Fighting windmills?

EU industrial interests and global climate negotiations

Urs Steiner Brandt
Gert Tinggaard Svendsen

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Urs Steiner Brandt
Department of Environmental and Business Economics
University of Southern Denmark
Niels Bohrs Vej 9-10
DK-6700 Esbjerg
Tel.: +45 6550 4184
Fax: +45 6550 1091
E-mail: usb@sam.sdu.dk

Gert Tinggaard Svendsen
The Aarhus School of Business
Department of Economics
Fuglsangs Allé 4
DK-8210 Aarhus V
Tel.: +45 8948 6408
Fax: +45 8615 5175
E-mail: gts@asb.dk

Abstract

Why has the EU been so eager to continue the climate negotiations? Can it be solely attributed to the EU feeling morally obliged to be the main initiator of continued progress on the climate change negotiations, or can industrial interests in the EU, at least partly, explain the behaviour of the EU? We suggest that the EU has a rational economic interest in forcing the technological development of renewable energy sources to get a first-mover advantage, which will only pay if a sufficient number of countries implement sufficiently stringent GHG reductions. The Kyoto Protocol, which imposes binding reductions on 38 OECD countries, implies that, as a first-mover, the EU will be to sell the necessary new renewable technologies, most prominently wind mills, to other countries, when they ratify and implement the Kyoto target levels. In the latest EU proposal made in Johannesburg, the EU pushed for setting a target of 15% of all energy to come from sources such as windmills, solar panels and waves by 2015. Such a target would further the EU's interests globally, and could explain, in economic terms, why the EU eagerly promotes GHG trade at a global level whereas the US has left the Kyoto agreement to save the import costs of buying the EU's renewable systems.

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Keywords: First mover advantages, Wind mill industry, greenhouse gases, Kyoto Protocol, EU.

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1. Introduction

During the negotiations that followed the Kyoto-agreement, and especially at the meetings in The Hague, the EU and the USA seemed to follow different paths regarding the alleviation of the climate change problem. According to Brandt and Svendsen (2002), the Kyoto agreement imposed unnecessarily high costs of implementing the targets. In particular, the hot air issue and free trade restrictions, together with the strong incentives to free ride on agreements to alleviate the climate change problems, explain well why the United States dropped out of the Kyoto agreement.

But why did the EU not drop out too? One explanation could be that the EU feels morally obliged to act on the basis of their responsibility for the present stock of anthropogenic greenhouse gasses in the atmosphere (see e.g. Woerdman, 2001). However, we offer an alternative explanation, which gives a more down to earth economic rationale for the EU to push forward ambitious greenhouse gas (GHG) reductions. The reason, it will be argued, is that the EU, and especially Denmark, has large potential first mover advantages if other countries face demanding GHG reduction obligations as well. These first mover advantages stem primarily from the EU knowledge in renewable energy sources, and for Denmark, primarily windmills. We argue that the subsidising of windmill production in Denmark has given this country a leading position in the windmill industry, and, as a consequence, an incentive to pursue a cooperative strategy in what otherwise resembles a prisoners' dilemma like problem.

Besides the effects of subsidies, the EU has also achieved a first-mover advantage compared to the United States because energy use has been more strictly regulated in the EU than in the United States. In other words, most exports of green technologies will be from the EU. That the EU is actively pursuing the promotion of renewable energy sources has also been seen at the summit in Johannesburg where: "*The European Union has been pushing for a target of making 15% of energy come from sources such as windmills, solar panels and* *waves by 2015. The US is vehemently opposed to those targets, judging them unrealistic, and so are petroleum-producing countries"* (UN, 2002).

The aim of this paper is to investigate how different ways of implementing of the Kyoto-agreement influence the relative competitiveness of windmills, and how this gives the EU incentives to shape policy in order to promote renewable energy sources.

This paper also adds to the debate about the feasibility of unilateral actions. Hoel (1991) mentions that if ”setting a good example” is the main reason for unilateral actions, then such actions will at best reduce the overall emission level (but by less than the unilateral reduction itself), but at worst, actually increase total emissions. Hoel (1991, p. 69) concludes that: ”it might not be particularly sensible for an environmental group in a country to try to force its government to unilaterally reduce the countries emissions”. Our paper presents a case where the presence of first mover advantages makes Hoel's finding less unequivocal. If unilateral actions can promote new technologies, and for example, verify that costs of reducing emissions are smaller than expected, there is potential for unilateral actions.[1]

Whether or not any particular first mover knowledge will also turn out to be successful in terms of export earnings hinges on numerous factors. In particular, two factors this paper focuses on are the evolution of the production costs and changes in the relative prices due to implementation of emissions reduction obligations. The evolution of the production costs depends on the shape of the learning curve for the relevant technology. The learning curve describes how unit costs of production change as the experience in using the technology increases. Ex ante, the exact shape of such a curve is uncertain, and a very interesting situation, from an analytical point of view, appears when the learning-by-doing cost reduction is not enough to make the technology competitive, unless

1 This issue is analysed in more details in Brandt (2002).

consumers abroad pay the full price for the energy.[2] This implies that whether or not the relevant technology can be exported to other countries depends on these countries' emission reduction plans. In this case, the country with the first mover knowledge has a strong incentive to convince other countries that they also have an obligation to implement policies to reduce CO_2 emissions. All this will be analysed by use of switch points, which describe how changes in the relative prices of different energy supply sources will change the composition of a country's energy supply sector.

By implementing the Kyoto-target, a country inevitably provides more favourable conditions for wind energy. Our paper shows that whether or not this makes wind energy competitive to conventional energy production depends on type of instrument used to make the relevant emissions reductions. If a sufficient number of countries agree on a common tradable permit market, and this market is well functioning, then it is not likely that changes in relative prices are sufficient to make wind-based energy competitive to conventional energy production. This means that the EU could promote their industry by not supporting unrestricted trade in permits, under the presumption that lack of full access to trade will not influence the countries' willingness to accept the original levels of reductions implied by the Kyoto-agreement.

