use renewable energy sources and thus have different marginal production cost curves[7], the exchange of green certificates enables quotas to be reached in an efficient way. In a system without such a

[6] This obligation concerns suppliers in the United Kingdom, producers in Italy and in the near future consumers in the Netherlands.
[7] In the case of wind energy, for example, it is obvious that a self-producer/distributor situated near to a coastal area will have greater resources, enabling him to achieve lower production costs than another one situated inland.

flexibility mechanism, (which could be seen as a "command and control" approach), operators with identical obligations would incur different marginal costs, which would be a source of inefficiency. With the exchangeable quotas, the general obligation is shared efficiently: marginal production costs are equalised among operators and specialised producers are encouraged to enter the market[8]. It is a decentralised quantity approach, but the general quota q_{obj} is reached with an equilibrium price *p* on the green certificates market that would be the same as the marginal price with the feed-in tariff and the bidding system in a perfect information situation.

Fig. 3: Differential rent in the quotas/green certificates system



Comparatively to the feed-in tariffs, there are few differential rents in this system. Every supplier is obliged to respect the quotas and to pay for the overcosts of its RES production and/or purchase. The operators' differential rents (here the triangle CBD for the seller of the certificates) result only from the advantage that some of them (the sellers of certificates) could draw from favourable local situations and low cost production capacity beyond their quotas.

It is noteworthy that this quantity-based instrument could be hybridised by price-based measures. On one hand-side a penalty has to be paid by operators who are unable to respect their quotas of RES by self-production, contractual purchases or certificate purchases. The penalty constitutes in fact a price cap on the certificates market; it could exert a limitation on the rent of the best-endowed developers and on the value of their marginal projects. On the other hand-side, the amount of funds gathered by the payment of penalties could be used to subsidise investment in new units.

3.2. Instruments and cost controllability

As with environmental policies, under the dual hypothesis of perfect information on the cost of RES projects and zero transaction costs, price-based and quantity-based schemes produce very similar results. It is therefore equivalent to introduce a feed-in tariff *p* resulting in an overall quantity of production *q*, or to fix a quota q_{obj} corresponding to the same quantity *q*, the equilibrium price (in the green certificates market) or marginal price (in the case of bidding processes) then becoming established at the level of the feed-in tariff *p*. The administrative authority can define the "price" in the case of the feed-in tariffs, or the "quantity" in the case of green certificates or competitive bidding, so as to reach the same green electricity production target.

However, as in environmental policies, price-based and quantity-based approaches are not equivalent in situations where information is incomplete and where there is uncertainty on the shape of the cost

[8] With the quotas, the same results could be achieved without flexibility mechanisms by assigning different objectives to each operator. However, in a situation where the public authority (and probably also the operators themselves) have only incomplete information, it is very difficult to allocate efficient quantities q_A and q_B that would equalise marginal costs (mc_A & mc_B).

curve (and damage curve) (Cropper and Oates, 1992). There is no symmetry at all between the price-based and quantity-based approaches, and one or the other may be preferred depending on the respective shape of the production cost curves (Weitzman, 1974). If it is assumed that the RES curves are relatively flat[9], it can be seen that a slight variation in the proposed feed-in price will have major repercussions in terms of quantities produced. As the overall cost of achieving an objective q is given by the product $p.q$, an overestimated fixed feed-in price will produce a significant increase in RES production and a large public subsidy total. In contrast, with the same assumptions, the quantity-based approach will help to limit this risk as fixing a quota or organising successive competitive bids are two ways of ensuring total control over quantities and hence indirectly over the volume of public subsidies.

However, when the production cost curves are unknown or difficult to anticipate, none of these three approaches allows anticipation of the overall cost of green electricity production sought by the government. Guaranteed feed-in tariffs offer a way of controlling the cost of the measures to be implemented, as by setting a ceiling for the marginal cost, guaranteed prices eliminate options that are too costly; however, as the marginal cost curve is unknown *ex ante* and only anticipated, the total burden to the economy cannot be foreseen. Moreover, in order to balance the RES productions from the different technologies, bands have to be organised for each of them in order to reach the overall objective without favouring solely the one nearest to commercial maturity, which could increase uncertainties. Conversely, the quantity-based approaches (bidding, quotas) by definition offers direct control over target production levels but does not judge in advance of the level of the price and the total cost so far.

The problem of controlling the overall cost can be partly overcome in both types of instrument. In the bidding device used in the UK, its drawback has been overcome by setting the global amount of subsidies to be allocated to the RES projects from the special fund fed by the Fossil Fuel Levy, which was also dedicated to supporting the nuclear units (Mitchell, 2000). In the exchangeable quotas system, if the price of certificates reveals that suppliers have much higher marginal costs than was anticipated by the government, it is perfectly at liberty to adjust the increasing quotas at a lower level in future. In the price-based approach, successive adjustments to the feed-in tariffs (particularly downwards, which is rarely acceptable politically) would have to be made to achieve the desired level of production.

