Wildlife impacts of and public attitudes towards small wind turbines

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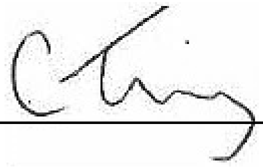
Declaration of authorship

I, Cerian Tatchley, declare that this thesis has been composed by me and it embodies the results of my own research. Where appropriate, I have acknowledged the nature and extend of work carried out in collaboration with others.

Signed: 

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Summary

Global wind power generation has grown rapidly in response to targets to reduce greenhouse gas emissions as part of efforts to mitigate climate change, and to increase energy security. While much of the focus in wind energy technology to date has been on wind farms, a relatively recent development is the expansion of the micro-wind sector (turbines generating < 100 kW), and there are now over 870,000 small wind turbines (SWTs) installed globally. However, official planning guidance for SWTs in the UK and elsewhere is lacking. This may be a barrier to SWT installations if there is confusion over the requirements to gain planning permission.

One reason for the lack of planning guidance is that our understanding of the wildlife impacts of SWTs is limited and therefore it is difficult to make recommendations for their mitigation. There are a range of potential negative effects wind power can exert on wildlife, in particular on birds and bats, yet to date, there has been very little published research into the wildlife impacts of SWTs. Mortality rates of wildlife at SWTs appear to be relatively low, but disturbance of bats, highly protected species, near SWTs has been previously demonstrated. However, the extent (if any) of this disturbance at habitat features of known importance was unclear. Therefore this thesis used acoustic surveys of bat activity to quantify disturbance of use of linear features (e.g. hedgerows, treelines), habitat important to bats for commuting and foraging, caused by SWTs. Firstly, bat activity did decline after experimental installation of SWTs 5m away from linear features. This decline was species-specific with *Pipistrellus pygmaeus* showing declines in activity in close proximity to the SWT associated with SWT operation, while *P. pipistrellus* activity declined in response to installation both at the SWT site and 30m away. Secondly, bat use of linear features is lower when SWTs are located nearby. In particular, *P. pygmaeus* activity at linear features is lower the closer a SWT is to the feature, and at high wind speeds *Myotis* spp. use of linear features is similarly lower where SWTs are located nearby. This disturbance did not dissipate along the linear features away from the SWT for at least 60m. This is much further than previously documented disturbance of bats by SWTs, which appeared fairly localised, and may be due to the importance of linear features specifically for commuting between habitat fragments. If so, the cumulative impacts of such disturbance will be important in areas where suitable foraging and roosting habitats is limited and fragmented, and linear features suitable for commuting between habitat fragments are already rare. These results offer support for recommendations that SWTs should be subject to siting restrictions that create a buffer distance between them and important bat habitats such as linear features. Specifically,

this thesis recommends that in landscapes with few alternative commuting routes or where particularly rare bat species are present SWT installations require buffer distances to ensure they are a minimum of 60m away from linear features.

There has also been a lack of research into public attitudes towards SWTs, despite local attitudes towards wind farm developments having been linked to planning outcomes, implying attitudes can be a barrier to installations. This thesis presents the results of the first survey of public attitudes specifically towards SWTs. Generally attitudes towards SWTs were positive, with over half of respondents rating SWTs as acceptable across a range of landscape settings. However, as for wind power where public attitudes in general are positive but local wind farm developments may still face opposition, only 35% of respondents were in favour of having a SWT installed in sight of their home. A key finding of this survey was that acceptance of SWTs significantly differed between landscape settings, with those in hedgerows and gardens being less well accepted compared to those on road signs, buildings and fields. Respondent comments highlighted visual impacts, efficient use of technology, noise impacts, wildlife impacts and educational value as important factors in their decisions regarding SWT acceptability. Public concern about wildlife impacts appears to be responsive to context, being important to the lower acceptance of SWTs in hedgerows, which were perceived to be particularly risky for wildlife. Potential SWT owners are also shown to be concerned about wildlife impacts from SWTs. Using a choice experiment methodology, an economics technique that allows valuation of non-market goods, farmers (a group most likely to own SWTs in the UK) were found to be willing-to-pay, through loss of SWT earnings from electricity generation, to avoid disturbance of birds and bats or collision mortality of bats. These findings also support the recommendation of the use of buffer distances for SWTs. Buffer distances between SWTs and linear features will help to alleviate public and SWT owner concerns about wildlife impacts, and also increase public acceptance of SWTs by encouraging their installation away from some of the least accepted landscape settings such as hedgerows. Further, potential SWT owners were also found to have no significant preference for avoiding siting restrictions of SWT installations, suggesting they are open to the use of buffer distances, although the suggested distances were substantially smaller than those this thesis ultimately recommends.

The findings presented in this thesis have implications for planning guidance, policy makers and developers, but also raise many questions that will require further study. A list of planning guidance recommendations and a list of recommendations for future SWT research are presented in the final section.

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Chapter 1

General Introduction

Increasing development, associated with a growing global population and its requirements, presents many challenges for conservation and the protection of wildlife. Developments have direct impacts on wildlife such as habitat loss and mortality, but may also have indirect impacts through anthropogenic disturbance (Tuomainen and Candolin 2011). Many countries are encouraging developments to be sustainable with planning processes that require environmental impacts to be considered alongside economic and social impacts. For example, many countries now require Environment Impact Assessments (EIAs) to be undertaken to evaluate the environmental impacts of large developments (e.g. Directive 2001/42/EC). However, balancing the need to allow development and the trade-offs between a range of positive and negative impacts is particularly difficult when development takes place rapidly, leaving little time for research quantifying and understanding its impacts. Wind power developments and in particular small wind turbines (SWTs) which have received very limited research attention despite their rapid growth, are an example of this.

1.1 Global climate change and the role of wind power

The production of renewable power is an important component of worldwide efforts to limit the scale and the impacts of global climate change. Global average surface temperature has been increasing since around 1950 with a warming of 0.85 (0.65-1.06)°C between 1880-2012 (Stocker *et al.* 2013). Alongside this, ocean temperatures have increased, snow cover has decreased in most regions, average global sea levels are rising at an estimated 1.7 (1.5-1.9)mm yr^{-1} and changes in long term trends in precipitation across large regions have been observed (Stocker *et al.* 2013). The potential ecological, social and economic impacts of these changes are large and widespread. It is predicted that by 2050 up to 37% of species will be committed to extinction (Thomas *et al.* 2004), with early observations of species' reactions to climate change supporting such predictions (Maclean and Wilson 2011). Rises in sea level and changes to precipitation trends will cause increased flooding in some areas and long-term drought in others, and will put pressure on our ability to produce enough food for a growing global population (Field *et al.* 2014). A comprehensive review of the economic costs of climate change and the associated impact risks suggests that failure to act to mitigate global climate change may cost 5% of global GDP each year, whilst taking immediate action to limit climate change is likely to cost much less at around 1% of global GDP each year (Stern 2006). That current global climate change is attributable to anthropogenic causes, such as the burning of fossil fuels, is widely accepted with the most recent Intergovernmental Panel on Climate

Change report stating "it is extremely likely that human activities caused more than half of the observed increase in global average surface temperature from 1951 to 2010" (Stocker *et al.* 2013).

Stabilising the amount of greenhouse gases in the atmosphere in order to limit global climate change is likely to require a reduction in annual emissions of around 80% of current levels (Stocker *et al.* 2013; Stern 2006). The UK government introduced legislation to reduce carbon dioxide and other greenhouse gas emissions in the Climate Change Act 2008. It sets a target to reduce the UK's net carbon emissions to at least 80% lower than the 1990 baseline by 2050. A major source of greenhouse gas emissions, and in particular carbon dioxide, is the burning of fossil fuels to generate power. The production of electricity from renewable sources including solar, hydro and wind power, produces much less carbon dioxide and other environmentally damaging gases than traditional fossil fuel energy sources such as coal and oil. The European Union has set legally binding renewable energy targets for its member states, with the UK needing to produce 15% of energy consumption from renewable sources by 2020 (Council Directive (EC) 2009). The UK Renewable Energy Roadmap (DECC 2011a; 2013a) sets out the government's action plan to achieve this target, which includes eight renewable technologies with the greatest potential for meeting the UK's energy needs: onshore wind, offshore wind, marine energy, biomass electricity, biomass heat, ground source heat pumps and renewable transport. These technologies are anticipated to deliver over 90% of the UK renewable energy production target, highlighting the importance of wind power in the UK.

1.1.1 Growth of Wind Power

Global wind power capacity currently sits close to 370 GW, following a 50 GW increase in 2014 (WWEA 2015a). Wind power generation occurs in over 100 countries worldwide, with China, the USA and Germany leading the market. The UK has the sixth largest installed capacity in the world at over 11,000 MW, contributing 9% of the UK's energy needs (Renewable UK 2014). This represents a rapid growth in wind power capacity from 400 MW fifteen years ago and an increase of nearly 15% in capacity in the past year (Renewable UK 2014). Alongside wind farm developments, micro-renewable technologies have also grown rapidly with almost 2,237 new small wind turbines (SWTs) installed in the UK in 2014 and 27,450 SWTs installed between 2005-2014, reaching a total installed capacity of 120 MW (Renewable UK 2015). There are over 870,000 SWTs installed worldwide (WWEA 2015b). Micro-renewable technologies, such as SWTs, are scaled down versions of standard renewable energy production technologies designed for use where space is limited. They have been utilised by businesses, communities and individuals to both provide their energy needs and to generate an income from feed-in tariffs (FITS; https://www.gov.uk/feed-in-tariffs/overview). There is currently no globally accepted definition of the term SWT but the World Wind Energy Association (WWEA) states they have a generational capacity of up to 100kW (WWEA 2015b). Within this definition there is wide variation in turbine height and design, as it encompasses both building mounted and free-standing SWTs, horizontal and vertical turbine models and on-grid and off-grid situations. Historically in the UK SWTs have been defined as having a generational capacity of up to 50kW (Department of Trade and Industry 2004), half the capacity of the WWEA definition. This reflected the fact that early installations of SWTs in the UK were very small scale, often below 15kW generational capacity, partly due to cost (Renewable UK 2015). However, technological improvements and the development of the micro-generation industry have meant turbines have become cheaper to purchase and install, and more efficient at generating electricity. This has led to a trend in the UK and elsewhere of SWTs becoming larger both in height and in generational capacity and this has been reflected in the definitions used within the industry, which now also reports statistics for UK SWT installations using the 100kW definition (Renewable UK 2015). Therefore, in order to increase the relevance of this thesis to future SWT trends, and to a global audience, I have utilised the WWEA definition of SWTs. A role for micro-renewable technologies in achieving the UK's 2020 renewable energy targets has been acknowledged by the UK government (DECC 2011b).

1.2 Wildlife Impacts of Wind Power

No form of renewable power generation is without some environmental or wildlife impacts (Abbasi and Abbasi 2000). Whilst these impacts may arguably be lesser than the wildlife impacts of continuing to use traditional power generation, it is still important that they are fully understood so they can be minimised by careful planning. For wind power, research to understand wildlife impacts has occurred almost exclusively at wind farms. This work has highlighted two main wildlife groups affected by wind turbines: birds and bats, and two main types of impact: collisions and disturbance/displacement (Schuster *et al.* 2015). Collisions result from animals flying into turbine masts or being hit by the rotating blades. This usually causes serious and typically fatal injury. Disturbance impacts occur when the presence or operation of the turbines interferes with animals' normal behaviour, including foraging, mating and ranging behaviours. Disturbance is closely linked to displacement impacts where animals move away from using an area due to the presence or operation of turbines. This represents a type of habitat loss, in addition to the direct loss caused by the wind farm infrastructure, and highlights the need to investigate not just the impacts of individual wind farms, but also the cumulative impact of increasing numbers of such sites.

Although this thesis focuses particularly on the impacts of SWTs on bats, due to the severely limited previous published research directly in this area, I have included in this literature review research regarding the impacts of SWTs on birds and also the impacts of wind farms on both bats and birds as it strongly influences current understanding of the wildlife impacts of wind turbines. Further to this, although not specifically covered by this thesis, there is also research covering impacts from the infrastructure associated with wind farms, such as access roads, which can increase direct mortality through traffic collisions and also cause habitat loss and fragmentation, and impacts on a wider range of taxa including non-aerial wildlife (Lovich and Ennen 2013).

1.2.1 Mortality at Wind Farms

1.2.1.1 Rates and Causes of Bird Mortality at Wind Farms

Whilst it is difficult to directly observe collisions with turbines, it is assumed that most collisions with a turbine are fatal and mortality rates of animals at wind farms can be estimated by searching for carcasses around the turbines. Avian mortality rates across sites are highly variable (table 1.1). For example, 20.9 deaths per turbine per year were recorded at a wind farm in Zeebrugge, Belgium (Everaert and Stienen 2007), while only 0.03 bird deaths per year were recorded at two sites in Spain (Barrios and Rodriguez 2004; Farfan *et al.* 2009). However, care must be taken when comparing mortality rates from wind farm studies as different methodologies and calculations are used, making comparisons difficult (Arnett *et al.* 2008). In particular there are differences in carcass search frequencies and areas, as well as whether corrections have been applied to the mortality rate calculations. The most reliable rates, regardless of the taxa considered, are those that have been corrected for searcher efficiency, search effort and scavenging rates. Without these corrections, which have only recently become standard practice, it is likely that mortality rates will frequently have been underestimated (Arnett *et al.* 2008) and therefore the mortality impact of wind turbines on wildlife may be greater than mortality rates suggest.

Local abundance is likely to be a causal factor in mortality rates at a particular wind farm, with higher collision rates expected at sites with higher abundance. For example, two wind farm sites in Gibraltar with different raptor siting frequencies also had significantly different raptor mortality rates (Barrios and Rodriguez 2004). However, this is not always the case. For example, no mortality was recorded of the most abundant species present (*Cathartes aura*) during a study at the Forewind Wind Energy Centre in Wisconsin, USA (Garvin *et al.* 2011). Similarly, species mortality rates do not always correlate with their index of collision risk based on proportions of species observed flying through the rotor blade zone within 500m of turbines, suggesting that collisions with turbines are not solely the result of random collisions.

There is also evidence of species-specific collision risks, with some species seemingly better at avoiding turbines than others. Larger birds with poorer manoeuvrability are expected to have higher collision risks (Drewitt and Langston 2006) and some studies confirm this. For example, collision rates were higher for large gulls than small ones at a wind farm in Zeebrugge, Belgium (Everaert and Stienen 2007). Different flight altitudes, avoidance behaviours, visual perception abilities and specific high-risk flight behaviours such as circular flight and soaring contribute to species differences in collision risks (Schuster *et al.* 2015).

Table 1.1: Bird mortality rates at wind farms.
Studies were identified by searching Web of Science using the terms wind turbine or wind farm and birds or wildlife in combination. Only those studies that quantified mortality using carcass searches and provided mortality rate data in either deaths per turbine per year or deaths per MW per year were included. Italics indicate mortality rates have been calculated using information provided in the paper.

Site	**Year**	**Season**	**Deaths Per Turbine Per Year**	**Deaths Per MW Per Year**	**Correction Applied?**	**Reference**
Zeebrugge, Belgium	2004	All year, surveys more frequent in breeding season	20.9	*60.8*	Search area, searcher efficiency & scavenger	Everaert & Stienen 2007
	2005		19.1			
PESUR, Campo de Gibraltar, Spain	1994	All year	0.36	*3.28*	Scavenger removal & searcher efficiency	Barrios & Rodriguez 2004
E3, Campo de Gibraltar, Spain	1994		0.03	*0.19*		
Sierra de Aguas, Malaga, Spain	2005-2007	All year	0.03		No	Farfan *et al*. 2009
Vasco Caves Regional Preserve, California, USA	2006-2007			7.89	Scavenger removal & searcher efficiency	Smallwood *et al.* 2010
Altamont Pass Wind Resource Area, California, USA	1998-2003			14.22	Scavenger removal & searcher efficiency	Smallwood & Karas 2009
	2005-2007			21.63		
Klondike Wind Project, Columbia, USA	2001	Full year	1.16 (small birds)		Scavenger removal and searcher efficiency	Johnson *et al.* 2003
			0.26 (large birds)			
McBride Lake Wind Farm, Alberta, USA	2003-2004	All year	0.36		No	Brown & Hamilton 2004
Castle River Wind Farm, Alberta, USA	2001	All year	0.15		No	Brown & Hamilton 2006
	2002		0.23			
Diablo Winds Energy Project, California, USA	2005-2006	All year	1.2	1.8	Scavenger removal & searcher efficiency	WEST 2006
High Winds Project Area, California, USA	2003-2005	All year	2.45	1.36	Scavenger removal & searcher efficiency	Kerlinger *et al.* 2006
Top of Iowa Wind Resource Area, Iowa, USA	2003	April-Dec	0.38		Scavenger removal & searcher efficiency	Jain 2005
	2004	March-Dec	0.76			
Foote Creek Rim Wind Power Project, Wyoming, USA	1999		2.04		Scavenger removal & searcher efficiency	Young *et al.* 2003
	2000		1.45			

	2001-2002		1.16			
Nine Canyon Wind Power Project, Washington, USA	2002-2003	All year	3.59		Scavenger removal & searcher efficiency	Erickson 2003
Vansycle Wind Project, Oregon, USA	1999		0.63		Scavenger removal & searcher efficiency	Erickson *et al.* 2000
Phase 1, Buffalo Ridge, Minnesota, USA	1996-1999	March-Nov	0.98		Scavenger removal & searcher efficiency	Johnson *et al.* 2000
Phase 2, Buffalo Ridge, Minnesota, USA	1998-1999		2.27			
Phase 3, Buffalo Ridge, Minnesota, USA	1999		4.45			
Oostdam, Belgium	2002		24		Search area, searcher efficiency & scavenger removal	Everaert 2003
Boudewijinkan, Belgium	2002		35		Search area, searcher efficiency & scavenger removal	Everaert 2003
Schelle, Belgium	2002		18		Search area, searcher efficiency & scavenger removal	Everaert 2003
Blyth, UK	1991-2002	All year	16.5-21.5		Searcher efficiency & scavenger removal	Newton & Little 2009
Canada			8.2		Search area, searcher efficiency & scavenger removal	Zimmerling 2013
Project West Wind, New Zealand			5-6		Searcher efficiency & scavenger removal	Bull *et al.* 2013

1.2.1.2 Rates and Causes of Bat Mortality at Wind Farms

As with birds, bat mortality rates also vary dramatically between wind farm sites (table 1.2). A review of bat mortality studies in North America found reported mortality rates ranged from 0.1 bats to 69.6 bats per turbine per year (Arnett *et al.* 2008). Similarly to bird mortality rates, it is unclear what causes site specific differences in bat mortality rates at wind farms, but there are numerous possible contributing factors under investigation. Spatial and seasonal variation in bat mortality rates can be related to bat abundance with the highest mortality rates frequently associated with wind farms sited on bat migration routes (Cryan and Barclay 2009). In these cases collisions may result from bats simply failing to detect turbine blades; even at short distances (0.5m) returning echolocation pulses reflecting off turbines have only 3-10% of the energy of the emitted pulse and not all pulses are reflected (Long *et al.* 2010). This may be a particular problem when bats encounter turbines on their regular flight paths, such as when travelling between roosts and foraging sites or when migrating, as at these times their echolocation call rate is less frequent than when actively foraging, increasing the likelihood that they will fail to notice the turbines presence (Arnett *et al.* 2008).

However, there are many sites where local species abundance and composition is not reflected in bat mortality rates (Cryan and Barclay 2009). Again, there is evidence that mortality rates may be higher for some species than others. Species adapted to open-air foraging appear to have particularly high collision risk, possibly due to their typical flight altitude (Rydell et al. 2010a), as do tree roosting species (Cryan and Barclay 2009). In the latter case, attraction to wind turbines as possible roosts has been suggested as a cause (Cryan and Barclay 2009) with thermal cameras showing bats repeatedly approaching and trying to land on turbines (Cryan *et al.* 2014; Horn *et al.* 2008). Attraction to turbines as foraging sites has also been suggested, alongside the proposal that nocturnal insects are attracted to turbines by heat or noise generated by operating machinery, the lights mounted on turbines or that wind turbines reach into part of the airspace used by nocturnally migrating insects, which the bats are then hunting (Rydell *et al.* 2010b). Turbines as foraging sites gains support from thermal camera footage of bats actively foraging around turbine blades (Horn et al. 2008). Attraction of bats to turbines by ultrasound noise emitted by turbine operation or as mating sites has also been proposed (Cryan and Barclay 2009). However, there is limited verification of bat activity being increased at wind farms (Cryan and Barclay 2009) and a recent study presents evidence that bat activity may instead be lower than at control sites (Millon *et al.* 2015).

Wind speed is related to bat mortality rates at wind farms with higher rates reported at lower wind speeds (Arnett *et al.* 2008). Utilising this finding, introducing higher wind speed cut-ins, so turbines are not operating until a higher wind speed is reached, has successfully reduced bat mortality. Mortality rates were reduced by 60% at a wind farm in Alberta, Canada using turbine cut-in speeds of 5.5m s^{-1} (Baerwald *et al.* 2009) and by 44-93% at the Casselman Wind Project in Pennsylvania, USA, using cut-in speeds of 5.0 and 6.5m s^{-1} (Arnett *et al.* 2011). As turbines do not generate much electricity at low wind speeds, cut-in speeds are a fairly efficient bat mortality mitigation method, with a power loss of less than 1% of annual output at the Casselman trial (Arnett *et al.* 2011).

Many other factors have been linked to bat mortality at turbines. Tower height has been positively related to bat mortality (Barclay *et al.* 2007; Rydell *et al.* 2010a), as has higher barometric pressure (Arnett *et al.* 2008). Conversely, high rainfall decreases bat activity and associated collisions (Arnett *et al.* 2008). No evidence was found that bat mortality events at Klondike Wind Project were related to poor weather with most carcasses found following clear weather conditions (Johnson *et al.* 2003), contradicting theories that poor visibility and storms increase collisions. There is little evidence for an effect of temperature (Arnett *et al.* 2008) or lighting (Cryan and Barclay 2009) on bat fatalities at wind farms, while more complex landscapes have been associated with higher bat collisions, likely due to higher bat activity in such landscapes which provide more foraging opportunities (Rydell et al. 2010a).

Table 1.2: Bat mortality rates at wind farms
Studies were identified by searching Web of Science using the terms wind turbine or wind farm and bats or wildlife in combination. Only those studies that quantified mortality using carcass searches and provided mortality rate data in either deaths per turbine per year or deaths per MW per year were included. Italics indicate mortality rates have been calculated using information provided in the paper.

Site	**Year**	**Season**	**Deaths Per Turbine Per Year**	**Deaths Per MW Per Year**	**Correction Applied?**	**Reference**
Southwestern Alberta, Canada	2005		21.7	12.06	Yes- unclear what	Baerwald *et al.* 2009
	2006		26.31	14.62		
Mountaineer Wind Energy Center, West Virginia, USA	2004	July-Sept	328.5		Scavenger removal and searcher efficiency	Arnett 2005
Meyersdale Wind Energy Center, Pennsylvania, USA			259.2			
Klondike Wind Project, Columbia, USA	2001	Full year	1.16		Scavenger removal and searcher efficiency	Johnson *et al.* 2003
McBride Lake Wind Farm, Alberta, USA	2003-2004	All year	0.47		No	Brown & Hamilton 2004
Castle River Wind Farm, Alberta, USA	2001	All year	0.89		No	Brown & Hamilton 2006
	2002		0.22			
Diablo Winds Energy Project, California, USA	2005-2006	All year	0	0		WEST 2006
High Winds Project Area, California, USA	2003-2005	All year	3.63	2.02	Scavenger removal & searcher efficiency	Kerlinger *et al.* 2006
Top of Iowa Wind Resource Area, Iowa, USA	2003	April-Dec	6.44		Scavenger removal & searcher efficiency	Jain 2005
	2004	March-Dec	9.24			
Foote Creek Rim Wind Power Project, Wyoming, USA	1999		2.38		Scavenger removal & searcher efficiency	Young *et al.* 2003
	2000		0.63			
	2001-2002		0.94			
Nine Canyon Wind Power Project, Washington, USA	2002-2003	All year	3.21		Scavenger removal & searcher efficiency	Erickson 2003
Vansycle Wind Project, Oregon, USA	1999		0.74		Scavenger removal & searcher efficiency	Erickson *et al.* 2000
Phase 1, Buffalo Ridge, Minnesota, USA	1999	March-Nov	0.26		Scavenger removal & searcher efficiency	Johnson *et al.* 2000

Phase 2, Buffalo Ridge, Minnesota, USA	1998-1999		1.78			
Phase 3, Buffalo Ridge, Minnesota, USA	1999		2.04			
Sapka, Greece	2009-2010		6.25		None	Georgiakakis *et al.* 2012
Kerveros, Greece			4.71			
Mati, Greece			3.00			
Peltastis, Greece			2.33			
Didymos Lofos, Greece			2.50			
Mytoula, Greece			2.44			
Monastiri, Greece			1.00			
Soros, Greece			0.62			
Geraki, Greece			0.62			
Oklahoma Wind Energy Center, Oklahoma, USA	2004	May-July		0.79-1.01	Searcher efficiency & scavenger removal	Piorkowski & O'Connell 2010
	2005			0.83-1.06		
Casselman Wind Project, Pennslyvania, USA	2008	July- Oct	2.67		None	Arnett *et al.* 2011
	2009		3.25			

1.2.2 Disturbance at Wind Farms

1.2.2.1 Disturbance of Birds

Disturbance and displacement impacts of wind farms have proven more difficult to study and quantify due to their indirect nature. Most commonly studies have looked for changes in abundance or activity to demonstrate displacement impacts. One effective method has been using before and after wind farm construction surveys, usually alongside surveying a control site to look for significant changes to species abundance (Before After Control Impact; BACI). For example, such a methodology revealed a 47% reduction in raptor abundance at the Foreward Wind Energy Centre in Wisconsin, USA post-construction, indicating the wind farm is displacing birds from the site (Garvin *et al.* 2011). However, a similar method used at a wind farm in Malpica, Spain, failed to show any significant differences between abundance of birds before and after installation or a nearby control site (De Lucas *et al.* 2005), highlighting that, as with mortality, disturbance impacts vary considerably between sites and species. Similarly, there was no evidence for avoidance of wind turbines in a study of UK wintering farmland birds (Devereux *et al.* 2008) contrasting with another UK study which reported lower densities of several bird species near to turbines during the breeding season at upland wind farm sites (Pearce-Higgins *et al.* 2009). The largest turbine avoidance distance, shown by the curlew (*Numenius arquata*), was 800m, arguably a considerable displacement from breeding habitat. Such levels of displacement lead to concerns about cumulative impacts of increasing numbers of wind turbines (Masden *et al.* 2010), although such impacts are very difficult to study. One study, of pink-footed geese (*Anser brachyrhynchus*), estimated the displacement of these geese by turbines represented an 8.5% loss of feeding habitat (Larsen and Madsen 2000), although the displacement caused by other anthropogenic structures such as settlements and roads was much higher.

