Wind energy future profitability and employment

M.W. Schepers, August 2009

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Erasmus University Rotterdam

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1 Introduction

The wind energy sector is one of the fastest growing industries in the world. From 1991 until the end of 2007, global installed wind energy capacity has increased from around 2,000 MW to 94,000 MW, at an average annual growth rate of 25 percent (EWEA, 2009). During this period, both prices of wind turbines and the cost of wind generated electricity have been reduced (Junginger, 2005). In spite of these developments, wind energy is not yet fully competitive with conventional energy sources. At present, the production cost of wind energy is generally higher than the cost of energy extracted from conventional energy sources such as coal and natural gas. However, this may change in the next decades.

This paper will give a glimpse of the future of wind energy, by estimating future cost development of wind energy, making use of the so-called experience curve concept. The resulting cost projection will be used to assess future competitiveness and profitability of the wind energy industry, vis-à-vis electricity produced from fossil fuel. The final objective of this study is to assess the effect of these shifting forces on employment. In addition to the employment effects in the wind energy industry, the net effect on employment in the entire economy will be discussed. This can be formulated in the following research question:

> *How will the cost and competitiveness of wind energy develop in the near future, and what will be its impact on employment?*

This research question can be decomposed in the following subquestions:

- What will be the estimated future cost development of wind energy?
- What will this mean in terms of wind energy competitiveness and profitability?
- What will be the impact on overall employment?

The methodology used in this thesis is theoretical, relying for a significant part on existing literature findings and general economic theories. The future cost development of wind energy will be estimated by reviewing literature on wind energy experience curves, resulting in an estimated progress ratio which is combined with capacity projections to assess cost reductions. Wind energy competitiveness is discussed by considering the cost of conventional energy sources. Taking into account government support policies and energy market fundamentals, wind energy profitability is considered from an investors' point of view. The employment impact is finally analysed by reviewing literature on the employment impact of a shift towards wind energy. The main outcome is that the cost of wind energy will significantly decrease in the next decades, resulting in an improved competitiveness with respect to conventional energy sources. Due to lower costs of capital and operation, investments in relatively expensive wind sites will become economically viable, resulting in an increase in wind energy production. The impact on employment is generally found to be positive, however frictional unemployment may occur due to the transition to wind energy. Moreover, the literature generally negates the contractive effect of the government support expenditures, and labor intensity of wind turbine production may decrease in the future. The relative size of these effects will determine if the future developments of the wind energy industry will have a positive or negative effect on employment.

This paper will begin with a general literature review of wind energy experience curves in chapter 2. In chapter 3 the future cost development of wind energy will be estimated, and its effect on wind energy competitiveness will be assessed. Using these results, chapter 4 will analyse the impact on employment. Conclusions will be drawn in chapter 5.

2 Wind energy experience curves

Experience curves are used extensively in different areas of application, in order to describe historic and future cost development of a technology. The concept is based on the observation that costs tend to decline when cumulative production increases, due to the fact that the productivity of a technology typically increases substantially as producers gain experience with this technology. Wright (1936) was the first to describe this phenomenon in the aircraft manufacturing industry. Experience curves have also been applied widely to the renewable energy technologies, including wind energy. This chapter will give a brief literature review of the empirical research concerning wind energy experience curves. The research results will be evaluated, leading to an experience curve estimation which will be used in the next chapter to describe the future cost development of wind energy.

Experience curves are used to analyse the cost development of a product or technology as a function of cumulative production[1]. By describing how unit costs decline with cumulative production, they may improve understanding of long term cost development. If the trend of such a curve may be extrapolated in the future, it may help to assess when a technology will reach a certain price level. A characteristic of experience curves is that costs decline with a specific percentage for each doubling of cumulative production. This may be expressed with the following equation (Neij, 1997):

$$C_{CUM} = C_1 * CUM^b \qquad (1)$$

Where C_{CUM} is the cost per unit[2] as a function of output, C_1 is the cost of the first unit, *CUM* is the cumulative production over time, and b is the experience curve index. One may express the size of cost reduction with each doubling of cumulative production, called the progress ratio (PR), using PR = 2^b. For example, a progress ratio of 0.8 (80%) means that with each doubling of cumulative production, costs decline by 20%. The lower the progress ratio, the faster costs decline with production as a consequence of learning effects. Specification of the progress ratio completely describes an experience curve.

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[1] Some research has discussed a two-factor learning curve, where cost reductions depend on both cumulative production and R&D investments (Klaassen, 2005). In this study we will focus on the one factor experience curve.

[2] The definition of the unit may vary. In many cases the unit is a product, however in the context of wind energy the unit is generally an energy capacity or amount of electricity produced.

The concept of experience curves cannot be considered an established theory or method, but rather a correlation phenomenon which has been observed in several kinds of technology (Neij, 1999). The equation states an empirical connection between unit costs and cumulative production, but it does not explain the mechanisms behind this relation – i.e. there is no natural law causing costs to decline with cumulative production. It is therefore important to take a closer look at the reasons why costs have declined for wind power in the past, and whether opportunities exist for further cost reductions in the future.

Ibenholt (2002) distinguishes between five driving factors behind cost reduction: Technological progress, input price changes, internal efficiency improvements, learning-by-doing, and economies of scale. The production cost of wind turbines and the cost of electricity from wind have both been reduced significantly over the last decades. The upscaling of the size and capacity of wind turbines has been a key driver behind this (Junginger, 2005). However, the potential of cost reduction through upscaling will become less significant in the future. On the other hand, mass production is likely to play a significant role for future cost reductions. Ordering a large number of turbines at once makes large rebates possible, due to a long-term continuous operation of turbine production plants, and reduced labor costs. Since the trend is to install very large wind farms of several hundred MW capacity, these large scale production orders will be a significant driver for future cost reduction (Junginger, 2005). The cost of financing is also coming down, due to increased confidence in the technology and thereby better financial conditions (Ibenholt, 2002). In summary, historic wind energy price reductions were mainly achieved by the upscaling of individual turbines, while in the future these costs are expected to further decline mainly through producing the same turbine type on a large scale. It is beyond the scope of this study to go into the technological factors driving the cost reduction, but since there clearly exist opportunities to further reduce wind energy costs, experience curves may be a good way to estimate these cost reductions.