4. Rent sharing and stimulation of technological progress

The second justification for public RES incentive policies is that they stimulate technological change, as none of the RES technologies are as yet sufficiently mature to compete on the electricity market. Technological change will partially depend on the intrinsic characteristics of the incentive instruments used (their respective success in terms of dissemination) and on competition between developers that they may induce (§ 4.1). It will also depend on the amount and sharing of the resulting technological rent which is an incentive to innovate if partly or completely appropriate; but the amount of this rent depends also upon the instruments to be used (§ 4.2).

4.1. Impact of the surplus profile on technological progress

By analysing the distribution of surplus between various players, we extend the approach beyond the ability of the instruments to reach a given objective at a lower cost with the existing basket of technologies (in static efficiency criteria). In fact, we include two combined but different factors of dynamic efficiency and technological progress: first, the performance improvement induced by scale economies and technological learning associated with increasing dissemination of new technologies,

[9] The shape of the cost curves is not precisely known but the latest studies suggest that they may be rather flat, below the objectives set by the European Directive for 2010 (ElGreen project, 2001*, Action Plan for a Green European Electricity Market*, European Commission).

which is called induced progress in the literature, and second, the technological progress resulting from dedicated R&D activities initiated by constructors and technology users seeking to reduce costs and gain temporary competitive advantage. These two dynamics are intrinsically combined. However, the relative importance of the second may vary according to the profit level that constructors could anticipate from their contracts with the developers, which depends on the instruments of the policies. Lower surplus for the developers would mean less favourable contracts for the constructors and weaker incentives to invest in ambitious R&D activities.

To keep near to the reality of the renewables industry, we have to consider two different players regarding innovations in renewable energy techniques:

- The constructors who invest in R&D programmes and introduce innovations according to the perspectives of market expansion and their strategy to increase market share; whatever the instruments, the constructors are exposed to more competitive pressure from the developers to introduce improved and more efficient technologies;
- The RES developers/producers who buy the technology from the constructors and who could accept to pay a mark-up in relation to the level of anticipated profits that will result from the sale of RES kWh produced by their new projects. They are also supposed to compete but the pressure is far lower with feed-in tariffs than with auctions or exchangeable quotas; in the second and third case, they have to compete in order to gain long-term contracts or sell their certificates and reduce their costs, when in the first case they are in a situation of a price-taker on a perfect market, which stimulates performance improvements, but the opportunity for rent beyond normal profitability allows a level of sharing of total profits with constructors. In each case, therefore, there are different incentives to seek cost reduction by introducing technological progress.

For reasons of convenience, we will adopt here the same simplification as in the literature on oligopolistic competition based upon innovations, especially the literature on incentives to promote technological change in pollution control in a competitive situation (Milliman & Prince, 1989). In this literature constructors and producers are likened to one type of player, the motor of the competition being the bet on the temporary competitive advantage to be won from innovation by gaining a prime mover position. Here, the same simplification leads to another problem. As a result of this simplification, we consider first that the investment in RES production that incorporates technological progress is mainly incited by opportunities for technological rent appropriation, and second that the cost decrease may result from R&D investment on one hand and economies of scale or increasing returns to adoption on the other hand. In other words, in our interpretation we do not give the first place to the constructors' market share strategy, which would only be a consequence of the rent maximisation.

In this interpretative model, two hypotheses could be set; they have to be checked with empirical observations (see below). If the producer's surplus increases with technical progress, he will be encouraged to innovate in order to increase its future surplus (the larger the surplus, the higher the incentive and ability to invest in new technologies). If the producer is subject to competitive pressure that prevents raising of its surplus, he will not be incited to innovate in the same way; he will have to cut its static costs, possibly by taking the best available technologies from the basket of existing technologies, but he will also have less margin of manoeuvre for investment in R&D for future technological progress. We have the three following profiles.

- With guaranteed feed-in tariffs, the maximum surplus is allocated to producers, so that they are better placed to develop new technologies or to incite constructors to do it, even though this will cost the community more. In a dynamic perspective, the system accumulates its good result in terms of dissemination associated with increasing returns on adoption, combined with the possibility to reinvest in R&D to obtain additional technological rent in the future.

- The bidding system that makes producers compete with one another through competitive bids forces them to adopt the most efficient available technologies in order to be awarded contracts. Competition imposes reduction of every static cost. However, as this involves restricting their profit margins (by eliminating the differential rent derived from technological progress) despite important risk projects, initiating the innovation process through investment in R&D may be difficult.

- With the quotas/green certificates system the suppliers are also incited to reduce the cost of reaching their RES obligations and developing projects beyond their quotas to sell competitively green certificates. This may be important for independent developers who seek to have long term contracts or to sell on the certificates market. In comparison with the bidding system, which dissociates the technologies, the quotas system is less favourable to R&D investment because differentiation of technologies is not possible; this leads to concentration on the business nearest to maturity stage. Conversely, however, the quota system is assumed to force development of capacity and thus could present a good foreseeable nature of returns to scale for the constructor/producer.