The paper is organized as follows. Section 2 gives the theoretical background in terms of basic incentives (2.1), first mover advantages and switch points (2.2) and energy price estimates (2.3). Section 3 then turns to the historical reasons why the EU has been more energy restrictive than the US. Section 4 analyses the wind energy market, and the prospects of future market developments are discussed in section 5. Section 6 concludes the paper.

2 That is, the price reflects all costs of production, both the private and the social costs of production.

2. Theoretical background

2.1 Basic incentives in the greenhouse

Several papers recognize that the basic incentive structure in the climate change issue resembles a multiplayer prisoner's dilemma game (Barrett, 1998, Sandler, 1997). In a prisoners dilemma game each player has a dominant strategy not to contribute with abatement efforts. In a two-player version, the normal form of the game looks as depicted in Table 1 below.

Table 1: Basic incentive structure: prisoners' dilemma

Country 1	**Country 2**	
	Cooperate	**Do not cooperate**
Cooperate	(10,10)	(0,20)
Do not cooperate	(20,0)	(4,4)

Note: (*,*) means pay-off (country 1, country 2).

Table 1 shows the non-cooperative equilibrium outcome in bold (4,4), which is clearly non-optimal compared to the cooperative outcome (10,10).

This implies that reaching an effective agreement to address the climate change issue is complicated. Even worse, the necessary carrot-stick approach to change the prevailing incentive structure is not easily identified (Barrett, 1998, Mabey et al., 1997). Barrett (1997) notes that credible compliance mechanisms and effective monitoring systems are crucial in situations with strong free-riding incentives. Under such circumstances it is necessary to find the right "carrot-stick" approach, since progress will only result by finding the right mix of threats (against non signers) and incentives to promote participation.

Barrett (1997) argues that credible threats containing multilateral sanctions were presumably the main reasons why full participation in the Montreal Protocol could be sustained. On the contrary, Mabey et al. (1997) state that such initiatives are useless in the climate change problem. One reason being that the main oil producing and oil consuming countries are different. If sanctioning is a non-feasible strategy the only remaining possible way to change incentives is to make participation in the agreement more beneficial (compared to non-participation). It has, however, not yet been possible to identify ways of doing this, other than trying to minimize the costs of participating, by, e.g., using a cost efficient approach such as a tradable permit market.

In the light of this, it has been surprising to observe the EU eagerly arguing in favour of implementing the Kyoto-agreement, in spite of the fact that the USA rejected the agreement.[3] Furthermore, Denmark has chosen a high 21% reduction in 2008-2012 compared to 1990 emission levels. By holding on to such high levels of reductions Denmark's actions resemble unilateral actions, since the total reduction of the Annex 1 countries is about 5.2% and, with the USA not ratifying the Kyoto-agreement, even less. The excessive reduction's by Denmark compared to the average reductions by the annex 1 countries, is undertaken in spite of the fact, that Denmark's reductions only have a non-significant effect on the global stock of GHG-gasses in the atmosphere.

A very concerned country might initiate unilateral actions if such actions act as "setting a good example". Unilateral actions appear in many areas of the international society, e.g., unilateral reductions in armaments, unilateral aid to developing countries, unilateral reductions in trade sanctions or increases of trade concessions, and in the field of transboundary pollution problems, unilateral cut backs in emissions. Unilateral actions to alleviate international environmental problems have been analysed in e.g. Hoel (1991) and Barrett (1990). A rather pessimistic result emerges in both and their conclusion is that leadership of this kind is seldom rewarded.

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3 Bush announced in March 2001 that he opposed the agreement because it largely exempts developing countries and would harm the economy. Washington Post, June 2, 2001.

However, this view does not take into account the possible existence of first mover advantages. The emergence of new technologies can make the difference between success and failure of negotiations. As an example, according to Benedict (1991) og Sandler (1997), a crucial breakthrough enabling an agreement on the control of ozone layer depleting substances occurred, when innovators succeeded in producing substitution substances, such that the economic inventive changed dramatically.

2.2 First mover advantages and switch points

First mover advantages in the case we consider relate to technological leadership that materializes in export opportunities. Such technological advances can result due to either deliberate R&D in a selected area, or result as side effects of other types of actions, e.g. political actions. As an example of the latter, it is argued that subsidizing of wind energy after the first oil crisis in 1973 caused the Danish development of the wind turbine industry. The most important subsidy has been a price guarantee per produced kWh (kilowatt-hour): ”Without these subsidies, windmills as suppliers of electricity would not have been competitive compared to traditional power plants and hence the producers of windmills would not have got a foothold in the Danish industry. This is also illustrated by the development in demand where a large part of the wind turbines produced in the pioneering years in the 1980s were sold domestically whereas exports made up a substantial part of sales in the 1990s”. (Hansen et al., 2002, p. 1). In Denmark, 15 per cent of all electricity in the year 2000 was from wind energy (BTM Consult, 2001). Technological progress can also be a by-product when a country engages in a unilateral move to cut emissions, since such a move provides incentives for investments in R&D to find less polluting technologies. More broadly, technological progress includes development of new technologies, invention of new goods, or simply new (or better) insights gained in managing the pollution substances.

These observations indicate, as suggested by Porter (1990), that, in this case, it may indeed pay a country to subsidise its infant industries initially and then hope for future exports. Still, the ability of the state to pick the future winners in the market can be questioned. First, it could simply be a lucky punch as no one knew back in the 1970s that the greenhouse effect would be taken seriously a couple of decades later. Furthermore, a new report by the Danish Economic Council (2002) has questioned the profitability of the Danish wind turbine sector so far. It argues in detail that the investments undertaken by the Danish state have not paid off yet.

