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Examining the financial performance of micro-generation wind projects and the subsidy effect of feed-in tariffs for urban locations in the United Kingdom

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ABSTRACT

This paper seeks to evaluate the effect of the upcoming 2010 UK Feed-in Tariff (UK FIT) on decentralised small wind-energy installations at the household and building level in urban locations. It is projected that the UK FIT will stimulate an unprecedented surge in building-mounted turbine installation. The tariff amount must stimulate incentive but mitigate the likelihood of distortions in the competitive electricity market. To analyse these issues, measured energy output from sites in the Warwick Wind Trials Project (WWTP) is converted into revenue in a net-present-value (NPV) framework for assessing commercial purchases of small wind systems. Variances in project variables are examined through NPV simulations using Monte Carlo analysis to capture permutations of small wind-project performance in the UK—with and without the UK FIT. Our research concludes that the proposed tariff amount of 30.5 p/kWh will not significantly boost the economic attractiveness of mildly selective (WWTP-based) sites in the UK. Furthermore, the fixed-tariff rate (£/kWh generated) could cause inefficiencies applied across uneven wind-resource distribution. The results of this study suggest further examination of policy related to micro-generation, in particular decentralised small wind projects.

1. Introduction

In accordance with the EU renewable energy directive, the UK Department of Energy and Climate Change set out an aggressive Renewable Energy Strategy in 2009 suggesting that over 30% of electricity should come from renewable sources as compared to 5.5% in 2008 (Department of Energy and Climate Change, 2009). The UK government mandates a strong role not only for large renewable projects, but also for small-scale renewable energy (otherwise known as "micro-generation") at the building and community level. The burgeoning importance of small-scale renewable energy was first recommended in 2006 in the UK's Micro-generation Strategy. Testament to the government's interest and support in this is its increasing offers of financial incentives to micro-generators, such as households and commercial building operators. According to the British Wind Energy Association (BWEA) the number of building mounted installations is forecasted (Fig. 1) to grow significantly as a percentage of small wind systems in 2010 (when the UK FIT is to be implemented).

In the UK, the subsidy for small-scale renewable energy generation has included capital grants and, most recently, Renewable Obligation Certificates (ROCs). A key recommendation of the Micro-generation Strategy was implementation of additional policy mechanisms to increase deployment in the small-scale sector. After many years operating in Europe – and not without controversy – the feed-in tariff (FIT)[1] is being implemented in the UK (UK FIT herein) to further promote and incentivise small-scale renewable energy projects.

Within small renewable technology there is a special interest for small wind applications. This is bolstered by claims that purport the UK to have "the best wind resources in Europe," holding as much as 40% of the EU wind capacity (British Wind Energy Association, 2009). Discussion and focus about harnessing the UK's wind power are on the rise, particularly involving the commercial market for small wind. Potential energy yields of small wind are being scrutinised along with the interaction of private investment and government subsidy. On the policy side, there is controversy surrounding the implications of heavily subsidising renewable energies in a competitive energy market. Experiences of the FIT in the EU demonstrate that, although the incentive shows success in stimulating renewable energy development, some countries have also experienced negative impacts, such as consumer backlash from higher wholesale electricity costs (Lesser and Su, 2008).

Purchase behaviour toward renewable energy technology is complicated by evidence that rational purchase decisions involving future savings or revenues are rarely made by consumers, although consumer surveys indicate that diffusion of urban small

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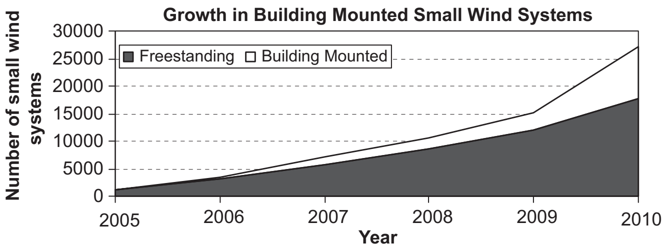

Fig. 1. Growth in building mounted small wind systems.
Source: BWEA 2009.

wind technology would be enhanced if positive financial benefits could be observed. This raises an important question for policy makers, "If the tendency is for consumers to not fully evaluate the economic benefit of their purchase on an ex-ante basis then what are the implications of policies that influence urban building owners to purchase small wind technology only to discover on an ex-post basis that it was not financially beneficial?" One approach to answering that question, and the principal purpose of this paper, is to undertake an ex-ante evaluation using metrics such as net present value (NPV) through energy savings as testable ways to gauge the general economic attractiveness of urban small wind systems across the UK, given existing incentive policies.

Effective and efficient subsidy policies for renewable energy will be addressed through an examination of experiences of the first EU countries to use the FIT. This research adds to the knowledge base in its evaluation of the application of FIT policy to urban wind micro-generation. Discussion of controversies surrounding energy policy mechanisms in Europe set the stage for identifying subsidy inefficiencies that can be observed through NPV testing of small wind projects under the UK FIT programme.

The NPV testing framework will be established using costs and revenues of building-mounted small wind installations in urban sites in the UK. Measured data from real wind sites monitored in the Warwick Wind Trials Project (WWTP) provides fundamental energy-generation information about small wind turbines that is then analysed and prepared for use as revenue in the NPV framework. By converting a study of wind energy output of small wind turbines from energy analysis into financial metrics, it is predicted that the financial return will conform to the disappointing results of the energy output measured in the WWTP and the implications for policy development arising from these results are identified.

2. Literature review

2.1. Liberalisation of electricity markets

In the context of electricity power networking, the literature refers to building micro-generation as distributed or decentralised energy. Bayod-Rujula (2009) notes the increasing liberalisation of energy networks is a trend seen in many countries, and is characterized by an open access to transmission and distribution grids to accommodate distributed energy sources. He describes a shift in the control of energy flows from the traditional energy systems of large central utilities to a more liberalised system where "much smaller amounts of energy are produced by numerous small, modular energy conversion units…often located close to the point of end use" (Bayod-Rujula, 2009, p. 377). The principal drivers of a distributed energy network are technological developments in energy devices and national commitments to renewable energy. Outlined benefits of distributed energy include: avoidance of transmission congestion, the prospect of substituting expensive infrastructure capital to distributed energy resources (DERs), and the fact that on-site production reduces transmission losses from a central utility. DERs provide new market opportunities for industrial competiveness, are easier to source locations for (rather than large plants), and improve localisation of resources (Bayod-Rujula, 2009).

The liberalisation of the electricity market offers the context within which individual electricity generation becomes an option. No longer constrained by the system control of the central electric utility, small-scale generators can take a proactive role in generating their own energy supply and selling excess energy back to the grid. The freedom to install renewable energy systems has further commercialized small-scale generating technology as manufacturers vie for prospective customers interested in new sources of energy.

2.2. Small wind purchase decisions in a liberalised electricity market

Small wind systems are typically purchased as commercial products, and understanding the relative weight of the various purchase-decision factors on the part of a prospective customer's (building owner's) mind is important. Unfortunately, there are a number of factors that are involved in the purchasing decision; price, product features, brand, performance, aesthetics, etc. Owners of possible urban small wind sites are limited in terms of information associated with their energy consumption patterns (typically monthly statements lacking in adequate load profile data). While a FIT might provide surety of income, making an optimal decision about product and price is difficult when the purchaser is faced with imperfect information related to product performance requirements (Friedman and Hausker, 1988). Complicating the matter is the risk that owners will tend to act irrationally when considering the purchase of renewable energy technology. Studies have indicated that it is unlikely that most potential purchasers will behave rationally and utilize financial methods to justify their purchase decision (Sauter and Watson, 2007).

The irrational purchase behaviour on the part of building owners may be further enhanced by policy decisions such as the UK FIT and capital grants. Surveys of UK households indicate that an important factor influencing the purchase of renewable energy technologies such as small wind devices is the initial investment cost (Sauter and Watson, 2007). Providing capital grants and tariffs for the generated power in excess of the market price can encourage the building owner to purchase the technology even though they may not be able to accurately determine whether a positive financial benefit will accrue to them over the life of the product. In addition to the financial incentive, the UK FIT and capital grant for urban small wind technology represent quasi-accreditation schemes that can have a significant influence on the acceptance of the technology and the positive investment decision of the UK building owner (Sauter and Watson, 2007).

In addition to energy cost savings, environmental concerns are often cited as motivators for considering small-scale renewable energy. Despite being praised for environmental-friendliness, a cursory overview of the literature suggests that environmental benefits of renewable energies would not factor highly in the purchase decision.

A report by EcoAlign in 2008, an environmental-attitude researcher, concluded that citizen concern about the environment generally does not extend where there is a monetary cost (Wimberly, 2008). Although this study was conducted on US citizens, a European survey of financial incentives similarly found that people primarily weighed their decisions to purchase DERs on economic merit, such as payback times, despite a strong awareness of environmental issues (Hack, 2006). Financial incentives offered by Germany and Greece to improve the financial returns for consumers were instrumental in the development of distributed solar energy markets. From an ethical consumer-behaviour perspective, researchers at Bournemouth University noticed that there is a large gap between those claiming they would pay a premium for environmentally friendly products and those who actually do (Bray and Grevett, 2009). Relating specifically to small wind energy, a recent study by the Energy Savings Trust, commissioned to monitor customer experiences with small wind systems, concluded that "customer feedback indicates that perception of the technology corresponds closely with technical performance. Customers were more positive about their wind turbines when receiving demonstrable cost and energy savings from their turbine" (Energy Saving Trust, 2009, p. 17).

The diffusion of urban small wind technology in the UK will rely on the positive appeal garnered through "demonstrable cost and energy savings". There may be a number of ways in which cost and energy savings may be demonstrated to the purchaser. In its simplest form, consumers may see the financial benefit as reduced monthly electricity bills or through more complicated calculations of return on investment (NPV) or payback multiples. While the literature suggests that purchasers of small wind technology would not employ more sophisticated economic evaluation methods such as an NPV calculation in making their purchase decision (Sauter and Watson, 2007), the acceptance of urban small wind generation in the UK ultimately hinges on the product's economic attractiveness to building owners.