2.1 Empirical estimates of wind energy experience curves

The basic method of constructing an experience curve is to collect historic data about costs[3] and cumulative production. The experience curve index *b* (and thus the progress ratio), can be estimated by applying least-squares regression to the logarithmic form of Eq. 1:

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[3] Due to data availability, experience curves are generally based on price data rather than cost data. This will be accurate only if price/cost margins are relatively stable over time (Neij, 2003)

$$\log C_{Cum} = \log C_1 + b \log CUM \tag{2}$$

Many studies have been devoted to estimating an experience curve of wind energy. The results of these studies differ significantly. This can partially be explained by a difference of system boundaries of the learning system: Experience curves may be devised for the manufacturing of turbines, where the production costs per kW are set against the cumulative production of turbines. The curve may also be constructed for wind farm installation costs, where the cost of wind turbines is component influencing this cost. Finally, the cost of wind power electricity may be taken as input data, plotted against the cumulative electricity production. Again, wind farm investment costs are only one component of the total cost of electricity from wind power. This relation is schematically displayed in Figure 1.

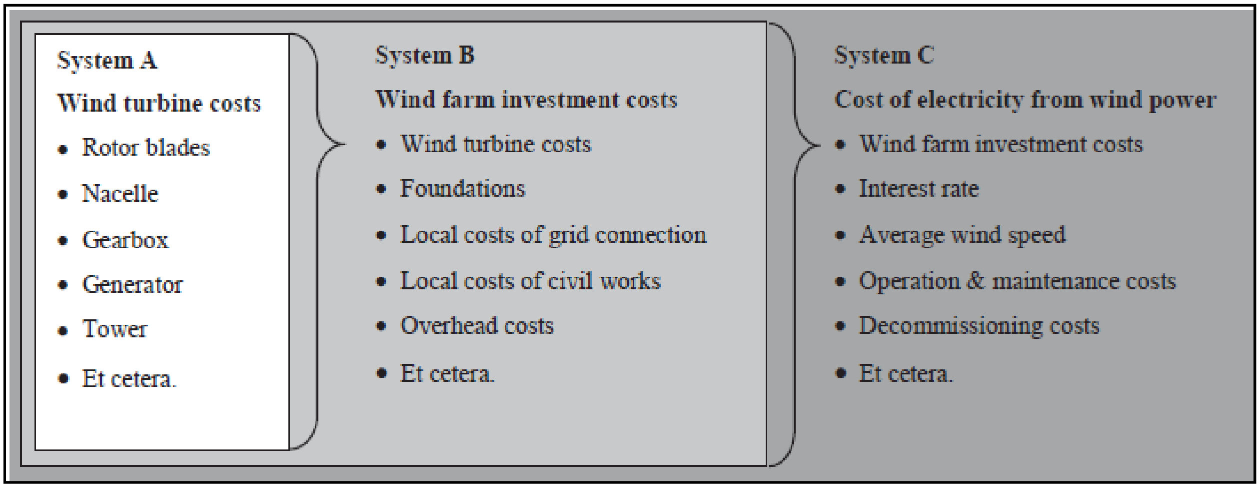

Figure 1 System boundaries for different wind energy learning systems, with major cost components (from Junginger, 2005)

Thus, for wind turbines, wind farms and wind energy different experience curves can be constructed. Also, many studies draw an experience curve based on national data. Local policy support measures and geographical differences may cause experience curves to differ between countries.

With these considerations in mind, a review of the empirical literature concerning wind energy experience curves has been done. As said before, there has been extensive research in this area, with diverging results. Table 1 lists an overview of the found studies of wind energy experience curves. The estimated progress ratio (PR) found in these studies is displayed in the second column. Following the above discussion, the table also states the system boundary (which learning system was analysed) and the geographical source of the data.

Table 1 Overview of results from empirical studies of wind energy experience curves

Source	PR (%)	System boundary	Region
Neij (1997)	96	Wind turbine	Denmark
Neij (1999)	92	Wind turbine	Denmark
Seebregts et al. (1998)	87	Wind turbine	Denmark
Mackay and Probert (1998)	85.7	Wind turbine	US
Dustewitz and Hoppe-Kilpper (1999)	92	Wind turbine	Germany
Lund (1995)	85	Wind turbine	Denmark
Neij et al. (2003)	89-96	Wind turbine	4 countries[a]
Junginger (2005)	77-85	Wind farm	UK and Spain
IEA (2000)	82	Wind energy	EU
Neij (1997)	91	Wind energy	Denmark
Ibenholt (2002)	88-93	Wind energy	Denmark
Ibenholt (2002)	75	Wind energy	UK
Neij et al. (2003)	83-88	Wind energy	4 countries[a]

[a] Denmark, Germany, Spain and Sweden

It is interesting to note that there is only one study that analyses the cost of wind farms. Note also that all studies construct a curve based on national data, sometimes collected for multiple countries. Finally, note that some authors have constructed more than one type of experience curve, and thus occur more than once in the table.

Due to the unavailability of empirical data (that has not previously been used in the listed studies), this thesis will not give an empirical estimation of a new experience curve. Rather, the large number of study results listed above will be used as a basis to give a realistic estimation of the experience curve – and associated progress ratio – of wind energy. This result will be used to calculate the expected future cost development of wind energy, which can then be compared to other energy sources in order to judge the future competitiveness of wind energy. This will be the subject of the next chapter.

3 Future cost and competitiveness of wind energy

Despite of the high growth and significant cost reduction of wind energy in the past decades, electricity derived from wind is generally not yet able to compete with electricity produced from fossil fuel such as coal and natural gas. However, it has been shown that historic cost trends can be formalized using the experience curve concept, which can be extrapolated to forecast future cost development of wind energy. The results from the previous chapter will now be used to give an estimation of the future cost development of wind energy, in order to judge future competitiveness of wind energy vis-à-vis conventional energy sources.

3.1 Future cost development of wind energy

Given the importance of system boundaries and geographical differences discussed before, it is important to explicitly state what cost exactly will be analysed before estimating a suitable progress ratio. Since we are interested in the competitiveness of wind energy compared to other energy sources, the cost of *wind energy* – in €/kWh - will be analysed (rather than the cost of wind turbines or wind farms). The focus will be on the cost of wind energy in the EU, although a global learning system exists for wind energy (Junginger, 2005). In order to forecast the cost development of wind energy, three types of data are needed: An estimated progress ratio, the current cost of wind energy, and current and projected development of cumulative wind energy capacity. Estimates for these three components will be discussed below.

