Assessing the use of Photorealistic and Computer Simulated Landscapes to Understand the Cumulative Landscape and Visual Impacts of Onshore Wind Turbines

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Abstract

There has been considerable research into issues around the social acceptance and visual impact of wind farms. However, relatively little is known about the factors that contribute to the cumulative landscape and visual impacts (CLVI) of wind turbines. With the continued growth of onshore wind power in the UK, understanding the CLVI of wind power developments is increasingly important. The majority of research which has studied the landscape and visual impact of wind turbines has used static photomontages. Some researchers have suggested that computer simulations should be used for research, as well as interactive design and planning. However, little if any research has been done which objectively assesses the validity of using these simulations. This thesis set out to address these methodological and theoretical gaps in the literature.

Chapters 3 and 4 present two studies that were carried out to assess physiological responses to videos of wind turbines in a real-world and computer-simulated landscape (created using Sketchup and Google Earth). The findings showed that participants' visual patterns were similar for the photorealistic and computer-simulated landscape, however the skin conductance response (SCR) data showed that affective responses were quite different. Given the different in affective response, these studies called into question the validity of using computer simulations to represent wind turbines in the landscape.

Chapter 5 presents a study which attempted to examine whether the differences found in studies 1 and 2 were of any practical significance. As such, it sought to examine if there were any differences in preferences based on whether people were present with a photomontage or a computer simulation. The study also sought to better understand the factors that contribute to the CLVI of wind farm extensions. Results suggest that people's preferences are not affected by whether they are presented with photomontages or computer simulations. The results also suggest that size, number, visual match, and turbine distribution are important factors in contributing to the visual impact of wind farm extensions.

Collectively, the three studies illustrate novel methods for research into the CLVI of wind turbines. The studies also provide support for the use of computer simulations in research and interactive design and planning, as well as giving some insights into the factors that affect the CLVI of wind farm extensions.

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Publications & Presentations

Publications

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List of Abbreviations/Acronyms

CLVI	Cumulative landscape and Visual Impacts
SCR	Skin Conductance Response
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
GHG	Greenhouse Gas Emissions
UK	The United Kingdom of Great Britain and Northern Ireland
EU	The European Union
PV	Photovoltaic
DECC	The Department of Energy and Climate Change
MW	Megawatts
GW	Gigawatts
UKWED	UK Wind Energy Database
NIMBY	Not In My Back Yard
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EC	European Commission
SNH	Scottish Natural Heritage
kW	Kilowatts
LVIA	Landscape and Visual Impact Assessment
2D	Two Dimensional
3D	Three Dimensional
KML	Keyhole Markup Language
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
ANS	Autonomic Nervous System
PNS	Peripheral Nervous System
SNS	Sympathetic Nervous System
HR	Heart Rate
EDA	Electrodermal Activity
MS	Milliseconds
ZTV	Zone of Theoretical Visibility
GIS	Geographical Information System
CRT	Cathode Ray Tube
TTL	Transistor-transistor logic
NEP	The Revised New Ecological Paradigm
PANAS	The Positive and Negative Affect Schedule
SES	Socio-economic Status
PA	Positive Affect
NA	Negative Affect
VR	Virtual Reality
AR	Augmented Reality
WEIRD	Western Educated Industrialised Rich

1 Literature Review

1.1 Climate Change

Though initially climate change was solely the domain of the scientific community, during the late 1980s and early 1990s it became a policy issue. The increased attention from world governments resulted in the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 (with its initial assessment of global warming in 1990) and the united nations framework convention on climate change (UNFCCC) been signed by 154 nations at the Earth Summit in Rio de Janeiro in 1992 (Bodansky, 2001). The UNFCCC came into force in 1994 and three years later the Kyoto Protocol was adopted (UNFCCC, 1998). The Kyoto protocol extended the UNFCCC and set binding emission reduction targets for 37 industrialised countries, as well as the European Union (EU). More recently, the Doha Amendment extended the agreement until 2020, though this has been ratified by far fewer countries (UNFCCC, 2012). The reports from the fourth and fifth IPCC assessments suggest that continued GHG emissions at current rates would result in even greater changes to the global climate system over the next century. These changes have the potential for global impacts on various aspects of human life (IPCC, 2007a, 2014b). Changing practices across sectors, such as energy supply, transport, buildings and industry are seen as key in reducing GHG globally (IPCC, 2007b, 2014a).

With overwhelming evidence of climate change and the predicted negative effects on the planet, the UK and the EU have committed to long-term reductions in GHG emissions. In 2008, the UK passed the climate change act, which legally binds the country to reduce GHG by at least 26% by 2020 and 80% by 2050, when compared with 1990 levels (UK Government, 2008). In its ‘Energy 2020’ communication, the EU also set ambitious reductions in GHG emissions, committing to a reduction on 1990 levels of 20% to 30% by 2020 and 80 to 95% by 2050 (European Commission, 2010). With energy-related emissions accounting for the majority of total GHG emissions in the EU and UK, decarbonising this sector is seen as particularly important (Jones, Orr, & Eiser, 2011). As such, the UK has set out legislation to increase renewable energy’s share of electricity generation.

1.2 UK Renewable Energy Strategy

In 2002, the Renewables Obligation Order came into force with the aim of increasing the installation of renewable energy capacity in the UK (UK Government, 2002), and it is the main mechanism through which the government drives development of large-scale renewable energy in the UK. The aim of the order was to ensure that energy suppliers progressively increased the share of their energy that was produced from renewable sources. The order obligated energy suppliers in the UK to generate 10% of their energy from renewable sources by 2010, which increased to 20% by 2020. The following year, the government published a white paper entitled 'Our energy future – creating a low carbon economy', which set a target of reducing carbon dioxide emission by 60% by the year 2050 (DTI, 2003). The paper highlighted the huge potential for wind energy development in the UK, suggesting that there was great scope for the development of these resources. The 2007 white paper on energy, 'Meeting the Energy Challenge', further outlined the importance of the renewable energy strategy, particularly in the context of growing energy demand (UK Government, 2007). It discussed the progress that had been made in renewable energy development (including wind energy) in the previous years and the forecast for growth over the following years. However, the paper also discussed some of the key challenges associated with renewable energy development in the UK, including the limited supply of suitable land, caps on the level of generation that qualified for the renewable obligation scheme, as well as the difficulty and delays in the planning process. These issues are particularly relevant in the case of onshore wind farm development.

In 2009, The UK Low Carbon Transition Plan was published, comprehensively outlining the UK government's strategy for climate and energy (UK Government, 2009). The report showed that although renewable energy generation had tripled since the introduction of the Renewable Obligation Order, the UK still generated 75% of its electricity from coal and gas in 2008. The plan estimated that renewables would account for around 30% of electricity generation by 2020, which would require the installation of approximately 20GW of new renewable generating capacity. In the plan, the government outlined a "…step-change in investment in the development of the offshore wind industry in the UK." (p. 124), in a push to further develop large-scale offshore wind projects. The plan also discussed the importance of the Planning Act 2008, which changed the planning system for infrastructure projects of national significance, in driving the development of low carbon energy development. This included onshore wind farms over 50MW and offshore wind farms over 100MW. This was a response to the government's concern over the length of time it took to get planning approval for projects that were deemed to be nationally significant. However, this change was short-lived with the decision-making powers returned to local planning authorities in 2016. This was to ensure that local people had the final say on any wind farm development applications (Smith, 2016).

The 2011 UK Renewable Energy Roadmap outlined the key renewable energy technologies that will be used to meet the 2020 targets. These are; solar PV, wave, tidal, onshore and offshore wind, hydro, and bioenergy. The report highlights in particular that the UK has the best wind and tidal resources in Europe. However, the issue of the planning system in the development of onshore wind projects was also discussed, with acceptance rates varying considerably within the UK. From 2007 to 2013, the consents rate in Wales and Scotland were approximately 60%, 80% in Northern Ireland, while only 54% in England (Department of Energy & Climate Change, 2011).

1.2.1 European Union's Renewable Energy Strategy

The UK's renewable energy strategy has been shaped in large part as a response to directives from the European Union (EU). In 2001, the EU Renewables Directive came into force, with the purpose of increasing the contribution of renewable energy to the internal market. It set a national target that 12% of energy production, and 22.1% of electricity production should come from renewable energy sources (European Parliament, 2001). In 2009, the original directive was replace with a new directive that set a target of 20% of the EU's total energy to come from renewable sources (European Parliament, 2009). It was part of the EU's '20/20/20' package, which also targets by 2020 a 20% reduction in greenhouse gas emissions below 1990 levels, and a 20% reduction in energy use through efficiency improvements (Langsdorf, 2011). Two years later, the EU's strategy paper "Energy Roadmap 2050" committed to reducing greenhouse gas emissions to 80-95% below 1990 levels (European Commission, 2012). The paper also suggest that "By 2050 wind power provides more electricity than any other technology in the high renewables scenario" (p. 11), which highlights the importance of wind energy in achieving the sustainability goals. Further, a recent EU report has shown that, when considering factors such as air quality and climate change, onshore wind is the cheapest source of energy (Alberici et al., 2014), providing a compelling case for maximising its contribution to the energy mix.

1.3 Wind Energy Options

1.3.1 Vertical vs Horizontal Axis Wind Turbines

Vertical axis wind turbines (VAWTs) tend to be used where the quality of the wind is more variable, as they can work effectively when the wind is unstable, making them particularly useful for urban environments (Aslam Bhutta et al., 2012). They can also work effectively no matter what direction the wind is coming from, and are inexpensive and quiet (Brusca, Lanzafame, & Messina, 2014).

Horizontal axis wind turbines (HAWTs) are the dominant type for large scale wind developments (Jin, Zhao, Gao, & Ju, 2014). The HAWTs are the most common wind turbine that are found in the landscape, and are usually quite large, with three turbine blades. The reason for the greater uptake of HAWTs for commercial development is that they can achieve higher efficiencies when there is a strong, high quality wind resource (Pope, Dincer, & Naterer, 2010). They also tend to be significantly larger and therefore have far greater landscape and visual impacts than VAWTs.