A last important remark has to be made on the geographic framework of this analysis, which is that of a closed economy. Instruments are frequently judged according to their effects at promotion in a national RES manufacturing industry and thus by the capability given to the nascent industry to innovate on the national market. However, if we reason in an open economy, the drawback that an instrument could present in terms of limited impacts on promotion of the national industry and innovation could be overcome by importing technology and equipment from the leading foreign industries, which have benefited from the use of another instrument much more efficient in promoting such an innovative industry. In this open case the cost reduction objective can be reached by seizing the best available technology on the international market, but also abandoning the objective to establish an efficient national industry to compete for the procurement of RES equipment on the national and international market.

4.2. The technological rent: a graphical analysis of the instruments

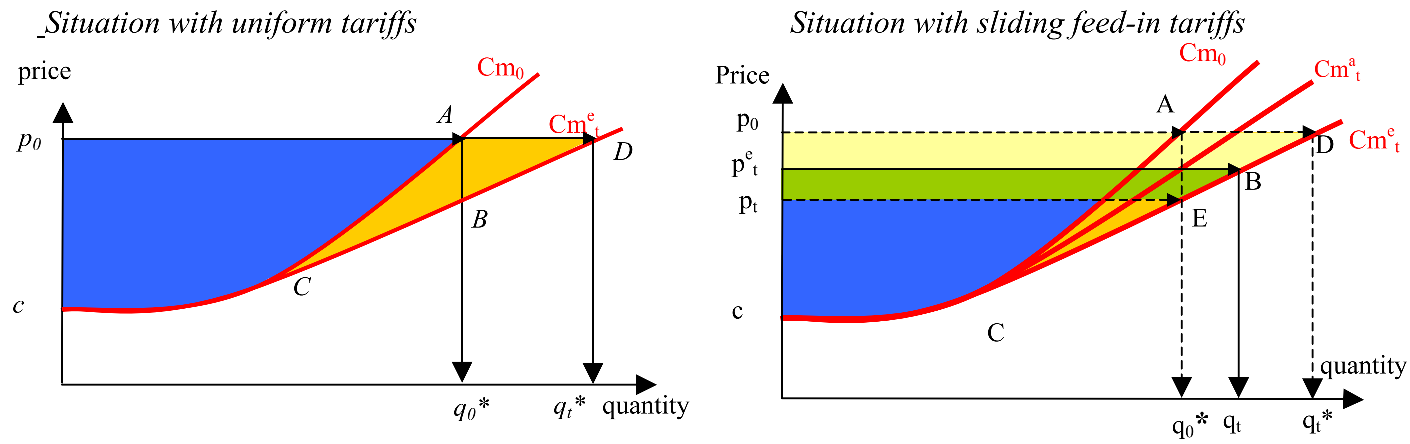
We also have to analyse the appropriation of the benefits resulting from technological progress. Extraction of technological rent is indeed a good incentive to innovate, but there is the same problem of equity and social acceptability as for the differential rent in the static approach. Whatever system of incentives is adopted, technological progress will produce a downward shift in the cost curve and the marginal cost of achieving a given goal will be lower following innovation. All else being equal, the effect will be to increase the surplus and the issue is to choose if all the benefits of the innovation have to be transferred to consumers or to the taxpayer. Depending upon the type of incentive used, the surplus created in this way will not be shared in the same manner.

- ***Guaranteed feed-in tariffs***

The consequence of price-based incentives is that the quantity of green electricity produced increases from q_0* to q_t*: for the same tariff level, producers can now exploit sites that were not economically profitable before the innovation (cf. Figure 4). This instrument gives producers the full benefit of the rent derived from technological progress (i.e. the area *ADBC*)[10]. In this case, therefore, technological progress leads to an unscheduled increase in the quantities produced. Consequently the producers' surplus increases by an amount represented by the area (*CA*)

[10] The rent derived from technological progress is defined as the increase in the producer's surplus, whereas new and more effective technologies are available.

Figure 4: Guaranteed feed-in tariffs and rent derived from technological progress



Key: Cm_0= marginal cost curve at 0; Cm^e_t= ex-post marginal cost curve at t.
Cm^a_t= anticipated marginal cost curve for defining sliding tariff
$q_0*_{(resp.\ t)}$= optimum production at 0 (resp. t);
q_t= production at t without sliding mechanism.
$p_{0(resp.\ t)}$= optimal fixed feed-in tariff at 0 (resp. t); p^e_t= effective feed-in tariff at t.

differential rent; rent from technological progress; gain (cf. text),
surplus allocated to producers owing to wrong estimate of real technological progress.