The previous chapter indicated that estimates of progress ratios differ significantly between studies. The results displayed in Table 1 will now be used to assess an appropriate progress ratio to be used for this study. Since we are projecting the cost of wind energy, the resulting experience curves for wind energy will be most important. Moreover, the complicated effects of geographical differences imply that it might be wise to combine results from different countries in order to get a representative global experience curve. Since the empirical results differ significantly, and because there is much uncertainty about the future cost reduction for wind energy, the progress ratio for future cost development of wind energy is taken to range between 82 and 88 percent (corresponding to an experience curve index of $b = -0.286$ and $b = -0.184$ respectively[4]).

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[4] This is obtained by taking the inverse of the equation for the progress ratio, resulting in $b = {}^{2}\log PR$

Second, the current cost of wind energy needs to be assessed. This is a complicated issue, because there is no single cost of wind energy. As Hoogwijk (2004) points out, the costs of wind energy are highly dependent on the location of the wind site, in other words wind energy costs are site specific. For example, wind turbines located at windy areas along the coast of Europe have a very high annual electricity production, driving the cost of energy per kWh down. Some of these sites are already able to compete with conventional energy sources. Turbines located at inland sites have a lower electricity production resulting in a higher price of electricity. The point is that future developments will drive the costs of electricity from all these wind sites down, making more turbine sites competitive with fossil fuel energy. Therefore, for the purpose of this discussion we will take the average cost of wind energy in the EU to illustrate future cost reductions, which is stated by the European Wind Energy Association (EWEA, 2009) to be between 5 and 6 c€/kWh. Because the publications of EWEA are found to be slightly optimistic, an average wind energy cost of 6 c€/kWh is taken in this study.

Recall that the experience curve relates the cost of a technology to cumulative production. In this case, the cost of wind energy is related to the cumulative wind power capacity installed. Therefore, in order to project future cost developments, we need to estimate future developments of cumulative capacity of wind power. Scenario studies of future capacity of wind power in the EU have been made in a number of studies (EWEA, 2005; EWEA, 2009; EC, 2008). The scenarios of these studies for installed wind power capacity in 2010 and 2020 are displayed in Figure 2.

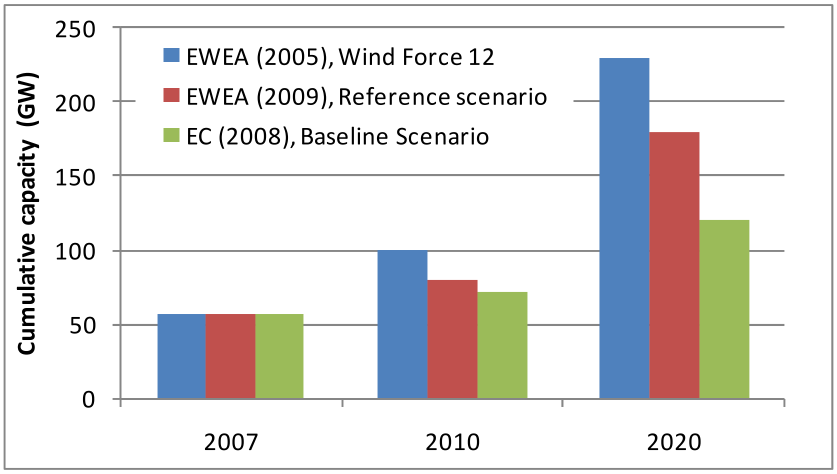

Figure 2 Scenarios of cumulative installed wind power capacity

It is striking to note that the European Wind Energy Association is much more optimistic in its predictions compared to the EC, especially in the Wind Force 12 scenario study. This is generally observed in publications of EWEA, which is not surprising since the EWEA has strong incentives to promote wind energy in Europe. Considering these differences and the subjective view of the EWEA, in this study we take a conservative estimation of cumulative wind power capacity, which is 75 GW in 2010, and 160 GW in 2020.

Now that all necessary input data is discussed and estimated, the future cost development of wind energy can be calculated by extrapolating the experience curve. Using the estimated range of progress ratio, a high- and low estimate is made. The results are displayed in Table 2 and Figure 3.

Table 2 Projected cost development of wind energy

	PR	Year		
		2007	**2010**	**2020**
Cumulative capacity (GW)	-	56.6	75	160
Cost of wind energy (c€/kWh)				
- Low estimate	0.82	6.00	5.43	4.38
- High estimate	0.88	6.00	5.63	4.90

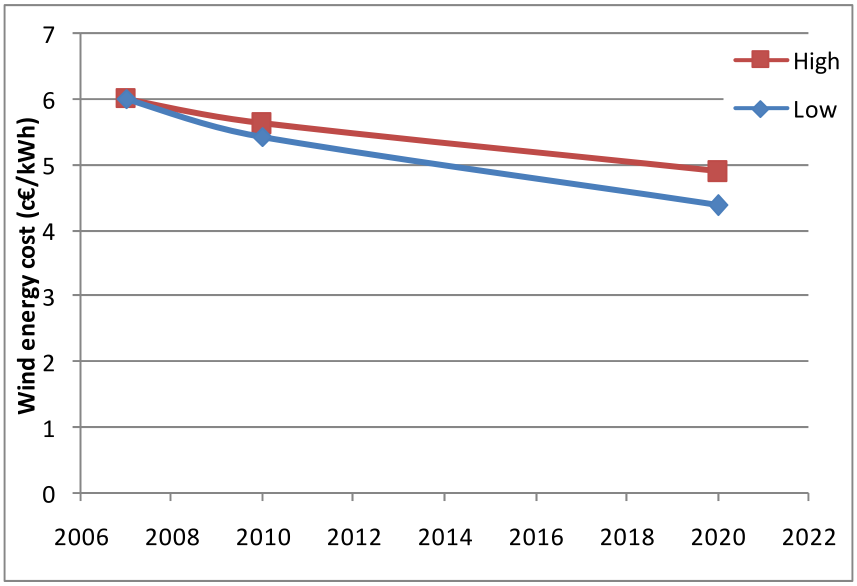

Figure 3 Projected cost development of wind energy

Note that the results depict the cost development for electricity obtained from a site with average wind speeds and an average current energy cost of 6 c€/kWh. Since the experience curve predicts a relative cost reduction, wind sites with different current electricity costs will reduce with the same ratio. Taking the average of the high and low scenarios, the cost of wind energy will decrease by approximately 23% by 2020. According to experience curve analysis, wind energy costs of relatively (in)expensive wind sites will decrease by the same percentage. For example, if the energy cost of an inland site is currently 7 c€/kWh, this cost is projected to go down to between 5.1 and 5.7 c€/kWh in 2020. This is an important consideration for the subsequent discussions.