2.3. Choice of method to determine economic attractiveness

In order to address the question, "If the tendency is for consumers to not fully evaluate the economic benefit of their purchase on an ex-ante basis then what are the implications of policies that influence urban building owners to purchase small wind technology only to discover on an ex-post basis that it was not financially beneficial?", the choice of an ex-ante approach to determining economic attractiveness will provide insight into whether the risk exists that urban small wind projects may not provide a financial benefit to the purchaser. Common methods for evaluating small wind projects include NPV and Payback Period (Kelleher and Ringwood, 2009; Falconett and Nagasaka, 2010) but for the purpose of this paper the authors have chosen to use the NPV method primarily because the Payback Period method provides no consideration for cash flows beyond the payback year and, as opposed to the NPV, provides no indication as to how much the project will improve the capital position of the purchaser or how much the project yields over the cost of capital (Brigham and Houston, 2007).

When employing the NPV method, establishing a base discount rate and purchase decision (project acceptance) rule for small wind projects is required for assessing their attractiveness. The purchase decision rule for the purpose of determining an economically attractive project in this paper is thus established as project NPV > 0 at a minimum discount rate of 2% (a reasonable estimate of an alternative return on a standard savings account for a deposit equal to the investment cost of the small wind project). Greater discount rates were considered and could be justified, for example relying on a discount rate equal to conventional householder loan rates, but a minimal rate was chosen as it provided a greater likelihood of positive economic return and project attractiveness while remaining justifiable in terms of alternative investment returns available to the consumer. In other words, if the project is not economically attractive at the chosen minimum discount rate, it certainly will not be at a higher discount rate. If the project is economically attractive at this lower discount rate then the flexibility exists to consider more expensive forms of financing other than from household savings.

2.4. Financial incentives for generating renewable energy

Several jurisdictions have introduced financial incentive policies that encourage development of renewable energy projects (Wang et al., 2006; Dinica, 2008; Mulder, 2008; Munksgaard and Morthorst, 2008; Couture and Gagnon, 2010). Financial incentives stimulate demand for renewable energy where there would otherwise be none with existing electricity prices (Lesser and Su, 2008). In economic terms, the problem stems from conventional electricity wholesale costs being incomplete – maybe even deceptive – in that they do not account for all external costs, such as environmental damage. Without internalised costing of all externalities, renewable energies cannot exploit their chief competitive advantage: fewer harmful emissions (Finon and Menanteau, 2003). As a more extreme voice, Herman Scheer states, "The big challenge for the renewable energy industry has been to make the cost of clean energy competitive with heavily subsidised conventional energy" (Scheer, 2007, p. 2). By incentivising renewable energy deployment, technologies can experience economies of scale and experience learning-curve advantages (Soderholm and Klaassen, 2007) thereby reducing costs and becoming competitively affordable, even without the environmental valuation benefit.

While a FIT to encourage renewable generation seems, at first glance, a reasonable solution, it is not without its controversies. It can be difficult to attribute mass renewable energy deployment solely to the FIT system; there are many other factors influencing renewable energy uptake within each national context, including planning permissions, energy prices, and social and political will (Dinica, 2008). While this clouds the ability to isolate FIT systems for empirical tests of effectiveness, potential market implications can still be gleaned and discussed.

2.5. The FIT system and related controversies

In the EU there are two ongoing debates about how to optimally subsidise renewable energy and design a FIT system. One relates to the challenges of setting an efficient tariff amount that encourages investment and development without causing excess advantage over the existing market (Mulder, 2008). The other questions the long-term conflicting goals of competition in a liberalised energy economy and the use of protective subsidies for renewable energy, in particular a fixed-rate FIT (Wang et al., 2006).

Germany provides a case where the FIT was successful in reaching high levels of renewable energy installation, but where the FIT also caused undercurrents of strife in the electricity market. Favourable FIT amounts created competitive distortions in the electricity markets (Sijm, 2002) where electric utilities were forced to purchase energy at too high a premium over generation costs. The high costs borne by electric utilities created a cost-diffusion problem in the market. In theory, any cost hikes to support renewable energy can be absorbed by all energy users, reducing it to a negligible increase (Scheer, 2007). However, at the introduction of the FIT in 1990, wind power in Germany was stimulated only in certain regions having the highest wind-energy resource. This meant the obligation to purchase the wind energy at a high FIT was disproportionately passed on to utilities of the Northern Region in Germany (Wüstenhagen and Bilharz, 2004). Customers in this region then threatened to switch suppliers if the utilities passed the cost hike down to end-users. This energy market turmoil culminated in claims that feed-in support schemes were in conflict with EU rules for state-aid (Meyer, 2003), and has led to many judicial actions by electric utility companies in protest (Sijm, 2002). Subsequent legislation, the Renewable Energy Sources Act (RESA), was introduced in

Germany in 2000 that effectively dealt with these disproportionate costs by creating a framework of cost-sharing amongst utilities and a tariff structure that employs an algorithmic determination of site-specific tariffs. This latter element provides lower-wind resource projects a higher tariff (when compared to a reference site) thereby allowing for a more reasonable project return (Jacobsson and Lauber, 2006; Meyer, 2003). The German example highlights the fact that FITs are subsidies that have delicate, conflicting interests between those who support the development of renewable energy and those who ultimately pay the tariff and that FIT policies must be carefully designed to avoid these conflicts. This problem is summarised as "too high a FIT will stimulate over-investment, causing too rapid development of above-market RETs [Renewable Energy Technologies] and triggering adverse economic impacts owing to higher than expected electric rates, as well as customer backlash" (Lesser and Su, 2008, p. 984).

Another problem in setting the efficient FIT amount concerns the rate of spurred development. If the rate is too low, the market cannot reach production levels that foster economies of scale that can reduce costs and stimulate wide-spread diffusion of the technology. However, too high a rate reduces financial risk and can encourage over-investment in, and development of, less efficient projects. While it is intuitively logical that profit-maximization tendencies on the part of developers should limit inefficiencies, other factors in the project development process such as urgency to market, vendor–client relationship effects and poor management decisions can mitigate those tendencies. Without customising the FIT amount to the range of ROIs earned on wind-energy projects, any amount is likely to cause inefficiencies. The problem arises from having a flat, fixed-tariff generation rate that is indiscriminately applicable to different renewable energy generators regardless of their productivity or site-specific wind endowment. For example, subsidy surpluses can be awarded to those projects experiencing technical progress (Menanteau et al., 2003) or securing the best wind sites. This problem was highlighted in Denmark where windfall profits were generated by developers who could secure the best wind locations (Meyer, 2003). Certain European jurisdictions (the UK excluded) have recently sought to remedy problems related to resource discrimination based on site-specific advantages by introducing initiatives that adjust the tariff based on performance. Germany's RESA allows for reduced tariffs if turbines performed in excess of a reference facility (Jacobsson and Lauber, 2006) while other countries such as the Netherlands, Portugal, Denmark, France and Cyprus have implemented stepped tariff designs that provide levels of tariffs based on the local conditions at the plant site (Klein et al., 2008) with reduced tariff support for higher yielding locations.

There also exists an incongruity in goals sought by liberalising electricity markets and the offering of financial incentives for renewable energy. Jensen and Skytte (2003) explore the conflict of electricity liberalisation goals in the EU as (a) seeking competitive efficiency in energy production to reduce consumer electricity costs, while (b) using the FIT, which has been known to raise retail electricity prices. Liberalisation has opened up commercial competitiveness of renewable energy technologies in a decentralised energy network. This can improve electricity markets because "DG can also stimulate competition in supply; adjusting price via market forces. In a free market environment, a DG operator can buy or sell power to the electricity grid, exporting only at peak demand and purchasing power at off-peak prices" (Bayod-Rujula, 2009, p. 380). However, distributed generation technologies currently also require subsidies in order to exist in the market at all. In the short term, it is hoped that increased manufacturing levels will create economies of scale and learning-curve improvements as to spur innovation and technological improvement so that renewable energy technologies will eventually become independently competitive in the energy market. But subsidies such as the FIT are argued as being fundamentally at odds with free-market principles (Lesser and Su, 2008; Couture and Gagnon, 2010) because they typically act as a fixed rate relative to the market price. If renewable energy production is always protected against market forces it will never be forced to compete against lower cost alternatives, limiting the potential for competition-driven efficiency and technological development. Influenced by subsidy rather than market drivers, renewable energy development runs the risk of eventually stagnating.

In designing a customised FIT amount, the problem lies in justifying subsidies for technologies in various stages of maturity given that technological advancement can be unpredictable. That is not to suggest that in all cases FIT programs are, or will be, in excess of market prices. Evidence from Denmark (Munksgaaard and Morthorst, 2008) highlights how market prices can rise above the fixed rate of a FIT in certain circumstances when, for example, more conventional sources of electrical generation, such as natural gas or oil, have increased in price subsequent to the introduction of the FIT. The concern lies with FIT policies that may set a tariff at levels well in excess of market prices contrary to the

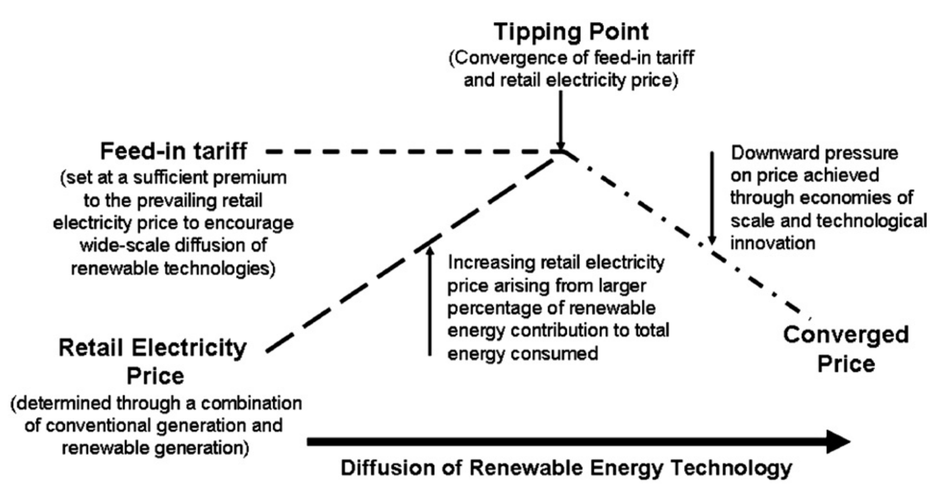

Fig. 2. Model for determining tipping point for diffusion of renewable energy. Independent of any influence from other factors such as increased costs related to distribution and transmission.