Let a country (or a firm in that country) develop a new technology for reducing emissions. Whether or not export opportunities exist for this technology depends on three main factors. Firstly, the installation and operation costs of the new technology are competitive compared to existing technologies. Secondly, the relative emission reduction from this new technology compared to existing technologies also increases the competitiveness of the new technology. Thirdly, the level of emissions reduction in the countries that import the new technology is decisive when considering the level or reduction and the type of instruments used to achieve the emission targets in question. Consequently, the cheaper the installation and operation costs, the higher the reduction targets and the higher the reduction that the new technology enables, the more likely it is that the new technology can be exported.

It is possible to identify two different types of first mover advantages. The first type results when the gain from the achieved technological progress only materializes in exports to countries engaging in serious reductions of emissions (such that relative prices in those countries change in favour of the new technologies). The second type of first mover advantages exists, when it is possible to develop new technologies that are competitive even in situations where countries do not have reduction targets for the relevant pollutant. A consequence of this second type is that they in themselves trigger reductions in other countries.

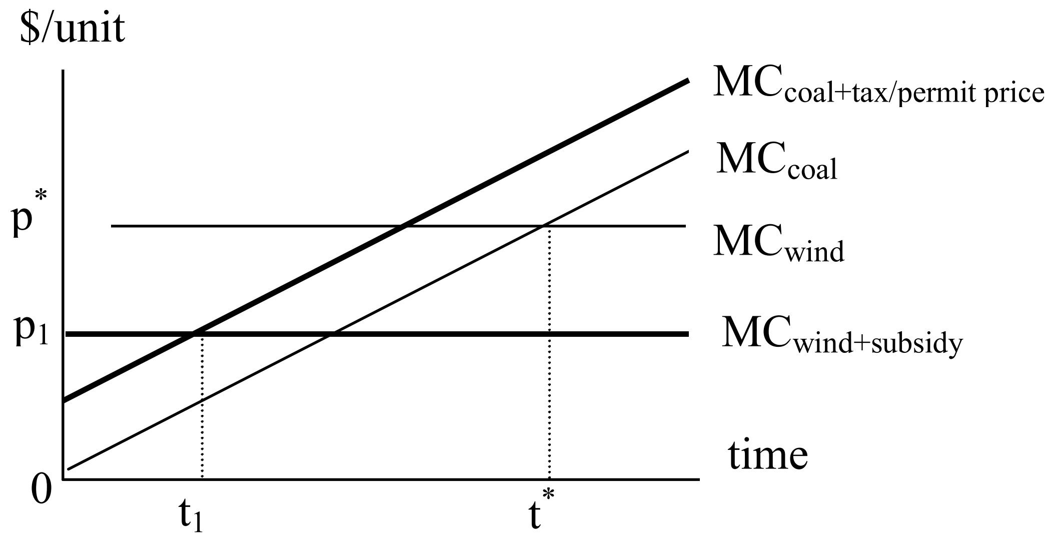
The windmill industry provides an example of the two different types of first mover advantages. As long as the price of energy remains between the prices of conventional energy supply with and without pollution control costs, the first type of first-mover advantage exists. On the other hand, when prices for energy from windmills fall below price of conventional energy supplies, regardless of prevailing state of emission reductions, there is an unconditional first-mover gain.[4] Consequently, the first mover advantages of the first type related to the climate change issue are closely connected to the relative price of energy output of different energy producing processes.

The shift from non-renewable fossil fuels to renewable wind energy will eventually happen because fossil fuel reserves are being slowly exhausted, while the wind reserves are inexhaustible, but the timing of events are, of course, important when analysing the potentials for first mover gains. The marginal costs of fossil-based energy production can be assumed to rise over time. For example, coal producers have to dig deeper mines or have to use less efficient coal. Eventually, it may suddenly pay to switch to a renewable resource, for example from oil to wind or solar energy in power plants. The essence of this switch (transition) point is that the marginal cost of energy production based on the substitute of wind energy sets the upper limit of the permit price.

Figure 1 depicts these ideas graphically. The vertical axis measures the cost per unit of energy (e.g., per mega watt) produced. The horizontal axis measures time. Marginal costs of energy production based on fossil fuels, here coal (MCcoal), rise over time. We use coal and wind energy as the main examples. We assume that the marginal costs of energy production based on wind energy are constant at p*. Within our interval, we expect that there is space and wind enough to produce one extra unit at the same marginal cost (MCwind). Without state intervention and regulation, it is cheaper to use coal than wind as an energy source until some future point in time, t^*. After the switch point t^*, wind energy becomes increasingly cheaper compared to coal-based energy.