1.3.2 Onshore vs Offshore Wind Turbines

Most of the commercial scale windfarm developments to date have been built on land (Kaldellis & Kapsali, 2013). Offshore wind developments comprised only 2.4% of the installed global capacity by 2014, with the highest installed offshore wind energy capacity in the UK (Kaldellis, Apostolou, Kapsali, & Kondili, 2016). In recent years, there has been a trend towards greater offshore wind development in Europe, and in the UK. This is because of the enormous offshore wind energy resource as well as the falling cost of development (Rodrigues et al., 2015).

However, onshore wind energy development is the currently the cheapest form of renewable energy in the UK, and is predicted to remain so up until 2030 (Bassi, Bowen, & Fankhauser, 2012). Also, as of the end of 2015, installed onshore wind capacity in the UK was approximately double that of offshore wind capacity (RenewableUK, 2015). Further, given the average capacity of offshore turbines is larger than onshore, there are several times more onshore wind turbines than offshore. This means that onshore wind developments are likely to have a greater visual impact on the landscape than offshore turbines (Rodrigues et al., 2015), especially as offshore wind development moves from nearshore to deep water (Kaldellis et al., 2016). As such, large scale onshore HAWTs are of most concern when it comes to the landscape and visual impacts of wind energy development.

1.3.3 UK Onshore Wind Energy

The UK's commercial wind energy generation began with a 6 MW wind farm being constructed at Carland Cross, Cornwall, in 1992. This wind farm consisted of fifteen 400 KW turbines with a tip height of 49 metres (Eltham, Harrison, & Allen, 2008). Development of onshore wind farms in the UK was quite slow up until around 2000. However, by 2005 the onshore wind capacity had trebled in just five years, passing the 1GW threshold for the first time and was approximately 8GW at the beginning of 2015 (see fig. 1.1). As wind power developed, turbine size and power capacity have increased dramatically, with turbine blades increasing by a factor of 8 within 20 years of the first commercial wind farm development, with the largest onshore turbines in operation in 2012 having a power capacity of 6.5MW (Leung & Yang, 2012). . As part of its renewable energy strategy, the UK government has targeted the installation of 28GW of wind power by 2020. The targeted capacity is split evenly between onshore and offshore developments, with 14 GW of each planned (Department of Energy & Climate Change, 2012)

Wind energy is anticipated to make the greatest single contribution to the UK's 2020 targets, providing approximately two thirds of the total renewable energy production (Department of Energy & Climate Change, 2011). In order to meet the targets outlined by the Department of Energy and Climate Change, there will need to be significant further development of onshore wind farms. McKay (2015) notes that "Despite the fact that the UK has the highest potential in the European Union to generate renewable energy from win, it lags behind its European partners" (p. 166). One of the obstacles to achieving this aim is the high rejection rate of wind power developments, which has increased dramatically in recent years, with more than half of applications being refused 2013-14 (Sturge, While, & Howell, 2014) (see figure 1.2).

There are many potential reasons as to why there may be local opposition to a wind farm development, e.g. visual impact, environmental concerns, place identity, or procedural justice (Gartman et al., 2014; Pasqualetti, 2011; Wüstenhagen, Wolsink, & Bürer, 2007). Given the high rejection rate of wind power development applications in the UK, understanding the factors that lead to the opposition of wind turbines, and therefore contribute towards acceptance or rejection of windfarm developments, is an increasingly important issue in the context of the UK's climate and energy strategy.

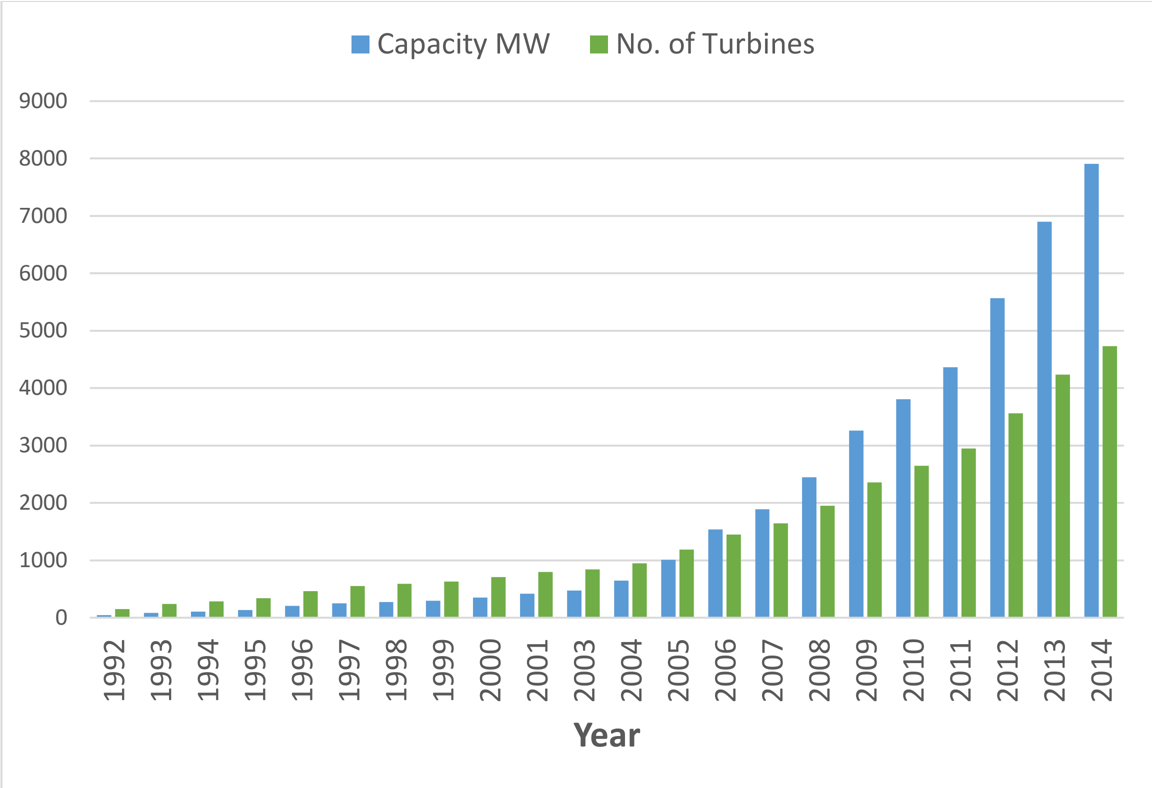


Figure 1.1 Number and Capacity of Onshore Wind Turbines in the UK: 1992-2014 (Source: UKWED)

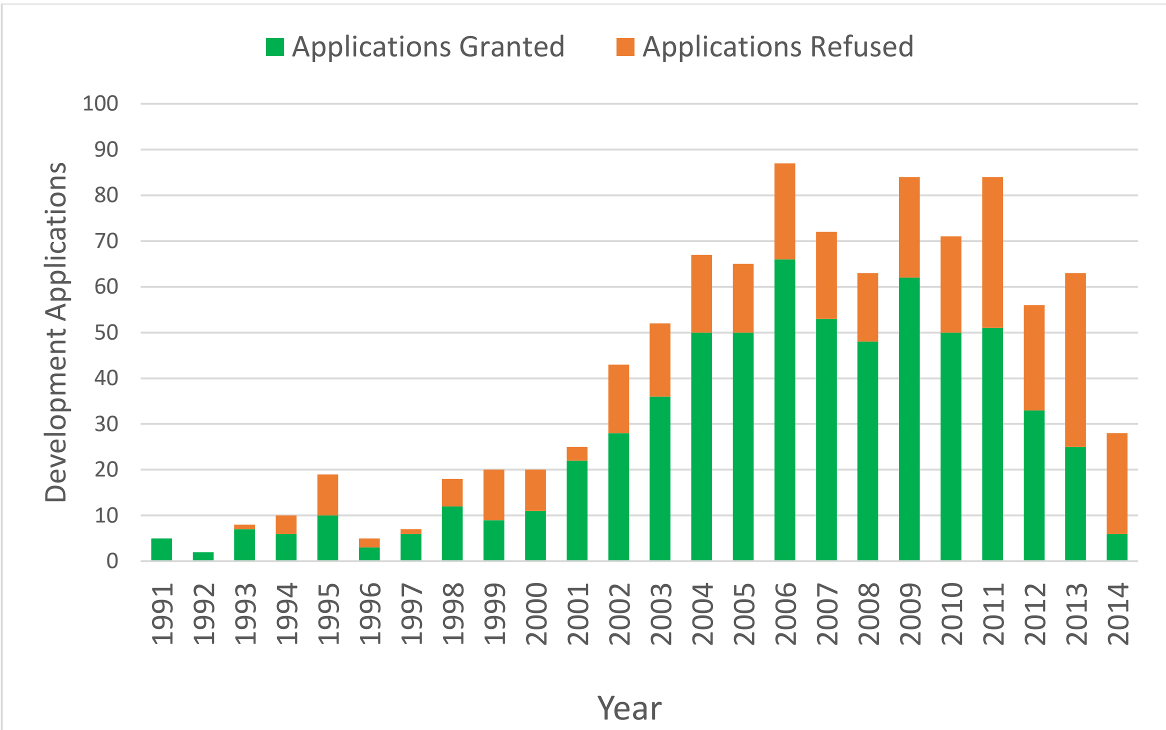


Figure 1.2: Onshore Wind Applications in the UK - Granted and Refused: 1991-2014 (Source: DECC)

1.4 Social Acceptance of Wind Energy

The issue of social acceptance, or lack thereof, is increasingly becoming a barrier to reaching wind energy development targets (Damborg & Krohn, 1998; Wüstenhagen et al., 2007). While, there is generally strong public support for wind power, there also tends to be strong local opposition to proposed developments (Eltham et al., 2008; Wolsink, 2000, 2007b). One of the explanations for this difference is the Not in My Back Yard (NIMBY) response. NIMBY is defined as an intense, often irrational opposition to local development or potential development (Kraft & Clary, 1991). Freudenburg and Paster (1992) propose that three main perspectives on NIMBY; irrational/ignorant, selfish, and prudent The first perspective suggests that the opposition to a development comes from a knowledge deficit, or irrational fear due to a lack of understanding. The selfish perspective suggests that local opposition is due to self-interest and not caring for the good of society in general. Freudenberg and Pastor argue that the prudent perspective is a response based on legitimate concerns about a proposed development However, Burningham (2000) argues that this prudent concept of NIMBY is not the way in which it is usually understood and that NIMBY has become synonymous with ignorance and selfishness.