EU's goal of seeking competitive efficiency in energy production to reduce consumer electricity costs (Jensen and Skytte, 2003).

Conclusions from the literature on FITs suggest that they are particularly successful when attempting to create a "tipping point" of minimum incentive necessary to catalyse quick deployment of renewable energy (Munksgaard and Morthorst, 2008; Couture and Gagnon, 2010). However, within this quick deployment, an "aggressively priced" tariff may unavoidably produce incentive inequalities due to variation in developer returns arising from regional resource availability. In the long term, sustained inflation of renewable valuation (outside of the free market) could prove to be problematic in a liberalised electricity market seeking to stimulate competitive commodity pricing and spurring technological innovation in renewable technologies. Renewable energy incentive policies that seek to introduce degressive FITs can mitigate the impact of windfall profits by producers through the reduction in financial support as the technology advances and better knowledge of the quality and quantity of the available renewable resource allows for reductions in capital and operating costs (Gonzalez and Del, 2008; Snyder and Kaiser, 2009; Couture and Gagnon, 2010; Valentine, 2010). Furthermore, the integration of economic and institutional interests in promoting wind energy through FIT programs by mutually working on determining the appropriate "tipping point" (Fig. 2) defined by the prevailing market electricity price, wind resources, project characteristics, etc. (Han et al., 2009), would increase the probability of successful diffusion of wind energy (Dinica, 2008; Perez and Ramos-Real, 2009).

However, the question remains as to what extent the experiences derived from FIT policies in other jurisdictions can be applied to urban small wind generation in the UK. An examination of the economics of the potential application of this technology given the proposed UK FIT amount is warranted, and suggested refinements to existing UK FIT policies may be required.

3. Evaluation methodology

A three-step process is undertaken as part of a framework for assessing the commercial attractiveness of urban small wind systems (Fig. 3). This framework is consistent with similar studies undertaken by Kelleher and Ringwood (2009) in their study of wind micro-generation in Ireland and Falconett and Nagasaka (2010) who employed this probabilistic methodology in their review of small wind projects.

The first step involves the determination of annual energy capacity for a typical small wind project in the United Kingdom. Energy data from the Warwick Wind Trials Project (WWTP) is analysed and interpreted in preparation for use in year-to-year project cash flow analysis. Monthly energy measurements from small wind turbines across a variety of urban sites in the UK are converted into average yearly output in kWh. Energy yields are grouped into low, base and high in preparation for Monte Carlo variance simulations and sensitivity analysis (RiskSim). In the second step, the annual energy capacity is applied to a series of profit/cost variables for use in the NPV modelling. The model framework calculates NPV using a set of cash inflows and outflows discounted to the present for combinations of different energy output, turbine cost and lifespan. Using the range of project variables affecting the NPV of wind sites, individual purchase decisions are extrapolated to assess the potential for widespread commercial viability. A Monte Carlo analysis is employed to run 1000 NPV simulations that capture the spectrum of NPV results arising from different combinations of variables.

The choice of the number of simulations to run was based on Monte Carlo methodologies employed in other scientific and engineering disciplines (Rushton and Lolonis, 1996; Hall and Strutt, 2003; Johnson and Gillingham, 2004; Fischer et al., 2005; Gibbons et al., 2006; Blijenberg, 2007; Damon, 2008; Demaria et al., 2009). The frequency of positive NPV simulations will be the measure of viability. The same variances can also be explored through a sensitivity analysis that illuminates the importance of different project variables in relation to energy output (revenue).

Finally, commercial analysis of small wind turbines in the current UK market (without FIT) provides the base-case scenario from which to analyse the effect of FIT. Resulting changes in NPV, and the related changes in economic attractiveness, are aggregated using another 1000-simulation NPV Monte Carlo.

The efficiency of the UK FIT on building-mounted small wind projects will be analysed three ways:

(1) Observing frequency, distributions and range of NPVs achieved in the Monte Carlo analysis with and without the UK FIT will show whether certain projects are over or under compensated.
(2) Determining and comparing a generation tariff amount that would be necessary to produce 50% or more of NPV >0 (majority of economic attractive projects) of 1000 NPV simulations.
(3) Evaluating the sensitivity analyses from the Monte Carlo simulations at different ranges of energy yield (low, base and high). This will show the circumstances at which government financial incentive analysis becomes an important project variable and thus makes FIT warranted.

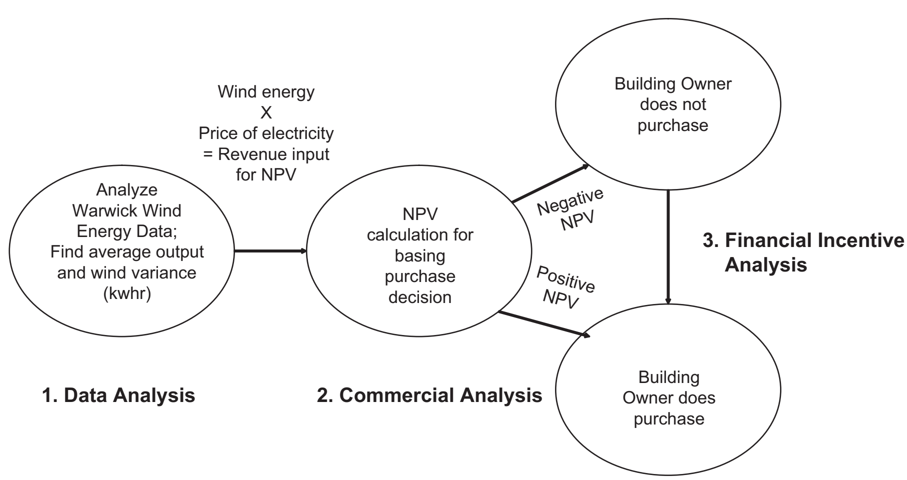

Fig. 3. Framework for assessing the economic attractiveness of urban small wind systems.

3.1. Variances for Monte Carlo and sensitivity NPV analysis

The Monte Carlo analysis is used to paint a picture of the likelihood of ROI among a sample population. This investigation captures the permutations of variance in the factors affecting profitability and intends to seek out the frequency of profitable combinations. As this analysis demands a more accurate "potential scenario" variation, it will account for the reality (as can be seen in the WWTP data) that two sites with identical wind speeds may generate different energy. To do this, the power curves of the three yield groupings (least, base and highest kWh) of the WWTP trialled sites were determined. The trend line of each group of 36 data points (monthly kWh versus wind speed across three sites within a set) represents the low-, base- and high-potential energy yield from a small wind turbine influenced by any given wind speed (as shown in Fig. 4).

These three power functions provide the base equations from which to calculate Monte Carlo variance of expected annual energy output (kWh/year) for a site with a certain affecting wind speed. The sensitivity analysis, in contrast to Monte Carlo, attempts to measure the impact of variables on profitability. This requires ranges (rather than actual variance determinants) of factors affecting profitability.

For the energy-output range, results from the nine WWTP trialled sites were grouped according to low, base and high and averaged. Regardless of indirect factors (such as wind speed), electricity output ranges from an average of 54–165 kWh/year, as shown in Fig. 5.

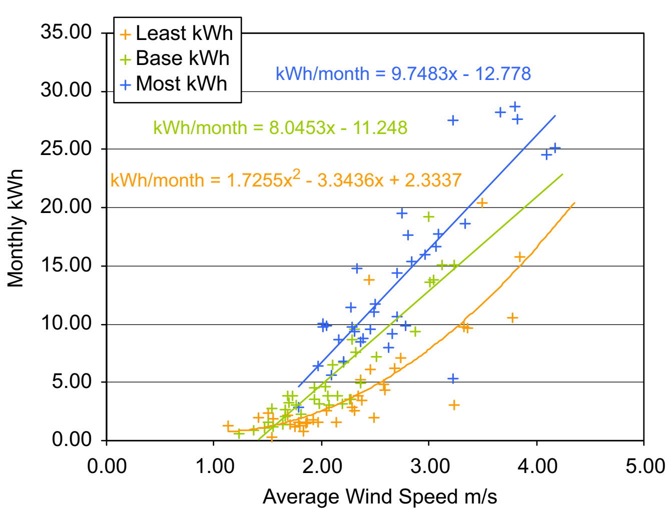

Fig. 4. Power curves for monthly kWh generation (sites grouped by kWh generation: least, base, most).

3.2. Commercial analysis

In analysing the financial return of different sites, the NPV framework (Table 1) employs a traditional financial evaluation of a proposed project with annual cash flows. Employing an Excel add-in tool called RiskSim, a Monte Carlo analysis is conducted on the NPV of wind energy sites. This tool runs a user-defined number of simulations based on variances in the inputs used to calculate the NPV. By running many simulations, RiskSim captures thousands of what-ifs (combinations of variables) that reflect the uncertainties surrounding the NPV of small, urban wind energy projects. Results are presented in histogram charts and cumulative distribution graphs.

Key wind-project input variances that affect NPV in the simulations include turbine operating life, turbine cost and energy yield. From a building owner's purchase perspective, these variables constitute the largest "risk" and NPV variation of purchasing a turbine. The Monte Carlo analysis is employed by running 1000 NPV simulations, where each simulation randomly selects energy data from within the WWTP-based spectrum of wind speed and energy yields. Combined with variance in other project variables, this creates a "microcosm" of possible building-mounted small wind energy projects in the UK. Aggregating 1000 individual NPVs (commercial purchases) for different projects allows for the

Table 1
Elements and calculations of the NPV framework.[a]

NPV project elements	Calculation
Discount rate	Rate at which cash flows are discounted to present value (PV). Set at nominal 2%
Project length (turbine operating life)	Sets the amount of years the small wind system will generate energy (revenue) and therefore equals the project life. Turbine lifespan is 10, 15 or 20 years
Year 0 project cost (negative cash flow)	Turbine cost installed × (1-capital grant %). Capital grant is set at 30% as per low carbon buildings programme
Project revenues [years 1–(turbine operating life)]	Yearly revenue = [(energy output (kWh) × generation tariff) + energy output (kWh)] × [electricity cost × electricity cost increase]
Net present value (NPV)	= PV (turbine operating life × yearly revenue) – turbine cost × (1-capital grant %)

[a] Sources and justifications for electricity cost, electricity cost increase and turbine costs are included for reference in the appendix.