4 Another example is the Montreal protocol, as discussed in section 3.

Figure 1: Switch point

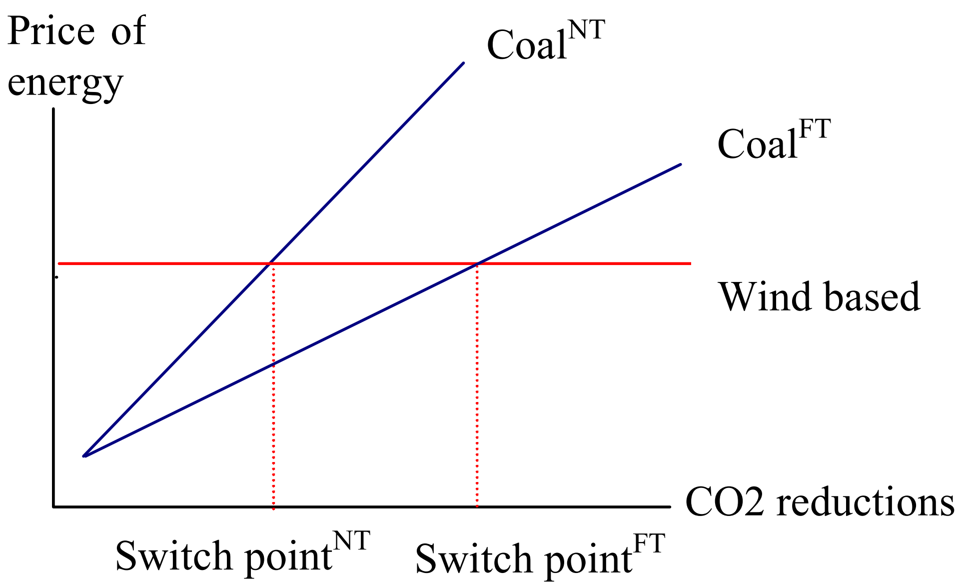


Source: Based on Tietenberg (2000, p. 134).

This development towards the use of renewable energy sources may be speed up if the environmental costs are added to the price of fossil fuels, for example by taxing fossil fuels or by adding the permit price of CO_2 emissions. At the same time, a renewable energy substitute may be subsidised. In this way, more stringent CO_2 reduction obligations increase the relative price of non-renewable fossil fuels compared to renewable wind energy. Figure 1 also depicts how governments can accelerate the switch point. If environmental costs are added to the MCcoal and if wind energy at the same time is subsidised, both lines will shift. MCcoal will be raised according to the added tax or permit price on CO_2, whereas MCwind will be lowered according to the subsidy. The new switch point occurs earlier on in time at t_1 with the marginal private cost of p_1. As argued by Tietenberg (2000), real prices of fossil fuels have in fact been falling (and not rising as shown in the figure) since the 1980s up until now for two reasons. First, world reserves of coal, oil and gas have continued to increase. Second, technological progress has fostered new low-cost methods of extracting fossil fuels. For example, reopening of old mines can, due to the new technology, be profitable. However, in the long run, reserves will be exhausted and the fossil fuel based energy production will face rising marginal costs as we assumed in figure 1.

The switch point approach can also yield valuable insights into how different policy options influence the timing of switch points. To illustrate this point, figure 2 shows a situation where only two possible types of energy production exist, coal fired and wind-based. Here we compare two policy options, a fully flexible situation, where no restriction on international trade in permits exists, and one where only domestic emission reductions are allowed. $Coal^{NT}$ identifies the price of energy produced by coal in a non-trade scenario, while $Coal^{FT}$ is defined as the coal based energy price in a full trade situation. Obviously, wind-based energy production becomes competitive compared to coal-based energy production at a lower emissions-reduction level in a non-trade situation.

Figure 2: Change in relative prices from different reductions policies



How does the appearance of first mover advantages relate to the switch-points? The appearance of technological improvements on non-renewable energy sources also changes the switch points, but now in all countries that can integrate the new technology into their energy supply sector less cheaply than without such technological changes. As discussed in section 4, a number of countries have a large potential for wind based energy production. Hence, technological improvements also accelerate the switch points abroad. Consequently, from the point of view of the country that makes the first move, this will make the investment in new technology more likely to be profitable.[5]

2.3 Energy price estimates

As demonstrated in Figure 2 above, we based our analysis on a static picture of the technological levels. Figure 3 illustrates the estimated average windmill price per kW over time.[6] Although prices of energy produced by windmills have been falling due to the ”learning by doing” effect, as discussed in Hansen et al. (2002),[7] the simple projection of trend presented in figure 3 shows that the potential for further cost reductions are likely to be small. A picture that is consistent with the more rigorous analysis in Hansen et al. (2002). Hence, the most likely reason why wind-energy will be competitive will be its environmental advantage.

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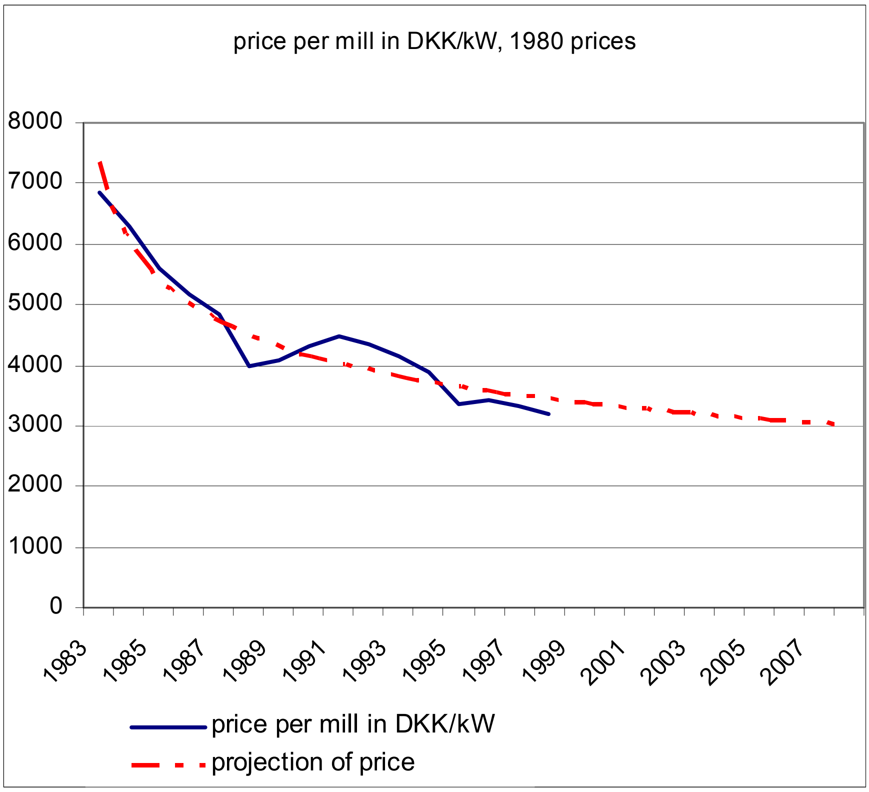
5 Note, however, that first mover advantages are not likely to be everlasting, since other technologies might also become competitive, see, e.g., figure 5.