The projected cost development is an estimate, depending on statistical estimations of the progress rate as obtained in the literature. These statistical estimates differ significantly between studies, which is why a range of progress ratios is adapted for the projection. Taking into account this variability increases the reliability of the projected cost development. However, the statistical estimation of the cost development should be treated with care. It expresses a general observed effect of cost reduction due to learning effects, however these normally only hold for the long run while short term fluctuations may deviate from the predicted cost path. In addition, many other cost determining factors are exogenous to the model. For example, a major cost component of a wind turbine is the input material used for wind turbine production, which is mainly steel and copper. Other factors such as labor market conditions and the global economic climate may affect wages and interest rates for example, which also influence to the cost of wind energy. Unforeseen fluctuations in these exogenous variables may significantly disturb the projected cost development depicted in Figure 3. It can be concluded that the estimated cost curve serves as a good general indication of the future, however its reliability and accuracy are limited - especially for the short run.

3.2 Wind energy competitiveness

This section discusses the impact of the estimated cost reduction of wind energy on its competitiveness vis-à-vis conventional energy sources. This is a difficult subject because the economics of wind energy are influenced by regulations. Because the competitiveness of wind energy cannot be considered without considering government intervention, the policies promoting wind energy in the EU will shortly be discussed. In addition, the future cost development of energy from fossil fuel will be discussed.

In a normal market, the joint forces of supply and demand determine an equilibrium price of a good. Although some citizens have found to be willing to pay a premium for green energy (European Opinion Research Group, 2003), conventional and green energy can be considered perfect substitutes, in other words energy is approximately a homogeneous good. Since the cost of wind energy is generally higher than conventional energy, wind energy would not be able to compete under given market circumstances. However in the case of energy production, significant externalities are in play. Examples are increased healthcare due to environmental pollution and climate change due to CO_2 emissions. Since the negative (or positive) effects are not born by the players in the market of supply and demand, market forces fail to reflect these externalities in the equilibrium price. In the ExternE project of the European commission, an attempt has been made to estimate the cost of different sources of energy production, taking into account all externalities involved in the production process of a specific technology (European Commission, 1999). Not surprisingly, they concluded that wind energy has a significantly lower total cost to society than conventional energy industries, and would outcompete conventional energy if externalities would be accounted for in the energy market. Since externalities are a known cause of market failure, government intervention is appropriate to pass the social costs of energy production on the corresponding energy producers. To reflect the costs to society of the polluting effect of conventional energy (such as increased health care and climate change), the government intervenes in the energy market in a number of ways. For example in the Netherlands, government support policy with respect to wind energy consists of fixed feed-in tariffs (FIT) and tax exemptions (EWEA, 2009). In the case of feed-in-tariffs, operators of wind farms are paid a fixed premium for every kWh of electricity they feed into the grid. The difference between this FIT and the market price of energy is borne by the taxpayers or electricity consumers. A feed-in tariff of 6.8 c€/kWh is paid for onshore wind sites in the Netherlands (EWEA, 2009). This way externalities are taken into account in the electricity price and wind power is able to compete with conventional energy. Other support systems in the EU are investment subsidies, fixed premium systems, auctions and certificate systems. These incentives will be required until technological development makes wind energy fully competitive with conventional sources, such as coal and gas.

The future competitiveness of wind energy with respect to conventional energy also greatly depends on the future price of conventional energy. Contrary to wind energy, the cost of conventional energy is largely determined by the cost of fuel[5]. Coal and gas are the common fuels for conventional power plants, and their price generally follows the international oil price. It is beyond the scope of this study to make detailed predictions regarding the oil price development. The unanticipated peak of $147/barrel in July 2008 demonstrated the high volatility and unpredictability of the oil price, which makes it a topic of its own to forecast the price of conventional energy. To give a basic impression of anticipated future oil price development, the International Energy Agency has projected the oil price to increase to $100/barrel in 2010 and $122/barrel in 2030 (IEA, 2008). Although it is very hard to predict oil price developments and the associated price of fossil fuel energy, the projections of the IEA suggest that the price of conventional energy will go up in the future. However in this paper we focus on the effect of a cost reduction of wind energy, therefore the conservative assumption is made that the price of oil - and the associated derivatives coal and gas - will remain constant in the next decades.

3.3 Market determination of the price for electricity

Before discussing the general effects of the projected cost decrease on profitability, it is important to highlight how the price of electricity that is fed into the grid is determined. This concerns the business-to-business electricity market, where producers of electricity get a certain amount of money for each kWh they feed into the grid (not to be confused with the electricity market of consumers, where companies at the end of the electricity supply chain deliver electricity to consumers at a higher price due to added costs and markups). To take the Netherlands as an example, TenneT is responsible for balancing the supply and demand of electricity on a daily basis. There is not a single price per kWh paid for electricity fed into the grid because of the existence of several markets for electricity, ranging from long term contracts fixing electricity supply several months ahead, to spot markets where electricity supply is traded on a daily basis to balance demand and supply in real time. Although it is beyond the scope of this thesis to go into detail about the electricity market, one important facet will be highlighted here. Regardless of the time scale of the traded electricity supply, the price paid for electricity is determined by bidding of the various suppliers (Ummels, 2008). In short, producers of wind energy, nuclear energy, gas and coal energy and other technologies all bid for a price at which they are willing to feed electricity from their power plant into the grid. These bids are sorted from low to high

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[5] The capital costs of conventional energy plants represent a relatively small fraction of total costs. In addition, the cost reducing effect described by experience curves is negligible for fossil fuel energy. This is because the estimated progress ratios are relatively high (Nakicenovic et al., 1995) - which corresponds to a low learning effect. Also, because conventional energy capacity is expected to increase only marginally – or even decrease – the learning effect is diminished.

and the suppliers with the lowest bid are contracted until the projected demand is reached. Figure 4 shows a conceptual diagram of this bidding procedure, where price is plotted against quantity and the various blocks represent bidding suppliers such as a wind farm operator or a gas power plant.