	Site	WWTP Average Wind Speed (m/s)	Annual Energy (kWh)	Average Annual (kWh)	Power Curves (kWh/m/s/Month)* *Annual Energy Output (kWh/year) = Wind Speed * Power Curve * 12 Months*
Low kWh Generated	Birds Hill	2.27	51.92	53.99	kWh = (1.7255x^2) – 3.3436x + 2.3337
	Hill Close Gardens	2.04	53.99		
	Delta Court	2.30	56.08		
Base kWh Generated	Daventry County Park	2.04	57.64	67.03	kWH = 8.0453x – 11.248
	Leicester	2.18	61.99		
	Lillington Road	2.22	81.48		
High kWh Generated	Deventry Civic Centre	2.74	151.89	165.13	kWh = 9.7483x – 12.778
	Park Farm	2.83	158.83		
	Napier	2.99	184.68		

Fig. 5. Chart of yield categories (low, base and high).

opportunity to comment on widespread commercial viability (i.e. frequency of projects with NPV > 0 at a 2% discount rate).

Although variances in average wind speed and energy output (captured from the WWTP trials) define the randomness of annual energy output (and project revenue) that produce different NPVs for each simulation, this Monte Carlo analysis does not include fluctuation randomness in energy yields given that wind energy is not distributed equally throughout the month, day, or even hour. Depending on when energy is generated, the value could change in accordance with tiered electricity pricing and supply/demand fluctuations which this does not account for. Instead, it is assumed that building owners will use all energy on-site and can store unused electricity (via battery) thus equally matching supply with demand within a building and ensuring the same value for all energy generated. Using sample site data from WWTP to extrapolate to 1000 simulations is justified because trial sites were specifically chosen by the WWTP as representative of diverse locations across the UK that hold potential for commercial success of small wind systems (as per the Warwick Wind Trial methodology). Wind speed and yield ranges captured from the WWTP give a good indication of variances other UK sites could experience. Turbine costs and operating life variances are also derived from research into turbines used in the WWTP.

3.3. How a simulation is conducted using variances

Site-specific inputs are a mix of fixed numbers and variables. For variables, data from the WWTP form the ranges of average wind speed and energy yield selected from lower, base and upper bounds according to a random selection method within that range (discrete or triangular). The random amounts are carried through the financial model to produce an NPV for that simulation. The NPV framework with example simulation numbers and calculations is shown in the appendix.

3.4. Turbine cost installed and operating life

Based on the analysis of the WWTP results, differences in annual energy yield did not significantly vary between different models of turbine. Cost and durability of turbines, however, do vary with significant impact to the NPV of a purchased small wind system. Turbines used in the WWTP could be purchased (Appendix—Chart of Turbine Life and Cost) and installed for as low as £1500, but were only estimated to last for 10 years. Units costing £2500 had longer expected operating times. To account for this correlation within the model, the cost of turbine was locked to its related lifespan (project length). Each simulation in the Monte Carlo analysis randomly selects a cost of turbine as £1500, £2000 or £2500 using a RANDDISCRETE Excel function. The related lifespan (project length) is then automatically selected using the corollary shown in Table 2.

In the simulation example below, the RANDDISCRETE Excel function chose a turbine cost of £1500 (£1050 after the 30% capital grant). For this simulation, the corresponding year 0 negative cash flow would be £-1050 and project revenues would continue until year 10.

Turbine cost installed w/grant	£1,050
Capital grant	30%
Turbine operating life	10

Using the range of turbine cost + operating life sampled in the WWTP allows the simulations to capture the fact that purchasers can choose between these available categories of turbines on the market. Every turbine used in the WWTP was individually selected and commercially purchased by the owners of a site. It is assumed in this paper that general selection of small wind turbines for urban building application would reflect similar patterns experienced in the WWTP.

3.5. Average wind speed and energy output function

Setting the variance of annual Energy Output (kWh) of small wind systems in urban sites required two steps. Given that the energy output of a turbine is a function of its efficiency (power curve) and influencing wind speed (average annual), these two variables were captured in the model. First, the complete range of average measured wind speeds found from the WWTP analysis was assembled: absolute minimum (low), average (base) and absolute highest (high). In the model, a RANDTRIANGULAR function selects a random number within that range for use as "Average wind speed" in a given NPV simulation. The randomly generated "Average wind speed" number is then applied to power curves experienced in the lowest, base and highest performing sites of the WWTP (power curves derived from data contained in the appendix—Graphed Power Curves Extrapolated from WWTP Data). This captures the variance in amount of energy (low, base or high) a site might generate when influenced by the given wind speed. The "Energy Output (kWh/year)" figure of a simulation is determined by a random selection within this range (RANDTRIANGULAR function). This annual energy-output figure is ready to be used in the yearly project revenue calculation (in combination with the variance in operating life, cost of turbine, and other fixed project inputs) to simulate the NPV of a small wind project.

3.6. Financial incentive analysis of FIT (generation tariff)

Three different scenarios are tested using the Monte Carlo analysis to assess commercial viability of small wind in urban building application. Commercial viability is measured as the frequency of simulations where NPV > 0 exists for different fixed tariff amounts.

Tests conducted:

1. 1000 NPV simulations with capital grant, but without generation tariff **(base case).**
2. 1000 NPV simulations where generation tariff = 30.5 p/kWh with capital grant **(proposed for UK)**.
3. Level of FIT needed to produce, on average, a positive NPV value for an urban UK wind site (arithmetic mean of NPV = 0 of 1000 simulations) **(economically attractive project)**.

Following the results of the Monte Carlo analysis, the NPV inputs and variances are evaluated in a sensitivity analysis. As the sensitivity analysis does not attempt to recreate the permutation NPV probability (like Monte Carlo does via simulation), the inputs concern the minimum–maximum ranges of financial-impacting variables from the base case where NPV is calculated using

Table 2
General range of UK turbine cost and hardware performance.[a]

Cost of turbine	Lifespan (years)	Cost used in model (with 30% grant)
£1500	10	£1050
£2000	15	£1400
£2500	20	£1750

[a] Information about turbine models can be found in the appendix.

averages of each variance. For example, the wind speed crucial to the Monte Carlo simulation becomes irrelevant as it is not a direct financial indicator. The energy range used for sensitivity is the average actual kWh of the low, middle and high performing sites as discussed and determined earlier. Other static variables in the Monte Carlo analysis are given lower and upper ranges that signify their actual volatility in the market. For example, the capital grant in the UK is currently at 30%, which is useful as a static figure for Monte Carlo simulation (testing scenarios of current turbine revenue). However, the sensitivity analysis strives to measure its current impact on the NVP in relation to very-possible levels of grants at 20% or 40%.

Isolating energy yield distribution compares how financially sensitive the tariff is across different small wind sites (low, base and high performance). For example, an NPV of −£1021 in the sensitivity analysis model (Fig. 6) represents the expected value of the base-case scenario of project variables. Sensitivities are measured based on the relative changes to the NPV resulting from different thresholds for each project variable. The results of the sensitivity analysis are outputted as one- and two-factor tornado charts that allow for an impact comparison of the project variables. Energy yields, isolated for low and high performance, are also outputted to allow for the comparison of project sensitivities between the performance ranges.

Site-specific inputs	**Input Cells**	**Minimum**	**Base case**	**Maximum**
Discount rate	2%	1%	2%	5%
Cost of Turbine	2000	1500	2000	2500
Turbine operating life	15	10	15	20
Energy Output (kWh)	67.03	53.99	67.03	165.13
Electricity Costs	0.15	0.15	0.15	0.15
Electricity cost increase	1.77%	0.51%	1.77%	2.72
Government Incentives				
Generation tariff	0.305	0.205	0.305	0.405
Capital grant	30%	20%	30%	40%
NPV	-1021.14			

Fig. 6. Sensitivity analysis model (adapted from Monte Carlo).

4. Results

Results of 1000 NPV simulations without the UK FIT are shown in Fig. 7. The histogram indicates the NPVs of a sample population of 1000 small wind projects in current market conditions where just the capital grant is applied. The mean NPV is −£1.160, and the maximum under the best circumstances of project variables is −£790. Given the fact that all projects would not generate enough revenue to cover costs, commercial viability is far from likely without further financial incentive. The three concentrations of frequency correlate with the three turbine operating life/cost settings. Isolating the turbine cost/life variable revealed that the best performing frequency concentration (−£1.000 to −£790 range) was the lowest turbine operating life. Without the tariff, an expensive but long-running turbine never makes up its cost.