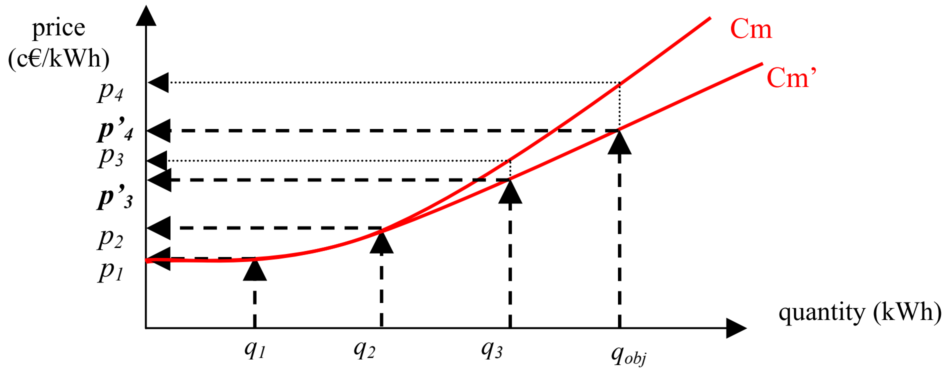
The numerous objections concerning the magnitude of the rent left to the developers through constant feed-in tariffs in case of technological progress has lead to the introduction of sliding feed-in tariffs, that is, anticipated decreasing tariffs to a specified horizon. The principle of a decreasing feed-in tariff involves anticipating technological progress (cf. figure 4) and hence the shift in the marginal cost curve. On the supposed new cost curve (Cm^e_t), the tariff needed to obtain the quantity q_0* is no longer p_0, but p_t.

However, the regulator does not know for certain how technology will develop, and he must therefore define a feed-in tariff p^e_t on the basis of anticipated technological curve (Cm^a_t). If the ex-post-cost curve (Cm^e_t) differs from the administratively anticipated cost curve (Cm^a_t) because of the moral hazard problem, the quantity produced will be q_t. A comparison of the two graphs (fig.4) shows that the decreasing price mechanism enables the area ($p_0DBp^e_t$) to be saved by consumers, in contrast to a uniform feed-in tariff, which grants the large surplus (cDp_0) to producers. In this way it is possible to limit, but not entirely eliminate, the rent derived from technological progress allocated to producers. Meanwhile this system ensures a more equitable distribution of the rent derived from technological progress; it reduces the overall cost for the community while at the same time giving an additional surplus to innovative producers (p_t EBp^e_t) comparatively to the situation the technological progress would be perfectly anticipated by the public authorities.

- ***Competitive bidding***

As in the static situation (see above), the procedure involving successive calls for bids means that the results of the competitive bidding can also follow the marginal cost curve without any intervention by the regulator (cf. Figure 6). The producers/developers integrate in their bids the anticipated cost decrease, which they hope has resulted from their innovative activities. The maximum prices p'_3 and p'_4 automatically replace the maximum prices p_3 and p_4 in the bids received from producers replying to the calls on $q_3 - q_2$ and $q_{obj} - q_3$, thus cancelling the potential rent derived from technological progress allocated to them[11].

Figure 5: Competitive bidding and rent derived from technological progress

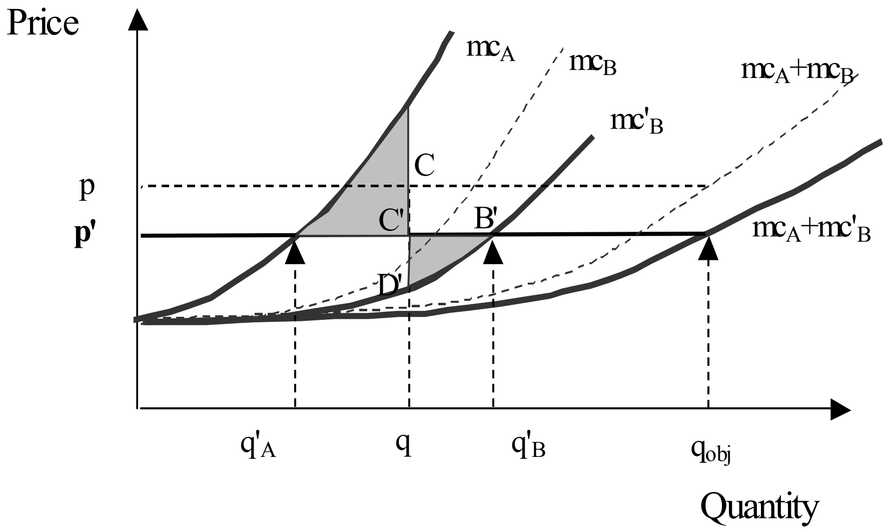


- ***Quotas and green certificates***

In the case of quotas, under the pressures of the mandated suppliers and the competitive pressures of the certificates market, technological progress is introduced by the RES-E producers who get different innovative capabilities. As in the static case, each player have indeed to fulfil their obligations at their own cost, and the technological rent could only be extracted by going beyond their quota by the exchange of certificates. In order to simplify we consider the simplest device of exchangeable quotas without penalty and we analyse briefly three cases: the case the sellers of certificates are much more rapid to exploit knowledge progress than the other ones, the case the buyers of certificates use innovation to reduce their cost handicap while the former certificates sellers are technologically static, and the case every producer is able to made the same technological effort on the leading technologies for their future units.