There has been some evidence for the habituation of birds to wind turbines. In a 10 year study of pink-footed geese at three small wind farms avoidance distances around turbines reduced from 200m, 125m and 100m to 100m, 50m and 40m respectively (Madsen and Boertmann 2008). At one site geese actively foraged between the turbines despite having initially not entered the wind farm area, highlighting the importance of long-term research on the impacts of wind turbines. However, the evidence for habituation is still limited, and is contradicted by the negative relationship between bird abundance and time since wind farm construction revealed by a meta-analysis of surveys at 19 wind farm sites across Europe and North America (Stewert *et al.* 2007). Overall, these findings suggest wind farms have mixed displacement impacts on local population densities, but generally there is limited evidence for significant long term impacts in either direction, except for in a few key species or at specific sites.

1.2.2.2 Disturbance of Bats

There are very limited data on whether bats are displaced from wind farms, with research focussing instead on the predominant concern of mortality. The theory that bats are attracted to wind turbines, rather than disturbed by them, is prominent in the literature as part of explanations of their sometimes high collision rates (e.g. Cryan and Barclay 2009; Kunz *et al.* 2007; section 1.2.1.2). However, there is little published evidence that bat abundance or activity does increase after construction of a wind farm. Thermal camera images show bats actively approaching turbine blades and foraging between them (Horn *et al.* 2008; Cryan *et al.* 2014) but bat activity has also been observed to be lower at a wind farm site than a control (Millon *et al.* 2015). The lack of data on bat activity before and after wind farm construction prevents drawing any conclusions regarding either the attraction or the disturbance of bats by wind farms.

1.2.3 Comparison to the Wildlife Impacts of Other Human Structures

Other human structures such as buildings, bridges, power lines and vehicles also impact on wildlife, particularly aerial wildlife, through collisions and disturbance (Erickson *et al.* 2005). As with turbines, these impacts are similarly difficult to study and quantify but attempts have been made to measure collision mortality from various human structures in North America. An estimated 34 million birds or 1.3 birds per hectare per year die across North America during the spring and fall migration periods from colliding with glass buildings and windows (Klem Jr. *et al.* 2009). Estimates for collision mortality with human structures varies widely, as seen for turbine estimates. A carcass survey of 5,500 residential buildings across North America during winter 1989-1990 estimated collisions at 0.85 birds per house per year (Dunn 1993) while the cumulative impact of anthropogenic sources of mortality has been estimated at 500 million to one billion bird deaths annually across the USA (Erickson *et al.* 2005). Wind turbines are estimated to cause only 0.003% of those fatalities, so in context the impacts of wind turbines are significantly less than the impacts of other anthropogenic structures.

1.2.4 Wildlife Impacts of Small Wind Turbines

Despite increased knowledge of the wildlife impacts of turbines at wind farms, very little is known about the wildlife impacts of small wind turbines (SWTs). The scale of collision rates of both birds and bats at wind farms has led to assumptions that SWTs will also impact upon wildlife via collisions, albeit at a smaller scale, but as yet, there are few data with which to support such an assumption. Due to the differences between SWTs and wind farms in size, location, numbers deployed and their direct modification of habitats, extrapolation from impact studies of wind farms to SWTs is not appropriate. There are some anecdotal reports of bird and bat collisions collated by the Bat Conservation Trust (2010). Recent estimates of mortality rates at SWTs in the UK based on field observations and surveys of SWT owners are that between 0.079-0.278 birds and 0.008-0.169 bats may be killed per SWT per year (Minderman *et al.* 2014). There was some evidence that mortality was related to abundance, but no association between mortality and local habitat could be found.

As mortality rates at SWTs are estimated to be fairly low further research has therefore focussed instead on assessing the disturbance of wildlife by SWTs. There is evidence that SWTs disturb bats. At high wind speeds (14 ms^{-1}) bat activity is lower in close proximity to SWTs (0-5m) compared to further away (20-25m) (Minderman *et al.* 2012). This difference did not occur when the SWT was braked or in the absence of wind, which implies the disturbance effect on bats is caused by the operation of the SWT, possibly due to the movement of the blades or the associated noise, rather than its presence. This avoidance behaviour at high winds should reduce the risk of bat collisions with SWTs at these times and is in line with evidence of higher mortality of bats at low wind speeds at wind farms (Arnett *et al.* 2008). However, the avoidance behaviour could also lead to habitat displacement of bats in high wind conditions, which may be a problem where turbines are located in prime foraging habitat or along common flight paths. While the scale of displacement may be limited for a single SWT, the possibility of cumulative impacts from increasing numbers of SWTs in the UK, in addition to those from wind farms, could lead to population level impacts, so further work in this area is needed. Although a previous study failed to find any evidence of cumulative disturbance effects on bats from SWTs (Minderman *et al. in review*), this study did not specifically investigate the effects on particularly important bat habitats so the effect of SWTs on bats use of these habitats is still unknown. Bird flight activity near SWTs was similar between near and far distance bands and was unaffected by the operation status of the turbines, suggesting birds do not show avoidance behaviour of SWTs at the scale investigated, although they may show avoidance of the SWT at a wider or finer scale than studied here.

There are still many gaps in our understanding of the wildlife impacts of SWTs and prioritising addressing these is difficult. While mortality at SWTs has been quantified, our knowledge of their disturbance impacts is very limited. In particular, although previous research has not been able to demonstrate evidence of disturbance of birds by SWTS, bats are known to reduce their activity around active SWTs but we still lack knowledge of the influence of habitat on this disturbance. Negative impacts of SWTs on bats are particularly concerning due to the conservation importance of bats for several reasons. For example, bats are highly protected across Europe, including in the UK, due to historic persecution and severe population declines (e.g. Council Directive 92/43/EEC, 1992). Bats face many conservation pressures, including habitat loss in terms of both foraging and roosting habitat, habitat degradation, persecution from humans, disease and climate change (Jones *et al.* 2009; Mickleburgh *et al.* 2002), and any further pressures from energy production may hamper conservation efforts and population recoveries. Bats are also important as indicator species for the health of ecosystems (Jones *et al.* 2009) and are thought to contribute economically through providing ecosystem services such as pest control (Boyles *et al.* 2011; McCracken *et al.* 2012), demonstrating that understanding the impacts of SWTs on them is imperative. Therefore, it is a priority for this thesis to provide further insights into the impact of SWTs specifically on bats and in particular on the role of habitat in their disturbance of bats.

Woodland is one of the most important habitats for bats, providing both roosting and foraging habitat for many species (Dietz *et al.* 2009). Fortunately, SWTs are not commonly installed in woodland as the trees block the wind flow causing turbulence and reducing wind speeds, so turbines cannot efficiently generate electricity (although there are some examples of key-holing: removing clusters of trees to allow installation of turbines within woodland areas). However, SWTs are regularly installed near woodland edges, which are also an important bat habitat. Woodland edges, and other linear habitat features such as hedgerows, are utilised by bats for several purposes including foraging, commuting and providing protection from inclement weather and predators (Downs and Racey 2006; Verboom and Huitema 1997). Woodland and other favoured habitats have become increasingly fragmented due to conversion to agricultural land, as well as to settlements, to provide for growing human populations. The role of linear features both as foraging habitat and as corridors and commuting routes allowing bats to navigate between remaining habitat patches is therefore crucial in a fragmented landscape, especially for those species which preferentially avoid crossing large open spaces (Kelm *et al.* 2014). Given that SWTs are often installed in the vicinity of linear features, it is essential we understand their impact on bat's utilisation of these features, particularly as these features have also become rarer in the environment due to agricultural intensification. While current evidence suggests disturbance of bats by SWTs in open space is relatively localised (Minderman *et al.* 2012), the potential for greater disturbance to occur at particularly important bat habitat, such as linear features, has not previously been tested, despite knowledge that anthropogenic disturbance at such features can greatly reduce their use by commuting bat (Stone *et al.* 2009). Therefore it is an aim of this thesis to test the disturbance of bats caused by SWTs installed near linear features.

1.3 Public Attitudes towards Wind Power

Negative attitudes towards proposed wind farms from the general public are widely publicised in the media giving the impression that there is widespread opposition for this technology. Despite this portrayal, research in the UK and across Europe consistently finds high levels of support for wind power generation (Warren and Birnie 2009). For example, government run surveys in the UK find 68% of the public support onshore wind power and 76% support offshore wind power (DECC 2013b). Support for wind power amongst Scottish populations living within 20km of a wind farm is even higher with 82% supportive of an increase in the proportion of electricity generated in Scotland from wind power and 54% support expansion of their local wind farm by an increase of half the current number of turbines (Braunholtz 2003). Support for wind farms can be stronger amongst those living closer to existing operational wind farms than those living further away (Warren *et al.* 2005). People living in close proximity often report that the actual visual and noise impacts of the wind farms were lower than anticipated (Braunholtz 2003; Warren *et al.* 2005). It has been suggested there is a U-shaped development of public attitudes towards wind power, with initial general high support, which decreases with the proposal of a local wind power site and then increases once more when the wind farm is operational (Wolsink 2007). Low support for locally proposed wind farms compared to the wider positive attitudes towards wind power, sometimes referred to as the 'social gap' (Bell *et al.* 2005), is frequently cited as an example of 'not in my backyard' attitudes or NIMBYism (Devine-Wright 2005; Wolsink 2006). However, a general positive attitude towards wind energy is still a strong predictor of support for local wind energy projects with positive attitudes decreasing in strength when a local site is proposed for a range of complicated reasons, rather than changing to negative attitudes (Jones and Eiser 2009). NIMBYism has been widely criticised in the literature as oversimplifying complex attitudes and failing to provide any real insight into the underlying factors that lead to this gap in attitudes towards wind power in general and specific local projects (Wolsink 2006 & 2007; Devine-Wright 2011; Batel and Devine-Wright 2014).

Moving beyond NIMBYism as an explanation for the social gap in wind power attitudes, recent studies have sought to explore the beliefs and values that underscore wind power attitudes. Egoistic values are not related to beliefs about wind farm developments (Bidwell 2013), suggesting selfish motives are not a main driver of these attitudes. Altruistic values increase positive wind power attitudes while traditionalism values decrease it, and the belief that a wind farm will provide economic benefits to the community is key to support of wind power development (Bidwell 2013). In line with this, community ownership can increase positive attitudes towards both wind energy in general and local wind farm sites (Warren and McFadyen 2010). There is a history of high levels of support for wind farms in European countries where wind farms are traditionally owned by cooperatives rather than private developers (Warren and Birnie 2009). Community benefits or payments are sometimes used by wind farm developers to increase local support (Munday *et al.* 2011). In the UK £18.4 million is currently paid annually in community benefit funding (Renewable UK 2014). However, strong positive attitudes towards wind energy can also be found in areas dominated by privately owned wind developments (Warren and McFadyen 2010) and community benefits are often seen as compensation for impacts rather than changing underlying attitudes (Cowell *et al.* 2011). Further, community benefit funds can be detrimental to local attitudes if they are interpreted as bribery or buying consent (Aitken 2010) and the revenue communities gain from them is generally less than could be achieved by community ownership (Munday *et al.* 2011).

Landscape impacts and perceptions have been central to debates about acceptability, siting of and planning for renewable energy, and particularly so for turbines which cannot be well hidden within landscapes due to their requirement for high wind speeds that are typically found in high, open rural areas. Divergences occur between perceptions of rural landscapes as natural and unspoilt, and those of renewable energy technologies, perceived as industrial and urban, and therefore as not belonging in rural landscapes (Batel *et al.* 2015). Further, people perceive the place where they live as having more of the essence of their country than other areas, increasing the perception that energy generation technologies do not belong there in particular (Batel *et al.* 2015). Also, physical environment has been linked to identity and strong identification with places and environments can lead to actions to protect that environment from apparent negative changes (Devine-Wright 2009) and to view those actions as pro-environmental even when they involve opposing green energy installations (Devine-Wright and Clayton 2010). Similarly, disagreements between environmentalists about renewable energy installations have been referred to as 'green on green' debates with conflicts between global and local environmental impacts of such technologies (Warren *et al.* 2005). There has been a call for renewable energy policy to better take such variation in perceptions of and personal identification with landscapes into account and to put greater emphasis on fostering societal engagement with implementation processes (Batel *et al.* 2015; Nadai and Labussiere 2009; Szarka 2006).

Another tool for exploring public attitudes is stated choice experiments (Hensher *et al.* 2005). These allow participants to be presented with realistic scenarios in which they have to choose between options with different attributes. By getting participants to make several choices it is possible to investigate which attributes are most important to their decision making in particular situations and what they are willing to pay to change those attributes. This type of study has been used to quantify the value placed by the public on some of the attributes of renewable power, including landscape impact, wildlife impact, air pollution and jobs created (Bergmann *et al.* 2006). Air pollution, landscape and wildlife impacts were significantly important attributes to the Scottish general public when making decisions about renewable power preferences with households willing to pay £14.13 per year in additional electricity costs for power generation to create no air pollution, £8.10 per year for energy generation that had no landscape impact and £11.98 per year for renewable energy generation that had positive wildlife impacts compared to slight negative wildlife impacts. Decision making and attribute valuation differed between rural and urban populations, with rural populations showing higher overall support for renewable energy projects and placing more value on job creation (Bergmann *et al.* 2008). Comparing these results to the most likely impacts of particular renewable energy projects, the Scottish population overall were estimated to have strongest support for offshore wind farms, while rural populations value biomass power plants most highly due to the likely higher levels of job creation. Similar factors appear important in forming public attitudes towards renewable energy elsewhere in Europe. In La Plana, Spain, respondents making choices about a possible wind farm project highly valued environmental attributes, and particularly the protection of fauna and flora (Alvarez-Farizo and Hanley 2002). Similarly, people in the Greek Aegean Islands, valued protecting the environment by not having wind farms in important nature sites (Dimitropoulos and Kontoleon 2009). Involving the local communities in the planning of the wind farm was also valued.

Much research into public attitudes towards renewable power investigates attitudes towards a generic "green" source of energy. While this has advantages in terms of removing respondents' assumptions about specific energy sources which are not being investigated in a particular study, it could be argued that the willingness to pay results from such studies do not reflect behaviour in the real world as different sources of renewable power are likely to be viewed differently. For example, willingness to pay for programs involving 'green energy' differ between a generic green energy source and various specific green energy sources (Borchers *et al.* 2007). Whilst willingness to pay for solar energy was higher than for a generic green energy source, willingness to pay for biomass and farm methane was lower, and wind power was not different from a generic green energy source. This suggests that studies investigating public attitudes and utility relating to generic renewable power may be over or under estimating utility for particular renewable energy sources and missing subtle differences in public attitudes towards them.

Public opposition to wind power developments is frequently cited as an explanation for difficulties in gaining planning permission for such developments (Toke *et al.* 2008). Local public attitudes have been demonstrated to have a key role in wind power development planning application outcomes (Toke 2005), although other studies suggest opposition merely delays a development obtaining planning permission rather than prevents it (Aitken *et al.* 2008). Either way, a lack of understanding of, and guidance relating to, public attitudes may cause poorly planned wind power and SWT proposals, unnecessary rejections of planning applications and higher levels of planning decision appeals, which can then lead to higher planning application costs, delays in the planning process and general uncertainties about planning application outcomes, all of which are disincentives to owning an SWT.

1.3.1 Public attitudes towards micro-generation and small wind turbines

Public attitudes towards micro-renewable projects including small wind power are less well studied. It is unclear whether attitudes towards SWTs differ from those towards larger wind turbines, making it difficult to assess whether attitudes are likely to be a barrier to SWT installations, but also to provide planning guidelines that limit negative impacts of SWTs on the public. A choice experiment focussing on household use of micro-generation technologies, including SWTs, found British households' willingness to pay for such technologies falls below their installation costs, suggesting micro renewable energy generation is not currently valued enough by the British public to have a high uptake without extra financial incentives such as subsidies or grants (Scarpa and Willis 2010). Currently specific evidence of the importance of wildlife impacts and other attributes to public decision making regarding SWTs and other microgeneration technologies is unavailable.

1.4 Planning guidance for small wind turbines in the UK

Currently, in the UK planning permission is required for the vast majority of SWTs (Park *et al.* 2013). Planning permission is granted by local authorities, with each case evaluated by following planning guidelines provided by government organisations. However, there is currently no single authoritative guidance explicitly for SWTs. Instead guidance is presented by numerous organisations, sometimes with differing priorities, and largely based on adapting guidance designed for wind farms. The need for guidance specifically covering SWTs is acknowledged by both the scientific literature and the Statutory Nature Conservation Organisations for the UK (Warren and Birnie 2009; Walsh *et al.* 2012; Park *et al.* 2013), although there is currently a lack of political will to create such guidance, alongside a general decline in governmental support for wind power generation (DECC 2015a & 2015b).

1.4.1 Planning Guidance Concerning Wildlife Impacts.

The most consistent guidance present in published advice to avoid wildlife impacts is that there should be a buffer distance between SWTs and habitat features likely to be used by birds or bats such as hedgerows and treelines. Recommended buffer distances are variable. Renewable UK (2011), a UK based commercial wind industry organisation, suggest that where possible, the tips of the turbine blades are at least 50m from such habitat features, as well as from neighbouring properties. This originates in a document produced by Natural England (2012) to provide advice for planners and wind turbine operators regarding bats and onshore wind turbines. However, the document also states that “this guidance is not intended for use in respect of micro installations.” Although there is currently limited evidence of the wildlife impacts of SWTs, that which is available suggests the impacts are unlikely to be at the same scale as those of wind farms. Combined with the differences between SWTs and wind farms in terms of turbine size, number deployed at one location and type of habitat deployed in, this calls into question the suitability of adapting planning guidance designed for wind farms to use with SWTs. More recently guidance published by EUROBATS recommends a smaller buffer of

25m (Rodrigues *et al.* 2015) based on the finding that SWTs have localised effects on bats, while there is currently little evidence of an effect on birds (Minderman *et al.* 2012). However, the many questions regarding the impacts of SWTs on wildlife still remain, including what their effect is on bat's use of important habitat features, and this makes it difficult to make appropriate recommendations.

Confusion about gaining planning permission for SWTs also comes from variation in how the available guidance is interpreted by local authorities. These differences are particularly clear when considering the wildlife survey requirements of applying for planning permission in different areas. Some local authorities always require pre-construction ecological surveys, whilst others never do (Park *et al.* 2013). Such surveys can add considerable costs and delays to the planning process, in some cases making SWTs uneconomical to construct.

1.4.2 Recent Changes to Planning Requirements for SWTs.

There has been movement to encourage the growth of the SWT industry in the UK. Firstly, permitted development has been introduced in both Scotland (Town and Country Planning Amendment Order 2010) and more recently England (Town and Country Planning Order 2011). Permitted development sets out the conditions under which SWTs may be installed without requiring planning permission. The permitted development system is not the same in both countries, for example in Scotland the SWT is still required to be registered, but the restrictions placed on turbine sizes and locations are similar for both and are fairly restrictive to the point that it has little impact, with the majority of SWTs still requiring planning permission under both systems (Park *et al.* 2013). Secondly, the recent National Planning Policy Framework (DCLG 2012) has introduced the 'presumption in favour of sustainable development' in England, which confirms the government's commitment to renewable power developments. However, it still does not provide clear, specific planning guidance for SWTs, so the confusion over what is needed to gain planning permission and the implications for the SWT industry and its role in achieving renewable energy targets remain.

1.5 Rationale and aims of this study

The UK, and other countries worldwide, are committed to increasing renewable energy production as part of efforts to limit climate change. Wind power is expected to make a large contribution to meeting renewable energy targets and SWTs are included in this. However, official planning guidance for SWTs is currently lacking, and this may be a barrier to installations if there is confusion over the requirements to gain planning permission (figure 1.1). One reason for the lack of planning guidance is that our understanding of the wildlife impacts of SWTs is limited and therefore it is difficult to make recommendations for their mitigation. There has also been a lack of research into public attitudes towards SWTs, despite calls for wind power policy that fosters social engagement with wind power implementation (Szarka 2006). Public attitudes towards wind farm developments have been linked to planning outcomes and negative attitudes towards SWTs may also be a barrier to installations (figure 1.1). Therefore, in order to make effective recommendations for SWT planning guidance, it is necessary for multi-disciplinary research to provide insights into both the wildlife impacts of SWTs and public attitudes towards them.

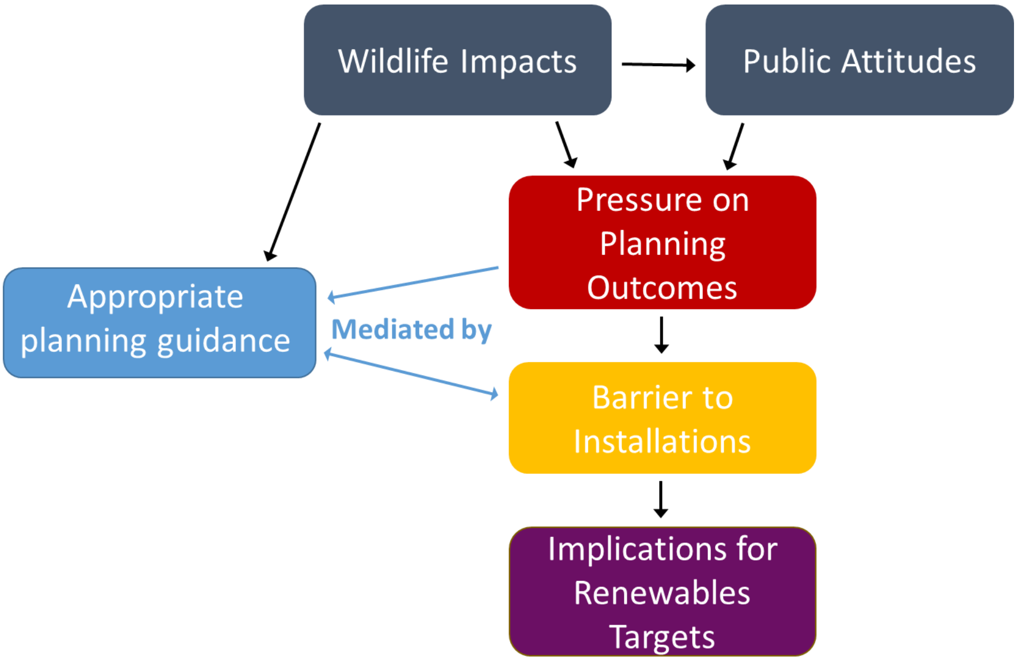


Figure 1.1: Summary diagram of the importance of wildlife impacts and public attitudes towards SWTs showing their potential impact on SWT installations and the role of planning guidance in mediating such impacts.

Following this, the main aims of this study were therefore:

1. To investigate the disturbance effects of SWTs on bats' use of linear features, habitat features of known importance for commuting, in order to make planning guidance recommendations to mitigate wildlife impacts (chapters 2 & 3)
2. To quantify general public attitudes towards SWTs in the UK in order to assess whether these are likely to be a barrier to SWT installations (chapter 4)

3. To assess the level of concern about wildlife impacts to potential SWT owners and their willingness to pay for wildlife mitigation to test the economic feasibility of mitigation recommendations (chapter 5)

Chapter 2

Pipistrelle bat activity at hedgerows is reduced by experimental installation of small wind turbines

2.1 Abstract

Wind power is an increasingly important method of electricity generation. While much of the focus in wind energy technology has been on wind farms, the small-wind sector (turbines generating < 100 kW) has also been expanding, and there are now over 870,000 Small Wind Turbines (SWTs) installed globally. Wind power can exert a range of effects on wildlife, particularly birds and bats, and quantification of these is necessary to inform planning guidance. However, there is little information on the wildlife effects of SWTs. Although there is some evidence that bat activity is lowered in close proximity to operating SWTs, no study has tested whether installation of SWTs has an adverse effect on bats. We therefore conducted a field experiment investigating the effect of installing SWTs on bat activity with particular focus on the role of proximity to known favoured bat foraging habitat (e.g. hedgerows, treelines). *Pipistrellus pygmaeus* activity declined near to operating turbines installed close to hedgerows (within 5m) but remained unchanged at a control site 30m away, while *Pipistrellus pipistrellus* activity declined after SWT installation, at both the turbine and the control site. Activity of both species declined rapidly with distance from the hedgerow. This highlights the importance of installing SWTs away from linear habitat features to reduce their disturbance effect on bats.

2.2 Introduction

There has been rapid growth in wind power generation globally in response to efforts to reduce carbon emissions and increase renewable energy generation, including micro-generational technologies such as Small Wind Turbines (SWTs, generational capacity of up to 100kW, WWEA 2015b). These turbines are typically up to 30m hub height enabling them to be installed in a wide range of locations not suitable for larger units including in urban areas mounted on buildings, as well as farms and large gardens. A total of 870,000 SWTs have now been installed globally with growth in installations highest in China, the USA and the UK (WWEA 2015b).

Wind turbines can have a negative effect on wildlife, particularly birds and bats. In birds, collision mortality at wind farms has been regularly documented (Smallwood 2007; Erickson *et al.* 2014). In addition, a range of studies show adverse effects of turbine proximity or presence on, for example, breeding densities (Pearce-Higgins *et al.* 2009), foraging behaviour (Larsen and Madsen 2000) and flight activity (Larsen and Guillemette 2007), although effects may differ greatly between sites (De Lucas *et al.* 2005). For bats, negative impacts of wind turbines are of particular concern as they are highly protected across Europe (e.g. Council Directive 92/43/EEC, 1992). A review of bat mortality studies at wind farm sites in North America found reported mortality rates varied widely by site with a range from 0.1 to 69.6 bats killed per turbine per year (Arnett *et al.* 2008). Although the causes of bat mortality at wind farms are complex and not fully understood, siting along migration routes (Baerwald and Barclay 2009), low wind speeds (Arnett *et al.* 2008) and increased tower height (Barclay *et al.* 2007) have all been associated with increased mortality. In spite of this uncertainty, for both bats and birds, adverse effects of large wind turbines are well documented.

In contrast to the extensive research on birds and bats at wind farms, effects of SWT remain relatively unknown. There have been anecdotal reports of mortality caused by SWTs (Bat Conservation Trust 2010), but recent estimates suggest mortality is relatively low; for example, between 0.008 and 0.169 bats may be killed per SWT in the UK per year (Minderman *et al.* 2014). Bat activity has also been shown to be negatively affected, with lower activity recorded in close proximity to operating SWTs (Minderman *et al.* 2012) relative to nearby control sites, although such effects seem to be fairly localised (Minderman *et al. in review*). In spite of these relatively recent findings, a number of questions about the effects of SWTs on bats remain unanswered. For example, although studies of large turbines show that bird abundance can change before and after wind farm construction (Pearce-Higgins *et al.* 2009 & 2011), to date no study has been able to quantify the effects of SWT installation on bat activity and disentangle effects of installation from those of SWT operation.