6 The technological development has been stimulated both by the process and product innovations as the capacity of the individual mill has increased; see Madsen et al. (2002).

7 The technological development following learning-by-doing within the wind turbine industry is impressive: ‘Wind turbines have grown dramatically in size and performance during the past 15 years. The early machines of 25 kW with 10.6-metre rotor diameter can still be found in Denmark, but today the most widely sold turbines have a rated power output of 750–1000 kW and a rotor diameter of 48–54 metres. The largest machines commercially available are 2,500 kW machines with 80-metre rotor diameter placed on 70–80 metre towers. Each 2,500 kW machine produces more energy than 200 old 1980 vintage machines. Productivity thus has increased rapidly.’ (Krohn, 2001). The crucial parameter is the diameter of the turbine – the longer the blades, the larger the areas swept by the turbine and the greater the energy output. Therefore, the trend is towards larger machines.

Figure 3: Price per mill DKK/kW, 1980 prices



Source: Hansen et al (2002), table 1, page 4.

In order to determine whether or not implementation of the Kyoto-protocol is sufficient to make the wind-based energy production competitive, we first need to establish the relevant size of the emission tax equal to the marginal cost of reduction (the implicit price of CO2). Next, we need an estimate of the marginal costs from using different instruments to implement the Kyoto-protocol. If the marginal cost of implementing Kyoto-protocol exceeds the necessary tax, then this indicates that wind-based energy will become more competitive.

Concerning the relevant size of the emission tax, Hansen et al. (2002) calculate how much the tax on CO_2 emissions must be in order for the wind-based energy production to be cheaper than coal-based production. Table 2 relates the present value of the yearly loss from all energy generated by windmills (compared to conventional energy production) to the total savings of CO_2 emissions for a period of production of 10 and 15 years, respectively. This means that a tax on

CO_2 per ton ranging from 9.2$ (in the 15 years and 3% case) to 29.8$ (in the 10 years and 5% case) will make windmills competitive compared to conventional energy production. This result makes it easier to analyse when windmills will gain comparative advantages.

Table 2: Implicit price of CO_2

	Real interest rate	$ per ton, 1998 prices
10 years	3%	25.5
	5%	29.8
15 years	3%	9.2
	5%	12.9

Reproduced from Hansen et al (2002), table 4, page 16.

Concerning the marginal costs of implementing the Kyoto-target, Table 3 shows estimates under the two policy options used in figure 2.

Table 3: Estimates of marginal costs of implementing the Kyoto-protocol

Reported in	Cost efficient ($ per ton)[a]	Domestic implementation ($ per ton)[b]
Clinton Administration (1998)	14-23	
Nordhaus and Boyer (1999)	11	125
Zhang (2000)	9.7	
Nentjes-Woerdman (2000)		250
Manne-Richels (1998)	70	240

a) The marginal costs of meeting the Kyoto target with unlimited access to flexible mechanisms.

b) The marginal costs of meeting the Kyoto target when no flexible mechanisms are feasible.

Note, that a large variation in the estimates presented in Table 3 exists. Thus, the comparison of numbers in table 2 and 3 should only be thought of as indicative. Keeping this reservation in mind, a comparison of Tables 2 and 3 reveals important information: While it is not assured that windmills will be competitive as long as cost efficient measures, and here in particular, a tradable permit system, is implemented, windmills receive a large competitive advantage when only domestic implementation is allowed.[8] The range of estimates for the marginal reduction costs is 9.7-70$/ton given a cost-efficient implementation of the Kyoto protocol. In comparison, the range of estimates for the necessary tax to make wind-based energy-production competitive is 9.2-29.8$/ton. Because the estimates are positioned within the same range of figures, it is not possible to establish whether wind-based energy production will become competitive even when implementing the Kyoto Protocol.

This result could also explain why the EU has been eager to make the costs of meeting the targets implied by the Kyoto agreement unnecessarily high by arguing for serious restrictions on free trade in CO2-permits. Free trade, under the best circumstances, could reduce marginal reduction costs significantly and keep conventional power plants more competitive than renewable energy sources.

However, the costs of producing energy by use of conventional energy systems could also change when exposed to greater pressure from competition. In order to get an idea of this, note that energy-technologies reflect differences in costs and levels of development and can (as done in Grübler et al., 1999), be placed into three groups. The mature technology has received widespread usage and has well known specifications (e.g. combustion gas turbine, gas combined and conventional coal power plants). Such technologies can be changed or improved under pressure from competition, but both the costs and the general level of energy efficiency is relative stable. The incremental technologies have higher costs and exist in niche markets (e.g., biomass power plants, coal combustion cycle power plants, nuclear power plants and wind). They have the po-

8 This comparison is only valid given a number of assumptions: reduction are only covered by making coal based energy production sufficiently more costly, energy prices are determined by marginal cost prices, and finally, that windmills are just as effective abroad as in Denmark.