Taking the view that NIMBY is commonly used to refer to an ignorant or irrational response, several researchers have argued that the concept is unfair and too simplistic to be a useful concept (Burningham, Barnett, & Thrush, 2006; Devine-Wright, 2005a, 2009, Wolsink, 2000, 2007b). Wolsink has studied opposition to wind power in-depth and argues that institutional factors are far more important when assessing public support for wind power. He contends that a more open and inclusive planning process is needed and that local resistance is often caused by the developers rather the turbines themselves. He further argues that the ideas of equity and fairness are central to the public response and that collaborative approaches to planning are far more preferable than top-down decision making.

Devine-Wright has also carried out important research into the factors affecting opposition to renewable energy infrastructure (Devine-Wright, 2005b, 2009, 2011). He conceptualises local opposition to wind development in terms of place attachment and identity, and conceives of it as a protective action. Place attachment is seen to be more emotional or social than physical, with people being attached to the community. As such, people with a stronger place attachment would be more likely to try to take action to prevent unwanted local change.

McClaren Loring (2007) carried out research into wind energy planning in England, Wales and Denmark that would appear to support the contentions of Wolsink and Devine-Wright. McClaren Loring looked at 18 case studies and found that projects with high levels of participatory planning were more accepted and successful. She also found that the stability of the network between opponents was inversely related to the success of the wind project. Krohn and Damborg's (1999) review of survey's into public attitudes to wind turbines further rejects the idea that wind power opposition is the result of NIMBYism. The key issues surrounding the acceptance of windfarm developments appear to be the impacts on the landscape and ideas of justice and fairness (Mason & Milbourne, 2014; Molnarova et al., 2012).

The focus on the current research is on the cumulative landscape and visual impact of wind turbines. As such, place attachment, participatory planning or other issues around procedural justice will not be part of the core research interests. The research into landscape and visual impact of wind turbines suggests that it is a multi-faceted issue, including landscape characteristics, respondent characteristics, as well as the physical characteristics of the wind turbines. Jones et al. (2011) note that there is a lack of understanding of the relationship between people's attitudes to wind turbines and the number of turbines or groups of turbines that they will accept within certain landscapes. If the UK is to meet the 2020 targets, it will need to more than double its current wind energy capacity, which will result in a significant increase in the number of turbines present in the landscape. As wind turbines become an increasingly common part of the UK landscape, understanding the response of people to the cumulative effects of these wind turbines will become increasingly important. The next section will provide a review of research that has looked into the landscape and visual impacts of wind turbines.

1.5 Visual Impact of Wind Turbines

There has been a considerable number of studies carried out looking at public perception and responses to wind turbines (Bishop, 2011; Devine-Wright, 2005a; Molnarova et al., 2012). The research has looked at various different aspects of the impact of wind turbines in the landscape, but can be grouped into two broad themes: 1) the physical characteristics of wind turbines, e.g. size, number, distance from viewer; and 2) the characteristics of the participants, e.g. attitudes, experience, socio-demographic characteristics.

1.5.1 Physical Characteristics

Previous research has looked at physical characteristics such as distance from turbines (Bishop, 2002; Jones & Eiser, 2010; Krohn & Damborg, 1999), number of turbines (Jones et al., 2011), and height of turbines (Dimitropoulos & Kontoleon, 2009).

1.5.1.1 Distance

Bishop (2002) found that for a turbine height of 50m, and blade length of 26m, it was very rare that a person would be able to see the turbine more than 20km away. In normal conditions, approximately 20% of people would recognise a turbine at distances of 10km or greater. Further, Bishop found that the visual impact of the turbine would be minimal over 5-7km away. Later research by Bishop and Miller found a decline in impact with distance when assessing visibility at 4km, 8km, and 12km, for offshore and onshore wind turbines (Bishop & Miller, 2007). Both of these studies look at several different weather conditions, offering different levels of visibility, e.g. hazy, clear sky. They also both used animated GIFs, composed of multiple frames with turbine blades at different rotations, to mimic the movement of real turbines in the landscape. Research on the visual effects of wind turbines in South Australia found similar results for visibility and distance, with impact dropping rapidly after 4km to below 10% by 5km (Lothian, 2008).

Attitudes to wind turbines, as a function of the distance people live from developments, have also been studied. Early research in Altamont, California found that those who lived closer to Altamont, as well as those who were more familiar with the area, liked the turbine development less than those who lived farther away and those who were less familiar with the area (Thayer & Freeman, 1987). Research carried out in Sydthy, Denmark found that there distance away from the closest turbine had no effect on people's attitudes to wind power (Krohn & Damborg, 1999). The two areas discussed in the aforementioned papers could be considered special cases, as more than 98% of electricity in Sydthy and is generated by wind turbines, and Altamont is one of the first areas in the world to undergo major wind farm development. A more recent study examined attitudes to wind turbines in Scotland and Ireland (Warren, Lumsden, O'Dowd, & Birnie, 2005). Warren et al. looked at people's attitudes to two windfarm developments in Ireland and tabulated the response with the distance from the residence of the respondents (at 0-5km, 5-10km, and 10-20km). They found a significant distance effect, with those living closest to the turbines having the most favourable attitudes, while those living farther has the least favourable. Johansson and Laike (2007) found that distance away from a proposed wind farm development did not affect a person's intention to oppose the development. Lastly, Eltham et al. (2008) looked at the change in attitudes to wind turbines in Cornwall between 1991 and 2006. The area studied is approximately 1.5km from the site of the first commercial wind farm in the UK – the Carland Cross Wind farm – built in 1992. The researchers found a significant increase in those who support the wind farm, from approximately 74% to 82%.

The research into the effects of distance on the impact of wind turbines suggests that visual impact falls off rapidly from approximately 5km and that distance of residence away from windfarms is inversely related to the level of support.

1.5.1.2 Number

Researchers have studied the effects of several physical characteristics of wind farms, including the number of turbines, using photographs of five real wind farms (Torres Sibille, Cloquell-Ballester, Cloquell-Ballester, & Darton, 2009). Three of these wind farms were in Spain, while two were in Wales, with the number of turbines varying from 16 to 50 across the sites. The research showed that the sites with the greater number of turbines were judged to have the greater impact, with the turbine number in order of impact being 50, 33, 25, 16, and 20. The last two are the opposite to what you would expect, though on closer inspection of the photographs used in the study, the pictures of the site with 20 turbines were taken on a day with a large amount of haze.

Jones et al. (2011) carried out research in the Humberhead Levels in the UK to assess residents' capacity estimates for onshore wind-power development. They found that the most common choice amongst respondents was 1-25 turbines, with about 21% choosing that option. There was a relatively steady decline in respondents choosing estimates that were higher, with only 5.8% believing that the area could accommodate 126-150 turbines. Research carried out on the impact of a wind farm on a Greek Island has also shown that more turbines result a higher impact (Tsoutsos, Tsouchlaraki, Tsiropoulos, & Serpetsidakis, 2009). Comparing two conditions, participants judged a wind farm with 22 turbines to have a greater visual impact than one with 11 turbines, which is what common sense would suggest.

Ladenburg and Dahlgaard (2012) carried out research into the cumulative effects of daily wind turbine exposure on negative attitudes to wind turbines. Based on survey data from 1,100 respondents, they found that the number of turbines has a significant negative effect. Further, they found that the effect increased up to 6 turbines and then plateaued. As such, there was no further increase in negative effect from 6-10, 11-20, or 20 or more turbines in a day. These findings are echoed in research carried out into attitudes towards wind farms in Ireland (Sustainable Energy

Ireland, 2003). Survey data showed that people's order of preference for wind farms was 1) a five-turbine farm, 2) two groups of 10 turbines, and 3) one group of 25 turbines.

The research into the number of turbines seems to support the idea that the greater the number of turbines, the larger the impact of the landscape. There is also some evidence to suggest that there is an optimal number of turbines within a group, perhaps between 5 and 10 turbines.

1.5.1.3 Height

The results from research into how the height of wind turbines affects social acceptance have been somewhat mixed. Meyerhoff, Ohl, and Hartje (2010) carried out research into public attitudes to wind turbines in two regions in Germany, Westsachsen and Nordhessen. Each of these regions was subdivided into three sections. Using interviews, the researchers asked participants to choose between several wind developments options. Each option varied according to four different characteristics, one of which was the size of the turbines in the development. In all but one of the six sections, there was no significant effect of the height of the turbine. One of the groups, however, supported a ceiling height of 150m on the turbines. Research on the Greek island by Tsoutsos et al. (2009) suggests that the height of wind turbines may have a significant impact of people's attitudes. Participants were given a choice between an 11x850kW turbine wind farm and a 22x850kW turbine wind farm. They were also give a third option of a single 5MW turbine option. The choice of a single turbine with a hub height of 120m was considered to have a greater negative impact than 11 turbines that are each 45m to hub. Other research carried out in Germany suggests that the effect of wind turbine height on the social acceptance of a development is insignificant (Erp, 1997).