Understanding the specific effect of SWT installation on bats is vital, because they are often installed in a much wider range of habitats compared to larger wind farms, for example in or near gardens or field boundaries, and often near hedgerows or tree lines (Park *et al.* 2013). Such linear habitat features are important to many bat species as foraging habitats, providing protection from predators and adverse weather, and as orientational aids; they also cross open landscapes providing connectivity to other bat habitats (Downs and Racey 2006, Verboom and Huitema 1997). Anthropogenic disturbance along linear habitats, such as light pollution, can greatly reduce their use by commuting bats (Stone *et al.* 2009). Thus, it is possible that SWTs installed near linear habitats similarly affect bats but to date this has not been assessed. Here, I experimentally test the prediction that the installation of an SWT near linear habitats (specifically, mature hedgerows and tree lines) reduces bat activity, relative to a nearby control site. This allows me to simultaneously separate the effect of SWT installation from operation, as well as specifically assess this effect in a habitat commonly used for SWT installations.

2.3 Methods

Data were collected at three farmland sites in Dorset (UK) with well-established linear hedgerows or tree lines at least five meters in height and 60m long with no gaps greater than one meter. Although sites were located in Dorset primarily for practical reasons of proximity to the Ampair warehouse which provided the turbine equipment and support staff, Dorset is an appropriate location for bat studies within the UK with most of the UK bat species present in the county, increasing the applicability of the results from these farmland sites to farmland across the UK. The data collection period was limited to June-September in order to focus on a seasonal period of high activity and avoiding the winter hibernation period when bat activity within the UK is greatly reduced. Data collection took place in 2012 and 2013. An experimental SWT was installed at three distances from the linear habitat: 5m, 20m and 40m, in order to allow assessment of how rapidly activity away from the linear features declines, in a randomised order at each site. Bat activity was recorded for an average of six nights (minimum = 2 nights) before and after SWT installation at each distance in each site (table 2.1), with variations in recording periods due to practical restrictions on access to the site.

Table 2.1: Number of recording nights at each site and distance.

Site	Distance	Before/After	No. of nights
1	5m	Before	7
1	5m	After	8
1	20m	Before	6
1	20m	After	13
1	40m	Before	6
1	40m	After	2
2	5m	Before	5
2	5m	After	4
2	20m	Before	6
2	20m	After	3
2	40m	Before	7
2	40m	After	8
3	5m	Before	4
3	5m	After	9
3	20m	Before	6
3	20m	After	4
3	40m	Before	4
3	40m	After	3

Two models of SWT were used: the Ampair 100, a 0.1kW, six bladed turbine with a diameter of 928mm and the Ampair 600, a 0.6kW, three bladed turbine with a diameter of 1750mm, mounted on a five meter pole on a 1m high trailer (figure 2.1). During the pre-installation period the trailer was at the installation site with the pole lowered to the ground. The turbines were raised to full height (6m) at installation, remaining in this position throughout the post-installation period.

Figure 2.1: Photograph of the experimental SWT in the field at site 3, fully raised with the Ampair 600 model in use. The focal linear feature is visible in the background.

Bat activity was measured using a Song Meter SM2BAT+ (Wildlife Acoustics Inc, Massachusetts, USA) that automatically records echolocation calls. The distance at which these bat detectors are able to reliably record bat calls varies according to many factors such as the bat species with species having different call amplitudes, their call frequencies as higher frequencies attenuate faster than lower frequencies, and the background noise levels. Two ultrasound omnidirectional microphones were used at a height of 1m, one mounted on the trailer within one metre of the turbine, the second on a pole 30m away from the SWT installation site, at the same distance from the linear feature, and from now referred to as the control site (figure 2.2). This control distance of 30m was selected based on previous research which found a difference in bat activity recorded within 0-5m and 25m of SWTs, suggesting the effect of SWTs on bat activity in open space is relatively localised and persists for less than 25m (Minderman *et al.* 2012).

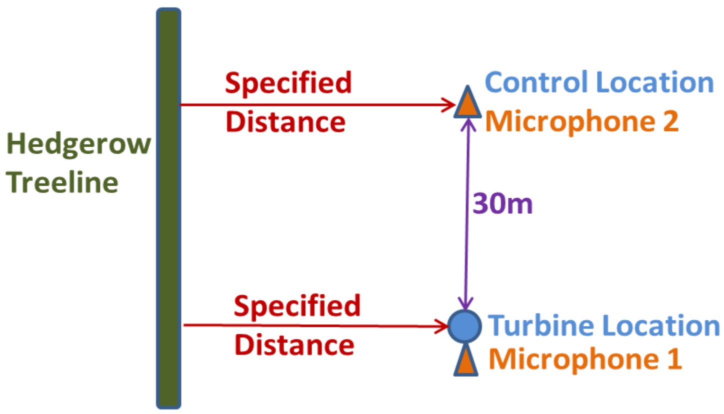


Figure 2.2: Diagram of field equipment set up used in this study showing the location of the turbine and the control microphones in relation to the experimental SWT and the linear feature.

Recordings were inspected manually in AnaLookW (version 3.9f 2013). Calls were identified to species or genus using the shape and frequency of the call (Russ 2012), and the number of "bat passes" was counted for each species per night. A bat pass was any sequence of at least two calls separated from the others by more than a second.

As bat activity is known to be influenced by weather conditions, minimum air temperature (°C) and average wind speed data (m s^{-1}) for each night (2100-0900) was obtained from the nearest possible Met Office MIDAS weather station that had a complete dataset for the study recording period (temperature: mean 31.24±3.62 km away; wind: mean 27.29±5.08 km away; Met Office 2012).

Bat activity was analysed using a Generalised Linear Mixed Effects Model (GLMM) (Gelman and Hill 2007) with a negative binomial error distribution, fitted using the glmmADMB package (Skaug *et al.* 2014) in R version 3.1.1 (R Core Team 2014). In all models site was a random factor, before/after SWT installation and control/turbine locations were included as fixed factors and mean nightly wind speed (m s^{-1}), minimum air temperature (°C) and Julian date were included as standardised covariates. Where they improved the model fit, quadratic terms for mean nightly wind speed and minimum air temperature were included as covariates. A two-way interaction between before/after and turbine/control was included in starting models for each species to test whether the effect of SWT installation on bat activity differed between the turbine and control site (test 1). Further to this, as wind speed is related to the operation status of the turbine, with the SWTs expected to spin more consistently once wind speeds of 3m s^{-1} are reached, starting models for each species also included the three-way interaction between before/after, turbine/control and mean nightly wind speed to test whether the effect of SWT installation (outlined in test 1) was dependent upon wind speed (i.e. SWT operation, test 2). Final models were obtained by removing any interactions which did not make a significant contribution to the model, tested using likelihood ratio tests (Faraway 2005). All main effects were retained in the model.

2.4 Results

The weather across the three sites was fairly consistent throughout the study period. Mean minimum air temperature across the study period was 13.2°C (range: 8.5-16.6°C) and mean nightly wind speed was 3.04m s^{-1} (range: 0.77-6.43m s^{-1}).

The Common Pipistrelle (*Pipistrellus pipistrellus,* Schreber 1774) was the most frequently recorded species during this study, recorded on 95% of nights with 14,738 passes in total (table 2.2). The Soprano Pipistrelle (*Pipistrellus pygmaeus,* Leach 1825) was less common, recorded on 72% of nights with a total of 2,862 passes (table 2.2). Activity of both species declined rapidly with distance from the linear features. The total number of *P. pipistrellus* passes recorded at 40m was over 20 times lower than at the 5m distance and the number of *P. pygmaeus* passes at 40m was 50 times lower than at the 5m distance (table 2.2). Activity levels of other species recorded are given in Appendix 2-A. Due to the low activity levels recorded for other species, and at greater distances from the linear feature, further analyses were restricted to *P. pipistrellus* and *P. pygmaeus* at 5m.

Table 2.2: Summary of the number of bat passes recorded for the *P. pipistrellus and P. pygmaeus* over the full study and for each distance from the linear features.

		Total Number of Passes	Mean Passes Per Night	Standard Deviation	Median Passes Per Night	Proportion of Nights Present
Pipistrellus pipistrellus	Overall	14738	70.18	214.54	11	0.95
	5m Distance	11303	152.74	340.44	23	1.00
	20m Distance	2892	38.05	67.27	14	0.92
	40m Distance	543	9.05	14.51	4	0.93
Pipistrellus pygmaeus	Overall	2862	13.63	56.12	1	0.72
	5m Distance	2456	33.19	90.54	4	0.89
	20m Distance	357	4.70	14.30	1	0.71
	40m Distance	49	0.82	2.00	0	0.53

The final GLMM model for *P. pipistrellus* activity with the turbine installed 5m from the linear habitats did not retain any interaction effects (tests 1 & 2, table 2.3). Controlling for influential weather variables (temperature and wind*)* and based on the coefficients from the model, *P. pipistrellus* activity is predicted to approximately halve following SWT installation (indicated by a negative main effect of before/after installation). However there was no significant effect of turbine/control indicating that this drop in bat activity following installation occurred at the control site as well as the turbine (figure 2.3).

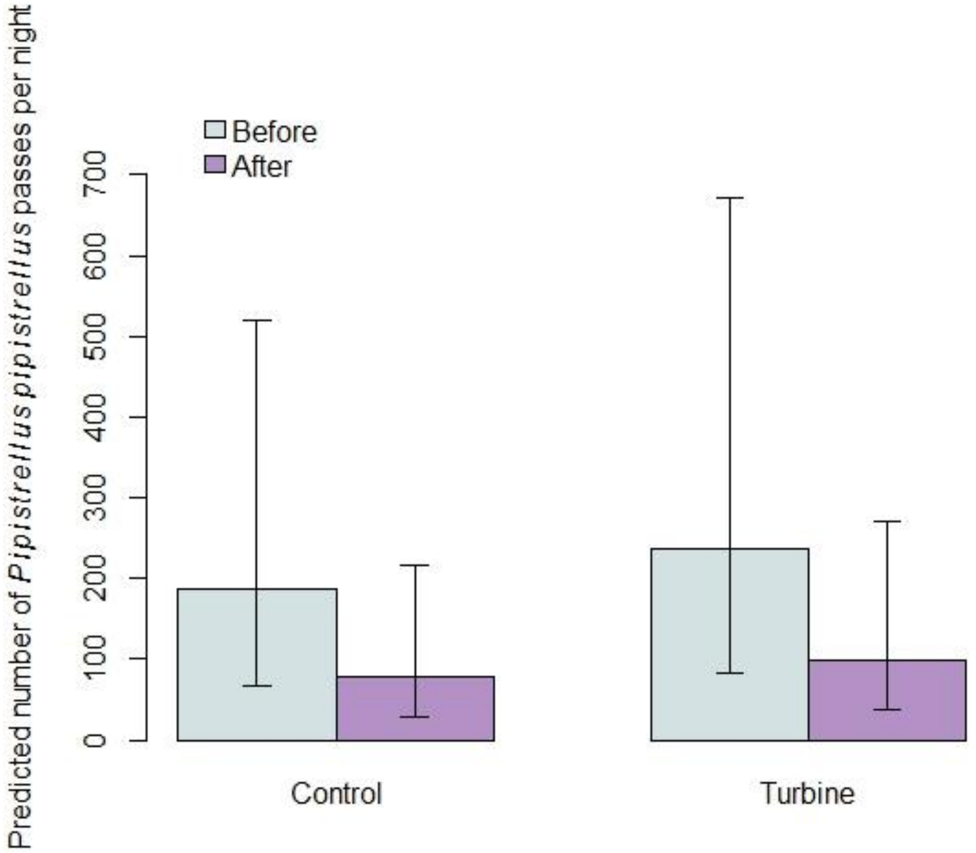


Figure 2.3: Predicted *P. pipistrellus* activity at the turbine and control sites at 5m distance from linear features before and after SWT installation. Predictions are from the final GLMM model for mean average wind speeds, minimum air temperature and Julian date. Whiskers show 95% confidence intervals of the predictions.

The final GLMM model for *P. pygmaeus* activity with the turbine installed at 5m from the linear habitats retains a significant negative three way interaction between before/after, control/turbine and wind speed (test 2, table 2.3). Controlling for date and influential weather variables (temperature and wind) *P. pygmaeus* activity before and after SWT installation is similar at both control and turbine sites at the average wind speed during our study period (3.04 m s^{-1}). However, at 3.77 m s^{-1} (75^{th} quantile of the maximum mean wind speed), when the SWT is expected to be spinning, *P. pygmaeus* activity is over four times lower at the turbine site post-SWT installation compared to pre-installation whilst there is no change in activity at the control site (figure 2.4).

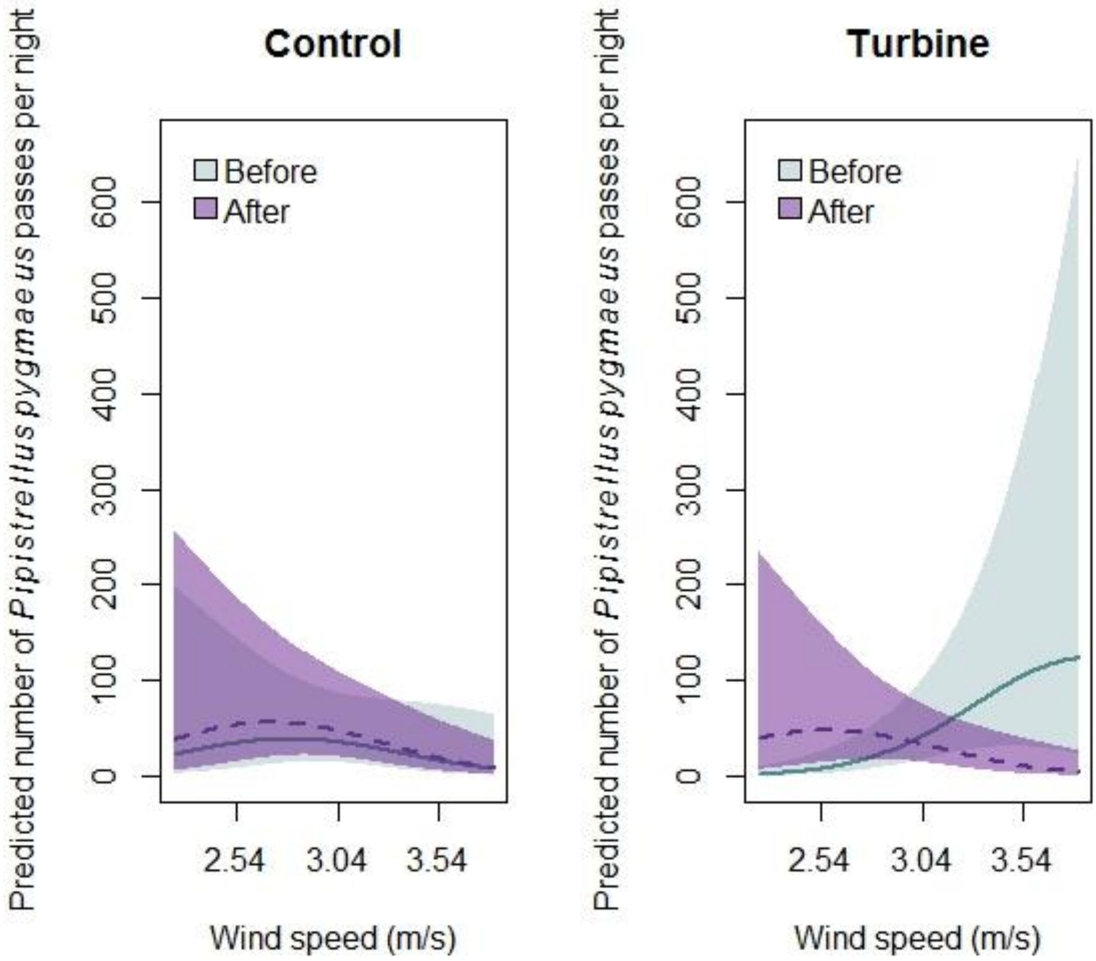


Figure 2.4: Predicted *P. pygmaeus* activity at the turbine and control sites at 5m distance from linear features pre-and post-SWT installation from the final GLMM model for mean minimum air temperature and Julian date and 95% quantiles of recorded wind speed. Solid line shows activity predictions pre-installation and dashed line activity post-installation. Comparison of these lines at the turbine site at higher wind speeds shows a decline in activity post-installation. Shading shows 95% confidence intervals of the predictions.

Table 2.3: Parameter estimates from final GLMM for the activity of the *P. pipistrellus and P. pygmaeus* at 5m from linear features. Reference levels are shown in bold. All predictor variables were standardised, unstandardized means (±SE) are as follows: before/after = 1.57(±0.50), control/turbine = 1.50(±0.50), nightly mean wind speed = 3.04(±1.27), minimum air temperature = 13.18(±2.40) and Julian date = 204.60(±20.90).

Species	*Pipistrellus pipistrellus*				*Pipistrellus pygmaeus*			
Fixed effects:	Estimate	Standard Error	Z Value	P Value	Estimate	Standard Error	Z Value	P Value
Intercept	4.86	0.45	10.80	<0.001	3.67	0.30	12.18	<0.001
Before/After	-0.86	0.40	-2.18	0.029	0.03	0.41	0.06	0.948
Control/Turbine	0.23	0.33	0.70	0.483	-0.13	0.36	-0.35	0.723
Nightly mean wind speed	-1.21	0.43	-2.64	0.008	-0.33	0.45	-0.73	0.465
Nightly mean wind speed^2					-1.63	0.64	-2.55	0.011
Minimum air temperature	1.19	0.41	2.93	0.003	1.33	0.49	2.74	0.006
Minimum air temperature^2	-2.23	0.94	-2.37	0.018	-3.52	0.99	-3.56	<0.001
Julian date	-1.27	0.73	-1.74	0.082	-1.72	0.37	-4.67	<0.001
Before/After***Control**/Turbine					-0.52	0.71	-0.74	0.461
Before/After*Nightly mean wind speed					-2.24	1.06	-2.10	0.035
Control/Turbine*Nightly mean wind speed					1.22	0.87	1.40	0.162
Before/After***Control**/Turbine*Nightly mean wind speed					-3.90	1.86	-2.10	0.036
Random effect variances								
Site	0.34	0.59			<0.01	<0.01		

2.5 Discussion

Here we show for the first time that Pipistrelle bats show species-specific responses to SWT installation and operation. Although previous studies have demonstrated that SWT operation at previously installed turbines can depress bat activity in their immediate vicinity (Minderman *et al.* 2012), those studies were not able to compare bat activity before and after installation.

P. pipistrellus activity declined after installation at both turbine and control sites whilst *P. pygmaeu*s activity declined after installation only at turbine sites at higher wind speeds. The decline in *P. pipistrellus* activity after installation is indicative of a disturbance effect of SWT presence, irrespective of whether the blades were rotating. The fact that I could not detect an interaction with wind speed for this effect is not due to a lack of power, as activity was higher for *P. pipistrellus* than *P. pygmaeus,* although as the wind speed data used in this study was recorded at a MIDAS weather station on average 27.29 km away from the field sites it is possible that an interaction with more local changes in wind speed may have occurred. Moreover, because this decline was observed at both turbine and control sites, we suggest that the effect persisted over a wider area than expected, although it is also possible other factors may be driving this decline. This is in contrast to previous research which found the negative effects of SWTs on bat activity to be relatively localised (Minderman *et al.* 2012; Minderman *et al. in review*).

At the higher wind speeds, predicted *P. pygmaeus* activity at the turbine site before installation was much higher than at the control site and the reasons for this are unclear. One speculative possibility is that sheep at the sites were observed to spend time around the trailer, which was present without the turbine during the before periods. An increase in livestock activity at this site may have increased insect activity which in turn would be expected to be attractive to insectivorous bats. Nevertheless, there was a large drop in activity after turbine installation only at the turbine site, indicating that for this species there was a disturbance effect that did not extend to the control sites. The interaction of this effect with wind speed suggests that it is the operation of the SWT that disturbs this species, as it is expected the SWT blades will be rotating faster at higher wind speeds. This corresponds with previous research where a decline in bat activity was found within 5m of SWTs at higher wind speeds but not further away (Minderman *et al.* 2012).

In order to access wind data for the entire recording period, this study has used average nightly wind speeds recorded at a MIDAS weather station that was on average 27.29 km away from the field sites. These wind speed data correlated highly with wind speed data sets from other MIDAS weather stations in the Dorset area, and also with some limited wind speed data available for sites 1 and 2. Therefore the data used in this study accurately reflects the general patterns in wind speed in Dorset during the study period, but some specific local patterns may not have been observed. The significant interaction between wind speed, SWT installation and turbine/control location could possibly have been stronger if any local wind speed patterns were able to be included. Future research in this area should aim to record wind speed and other weather variables directly at the study sites if possible.

It has been suggested that mortality at wind farms may be due to bats being attracted to turbines (Cryan and Barclay 2009). However, our results do not support this theory, as we found no evidence of an increase in bat activity around the turbine at our installation sites. Many possible causative mechanisms of such an attraction have been suggested including attraction to the sounds made by operating turbines, attraction to turbines as possible roost sites and attraction to insects that may accumulate at turbines (Cryan and Barclay 2009). It is likely these mechanisms differ between larger turbines and SWTs. For example, SWTs may be less likely to be confused for suitable roost trees than taller, larger turbines and the noise generated by turbines is likely to differ between sizes and models, so although we do not find evidence of attraction of bats to our experimental SWTs it may still occur at other turbine models.

P. pipistrellus and *P. pygmaeus* are cryptic species which are morphologically very similar (Jones and Van Parijs 1999), so might be expected to show similar responses to SWTs. However, the species-specific responses reported here are part of a wider picture of known species differences including in echolocation call frequency (Jones and Van Parijs 1999), foraging behaviour, habitat preference and distribution (Davidson-Watts and Jones 2006, Davidson-Watts *et al.* 2006). For example, they respond differentially to fine-scale habitat structure with *P. pygmaeus* activity much higher than *P. pipistrellus* in woodlands with low clutter and understory cover (Lintott *et al.* 2015). Therefore, it is not surprising to find species-specific differences in response to SWT installation between these species although it is unclear what the mechanism behind these differences may be in this case. This highlights a clear need for further research that is able to quantify the impact of SWTs on other bat species which may also show species-specific responses to SWT installation, particularly adjacent to roost sites and commuting routes.

Disturbance of bats by SWTs can be beneficial if it reduces potential collision mortality and our results complement current estimates of mortality at SWTs in the UK, which are lower for bats than for birds (Minderman *et al.* 2014) for whom no such disturbance effect has been demonstrated (Minderman *et al.* 2012). However, where SWTs displace bats from important habitat areas there is the possibility of cumulative negative impacts as the number of SWTs installed continues to increase. Both Pipistrelle species showed marked reductions in activity at greater distances away from linear habitats and it is expected the effects of SWT installation near linear features on bat activity presented here can be generalised to farmland sites across the UK within the normal distribution of these Pipistrelle species. These results provide a strong argument for encouraging installation of SWTs away from linear habitats to limit possible disturbance effects on bats, particularly in sites where such features are rare. The lack of separation of effect between the turbine and control site for *P. pipistrellus* suggests that, at least for some species, such adverse effects may persist for longer distances than previously suggested (Rodrigues *et al.* 2015). Thus, a precautionary approach would include an installation distance of at least 30m from hedgerows and other linear features.

2.6 Acknowledgements

I thank all landowners and staff at Ampair for their support and in particular David Sharman, Elizabeth Plasencia, Alison Fulford, David Brownstein, Graeme Birrell and Sarah Bedingham for their efforts in collecting the data.

Appendix 2-A: Summary of the number of bat passes recorded for two bat guilds, *Myotis* genus and the big bats (*Eptesicus serotinus, Nyctalus noctula & Nyctalus leisleri)*, over the full study and for each distance from the linear features.

		Total Number of Passes	Mean Passes Per Night	Standard Deviation	Median Passes Per Night	Proportion of Nights Present
Myotis species	Overall	565	2.70	5.48	1.00	0.76
	5m Distance	280	3.78	7.34	1.50	0.76
	20m Distance	213	2.80	4.46	1.00	0.89
	40m Distance	74	1.23	3.26	0.00	0.60
"Big" bats	Overall	1032	4.91	9.67	1.00	0.77
	5m Distance	296	4.00	6.68	1.00	0.70
	20m Distance	654	8.60	13.70	3.00	0.92
	40m Distance	82	1.37	2.48	0.00	0.67

Chapter 3

Species-specific disturbance effects of small wind turbines on bat activity at linear habitat features

3.1 Abstract

Wind power generation using turbines can have a negative effect on wildlife, particularly on birds and bats. These negative effects include collision mortality and disturbance of normal behaviours, both of which have been demonstrated at wind farms. Small wind turbines (SWTs; generational capacity of up to 100kW) are a more recent development but are becoming increasingly popular. Whilst collision mortality at SWTs is relatively low, they can disturb bats, reducing activity levels in their vicinity. Such effects are likely to be particularly problematic when they occur in valuable habitats but this has not yet been tested. We tested the effect of SWTs on bat activity at linear habitat features (hedgerows and treelines), which are highly valuable for many bat species. We show that the activity of *Pipistrellus pygmaeus* is lower where SWTs are located near to linear features. At high wind speeds *Myotis* sp. activity is also lower where SWTs are located near to linear features, but this effect was not present at lower wind speeds. These effects were independent of distance along the linear feature (detector proximity), suggesting that SWTs installed near linear features can affect their use by bats over substantial distances (up 60m). These results suggest that SWT presence may lower the suitability of whole valuable habitat features and offer support for siting recommendations, particularly minimum distances between new SWT installations and important wildlife habitat features (buffer distances).

3.2 Introduction

Renewable energy production is currently of global importance in a context of climate change and carbon emission reductions. Wind power is one commonly used method of renewable energy generation with a global capacity reaching almost 370 GW by the end of 2014, close to 5% of global electricity demand (WWEA 2015a). Included in this growth in wind power has been a global growth in small wind turbine (SWT) installations. SWTs are smaller versions of the turbines used in wind farms, designed to allow private companies, small communities and individuals to generate their own electricity. Although a global definition of what constitutes a SWT has yet to be determined, the World Wind Energy Association currently defines them as having a generational capacity of up to 100kW (WWEA 2015b). By the end of 2013 a total of 870,000 SWTs were installed globally, an increase of 8% on the previous year, with China, the USA and the UK leading this growth (WWEA 2015b).

Whilst renewable energy generation can be beneficial for the environment in terms of reducing greenhouse gas emissions, wind turbines can exert negative impacts on wildlife, particularly on bats and birds. Generally these impacts can be split into two broad categories. Firstly, they can cause mortality when wildlife collides with the turbine structure or spinning blades. Bird and bat collision mortality has been recorded at a range of wind farm sites, although mortality rates vary widely between sites and even between turbines at the same wind farm (Erickson *et al.* 2014; Arnett *et al.* 2008). Careful wildlife surveying when planning the siting of the turbines and other mitigation methods may all contribute to reducing wildlife mortality rates at wind farms. Possible other methods include increasing wind cut-in speeds, which has been demonstrated to reduce bat mortality at turbines (Arnett *et al.* 2011), turning off particularly problematic turbines, and possibly acoustic deterrent devices (Arnett *et al.* 2013). Although mortality of wildlife at SWTs has been anecdotally reported (Bat Conservation Trust 2010), recent estimates of mortality rates at SWTs were fairly low (Minderman *et al.* 2014).