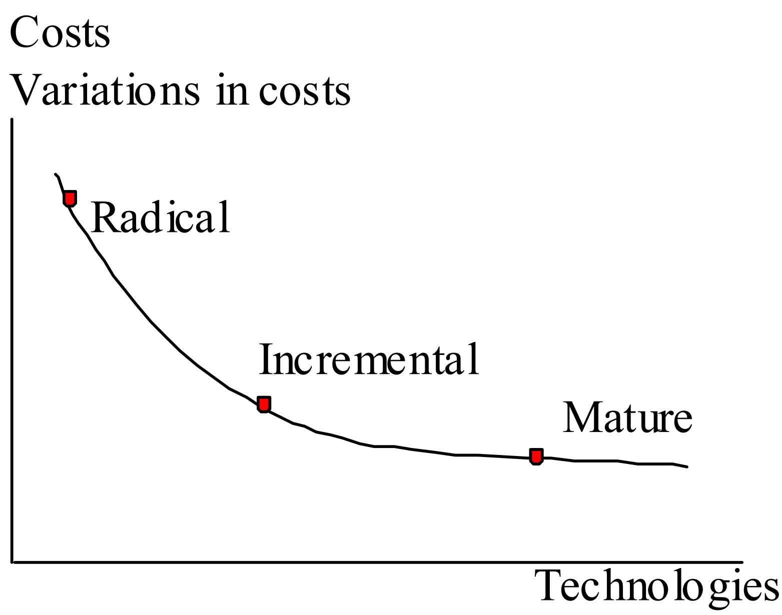
tential for higher efficiency and potential cost reductions if investment and development continue. The radical technologies are, by definition not widespread, but open to radical improvements in performance and costs (e.g., geothermal power plants, solar thermal power plants and PV-solar).[9]

This is important, since environmental targets change relative prices, and then also create incentives to make existing technologies more (energy) efficient. As seen from figure 4, since the conventional energy-producing sector can be placed into the mature sector, costs of production will probably not change significantly as competition increases.

The conclusion so far is that within the range of estimates presented in this paper, whether or not the implementation of the Kyoto-protocol makes wind energy competitive depends on which instruments are used to achieve the Kyoto-targets. If the Kyoto targets are met without the use of flexible mechanisms, then wind energy will be competitive compared to coal-based energy production. On the other hand, if the full use of flexible mechanisms is allowed, then whether or not wind energy will be competitive is ambiguous. Figure 4 also reveals that new and radical technologies also have the potential to be more competitive, if the price of conventional energy production increases. In light of this, the EU proposal in Johannesburg the EU has been pushing for a target of 15% of energy to come from sources such as windmills, solar panels and waves by 2015 might have result from interests other than purely environmental ones.

9 See Grübler et al (1999) for a very detailed discussion of the dynamics of energy technologies and a more thorough description of the different phases in the development of new technologies.

Figure 4: Position of technologies on the learning curve[10]



However, as we will discus further in section 5, new types of windmills that are offshore may even reduce the costs of windmill production further, and have the potential to make windmill based energy production competitive even in case where reductions of emissions are not done efficiently. But first, let us now turn to the empirical side, to get a more precise picture of the dominant position of the European windmill industry, and how the markets for wind energy have evolved.

3. Why the EU has been more energy restrictive than the US?

The development of more energy efficient technologies in the EU could be due to three main reasons. First, the EU had huge imports of oil in the 1960s and 1970s whereas the United States was self-supplying. The EU dependency on oil

10 Mature technologies in widespread use have lower costs with lower variance; the costs of radical new technologies are higher and more variable. Variability of costs is also an indicator of the uncertainty of technology costs. Radical technologies are little tried.

meant that the first oil crisis in 1973, where the oil price increased four-fold, had a severe impact on the economies of EU member states thus forcing them to develop new and more energy efficient technologies, see Darmstadter et al., 1971 concerning the EU oil dependency. Second, the level of taxation, including energy taxation, has generally been higher in the EU than in the United States (OECD, 2002). Therefore, energy savings give a better return in the EU due to a higher level of tax savings. Third, the geographical travelling distances between home and work, etc., are generally higher in the United States than in the EU. Therefore, Americans are more dependent on cars and cannot tax them as highly as the Europeans can for political reasons. The petrol price of one litre in the EU typically matches the price of a gallon (3.8 litres) in the United States. It is a common everyday observation in the United States that politicians do not dare to increase the petrol prices because their voters will be aggressively aware of any such step. For these reasons, we find most ”green industries” in EU member states. For example, German car producers have developed the so-called ”3-Litre-cars” enabling a car to run 100 km on three litres of diesel (Svendsen, 2003). Furthermore, numerous energy-efficiency and recycling technologies are prevalent in the EU. Another example is the wind turbine industry which we now turn to.

4. Wind Energy Market

The wind power share of world electricity generation was 0.08 per cent in 1996. In the year 2000 it had tripled to 0.25 per cent and in 2010 the share is projected to be 1.78 per cent, which is more than seven times higher than the 2000 level (BTM Consult, 2001, p. 37). Economically attractive subsidy schemes listed in Svendsen (2003) have promoted earlier shifts to wind energy and have fostered rapid market growth. Table 1 shows that total installed mega watts (MW) have almost been doubled in size from 1998 to 2000. Of course, the wind does not always blow. In Denmark, for example, wind turbines produce electricity about 75 per cent of a year and only occasionally at the maximum level. Furthermore, wind turbines need a wind speed of 4–5 metres per second to start operating.[11] If wind-electricity replaces coal or diesel generation, about 1 ton of CO_2 is saved for every MW hour of wind power production (IEA, 2002b).

Table 4: The 10 largest markets for wind energy at the end of 2001 (cumulative MW)

Country	1998	1999	2000	2001	Share %
Germany	2,874	4,442	6,107	8,734	35.0
Spain	880	1,812	2,836	3,550	14.2
USA	2,141	2,445	2,610	4,245	17.0
Denmark	1,420	1,738	2,341	2,456	9.9
India	992	1,035	1,220	1,456	5.8
Netherlands	379	433	473	523	2.1
UK	338	362	425	525	2.1
Italy	197	277	424	700	2.8
China	200	262	352	406	1.6
Greece	55	158	274	358	1.4
Total	9,476	12,964	17,062	22,953	24,927

Source: BTM Consult (2002).