[11] Depending on marginal cost curve shapes and technological progress rates, average bidding prices for successive tenders may even fall (see below).

Figure 6 .Technological rent in the quotas/green certificates system:
The case of the certificates seller's active innovative strategy



In the first case (see Figure 6), Producer B, who is initially a seller of certificates, is much more dynamic in the introduction of technological progress in its new projects than Producer A, who is a buyer of certificates. This lowers its marginal production cost curve mc_B to mc'_B. This has paradoxical effects in the case of exchange of certificates: with the same quota q, the equilibrium price decreases from p to p', Producer A (who is a buyer) has an interest in buying a larger share of its certificates on the market, and Producer B is encouraged to produce more certificates because of its lower costs in order to sell them. But he would not automatically benefit from a technological rent because of the certificates price decrease which limits the gains on the market. It will be beneficial only if the area *C'B'D'* (fig 6) is higher than the area *CBD* in the static case (fig 3 replicated), which will be realised only under strict conditions on the respective slopes of the former and new marginal cost curves of the producers B.

The second case is a situation in which buyers of certificates try to compensate for their initial capacity handicap by exploiting technical progress for installing future RES capacities, while the former sellers do not move its technology. We could logically guess that this would reduce the price and the number of certificates exchanged on the market, and thus reduce Operator B's differential rent.

In the third case the marginal cost curves of the two representative producers decrease in a very similar way to the static approach. By and large the exchange of certificates will be quite similar, but in contrast to a situation they do not make innovation. No real technological rent is added to the small differential rent of the static analysis (triangle *BCD* in figure 3). The price of certificates will decrease. However, there is a positive difference for the consumers in terms of the RES equilibrium price on the certificate market because the marginal cost curves of the two producers is lower.

The framework of this paper does not allow this analysis to be developed further. However, this brief development is sufficient to argue that from a dynamic viewpoint, in the quota system the technological rent is either non-existent or very limited compared to the case of the feed-in tariffs. We are neither in a logic of virtual competition referring to an administrative price, as in the feed-in tariff case, nor in a logic of oligopolistic competition by innovation where temporary monopoly positions are searched, because of the nature of the quotas/green certificates system and the price-making on the certificate market. The real motive for innovation in this system is not the perspective of increasing market share on the green certificate market but the incentive for the producers to reduce their costs in order to reach the quotas because they themselves have to finance the overcost of the RES-E obligation. Finally, consumers could be the winners if the competition between the suppliers is such that their marginal cost decrease surpasses the market retail price in the configuration of the total opening up of the market.

- ***Comparison of dynamic efficiency***

To conclude on the issue of stimulation of technological progress by different instruments, a delicate balance has to be struck between the amount of differential and technological rent to be given to the producers and their equipment manufacturers in order to stimulate R&D investment in risky technologies on one hand, and the collective cost of the incentive policy to the economy, on the other hand.

With quantity-based instruments governed by market mechanisms, technological progress sharply reduces the rent allocated to producers and consequently the cost for the community. Moreover, making producers compete with one another through competitive bids forces them to adopt the most efficient technologies in order to be awarded contracts. However, as this involves restricting their profit margins by eliminating or limiting the rent derived from technological progress, they have difficulty in initiating the innovation process by investing in R&D. So it is with the quotas system to a certain extent: the logic of decentralised competition on the certificates market does not allow the producers/constructors to contemplate a perspective of profit by innovations. In both cases they are limiting their cost decrease strategies to the choice of the best available technologies. In this situation, public R&D is the only way to improve technology.

Table 1: Comparison of total producers' surpluses according to support instruments

	Differential rent (static)	Differential and technological rent (dynamic)
Competitive bidding (fig 2/fig 5)	None	None
Quotas/Green certificates (fig 3/ fig 6)	Low (CBD)	Uncertain (CBD - C'B'D')
Constant feed-in tariff (fig 1)	Maximum (*cAp*)	Maximum (cDp_0)
Sliding feed-in tariff (fig 4)	-	Average (cEp^e_t)

With feed-in tariffs, the maximum surplus is allocated to producers, so that they are better placed to develop new technologies. None of these extreme solutions is really satisfactory. This is especially true of constant feed-in tariffs, which award the benefits of technological progress only to producers. From this point of view, sliding rates are the most attractive options as they do not entirely eliminate the surplus derived from technological progress as bidding processes do, while at the same time they enable consumers to benefit from the improved performance levels due to technological progress (Table 1).