Applying the proposed generation tariff of 30.5 p/kWh improves the commercial prospects, but only slightly (Fig. 8). The mean NPV increases by 32% to −£793 and, interestingly, the distribution of NPV simulations now follows a normal pattern in contrast to the market without the tariff. This would suggest that sensitivity to cost and operating life have decreased in importance as a contributing factor to the final NPV. Whereas without the tariff it could be suggested that the highest cost/longest operating turbine should be avoided, now it is less clear which variables hold the highest sensitivity to NPV under the UK FIT. NPV simulations range from −£298 to −£1401 (−£810) representing an increase of 36% from the range without the tariff (−£1103) (Fig. 9). The maximum NPV achieved increases by 62% (to −£298), almost twice as much as the mean NPV increase (32%), showing a larger increase with the highest performing sites

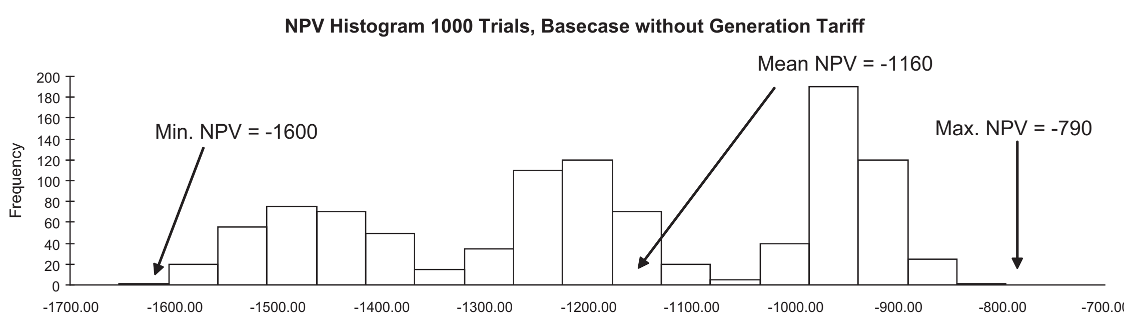

Fig. 7. Monte Carlo analysis: base case.

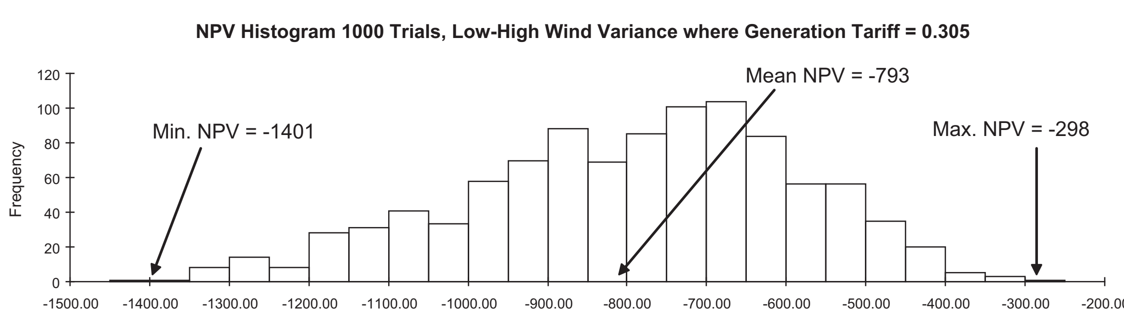

Fig. 8. Monte Carlo analysis: base case+UK FIT.

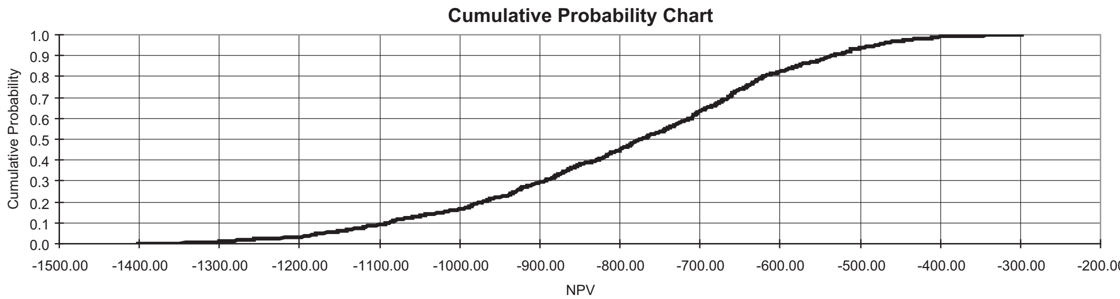

Fig. 9. Probabilities of return for base case+UK FIT.

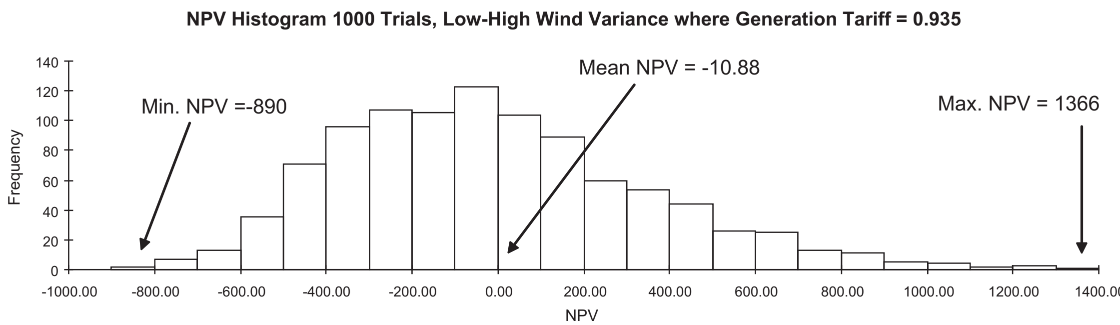

Fig. 10. Monte Carlo analysis: base case+UK FIT of 93.5 p.

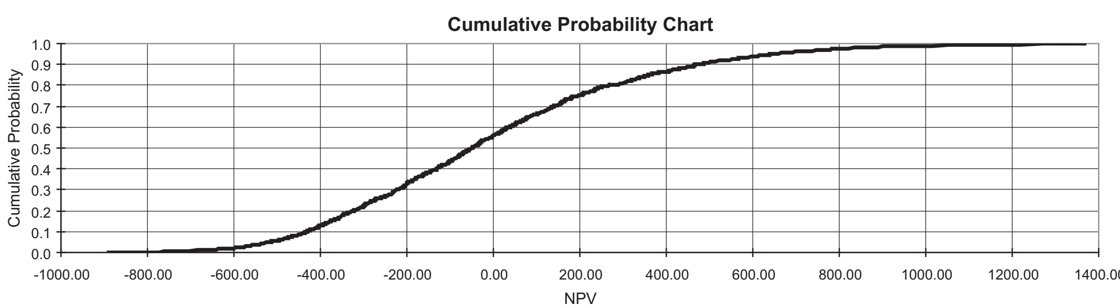

Fig. 11. Probabilities of return for base case+UK FIT of 93.5 p.

than with the average performing sites. Project input combinations analysed for revenue sensitivity will determine if best-combination project inputs (top percentile of NPV simulations) are only accessible to some.

If a building owner had a lower personal discount rate, an NPV of −£400 and higher could possibly be perceived as motivation to purchase. However, even with a lower discount rate, there is only a 2% chance of achieving an NPV of −£400 or greater (Fig. 10). Instead, the highest frequency (steepest slope) centres around the −£900 to −£600 range as the average NPV a building owner could expect from purchasing a small wind system. Although the tariff improves the average range of NPVs, widespread commercial deployment would appear to be unlikely, given the current inputs.

The required generation tariff amount for achieving a mean NPV of around zero (using a discount rate of 2% p.a.) would require a generation tariff amount of 93.5 p/kWh, as shown in Fig. 11. This tariff would be an unprecedented subsidy amount well above the proposed FIT (30.5 p) and five times the retail price of electricity (15 p). While about 50% of projects become economically attractive to potential customers under this tariff (Fig. 11), the range of NPV now skyrockets to £2256, with some projects remaining relatively costly (−£890) while others enjoy substantial profits (+£1366).

Those at the highest end of profit reward would likely be regarded as reaping unfair compensation at the expense of utility customers, who will bear the higher price of electricity that the high tariff amount would cause. This also shows that to stimulate widespread deployment in this sector (where the average building owner could invest in small wind) there is an inherent inefficiency of windfall profits reaped by the generators with the best combinations of project inputs.

4.1. *Sensitivity analysis results*

The sensitivity analysis of the Monte Carlo testing produces a one-factor tornado chart (Fig. 12) where the average of wind speed, energy yield and cost of turbine are used to calculate the base-case NPV. The cost of the turbine is the most sensitive variable, which comes as no surprise given the front-loaded nature of renewable energy technology costs. However, it does show that the generation tariff is overshadowed by other project inputs (such as capital grants and turbine operating life).

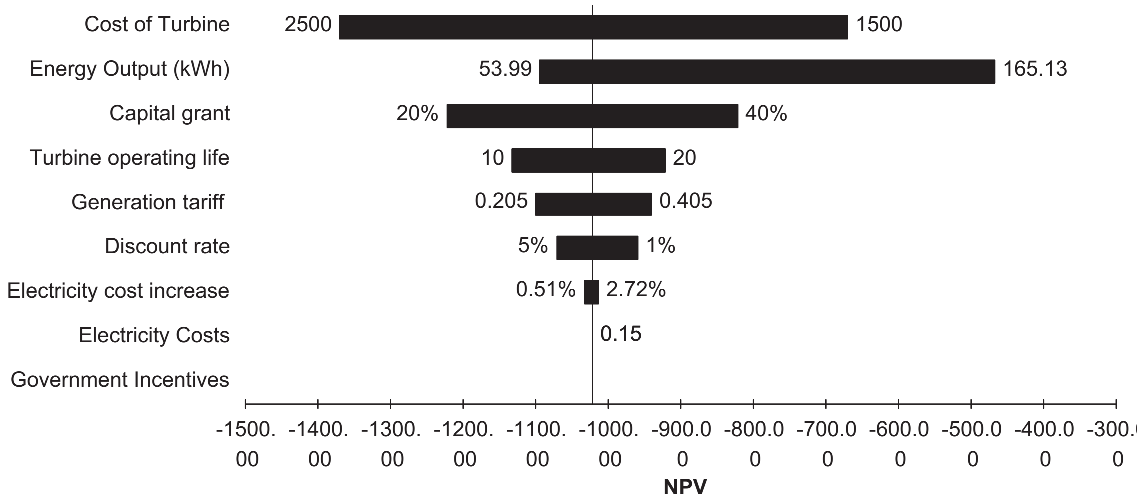

Fig. 12. One factor sensitivity analysis.