The effect of the height of wind turbines on people's judgement of impact isn't clear. There is some research to suggest that it does not have a significant effect, whereas other research suggests that, in certain conditions, it may affect people's attitudes.

1.5.2 Sociodemographic Characteristics

The majority of research into attitudes to wind turbines includes at least some analysis of sociodemographic data (e.g. Álvarez-Farizo & Hanley, 2002; Bishop & Miller, 2007; Devine-Wright, 2005; Ek, 2005; Meyerhoff et al., 2010). Some of the research has not shown a significant effect of sociodemographic factors on attitudes to wind turbines. Meyerhoff et al. (2010) included several demographic variables in their model, such as age, gender, and income but found no significant covariates with wind turbine preference. Thayler and Freeman (1987) also included similar demographic variables in their analysis. Few significant differences were found among the variables, however, they did find that those with lower education tended to consider wind turbines more beautiful and liked them more than others. The researchers also noted gender differences, with women being more positive generally about wind energy, while men tended to view it more negatively and considered them tax shelters for investors. Some of these findings could be attributed to the fact that commercial wind energy was in its infancy at that time, and that some of the turbines genuinely were tax shelters. However, when looking at the literature, several trends do appear. Age has been consistently shown to a significant effect on acceptance of wind turbines (e.g. Álvarez-Farizo & Hanley, 2002; Bishop & Miller, 2007; Devine-Wright, 2005a), with younger people tending to be more accepting of wind turbines. Income has also been shown to be a significant factor (Ek, 2005), with the probability of someone supporting a wind farm development decreasing with increasing income.

Two key components of the characteristics of participants that have been looked at are attitudes and experience. The more knowledgeable a person is about wind energy and renewables, the more likely they are to be in favour of them (Krohn & Damborg, 1999). Research carried out by Swofford and Slattery (2010) also supports this conclusion, as well as suggesting that people who support wind power have positive views on wind energy, while those who are against wind power, have negative views on the turbines. This is further supported by the difference in general support for wind energy but local resistance to development (Jones & Eiser, 2009). Experience of wind turbines has been shown to affect people's attitudes to developments, with levels of approval dropping during the construction phase and rebounding after habituating to their presence (Damborg & Krohn, 1998). Eltham et al. (2008) showed that support for a wind farm in Cornwall increased over the course of 15 years. It is possible that the turbines become part of the place identity.

1.6 Cumulative Effects

Any human development may have direct or indirect impacts upon the environment, and these impacts may interact in space and time (Piper, 2004). Piper states that cumulative effects can occur where '…developments either cluster to affect a "local" environment, or where a plan or programme of developments has the potential to give rise to accumulating effects' (p. 41). The consideration of cumulative effects of developments within Environmental Impacts Assessments (EIAs) has been a legal requirement in the UK since 1998 (Cooper & Sheate, 2002; Piper, 2004). In essence, when assessing the impact of a proposed development, consideration needs to be given to existing human development within the landscape, potential future developments, the current development under proposal, as well as any interactive or additive effects from the combination of all of them (McCold & Saulsbury, 1996; Rumrill & Canter, 1997). Several researchers have looked at possible environmental and social indicators that may be used to model cumulative effects on the environment (Canter & Atkinson, 2011; Parkins & Mitchell, 2011). Cooper and Sheate (2002) carried out a review of 50 UK environmental impact statements (EIS) and found that only 8 had definitions of cumulative effects, noting that the definitions within those 8 were quite different. They suggested that the reason they found no accepted definition was due to no definition being provided in either the UK regulations or the EC directive. This is backed up by more recent research in Canadian context, which suggests that there is a good deal of confusion over the exact nature of cumulative effects (Gunn & Noble, 2011).

The issue of the cumulative effects of wind turbines has been given greater importance in recent years, with Scottish Natural Heritage releasing a guidance document entitled 'Assessing the

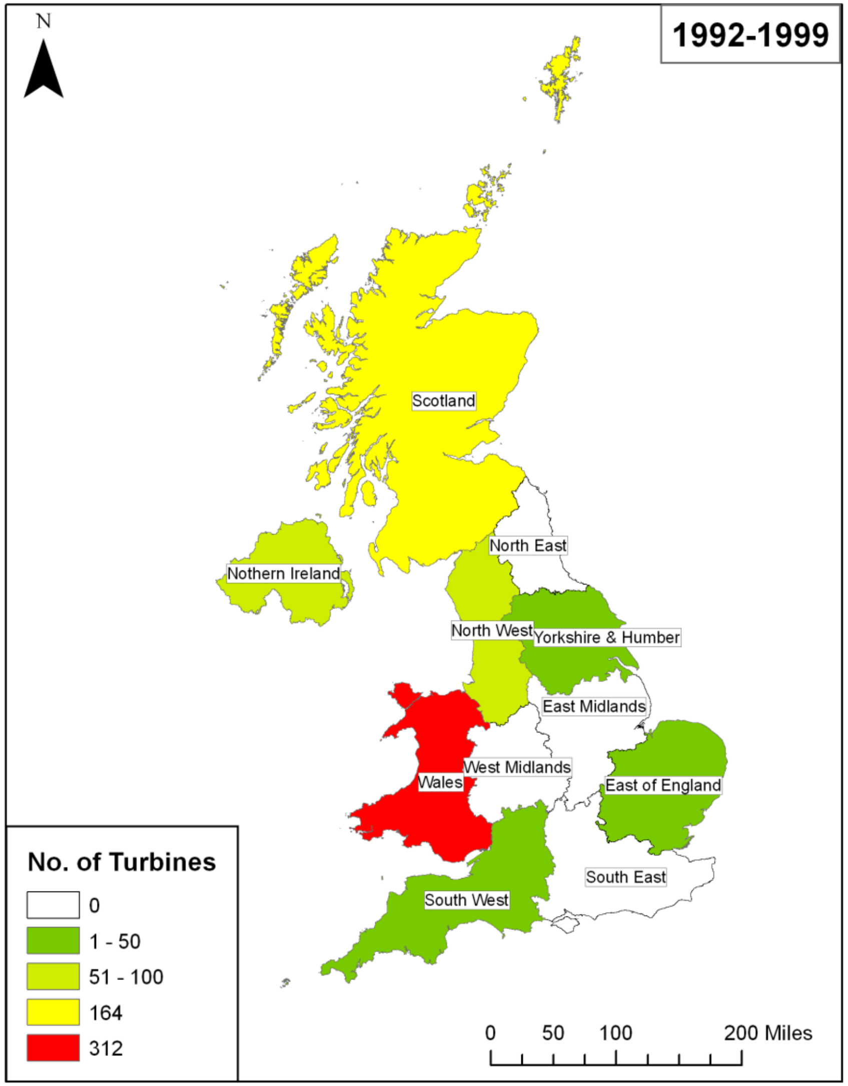
Cumulative Impact of Onshore Wind Energy Developments' (Scottish Natural Heritage, 2012). The SNH guidance document suggests that the cumulative landscape and visual impact (CLVI) of a wind farm is a product of five key factors: 1) the distance between individual windfarms (or turbines); 2) the distance over which they are visible; 3) the overall character of the landscape and its sensitivity to windfarms; 4) the siting and design of the windfarms themselves; and 5) the way in which the landscape is experienced. The document further distinguishes between: i) *combined visibility:* where multiple wind farms are visible from a single view point, within a single arc of vision, or in succession by turning on the spot; and ii) *sequential effects:* where a single observer may view several wind farms while travelling along a common route, e.g. major roads, railways, popular walkways. Although helpful, these guidelines are quite broad and lack specifics, e.g. what distance between wind farms is deemed acceptable, or in what way does the siting and design affect the CLVI of windfarms? Within the document, SNH note that 'Few detailed perception studies have been undertaken to date…' which supports the idea that there is insufficient knowledge about the CLVI of onshore wind turbines, particularly within the UK.

1.7 Repowering/Extending

Two important issues that contribute to the cumulative impacts associated with long-term wind power development are repowering and extending wind farms. As turbines near the end of their life cycle, the issues of repowering or extending comes to the fore. Developers may wish to replace older turbines with larger and more efficient turbines, or to add new turbines on existing wind farm sites rather than develop new wind farms in less productive areas (Frantál, 2014). Repowering is the replacement of existing wind turbines with more efficient, and usually larger turbines, whereas wind farm extension is adding turbines to a wind farm without removing any of the existing turbines. Several countries in Europe already have legislation in place to deal with repowering, including Denmark, Germany and Spain (Colmenar-Santos, Campíñez-Romero, Pérez-Molina, & Mur-Pérez, 2015; Del Río, Calvo Silvosa, & Iglesias Gómez, 2011). The legislation in each country focussed on two core issues. The first, that the turbines being replaced needed to below a certain energy capacity e.g. 100 kW and/or need to have been installed before a certain year. The second focus of the legislation was to encourage larger, higher capacity turbines as replacements. As such, the general trend of repowering is that smaller, older turbines are removed and replaced with larger turbines that produce more energy but also have a larger visual impact. Extending wind farms has been given less focus in the literature, though it has been discussed as an issue in terms of cumulative landscape and visual impact assessment (Entec, 2008).

Understanding how people perceive this change in the UK will become more important as older turbines begin to be replaced. Carland Cross, the first commercial wind farm in the UK, was repowered in 2013. The repowering followed the trend outlined in the previous paragraph with fifteen 400 kW turbines with a height of 49m being replaced by ten 2 MW turbines with a height of 100m, which resulted in over three times the generating capacity (Scottish Power Renewables, 2013). This repowering project was not without opposition, with local residents forming a ‘wind farm action group’ (Carland Cross Wind Farm Action Group, 2008), and the project initially being rejected by the local council (The Low Carbon Economy, 2009).