5. Comparison of European experiences: relative performances of the instruments

As incentive programs based on these instruments in the European countries correspond to an experience of 10 years, an examination of the results obtained as a consequence of the incentives allow the analysis of the economic and social efficiency of these instruments to be complemented. It will now be examined in terms of cost-efficiency and in dynamic terms - technological and industrial impacts -, under the important caveat that, as the preceding analysis does not take into account the characters of the institutions and the transaction costs associated to each instrument, their observed performances are not only explainable by their theoretical properties.

The impact of these instruments appears to underline the fact that feed-in tariffs are better than competitive bidding procedures in terms of installed capacities, industrial development and technological learning, but with an important cost which could be viewed as the price to be paid to initiate the process in the first stage of the new technological cycle. Despite its novelty the quotas/green certificates systems could challenge some advantages of the feed-in tariffs during the second stage when technological and industrial maturity gets closer.

5.1. Effectiveness and cost of the instruments

The performances in terms of stimulation of RES-E installations must be balanced with the collective costs of the instruments.

- ***Stimulation of RES installations***

The two first systems exhibit radically different characteristics in terms of project profitability, risks and transaction costs that directly affect the investment.

If we refer to wind power as reference RES, the fixed feed-in tariffs in operation in Germany, Denmark and Spain have led to sustained development of wind power production: these three countries alone accounted for around 85% of additional installed capacity in Europe between 1998 and 2001. Total installed wind capacity in Germany, Denmark and Spain reached 7717 MW at the end of 2000, while it did not exceed 760 MW in the UK, Ireland and France.

Table 2. Comparison of installed wind power capacities in 2000 (in MW)

Incentives	Countries	Capacity end 1999	Additional capacity in 2000
Feed-in tariffs	Germany Spain Denmark	6113 2402 2297	1668 872 555
	TOTAL	10812	3095
Competitive bidding	UK Ireland France	409 118 79	53 45 56
	TOTAL	606	154

Source: *WindPower Monthly*, The Windindicator (http://www.wpm.co.nz), April 2002.

This result can be partly explained by the high price level proposed in the fixed feed-in tariff systems (7-9 c€/kWh) while the competitive bidding systems led to significantly lower prices (4-5 c€/kWh). All else being equal, it is perfectly logical for higher feed-in tariffs to correspond to greater quantities of RES. The differences between the respective prices do not however explain all the very significant differences between the installed capacities. The explanation also lies in institutional parameters, especially the very nature of each incentive device, its capacity to limit price risk, and the transaction cost around project definition and implementation. The more incentive nature of feed-in tariffs lies also partly in the fact that they are more predictable and limit transaction costs (Van Dijk et al, 2003; Haas, 2001).

By comparison, the bidding system means lower expected profitability than those associated with fixed feed-in tariffs and higher exposure to technological and political risks. Moreover, the British experience [[12]] revealed two other drawbacks: firstly dependence on governmental decisions to open auction rounds which creates uncertainty that does exist in the feed-in tariff system and in the

[12] See for instance (Mitchell, 2000).

exchangeable quotas systems; secondly even when numerous candidates have been selected, remaining uncertainty regarding the feasibility of projects, which is reflected by the cancellation of most of them.

Firstly, indeed, the fact that bidding procedures take place at irregular and particularly unscheduled intervals creates a climate of instability that works to the disadvantage of operators, in contrast to feed-in tariff systems. Secondly, the high transaction costs incurred by the bidding procedures (for project formulation and monitoring), in addition to the cost of obtaining building permission, has undeniably been an obstacle. High transaction costs have led to larger projects, and this in return has meant difficulties in obtaining planning permission. Feed-in tariffs (FIT) may also appear less sensible to political will than bidding systems. It is noteworthy that this could play also against the adaptability of the instrument when the collective cost reaches the limit of social acceptance. Of course, FITs can be removed or the prices lowered by the regulating authority but the opportunities of administrative interference seem rather limited when the tariffs has been set. Comparatively, there are numerous possibilities in the bidding system to influence the system by modifying the selection criteria or the relative importance of each technology band. In other words, the balance between the risks involved and expected profits is thus clearly to the disadvantage of competitive bidding.

Conversely, the quotas system is by nature more effective that the competitive bidding system to incite to develop RES for two reasons. It is a foreseeable mandatory system with an individual obligation to respect the quota under the incentive of a penalty; and the foreseeable nature of the quota and the penalty allows the possibility of anticipating and adapting in order to overcome project risks. This system is not exempt from transaction costs and market uncertainties, especially for the green certificates exchanges, but adaptations are observed that allow transaction costs to be minimised: the creation of organised market with standardized transactions, and the development of long-term contracts between developers and suppliers subject to the RES obligation in order to secure RES investment. The experience of the Texas renewable portfolio standards demonstrates that almost all the RES-E capacity development has occurred in this institutional framework (Langniss and Wiser, 2003).