Table 4 shows that Germany, Spain and the United States were the three largest markets in 2001 on an accumulated basis. The markets of the United States, India and China are still relatively small compared to Germany and Denmark, for example. Russia, which also has a huge potential, is not even within the top ten.[12]

11 Note, that the capacity in MW does not say anything about how much energy is actually being produced. If a 1 MW wind turbine (corresponding to 1000 kW) is installed, then it can produce 1 MW per production hour at its maximum, that is, at wind speeds above 15 meters per second.

12 As suggested by BTM Consult (2001), a number of huge potential markets exist for profitable wind energy production. In particular, Canada and Mexico (non-Annex B countries) have favourable land and wind conditions. China has severe pollution problems along its east coast due to the extensive use of fossil fuels (coal, oil and gas) that create local pollution, such as oxides of sulphur and nitrogen (which are a cause of acid rain). China, which is in the need of clean energy, is also therefore a huge potential market, with its enormous potential of wind resources along the coastal area, on the offshore islands and Inner Mongolia. Similarly, the wind market potential of Russia with its vast areas and excellent wind conditions is unique.

Concerning the top ten turbine manufacturers world wide, Table 5 shows that the Danish company, Vestas, was the biggest wind turbine producer in 2000 with roughly 18 per cent of the total. The Spanish company, Gamesa, is number two closely followed by other German and Danish producers. Each nation's share of the market in 2000 amounts to 51 per cent for Denmark, 18 per cent for Spain, 16 per cent for Germany and 15 per cent for the rest. Thus, the market is clearly dominated by EU wind turbine producers who have more than 85 per cent of the market share, as many producers in the ”Others” group are also located in the EU.

Table 5: Firm market shares in 2000

	Sold MW 2000	**Share 2000**
1. VESTAS (DK)	805	17.9%
2. GAMESA (ES)	623	13.9%
3. ENERCON (GE)	617	13.7%
4. NEG MICON (DK)	601	13.4%
5. BONUS (DK)	516	11.5%
6. NORDEX (DK/GE)	375	8.3%
7. ENRON (US)	270	6.0%
8. ECOTECNIA (ES)	174	3.9%
9. SUZLON (India)	103	2.3%
10. DEWIND (GE)	94	2.1%
11. MADE (ES)	85	1.9%
12. MITSUBISHI (JP)	64	1.4%
13. DESARROLLOS (ES)	27	0.6%
Others	195	4.3%
Total	4,548	100%

Source: BTM Consult (2001, p. 13). Reprinted by permission of Per Krogsgaard.

Note: Export is defined as the sales from the nation where the headquarters are situated.

Table 5 shows that the first 13 wind turbine manufacturers supply more than 95 per cent of the world market. Of these, ten are European. Important European turbine manufacturers include Vestas, Gamesa, Enercon, NEG Micon, Bonus, and Nordex. The majority of the turbine producers are Danish companies (DK), which operate worldwide, typically exporting 70- 90 per cent of their total production. For example, the biggest firm, Danish Vestas, had an average export share of 83.4 per cent for 1998–2000 (BTM consult, 2001, p. 15).

5. Future Market Developments

In section 2.3 we discussed the possibilities for wind energy to become competitive compared to fossil fuels in the future. So far, wind markets have primarily been driven by environmental concerns and political reasons in Western Europe. However, the learning curve in figure 3 might underestimate the potential of wind energy. The reason is that offshore wind power is expected by some to be the big thing in the future. According to Eddie O'Connor, Vice President of the European Wind Energy Association: ”The development of major offshore wind energy parks will be the biggest energy revolution since the internal combustion engine” EWEA (2002a). Three main reasons support this forceful statement. First, offshore wind turbines have the potential to become profitable due to the size of new wind turbines (2–3 MW). Second, offshore projects allow large developments because there is plenty of space. If placed more than 10 km from shore, the wind turbines will normally be off-sight and there will be sufficient water depth for installation and access for operation and maintenance. Third, the potential for supply of wind based energy is huge. A low estimate would be that 1/3 of total electricity consumption in the EU today could be produced by wind turbines (BTM Consult, 2001, p. 39). EWEA (2002a) estimates that offshore wind energy alone could provide up to two thirds of Europe's electricity needs by 2020. However, the main problem linked to offshore wind power is the accessibility. In bad weather with high winds, ice, etc., advanced remote and self-operation and maintenance schemes are necessary. The full development of such off-shore technology means huge investments and may create new alliances among firms (BTM Consult (2001, p. 42).

Table 6 shows the offshore wind farms in operation at the end of 2000. In total, 86 MW of offshore wind capacity is installed in the seas of Northern Europe. The biggest wind farm at the moment is ”Middelgrunden” in Denmark with its 20 2MW wind turbines (close to the Copenhagen harbour). There are several reasons to believe that the off-shore wind industry is likely to boom in the near future. For example, the German government has recently announced an ambitious plan to boost wind power’s share of electricity consumption to ”at least 25 per cent by 2025”. The lion’s share of this will come from a 20–25,000 MW offshore wind capacity in the North and Baltic Seas. ”Within a generation (…) one fourth of our current electricity needs will be generated with environmentally-friendly wind power”, says Environment Minister Jürgen Trittin (EWEA, 2002b).