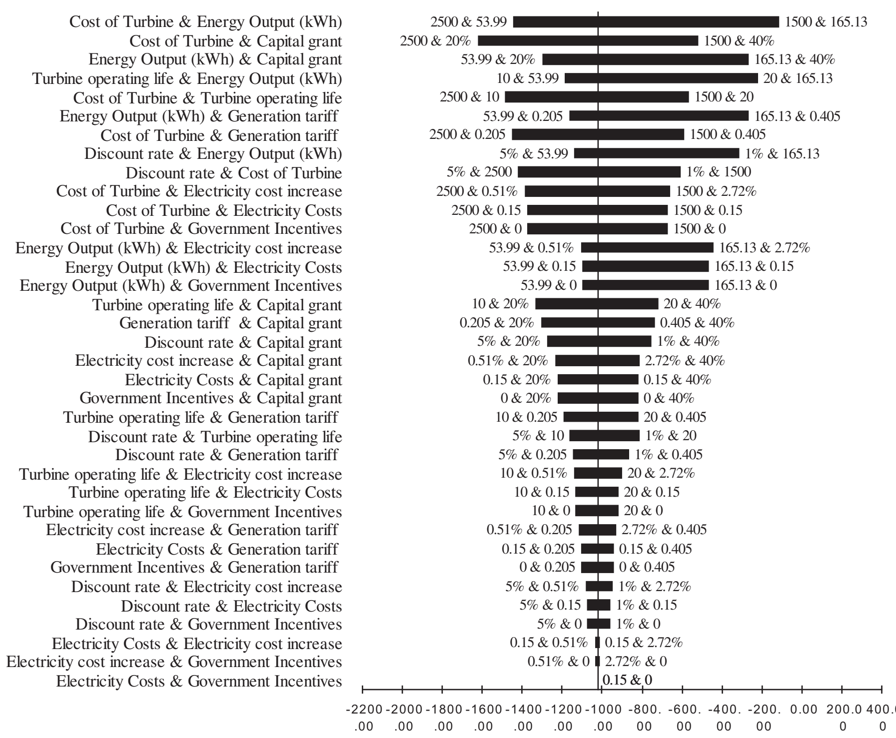

Fig. 13. Two-factor sensitivity analysis.

This would suggest that other project variables would need to improve before the generation tariff is effective (i.e. where the tariff becomes significant to a project's commercial success). The sensitivities can be explored further by employing a two-factor tornado chart as shown in Fig. 13.

The results of the two-factor tornado chart present some interesting findings, especially when separately categorized as financial incentive-based or technology/risk-based (Table 3).

The generation tariff appears as a sensitive variable in only the 6th and 7th most sensitive combination. Indeed, of the two government financial incentives, the capital grant is more crucial to commercial success although without the addition of the generation tariff the capital grant alone would be insufficient to stimulate small-wind development. In general, project variables related to technology or operational performance rank higher than government incentives, which may not be surprising as the small wind market is in its infancy. However, the results of this analysis suggest that tariffs could be more efficiently applied to other small-scale renewable energy technologies or different applications of small wind.

After the UK FIT was introduced into the Monte Carlo analysis, the maximum NPV increased more than the mean. This highlights a potential inefficiency in the UK FIT programme if the emergence of high NPVs encompassed project input combinations that were only accessible to some (e.g. those with good wind locations). Energy yields can be independently fixed (average low and average high) in order to determine which project inputs (other than yield) are now contributing to the highest performing sites. A fixed high-energy performance results in a change in the order of sensitive variables (Fig. 14). Turbine operating life is now highly sensitive, suggesting its role as a project input in the best performing NPV simulations. It can also be interpreted that the higher cost of long-lasting turbines becomes justified under the UK FIT and that the highest small wind project NPVs are contingent on spending more up-front capital, which not everyone has the disposable income to do.

Table 3
Grouping of 10 highest sensitivity combinations.

Sensitivity ranking	Technology-based/risk-based	Government incentive-based
1	Cost of turbine, energy output	
2	Cost of turbine	Capital grant
3	Energy output	Capital grant
4	Turbine operating life, energy output	
5	Cost of turbine, turbine operating life	
6	Energy output	Generation tariff
7	Cost of turbine	Generation tariff
8	Discount rate, energy output	
9	Cost of turbine, discount rate	
10	Cost of turbine, electricity cost increase	

At sites with low energy yield (Fig. 15), the 30.5 p tariff does little to help projects become economically attractive while they struggle to produce enough revenue to cover the cost of the turbine regardless of the turbine operating life. This result suggests that either a minimum energy yield or high tariff amount is necessary for the tariff to stimulate widespread commercial purchases. The best combination of project inputs – whether wind access or ability to purchase better turbines – will always produce inequitably high returns under a fixed-tariff amount of this magnitude. Combinations of average project inputs may become economically attractive at 93.5 p/kWh but the best combinations would then benefit excessively. In addition, this level of tariff would be seen as unreasonable given the current tariff of 30.5 p/kWh and the presumption that this latter rate has been determined based on a fundamental provision of FIT policies; that the tariff is sufficient to cover generation costs plus a reasonable rate of return.

5. Conclusions

The proposed 2010 UK FIT small wind generation tariff amount (30.5 p/kWh) is unlikely to initially stimulate widespread commercial viability of small wind projects in urban locations. More than 95% of locations (reflective of the WWTP-measured wind range) would

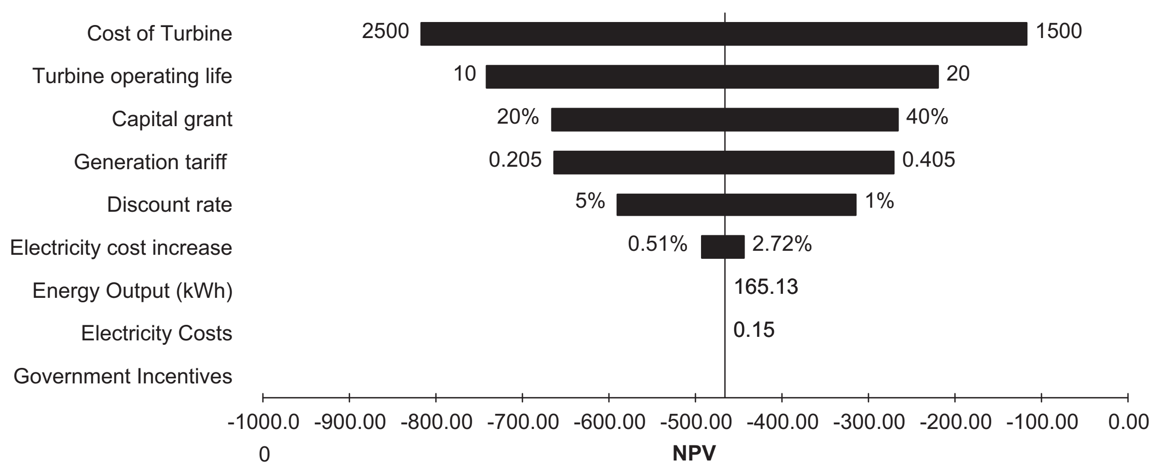

Fig. 14. High energy yield one factor sensitivity analysis.

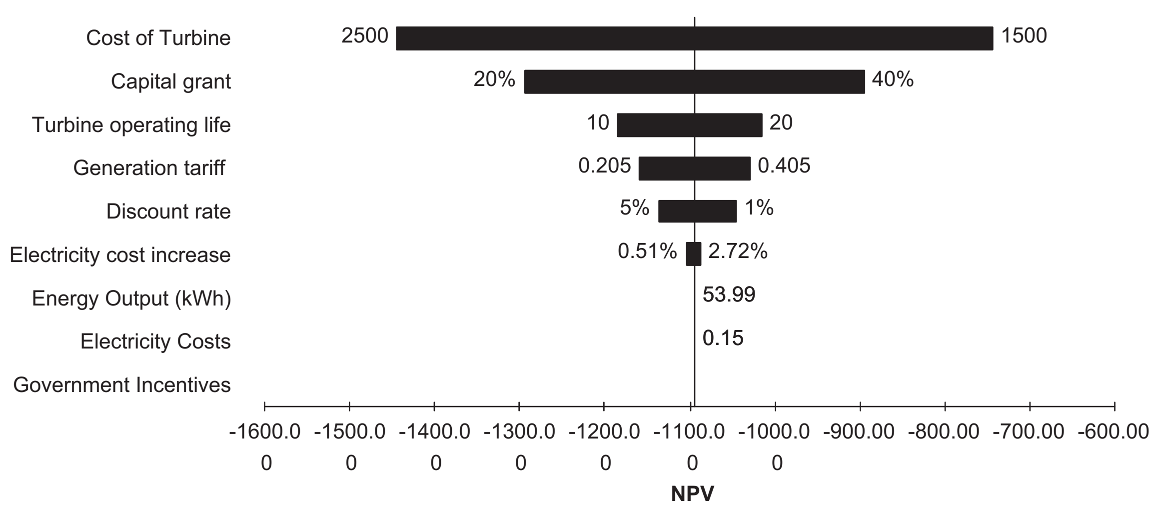

Fig. 15. Low energy yield one factor sensitivity analysis.

produce less than desirable NPVs. What impact this may have on purchasing behaviour as a whole, considering additional motivations such as energy independence and environmental benefit, remains difficult to quantify, but from a strictly investment perspective, the installation of small wind turbines in urban sites seems to be at a loss at this time.

Application of the proposed UK FIT for micro-generation wind projects across mildly selective, urban (building-mounted) sites produces a few attractive project NPVs over −£500 but less than one-tenth of mildly discriminate projects reach this level, even with the assistance of a subsidy. Because the top tier of project permutations comes close to reaching a positive NPV (−£298) using the UK FIT, it is not a far stretch to assume technological developments (manufacturing cost decreases and efficiency increases) will improve in the near future to deployable levels of investment attractiveness. The caveat of this positive outlook is that it applies only to high-performing sites. Low-performing sites do not fare well even with the tariff—low energy yield simply is not enough to cover installation cost by any reasonable amount. Given that there is promise for high-performing sites, the problem thus becomes how to screen for these projects. The top-performing sites require the best combination of project inputs, including expensive, long-lasting turbines and good wind resources. However, accurately predicting energy capacity from specific urban or semi-urban small wind sites may be problematic. Testing for wind performance adds costs and time that reduce the attractiveness of the project while relying on generous subsidy levels alone in making the purchase decision may result in disappointing returns on the part of the purchaser as a result of lower wind speeds.