- ***The collective cost of each instrument***

Efficiency in terms of installed capacities has to be balanced with the collective cost to the economy. The policy of guaranteed feed-in tariffs has proved very costly in terms of public subsidies. This is the direct result of its positive effect on RES. Subsidies paid in 1998 by the Danish government represented more than 100 million euros and this amount had to continue growing because of the regular increase in capacity, creating an ever-increasing burden on the State budget (Morthorst, 1999) until the new government challenged it in 2002. This policy also requires costly cross-subsidies that have been estimated at around 200 million euros in Germany in 2000. In France, two years after the adoption of feed-in tariffs, control of the future amount of the subsidy (financed by a tax on each transmitted kWh) is a motive to slow down developers by means of bureaucratic hurdles and envisage the adoption of a quota system in the future.

In the case of bidding systems, the possibility of controlling quantities or the amount of public subsidies allocated to RES is a major advantage. In this respect, a quantity-based approach enables public expenditure to be controlled more efficiently by organising incremental increases, or conversely to slow down, progressively revealing the shape of the cost curves. A comparable result could have been obtained with guaranteed feed-in tariffs, but the system is rigid from the institutional standpoint, making it difficult to adjust guaranteed prices in accordance with technological progress and installed capacities. Introducing sliding rates is a real progress in this respect, with price changes announced from the outset.

In the quotas/certificates system, the quantities are also directly controlled; however, the problem of controlling public subsidies is overcome because all expenses are directly financed by the mandated suppliers, which is a trump card for its political acceptation. As for the bidding system, the issue stays in the definition of the national goal and the derived quotas, given the country's endowment of resources and the reasonable rhythm of development of the RES capacity. It is a matter of not overcharging the suppliers, increasing their expenses in order to respect their RES obligation, and raising electricity price levels. With an established objective, however, the certificate exchange mechanism clearly works in the direction of the overall economic efficiency.

The social efficiency of each instrument can be assessed at this stage by balancing their collective cost (so important in the case of the feed-in tariffs) with the implicit value allocated to preservation of collective goods (environment quality, climate stability). We have already stressed the fact that the damages avoided cannot be precisely and reliably assessed. The answer to this problem is the definition of the quantitative RES installation objective, which corresponds to a quantitative avoided emissions objective. Other things being equal (such as endowment in resources), each governmental objective could be assumed to reflect the collective preference of each country to preserve the global environment.

The social efficiency of instruments cannot be assessed independently of their context of collective preference. In other words, the high collective cost of a support instrument that allows a large installed RES capacity to be promoted does not reflect *a priori* excessive investment by an economy. It should therefore be stressed that the objectives initially set by the governments that opted for competitive bidding systems (UK, Ireland, France) were much less ambitious at the outset than those of the German, Danish and Spanish governments, which chose the feed-in tariffs. The difference between the results obtained with competitive bidding and feed-in prices is thus due in part to the fact that the implicit aims in the two cases were significantly different, in particular in terms of policies costs. However, the European harmonisation process, marked at the present stage by the RES Directive, could in future unify the perception of the RES benefits and the instruments used to support them, especially the quotas system.

- ***5.2. Dynamic efficiency: technological and industrial impacts***

As explained before, feed-in tariffs and pay-as-bid tendering schemes differ in terms of how the surplus resulting from differential rent and technological innovation is shared out. In the first case, it is producers/investors and manufacturers who benefit from lower costs, if prices are not adjusted in step with technological change, while in the second case, producers pass on cost savings to taxpayers or consumers. Innovation incentives are thus different from one scheme to another if one considers the surplus increase expected from technical change.

Innovation and adoption must be differentiated here. In the bidding system, competitive pressure has indisputably forced the developers/producers to cut their costs down, in order to remain competitive: in England and Wales, for example, since the first Order was made in 1990, the average price paid to projects awarded contracts has decreased from 6.5 p/kWh to 2.71 p/kWh (Haas et al., 2001). This result has been obtained by seeking more favourable sites and economies of scale, organisational and technological learning, and the adoption of available more efficient technologies. The unfavourable sharing of surplus, however, does not favour investment in technological innovation programs and narrows the potential for emergence of new RES equipment manufacturers.

Available empirical data are insufficient for performing a detailed analysis of surplus-sharing between producers and consumers and its consequences in terms of industrial development and technological progress. However, an examination of the incentive systems implemented in the various European countries confirms the results obtained by our analysis.

On the industrial level, the impact differs between countries that have set up guaranteed tariffs and those that use competitive bidding schemes. In 2000-2002, Germany, Denmark and Spain were home to eight of the ten biggest wind turbine manufacturers in the world (Table 3). On the other hand, in the United Kingdom, the government has not reached its goal of developing a competitive renewable energy industry. The premature opening of the market to competition has had an eviction effect on inexperienced British manufacturers to the advantage of Danish manufacturers who, better prepared by a much larger national market, have supplied Britain with most of its wind energy generating equipment.