Table 6: Offshore wind farms

Country	Site	No. of Turbines	Individual Turbine Capacity KW	Total Capacity MW	Year On-Line
Sweden	Norgersund	1	220	0.22	1990
Denmark	Vindeby	11	450	4.95	1991
Denmark	Tunø Knob	10	500	5.00	1995
Denmark	Middelgrunden, Copenhagen	20	2000	40.00	2001
The Netherlands	Lely (Ijsselmeer)	4	500	2.00	1994
The Netherlands	Dronten (Ijsselmeer)	28	600	16.80	1996
Sweden	Gotland (Bockstigen)	5	550	2.75	1997
Sweden	Uttgrunden, Kalmar Sound	7	1500	10.50	2000
UK	Blyth Offshore	2	2000	3.80	2000
Total		88		86.02	

Source: EWEA (2002a). Reprinted by permission from the European Wind Energy Association (EWEA).

When the off-shore industry starts to reap economies of scale and learning-by-doing effects, the costs of wind power will probably fall dramatically, as we have seen onshore (EWEA, 2002a; Svendsen 2003).[13] Off-shore wind experts

13 In Madsen et all. (2002) the relationship between size of a windmill and the costs/kW is estimated and it is clearly negative (as indicated in Table 6). Off shore wind turbines are expected

are now drawing on experience from existing offshore wind plants and also from the experience of other offshore industries. It should be noted that the development of offshore wind plants has increased significantly in the last couple of years, and the effect of this development on the learning by doing costs curve is not (fully) captured in figure 3. If offshore based energy production turns out to reduce production costs more than estimated in figure 3, then the likelihood that windmills become competitive, even if a cost effective approach is chosen to implement the Kyoto targets, is increased.

6. Conclusions

It is argued that the reason for the development of the wind turbine industry is that wind energy has been subsidised following the first oil crisis in 1973. The most important subsidy has been a price guarantee per produced kWh (kilowatt-hour), which enabled the windmill industry to gain a foothold in Denmark.

Does this fit the ideas of Porter (1990) who argues that it may pay a country to subsidise its industries for a period? Building up a strong home market will clear the road for exports and a profitable industry in the longer run. Not necessarily, since the past and current export is caused largely be subsiding windmill production. Without subsidies, our analysis shows that implementing the Kyoto-targets is not necessarily enough to make wind-based energy systems competitive under free market conditions. As seen from our analysis, the potential for much larger exports can only be realised, when the Kyoto-targets are implemented successfully, but, in particular, if not implemented in cost-efficient way. This suggests another explanation for why the EU proposed restrictions on to trade in permits after the Kyoto agreement at The Hague in 2000. This could also have been in order to promote own export industry.

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to reach the size of 5 MW in the beginning of the next decade, which will reduce costs of wind-based energy production considerably (EWEA, 2002c).

However, the effort of the EU to make the Kyoto-agreement unnecessarily expensive has had the drawback of giving the USA a perfect opportunity to leave the Kyoto-agreement: The individual reduction targets implied by the Kyoto-agreement were accepted under the premise of access to flexible mechanisms (Brandt and Svendsen, 2002). What is obvious now is that the reduction targets cannot be isolated from the means by which these targets are supposed to be implemented.

This also shows the curse of being committed to cooperation in a prisoner's dilemma environment. It is only in cases where a country making a unilateral move gets an unconditional first mover advantage that it is able to escape the observation in Hoel (1991) that unilateral reductions never increase other countries' reductions. Here countries must try to convince the other countries that they should implement renewable energy systems. Could this explain why the EU so eagerly tried to promote their industrial interests in Johannesburg by proposing a target of 15% of all energy to come from sources such as windmills? On the contrary, Brandt (2002) shows that unilateral reductions can decrease other countries' emissions if such actions reveal that costs are low. But this is only true if there exists an unconditional first mover advantage (which could be the case for off shore windmills).

However, one of the important lessons is that it is not possible for a government to can pick the right winners in advance. What infant industries should be protected to promote exports in the longer run? Here, luck and chances also play a role as argued by Porter (1990). It might very well be that the best way for a government to promote technological progress is to get the prices right. By internalising all external costs of production, the right prices will emerge, sending the right signals to the markets, resulting in necessary structural changes that reflect our knowledge about the state of the environment.

Energy markets are dynamic and the existence of a future need for more "sustainable" energy sources is hardly doubtable. As the Executive Director of the International Energy Agency (IEA), Robert Priddle, puts it: "We are not on a sustainable energy path unless we make considerable changes". (IEA, 2002a). Furthermore, "The IEA notes that a projected 57 per cent increase in mainly fossil-fuel based energy demand over the next 20 years will exert enormous pressure on the global environment. Huge investment demands, continued distortions in energy markets, growing problems caused by the insatiable demand for transportation, and barriers to deployment of renewable energy technologies, all point to a need for countries to do more" (ibid.). Here, one of the main instruments will be to develop renewable energy further. In light of this, first mover advantages are not unrealistic for those countries that support innovativeness in the field of less polluting energy producing technologies.

The most optimistic future scenario for a windmill producing country is given by three conditions. Firstly, off shore windmill technology will generate a new downward trend in the learning-by-doing curve. Secondly, tighter future regulation of GHG gasses world-wide will occur, at least in countries possessing high potentials for wind energy production. Thirdly, no alternative technologies will become more competitive than off shore wind energy. If so, the best strategy for a country will be to promote its windmill industry indeed by keeping investing (subsidising) the development of off shore based windmills, and consequently promote a fully tradable GHG permit market at the global market. Only in this way is it possible to include all the main actors in the climate change issue, as it is not obvious that there are other means through which the USA, China and India could be expected to enter binding agreements in the near future. Once a price on permits is established, this will make windmills more competitive, and will work as an implicit subsidy on windmills abroad.

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Institut for Miljø- og Erhvervsøkonomi (IME)

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