Accordingly, reports indicating growth in small wind power generation are likely overestimated if they are relying on expansion of the urban market. Furthermore, forecasts of increasing contribution of small wind energy to national energy targets by both the government and small wind turbine manufacturers should be considered with caution. Given current market conditions, stimulating significant purchase interest in urban small wind may require a greater tariff than that proposed by the UK FIT. Higher levels of tariffs related to urban wind generation could have serious implications for the general electricity market in terms of competitive distortions and resultant higher electricity prices from utilities mandated to pay tariff-electricity-prices for renewable energy obligations.

To ensure tariff efficiency within the urban building sector, UK policy makers may need to withhold the FIT for this application of small wind until more technical research projects – such as the WWTP – can provide better insight as to how to predict urban wind performance (and thus NPV). Without such a measure, the probability is that projects will never reach their NPV expectations because of lower-than-estimated energy yield, creating consumer distrust and declining demand for installations. Small wind

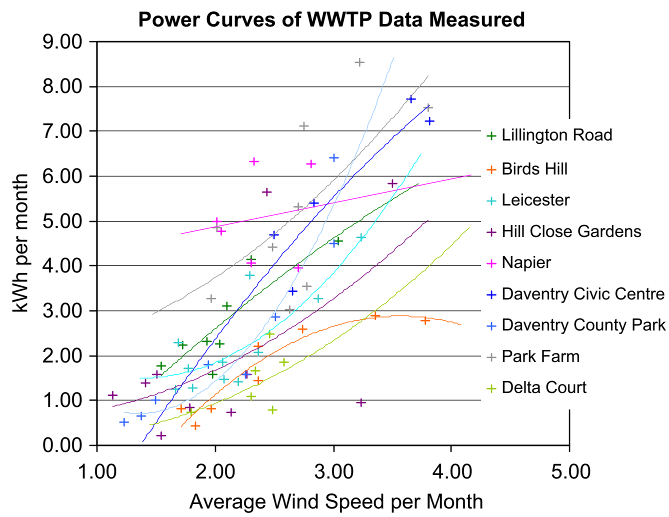

Fig. A2. Graphed Power Curves Extrapolated from WWTP Data.

Site	WWTP Average (Measured)	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
Lillington Road	2.22		1.73	2.31	3.04	2.21	3.12	2.32	2.10	1.93	2.04	1.98	1.54
Hill Close Gardens	2.04		1.51	2.44	3.50	2.27	3.23	2.14	1.41	1.68	1.54	1.79	1.13
Birds Hill*	2.27		1.71	2.74	3.78	2.36	3.36	2.37	1.97		2.05	2.68	1.87
Leicester	2.18		1.66	2.36	3.24	2.29	2.87	2.06	2.07	1.77	1.81	2.20	1.69
Napier	2.99		3.07	3.34	4.17		4.10	2.81	2.70	2.33	2.31	2.05	2.01
Daventry Civic Ctr.	2.74				3.82	2.66	3.66	2.84	2.50	2.46	2.39	2.36	1.79
Daventry County Pk.	2.04			2.51	3.01	2.15	3.00	2.26	1.94	1.23	1.50	1.37	
Park Farm	2.83			3.22	3.22	2.75	3.80	2.70	2.01	2.49	2.63	2.78	1.97
Delta Court	2.30						3.85	2.49	2.46	2.34	2.58	2.31	1.80

*Birds Hill October 2007 measurement was not used from WWTP due to its perceived isolated discontinuity

Site	WWTP Total Energy Exported (kWh)	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
Lillington Road	53.67		129	319	461				218	150	154	105	91
Hill Close Gardens*	54.88		80	460	680	119	103	52	66	0	11	51	42
Birds Hill	47.39	27	47	236	352	173	323	115	54				
Leicester	63.75		70	164	502	289	313	127	102	101	77	105	129
Napier	91.84		142					588	355	492	312	327	335
Daventry Civic Ctr.	109.13				919	305	940	512	390				
Daventry County Pk.	55.79			239	452		640	119	117	21	51	30	
Park Farm	178.62			916	177	652	955	479	325	367	266	329	215
Delta Court	19.44							66	204	129	160	84	44

*Hill Close Gardens values are lower than operating efficiency because a turbine switched off intermittently according to WWTP
(SOURCE: Results PDF for Hill Close Gardens http://www.warwickwindtrials.org.uk/8.html)

Fig. A1. Warwick Wind Trials Results (Measured Data).

manufacturers and eager government initiatives exploiting optimistic energy yield predictions would, in the long run, erode consumer confidence and damage real potential capacity increases in renewable energy. If urban (building-mounted) small wind generation is to continue, future UK FIT policy must consider that these projects are economically more sensitive to factors other than a tariff incentive, such as capital cost reductions through incentive grants. Furthermore, as found with the German policy of higher tariffs for roof-mounted solar photovoltaic (PV) systems versus ground-mounted PV projects, future UK FIT policy may need to consider micro-wind tariffs that provide additional incentives for costlier applications of the same technology.

POWER CURVES PER SITE - WWTP and Estimated kWh/m/s/

Site	Oct 07	Nov 07	Dec 07	Jan 08	Feb 08	Mar 08	Apr 08	May 08	Jun 08	Jul 08	Aug 08	Sep 08
Lillington Road	1.69	1.73	2.31	3.04	2.21	3.12	2.32	2.10	1.93	2.04	1.98	1.54
kWh/m/s = -0.1817x² + 2.9241x - 2.5212	1.91	2.24	4.14	4.55	3.05	4.83	3.28	3.11	2.33	2.26	1.59	1.77
Hill Close Gardens	1.55	1.51	2.44	3.50	2.27	3.23	2.14	1.41	1.68	1.54	1.79	1.13
kWh/m/s = 0.346x² - 0.1459x + 0.5852	1.19	1.59	5.66	5.83	1.57	0.96	0.73	1.40	1.32	0.21	0.85	1.12
Birds Hill	1.83	1.71	2.74	3.78	2.36	3.36	2.37	1.97	1.92	2.05	2.68	1.87
kWh/m/s = -0.7146x² + 5.0975x - 6.2079	0.44	0.82	2.58	2.79	2.20	2.88	1.46	0.82	0.94	1.24	2.32	0.83
Leicester	1.66	1.66	2.36	3.24	2.29	2.87	2.06	2.07	1.77	1.81	2.20	1.69
kWh/m/s = 0.9018x² - 2.504x + 3.2452	1.57	1.27	2.08	4.65	3.79	3.27	1.85	1.48	1.71	1.28	1.43	2.29
Napier	2.28	3.07	3.34	4.17	2.97	4.10	2.81	2.70	2.33	2.31	2.05	2.01
kWh/m/s = 0.5311x + 3.8078	5.02	5.44	5.58	6.02	5.38	5.99	6.28	3.94	6.33	4.05	4.79	5.00
Daventry Civic Centre	2.09	2.21	3.08	3.82	2.66	3.66	2.84	2.50	2.46	2.39	2.36	1.79
kWh/m/s = -0.3524x² + 4.9242x - 6.0749	2.67	3.08	5.76	7.22	3.44	7.70	5.41	4.68	3.91	3.68	3.58	1.61
Daventry County Park	1.55	1.64	2.51	3.01	2.15	3.00	2.26	1.94	1.23	1.50	1.37	1.47
kWh/m/s = 1.7028x² - 4.6045x + 3.8248	0.78	0.86	2.86	4.50	1.80	6.40	1.58	1.81	0.51	1.02	0.66	0.73
Park Farm	2.16	2.28	3.22	3.22	2.75	3.80	2.70	2.01	2.49	2.63	2.78	1.97
kWh/m/s = 0.4146x² + 0.0876x + 1.9043	4.02	4.26	8.53	1.65	7.11	7.54	5.32	4.85	4.42	3.03	3.55	3.27
Delta Court	1.75	1.85	2.59	3.33	2.28	3.85	2.49	2.46	2.34	2.58	2.31	1.80
kWh/m/s = 0.1969x^2.2509	0.70	0.79	1.68	2.95	1.26	4.09	0.80	2.49	1.65	1.86	1.09	0.73

36 Power Estimates: 72 WWTP Data Points

20 Estimated Wind Speeds: 88 WWTP Data Points

Fig. A3. Chart of Power Curves, Wind Speed and Energy Output per WWTP Site.

Turbine & WWTP Sites	Power	Cost (£)	Lifespan (Years)
Ampair 600 230 Hill Close Gardens Lillington Road Park Farm Napier	600W	2,655	15
Eclectic StealthGen D400 Birds Hill Delta Court	400W	1,500	20**
Windsave WS1200 Daventry County Park Daventry Civic Centre	1.2 kW	1,498	10
Zephyr AirDolphin Z1000 Leicester	1 kW	3,000*	20*

*AirDolphin costs £5,000 lasting a guaranteed 25 years to expected 30 years, prorated for 20 year lifespan is about £3,000.

**StealthGen lasts 25 years according to manufacturers

Sources:

Eclectic StealthGen D400 http://www.energyenv.co.uk/D400WindTurbine.asp

Ampair 600 230 http://www.boost-energy.com

(Ampair Inverter) http://www.bettergeneration.com/wind-turbine-reviews/ampair-600.html

Windsave WS1200 http://www.bettergeneration.com/wind-turbine-review/windsave-ws1000.html

Fig. A4. Chart of Turbine Cost and Life.

If FIT policies are pursued, policy makers should consider the need for degressive tariffs that are initially set at levels sufficient to reduce economic risk and promote the application of this technology and which, over time and with the mutual involvement of public and private institutions, reasonably sets staged-reductions in the tariffs that mirrors producer savings in terms of lower costs arising from economies of scale and innovation efficiencies. Understanding where that "tipping point" exists will be crucial in order to encourage investment and development of urban wind micro-generation without causing sustained excess advantages over the existing energy market.