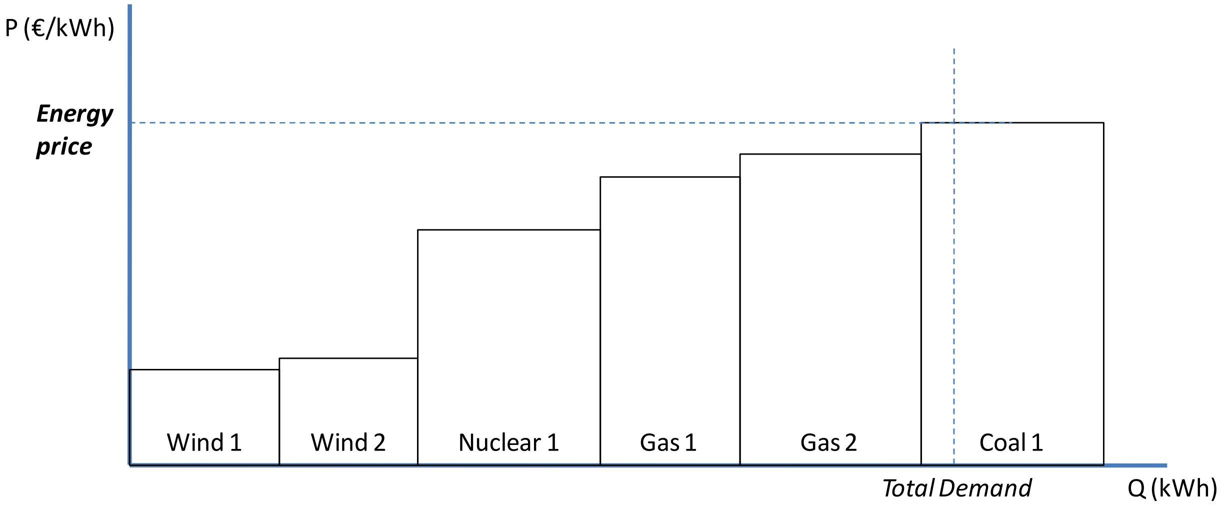

Figure 4 Simplified diagram of feed-in price determination

Since wind energy has very low operating costs, the corresponding bids are very low and always the first to supply. The important point of this figure is the fact that the price paid for electricity fed into the grid is determined by the bid of the last supplier, in the example the "Coal 1" power plant. Every party contributing to the total energy demand will be paid this price for every kWh they feed into the grid. In order to make a statement on the profitability of wind energy, the cost of wind energy must be compared to the remuneration for wind energy fed into the grid. In line with the assumption of a constant oil price (from the previous section), we will assume that the costs of conventional electricity generation will be constant in the time period considered in this thesis. In addition, the assumption is made that the price-determining bid – which can safely be assumed to be a conventional energy supplier – will remain constant, corresponding to a constant price paid for electricity. This means that in the subsequent discussions, it is assumed that wind energy producers get a fixed and constant amount of money for each kWh they produce and feed into the grid, in other words the revenue from each unit of energy production is constant.

3.4 General effects of wind energy cost reduction

It is now time to discuss the general impact of the projected cost reduction of wind energy discussed in the previous chapter. Two main effects will be treated in this paper: More wind sites will become profitable under given market conditions, and government expenditures for wind energy support programs may go down. These two factors are the point of departure for the next chapter on employment effects, and will now be discussed in more detail.

There is no single cost of wind energy, since this cost is highly dependent on the location of a wind farm (Hoogwijk, 2004). Experience curve analysis of the previous section predicts that the costs of wind energy will go down by approximately 23 percent by 2020. Due to this general decrease in the cost of wind energy, more wind sites will become profitable under given market conditions, causing new turbines to be installed on these locations. This is because the relatively high energy cost of wind sites on a remote or less windy location will be driven down, many of which will become sufficiently low cost to allow for a normal profit. The decision whether or not to invest in a specific wind farm is generally driven by a determination of the net present value (NPV). Calculation of the NPV is based on the estimated future cash flows of a projected, discounted by the interest rate which is the opportunity cost of capital. Wind energy farms involve a very high upfront investment, which has to be offset by net revenues coming from operation until the time of disposal, which is typically around 20 years. Uncertainties in future energy prices, policy support programs and operation and maintenance costs make a wind energy investment inherently risky. This risk may reduce when wind energy technology becomes more and more a proven technology, because operating costs are easier to assess. Learning effects and technology improvements covered by experience curve analysis will drive down the upfront capital investment and the costs of operation of a wind farm, affecting the net present value of a project. By 2020 the costs of wind energy are expected to be decreased by approximately 23 percent. Together with the previously discussed assumption of a constant remuneration for wind energy fed into the grid – i.e. a constant gross cash inflow for the years of operation, the projected cost decrease will significantly affect the outcome of a financial investment assessment such as calculation of the NPV. These cost improvements might turn an economically unprofitable investment into a profitable investment, corresponding to a positive NPV.

The numerical findings of the previous section suggest that costs will go down by as much as 23 percent for 2020. The number of wind sites that will become financially attractive due to this cost reduction is very large, because many wind sites are only slightly too expensive in order to attract investment at current cost levels. A minor decrease in costs for wind turbines and wind farms will turn these formerly unprofitable wind sites into profitable opportunities for investment. Given that only slight cost reductions already convert many wind sites into profitable projects, the significant estimated cost reduction of 23 percent will have a huge effect on the number of wind site projects that will become financially viable by 2020.

The effect discussed above will attract investment and cause a very significant expansion of the wind power capacity in Europe, leading to a higher production of wind energy. In essence, the competitiveness and profitability of wind energy will thus increase. It is interesting to remark that according to the experience curve analysis, cost reduction is caused by an expansion of capacity. In turn, this cost reduction will cause wind power capacity to increase. There is thus a two-way causal relation between capacity expansion and wind energy cost reduction.