There are around 4,800 onshore wind turbines in the UK with a generating capacity of approximately 8GW of energy (Renewable UK, 2015). Of those, 632 turbines were built in the 1990s and 641 were built from 2000-2005. The majority of these turbines are likely to be considered for repowering or extension in the next few years (see fig 1.3. for a breakdown by region). This highlights the increasing importance of understanding the potential visual impacts of these repowering and extension projects, particularly in light of the community response to the Carland Cross repowering project in Cornwall.



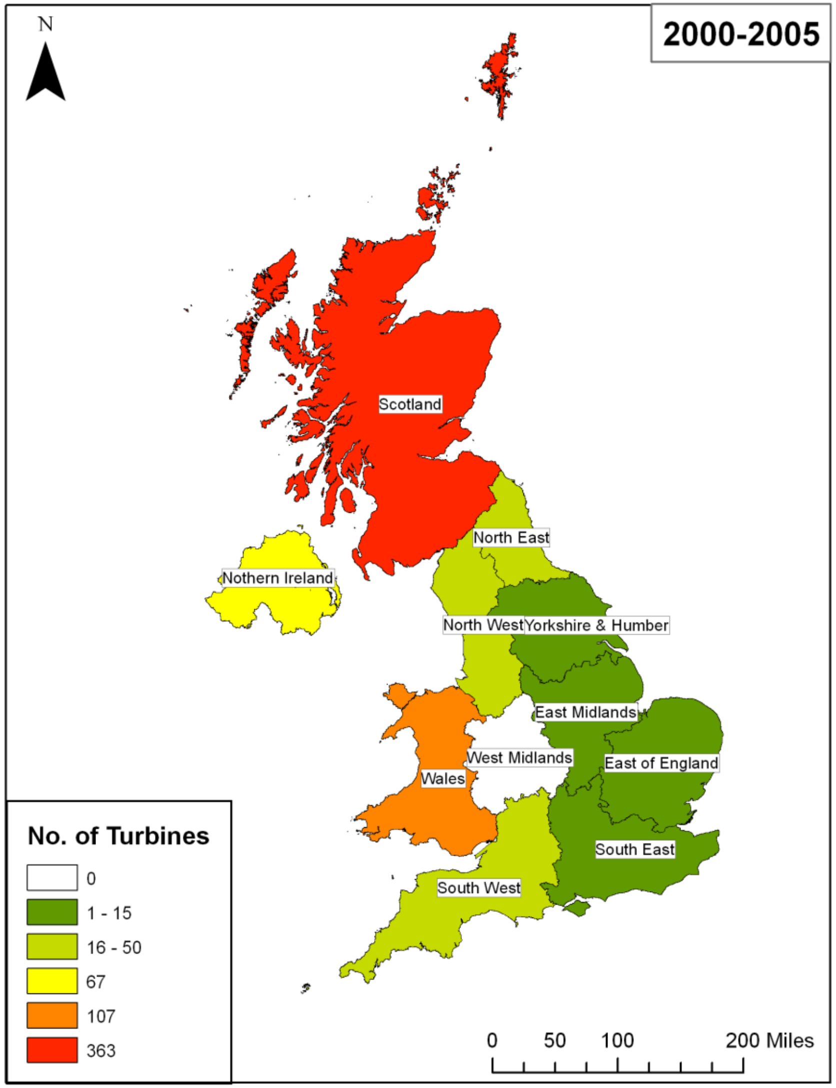


Figure 1.3: Onshore Wind Turbines by UK Region from '92-'00 and '00-'05

1.8 Gaps in Research

While there has been a great deal of research into the social acceptance of wind turbines, which has focussed broadly on characteristics of the turbines and the respondents, there are some deficiencies within the literature which need to be addressed (Devine-Wright, 2005a). Devine-Wright notes that there is an over reliance on surveys in previous research, and a lack of use of probabilistic multivariate statistical tools. He suggests that the use of quasi-experimental designs using photomontages could be a good way to systematically unravel the complex relationships between type, size, shape, and landscape context. Molnarova et al. (2012) acknowledge that there is a lack of multi-dimensional analysis of wind turbine preferences based on visual evaluation, but suggest that their work, along with that of Tsoutsos et al. (2009), has addressed this issue.

While the work by Molnarova and colleagues is perhaps the most exhaustive to date, like other research in this area, it did not address all of the potential issues. Most of the previous research had limited options for the number of turbines and landscape types. Molnarova et al (2012) only offered two options for number; one or four turbines, and three landscape options. Torres et al. (2009) used real wind farms so the number of turbine was somewhat haphazard (16, 20, 33, 35, and 50), though they did attempt to create an objective measure of aesthetic impact. Tsoutos et al. (2009) had the options of 5, 11, or 22 turbines or 1 significantly larger turbine, though all in the same landscape. Jones et al. (2011) used groupings with large ranges e.g. 1-25, 26-50 etc. but without accompanying visualisations. A more systematic approach to the physical characteristics of size, number, and landscape type may yield more information.

Further, the majority of research has used static photomontages to visualise wind turbines. This is an important issue for two reasons: 1) motion is an important aspect of the representation of dynamic landscapes (Hetherington, Daniel, & Brown, 1993), particularly for wind turbines; and 2) there may be problems of validity in using 2D photographs to represent a real-world landscape (Daniel & Meitner, 2001; Palmer & Hoffman, 2001). Bishop (2002) states that the movement of wind turbine blades can result in an apparent increase in size of 10 to 20%, which would call into question the validity of static photomontages. While some researchers have addressed this issue by using animated gifs (Bishop & Miller, 2007; Bishop, 2002), one of these studies addressed offshore wind turbines and the other only assessed the impact of a single turbine. Some researchers have suggested that, with recent advances in computing, 3D computer simulations may be used as a research and participatory planning tool (Danahy, 2001; Ghadirian & Bishop, 2008; Lange, 2011; Orland, Budthimedhee, & Uusitalo, 2001; Sevenant & Antrop, 2011; Wissen Hayek, 2011). For a full methodological review, see chapter 2.

1.9 Summary

The weight of scientific evidence supports the assertion that climate change is real and that anthropogenic causes are responsible (IPCC, 2007c). As a result of the threat that this climate changes poses to the human population (IPCC, 2007a), mitigation measures need to be taken to reduce greenhouse gas (GHG) emissions (IPCC, 2007b). One of the key ways that the UK government is trying to reduce GHG emission is by decarbonising the UK's electricity, which is the largest single contributor to UK emissions

As part of the drive to decarbonise the energy sector, the government has committed to installed 14GW of onshore wind energy by 2020 (Department of Energy & Climate Change, 2012). This will result in considerably more construction of onshore wind power as well as repowering of older wind developments. The cumulative effects of these wind turbines is poorly understood (Jones et al., 2011). As the level of wind turbine development increases across the UK, and more of the older developments are repowered, understanding the factors that affect the cumulative landscape and visual impact of wind turbines becomes increasingly important.

Previous research into the public acceptance of wind turbines has focussed on the physical characteristics of the turbines, as well as the characteristics of the participants in the research. The research has shown that several physical characteristics of wind turbines may affect people's acceptance levels, including; height, number and distance from resident (Devine-Wright, 2005a). Larger turbines have been shown to have a greater visual impact, while impacts from turbines have been shown to reduce dramatically at a distance of around 5-7km Smaller groups of 5-10 turbines have also been shown to be preferential to larger groups (Bishop, 2011). Participant characteristics, such as age, education, experience and knowledge have been shown to affect acceptance of wind turbines. Older and better-educated people tend have more negative attitudes to wind power developments, while experience seems to have no or a positive effect on attitudes. A greater understanding of wind power also seems to result in higher levels of acceptance (Molnarova et al., 2012).

There has been an over reliance on survey data and most visualisations used in previous research have been static photomontages. A more systematic analysis of the factors affecting the CLVI of wind turbines is needed, as well as an assessment of visualisation methods.

2 Methodological Review

2.1 Visual Representation of Landscape

The representation of visual changes to a landscape that may be caused by a proposed development is an important part of landscape and environmental planning (Bishop & Lange, 2005; Oh, 1994). One of the most important early examples of visualisations of landscapes are Hemphry Repton's 'Red Books' (Gill & Lange, 2016). Repton's 'Red Books' are a collection of books which include maps, plans and watercolour paintings to showcase "before" and "after" visualisations of proposed changes to his clients' estates (Koliji, 2011). Using overlays, these before and after visualisations were designed to seamlessly showcase the projected improvements for his clients. Repton is considered to be one of England's most influential landscape gardeners, and his ideas helped to shape subsequent approaches to landscape visualisation, in particular the focus on communicating potential change from future proposals to sites. Kullmann (2014) notes these books as the beginning of a disciplinary ideal for "…a complete and truthful mechanism with which to visually communicate landscape design propositions." (p. 20). Kullman also suggests that increasingly sophisticated visualisation software now allows for the generation of highly accurate and believable landscape visualisation. However, MacFarlane et al. (2005) acknowledge that, while there have been great advances in realism, the level of detail is never equal to that of reality. Further, they highlight the importance of the landscape visualisation practitioner in a range of decisions that affect the visualisation, e.g. seasonal selection, colouring facets, viewpoint selection. As such, the final visualisation is a combination of technological capabilities and the practitioner's own values or perspectives.

An early review of landscape simulations assessed the various methods being used, including; photography, drawings, composite techniques, models, videos, and computer generated graphics (Zube, Simcox, & Law, 1987). Zube et al. concluded that very little was known about the validity or reliability of the various methods for simulating landscapes, though they did suggest that the most realistic simulations were 'those that have the greatest similitude with the landscape they represent' (p. 76).

In 1989, Sheppard proposed five general principles for landscape visualisations with the aim of creating response equivalence and acceptability to the audience (see table 2.1) (Sheppard, 1989, 2001).