The second main type of wildlife impact of turbines is disturbance of behaviour, which can further lead to displacement from areas of previously used habitat. In birds, disturbance of normal foraging (Larsen and Madsen 2000), breeding (Pearce-Higgins *et al.* 2009) and flight behaviour (Larsen and Guillemette 2007) has been demonstrated in response to wind farms. Similarly, there is evidence that bat activity is affected by SWT presence or operation. In particular, at high wind speeds, bat activity was found to be lower near to SWTs (5m away) when compared to activity at a greater distance (25m; Minderman *et al.* 2012). Importantly, the latter study was not able to test how such disturbance effects vary by habitat, but suggested that their consequences could be particularly important in areas where suitable habitat was already limited. Hedgerows and other linear habitat features such as treelines are of known importance to bats as foraging habitat as well as providing protection from predators and inclement weather (Downs and Racey 2006; Verboom and Huitema 1997). Linear features are also important for increasing the connectivity of other foraging and roosting habitats, particularly for bat species that avoid open areas. It is known that anthropogenic disturbance at linear features can greatly reduce their use by bats. For example, light pollution was experimentally shown to decrease the activity of lesser horseshoe bats (*Rhinolophus hipposideros*) along hedgerows by more than half (Stone *et al.* 2009). I recently demonstrated experimental installation of SWT close to linear features has similar effects on the activity of two *Pipistrellus* bat species (chapter 2). However, no study has yet quantified how use of linear features is affected by SWTs installed at different distances from such features. Further, as bat species differ in their use and reliance on linear habitat features, it is likely that such effects will also differ between species.

Therefore, the aim of this study was to investigate the effect of SWTs on bat activity at linear habitat features. Bat activity was acoustically measured at 25 hedgerows and treelines across the UK with a SWT located within 0-100m (*turbine distance*). Bat detectors recorded bat echolocation calls along the linear feature in-line with the SWT (0m) and then at 20m, 40m and 60m along the feature (*detector proximity*). This allows the testing of the following hypotheses:

1. There is an effect of SWT on bats at linear features that diminishes along the linear feature.
2. The effect of SWT on bats at the linear feature is weaker as the distance between the linear feature and the SWT increases.

3.3 Methods

Bat activity at linear features was surveyed at 25 SWT sites in the UK; across the Central and Borders area of Scotland (14 sites), central Wales (5 sites) and central England (6 sites) during June to September 2014 (figure 3.1). These locations were chosen to ensure the field sites were spread across the UK, covering a range of farmland habitats and increasing the generalisability of the results, and also to increase my ability to record data on multiple bat species with differing UK distributions. Sites were clustered within this range to increase the practicality of the surveying work, enabling multiple sites to be surveyed simultaneously and increasing the number of sites surveying within the study period. All the SWTs were free-standing with hub heights between 10-20m. The turbines were all either located on farmland or gardens adjacent to farmland and were located within 100m (maximum 102m) straight line distance of a hedgerow or treeline, the focal linear feature, as previous research suggested the effect of SWTs on bat activity is fairly localised (Minderman *et al.* 2012). Sites were selected to ensure that the full range of distances from the linear feature within the specified 100m were utilised; the closest SWT was 2m from the linear feature and the average distance between SWT and linear feature was 42m. Distances between the linear features and SWTs were measured in Google Earth and ground-truthed in the field. The linear features were required to be at least 60m in length and at least 1m high with no gaps of more than 1m within the length surveyed.

Figure 3.1 Example photographs of field sites surveyed as part of this study showing different SWT designs and distances to linear features.

Data was collected between June and September 2014 in order to coincide with the seasonal period of high bat activity and avoid winter hibernation during which bat activity and behaviour changes significantly. Bat activity was measured using the Song Meter SM2BAT+ (Wildlife Acoustics Inc, Massachusetts, USA) detector that automatically records echolocation calls. Two detectors, each with two omnidirectional microphones, were used at each site. One microphone was deployed at the linear feature in-line with the SWT (0m) with the remaining microphones deployed 20m, 40m and 60m along the linear feature, now referred to as the detector proximity (figure 3.2). As previous research showed the effect of SWTs on bat activity to be localised to less than 30m for some bat species and to persist for at least 30m in other species (chapter 2; Minderman *et al.* 2012), this range of detector proximity distances was chosen to both include and exceed this distance to allow comparison of the results with this earlier research. Microphones were either attached directly to the linear feature whilst ensuring the microphone was not overhung by vegetation, or mounted on a pole directly in front of the feature, always at a height of approximately 1m. The direction of deployment along the linear feature was randomised as far as possible whilst minimising any change in surrounding habitat. Typically the microphones were offset so both directions along the linear feature from the SWT were utilised (figure 3.2). At three sites it was not possible to install a microphone at the 60m detector proximity. The bat detectors recorded echolocation calls continuously from one hour before sunset until one hour after sunrise. The average number of recording nights per site, which varied due to site access and detector battery life, was 3 (min = 2, max = 5) and the total across all sites was 80 recording nights.

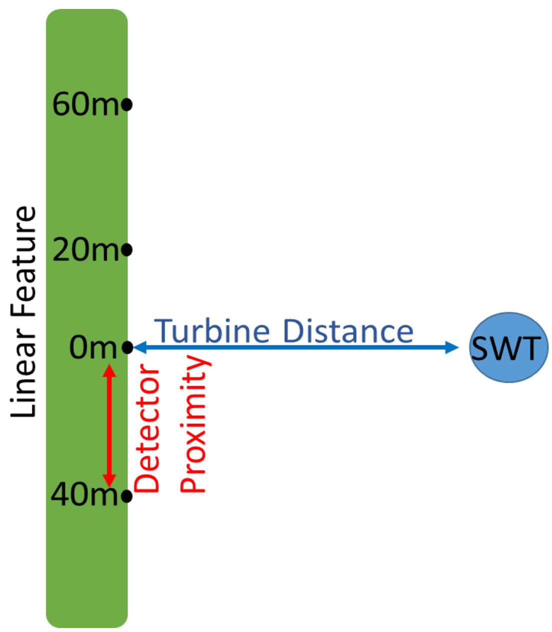


Figure 3.2: Diagram of field equipment set up. 0m, 20m, 40m and 60m represent detector microphones. The direction from the SWT each microphone was located was randomised as far as possible.

Recordings were inspected manually in AnaLookW (version 3.9f 2013). Calls were identified to species or genus using the shape and frequency of the call (Russ 2012), and the number of "bat passes" was counted for each species per night. A bat pass was any sequence of at least two calls separated from the others by more than a second. *Pipistrellus pipistrellus* (Schreber 1774) and *Pipistrellus pygmaeus* (Leach 1825) calls can be reliably identified using the shape and characteristic frequency of their foraging calls (Russ 2012; Jones and Barratt 1999). *Pipistrellus* calls with an ambiguous characteristic frequency between 49 and 51 kHz were excluded from this analysis. Other species are harder to identify due to similar call structures within the genus. Species within the *Myotis* (Kaup 1829) and *Nyctalus* (Bowdich 1825) genera are good examples of this and therefore were identified only to genus level. Another UK species, *Eptesicus serotinus* (Schreber 1774), also has a call structure similar to the species in the UK *Nyctalus* genus *(N. noctula* (Schreber 1774) *& N. leisleri* (Kuhl 1817)). These three species are relatively large, high flying bats (Altringham 2003) and have been analysed together as the Big bat guild.

As bat activity is known to be influenced by weather conditions, minimum air temperature (°C, measured over 24 hours from 9am-9am) and average wind speed data (m s^{-1}, measured over 12 hours from 9pm-9am) for each night was obtained from the nearest possible Met Office MIDAS weather station (mean: 27.0 ± 10.5 km away for wind, 28.4 ± 11.0 km away for temperature; UK Met Office 2012).

Bat activity was analysed using a Generalised Linear Mixed Effects Model (GLMM) (Gelman and Hill 2007) with a negative binomial error distribution, fitted using the glmmADMB package (Skaug *et al.* 2014) in R version 3.1.1 (R Core Team 2014). Site and night nested in site were included as random factors. Turbine distance (m), detector proximity (m), mean nightly wind speed (ms^{-1}), minimum daily temperature (°C) and day of the year were included as standardised covariates. Initial models included the 3-way interaction between turbine distance, detector proximity and mean nightly wind speed and all related 2-way interactions. Each interaction was tested for significance using likelihood ratio tests (Faraway 2005) and removed if not found to be making a significant contribution to the model. All main effects were retained in the final models regardless of significance. We tested our two predictions by assessing the significance of the main effect of detector proximity (Prediction 1) and the interaction between detector proximity and turbine distance (Prediction 2). Fixed predictions from the final models and associated confidence intervals used in the figures presented here were calculated using the predict function in R.

3.4 Results

Bat activity was recorded at all sites (table 3.1). In total, across all sites and detector proximities, 30,229 bat passes were recorded, an average of 383 passes per night. *Pipistrellus pygmaeus* was the most commonly recorded bat with 16,367 passes, an average of 205 passes per night. High levels of *Pipistrellus pipistrellus* activity was also recorded; 11,228 passes in total averaging 140 passes per night. Several other bat species were recorded at much lower activity levels. A total of 1810 passes from bats in the genus *Myotis* were recorded, an average of 23 passes per night and the three species that make up the 'Big' bat guild (*Eptesicus serotinus, Nyctalus noctula & Nyctalus leisleri*) were recorded making 824 passes, an average of 10 per night. Although other bat species were also recorded during the study (*Rhinolophus hipposideros, Barbastella barbastellus, Plecotus auritus*), their activity levels were too low to allow further analysis (table 3.1). Over the full data collection period, nightly mean wind speed was 5.5 ms^{-1} (range: 1.6-13.4 ms^{-1}) and sites and mean minimum air temperature was 11.0°C (range: 2.4-16.3°C).

Table 3.1: Total and mean number of bat calls per night across all sites and nights.

Species/Guild	Total calls recorded	Mean calls per night
Pipistrellus pipistrellus	11228	140.35
Pipistrellus pygmaeus	16367	204.59
Myotis sp.	1810	22.63
Big bats	824	10.30
Plecotus auritus	61	0.76
Rhinolophus hipposideros	1	0.01
Barbastella barbastellus	1	0.01

The final GLMM model for *P. pygmaeus* activity did not retain any interactions (table 3.2). SWT distance from the linear feature had a significant positive effect on *P. pygmaeus* activity, with higher numbers of passes recorded when the SWT was located at greater distances from the linear feature (figure 3.3). Minimum air temperature also had a significant positive effect on activity with more passes recorded at higher air temperatures. The final GLMM models for *P. pipistrellus* and big bat activity also did not retain any interactions between covariates (table 3.2). None of the covariates included in the final model had a significant effect on the activity of the big bat species, but minimum air temperature did exert a significant positive effect on *P. pipistrellus* activity. The final GLMM model for *Myotis* species activity was the only final model to retain an interaction. The effect of SWT distance on *Myotis* activity varied with mean nightly wind speed; *Myotis* activity at higher wind speeds (e.g. 10 ms^{-1}) was greater when the SWT was further away from the linear feature, an effect that was not present at average wind speeds for the period of this study (5.5 ms^{-1}, figure 3.4). Minimum air temperature and mean nightly wind speed also had a significant effect on *Myotis* species activity; higher numbers of passes were recorded at higher temperatures and at lower wind speeds.

Table 3.2: Parameter estimates from final GLMMs for the activity of the *P. pipistrellus*, *P. pygmaeus, Myotis* species and big bats at linear features. All predictor variables were standardised, unstandardized means (±SE) are as follows: turbine distance 42.20m ± 28.68, detector proximity 28.51m±21.84, mean nightly wind speed 5.50 ms^{-1}±2.90, minimum temperature 10.91°C±2.71 and day of the year 205.81 days ±24.73. Bold font indicates a Wald test P value significant at the 5% level.

Species	***Pipistrellus pipistrellus***				***Pipistrellus pygmaeus***				***Myotis species***				**"Big" bats**			
Covariates	Estimate	Standard Error	Z Value	P Value	Estimate	Standard Error	Z Value	P Value	Estimate	Standard Error	Z Value	P Value	Estimate	Standard Error	Z Value	P Value
Intercept	3.16	0.20	15.83	**<0.001**	3.05	0.34	9.02	**<0.001**	0.92	0.30	3.07	**0.002**	-0.24	0.43	-0.56	0.580
Turbine distance	-0.47	0.40	-1.18	0.237	1.37	0.69	1.97	**0.049**	-0.24	0.62	-0.38	0.703	0.35	0.87	0.41	0.680
Detector proximity	-0.09	0.21	-0.45	0.650	0.23	0.20	1.15	0.252	-0.13	0.19	-0.68	0.495	0.33	0.24	1.38	0.171
Mean nightly wind speed	-0.20	0.28	-0.71	0.478	-0.12	0.33	-0.37	0.711	-0.98	0.42	-2.34	**0.019**	0.23	0.64	0.36	0.720
Minimum temperature	0.86	0.27	3.14	**0.002**	1.05	0.36	2.93	**0.003**	1.04	0.40	2.58	**0.010**	0.10	0.68	0.15	0.880
Day of the year	-0.01	0.43	-0.03	0.978	0.16	0.72	0.22	0.824	0.62	0.69	0.91	0.364	-0.06	0.98	-0.06	0.950
Turbine distance* Mean nightly wind speed									1.48	0.72	2.05	**0.040**				
No. of farms	25				25				22				19			
No. of nights	80				80				72				61			
Random effects																
Farm	0.73	0.85			2.64	1.62			2.22	1.49			5.37	2.32		
Farm:Night	<0.01	0.05			<0.01	<0.01			0.38	0.62			0.57	0.75		

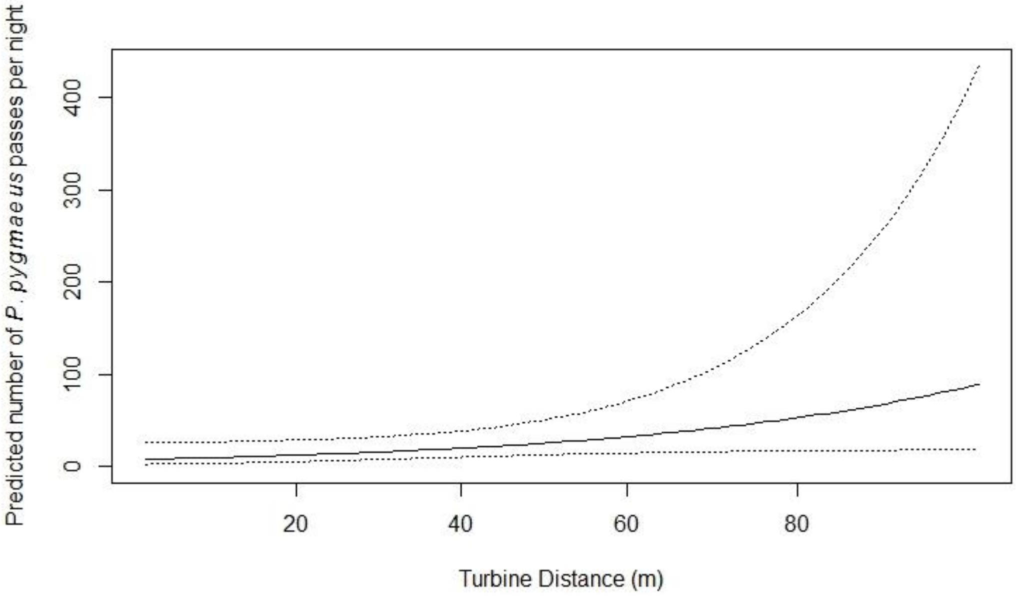


Figure 3.3: Predicted number of *Pipistrellus pygmaeus* passes per night at a linear feature in response to SWT distance from the linear feature from the final GLMM model for mean minimum air temperature, mean nightly wind speed, day of the year and detector proximity. Dotted lines show 95% confidence intervals.

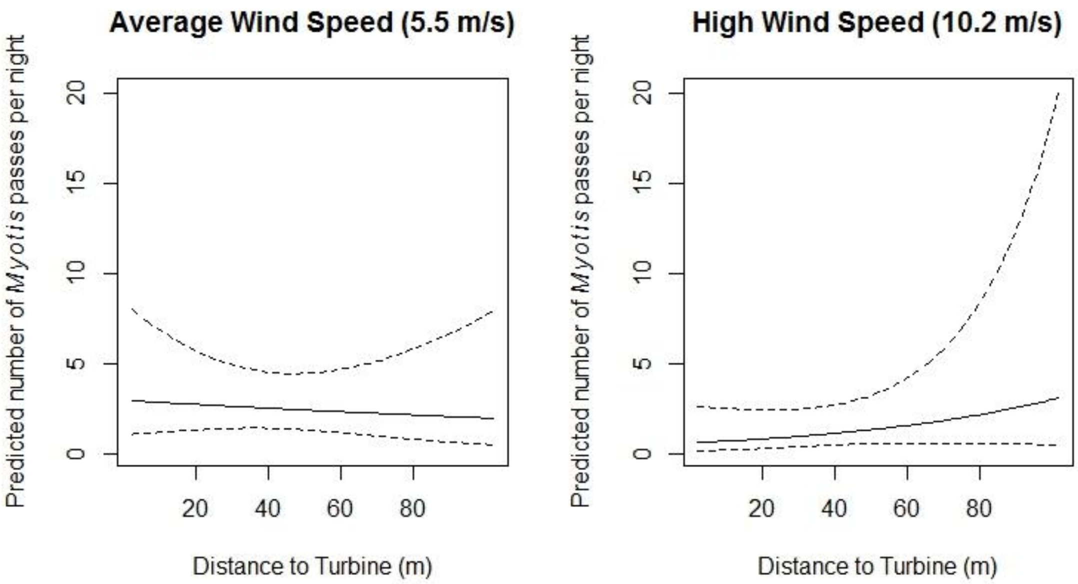


Figure 3.4: Predicted number of *Myotis* passes per night at a linear feature in response to SWT distance from the linear feature. Predictions are from the final GLMM model for mean minimum air temperature, day of the year and detector proximity. Dotted lines show 95% confidence intervals of the predictions.

3.5 Discussion

This study has found evidence of species-specific disturbance effects of SWTs on bats' use of linear features such as hedgerows, known to be important in linking fragmented habitats, for the first time. Whilst we found no evidence of a disturbance effect on *Pipistrellus pipistrellus* or the bats making up the big bat guild (*Eptesicus serotinus, Nyctalus noctula & Nyctalus leisleri*), there was evidence that *Pipistrellus pygmaeus*' use of linear features was negatively affected by SWT proximity. *P. pygmaeus* activity at the linear features was lower the closer the SWT was located to the linear feature. There was also evidence of an effect on *Myotis* activity at linear features with activity declining the closer the SWT was to the linear feature, but only at higher wind speeds. This could be evidence of an effect of SWT operation, as the SWT operation is directly affected by the wind speeds, with many SWTs not beginning to spin until wind speeds of around 3-4 ms^{-1} have been reached. This finding is particularly interesting as it is the first evidence of a disturbance effect of SWTs specifically on *Myotis* species. Although ideally climate data would be collected directly at the SWT sites, due to resource and logistical reasons the wind data used in this study came from an average of 27.0 km away. I am confident that this data still accurately reflects the wind speeds at the SWTs as previous research that used similarly distant wind data in studying the effect of SWTs on bat activity was able to demonstrate high correlations between locally collected wind data and that from more distant weather stations (chapter 2; Minderman *et al.* 2012). Further, if the wind data did not reflect wind speed at the SWT sites then it would be expected to increase the random variation in the dataset, making it harder to obtain significant effects of wind speed on bat activity as has been found in this case.

Linear features are used as navigational aids by bats, connecting other key habitat areas, particularly for those species which avoid crossing open areas. If SWTs located near to linear features reduce their utilisation by bats this could make otherwise suitable habitats inaccessible, especially in areas where linear features are already uncommon due to other pressures such as the increasing industrialisation of farming (Robinson and Sutherland 2002). Further, many insectivorous bat species utilise linear features as foraging grounds, with bats having been observed to catch more insects closer to linear features than further into open space (Downs and Racey 2006), whilst they also provide protection from inclement weather, potentially increasing flight efficiency, and from predation (Downs and Racey, 2006; Verboom and Huitema, 1997). Therefore the disturbance effects of SWTs on bats' use of linear features reported here could have negative impacts on fitness and reproductive success.

Anthropogenic disturbance at linear features is likely to have both direct costs, such as increased flight times and stress, and indirect costs such as loss of foraging time leading to lower energetic gains (Stone *et al.* 2009). It is unclear from this research how bats responded to the disturbance at the linear features but they may find an alternative route to their destination, seek out an alternative foraging area or simply return to their roost. These options have implications for their ability to feed and the associated energetic costs of foraging, which are further affected by the availability of other linear features and foraging habitats and the quality of those alternatives. These costs may be particularly severe for reproductive females whilst they are pregnant and lactating due to their increased energetic demands at this time, but also they may be more restricted in their ability to travel further away to find alternative good quality foraging sites when they must return to their young.

Although we have found evidence of an effect of SWTs on bat activity at linear features, we did not find any evidence that this effect dissipates at longer distances along the feature: detector proximity did not alter the effect of turbine distance on bat activity for any of the species. This implies that any effect of the SWT on activity at the linear feature persists for at least 60m along the feature. This is further than expected based on previous research (Minderman *et al.* 2012 & *in review*, chapter 2), and suggests that the presence of a nearby SWT could substantially reduce or even remove the utility of the linear feature for commuting or foraging bats. The previous experimental study investigating bat activity at SWTs installed close to hedgerows also found evidence of a disturbance effect on *P. pygmaeus*, with activity declining after the SWT was installed, although again this effect did not appear to persist 30m away (chapter 2). The same study additionally found a negative effect of SWTs on *P. pipistrellus* activity that there was no evidence of in this study. Although the reasons for the discrepancy between these earlier findings and the ones presented here require further investigation, it should be noted that in chapter 2 I used newly (experimentally) installed turbines, whereas the turbines studied here had been installed for varying periods of time before this study took place. It is possible that the larger-scale avoidance as demonstrated here develops over a longer time frame in some species, while others may perhaps habituate to the disturbance. Moreover, the turbine models studied in the previous experimental study were relatively small compared to the models in the present sample, which might affect the spatial extent of any disturbance effects.

The differences highlighted here in species responses to SWTs underline the importance of analysing bat activity at the species level as far as is possible. Bat species occupy a wide range of ecological niches and therefore it should be expected that they may show different responses to anthropogenic disturbance such as that potentially caused by SWTs. Even morphologically very similar species, such as *P. pipistrellus* and *P. pygmaeus,* show differences in habitat preference, foraging behaviour and distribution (Davidson-Watts and Jones 2006; Davidson-Watts *et al*. 2006; Lintott *et al.* 2015). Species use of linear features is known to differ and this would be expected to influence the impact of any disturbance at linear features. For example, some species, such as *P. pipistrellus, P. pygmaeus* and *Myotis* species, are more closely associated with hedgerows than other species, including members of the *Nyctalus* and *Eptesicus* genera (Kelm *et al.* 2014). These are large, fast flying bats that tend to fly at greater heights than other UK species and may therefore be less reliant on landscape features. There may also be seasonal changes in the disturbance of bat activity at linear features by SWTs related to seasonal changes in usage of the features which this study did not specifically investigate, although day of year was only found to have a significant effect on *Myotis* activity. For example, *P. pygmaeus* has been observed to show lower activity at hedgerows in summer compared to spring (Kelm *et al.* 2014) and it would be of interest for further research to study whether this alters the disturbance effect of SWTs on activity. Despite the practical difficulties of obtaining data that allows bat activity to be analysed at the species level, particularly for rarer species, it is clear that in order to fully understand the effect of SWTs on bats it is necessary to do this and this is an important focus for future research.

The results presented here are likely generalisable to SWTs located near hedgerows and treelines on farmland across the UK due to the underlying data being collected at field sites which included natural variation in several relevant factors. The field sites were spread across the UK, specifically in three clustered areas in the Central and Borders area of Scotland, central Wales and central England ensuring a variety of locations were used and that data came from sites with different local bat species distributions. The field sites were all farmland or garden sites, reflecting the fact that these are the habitats in which free standing SWTs are predominantly installed (Park *et al.* 2013) but did include both arable and livestock farms and a variety of surrounding habitats. The linear features studied included hedgerows and treelines and varied in terms of species composition and feature height, length and density within the specifications set out in the methods and the SWTs were of various models and blade designs, therefore these results apply across all of this included variation in specific situation.

Despite the existing evidence that SWTs can have a negative impact on wildlife such as bats which are highly protected throughout Europe (Council Directive 92/43/EEC, 1992), there is currently a lack of official planning guidance concerning the installation of SWTs in the UK and elsewhere (Park *et al.* 2013). My results indicate that disturbance of bat activity at linear features by SWTs may be a problem for some species and therefore it is recommended that SWTs are installed as far away from linear features as possible. This is consistent with other recommended guidelines for SWT installations such as those produced by EUROBATS which suggest SWTs should be installed at least 25m from hedgerows and treelines along with other important bat habitats (Rodrigues *et al.* 2015), and my previous research which recommended a buffer distance of 30m (chapter 2), although the results presented here imply that greater buffer distances than this, a minimum of 60m, may be preferable to protect the most sensitive species from disturbance.

3.6 Acknowledgements

I would like to thank all the land owners of the study sites for their cooperation with this study. Thanks also go to Jenny Wallace for her assistance with bat call identification.

Chapter 4

Drivers of public attitudes towards small wind turbines in the UK

4.1 Abstract

Small Wind Turbines (SWTs) are a growing micro-generation industry with over 870,000 installed units worldwide. No research has focussed on public attitudes towards SWTs, despite evidence the perception of such attitudes are key to planning outcomes and can be a barrier to installations. Here we present the results of a UK wide mail survey investigating public attitudes towards SWTs. Just over half of respondents felt that SWTs were acceptable across a range of settings, with SWTs on road signs being most accepted and those in hedgerows and gardens least accepted. Concern about climate change positively influenced how respondents felt about SWTs. Respondent comments highlight visual impacts and perceptions of the efficiency of this technology are particularly important to the UK public. Taking this into careful consideration, alongside avoiding locating SWTs in contentious settings such as hedgerows and gardens where possible, may help to minimise public opposition to proposed SWT installations.