A second effect of decreasing wind energy costs is that less government expenditure will be needed to support wind farms that are currently already profitable. Since the cost of these wind sites will go down, less money is needed to fill the gap between wind energy costs and market prices for energy. Due to increased competitiveness of these wind farms, government support schemes may be reduced or even eliminated. Of course, this is the effect of a general cost reduction of wind energy over a long time period, which is mainly experienced when ordering and installing new wind turbines on a wind site. However it is not unlikely that many wind farms that are currently profitable will be replaced with more modern wind turbines, causing the experience curve cost effect to drive the cost of electricity from these wind farms down. To illustrate the effect, consider feed-in tariffs. Feed-in tariffs used for existing wind farms may go down since wind electricity producers are willing to feed electricity into the grid at a lower remuneration, due to decreased energy production costs. For example, if a farm operator is making a normal profit under the current FIT of 6.8 c€/kWh in the Netherlands, the anticipated decrease of his energy production costs will increase his profit margins. The government may lower the FIT for these wind sites without losing investment, since the operator can still make a normal profit under the condition of a FIT of e.g. 6.3 c€/kWh[6]. Assuming that energy prices are constant, the gap between the feed-in tariff and the energy price will decrease, which essentially means that less money is drawn from taxpayers and electricity consumers to support the production of wind energy.

An important thing to note is that the first effect is valid under current market conditions, which entails that government support will stay at the current level. On the other hand, the second effect states that government support expenditures may go down. This may seem contradicting, but in

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[6] The drawback of such a policy with variable FIT following the general cost development - as predicted by experience curve analysis – is the uncertainty it produces for future profitability. This may deter investment (Junginger, 2005).

practice this can be realized. At present, governments already differentiate government support programs according to the cost characteristics of wind sites. In the example of feed-in tariffs, multiple FIT's are in use for different categories of wind sites (EWEA, 2009). Following this strategy, government may keep current FIT tariffs for wind sites that just become profitable with decreasing costs, while it may lower its tariff for wind sites already profitable as discussed in the second effect.

Summarising, the projected future decrease of wind energy costs will cause an expansion of the installed capacity of wind energy, due to new wind sites that become profitable and attract investment. This may correspond to a shift in energy production from conventional energy sources - such as coal and gas – to wind energy. The cost reduction described by the experience curve also reduces government expenditures for existing wind sites, since less policy support is needed to stimulate wind energy production at these wind sites. These two main results of anticipated cost reduction will have much economic impact. This paper focuses on one important economic factor influenced by the effect of cost reduction: employment. This will be the subject of the next chapter.

4 Impact of wind energy cost reductions on employment

The wind energy sector in the EU currently employs around 108,600 people. When indirect jobs are taken into account, this figure rises to more than 150,000 (EWEA, 2009). Employment is one of the main economic objectives of any government, and is therefore an important subject when considering the effect of renewable energy policies. There are many concerns about the supposedly negative employment effect of policies supporting the development of wind energy (and renewable energy in general), which makes this an interesting aspect to analyse in this study. This chapter will deal with the employment impact stemming from the wind energy cost reduction (projected by experience curve analysis). The cost reduction effect on wind energy profitability, capacity and government expenditures as discussed in the previous chapter will be the starting point in considering employment consequences. The chapter will begin with a review of the literature concerning employment effects of renewable energy (policies), concluding with a number of research results of particular relevance to this study. We will then discuss the net employment effects of a wind energy capacity expansion, or more specifically a shift in energy production from fossil fuel plants to wind energy. Also, the type of jobs created by wind energy vis-à-vis conventional energy will be analysed to give a more detailed description of the employment effects of a production shift from conventional to wind energy. We will finally discuss the employment impact of the second effect discussed in the previous chapter, the reduced need for government support policies.

4.1 Literature concerning wind energy and employment

There is an extensive amount of research analyzing the employment effect of wind energy (or renewable energy in general). However, these studies have significant differences in a number of aspects, which is important to realize when using the research results. Before giving an overview of these studies, we will discuss the main aspects in which the studies differ.

The root cause of the employment effect

Studies concerning employment effects of wind energy are mainly different in the effect they want to analyse. For example, some studies focus on the employment effect of a shift in production from conventional energy to renewable (or wind) energy. Within this category, some studies estimate this effect by assuming different scenarios of a future mix in production between conventional and different sorts of renewable energy. For example, they compare a pessimistic scenario of 5 percent renewable energy and 95 percent conventional energy, to an optimistic scenario of 20 percent renewable energy and 80 percent fossil fuel energy. Other studies directly analyse whether the renewable energy sector creates more jobs than the conventional energy sector, in terms of capacity, energy production or investment.

Another branch of studies analyses the employment effect of a specific government policy concerning renewable energy. For example, the employment effect of a policy aimed at reducing carbon emissions may be analysed. Also, the employment effect of a compensation policy for wind energy has been analysed. In the context of this study, the former type of studies will be most relevant.

Method of analysis

In studies concerning employment and renewable energy, a major distinction can be made between studies employing analytical models and studies using input-output (I-O) models to judge employment effects. Analytical models are generally simpler, spreadsheet-based models. They typically only calculate direct employment effects (which in the case of wind energy include jobs created in the manufacturing, delivery, installation, project management and operation & maintenance). I-O models also account for indirect employment which is induced through multiplier effects of the industry, by using a matrix representation of the linkages between different industries in an economy. For example, the installation of a wind turbine is a direct job, whereas the manufacturing of the steel used for the turbine blades is an indirect job. I-O models provide the most complete picture of employment effects, however the analytical models are much more transparent which allows to extract the effect of different energy scenario’s or energy technologies (Kammen, 2004).

Gross or net employment effects

Studies also differ in whether they analyse the gross- or net effect on employment. Many studies only consider the gross effect of e.g. an expansion of wind energy capacity, by assessing how many extra jobs this would produce. However, a more complete and accurate analysis would also take into account the job losses in conventional energy when considering a shift from fossil fuel to renewable energy, to assess the net effect on employment.

Industry scope

A final distinction is whether a study focuses on the renewable energy industry as a whole, or analyses the wind energy industry separately. The majority of studies analyses the renewable energy industry as a whole. However, some studies do distinguish between the effects of different energy technologies. Because this thesis is focused on the employment effect of wind energy, the latter studies are most useful.

With these differentiating factors in mind, we will now briefly discuss some important studies concerning wind energy and employment.

Hillebrand et. al (2006) discuss the effect of German policy support schemes to increase the share of renewable energies. They employ a dynamic econometric model to assess the effect of a fixed feed-in tariff, which they state to be twofold: On the one hand, FIT's induce investment and increase production, which give rise to a growth of employment. On the other hand, the cost of this policy and/or production adjustments will be shifted to consumers and have a contractive effect on the economy and employment. They conclude that the first effect will dominate in the first years, while the contractive effect will lead to a slightly negative net employment effect by 2010.