Table 2.1: General Principles for Landscape Visualisation (S. R. J. Sheppard, 1989, 2001)

Principles	**Definition**
Accuracy	Visualizations should simulate the actual or expected appearance of the landscape (at least for those landscape factors being judged).
Representativeness	Visualizations should represent the typical or important views/conditions of the landscape
Visual Clarity	The details, components, and overall content of the visualization should be clearly communicated
Interest	The visualisation should engage and hold the interest of the audience
Legitimacy	The visualization should be defensible and its level of accuracy demonstrable

2.1.1 Photographs/Photomontages

The use of photographs in landscape assessment and landscape preference studies has a long history (Shuttleworth, 1980; Stamps, 1990; Stewart, Middleton, Downton, & Ely, 1984). Stamps carried out a meta-analysis of research that had used photographs to assess environmental preference and found 1300 studies. Of those, Stamps found that only 11 papers that attempted to test the validity of the photographic representations. Palmer and Hoffman (2001) have suggested that previous reliability assessments of the validity of photographic landscape representations have been flawed. This is because they have only focussed on the assessment of scenic preferences, and often averaged over a group of views instead of being based on individual views. More recent research has tried to address these issue and to objectively assess the reliability and validity of photographic landscape representations (Meitner, 2004; Roth, 2006; Sevenant & Antrop, 2011)

Using the Colorado River in the Grand Canyon National Park, Meitner (2004) carried out research photographic presentation options that could be used to assess people's perceptions of the scenic beauty of landscapes, while travelling along a linear feature such as a road or river. Meitner created multiple 360^0 panoramas at different sites along the river. He presented the participants with either individual photos, multiple orthogonal views, panoramic views, or interactive panoramic views. Findings from the research suggest that the presentation medium is important and that the individual photos were the least valid. The other methods were found to be quite similar and Meitner suggests that, due to ease of creation, orthogonal view photos might be a preferable method. Danahy (2001) also supports the idea of panoramic views being more realistic and a more valid way to represent landscape vistas.

Roth (2006) compared visual landscape ratings of an area in Germany in three ways, 1) on-site, 2) paper-based survey, and 3) internet-based survey. Participants were asked to rate landscape vistas on a scale of 1-10 using various descriptive terms e.g. artificial, beautiful, wild, and depressing. Roth found that several of the descriptive terms could be reliably measured using photos in an online survey, including; visual naturalness and beauty, However, several other variables could not be accurately measured, such as typical and characteristic. Sevenant and Antrop (2011) carried out a study comparing the validity of photographs as a means of landscape representation and for use in landscape preference or perception research. They compared on-site observations with photographs of twelve landscape vistas, using two different angles of view, standard frame and panoramic. In general, they found high correlations between the three mediums of presentation. However, for variables such as 'beautiful', 'well-maintained' and 'of historical importance' they found that normal photographs were considered more valid than panoramic photos. They also found that vastness was something that couldn't be captured in either photograph type and necessitated a site visit. Dupont, Antrop, and Van Eetvelde (2013) used eyetracking to examine the effect of photographic properties on landscape characteristics and found that people visually process landscapes differently depending on the type of photo used (e.g. panoramic, wide angle, standard, zoomed). Contrary to Sevenant and Antrop (2011), Dupont and colleagues argue that panoramic are the most appropriate type of photograph to use for landscape visualisation.

Several studies have tried to compare the use of photomontages and other computer simulation methods in communicating with communities about potential development scenarios. When looking at landscape planning in an agricultural community in Koenigslutter, Germany, Warren-Kretzschmar and Tiedtke (2005) used sketches, photomontages, as well as 3D computer simulations to identify what aspects of visualisations citizens considered important. The participants in the study were given the chance to assess the visualisations in person, as well as online through a questionnaire and discussion forum. The researchers noted that participants were somewhat disappointed in the realism of the visualisations, and would often subsequently challenge the validity of further visualisations. In general, the researchers suggest that participants showed a preference for static 3D images over virtual reality representations. In another paper, based on the same research project, von Haaren & Warren-Kretzschmar (2006) suggest that the combination of different visualisation methods was important to meet the perceptual needs of diverse groups. The photo-realistic visualisations were helpful for the citizens in understanding the visual effects of the planning measures, although the virtual reality visualisations were considered sufficient for assessing the planning proposals.

In a case study looking at future climate change scenarios in the Humberhead Levels, UK, Dockerty et al. (2006) compared photomontages and real-time landscape modelling. The researchers created photomontages of potential future landscapes to include things like biofuel crops, alternative energies or leisure developments. These were replicated in the real-time landscape models, which were created using Visual Nature Studio and GIS data. During a one-day conference, local people were presented with the different visualisations and asked about their preferences. From the survey, the researchers found that 78% of the respondents found the photomontages helpful, as compared to 65% for the real-time models. Further, they found that approximately half of the respondents preferred the photomontages, with the other half preferring the real-time model. As part of the RUFUS (Rural Future Networks) project, researchers compared the use of photomontages and other computer generated visualisations for community engagement in Melgaco, Portugal (Lovett, Carvalho Ribeiro, Van Berkel, Verburg, & Firmino, 2010). The researchers developed scenarios that included greater levels of woodlands in the valley, as well as rewilding of some farmland. They created photomontages of key viewpoints, as well as overview 3D models using ArcScene. The results suggest that the photomontages were more useful in helping the community to imagine the changes, while the ArcScene model was more useful for understanding the drivers of the changes.

One study compared the use of photomontages and 2D maps to consult on forest management scenarios with an indigenous, First Nation community in British Columbia, Canada (Lewis & Sheppard, 2006). They found that both visualisation methods were useful for at least some discussion and commentary. They noted however that there was complete acceptance of the photomontages, even though it was the first time many of the participants had been exposed to these kinds of realistic landscape visualisations. Moreover, the researcher note that the reactions and comments suggest that the participants believed the photomontages to be real photographs.

Previous research into the use of photographs to represent landscapes has shown mixed results. How representative or accurate the photographs are, compared to the real landscape or to other visualisation methods, seems to depend on the variables of interest and also on the perceptual preferences of the participants. Further, the angle of view of the photographs used seems to affect people's responses in sometimes contradictory ways.

2.1.2 3D Computer Visualisations

The use of 3D computer simulations to represent landscape dates back to the early 1970s, when the US Forest Service was a key driver in developing new techniques to landscape assessment, with the first publications using digital landscape representation coming in the late 1970s (Lange, 2011). Lange notes that the relative ease of creating digital photomontages revolutionised the landscape preference research. Overtime, increasingly realistic methods of landscape representation have been developed, due to increased computational power and ever more sophisticated software development. (Lovett, Appleton, Warren-Kretzschmar, & Von Haaren, 2015; Thompson & Horne, 2006). It is important to note that computer visualisations can vary in complexity, as well as abstractedness, and are dependent on the skill of the creator and the viewer. Moreover, visualisations can be created for a variety of reasons, such as explaining or investigating issues, and are heavily reliant on the sophistication of the technology that is available at the time (Johnson, Thompson, & Coventry, 2010). Indeed, it is important to accept that 3D computer visualisations have strengths and limitations in effectively communicating landscape scenarios (Pettit, Raymond, Bryan, & Lewis, 2011)

In an example of the use of 3D computer visualisations to study landscape preferences, Chamberlain, Liu, and Canfield (2016) used 3D visualisations to assess the impact of green infrastructure on perceptions of safety and attractiveness on a streetscape in a small U.S. college town. Using a combination of CAD, Sketchup, and Lumion, the researchers created visualisations with various forms of green infrastructure, e.g. bike lanes, and trees. Using the visualisations in conjunction with a questionnaire, they found that the green infrastructure increased the perception of safety and attractiveness for the streetscape. While this example highlights the usefulness of 3D computer visualisations, several researchers have compared computer simulations with other visualisation methods, as well as the real world, to assess the realism of these simulations.

Bishop and Leahy (1989) compared people's ratings of photographs and computer simulations of landscapes. They found a high correlation between the rating of the simulated and photorealistic landscapes, however they did instruct participants that '…they should expect the images to have more of the quality of a painting than a photograph…' (p. 94). Further, they cautioned that simulated landscapes should be used for assessing specific changes rather than used in general landscape analysis. Perkins (1992) also raised the issue of the use of simulation as real-world substitutes. He proposed three questions; 1) What variables predict the quality of an image and how do these variables relate to each other?, 2) How is the image quality related to perceived realism?, 3) What image quality is sufficient to act as a valid and reliable surrogate for real world conditions or 'how good is good enough'? (Perkins, 1992). Oh (1994) tried to address some of these questions by assessing the four most commonly used simulation at that time. These were; 1) wire frame, 2) surface model, 3) combination of surface model with photographic images, and 4) image processing. The findings from this study suggest that people felt the processed images were the most realistic while the wireframes simulations the least. They also felt that, while the background images helped with the combination model, both surface models had insufficient detail and felt artificial.

Ian Bishop and Bernd Rohrmann ran a series of lab and field studies looking at subjective responses to a real park in Melbourne, Australia, and a computer simulation of that park (Bishop & Rohrmann, 2003; Rohrmann, Palmer, & Bishop, 2000; Rohrmann & Bishop, 2002). The aim of these studies was to test the validity of a computer simulation of a park. The researchers created a simulated walk through the park, recorded a real walk through the park, and also had some participants visit the real park. They also assessed several different simulation conditions, such as time of day and weather, with and without sound. Participants' perception of the simulations and the real park were assessed using a questionnaire that was designed to measure cognitive and affective aspects of their reactions. The findings from these studies were somewhat mixed. While most participants believed that the simulations were valid representations of the park, the simulations do not elicit the same response as the real park in every way. Bishop and Rohrmann found that participants appreciation of the park wasn't as positive in the simulation condition, nor did participants retain as much detailed information. They also found that the inclusion of sound was an important aspect in creating realism. Further, they suggest caution in the interpretation of the findings, as participants' liking of the park environment may have confounded with their ratings of the simulation quality.