4.2 Introduction

The world is currently experiencing a period of anthropogenically driven climate change with global mean surface temperature increasing since the late 19th century, a warming of 0.85 (0.65 - 1.06)°C between 1880 and 2012 (Stocker *et al.* 2013). The potential ecological, social and economic impacts of these changes are profound and widespread. Rises in sea level and changes to precipitation trends will cause increased flooding in some areas and long-term drought in others, and will put pressure on our ability to produce enough food for a growing global population (Field *et al.* 2014). It is predicted that by 2050 up to 37% of species will be committed to extinction (Thomas *et al.* 2004; Thomas and Williamson 2012). A comprehensive review of the economic costs of climate change and the associated impact risks suggests that failure to act to mitigate global climate change may cost 5% of global Gross Domestic Product (GDP) each year, whilst taking immediate action to limit climate change is likely to cost much less at around 1% of global GDP each year (Stern 2006). Despite this, while 66% of respondents to a UK governmental public attitudes survey were concerned about climate change, only 5% saw climate change as the top challenge facing Britain (DECC 2013b).

The production of renewable power is one component of worldwide efforts to limit the scale and impacts of global climate change. Wind power is a method of electricity generation identified as one of eight key technologies central to achieving the UK government’s target of delivering 15% of the UK’s energy consumption from renewable energy sources by 2020

(Climate Change Act 2008; DECC 2011a; DECC 2013a). The UK has the sixth largest installed wind power capacity in the world at over 11,000 MW, with more wind farms awaiting construction or in planning (Renewable UK 2014).

Alongside these large wind farm developments, micro-generation of wind power is a growing industry with over 27,450 small and medium wind turbines installed in the UK between 2005 and 2014 with an installed generational capacity of 120 MW (Renewable UK 2015). There has been similar growth globally with at least 870,000 Small Wind Turbines (SWTs) installed by the end of 2013 (WWEA 2015b). Micro-renewable technologies, such as SWTs, are scaled down versions of standard renewable energy production technologies designed for use where space is limited. They have been utilised by businesses, communities and individual households to both provide their energy needs and to generate an income from feed-in tariffs (FITs). SWTs are legally defined in the UK as having an electricity generation capacity of up to 50kW (Energy Act 2004), however there is no globally accepted definition with the upper limit of individual countries' definitions typically ranging from 15-100kW generational capacity (WWEA 2015). Within these definitions there is wide variation in turbine height and design, as it encompasses both building mounted and free-standing SWTs, horizontal and vertical turbine models and on-grid and off-grid situations (Park *et al.* 2013).

4.2.1 Attitudes towards wind power

Negative attitudes towards proposed wind farms from the general public are commonly publicised in the media giving the impression that there is widespread opposition for this technology with negative visual, noise, economic and wildlife impacts often cited. Despite this portrayal, research in the UK and across Europe consistently finds high levels of support for wind power generation (Warren and Birnie 2009). A survey of over 2000 UK households in 2012 found 68% supported onshore wind power, rising to 76% for offshore wind power (DECC 2013b). Given this high general support for wind power in principle, negative attitudes towards specific wind farm developments are often assumed to be the result of 'not in my backyard' attitudes or NIMBYism. However, it has been argued that this oversimplifies complex and varied explanations given by people for opposition to local wind projects and does little to increase our understanding of attitudes towards wind power (Wolsink 2007). For example research has uncovered unexpected patterns in attitudes such as those living closest to wind farms being more in favour of them once they are operational (Braunholtz 2003; Warren *et al.* 2005). This is thought to be the result of greater experience of wind farms allowing people to better evaluate their impacts, with participants in the research often reporting the negative impacts being less than was anticipated. Thus greater familiarity with turbines may improve public attitudes towards them.

The main public concerns about wind power include landscape or visual impacts, wildlife impacts and noise pollution, particularly where there are few local benefits to offset any costs (Warren *et al.* 2005). To date most research into public attitudes towards wind power has been conducted in relation to large turbines and wind farm developments (Warren and Birnie 2009; Warren *et al.* 2005), or has focussed on attitudes towards generic green power sources (e.g. Bergmann *et al.* 2008; Scarpa and Willis 2010). The nature and location of SWTs differs markedly from these large wind developments. For example, they can be installed in more urbanised environments such as on buildings, factories and in gardens: places where the public may be more likely to live and work in close proximity and can be owned by individuals and local communities (Park *et al.* 2013). In contrast, large wind farms require large, open spaces in relatively remote areas and are typically owned by large private companies. This makes it inappropriate to extrapolate findings from studies of public attitudes towards wind farms to public attitudes towards SWTs.

4.2.2 Implications of public attitudes for SWT installations

At present in the UK the majority of SWT installations require planning permission (Park *et al.* 2013). Despite this there is currently a lack of national planning guidance specific to SWTs and there can be significant differences in the requirements and restrictions placed on installations between local councils. For example, a survey across local UK councils of when ecological surveys are requested as part of an SWT planning application found they varied from being requested for almost all applications to never being requested except where the installation was within a designated site (Park *et al.* 2013). Local public attitudes are known to have a key role in determining the outcome of planning applications (Toke 2005; Bell *et al.* 2013). A lack of understanding of, and guidance relating to, public attitudes could result in increased antipathy towards SWTs if they are installed in unpopular locations. Equally, it may cause unnecessary rejections of SWT applications and higher levels of decision appeals, which can lead to higher planning application costs, delays in the planning process and general uncertainties about application outcomes. These are all disincentives to owning an SWT which has implications for the growth of the micro-generation industry and may influence whether government targets for renewable energy generation are met. It is thus vital to better understand what drives public attitudes to SWTs.

Using a nationwide postal survey, we aimed to identify which factors influence public attitudes towards SWTs in the UK. Specifically, we focused on the following questions:

(1) What is the degree of acceptance by the UK public of small wind turbines?
(2) How important is the context of SWT installation (e.g. which habitats / areas they are installed in) in determining how acceptable they are?
(3) Does concern over climate change influence attitudes towards small wind turbines?
(4) What factors, including familiarity with turbines and demographic factors, influence attitudes towards SWTs?

4.3 Methods

4.3.1 Questionnaire design

The full postal questionnaire is included in Appendix 4-A. In summary, it consisted of eight pages and was divided into four sections dealing with the following issues: 1) attitudes towards climate change; 2) attitudes towards wind turbines; 3) attitudes towards SWT in general and in typical settings; and 4) personal details including demographic information. For each of six typical settings for SWT (on domestic buildings, in domestic gardens, on road signs, in fields, in hedgerows, and on schools premises), respondents were presented with three example photographs and asked to rate the acceptability of SWTs in that setting to them on a balanced five-point Likert-type scale (from very acceptable to very unacceptable). Several other questions employed a similar five-point scale including asking respondents to state how strongly they agreed with statements on climate change and typical wind turbine concerns from strongly agree to strongly disagree. Space was provided to allow participants to make comments both on specific questions and on the survey topic overall. To limit any order effects (Siminski 2008) two versions of the questionnaire were created; in these the order in which statements were presented for questions 2 and 11 were varied. Similarly, to limit any acquiescence or primacy effect both negatively and positively worded statements were used (De Vaus 2002). The questionnaire was posted with a two-page letter that included a description of SWTs along with a pre-paid self-addressed envelope and an option to complete the questionnaire online if preferred. The online version of the questionnaire was identical to the printed version, barring some minor formatting changes.

A pilot test of the questionnaire was conducted in and around Stirling, Scotland, UK. Forty participants completed the printed version of the questionnaire in the presence of a researcher who observed them for any apparent difficulties answering any question and used follow-up questions to test understanding of the questionnaire. The pilot test confirmed the questionnaire took about ten minutes to complete.

A UK address database based upon the white pages directory and births, marriages and deaths register was purchased from www.customlists.net and the 2000 addresses were selected by generating random numbers and taking the address contained in the corresponding database row number. In order for the respondents views to be representative of the UK public as far as possible, the sample (n=2000) was proportionally stratified by population size of country, and then further into the 10 regions for England (Office for National Statistics 2012; National Records of Scotland 2012; Northern Ireland Statistics and Research Agency 2012), so reflecting the actual distribution of the population (Sapsford and Jupp 1996). To encourage return we followed up with a reminder postcard two weeks later and completion of the questionnaire gave entry to a prize draw for £50.

4.3.2 Data analysis

As the majority of data collected were ordinal, non-parametric statistical techniques were used for analysis. Friedman's Test was used to assess differences in the acceptability of SWTs in different settings. Post hoc analysis with Wilcoxon signed-ranks was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.003$. The mean scores for each respondent across all six settings were used as the measure of level of SWT acceptance in all further analyses. A score for climate change belief and concern was calculated for each respondent by taking the mean of their agreement with six statements regarding climate change acceptance and concern (adjusting for negatively worded questions). Whilst data analysis used all five levels for both scores (unless stated otherwise) for ease of reporting scores are simplified to three levels (agree=strongly agree & agree, neutral=neither agree nor disagree, disagree=disagree & strongly disagree) unless stated otherwise. The influence of potential explanatory variables on acceptance of SWTs was tested using an ordinal regression with main effects only (Norusis 2011). All variables were entered as factors. The starting model included the socio-economic factors age (four levels), gender (two levels), employment status (six levels), education status (five levels) and type of newspaper read (four variables with two levels each: broadsheet, mid-market, tabloid and other). Familiarity with SWTs (three levels: high, medium, low) and presence of turbines within one kilometre of the home (four levels: both small & large, large only, small only, none) were also included as familiarity with turbines has previously been found to influence attitudes to wind farms (Warren *et al.* 2005). Engagement in outdoor activities (two levels: yes, no) was designed to be a reflection of time spent outdoors and connectedness to the environment. Membership of environmental organisations (two levels: member, non-member), alongside education and type of newspaper read, was expected to influence knowledge of, and access to information about, climate change and renewable energy generation. Finally, because of the distribution of responses for climate change belief and concern, respondent score was simplified to three levels (high, medium and low belief and concern) and included in the starting model as this was expected to affect attitudes towards renewable energy generation. In order to use ordinal regressions, mean agreement scores were rounded to the nearest whole number. From a starting model containing all 13 of the explanatory variables outlined above, a model simplification process sequentially removed the variable with the highest p value until only variables with p values ≤ 0.1 remained in the model. We also assessed respondents' voluntary comments and broadly categorised them into types of concern. All statistical analyses were performed in SPSS version 19 (IBM Corp 2010). Averages are expressed as means and confidence intervals at the 95% confidence level.

4.4 Results

4.4.1 Response rate

Of 2000 questionnaires posted, 335 were returned undeliverable. Of the remaining 1665 questionnaires, 199 completed questionnaires were returned, a response rate of 12.0%. A further seven responses were removed from some analyses due to questionnaires being incomplete. Fourteen of the questionnaires were completed online. Regional response rate ranged from 7.7% for London to 17.4% for the North East of England. There were no significant differences in response rates between regions (χ^2 (11)=13.5, p=0.26).

4.4.2 Demographic statistics

The gender and age structure of our sample was significantly different from that of the UK population (Gender: $\chi^2(1)=49.6$, $p<0.001$; Age: $\chi^2(5)=170.2$, $p<0.001$). Respondents were predominantly male (74.7%) and 65 years of age or older (51.6%) in contrast to 49% male and 21% 65 years or older in the UK population (Office for National Statistics 2011). Only two respondents were under 35 years. In line with this, over half of respondents were retired (55.3%), with 33.7% in formal employment (full or part time). A total of 30 respondents (16.6%) had no formal qualifications, while 58 (32.0%) had a first degree or higher.

4.4.3 Familiarity with turbines

All respondents were familiar with large wind turbines but 7.7% (± 3.8) of respondents reported they were not familiar with SWTs. Only one respondent owned a turbine, while 4.7% (± 3.0) of respondents had a large turbine, and 10.9% (± 4.4) had a SWT, within 1km of their home.

4.4.4 Attitudes towards turbines

Fewer respondents were opposed to having a SWT (25.3% ± 6.1) than a large turbine (52.1% ± 7.0) in sight of their home while 33.5% (± 6.6) and 18.0% (± 5.4) of respondents were in favour of having a small or large turbine respectively in sight of their home (Wilcoxon signed ranks: $Z=-3.11$,$p<0.01$).

More respondents were willing to consider installing an SWT of their own in order to reduce electricity bills (57.9% ± 1.1) than to reduce CO_2 emissions (47.2% ± 1.0), while 39.6% (± 0.9) of respondents stated that they would not consider installing an SWT. The cost of installation or feeling that SWTs were a poor investment, not living in a suitable location, concern about a negative visual impact and doubting the efficiency of this method of power generation were the most commonly given reasons for this (appendix table 4-A).

The setting of SWTs had a marked effect on the public's level of acceptance (Friedman Test: $\chi^2(5)=126.28$, $p<0.001$, figure 4.1). SWTs associated with road signs were more acceptable than all other SWT settings presented while SWTs in hedgerows were less acceptable than those on buildings, school premises and in fields, and SWTs in fields were more acceptable than those in gardens (table 4.1). Reasons given by respondents for their views on SWT acceptability often focussed on their visual impact (appendix table 4-B). Typically more respondents felt that SWTs had negative than positive visual impacts, with the exception of those on road signs, while SWTs on buildings showed an almost equal split between those who felt they had positive versus negative visual impacts. Reasons for the high acceptance of SWTs on road signs were based on the perceived economics, efficiency and practicality of the technology. Noise impacts were not raised as frequently as visual impacts, but when they were the reasons given were largely negative and this is particularly true for the more urban settings of SWTs on buildings, in school premises and in gardens. Some respondents reported needing to know more about noise impacts before they could judge how acceptable SWTs would be in that setting. Overall concerns over wildlife impacts were relatively few but 31 respondents (16.0% ± 5.2) reported concerns about negative wildlife impacts of SWTs sited in hedgerows. Negative comments about safety were prominent for SWTs on road signs and school premises but were of little concern elsewhere. The high number of "other" reasons given for SWTs on school premises includes 27 positive and 2 negative comments concerning the potential for education about renewable energy (appendix table 4-B). When respondents' acceptance of SWTs is averaged across all six settings 50.5% (± 7.0) found SWTs acceptable or very acceptable, while 22.2% (± 5.8) found them unacceptable or very unacceptable and the remaining 27.3% (±6.3) were undecided.

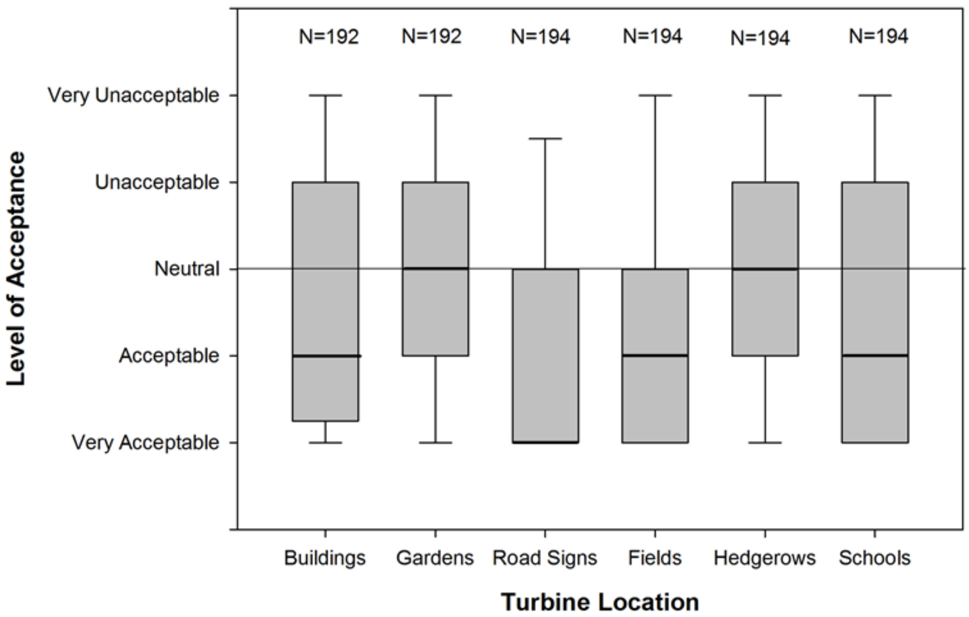


Figure 4.1: The acceptability of SWTs in different settings. The thick line shows the median while the outer edge of boxes shows 25th & 75th percentile. Confidence intervals represent 10th & 90th percentiles.

There were small differences in the acceptability of SWTs between regions with London and the North West having the highest proportion of respondents who found SWTs acceptable whilst the South West had the highest proportion who found SWTs unacceptable (figure 4.2).

However these differences were not statistically significant (χ^2 (44)=54.8, *p*=0.13).

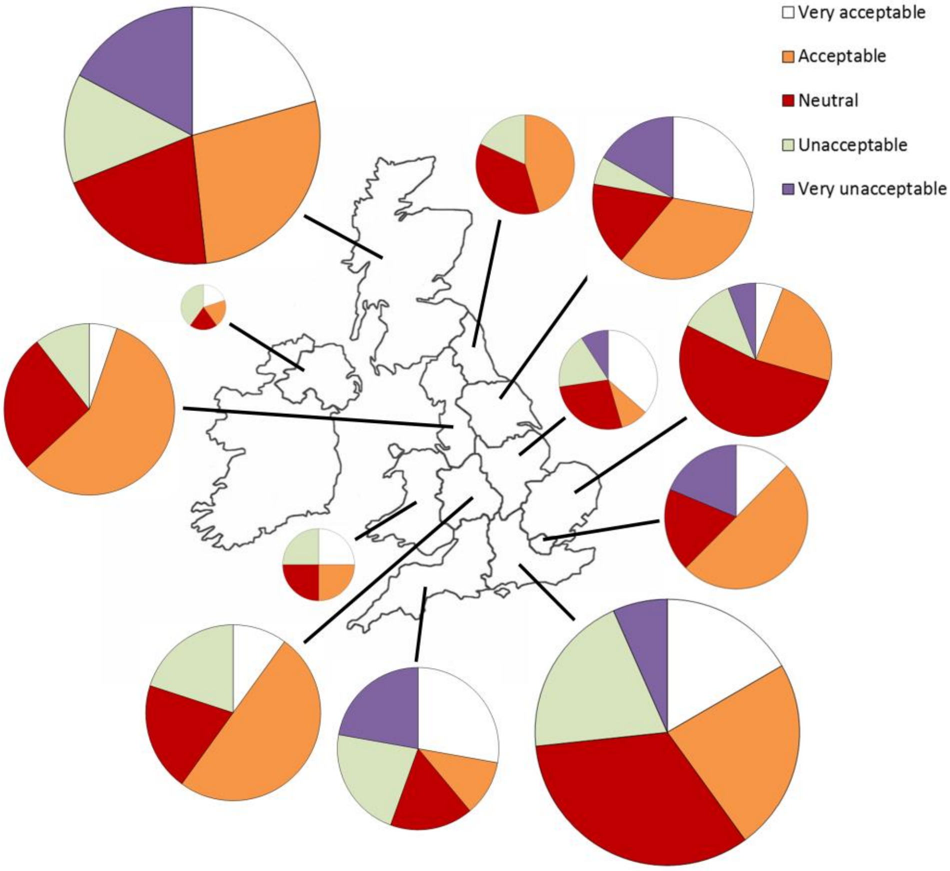


Figure 4.2: The acceptability of SWTs across the UK. Pie charts show the average acceptance of SWTs across six settings split by region. Numbers are percentages of respondents in each category of acceptance. Size of pie charts reflects the number of respondents from each region.

Over half of respondents felt that SWTs made a positive contribution to tackling climate change (57.3% ± 7.0) and that the government should provide financial incentives to encourage people to install them (61.3% ± 6.9, figure 4.3). Almost equal numbers of respondents felt that SWT were (30.2% ± 6.5) and were not (34.4% ± 6.7) visually intrusive. There was also little consensus over noise impacts with 22.9% (± 6.0) agreeing and 30.3% (± 6.6) disagreeing with the statement that SWTs are really noisy and should not be put up near homes. Over a third (35.4% ± 6.8) of respondents were concerned that SWTs might injure or kill wildlife and 30.7% (± 6.5) felt they would disturb wildlife living nearby. Approximately half of respondents were undecided as to whether SWTs have a positive impact on wildlife (50.0% ± 7.1).

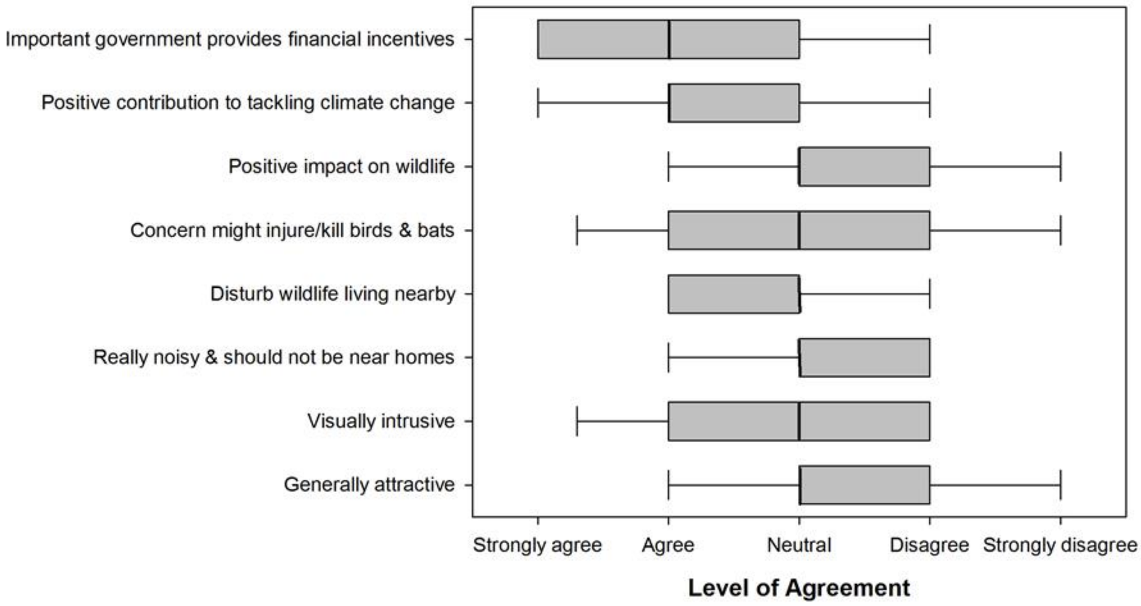


Figure 4.3: Agreement with statements about typical turbine concerns with regard to SWTs. The thick line shows the median while the outer edge of boxes shows 25th & 75th percentile. Confidence intervals represent 10th & 90th percentiles. N=192

Table 4.1: Results of post hoc analysis with Wilcoxon signed-ranks showing pairwise differences in acceptability levels of SWTs in different settings. Pairwise differences remaining signficant after bonferroni corrections were applied are highlighted in bold. Italic typeface indicates top row setting was more accepted than left column setting.

	Gardens			**Road Signs**			**Fields**			**Hedgerows**			**School Premises**		
SWT Setting	N	Z-statistic	P value	N	Z-statistic	P value	N	Z-statistic	P value	N	Z-statistic	P value	N	Z-statistic	P value
Buildings	192	-1.723	0.085	*192*	***-5.924***	***<0.001***	192	-2.968	0.003	192	**-3.055**	**0.002**	192	-1.242	0.214
Gardens				*192*	***-6.494***	***<0.001***	*192*	***-4.423***	***<0.001***	192	-1.777	0.076	*192*	*-2.638*	*0.008*
Road Signs							194	**-3.428**	**0.001**	194	**-7.975**	**<0.001**	194	**-5.433**	**<0.001**
Fields										194	**-6.265**	**<0.001**	194	-1.781	0.75
Hedgerows													*194*	***-3.747***	***<0.001***

4.4.5 Attitudes to climate change

The majority of respondents felt they were at least fairly well informed about the causes (80.8% ± 2.8) and consequences (83.8% ± 2.7) of climate change and the ways we can mitigate this (70.8% ± 3.3). Very few respondents felt they were not at all well informed on these issues (≤1% for all).

Almost 80.8% (± 5.6) of respondents agreed with the statement 'we are in a period of global climate change' and 58.2% (± 6.9) agreed they were worried about climate change while 28.0% (± 6.3) felt that the seriousness of climate change has been exaggerated. Just over half of respondents (51.6% ± 7.1) disagree with the statement that climate change is an unstoppable process and 81.3% (± 2.8) felt that renewable energy makes a useful contribution to reducing carbon emissions. The mean agreement with these statements was calculated for each respondent as a measure of their level of belief in, and concern about, climate change. This measure was positively correlated with how well informed respondents felt about the causes and consequences of climate change (Spearman's rank: $r_s(190)=0.18$, $p=0.008$). The role of this measure in influencing attitudes towards SWTs was then further explored, alongside other potential drivers of attitudes.

4.4.6 Factors influencing attitudes towards SWTs

Belief in and concern about climate change, age and participation in outdoor activities significantly influenced average acceptance of SWTs across all settings (table 4.2). Those respondents with high levels of climate change concern were eight times more likely to find SWTs acceptable compared to those with low levels of concern (figure 4.4). Respondents who were aged 45-54 years were nearly six times more likely to find SWTs acceptable than those aged 65 years or older. Those who participated in outdoor activities were over nine times less likely to find SWT acceptable than those who did not take part in such activities. Membership of environmental organisations and readership of midmarket and other newspapers also had an important influence on average acceptance of SWTs. Readers of both midmarket and other (mostly local) newspapers were less likely to find SWTs acceptable than those who did not read these classes of newspaper (two and three times less likely respectively), while members of environmental organisations were almost three times more likely to find SWTs more acceptable than non-members.

Table 4.2: Coefficients and P-values from the final (PLUM) regression model of SWT acceptance across all settings. Nagelkerke R^2=0.35. A negative coefficient indicates an increase in likelihood of finding SWTs acceptable (acceptance was coded 1=Very Acceptable to 5=Very Unacceptable).