Moreno et. al (2006) employ an analytical model to estimate the effects of a energy production shift from fossil fuel to renewable energy, in the region of Asturias, Spain (characterized by an intensive coal mining industry). The model is based on an estimate of the number of jobs per MW installed capacity, for each of the energy technologies. Using three scenario's of future energy production composition, they conclude that "the development of renewable energies will have an outstanding effect on employment, thus compensating the gradual losses in employment in the traditional mining industries."

Ziegelmann et. al (2000) assess the net employment effect of a shift to renewable energy production in the German region of North-Rhine Westphalia. They employ input-output models, concluding that the shift to an energy-supply system that is based on renewable-energy carriers would have positive net employment effects. They do not distinguish between the separate effects of the different renewable energy technologies.

The European Commission (2006) has also employed input-output analysis to assess the employment effects of meeting the target of 20% renewable energy production by 2020. They conclude that this will entail a net increase of 650,000 jobs in the EU. However, they also do not separate the effect of different renewable energy technologies.

Algoso and Rusch (2004) analyse the job growth potential of a wind energy capacity increase in the mid-atlantic states of the US. They employ an input-output model to account for both direct and indirect jobs. Apart from estimating gross employment effects of an increase in wind power capacity, they estimate the jobs/MW ratio to be 2.48 for wind energy and use this to assess the net employment effect of a shift to wind energy. Their main conclusion is that choosing wind energy over a comparable amount of natural gas installations (i.e. a shift from natural gas to wind energy) would create twice as many jobs, corresponding to a significantly positive net employment effect of a shift towards wind energy production.

Whitely et. al (1999) analyse the net effects of different future energy scenario's for employment in the wind energy sector, using I-O analysis. Their conclusion is that the wind energy sector will create between 162,000 jobs (with current policies) and 368,000 jobs (with advanced renewable strategies) in the EU by 2020. These figures represent net employment effects, including indirect jobs.

The renewable energy policy project (REPP, 2001) has conducted a study estimating the total hours required to manufacture, install and service a typical wind farm, per MW of energy capacity and per dollar of investment. They use an analytical approach. One interesting conclusion is that the wind energy industry offers 40 percent more jobs per dollar invested than coal. They do remark that future technological advancement will cut the need for labor, due to economies of scale.

Finally, Kammen et. al (2004) has conducted an extensive analysis of previous employment studies and converted results to one common unit in order to compare the employment impact numbers from these studies. The overall conclusion is that the renewable energy sector generates more jobs per MW of power installed, per unit of energy produced and per dollar of investment than the fossil based energy sector. The specific net employment effect of wind energy is also found to be positive. A main conclusion of their research is that a shift in energy production from fossil fuel energy to wind energy would induce a positive net effect in employment.

Reflecting on the research literature discussed in this section, it can be said that all studies indicate that wind energy production has a positive impact on employment. A shift from conventional energy to wind energy will cause a net growth of jobs, because wind energy produces more jobs per MW, per unit of energy produced and per dollar of investment. However, there are some critics to be pointed out here. One major drawback of the studies discussed here is that none of them take into account the contractive effect of government programs supporting wind energy. Their line of reasoning is somewhat similar to the argument to build a bridge – funded by the government – because it creates additional employment. What is often unmentioned is that the taxes needed for funding will decrease disposable income, having contractive effects on other industries in an economy. Money spend on taxes to build a bridge, cannot be spend in other industries where labor might be employed in a more optimal way. Of course, the production of wind energy is not entirely funded by the government, but the general point remains the same. The employment studies discussed above neglect the contractive effects that government support programs have on the rest of the economy.

In the next section we will assess the employment effects of the wind energy cost scenario predicted by experience curve analysis.

4.2 The employment impact of the projected decrease of wind energy costs

Recall from the previous chapter that one main result of the anticipated wind energy cost decrease is that more wind sites will become profitable, giving rise to an increase in wind power capacity. Because of the energy market bidding scheme discussed in the previous chapter, an increase of supply of wind energy will shift Figure 4 to the right, replacing conventional energy sources. This means that relatively more energy will be supplied by wind power, corresponding to a shift of energy production from conventional energy to wind energy. The literature review of the previous section turned out that such a shift will have positive effects on employment, because the wind energy sector generates more jobs than the fossil fuel sector. If one kWh formerly produced by a conventional power plant will be replaced by wind energy production, this should have a positive effect on net employment, according to the literature. Therefore, it can be stated that the capacity expansion effect of the experience curve analysis will have a positive net effect on employment in the energy industry.

In more general terms, the learning effects and technological progress underlying the experience curve theory will increase total factor productivity (TFP). This progress of technology is the driving factor behind long term GDP growth in the Solow growth model. In the economic theory of the firm, technological progress will shift the production function upwards and increase the marginal productivity of labor, shifting the labor demand schedule outwards (Burda and Wyplosz, 2005). In the context of this thesis, technological progress brings down the production cost of wind energy, increasing the marginal productivity of labor resulting in a growth of labor demand. Depending on the elasticity of labor supply, this will result in higher wages if labor supply is inelastic whereas it will result in higher employment if supply is elastic (Burda and Wyplosz, 2005).

As stated earlier the positive findings in the literature have a significant flaw. In determining the employment benefits of wind energy, one should not only look at the number of jobs wind energy produces per unit of production or investment, but one should also take into account the role of government support policies on employment in other industries. A shift towards wind energy production would involve an increase of employment in the energy sector, however the overall employment might decrease due to contractive effects of government policies aimed at supporting the development of wind energy.