Similar differences in perceptions of computer visualisations and on-site visits have been found in a research study that looked at an urban design project in a square in Vienna, Austria (Wergles & Muhar, 2009). The researchers compared perceptions of a group of participants who viewed visualisations based on a 3D model of Schwarzenbergplatz, created using 3D Studio Max, and a group who spent about 30 minutes on site viewing the square. From the findings, it was clear that the participants in both groups had qualitatively different perceptions of the square. For instance, all of the participants who had the on-site visit noted dynamic aspects of the landscape, such as the play of the light (which was a key intention of the architect). Moreover, those who visited the square were affected by the traffic and noise, and rated the project more negatively as a results. The visualisations has no such effect on the other group.

Research using 3D computer simulations has shown that they can be a useful method for landscape representation. The simulations are becoming ever more realistic due to advances in technology and will continue to do so into the future. However, it is worth noting that the evidence suggests that people perceive the computer simulations differently from photomontages, or from real landscapes.

2.1.3 Dynamic Simulations

In their review of visualisation methods, Zube et al. (1987) highlighted two key groups of simulations; static and dynamic. They noted that the vast majority of research in the field used static photographs, both aerial and site-based. However, they also discussed the use of dynamic simulations such as the creation of videos from images taken while moving a camera through a landscape model, and videos of real world environments, seeing them as a potentially useful new tool for research.

Heft and Nasar (2000) argue that the environment, as experienced, has dynamic qualities and, inspired by Gibson's ecological approach to perception, compared dynamic and static displays of environmental scenes. They created a video by driving along a rural road in a van. From this, they presented participants with six second segments from the video, or displayed a static image from the segment for six seconds. Participants then completed surveys on epistemic variables e.g. whether they wanted to explore further, and evaluation variables, e.g. how much they liked the scene. Heft and Nasar's finding suggest that people respond differently to dynamic and static displays. They found that participants rated dynamic displays higher on epistemic values of wanting to learn more and explore further. However, participants rated preference as higher for the static display. They conclude that it is incorrect to assume that people respond similarly to static and dynamic landscape representations, and by extension, it is incorrect to assume that people's reactions to static images will be the same as they reactions to the real landscape.

Danahy (2001) also highlights the issue of dynamism in landscape visualisation, but from another perspective. He discusses the dynamic qualities of vision, using foveal and peripheral aspects to look around a scene. Danahy argues that the ability to 'look around' or 'move about' are important aspects of perceiving a landscape, also using the framework of Gibson's ecological approach to visual perception (Gibson, 1986). To best represent the natural way people view landscapes, he suggests that researchers use panoramic landscape representations that allow the viewer to move their head around to get the sense of scale. Hetherington, Daniel, & Brown (1993) also found that both motion and sound are important in influencing assessment of landscape representations.

In 2008, Ghadirian and Bishop published a method for creating off-line augmented reality (AR) landscape visualisations. This involved using GIS-based modelling and integrating it into video frames to create a dynamic, augmented landscape visualisation. They used an example of computer generated weeds superimposed over panoramic video frames to show how the method allowed for spatially accurate, realistically rendered scenarios. More recently, researchers have presented an interactive AR smartphone application that can provide real-time visualisations of potential flood levels in an urban riverside landscape (Haynes & Lange, 2016). Through the presentation of occlusion geometry, the app allows a user to visualise different flood scenarios use a smartphone on-site. Another recent publication has discussed the development of a virtual simulation platform that allows for a sense of space and greater immersion that most 3D simulations (Ye & Minghan, 2016). The authors describe a real-time three-dimensional platform, with the visualisation project on the ground beneath the user, as well as on the wall in front of them. The platform also involves a controller that allows the user to navigate through the environment along selected routes.

Immersive virtual reality (VR), in the form of a VR headset, has also recently been studied as an immersive environment for assessing landscape change (Hayek, Waltisberg, Philipp, & Gret-Regamey, 2016). Using ESRI's CityEngine and the Unity gaming engine, the researchers created two virtual realities: a watercourse corridor in an urban area, and a wind park in a hilly landscape. The researchers found the VR headset was more immersive than VR using large projections screens or on a desktop computer. Most participants had a positive experience and stated that they felt present in the virtual realities. However, nearly all of the participants perceived latency while using the headset, and noticed some image flickering which they found annoying. All of these more recent developments in visualisation incorporate dynamic elements, which helps to increase the level of realism and presence.

Bishop and Lange (2005) list six features that are considered important factors for virtual environments; immersion, interaction, intensity (realism), intelligence, illustration, intuition (p. 32). They consider the first three to be the most important in created a virtual environment though warn that there is still a trade-off between detail and interactivity. Given the recent advances in visualisation technology, particularly with regard to immersive VR using headsets which allow free head movement, in the near future it may be possible to create virtual environments that can achieve much higher levels of realism and presence than traditional visualisation methods.

2.2 Wind Farm Visualisations

Photographs and photomontages are a common requirement as part of a visual impact assessment for wind farm developments (Danese, Casas, & Murgante, 2008; Scottish Natural Heritage, 2006, 2012; Sullivan & Meyer, 2014; The Highland Council, 2010). With recent advances in computing power and visualisation software, using computer generated 3D simulations may become more common in visual impact assessment and research. These advances in computing have resulted in the possibility of creating more realistic visualisations in less time than ever before. Several papers have suggested that computer visualisations could be used to model landscapes for interactive design and planning, as well as research (Lange, 1994, 2002, 2011; Lange & Hehl-Lange, 2005; Orland et al., 2001). Creating 3D visualisations of proposed wind farms could provide greater levels of realism than the use 2D photomontages, while maintaining the ability to control and manipulate the variables of interest. However, this is something that need to be tested.

GIS-based visualisation methodologies have been presented by several researchers as a way of enabling an integrated approach to visual impact assessment and community engagement around wind farm developments.(Chias & Abad, 2013; Hurtado, Fernández, Parrondo, & Blanco, 2004; Manyoky, Wissen Hayek, Heutschi, Pieren, & Grêt-Regamey, 2014; Wang, Mwirigi, & Isami, 2013). Chias et al. (2013) used a case study of a wind farm in Sierra de Pela, Spain to develop a methodology that involves geographic analysis, photographic modelling, and 3D computer modelling. Their focus was on developing a method that involved qualitative and quantitative aspects of the landscape and also to incorporate the cumulative impacts of wind farms into their methodology. Wang et al. (2014) compared the Spanish Method of visual impact assessment, which is created using a GIS-based method for calculating a visual impact coefficient (Hurtado et al., 2004), with a questionnaire on the visual impact that was given to a community near Choshi City, in Japan. They found that residents' visual impact ratings on the questionnaire were higher than those that were produced using the GIS-based methodology. Manyoky et al. (2014) used GIS data, the Crysis game engine, and noise simulation to create a multisensory visual-acoustic simulation methodology. The addition of audio should allow for improved assessment of the impacts of a wind farm development.

The use of 3D simulations for participatory planning of wind turbine developments could provide developers and communities with an interactive model to help with information exchange and decision-making. Google Earth and Sketchup are two computer programmes that, when combined, could provide an ideal platform for the creation and viewing of these simulations (Wolk, 2008). Google earth is free to download for anyone with a computer and internet access and would allow anyone interested to view a proposed site as well as load models of wind turbines or other landscape features. Sketchup is also free and, though more complicated than Google Earth, it would be possible for developers or planners to create models of the proposed wind turbines. Further, Sketchup have existing models of wind turbines that could be loaded directly into Google Earth to allow local community members to see other wind developments around the world.

Adding dynamic elements to models is possible in Google Earth using keyhole markup language (KML) (Peterson, Dobson, Fandry, & Shrader, 2012; Wilson, 2008; Zhu, Wang, & Pan, 2014). Peterson et al. (2012) outlined the use of the 'timespan' function to animate geological cross sections to illustrate the subsurface geology of an area. This KML timespan function could be used to animate a turbine model by rotating the turbine blades. The combination of programmes, along with the animation of the turbines, could be a useful tool for research. Together, they would allow for a high level of control in manipulating variables of interest and to create many different wind farm landscape scenarios, as well as addressing the weakness of static wind farm representations. This could be ideal for the assessment of the cumulative landscape and visual impact (CLVI) of wind turbines.

While the benefits of using these programmes to create the 3D simulation is clear, there is still the issue of validity to address. As discussed previously, some research suggests that there may be limits to the level of realism achievable using virtual landscapes (Lange, 2001), even with extremely time-consuming and detailed simulations (Bishop & Rohrmann, 2003). However, most of this research has not been carried out on landscapes with wind turbines.

A study in Wales assessed the use of online tools for use in public participation in wind development planning (Berry, Higgs, Fry, & Langford, 2011; Berry, Higgs, Langford, & Fry, 2010). The researchers used Sketchup, Lightwave 3D and Visual Nature Studio to model the turbines and buildings in the landscape. They compared participants' ratings of these simulations with other visualisations, including; zone of theoretical visibility map, wireframe model, and photomontage. The participants believed that the photomontage was the most effective in visualising the impact on the landscape character, with an animation of the 3D simulation considered the second best. However, there was no assessment and comparison to the real impact as the wind farm was only at the proposal stage of the development process.

In order to assess the realism of a 3D simulation of a wind farm, an objective measure is needed. Further, it would be important to compare that measure with the real world. Psychophysiological measures could be used to assess the presence and immersion of the simulation (Meehan, Insko, Whitton, & Brooks, 2002). A video of a real landscape could be used as a baseline to compare with the simulation. Previous research has suggested that videos of the real world have high levels of presence (Bracken, Pettey, Guha, & Rubenking, 2010; Lombard, Reich, Grabe, Bracken, & Ditton, 2000; Rooney, Benson, & Hennessy, 2012). A comparison of participants' physiological responses to a video of a real wind turbine landscape and a 3D simulation of the same landscape could provide an objective method to assess the realism of the simulation created.