Explanatory Variables	**Level**	**Coefficient**	**SE**	**Wald**	**Sig. (P)**	**Odds Ratio**
Climate change belief & concern	High	-2.083	0.760	7.518	**0.006**	0.12
	Neutral	-0.732	0.742	0.972	0.324	0.48
	Low					
Age	35-44	-1.766	1.163	2.305	0.129	0.17
	45-54	-1.728	0.686	6.342	**0.012**	0.18
	55-64	-0.420	0.476	0.78	0.377	0.66
	65+					
Outdoor Activities	None	-2.224	0.668	11.076	**0.001**	0.11
	One or more					
Environmental Organisations	Member	-1.002	0.524	3.656	0.056	0.37
	Non-member					
Midmarket Newspaper	Not read	-0.815	0.493	2.733	0.098	0.44
	Read					
Other Newspapers	Not read	-0.939	0.482	3.803	0.051	0.39
	Read					

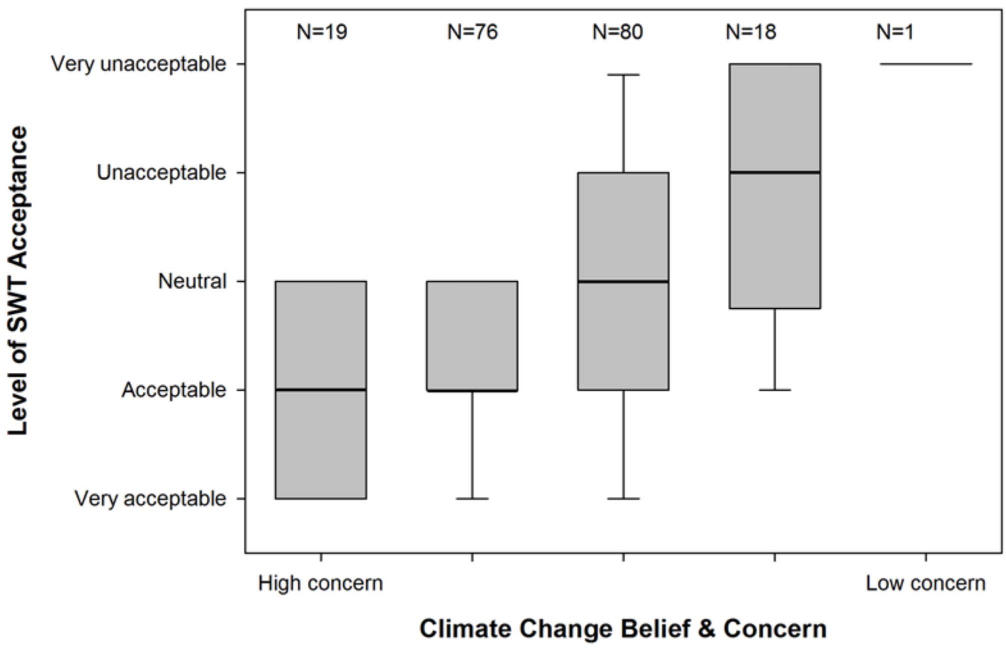


Figure 4.4: The difference in SWT acceptance between respondents with different levels of climate change belief and concern. The thick line shows the median while the outer edge of boxes shows 25th & 75th percentile. Confidence intervals represent 10th & 90th percentile

4.5 Discussion

In this study I assessed public attitudes towards small wind turbines in the UK, and have identified several potential influential drivers that underlie variation in attitudes. Overall, the acceptance levels of small wind turbines amongst the respondents in our survey was relatively high. However, attitudes towards SWTs differ depending on the type of setting the turbine is installed in, with SWTs in hedgerows and gardens being the least well accepted while those on road signs were most accepted. Belief in, and concern about, climate change was related to higher acceptance of SWTs and there is some evidence that membership of environmental organisations also increased acceptance. However, participation in outdoor activities was related to lower acceptance of SWTs and there is some evidence that reading midmarket and local papers is associated with reduced acceptance. Age was also related to SWT acceptance, with those aged 45-54 years being more likely to find SWTs acceptable than older respondents.

4.5.1 Attitudes towards SWTs

With the caveat that our sample is more likely to reflect the views of older generations who are male, the results of this survey suggest a large proportion of the UK public generally finds SWTs acceptable (50.5% ± 7.0) but there is still currently a section of the population that find them to be unacceptable (22.2% ± 5.8), a pattern also seen in attitudes towards large scale onshore wind power in the UK (DECC 2013b).

Despite a general acceptance of SWTs, the majority of respondents would not be in favour of having one in sight of their home (66.5% ± 6.6), although only a quarter would oppose it (25.3% ± 6.1). This could be seen as an example of NIMBYism, and reflects patterns seen in attitudes towards wind farms where proposals for new wind farms may be met with widespread public opposition despite high acceptance of wind power in general. However, looking beyond NIMBYism as an explanation for such patterns, it has been suggested they are examples of a U-shaped development of attitudes (Devine-Wright 2005), whereby attitudes change pre-, during- and post-construction. For example, initially, attitudes are positive to turbines in general but decrease with the announcement of a local development. Possible reasons for this include genuine specific concerns about the proposed development, misunderstandings about the development due to poor communication by the developers or a retaliation against a perceived lack of fairness and equality in the planning decision process (Wolsink 2007). Once the wind farm is built and the local community becomes familiar with its presence, positive attitudes towards wind farms increase once more to their former levels, or possibly even exceed them. This may be due to the wind farms not having the anticipated negative impacts or they may just become an accepted part of the scenery over time. This suggests familiarity is important to the development of attitudes towards wind power. There is some supporting evidence for this with wind farms; for example, survey respondents living within 1.5km of four proposed wind farm sites around Sheffield, UK were significantly less positive towards wind power development than respondents from matched comparison towns further away from the proposed sites (Jones and Eiser 2009), while Scottish surveys of people living in areas with existing wind farms find people living closest to them (within 5km) are most positive about them and most supportive towards the idea of expanding them when compared to those living 10-20 km away (Braunholtz 2003). Yet in this study I did not find any relationship between familiarity with SWTs and attitudes towards them. One possible explanation for this difference is that my measure of familiarity focussed largely on whether respondents were familiar with the concept and appearance of SWTs. Very few respondents reported having a local SWT and, given the lack of a centralised database for SWT installations, it is not possible to estimate their proximity to respondent's homes. Previous research has demonstrated U-shaped development curves for attitudes towards solitary turbines, but not yet for SWTs (Wolsink 2007 & 1988), so this may be a useful area to focus on in the future.

The landscape setting of an SWT had a substantial effect on the acceptability of the turbine, with

SWTs on road signs and in fields being particularly well accepted while those in hedgerows and gardens were the least accepted out of the six typical settings covered in this survey. Farmland and gardens are currently the most common locations for SWT installations (Park *et al*. 2013), with farmland SWTs often being installed close to hedgerows to minimise disruptions to farm operations, so this may be an area of conflict between public attitudes and current practice. The comments offered by respondents to explain their attitudes illustrates that different settings raised different types of concerns. Comments about the visual impact were prominent across all settings and the majority of respondents felt that this impact was negative, with the exception of road signs where many respondents suggested they visually had no greater impact than the road sign itself and to some extent SWTs mounted on buildings which were compared by some respondents to TV aerials. The prominence of comments about visual impact corresponds with suggestions that visual and landscape impacts are of most importance to the public with respect to wind farms (e.g. Wolsink 1988; Wolsink in Ellis *et al.* 2009). The photos of SWTs on road signs used in the survey were also the smallest examples suggesting the size of the SWT may influence its perceived visual impact, although it is hard to disentangle effects of size from setting.

There were relatively few comments on the possible wildlife impacts of SWTs despite 35.4% (± 6.8) of respondents expressing concern that they may injure or kill birds and bats. Small Wind Turbines in hedgerows are the main exception to this and the large number of negative wildlife impact comments raised here (e.g. "Very hazardous for hedgerow animals and birds"), alongside negative visual impact comments, explains the lower acceptance of SWTs in this setting. Negative comments about noise impacts were largely made in relation to SWTs in more urban settings such as on buildings, school premises and in gardens (22.9% ± 6.0 of respondents felt that SWTs should not be put up near homes), although these were less common than comments regarding negative visual impacts. Respondents' comments also revealed that some concerns are very specific to a setting. For example, SWTs on school premises raised a high number of positive comments about their potential contribution to raising awareness and educating children about renewable power and climate change (e.g. "Good learning about alternative options for energy sources"), a comment not made about the other settings surveyed. Across the six settings explored here, very few respondents rated SWTs as all very unacceptable or all very acceptable. This indicates that attitudes towards, and acceptance of, SWTs is complex and that people may be positive towards wind power and SWTs in general and still have a negative attitude towards SWTs in particular settings, reflective of the apparent discrepancy between high positive attitudes towards wind power and much lower support for local wind developments (Bell *et al.* 2005 & 2013).

We found that there was a considerable degree of uncertainty as to what the actual impacts of SWT may be. These types of comment were highest in relation to wildlife and noise impacts indicating that the UK public is particularly unclear on what evidence there is for these potential impacts (e.g. "Would they disturb nesting birds?", "Are they noisy? Cause vibrations?"). This is not surprising given the lack of impartial information available on these impacts of SWTs. For example, there is very little published research attempting to quantify the wildlife impacts of SWTs (Minderman *et al.* 2012; chapters 2 & 3) making it difficult for ecologists and council planning officers to assess the likely impacts of SWTs on wildlife (Park *et al.* 2013). This suggests the need for further research into the impacts of SWTs, particularly those the public are unclear about, such as noise and wildlife, and that findings should be made easily accessible to the public.

4.5.2 Attitudes towards climate change

Overall, most respondents (80.8% ± 5.6) did believe in climate change and over half of the respondents were worried about it. This is consistent with the results of other recent UK nationwide surveys. The British Social Attitudes survey found 92% of respondents believed climate change is occurring (Park *et al.* 2012a) and the UK governmental public attitudes tracker found 66% of respondents were concerned about climate change (DECC 2013b). Despite this high acceptance of climate change, nearly a third of respondents in our study (28.0% ± 6.3) felt the seriousness of the issue had been exaggerated. Again, this is consistent with other UK surveys with the British Social Attitudes survey reporting 37% of respondents thinking the environmental threats from climate change are exaggerated (Park *et al.* 2012b). Respondents who felt relatively well informed about climate change were more likely to be concerned about it, highlighting the importance of education and access to information, although this could also be the result of those with more concern about climate change choosing to seek out further information.

4.5.3 Influences on attitudes towards SWTs

Our measure of belief in, and concern about, climate change was positively related to acceptance of SWTs across landscape settings, again implying that greater education and access to information about climate change may increase the acceptance of SWTs in the UK. However, belief in climate change was shown to already be high both in our sample and in other national surveys (e.g. Park *et al.* 2012a) so there may be limited scope for education to raise belief in climate change to higher levels. Changing attitudes towards environmental issues using education programs is often very difficult and structural solutions such as changes in government policy that incentivise positive environmental behaviours are frequently more effective in changing behaviour (Herberlein 2012).

Further, opposition to wind farm developments is rarely due to ignorance and as such education is unlikely to change the attitudes of such opponents, whose opposition is often linked to values and beliefs (Ellis *et al.* 2009, Bidwell 2013).

Very few of the demographic variables we investigated were strongly associated with attitudes towards SWTs. Respondents aged 45-54 years old were six times more likely to be accepting of SWTs than those aged 65 years or older. Given the majority of our respondents were over 65 years this may indicate our results underestimate the UK public's belief in climate change and acceptance of SWTs. Further research surveys targeted at younger age groups will be needed to investigate this possibility. Newspapers read were classified into broadsheet, mid-market and tabloid in order of level of seriousness of content with broadsheet papers being those that are perceived as more intellectual in content, tabloids being more sensationalist in content, and the mid-market being inbetween with a mixture of intellectual and sensationalist content. Those who read midmarket newspapers are more likely to have lower acceptance of SWTs than those who do not read this class of newspaper, possibly reflecting a bias in the information on climate change and wind power presented in these papers. Alternately, those who choose to read these papers may already have low acceptance of wind power and choose to read them because they share information that fits their beliefs. Readers of other papers, mostly consisting of local papers, were also more likely to be unaccepting of SWTs. These papers may have greater coverage of local wind power related planning applications and objections. Members of environmental organisations were more likely to be accepting of SWTs but those that participate regularly in outdoor activities were more likely to find SWTs unacceptable, perhaps reflecting concerns that turbines may interfere with these activities through issues around safety and access or through visual and noise impacts affecting enjoyment.

4.5.4 Survey methodology

There are a number of strengths and weaknesses to using postal questionnaires as a method of assessing public attitudes. They enable researchers to target a large sample of people efficiently, both in terms of cost and time, when compared to other methods such as telephone and face to face interviewing (De Vaus 2002). However, postal questionnaires can suffer from low response rates, and there is evidence from several countries that response rates to questionnaires may be declining (Tourangeau 2004; Tolonen *et al.* 2006). Low response rates may result in a non-response bias in the sample, where those that have not responded belong to a particular demographic or belief group (De Vaus 2002; Tourangeau 2004). This study, which elicited a 12.0% response rate, used follow up contact, the opportunity to respond quickly online and the opportunity to enter a prize draw, methods that are commonly recommended to help maximise response rates (De Vaus 2002). Still, my sample was biased towards males and older people, and therefore care must be taken when extrapolating the findings of this study to apply to the wider UK population. Nevertheless, I was able to survey participants covering a range of educational backgrounds and levels of climate change concern from all regions of the UK enabling the detection of influential variables on SWT attitude.

4.6 Conclusions and Policy Implications

The majority of my respondents are accepting of SWTs. However, this general finding does not guarantee acceptance of specific SWT developments for two main reasons. Firstly, acceptance of SWTs was far from universal. Just under a quarter of respondents found SWTs unacceptable with a similar proportion directly opposed to having an SWT in sight of their homes, making it likely there will always be some opposition to proposed developments. Secondly, as has been seen for wind farm developments, a general acceptance may not translate readily into acceptance of a specific development proposal (Wolsink 2007). It is likely that local development proposals will cause concerns about impacts specific to that site even amongst those who are generally accepting of SWTs.

An urgent need for clearer planning guidance for SWT installations in the UK has been identified (Park *et al.* 2013). The results of this survey provide some useful insights for policy makers, and for developers who wish to minimise the public opposition to a proposed SWT installation. Firstly, the setting of an SWT has been shown to have a significant impact on acceptance so a focus on installing SWTs in more accepted settings such as in fields and avoiding least accepted settings such as hedgerows may help to limit any opposition. Further research looking at acceptance in other settings such as industrial estates may highlight additional well accepted settings. Planning guidance could encourage avoidance of least accepted settings by requiring buffer distances between hedgerows and similar settings as is currently implemented by some, but not all, local councils in the UK, with similar situations elsewhere in Europe. This would have additional benefits of helping to mitigate the demonstrated disturbance of bats by SWTs near hedgerows (chapters 2 & 3). Permitted Development Rights (PDR) were introduced in Scotland in 2010 (http://www.legislation.gov.uk/ssi/2010/27/pdfs/ssi_20100027_en.pdf) and England in 2011 (http://www.legislation.gov.uk/uksi/2011/2056/made) partly to reduce any barrier effect the planning process may have on the expansion of the micro-generation industry (Park *et al.* 2013). PDR relaxes the need for planning permission for those SWTs that meet certain criteria including size and distance to boundary measures, although current PDRs guidelines are only likely to affect a small proportion of SWTs being installed (Park *et al.* 2013). However, there may be scope for PDR to encourage the installation of SWTs in the most accepted settings, and those least likely to harm wildlife; this could be achieved by modifying the criteria so that planning permission is not required for installations in particular settings, shortening the time and financial costs involved in those installations. Secondly, we have drawn attention to the potential impacts of SWTs that are of most concern to the UK public, namely visual impacts and contrasting perceptions on whether the technology is an efficient and practical method of energy generation. These should be taken into consideration when proposing an SWT installation with steps taken to minimise any negative impacts whilst enhancing potential positive effects; planning guidance should highlight the importance of these factors in particular. Thirdly, the links found between climate knowledge, climate change concern and SWT acceptance, alongside the comments from respondents requesting further information on potential SWT impacts, highlights a role for targeted education and easy access to information in increasing acceptance of SWTs across a range of settings.

4.7 Acknowledgements

I thank all those who responded to the survey. Thanks also to everyone who helped with the practical aspects of posting out the survey.

Appendix 4-A: The Questionnaire

Section 1: Your views on climate change

This section asks about how well informed you feel about, and your views on, climate change.

1. **How well informed do you feel about climate change? Please tick the appropriate boxes for a, b and c below:**

How much do you think you know about the following?:	Very well informed	Fairly well informed	Not very well informed	Not at all well informed
a. The causes of climate change				
b. The consequences of climate change				
c. Ways in which we can fight climate change				

2. **Please give your opinions on the following statements concerning climate change by ticking the appropriate boxes:**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
a. We are in a period of global climate change					
b. Emissions of CO_2 (Carbon dioxide) has only a small impact on climate change					
c. I am worried about climate change					
d. Climate change is an unstoppable process; we cannot do anything about it					
e. Renewable energy makes a useful contribution to reducing carbon emissions					
f. The seriousness of climate change has been exaggerated					

Section 2: Your views on wind turbines

This section asks about your views on wind turbines in general, and then specifically on small wind turbines.

Page 2 of the letter accompanying this questionnaire provides information about small wind turbines and example photographs of a variety of small wind turbines are shown on pages 3 - 5 of this survey

Large Wind Turbines:

3. Are you familiar with what large wind turbines look like?

Yes ☐ Somewhat ☐ No ☐

4. How would you feel towards a large wind turbine installation in sight of your home?

Very opposed ☐ Opposed ☐ Indifferent ☐ In favour ☐ Very in favour ☐

Small Wind Turbines:

5. Are you familiar with what small wind turbines look like?

Yes ☐ Somewhat ☐ No ☐

6. How would you feel towards a small wind turbine installation in sight of your home?

Very opposed ☐ Opposed ☐ Indifferent ☐ In favour ☐ Very in favour ☐

7. Do you own a small wind turbine?

Yes ☐ No ☐

8. Are you aware of any large scale (> 30m in height) or small scale (< 30m height) wind turbines within 1km of your home? Tick all that apply

Large ☐ Small ☐ Neither ☐

9. Would you consider installing a small wind turbine on your property for any of the following reasons (tick as many as apply to you):

Reduce electricity bill ☐

Reduce CO_2 emissions ☐

Other reason ____

I would not consider installing a small wind turbine ☐ Please state why:____

____

Section 3: Your views on types of small wind turbines

Below are sets of photographs showing the types of situations in which small wind turbines may be installed.

10. For each group of photos, please give your opinion on how acceptable you think their use is in this situation (please note you are not being asked to rate each individual photograph).

a) Turbines on buildings:



Very Acceptable ————————————————→ Very Unacceptable

1 □ 2 □ 3 □ 4 □ 5 □

Can you give a reason for your answer?

____

____

b) Turbines in gardens:



Very Acceptable ————————————————→ Very Unacceptable

1 □ 2 □ 3 □ 4 □ 5 □

Can you give a reason for your answer?

____

____

c) Turbines on road signs:

Very Acceptable → Very Unacceptable

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Can you give a reason for your answer?

____

____

d) Turbines in fields:

Very Acceptable → Very Unacceptable

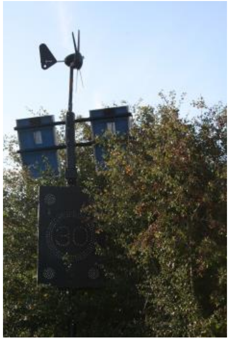
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Can you give a reason for your answer?

____

____

e) Turbines in hedgerows:



Very Acceptable → Very Unacceptable

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Can you give a reason for your answer?

____

____

f) Turbines on school premises:

Very Acceptable → Very Unacceptable

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Can you give a reason for your answer?

____

____

11. Please give your opinions on the following statements concerning small wind turbines by ticking the appropriate boxes:

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
a. I am concerned that small wind turbines might injure or kill birds and bats					
b. It is important the government provides financial incentives to encourage people to install small wind turbines					
c. Small wind turbines are generally attractive					
d. Small wind turbines are really noisy and should not be put up near homes					
e. Small wind turbines have a positive impact on wildlife					
f. Small wind turbines make a positive contribution to tackling climate change					
g. Small wind turbines are visually intrusive					
h. Small wind turbines disturb wildlife living nearby					

Section 4: About you

This section seeks general information about you.

12. What is your postcode? ______________________________

13. Are you….?

Female ☐ Male ☐

14. What age are you?

Under 25 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65+ ☐

15. What is the highest education qualification you have?

No education qualification ☐ GCSEs / Scottish standard grade or equivalent ☐

A-levels / Scottish Highers or equivalent ☐ First degree or higher ☐

Other____

16. Which of the following best describes your employment status:

Full-time paid employment (35 hrs + per week) ☐

Part-time paid employment (less than 35 hrs per week) ☐

Casual employment ☐

Not currently in paid employment ☐

Undertaking voluntary work ☐

Retired ☐

Other: ____

17. Are you a member of any environmental/conservation organisations?

Yes ☐ No ☐

If so, which group(s)? ____

18. Where do you obtain most information about environmental issues such as…?

Radio ☐ Television ☐ Friends/Family/Neighbours ☐

Government bodies ☐ Internet ☐ Environmental Groups ☐

Newspaper ☐ I do not hear about such issues ☐

Other: ____

If you regularly read a newspaper (once or more a week) please specify title(s):

____

19. Which of the following outdoor activities do you regularly undertake? Tick all that apply

Walking	☐	Running	☐	Wildlife Watching	☐	Cycling	☐
Climbing	☐	Shooting	☐	Kayaking/canoeing	☐		

Other____

20. Do you have any other comments you would like to make?

____

____

____

____

Thank you for completing the questionnaire. Please return using the self-addressed envelope enclosed.

If you would you like to be entered into the prize draw please fill in your name and email address (if available[1]) below and tick this box ☐

If you would like to find out the results of this survey please fill in your name and email address (if available[1]) below and tick this box ☐

[1]If you are unable to provide an email address we will contact you by post.

Name: ____

Email: ____

Appendix 4-B: Respondent Comments

Table 4-A: Summary of reasons volunteered to explain why respondents would not install an SWT at their property showing the number of comments related to each topic and whether they were negative or statements that more information on this potential negative impact is needed before they can decide. Respondents were free to give multiple reasons. A total of 78 respondents (40%) would not install an SWT at their property.

Type of Comment	Negative	Need info
Noise	7	1
Visual	22	0
Wildlife	4	0
Economics	24	2
Efficiency	14	1
Location/ Space	16	0
Safety	0	1
Neighbours	10	0

Table 4-B: Summary of reasons offered to explain the given acceptability rating of SWTs in different settings showing the % of respondents that made comments related to each subject and whether they were positive, negative or stating they would need to know more about that possible impact before deciding.

Turbine Location	Type of Comment	Noise	Visual	Wildlife	Economics, Efficiency & Practicality	Safety	Climate Change & Greenhouse Gases
On buildings	Positive	0.5	18.8	0.0	1.6	0.0	6.3
	Negative	6.8	18.2	0.0	1.6	0.5	0.5
	Need more information	4.2	1.0	0.0	0.0	0.0	0.0
In gardens	Positive	1.0	13.0	0.0	2.6	0.0	4.2
	Negative	5.2	21.4	0.5	1.0	0.5	0.0
	Need more information	2.6	1.6	0.5	0.0	0.0	0.0
On road signs	Positive	1.5	16.5	0.0	16.0	1.0	3.6
	Negative	0.0	2.1	0.0	2.6	7.2	0.0
	Need more information	1.0	0.5	0.0	1.5	2.1	0.0
In fields	Positive	0.5	9.3	0.0	2.6	0.0	2.6
	Negative	2.6	17.5	2.6	4.1	0.0	0.5
	Need more information	0.0	1.0	1.5	1.0	0.0	0.5
In hedgerows	Positive	0.5	7.2	0.5	2.1	0.0	2.6
	Negative	1.0	12.4	16.0	4.1	0.5	0.0
	Need more information	0.0	0.5	4.6	0.5	0.5	0.0
On school premises	Positive	0.0	3.6	0.0	9.3	0.5	3.1
	Negative	7.7	7.2	0.0	2.6	8.2	0.0
	Need more information	2.6	0.5	0.0	1.5	3.1	0.0

Chapter 5

Willingness-to -pay to reduce the wildlife impacts of small wind turbines amongst potential owners

5.1 Abstract

The number of Small wind turbines (SWTs; generational capacity of up to 100kW) is rapidly growing with over 870,000 now installed globally, yet planning guidance for their installation is mostly lacking. It is known that turbines can exert negative wildlife impacts, particularly on birds and bats, with mortality from collisions and disturbance effects documented at wind farms and SWTs. Mitigation options for avoiding wildlife impacts from turbines are being developed with some possibilities having been successfully tested on wind farms, including altering the cut-in speeds for when turbines begin to generate electricity and acoustic deterrents, although the relevance of these for SWTs is currently unclear. Other mitigation possibilities for wildlife impacts from SWTs include siting restrictions on where they can be installed, currently the most commonly employed mitigation method, and turning the SWT off during periods of high wildlife activity. Information on potential SWT owners' preferences for wildlife mitigation will be useful for the development of planning guidance for SWT installations. A choice experiment methodology, a commonly used technique in economics to elicit preferences, is used to begin to quantify the wildlife mitigation preferences of potential SWT owners. Potential SWT owners were consistently willing-to-pay to avoid disturbance impacts on birds and bats and to avoid bats being killed by SWTs. However, they were not willing-to-pay to avoid bird collision mortality. Arable farmers valued avoiding having siting restrictions imposed on the SWT, indicating such restrictions can be of considerable inconvenience to some potential SWT owners. Therefore, whilst siting restrictions appear to be a good mitigation option for many potential SWT owners, there is a market for alternative mitigation methods.

5.2 Introduction

5.2.1 Renewable power generation

The production of renewable power is an important component of worldwide efforts to limit the scale and the impacts of global climate change. The production of electricity from renewable sources including solar, hydro and wind power, produces much less carbon dioxide and other environmentally damaging gases than traditional fossil fuel energy sources such as coal and oil (Sims *et al.* 2003). The European Union has set legally binding renewable energy targets for its member states to help achieve carbon dioxide emissions reduction targets; for the UK this target is to produce 15% of energy consumption from renewable sources by 2020

(Council Directive (EC) 2009). The UK Renewable Energy Roadmap (DECC 2011a; 2013a) sets out the government's action plan to achieve this target. It includes both onshore and offshore wind power as key technologies in meeting the target, highlighting the importance of wind power in the UK.

The generation of power from wind is growing rapidly in the UK with the latest figures released by the Department of Energy and Climate Change (DECC) showing that onshore wind generation in 2014 rose by 10% from the previous year and offshore wind generation by 17% (DECC 2015c), growing from less than 400MW to over 11,000MW since 2000 (RenewableUK 2014). Alongside on- and off-shore wind farm developments, micro-renewable technologies have grown rapidly with over 870,000 small wind turbines (SWTs) installed globally (WWEA 2015b). There is currently no globally accepted definition of the term SWT, but the World Wind Energy Association defines them as having a generational capacity of up to 100kW (WWEA 2015b) while in the UK the Energy Act 2004 uses a generational capacity of up to 50kW with rotor areas of up to 200m^2 (DTI 2004). Growth in SWT installations is currently highest in China, the USA and the UK. Designed for use in sites were space is limited, SWTs have been utilised by businesses, communities and individual households to both provide their energy needs and to generate an income from feed-in tariffs (FITS) paid to encourage renewable energy generation. FITs constitute the main policy instrument used to date in the UK to incentivise the expansion of SWTs at the household and small business level. There is wide variation in SWT height and design, including building mounted and free-standing SWTs and horizontal and vertical turbine models and they are used in both on-grid and off-grid situations. In the UK a large proportion of SWTs are installed on farmland (Park *et al*. 2013).