One topic that deserves some special attention is the type and location of the jobs produced by wind energy. Many studies (e.g. Kammen et. al, 2004; REPP, 2001; Whitely et al, 1999) point to the importance of distinguishing between the type of jobs created. All studies state that the fossil fuel energy sector has a large component of jobs in fuel processing and operation and maintenance (O&M). Because of its capital intensity and no need for fuel, the majority of jobs generated by wind energy are in manufacturing and construction. More specific, the majority of wind energy jobs are estimated to be in blade manufacturing (26%), turbine servicing (20%) and installation (11%) (REPP, 2001). This significant difference in the type of jobs created by the fossil fuel and wind energy industry is important when considering the employment impacts of a shift towards wind energy production. Although we have seen that such a shift corresponds to a net gain in terms of employment and the winners outnumber the losers, there will still be a group of people that will lose their job because of this shift. People employed in for example the fuel extraction industry may become unemployed and may not have the required skills for a job in the wind energy sector. There might be plenty of vacancies in the wind energy sector and many unemployed people who formerly worked in the conventional energy industry. The time it takes to pair these workers with the unfilled job openings might be significant. If this transition time takes too long a person might become locked in the so-called unemployment trap, where skills and re-employability may deteriorate creating a vicious circle of eroding competencies for the labor market (Burda and Wyplosz, 2005). This temporary unemployment, also known as frictional unemployment, should be minimized as much as possible. Providing training and relocation support are general methods to decrease this frictional unemployment. In the context of the shift towards the wind energy industry, it is therefore important to provide retraining for people employed in the fossil fuel energy sector, so that this effect can be minimized. This sounds easier than it might turn out, because the general type of jobs generated by the wind energy industry is significantly different from conventional energy, as discussed earlier. It involves much more work in design and manufacturing rather than fuel processing and operation and maintenance. Retraining people in order to make this transition is likely to be very complicated, needing careful attention of the government.

Also, local differences in job creation potential of wind energy should be taken into account. The wind turbine manufacturing industry is highly concentrated in Europe; with Denmark, Germany and Spain together representing more than 90% of the employment in turbine manufacturing and construction (EWEA, 2009). The anticipated increase in employment will likely be concentrated in these countries, while other countries may not benefit as much from a growth of the wind energy industry in the EU.

It can be concluded that the predicted capacity expansion of wind energy will have a positive net effect on employment in the energy industry. Although the winners outnumber the losers, some people in the fossil fuel industry will lose their jobs. Retraining is needed in order to make the transition, however in practice this may be highly difficult. In addition, the employment growth may be concentrated in countries such as Denmark, Germany and Spain, which currently represent the vast majority of jobs for the wind turbine manufacturing industry. Finally, the contractive effect of government support policies is likely to be considerate, a factor which has been kept out of the analysis in the literature on wind energy employment. Given these critics, the supposedly positive effect of wind energy production on employment might not be as beneficial as the literature suggests. Frictional unemployment, geographical concentration of jobs and negative employment effects of government support expenditures put the employment potential of wind energy in a much darker perspective.

In addition to the projected capacity expansion, the previous chapter discussed a second effect of future wind energy cost reduction: A decrease in government expenditures, due to lowering need of support policies for wind energy. As described, government may lower its support for wind farms, which are still able to make a normal profit – due to declined energy production costs. This support is paid for by consumers: Either through taxes or – if the subsidy for wind energy is funded by taxes on polluting energy production technologies – through higher electricity prices. Since less money is needed to stimulate wind energy, this money may be spent by consumers on other things. Disposable income of the population will increase if government support expenditures go down. Given unchanging spending patterns, the effect is an increase of aggregate demand in the economy, which in turn will foster production and increase GDP. The impact on employment is a growth of jobs in the economy, in sectors which may be entirely unrelated to the wind energy sector but which are stimulated by the projected increase of dispensable income. According to the multiplier effect, the growth in employment may supersede the initial growth in aggregate demand. This is because new jobs create income that will be (partially) spent, giving room for even more jobs. Depending on the savings rate, these effects may ripple through the economy several times. In summary, the projected decrease of government expenditures will increase aggregate demand, giving room for additional employment in all sectors of the economy.

Before concluding, there is one more critical point to be made. The cost reduction projected by experience curve analysis may create employment in the wind energy sector as described in the previous discussions. However, these discussions are based on literature studies regarding the employment of wind energy, which analyse the employment potential of wind energy by assuming present conditions of the wind energy industry. These conditions – including labor conditions – may change in the next decades, which is mentioned by one of the reviewed studies (REPP, 2001). Experience curve analysis projects a cost reduction, explained by a number of factors as discussed in chapter 1. Technological progress, efficiency improvement and mass production may cut the need for labor in the future. Such a decrease of labor intensity in the wind energy production process may be one of the factors underlying the declining cost trend described by the experience curve. Although decreased wind energy costs will increase wind energy production as discussed earlier, the employment growth potential will very much depend on the future labor intensity of wind energy production. A future decrease of labor intensity may dampen or even reverse the positive employment effect of a shift in production from conventional energy to wind energy: If the share of labor will fall significantly in the next decades, the projected increase of wind energy production may be offset by a reduced need for labor, resulting in a negative employment effect. Since experience curves describe an empirical phenomenon and do not explain the factors underlying cost reduction, they cannot be used to examine the future labor intensity of the wind energy industry. In order to assess the plausibility of the negative effect on employment described above, further research is needed to study the future intensity of labor in the wind energy industry.

5 Conclusion

The research conducted in this study has given a glimpse of the future of wind energy. Application of experience curve research indicated that wind energy will become significantly cheaper in the next decades, due to a capacity expansion of wind energy. This cost reduction will improve wind energy competitiveness vis-à-vis conventional energy. One main effect will be an increase of wind energy production, because less ideally located wind sites will become profitable and induce investment. A second effect is a reduced need of government support policy expenditures, resulting in an increase of aggregate demand in the economy. The final objective of this thesis was to estimate the impact on employment. According to the literature, both effects of improved wind energy competitiveness will have a positive effect on employment in the energy industry. All studies found in the literature conclude that wind energy produces more jobs per MW, per unit of energy produced and per dollar of investment than the conventional energy industry. The projected shift in energy production from conventional sources to wind energy will thus likely induce a net growth of employment in the energy sector. In addition, the projected increase of aggregate demand will give room for employment in all sectors of the economy.

However, there are some significant negative effects as well – some of which have not been accounted for in the wind energy employment literature: The shift towards wind energy will induce a change in the type and location of jobs, causing significant frictional unemployment and a need for retraining and mobilization of labor. In addition, the positive effect on employment may be partially offset or even reversed by a future decrease of labor intensity in the wind energy production process. Reduced need for labor may be one of the underlying factors of the cost reduction described by the experience curve, the size of this effect will determine if a shift towards wind energy will have a positive effect on employment in the future. Finally, the contractive effect of government support expenditures on employment in other sectors is not accounted for in the literature, and can be significant. It can be concluded that the supposedly positive effects of wind energy on employment should not be taken for granted and approached with a critical attitude. The fact that most negative employment effects are ignored in the literature is a reason to be skeptical towards the objectiveness of this literature. Given these limitations, future research is needed to give a more thorough insight in the net employment effect of wind energy support policies and cost reductions.

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