The conclusions of this investigation are limited by the sample energy yield being analysed as representative of the UK's complex, urban wind resources and that annual energy data is assumed to be valued equally in the NPV calculations regardless of when it is generated and consumed. The Monte Carlo analysis captures the range of urban wind speed and energy yield evidenced across the UK, but simulates a random distribution frequency when in reality a basic pre-screening of projects could limit uptake of intuitively poorer-performing sites. Empirical tests and country comparisons of FIT efficiency are inherently difficult as electricity markets, renewable energy resources and subsidy policies typically exist within a specific national context. Furthermore, our study did not explore the influence of building owner demographics and household categories in the adoption of urban small wind technology and future research into this area would identify important contributions to policy development.

Appendix A

The NPV framework with example simulation numbers and calculations is shown in Figs. A1–A4.

Element Energy Ltd (2009) published a quantitative analysis report for the Department of Energy and Climate Change on the market impact of increasing renewable electricity technologies

2008 Actual Cost (p/kWh)
14.93

2020 Predicted Cost (p/kWh)	Increase over 12 years	Increase per year (compound annual)	Scenario description by Element Energy Ltd.
15.87	6%	0.51%	Moderate demand, timely investment
18.42	23%	1.77%	High demand, producers' market power
20.61	38%	2.72%	High demand, significant supply constraints

Fig. A5. Electricity Price and Annual Increase.

Site-specific inputs	Input Cells	Lower Bound	Base Case	Upper bound	Selection Method
Discount Rate	2%				
Turbine Cost after Grant	1050	1050	1400	1750	← Random Discrete
Capital Grant	30%				
Turbine Operating Life	10	10	15	20	← Random Discrete
Average Wind Speed	2.33	2.04	2.4	2.99	← Random Triangular
Annual Energy Output (kWh)	110.69	47.20	90.43	119.79	← Random Triangular

Retail Electricity Price	0.15
Generation Tariff	0.305
Electricity price increase (Annual)	1.77%

NPV Analysis

Year	0	1	2	3	4	5	6	7	8	9	
Cashflows	-1050.0	50.36	50.66	50.96	51.26	51.57	51.89	52.21	52.53	52.87	
PV	-1050.0	49.38	48.69	48.02	47.36	46.71	46.07	45.45	44.84	44.24	
Year	10	11	12	13	14	15	16	17	18	19	20
Cashflows	53.21	53.55	53.90	54.26	54.62	54.99	55.36	55.75	56.14	56.53	56.93
PV	43.65	43.07	42.50	41.94	41.39	40.86	40.33	39.81	39.30	38.80	38.32
CUM. NPV	-585.60					- 375.84					-179.27
NPV	**-585.60**										

Fig. A6. Sample NPV Framework.

containing a key analysis of projected future electricity and gas prices in the UK. Several scenarios of changes to the price of consumer electricity were outlined as good projections for the future of electricity prices and then converted into a yearly % increase for use in the NPV model. This is shown in Fig. A5.

Sample NPV Framework is shown in Fig. A6.

Institutional Barriers (UK) to Installation of Small Wind Systems:

Noise and Vibration Standards.

Local Authority Planning Permission.

Building Control Approvals – Structural Assessment and Electrical Connection.

References

Bayod-Rujula, A.A., 2009. Future development of the electricity systems with distributed generation. Energy 34 (3), 377–383.

Blijenberg, H.M., 2007. Application of physical modelling of debris flow triggering to field conditions: limitations posed by boundary conditions. Engineering Geology 91 (1), 25–33.

Bray, J., Grevett, A., 2009. Exploratory study into the factors impeding ethical consumerism. In: Proceedings of the European Association for Education and Research in Commercial Distribution Conference, University of Surrey, Guildford, UK, July 2009.

Brigham, E.F., Houston, J.F., 2007. Fundamentals of Financial Management 11th ed. Cengage Learning, Florence, KY.

British Wind Energy Association, 2009. Small Wind Systems UK Market Report 2009.

Couture, T., Gagnon, Y., 2010. An analysis of feed-in tariff remuneration models: implications for renewable energy investment. Energy Policy 38 (2), 955–965.

Damon, B.M., 2008. Effects of image noise in muscle diffusion tensor (DT)-MRI assessed using numerical simulations. Magnetic Resonance in Medicine 60 (4), 934–944.

Demaria, M., Knaff, J.A., Knabb, R., Lauer, C., Sampson, C.R., DeMaria, R.T., 2009. A new method for estimating tropical cyclone wind speed probabilities. Weather and Forecasting 24 (6), 1573–1591.

Dinica, V., 2008. Initiating a sustained diffusion of wind power: the role of public–private partnerships in Spain. Energy Policy 36 (9), 3562–3571.

Department of Energy and Climate Change, 2009. Consultation on Renewable Electricity Financial Incentives 2009. UK Department of Energy and Climate ChangeUK Department of Energy and Climate Change.

Energy Saving Trust, 2009. Location, Location, Location: Domestic Small-Scale Wind Field Trial Report, July 2009.

Falconett, I., Nagasaka, K., 2010. Comparative analysis of support mechanisms for renewable energy technologies using probability distributions. Renewable Energy 35 (6), 1135–1144.

Finon, D., Menanteau, P., 2003. The static and dynamic efficiency of instruments of promotion of renewables. Energy Studies Review 12 (1), 53–81.

Fischer, E.A.J., van Roermund, H.J.W., Hemerick, L., van Asseldonk, M.A.P.M., de Jong, M.C.M., 2005. Evaluation of surveillance strategies for bovine tuberculosis (*Mycobacterium bovis*) using an individual based epidemiological model. Preventive Veterinary Medicine 67 (4), 283–301.

Friedman, L.S., Hausker, K., 1988. Residential energy consumption: models of consumer behavior and their implications for rate design. Journal of Consumer Policy 11 (3), 287–313.

Gibbons, J.M., Ramsden, S.J., Blake, A., 2006. Modelling uncertainty in greenhouse gas emissions from UK agriculture at the farm level. Agriculture, Ecosystems and Environment 112 (4), 347–355.

Gonzalez, P., Del, R., 2008. Ten years of renewable electricity policies in Spain: an analysis of successive feed-in tariff reforms. Energy Policy 36 (8), 2917–2929.

Hack, S., 2006. International Experiences with the Promotion of Solar Water Heaters (SWH) at Household-level, Mexico City, October 2006.

Hall, P.L., Strutt, J.E., 2003. Probabilistic physics-of-failure models for component reliabilities using Monte Carlo simulation and Weibull analysis: a parametric study. Reliability Engineering and System Safety 80 (3), 233–242.

Han, J., Mol, A.P.J., Lu, Y., Zhang, L., 2009. Onshore wind power development in China: challenges behind a successful story. Energy Policy 37 (8), 2941–2951.

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 34 (3), 256–276.

Jensen, S.G., Skytte, K., 2003. Simultaneous attainment of energy goals by means of green certificates and emissions permits. Energy Policy 31 (1), 63–71.

Johnson, C.J., Gillingham, M.P., 2004. Mapping uncertainty: sensitivity of wildlife habitat ratings to expert opinion. Journal of Applied Ecology 41 (6), 1032–1041.

Kelleher, J., Ringwood, J.V., 2009. A computational tool for evaluating the economics of solar and wind micro-generation of electricity. Energy 34 (4), 401–409.

Klein, A., Pfluger, B., Held, A., Ragwitz, M., Resch, G., Faber, T., 2008. Evaluation of different feed-in tariff design options—best practice paper for the international feed-in cooperation, Ministry for the Environment second ed. Nature Conservation and Nuclear Safety (BMU) Available from: 〈http://www.sunwindandwater.org/FITs_Best_Practices_Paper_2nd_edition_final.pdf〉 (accessed 29.09.10).

Lesser, J.A., Su, X., 2008. Design of an economically efficient feed-in tariff structure for renewable energy deployment. Energy Policy 36 (3), 981–990.

Menanteau, P., Finon, D., Lamy, M.-L., 2003. Prices versus quantities: choosing policies for promoting the development of renewable energy. Energy Policy 31 (8), 799–812.

Meyer, N.I., 2003. European schemes for promoting renewables in liberalised markets. Energy Policy 31 (7), 655–676.

Mulder, A., 2008. Do economic instruments matter? Wind turbine investments in the EU(15). Energy Economics 30 (6), 2980–2991.

Munksgaard, J., Morthorst, P.E., 2008. Wind power in the Danish liberalised power market—policy measures, price impact and investor incentives. Energy Policy 36 (10), 3940–3947.

Perez, Y., Ramos-Real, F.J., 2009. The public promotion of wind energy in Spain from the transaction costs perspective 1986–2007. Renewable and Sustainable Energy Reviews 13 (5), 1058–1066.

Rushton, G., Lolonis, P., 1996. Exploratory spatial analysis of birth defect rates in an urban population. Statistics in Medicine 15 (7–9), 717–726.

Sauter, R., Watson, J., 2007. Strategies for the deployment of micro-generation: implications for social acceptance. Energy Policy 35 (5), 2770–2779.

Scheer, H., 2007. Feed-in Tariffs—Boosting Energy for our Future. World Future Council.

Sijm, J., 2002. The Performance of Feed-in Tariffs to Promote Renewable Electricity in European Countries, ECN-C-02-083, November 2002.

Snyder, B., Kaiser, M.J., 2009. Ecological and economic cost–benefit analysis of offshore wind energy. Renewable Energy 34 (6), 1567–1578.

Soderholm, P., Klaassen, G., 2007. Wind power in Europe: a simultaneous innovation–diffusion model. Environmental and Resource Economics 36 (2), 163–190.

Valentine, S.V., 2010. Disputed wind directions: reinvigorating wind power development in Taiwan. Energy for Sustainable Development 14 (1), 22–34.

Wang, Y., Sheble, G.B., Pecas Lopes, J.A., Matos, M.A., 2006. Valuation of switchable tariff for wind energy. Electric Power Systems Research 76 (5), 382–388.

Wimberly, J., 2008. Banking the Green: Customer Incentives for EE and Renewable. EcoAlign, Survey Report, Issue 4, August 2008.

Wüstenhagen, R., Bilharz, M., 2004. Green Energy Market Development in Germany: Effective Public Policy and Emerging Customer Demand, IWOe Discussion Paper No. 111, June 2004.