5.2.2 Wildlife impacts of wind turbines

There is strong evidence that large wind turbines can have a negative impact on wildlife in some circumstances, particularly birds and bats. Mortality from collisions with turbines and their associated infrastructure has been documented through the finding of animal carcasses at many wind farm sites, particularly in North America and Europe (Arnett *et al.* 2008; Barrios and Rodriguez 2004; Erickson *et al.* 2014; Smallwood 2007). Mortality rates vary between sites, for example, a review of bat mortality studies at wind farm sites in North America found reported mortality rates ranged from 0.1 to 69.6 bats killed per turbine per year (Arnett *et al.* 2008), and variation also occurs across and within sites both temporally (e.g. Jain 2005) and spatially (e.g. Everaert and Stienen 2007). The precise reasons for this variation are unknown, but siting along migration routes is strongly implicated at sites with the highest mortality rates

(Baerwald and Barclay 2009). As well as mortality risks, disturbance of normal behaviours and displacement of wildlife from areas of important habitat are also a concern with for example, breeding densities (Pearce-Higgins *et al.* 2009), foraging behaviour (Larsen and Madsen 2000) and flight activity (Larsen and Guillemette 2007) having all been demonstrated to have been affected by turbine proximity, although again effects may differ greatly between sites (Garvin *et al.* 2011).

Despite evidence of wildlife impacts occurring at wind farms, there has been limited research into the impact of SWTs on wildlife. There have been anecdotal reports of collision mortality (Bat Conservation Trust 2010) and recent efforts to quantify the mortality rates caused by SWTs in the UK indicated that between 0.079 and 0.278 birds and 0.008 and 0.169 bats may be killed per SWT per year (Minderman *et al.* 2014). There is also some evidence that bat activity can be reduced in close proximity to SWTs (Minderman *et al.* 2012; chapters 2 & 3), an indication that they may also have disturbance effects upon some species.

5.2.3 Planning guidance for SWT installations in the UK and mitigation of potential negative impacts

Whilst Permitted Development legislation (Town and Country Planning (General Permitted Development) (England) Order 2015) in the UK included the installation of SWT, the specifications are such that the majority of installations require planning permission (Park *et al*. 2013). Planning permission is granted by local authorities, with each case evaluated by following planning guidelines provided by government organisations. However, there is currently no single authoritative guidance explicitly for SWTs. Instead, guidance is offered by numerous organisations, sometimes with differing priorities, and largely based on adapting guidance designed for wind farms. The need for guidance specifically covering SWTs is acknowledged in the scientific literature and by Statutory Nature Conservation Organisations for the UK (Park *et al.* 2013, Walsh *et al.* 2012, Warren and Birnie 2009). This lack of guidance has led to variations in how SWT applications are handled, and has resulted in uncertainty in the requirements needed to obtain planning permission to install SWTs. Awareness of both the potential environmental and social impacts and effective methods for mitigating them is needed to inform planning guidance.

At present, few methods of limiting any negative wildlife effects of SWTs have been used, although more have been tested at wind farms. The most commonly recommended mitigation method for SWTs is buffer distances, whereby restrictions are placed on the siting of the turbine so that it is not installed close to important foraging or roosting habitats. For example, current recommendations in Europe produced by EUROBATS are for SWTs to be sited at least 25m away from habitats commonly associated with bats (Rodrigues *et al.* 2015). However, such buffer distances can be inconvenient, increasing the amount of land needed to install an SWT. Other types of mitigation currently used at wind farms include reducing the activity of the turbine at times of high risk, such as during migration, breeding seasons or other times of high activity in the vicinity of the turbines (De Lucas *et al.* 2012) and altering the cut-in speed of the turbines so they do not generate electricity until higher wind speeds have been reached (Arnett *et al.* 2011, Baerwald *et al.* 2009). There has also been some work on developing deterrent devices to keep aerial wildlife away from large scale turbines to prevent collisions. An ultrasound deterrent has been demonstrated to reduce bat mortality at a wind farm in the US (Arnett *et al.* 2013) and electromagnetic radiation pulses have been shown to reduce bat activity (Nicholls and Racey 2009), but no such deterrent devices are available commercially yet. Some of these mitigation methods may in the future be applicable to SWTs but the lack of testing and availability for SWTs makes it difficult to assess whether SWT owners would be interested in and willing to pay for such mitigation methods as a way of reducing the environmental impacts of their actions.

Choice experiments are an economic technique that allow the valuation of non-market goods, which are appropriate for assessing the potential willingness to pay of owners of SWTs to avoid any potential adverse wildlife impacts associated with their investments (Hanley *et al.* 1998; Hanley and Barbier 2009). Based on Lancaster's characteristics theory of value (Lancaster 1966), which states that consumers derive utility, or satisfaction, from the characteristics of a good, and random utility theory (McFadden 1974), they follow the principle that consumers make rational choices to maximise their utility and therefore studying choices can allow estimation of the utility associated with each characteristic of a good and prediction of preferences for non-market goods. This method of modelling choice preferences has been widely used in marketing and more recently environmental valuation, including many applications to the environmental impacts of renewable energy generation (e.g. Bergmann *et al.* 2006). Stated preference methods such as contingent valuation and choice experiments have also been used as a means of guiding environmental policy decisions in the UK (eg. Hanley *et al.* 2007). Choice experiments have an advantage over contingent valuation in this case, enabling the use of more complex choice sets which include multiple choice alternatives, better reflecting the reality of choosing to install an SWT. Therefore this study utilised the choice experiment method to investigate the importance of SWT wildlife impacts to potential owners and to quantify their willingness-to-pay for reducing the probable wildlife impacts of SWTs. Specifically, this paper aims to answer the following questions:

1. Are potential SWT owners willing to pay to reduce the wildlife impacts of their SWT?
2. Does this willingness to pay differ depending on the type of impact reduced (collision mortality v disturbance effects)?
3. Does willingness to pay differ depending on the type of wildlife impacted (birds and bats)?
4. Are potential SWT owners willing to pay to avoid having siting restrictions imposed on their SWT installation?

5.3 Methods

5.3.1 The Multinomial Logit (MNL) model of choice

Choice modelling is based on Lancaster's characteristics theory of value (Lancaster 1966), which states that consumers derive utility, or satisfaction, from the characteristics of a good, combined with random utility theory (McFadden 1974), which states that utility can be decomposed into observable and unobservable components:

$$U_{ni} = V_{ni} + e_{ni},$$

where U_{ni} is the utility for respondent *n* for choice alternative *i*, V_{ni} is the observable component of utility for respondent *n* for choice alternative *i* and e_{ni} is the random unobservable component. If V_{ni} is assumed to be linear then:

$$V_{ni} = \beta' x_{ni}$$

where x_{ni} is the attributes of alternative *i* faced by respondent *n* and β is a set of parameters. Socio-economic characteristics of the respondents can also be included as interactions with the attributes or the choice alternatives. People are assumed to make choices that maximise their utility. Therefore the probability of respondent *n* choosing alternative *i* from a choice set *C* is:

$$P_{ni} = P(U_{ni} > U_{nj}, ; \forall j \in C)$$

In order to estimate the observable parameters of the utility function it is necessary to make some assumptions about the random component of the model. In the MNL model it is assumed the random components are independently and identically distributed with a Type 1 Extreme Value distribution. The probability then of person *n* choosing alternative *i* from the choice set *C* becomes:

$P_{ni} = exp(V_{ni}) / \sum_j exp(V_{nj}); \forall j \in C)$

The estimates of the utility parameters also include a scale parameter which remains unidentified in estimation. This limits direct interpretation of the estimated parameters as they are confounded with the scale parameter. By using ratios of parameters to calculate trade-off rates across attributes, such as in the calculation of WTP estimates, the scale parameter drops out (Bergmann *et al.* 2006).

5.3.2 Designing the choice experiment

Choice experiment design requires careful consideration in the creation of the choice attributes. They need to meet several requirements including being relevant, credible and capable of being understood (Bergmann *et al*. 2006). Since installations of SWTs on farmland represent a substantial proportion of current UK installations, we decided to focus on farmers as the target population. The overall choice scenario selected for this study asked participants to consider a plan to install an SWT on their land and asked them to choose between different possible SWT options. In order to avoid problems associated with forced choices, the option of not installing an SWT was included as the status quo in each choice scenario (Dhar and Simonson 2003).

Choice set attributes were selected to maximise relevance to the research questions. As birds and bats are the groups most commonly affected by SWTs, these were the focus of the two wildlife impact attributes included. The levels of these attributes were defined in terms of both mortality impact from collisions and disturbance effects around the SWT, and were based on previous research to ensure they were realistic for the UK (Minderman *et al.* 2012 & 2014). To reduce task complexity, levels were simplified so the SWT either killed 2 birds or bats or did not kill any; and either caused a 50% reduction in activity or did not disturb activity at all. This led to four attribute levels in total, each combination of mortality and disturbance impact, for both of the wildlife impact attributes (table 5.1). The levels were kept the same for both the bird and the bat impact attribute to allow direct comparisons of WTP to avoid impacts on each group.

Siting restrictions are currently the most commonly used wildlife mitigation for SWTs but are potentially restrictive and could incur the loss of productive land if farmers are required to avoid field edges. Including siting restrictions as an attribute enabled assessment of whether this common method of wildlife mitigation is seen as a problem by potential SWT owners.

The cost attribute chosen was the loss of electricity generated by the turbine due to measures taken to reduce adverse impacts on birds and bats, and we assigned a monetary value in terms of the loss of FIT income generated. Although not all potential methods of wildlife impact mitigation would have a cost of this type, many would (for example, switching off turbine at times of high activity). In addition, as the economics of SWT ownership are quite complicated and site-specific, it was important to find a cost vehicle that was easy for respondents to understand. Costs were included as both a percentage of the typical electricity income inclusive of subsidies generated per quarter and the equivalent loss of income in absolute amounts. The respondent's ability to understand the implications of this cost was supported by a summary of the typical costs of installing a SWT and the kinds of income these bring in provided in the introduction to the survey, to allow respondents to put such costs into context. Four levels of electricity loss were chosen. The highest cost, a loss of 50% of typical electricity generation, was chosen to represent a high cost mitigation method such as being required to turn off the SWT all night to avoid impacts on bats. The remaining levels were distributed equally between this 50% high cost level and having no cost (0%). The credibility and ease of understanding the choice scenarios and attributes as intended was tested at one-to-one meetings with local farmers where they were observed completing the survey and then asked several feedback questions.

Overall including these attributes led to a design with four choice attributes and 14 attribute levels (table 5.1). Each choice card offered three SWT options plus the status quo option of not installing an SWT. A D-efficient design with two blocks and a total of 12 choice cards was used, generated in Ngene (Econometric Software, version 1.1.1) using informed priors from a pilot postal survey with 19 participants. An example choice card is included in figure 5.1. A range of socio-economic and attitude questions relating to participants were also included in the survey to help understand which were influential on the choices made. These focussed on basic socio-economic information, attitudes towards renewable energy generation and climate change and interest in wildlife.

Table 5.1: Attribute variables and levels included in the choice experiment

Attribute	Description	Levels			
Impact on Bats	The negative impact of the SWT on bats, defined in terms of collision mortality and disturbance of normal activity.	Does not kill bats Does not disturb bats	Does not kill bats 50% reduction in activity	Kills 2 bats per year Does not disturb bats	Kills 2 bats per year 50% reduction in activity
Impact on Birds	The negative impact of the SWT on birds, defined in terms of collision mortality and disturbance of normal activity.	Does not kill birds Does not disturb birds	Does not kill birds 50% reduction in activity	Kills 2 birds per year Does not disturb birds	Kills 2 birds per year 50% reduction in activity
Siting Restrictions	Restrictions on the location where the SWT can be installed.	None-can be sited anywhere	Must be 50m from trees, hedges & buildings		
Loss of electricity generation per quarter	The loss of the electricity generated by the SWT due to the mitigation of wildlife impacts, defined in terms of loss of income from the turbine as an amount and a % of typical quarterly income.	£6.50 -1%	£112 -17%	£218.50 -34%	£325 -50%

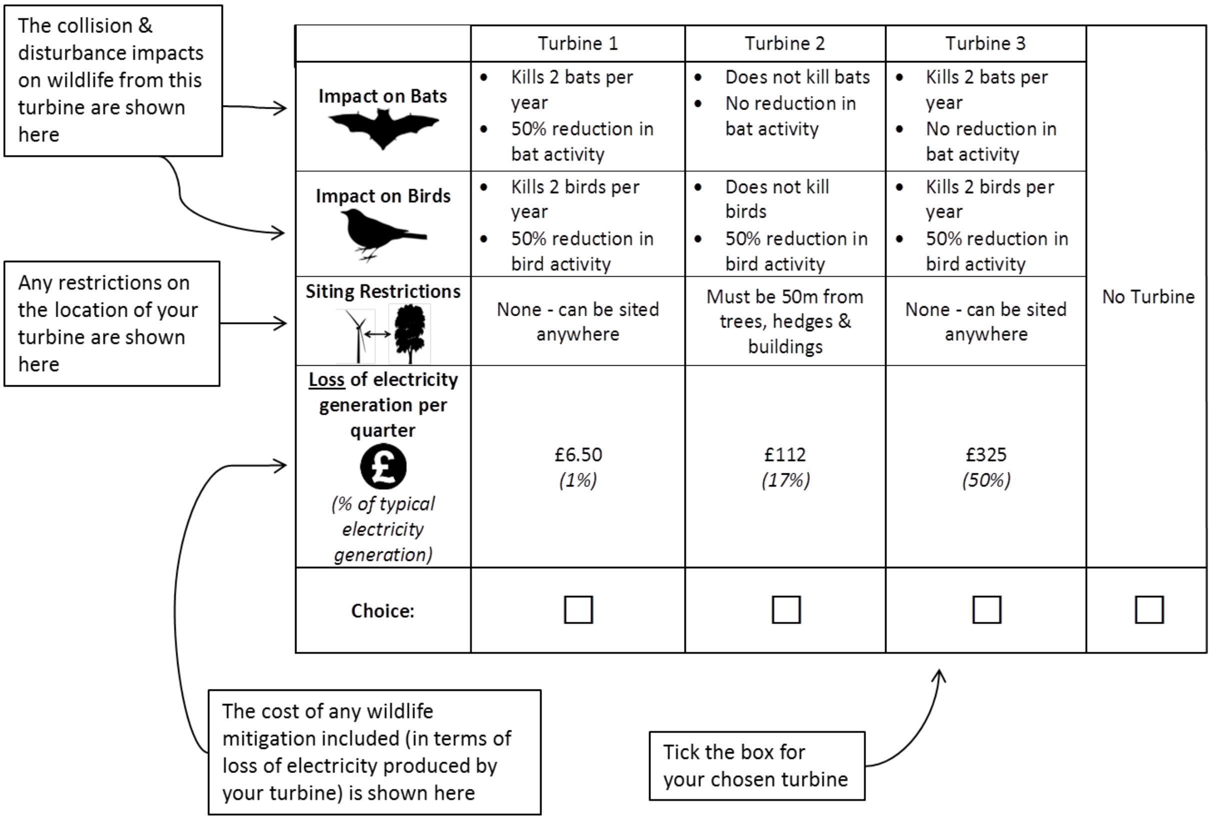


Figure 5.1: Example choice card included in survey introduction

5.3.3 Sample selection and survey delivery

The choice experiment was conducted as a postal survey sent out to 2000 farmers in winter 2014. Two thousand postcodes were randomly selected from a postcode list for the UK (downloaded from www.doogal.co.uk). Farms nearby each postcode were searched for in Google maps (maps.google.co.uk) using the 'explore nearby' function. The nearest farm to the centre of the postcode was selected for inclusion in the sample.

The survey consisted of a letter explaining the purpose of the survey and the choice experiment, consisting of instructions and 6 choice cards, followed by the socio-economic and attitude questions. There were two versions of the survey containing different choice cards; 12 choice cards were used in total. To encourage responses, each survey was accompanied by a pre-paid return envelope, included a link to an alternative online version of the survey and each respondent was given the opportunity to enter a raffle to win £100. Further to this, a reminder postcard was sent to any farmer that had not responded after 3 weeks, again including the link to the online version.

5.3.4 Statistical analysis

Multinomial logit models (MNL, also known as the conditional logit model) were used in the statistical analysis of this choice experiment using Nlogit (Econometric Software, Inc. version 4.0) to model choice preferences (see section 5.3.1). The initial simple MNL model contained only the choice attributes and a constant for the status quo option of not having an SWT. The wildlife impact attributes were dummy coded into presence or absence of mortality or disturbance separately. The explanatory factors included in the simple MNL model were therefore the disturbance of bats by the SWT, the killing of bats by the SWT, the disturbance of birds by the SWT, the killing of birds by the SWT and the requirement of siting restrictions on the SWT installation with loss of electricity included as a covariate. Expanded models also included the following socio-economic variables as interactions with the status quo option: age, gender, land size, level of climate change belief and concern, level of renewable energy support, feeding the birds at home, seeing bats around the home and membership of an environmental organisation. Level of climate change belief and concern and level of renewable energy support were scores calculated by summing their agreement with two statements on each topic (adjusted for negatively worded questions). Land size is included as a socio-economic variable only in the second expanded model as few respondents provided this information reducing the sample size to 93 respondents, therefore the same expanded model without the inclusion of land size is also presented (expanded model 1). An interaction between siting restrictions on the SWT installation and the land owned being used for arable farming was also included in the expanded models, as it was expected that siting restrictions would be particularly inconvenient for this type of land use.

After model estimation, WTP estimates and 95% confidence intervals were then calculated in Nlogit for all significant attributes using the Wald method. WTP is calculated as the ratio of the coefficient of the non-market attribute over the coefficient of the monetary attribute, in this case the cost of the loss of electricity generated per quarter.

5.4 Results

5.4.1 Response rates and sample descriptives

Of the 2000 surveys mailed out 92 were unable to be delivered. Of the remaining 1908 surveys, 179 were returned at least partially completed, a response rate of 9.4%. Of these, 64 questionnaires were removed from the analysis due non completion of any choice cards (23) or consistently choosing the status quo option to not install a turbine in all choice cards presented (41) which results from being unable or unwilling to engage with the presented choice situation. This could be due to being opposed to wind power in general or SWTs specifically, due to inability to own an SWT resulting from a lack of space or finances, or due to an objection to choice experiment methodology. A main sample for analysis of 115 responses remained (making a combined total of 689 choices). Thirteen responses were made using the online version of the survey. More than half (53.6%) of the responses were received after sending reminder postcards.

The respondents were predominantly male (69.6%), white (75.7%) and aged 45 years or more (78.3%, table 5.2). This is similar to available demographic data on the UK farming population. For example, 87% of farm holders were 45 years or older in England in 2013 (Defra 2014) and 27.2% of people in England and Wales employed in agriculture, forestry and fishing in the 2011 census were female (Office for National Statistics September 2012).

Table 5.2: Demographic data for the sample population of UK farmers and landowners.

		Number	Proportion
Gender	Female	35	0.30
	Male	80	0.70
Age	18-34	10	0.09
	35-44	15	0.13
	45-54	26	0.23
	55-64	29	0.25
	65-74	28	0.24
	75+	7	0.06
Ethnicity	White	110	0.96
	Asian	4	0.03
	Black	0	0.00
	Chinese	1	0.01
	Other	0	0.00
Qualification	None	10	0.09
	GCSEs	22	0.19
	A-Levels	6	0.05
	Degree	27	0.23
	Professional	40	0.35
	Other	10	0.09

5.4.2 Model results

Choice analysis MNL model results are presented for the simple model, which contains only the choice attributes, and two expanded models, which include several socio-economic variables expected to be relevant to the choices made (table 5.3). All MNL models showed a significant (1% level) negative coefficient for the cost attribute, loss of electricity generated each quarter, implying that other things being equal, farmers always preferred the option with the lowest cost. All wildlife impact attributes had negative coefficient signs. These negative coefficients were significant in all three models for disturbing bats, killing bats and disturbing birds, demonstrating a preference for avoiding these wildlife impacts. Although killing birds also had a negative coefficient in all models, this was not significant, suggesting that whether the SWT killed birds did not influence choices. The presence of siting restrictions imposed on SWT installation had a positive coefficient in all models but again this was not significant in any model. The expanded models also included an interaction between siting restrictions and arable farming. This interaction had a negative coefficient in both models. Although this negative coefficient was only significant in expanded model two, it provides some evidence that arable farmers may prefer to not have siting restrictions placed on SWT installation.

Significant WTP, calculated for choice attributes with significant coefficients, was found for avoiding the disturbance of bats, the killing of bats and the disturbance of birds from all three models (table 5.3). For example, using the first expanded model, respondents were found to be WTP on average £105.52 and £79.88 per quarter to avoid disturbing bat activity around the SWT and killing bats respectively; and WTP £143.54 per quarter to avoid disturbing birds. WTP amounts were similar in the simple and second expanded MNL models. Over all three models, WTP to avoid wildlife impacts of SWT installations was on average highest for avoiding disturbance of bird activity and lowest for avoiding killing birds, but there is large overlap in the confidence intervals of these WTP estimates. In addition, using the coefficients from the second expanded model only, significant WTP of on average £89.23 per quarter was found to avoid siting restrictions by arable farmers.

There were significant negative coefficients for the status quo option in all three models, indicating a preference for choosing a SWT option over not having one (table 5.3). Several of the socio-economic variables included in the utility equation for the status quo option also had significant coefficients. Being a member of an environmental organisation, seeing bats around your home, concern about climate change and being female had significant positive coefficients in at least one of the expanded models, increasing the probability of choosing the status quo option to not install an SWT; whilst supporting renewable energy and land size had significant negative coefficients on the choice of the status quo in at least one of the expanded models, indicating an increased preference for owning an SWT. Feeding the birds at home and respondent's age were not found to have a significant influence on choice preference for the status quo option.

McFadden pseudo-R^2, utilised as a measure of model goodness-of-fit, is 0.21 for the simple model and increases to 0.41 with the addition of the socio-economic variables. A McFadden statistic of between 0.20-0.30 is comparable to an ordinary least squares R^2 of between 0.70-0.90 (Louviere *et al.* 2000), indicating that model fit for our data is high for all the models.

Table 5.3: Model summaries for the simple and expanded MNL models explaining choice preferences for SWTs. Expanded model 2 contains the land size variable in addition to the other socio-economic variables included in expanded model 1. WTP values were calculated for all choice attributes with significant coefficients, using the ratio of the coefficient of the non-market attribute over the coefficient of the monetary attribute (loss of electricity generation). *P value ≤0.05 **P value ≤0.01 ***P value ≤0.001

	Simple Model				**Expanded Model 1**				**Expanded Model 2**			
Variable	Coefficient	S.E.	WTP (£ per quarter)	95% Confidence Interval	Coefficient	S.E.	WTP (£ per quarter)	95% Confidence Interval	Coefficient	S.E.	WTP (£ per quarter)	95% Confidence Interval
Disturb bats	-0.671 ***	0.180	96.71***	(42.19, 151.22)	-0.750 ***	0.192	105.52***	(48.28, 162.76)	-0.860 ***	0.228	109.04***	(50.08, 168.01)
Kill bats	-0.558 **	0.179	80.43***	(42.23, 118.63)	-0.568 **	0.187	79.88***	(40.78, 118.97)	-0.562 **	0.210	71.21***	(30.92, 111.50)
Disturb birds	-1.011 ***	0.173	145.79***	(94.75, 196.84)	-1.021 ***	0.185	143.54***	(90.99, 196.09)	-1.290 ***	0.223	163.50***	(109.15, 217.85)
Kill birds	-0.280	0.157			-0.277	0.165			-0.146	0.182		
Siting Restrictions	0.378	0.206			0.430	0.221			0.418	0.255		
Loss of electricity generation	-0.007 ***	0.001			-0.007 ***	0.001			-0.008 ***	0.001		
Arable farming * Siting Restrictions					-0.461	0.267			-0.704 *	0.282	89.23*	(15.54, 162.91)
No turbine (Status Quo constant)	-2.172 ***	0.402			-3.499 ***	0.913			-2.884 **	1.009		
Environmental organisation member					0.757 **	0.234			0.761 **	0.247		
See bats around home					0.500 **	0.163			0.349 *	0.176		
Feed the birds					-0.155	0.165			-0.033	0.176		
Renewable energy support					-0.213 **	0.076			-0.226 **	0.078		
Climate change belief and concern					0.190 *	0.079			0.137	0.081		
Age					-0.081	0.086			-0.169	0.100		
Female					0.362	0.234			0.664 **	0.251		
Land size									-0.001 *	0.001		
N	115 (689 choices)				108 (646 choices)				93 (555 choices)			
LogLikelihood	-743.6370				-666.9564				-561.5193			
Pseudo-R2	0.214				0.295				0.407			

5.5 Discussion

This study has demonstrated that potential SWT owners are willing to forgo significant revenues from electricity generation to avoid wildlife impacts to birds and bats from their turbine, highlighting the economic potential for mitigation of the wildlife impacts of SWTs. Farmers are significantly willing to pay to avoid disturbing or killing bats and disturbing birds. The only wildlife impact included in this study that farmers were not found to be willing to pay to reduce was killing birds. The WTP to avoid killing bats but not birds could be attributable to the legal protection status of bats in the UK (and across Europe) which makes the killing and disturbance of bats illegal, punishable by fines or imprisonment, whereas many of the bird species likely to suffer from collisions with SWTs do not have the same level of legal protection (e.g. Council Directive 92/43/EEC. 1992). This may influence potential SWT owners to be WTP to avoid even low levels of bat mortality from their SWT, whilst being less concerned about low levels of bird mortality, particularly as some common bird species are controlled on farmland in the UK. There is a clear preference amongst potential SWT owners to avoid or reduce disturbance impacts on wildlife, regardless of whether this effects birds or bats.

The majority of respondents showed a preference for owning an SWT, with only 29.5% of respondents removed from analysis for consistently choosing the status quo option of not installing a SWT (protest votes), and the analysis of the remaining responses showing a significant negative constant for choosing the status quo in all models. This is consistent with previous research showing the UK population is generally positive and accepting of SWTs (chapter 4) and the observation that currently a significant proportion of the increasing numbers of SWTs installed in the UK are found on farmland (Park *et al.* 2013). Several socio-economic and attitude variables were found to influence whether the respondents chose a SWT option or the status quo option of not installing an SWT. Of particular relevance to wildlife impacts is that respondents who reported regularly seeing bats around their home were more likely to choose to not to have an SWT. This could be evidence of a familiarity effect, with those who are familiar with bats being more concerned about the potential negative impacts of SWT on bats. However, feeding the birds at home, which presumably also makes respondents more familiar with local bird species, did not have a significant influence on status quo choice. The effect of seeing bats could also be linked again to the legal protection of bats which is likely of greater concern when bats are known to be present. Those who were members of environmental organisations were also more likely to choose not to have an SWT. This contradicts previous research into public attitudes towards SWTs in the

UK that showed members of environmental organisations were more accepting of SWTs (chapter 4), perhaps highlighting differences in attitudes between farmers and the general public in the UK. As might be expected, respondents who were strongly supportive of renewable energy were less likely to choose not to have an SWT. However, respondents expressing higher levels of concern about anthropogenic climate change were more likely to choose not to have an SWT, perhaps suggesting that SWTs are not viewed by farmers as useful in reducing climate change or that climate change mitigation is not a strong motivational factor when deciding to own an SWT. Interestingly, this again contradicts previous research which found that amongst the UK public those with the highest levels of concern regarding climate change were eight times more accepting of SWTs than those with low concern (chapter 4). Preference for choosing an SWT option over the status quo was also increased by the amount of land owned. Those with more land may be more likely to have suitable space for installing an SWT and may also have more financial ability to pay the considerable installation costs.