Table 3: Top ten manufacturers in 2001

Manufacturer	Country	MW sold in 2001	Market share in 2001 (%)
Vestas	DK	1630	*23*
Enercon	D	989	*14*
Neg Micon	DK	875	*13*
Enron Wind	USA	861	*12*
Gamesa	SP	649	*9*
Bonus	DK	593	*9*
Nordex	D	461	*7*
Made	SP	191	*3*
Mitsubishi	JP	178	*3*
Repower	D	133	*2*

Source : Observ'ER, 2003

The constitution of a competitive industry parallel to the innovative process can be viewed as the justification of the important cost of the feed-in tariff system, much larger than with the quantity-driven approaches. It also has had a clear positive effect in terms of innovation and investment cost decrease in Denmark and Germany (IEA, 2000). The wider diffusion observed, and the more favourable sharing of surpluses, has been profitable to RES producers and constructors who have had time to consolidate their industrial basis and invest in R&D programs. Conversely, the experience with the bidding system in the United Kingdom shows that the reduced margins inherent in the system limit the budgets of developers and manufacturers. It has encouraged producers to adopt foreign best-available technologies in order to remain competitive, but it has not enabled them to present well-structured industrial supplies or invest major resources in R&D. Consequently, in interdependent economies operating different support mechanisms, the reduction in observed costs for wind generating systems with bidding systems is supported by the technical progress made by manufacturers in countries where support policies are deliberately favourable. In these countries, since firms are allowed to benefit from the differential rent, feed-in tariffs make it possible for manufacturers to invest more heavily in R&D and consolidate their industrial base.

The adoption of the quota system could re-shuffle the cards. However, on the basis of the preceding analysis, the limitation of differential rent and technological rent for manufacturers and RES producers, and the need for the mandated suppliers to limit the cost of their obligation, do not create a favourable context for a RD effort. Fortunately, this device is being adopted in Europe at a time when some national RES equipment industries have had time to reach the stage of maturity by consolidation allowed by the feed-in tariffs systems; but it appears probable that the quotas system will not promote home technological effort or national industry.

6. Conclusion

The theoretical discussion of the search for a more economically and socially efficient support system and a fairer distribution of the surplus resulting from public incentive policies between producers and the community reflects the public authorities' anxiety for supporting the development of RES and their technological progress while at the same time improving public welfare.

Comparing the efficiency of price-based and quantity-based systems is thus a way of helping to improve the manner in which they are supported rather than one of backing the partisans of one system or the other.

In terms of installed capacity, much better results have been obtained with price-based approaches than with the quantity-based approaches that have been used until recently. In theory, this difference should not exist, as bidding prices set at the same level as feed-in tariffs should logically lead to comparable installed capacities. The difference can be explained by the higher feed-in tariffs and the stronger incentive effect of guaranteed prices, which makes this incentive system more stable and more predictable in the eyes of investors. On the other hand, quantity-based approaches are more efficient as bidding for defining and adjusting the overall goals and adjusting the quotas provides an indirect way of controlling overall costs.

Table 3. Comparative advantages of the different instruments

	Triggering new capacities	**Competition between generators**	**Collective cost**	**Incentive to innovate (RD, etc)**
Feed-in tariffs	Effective	No	High	Effective
Bidding	Weak (political influence)	Partial (auctions)	Controlled	Weak, but adoption of foreign BAT*
Quotas/certificates	Effective (quotas)	Yes	Controlled	Not yet, but adoption of foreign BAT*

*BAT: business as usual technology

Fixed-price and pay-as-bid systems lead to two situations that differ in the way in which the differential rent is distributed. In the case of fixed feed-in tariffs it is the producers who benefit entirely, whereas in the auction/pay-as-bid system and the quota/certificate system, very little or no rent is given to them. Similarly, the surplus resulting from technological progress is distributed solely to the benefit of producers in the case of fixed price systems and solely to the benefit of consumers in the auction/pay-as-bid system and quotas system. Consequently, they have different impacts on the possibility of developing a national RES manufacturing industry and benefiting from the learning.

European experience in supporting wind energy shows that in the first case, conditions are more favourable for the development of new technologies but at a high cost to the community, whereas in the second case the lower margins for producers raise questions concerning ongoing technological progress. Between these two extremes, sliding feed-in tariffs that make allowance for improved performance levels are incentive systems that distribute surplus more fairly between producers and consumers and are thus of obvious interest in supporting the development of new energy technologies without the entire cost burden falling on the consumer.

The potential advantages offered by green certificate trading systems based on fixed quotas are encouraging a number of countries to introduce them in order to achieve high installation targets in an economically efficient way. Greater control over quantities, competition among producers and the incentive to lower costs are among the main reasons for adopting green certificates. This system also has an advantage over the others in terms of efficiency of allocation. This advantage, which is based on the exploitation of differences in marginal costs, can be usefully applied at European level to reach the targets fixed by the European Directive at the lowest cost to the community (REBUS, 2001). However, as long as uncertainties remain, especially concerning the operation of the certificates markets and the creation of a framework that investors consider stable, its actual efficiency and its ability to stimulate innovation remain to be proven.

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