The average WTP to avoid wildlife impacts of SWTs amongst our respondents of farmers, a major group of SWT installers in the UK, demonstrates the economic potential for wildlife mitigation options for SWTs, since it shows that farmers would be willing to forgo significant revenues from electricity generation if this meant avoiding undesirable impacts on birds and bats. This choice experiment only directly explored WTP for one type of wildlife mitigation currently used with turbines, namely siting restrictions. Respondents did not show any preference for avoiding for siting restrictions being imposed suggesting that, contrary to our expectations, siting restrictions may not be viewed as generally inconvenient by farmers. As siting restrictions are a well-known mitigation method for avoiding wildlife impacts perhaps this is a result of respondents linking siting restrictions and reduction in wildlife impacts. Alternatively, previous work has highlighted a preference for SWTs to not be installed in sight of homes (chapter 4), so the preference for siting restrictions may be driven by an underlying preference to avoid having the SWT near their own home or their neighbours to limit any noise and visual impacts. However, those respondents whose land was used for arable farming were found to be WTP to avoid having siting restrictions imposed on their SWT in one model suggesting that such restrictions may be inconvenient to some potential owners, likely due to having to install the SWT within the middle of fields rather than along their boundaries in terms of losing land that could be used for crops.

Varied alternative mitigation options have been used or tested on wind farms including stopping the turbine from spinning during times when the impact is most likely to occur such as at night, to help reduce impacts on nocturnal wildlife like bats or during migration or breeding seasons and deterrent devices, such as acoustic deterrents. Some of these mitigation methods may also be applicable to SWTs and although this study has not directly investigated preferences between mitigation methods, the WTP values presented here for the avoidance of wildlife impacts are of relevance to estimating likely uptake of such mitigation methods given their likely cost, particularly those methods whose cost will occur in terms of loss of electricity generation such as reducing turbine activity. Further work will be needed to explore preferences on specific mitigation options in terms of the type of mitigation, the type of costs it involves and what wildlife impacts it actually mitigates.

It is important that mitigation works to reduce known impacts of SWTs on wildlife. Recent research suggests that although mortality rates at SWTs are estimated to be fairly low (Minderman *et al.* 2014), disturbance can be a problem, particularly disturbance of bats at important foraging and commuting habitats such as hedgerows (chapters 2 & 3, Minderman *et al.* 2012). Therefore, deterrent devices may not be necessary mitigation for SWTs and instead mitigation should focus on reducing any disturbance. Siting restrictions are an appropriate method of reducing such impacts by ensuring SWTs are not installed close to such habitats. Where siting restrictions are inconvenient, such as possibly on arable farms, disturbance might instead be suitably mitigated through stopping the turbine during periods of high bat activity. However, the effectiveness of such mitigation at SWTs is yet to be tested.

5.6 Conclusion

This study has shown that potential SWT owners in the UK are willing to pay in terms of reduced revenues from electricity generation to mitigate the undesirable wildlife impacts that may arise from installing SWTs. Farmers and landowners were WTP to avoid disturbing birds and bats and to avoid killing bats. However, they were not WTP to avoid killing birds. Siting restrictions, currently a commonly-used wildlife impact mitigation method, are acceptable to the majority of potential SWT owners and are an appropriate mitigation method for the disturbance impacts of SWTs on bats in particular that recent research has highlighted as a problem. As such their use should continue to be recommended in guidance. However, arable farmers were WTP to avoid having siting restrictions imposed on their SWT installation, suggesting there is a market for alternative methods of wildlife mitigation in such cases.

Further research is needed both to elucidate specific preferences for these alternatives and to test the effectiveness of alternative mitigation methods at SWTs.

5.7 Acknowledgements

I would like to thank all of the respondents to this choice experiment, including the pilot surveys, for their time and willingness to share their opinions on this topic. Thanks also go to everyone who contributed to the practical elements of posting the survey.

Chapter 6

General Discussion

6.1 General discussion

Official planning guidance for SWTs is lacking in the UK and elsewhere (Park *et al.* 2013). Instead planning requirements and decisions are largely left to local authorities who may utilise the guidelines regarding wind farms produced by government statutory bodies, guidelines created by other bodies, such as that produced by EUROBATs or implement their own guidelines, leading to variation in the handling of SWT planning applications by different local authorities and uncertainty. This has implications for the conservation of wildlife affected by these turbines, which may not be adequately protected under the current planning situation, and uncertainty over the planning permission requirements for SWTs may also be a barrier to installations (figure 1.1) A major reason for the lack of official planning guidance for SWTs is the lack of research into, and therefore understanding of, factors that are integral to creating rational guidance, although there is also a current lack of political will (DECC 2015a). This includes understanding of the wildlife impacts of SWTs and how they might be mitigated and also understanding public attitudes towards SWTs and their wildlife and other impacts. The purpose of this study was therefore to quantify the effects of SWTs on bats, quantify public attitudes towards SWTs and explore attitudes towards possible mitigation of wildlife impacts in order to inform SWT planning guidance and wildlife impact mitigation.

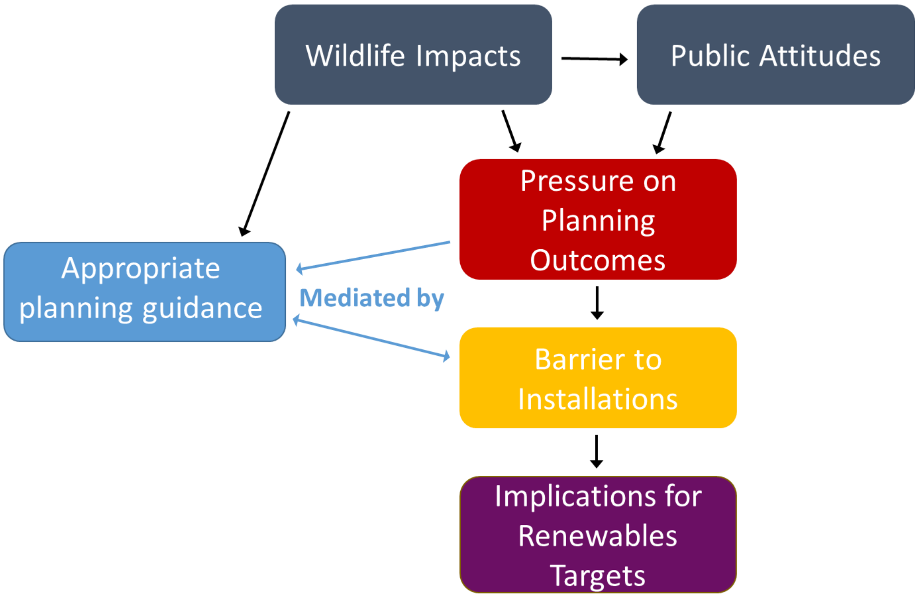


Figure 1.1: Summary diagram of the importance of wildlife impacts and public attitudes towards SWTs showing their potential impact on SWT installations and the role of planning guidance in mediating such impacts (from chapter 1).

6.2 Disturbance of bats by SWTs

This study has demonstrated that bats are disturbed by SWTs, particularly at linear features. This contrasts with another study which failed to find evidence of disturbance by SWTs (Minderman *et al. in review*), although this study focussed on disturbance at larger scales than considered here and disturbance in close proximity to SWTs (within 25m) has been previously documented (Minderman *et al.* 2012). In this thesis , two separate studies show that bat activity can be suppressed by SWTs: an experimental before and after installation study of SWTs installed near linear features (chapter 2) and a field study of activity along linear features near pre-installed SWTs (chapter 3). *Pipistrellus pipistrellus* and *P. pygmaeus* activity at the SWT site declined after experimental SWT installation 5m away from linear features. *P. pygmaeus* activity was also lower at linear features with SWTs installed nearby, as was *Myotis* activity.

6.2.1 SWTs are not wind farms

The disturbance of bats by SWTs contrasts with the premise that high collision mortality rates at wind farms are due to bats being attracted (Cryan and Barclay 2009). Bats have been observed using thermal cameras to directly approach large turbines, hovering close by and following the spinning blades, attempting to land and foraging amongst the blades suggesting they are attracted to turbines due to accumulation of insects or as possible roosting sites (Cryan *et al.* 2014; Horn *et al.*

2008). No evidence of attraction of bats to SWTs was found in this or previous studies (Chapter 2 & 3, Minderman *et al.* 2012), with the only significant effects on any species or guild analysed being disturbance and reductions in activity. This provides support for our assertion that there are differences in wildlife responses to wind farms and SWTs that makes it inappropriate to make decisions about SWT installations by extrapolating from the available planning guidance for wind farms (chapter 1), although a recent study has reported evidence of disturbance of bats also occurring at wind farms for the first time, with recorded bat activity being lower near large wind turbines than at similar control sites (Millon *et al.* 2015). Further, SWTs, due to their small size, do not directly change the surrounding habitat in the same way as wind farms, which often cover large areas and may require the removal of trees, possibly creating new tree lines and edge habitats. Such changes alter the utility of the area for foraging, providing a possible mechanism for attraction of bats to wind farms which is not present for SWTs.

6.2.2 Disturbance of bats is caused by both SWT presence and operation

Disturbance at SWTs may have different underlying causes. It may be the presence of the turbine in the environment that causes the disturbance, possibly as a novel object in the environment or a barrier to normal movement, or there could be more specific causes such as the spinning of the blades or noise emitted by the SWT during its operation. This study finds evidence of both disturbance due to SWT presence and due to SWT operation occurring. As SWT operation is dependent on wind speed, with most SWTs needing a wind speed of at least $3ms^{-1}$ to begin generating electricity, and speed of blade turning increases with increasing wind speed, then disturbance caused by SWT operation is expected to increase with wind speed, and potentially to cease when there is no wind and the SWT is not operating. The decline in *P. pygmaeus* activity at the experimentally installed SWTs only occurred at higher wind speeds (chapter 2). Similarly, the decline in use of linear features by *Myotis* bat species also occurred at higher wind speeds (chapter 3), indicating disturbance caused by SWT operation. Whereas a disturbance effect caused by SWT presence would not be expected to show any interaction with wind speed and to remain the same regardless of whether the SWT is generating electricity or not. Both the negative effect of SWT experimental installation on *P. pipistrellus* activity (chapter 2) and the decline in linear feature use by *P. pygmaeus* in close proximity to SWTs (chapter 3) was not influenced by wind speed suggesting this effect occurs regardless of SWT operation and is therefore caused by SWT presence.

6.2.3 Disturbance effects are species specific

Research is frequently conducted at taxonomic levels above species level, often due to practical issues around accurate species identification and obtaining adequate sample sizes for individual species, particularly those that are less common. For example, the only previous research investigating the wildlife impacts of SWTs successfully identified disturbance of bats in close proximity to SWTs but was not able to quantify individual species specific responses (Minderman *et al.* 2012). This project has identified species-specific responses to SWTs for the first time. Firstly, two cryptic species, *P. pipistrellus* and *P. pygmaeus*, showed different responses to experimental SWT installation near hedgerows, with the former showing a disturbance response to SWT presence and the latter to SWT operation (chapter 2). Secondly, use of linear features in proximity to SWTs also differed between species, with *P. pipistrellus* and big bats not showing any response to SWT proximity while *P. pygmaeus* and *Myotis* showed declines in linear feature use (chapter 3). This highlights a need for species level study in order to fully understand the impacts of SWTs on bats. In this case it is likely that differing responses are at least partly the result of different levels of reliance on linear features (Kelm *et al.* 2014; Verboom and Huitema 1997). Species-specific effects of wind farms on bats according to their ecology also occur, with evidence that long-distance migratory bats (Arnett *et al.* 2008; Cryan and Barclay 2009), tree roosting species (Arnett *et al.* 2008; Cryan and Barclay 2009) and open-air foragers (Rydell *et al.* 2010a) are more susceptible to collision mortality.

However, this study also could not conduct species level analyses for all recorded species. For example, due to inability to distinguish species from their echolocation calls and low sample sizes, some analyses took place at the genus level or in guilds based on morphology. Further, this study was unable to quantify disturbance effects on rarer UK bat species such as the horseshoe bats (*Rhinolophus* sp.) and the Barbastelle (*Barbastella barbastellus*) due to lack of adequate sample size for analyses. The impact of SWTs on these rarer species is arguably of most importance as these species already face many pressures which have led to their current rarity, and may be more likely to suffer population level impacts from further anthropogenic disturbance. It is possible these species will also show their own specific responses to SWTs and for those particularly reliant on linear features or particularly sensitive to anthropogenic disturbance the negative impacts may be larger than those identified in this research. For example, *Rhinolophus hipposideros* is already known to be sensitive to anthropogenic disturbance at linear features, such as from artificial lighting (Stone *et al.* 2009). Despite this, the research presented here is an important first step towards understanding that SWTs do have species specific impacts on bats and should encourage further work to gain understanding of the responses of other species. In the meantime, the precautionary principle allows the suggestion that rarer bat species may also be disturbed by SWTs and this should be considered in planning guidance.

6.2.4 Disturbance of bats at linear habitat features

Disturbance effects on bat use of linear features differed to disturbance of bat activity at the experimental SWT installation sites. Specifically, there is a contrast in the response of *P. pygmaeus* at the site of the SWT and at linear features in close proximity to SWTs, with evidence of disturbance caused by SWT proximity at the latter (chapter 3) and by SWT operation at the former (chapter 2). Likewise, disturbance of *P. pipistrellus* occurred at the SWT site following installation (chapter 2), but no evidence of disturbance of this species was found along linear features near to SWTs (chapter 3). Although this study cannot directly explain these differences, the context of the two studies was dissimilar. The experimental SWTs were particularly small, with hub heights of only 6m and correspondingly narrow blade diameters, while the SWTs in the field study had hub heights between 10-20m and much wider blade diameters and therefore may be perceived and responded to differently by the bats, something not yet directly tested. Similarly, the experimental SWTs were novel in the environment having been installed specifically for the study, while the SWTs in the field study were installed prior, and separately to the research with the majority having been in place for several years. It is possible that changes in responses to SWTs may occur over time. One possibility is that habituation to SWTs may occur in some species, and there is some evidence of habituation to wind farms from studies of foraging geese (Madsen and Boertmann 2008), emphasising a need for long term before and after installation studies to test whether response to SWTs changes over time. Finally, normal use by bats of linear features and the open areas nearby them where the experimental SWTs were installed may differ and this would likely lead to differing responses. For example, although many bat species are known to use both linear features and the open areas alongside them to forage, linear features are also used for commuting and navigating between other habitat areas and for protection from inclement weather and predators (Downs and Racey 2006, Verboom and Huitema 1997) and this increased utility of linear features over open space was evidenced in the observed rapid decline in bat activity away from hedgerows (chapter 2).

Disturbance at linear features appeared to persist for a considerable distance along the feature, with no evidence that disturbance decreased along the study distance of 60m (chapter 3). This is a greater disturbance distance than earlier research would predict, with the experimental study finding some disturbance of bat activity did not persist at the control site 30m away, although the effect on one species was still present at the control site (chapter 2). Similarly, previous research reports a suppression of bat activity only in close proximity to the SWT (within 25m), with no disturbance evident at larger landscape scales (Minderman *et al.* 2012 & *in review*). A disturbance distance of 60m or more is comparable to the lower range of avoidance distances found for birds around wind farms. For example, some bird species at UK upland wind farms avoided the turbines from distances between 100-800m (Pearce-Higgins *et al.* 2009) and pink-footed geese (*Anser brachyrhynchus*) showed initial avoidance distances around small wind farms of 100-200m which reduced over 10 years to 40-100m (Madsen and Boertmann 2008). This larger disturbance distance than found in previous SWT studies is likely related to the importance of linear features for commuting. A disturbance at any point on a commuting route may make that route no longer suitable, particularly for species which are averse to crossing open space and therefore less able to go around the cause of the disturbance and rejoin the linear feature further on, possibly resulting in lower utility for a considerable length of the linear feature. If so, the cumulative impacts of such disturbance could be important in areas where suitable foraging and roosting habitats is limited and fragmented, and linear features suitable for commuting between habitat fragments are already rare. For example, in areas where many hedgerows have been removed due to agricultural intensification or where other anthropogenic developments are also causing disturbance (Stone *et al.* 2009; Tuomainen and Candolin 2011), SWTs sited near linear features may further reduce connectivity between habitat patches. It is feasible that this could have fitness effects on individuals by increasing stress, flight times and energetic requirements to reach foraging areas, correspondingly reducing available foraging time and energetic input and increasing predation risk (Stone *et al.* 2009). Such effects may be particularly pronounced in reproductive females during pregnancy and lactation due to higher energetic requirements and potential constraints on travel distances. In this way, disturbance caused by SWTs at linear features could lead to negative population level impacts which is of concern for conservation. However, evidence of population impacts caused by wind power is still lacking, and is a key priority for future research for both large and small turbines, although the high mortality rates recorded at some wind farm sites make the occurrence of such impacts likely (e.g. Arnett 2005).

6.3 General attitudes towards SWTs and their wildlife impacts

The postal survey of the general public's attitudes towards SWTs in the UK, the first survey of its kind, revealed that, similar to positive attitudes towards wind farms and wind power generation in general (Warren and Birnie 2009; DECC 2013b), acceptance of SWTs was high (chapter 4). Likewise, the farmers surveyed in the choice experiment as potential future SWT owners, also showed positive attitudes towards SWTs, with less than 30% consistently choosing to not install an SWT across all choices and the remaining respondents being more likely to choose a SWT option than the included status quo option to not install an SWT (chapter 5). Despite this, the majority of the general public were still not in favour of having an SWT in sight of their home (chapter 4), similarly to the social gap between positive attitudes towards wind power but lower acceptance of local wind developments (Bell *et al*. 2005 & 2013). Such an attitude gap could be seen as evidence of NIMBYism, the concept that people are generally accepting of something as long as it does not directly impact them. However, NIMBYism in relation to wind power is likely an oversimplification of a complex issue (Wolsink 2007). For example, the survey revealed a range of concerns the public hold about SWTs including visual impacts, noise impacts and wildlife impacts and concerns over lack of knowledge of what these impacts may be (chapter 4).

The significant role of setting in the acceptability of SWTs is a key finding, with SWTs installed on road signs being most accepted and those in hedgerows and gardens least accepted (chapter 4). Although there is much evidence that the landscape siting of wind farms is important for public acceptance of them (Wolsink 2007), this is the first clear demonstration that the same is true for SWTs. It also has clear implications for increasing public acceptance of local SWT installations by ensuring they are sited away from these least accepted settings. Whilst wildlife impacts of SWTs did not seem to be a primary concern for most respondents when evaluating the acceptableness of SWTs in different settings, they were an important concern for SWTs in hedgerows, indicating that public concern about wildlife impacts is responsive to context. This suggests support for SWTs may fit what Bell *et al.* (2013) term qualified support in that acceptance of SWTs depends on the specific proposal meeting certain terms such as not harming wildlife. When asked directly, a third of respondents were concerned that SWTs would injure or disturb wildlife (35.4% & 30.7% respectively), similar to the level of concern expressed regarding visual and noise impacts. This indication that wildlife impacts matter to the public is supported by farmers, a group most likely to install SWTs in the UK, being willing-to-pay through loss of income from an SWT to avoid negatively impacting on wildlife, specifically to avoid disturbance of birds and bats or collision mortality of bats (chapter 5).

Overall, these results suggest that public attitudes towards SWTs are unlikely to be a considerable barrier to their installation, although local support for installations is not guaranteed and some opposition, particularly to proposed installations in less accepted settings such as gardens, should be expected. Further, there is currently debate over the nature of the perceived ‘planning problem’ in relation to wind power (e.g. Ellis *et al.* 2009) and whether the role of public attitudes and opposition in preventing wind farm installations and restricting the implementation of wind power generation has been overstated. It is suggested that public opposition to wind farm proposals tends to delay rather than prevent their planning approval (Aitken 2008; Rydin *et al.* 2015) and there are more significant restrictions on wind power developments such as infrastructure and hardware supply issues (Ellis *et al.* 2009).

6.4 Implications and recommendations for SWT wildlife mitigation and planning guidance

The results presented here confirm that SWTs disturb bats, and in particular effect their use of linear features, habitat of known importance for connecting other habitat fragments as well as providing foraging opportunities and protection from inclement weather and predators (chapters 2 & 3). The disturbance effect at linear features persists further along the feature than expected from previous research and could result in complete displacement from using those features. This in turn has implications for the connectivity of foraging and roosting habitats in the wider landscape. As such there is a need to mitigate such disturbance. Although the effectiveness of wildlife mitigation methods have not been explicitly tested in SWTs, the most commonly recommended method is the imposition of siting restrictions on the turbine's installation that require a buffer distance between the SWT and important habitat. Our evidence suggests buffer distances should be an effective method of mitigation of the disturbance impact of SWTs on bats. Firstly, bat activity declined rapidly with distance from linear features, with only very low bat activity being recorded at 20m and 40m away from hedgerows in open farmland (chapter 2). If fewer bats are using the open fields away from the hedgerows then moving SWTs further out into the fields should mean that fewer bats are affected. Secondly, the disturbance of bat use of linear features was related to SWT proximity to the feature, with bat activity declining with greater SWT proximity (chapter 3). Therefore reducing the proximity of SWTs to this important bat habitat feature should reduce the size of the disturbance effect.

Further to the ecological evidence to support the recommendation of buffer distances to mitigate the disturbance effect of SWTs on bats, there is also evidence that the public would support their use. The UK public were least accepting of SWTs installed in hedgerows and in gardens (chapter 4). Regardless of the underlying reasons for this significant reduction in acceptance compared to other settings, buffer distances that prevent SWTs being installed in or close to hedgerows are likely to be supported by the public and potentially increase their general acceptance of SWTs. The choice experiment of potential SWT owners revealed that they value reducing potential wildlife impacts of SWTs and would be WTP to avoid disturbing birds and bats when installing a SWT (chapter 5). Additionally, having siting restrictions in the form of buffer distances imposed on their future SWT did not significantly influence their choices, indicating they are tolerant of such restrictions. In combination these results suggest that future SWT owners would not be put off installing an SWT by having to ensure buffer distances between the SWT and important habitats are met, even if this lead to a loss of income from the SWT as long as this was effective mitigation of some wildlife impacts.

Overall, therefore this study can recommend that planning guidance for SWTs should include a buffer distance between the SWT site and linear habitat features, including hedgerows and treelines, and possibly also other important bat habitats such as woodland, water bodies and known roost sites until the effect of SWT proximity to these habitats has been specifically quantified. Previous unofficial recommendations for buffer distances include that suggested by EUROBATS at 25m (Rodrigues *et al.* 2015). This study suggests such a distance may not be large enough to protect all bat species from disturbance. The disturbance of *P. pipistrellus* after experimental SWT installation could be observed 30m away from the SWT site (chapter 2). The decline in bats' use of linear features when in close proximity to SWTs was still present 60m along the linear feature indicating that the disturbance effects of SWTs can persist at least over this distance (chapter 3). Therefore this study supports the recommendation that SWT installations require buffer distances of a minimum of 60m away from linear features, particularly in landscapes with few alternative commuting routes or where particularly rare bat species are present.

In many situations such a large buffer distance may not be practical and may be a barrier to installations, discouraging SWT ownership. One such example raised in this study is when the land owned is used for arable farming. It is expected that requirement to install SWTs in the middle of fields away from linear features such as hedgerows and treelines will be inconvenient as it causes the loss of productive farmed land rather than field margins and increases the difficulty of using heavy machinery around the SWT in arable farm operations. This was supported by an increased likelihood of arable farmers choosing to not install an SWT when siting restrictions in the form of 25m buffer distances were imposed in the choice experiment (chapter 5). Therefore consideration of whether there are alternative options for mitigating the disturbance effects on SWTs on bats is necessary. Other wildlife mitigation options that have been tested at wind farms include acoustic deterrent devices (Arnett *et al.* 2013), increasing wind cut-in speeds (Arnett *et al.* 2011; Baerwald *et al.* 2009) and turning turbines off at times of peak wildlife activity (de Lucas *et al.* 2012). The first two options, deterrent devices and wind cut-in speeds, provide reductions in bat mortality at wind farms and are therefore not suitable for reducing the disturbance effect of SWTs. Turning the SWT off at key times may be a suitable alternative to buffer distances. Bats are nocturnal, so by turning the SWT off at night disturbance caused to bats by turbine operation should be prevented, although this will need to be tested. Such a mitigation method will also be costly, potentially reducing electricity generation by around 50%. However, whilst some bat species are disturbed by SWT operation, others are disturbed in their use of linear features by SWT presence, and this cannot be avoided by turning the SWT off. Consequently, the appropriateness of this method is dependent on the bat species found locally and their species specific responses to SWTs. In addition, SWT installations near to hedgerows or other linear features are likely to face greater opposition from the public given their lower acceptance of SWTs in such settings (chapter 4). Offsetting, by providing additional or improved habitat elsewhere to compensate for any effects of a SWT, may also be suitable in some cases, although the mitigation hierarchy calls for offsetting to be a last resort where impacts on wildlife are unavoidable (Peste *et al.* 2015) and assessing the effectiveness of such techniques is difficult.

6.4.1 List of recommendations for planning guidance

1. Buffer distances between SWTs and linear features to limit disturbance of wildlife and improve public acceptance are recommended. This research finds disturbance at linear features can persist for at least 60m and therefore suggests this as the minimum buffer distance.
2. Buffer distances between SWTs and other important bat habitats are also recommended. However, as this study and previous research suggest disturbance distances are increased at linear features in comparison to other habitats, a smaller minimum buffer distance for these habitats may be more appropriate.
3. Consider utilising Permitted Development Rights to encourage installations in more publically accepted settings such as those away from linear features and gardens.
4. Require SWTs to be registered on a central database to enable studies of cumulative impacts on wildlife and public attitudes, an area it is currently very difficult to research.

6.4.2 List of recommendations for future SWT research

1. Test whether SWT installations have an impact on wildlife using before and after installation surveys, focussing in particular on habitats of known importance to bats including linear features, roost sites, woodland and water bodies.
2. Quantify impacts on individual species, particularly focussing on rarer species such as *Rhinolophus sp., Barbastella barbastellus* and *Plecotus austriacus*, to check whether recommended buffer distances protect these species from disturbance. This will require longer term, intensive studies concentrated in areas where these species are known to be found to enable sample sizes large enough for analysis.
3. Habituation of bats to SWTs may alter planning recommendations. Long term studies of bat activity near SWTs is required to identify whether any habituation occurs, or whether disturbance increases over time.

4. Test the effectiveness of alternative mitigation methods, such as turning the turbine off at times of peak activity, on SWTs.
5. Quantify public acceptance of SWTs in a wider range of settings, to enable encouraging SWT installations at sites the public finds appropriate.
6. Use revealed preference methods to confirm SWT owners’ WTP to pay for wildlife mitigation.

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