2.3 Social Neuroscience

Social neuroscience (also called social cognitive neuroscience, or social psychophysiology) is the field of study where researchers seek to identify the biological underpinnings of social processes and behaviour (Cacioppo, Berntson, & Decety, 2010). Underlying the field, is the assumption that neuroscientific or psychophysiological methods can contribute to the understanding of social psychological problems. Common psychophysiological measurements used in social neuroscience include skin conductance response (SCR), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and electrocardiograms (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). It is an interdisciplinary field that studies the interactions between the nervous system and social psychology. Although the field of social neuroscience has existed for some time, it started to become more popular about 20 years ago (Cacioppo & Decety, 2011; Harmon-Jones & Devine, 2003).

2.3.1 Psychophysiological Measures of Emotion

The autonomic nervous system (ANS) is part of the peripheral nervous system (PNS), and is composed of the sympathetic nervous system (SNS), which controls activation, and the parasympathetic nervous system (PN). The SNS and PN work together to control the body's unconscious actions. The SNS is associated with activation or priming the body for action, whereas the PN controls relaxation (Mauss & Robinson, 2009). Electrodermal and cardiovascular responses are most commonly used as measures of ANS activation. These tend to be measured using heart rate (HR) and electrodermal activity (EDA). Some researchers argue that there is an autonomic specificity of basic emotions, i.e. different emotions are characterised by different autonomic response patterns (Stephens, Christie, & Friedman, 2010). However, others argue that the evidence for autonomic specificity is limited and that it is better to think of ANS response in a more general sense, as physiological arousal (Cacioppo et al., 2000). In this thesis, EDA is treated as a more general measure of emotions. In line with Cacioppo et al., the valence of the emotional response, i.e. the degree to which the emotional response is positive of negative, is not assumed to be captured by recording EDA.

EDA, usually measured using skin conductance response (SCR), is used to measure ANS response, and has been one of the most widely used measures in psychophysiological history (Dawson, Schell, & Filion, 2007). It works by sending a small current across two electrodes places on the surface of the skin. Small changes in skin resistance, due to a response to external stimuli, are measured. Any change in conductance response as a result of presentation of a stimulus tends to occur between one and four seconds after the presentation of the stimulus. It has been used extensively to study people's emotional responses to visual stimuli (Bianchin & Angrilli, 2012; Burriss, Powell, & White, 2007; Jun, Ou, Oicherman, & Wei, 2010). In this thesis, as SCR is a measure of EDA, it is treated as a general measure of arousal, or affective response. No assumptions are made as to the type or valance of the emotional response, in line with the interpretation of Cacioppo et al. (2000).

HR is also considered a good measure of ANS activity (Cacioppo et al., 2000). HR has also been used is a large body of research studies to assess emotional arousal in response to visual stimuli (Fernández et al., 2012; Gu, Wong, & Tan, 2012; Reinerman-Jones, Taylor, Cosenzo, & Lackey, 2011). Cacioppo et al. (2000) found that there was greater heart rate acceleration as a result of fear, anger and sadness than disgust. They also found larger heart rate responses for anger and fear than happiness, as well as a greater response for fear than sadness. Again, it is important to caution over interpretation of this measure of ANS and instead consider it another general measure of physiological arousal.

As both HR and EDA are considered general measures of arousal, it is possible that any recorded change in ANS activity is due to a reaction to an element in the landscape, other than a wind turbine. To ensure that any physiological changes are attributed to the correct stimuli, it is necessary to use a measure of visual attention. The use of eye tracking equipment to measure has a long history in visual attention research (Holmqvist et al., 2011) and would be ideal in this situation. Eye tracking has also been used in conjunction with measures of emotional arousal such as SCR and HR in several previous studies (Felmingham, Rennie, Manor, & Bryant, 2011; Helminen, Kaasinen, & Hietanen, 2011; Wieser, Pauli, Alpers, & Mühlberger, 2009).

2.3.2 Eye-tracking

Eye tracking has been used to study a wide variety of research questions, from neuroscience to visual search tasks (Duchowski, 2002). Understanding how and where people focus their visual attention can give great insight into cognitive processes (Rayner, 1998, 2009). Marketing research has been carried out using eye tracking to study the visual search patterns of shoppers in supermarkets (Chandon, Hutchinson, Bradlow, & Young, 2009), as well as visual search patterns of those looking at print and television advertisements (Wedel & Pieters, 2008). Eye tracking has also been used to study the differences between experienced and novice drivers, in terms of where they focus their attention (Gegenfurtner, Lehtinen, & Säljö, 2011). The use of eye tracking in landscape representation research is more limited, though it has been used by some researchers to study landscape perception and exploration studies (De Lucio, Mohamadian, Ruiz, Banayas, & Bernaldez, 1996; Dupont et al., 2013).

Eye movements are made up of a series of saccades and fixations. A fixation is when the eye stops moving for a duration of 200-300ms. Saccades are fast movements of around 30-80ms as the eye moves from one fixation to another (Holmqvist et al., 2011). Through analysis of the number of fixations, as well as the duration of fixations on areas/objects of interest, it is possible to get a picture of where people focus their visual attention (Nuthmann & Henderson, 2010). Combining this information with time data, it would be possible to assess whether changes in ANS, as measured by EDA and HR, occurred directly after a participant fixated on a wind turbine in the visualisation. This information could be used to draw conclusions about whether a computer simulation is as realistic as a video recording.

2.4 Methodological Approach to Current Research

The three studies that are discussed in this thesis were designed to complement each other and to address some of the methodological concerns that have been discussed in this chapter (see figure 2.1 for a visual representation). Studies 1 and 2 work as pair. They were both laboratory experiments using videos of moving wind turbines landscapes, with objective psychophysiological measures to assess participant responses (see sections 3.2 and 4.2 for full methodological details). The only difference between the two studies is that Study 1 used videos of a real landscape in the UK, while Study 2 used videos of an animated computer simulation of the same landscape. Study 3 used an online survey to explore visual preferences for wind turbine extension layout options, using animated 2D photorealistic and simulated wind-turbine landscapes (see section 5.2 for full details).

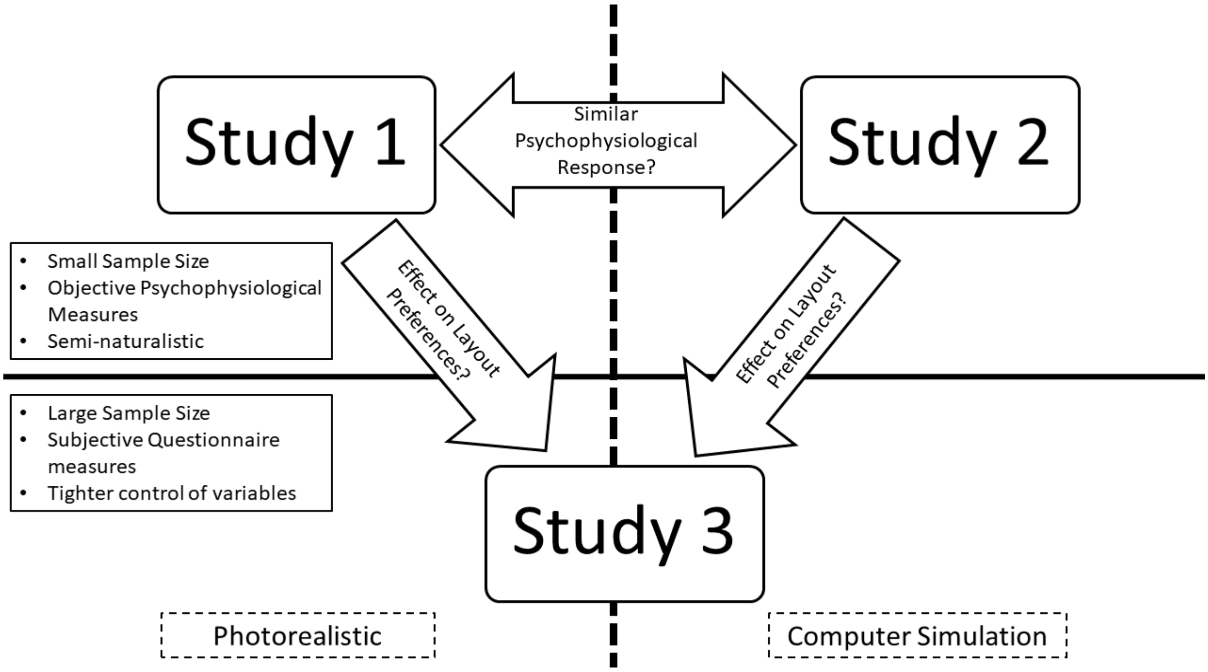


Figure 2.1 Methodological Overview of Studies

The first two studies were designed to address three issues: 1) the subjective response measures, e.g. surveys, or interviews, that have been used in previous research (e.g. Jones & Eiser, 2009; Ladenburg & Krause, 2011; Molnarova et al., 2012), 2) the static images that have been used in previous research (e.g. Dupont et al., 2013; Meitner, 2004; Roth, 2006), and 3) whether people respond similarly to computer simulations of wind-turbine landscapes (see Bishop & Rohrmann, 2003; Lange, 2001; Rohrmann et al., 2000 for discussions on the topic of realism of simulations).

Though studies 1 and 2 addressed the issued listed above, there were several drawbacks to their design. While they contained relatively large samples for experiments using psychophysiological measures such as SCR and eyetracking measures (e.g. Bianchin & Angrilli, 2012; Foulsham, Walker, & Kingstone, 2011; Maehr, Watts, Hanratty, & Talmi, 2015; Reinerman-Jones et al., 2011; Risko, Anderson, Lanthier, & Kingstone, 2012), the sample sizes were small compared to research using subjective measures (e.g. Jones et al., 2011; Kaldellis, Kapsali, Kaldelli, & Katsanou, 2013; Tampakis & Tsantopoulos, 2013). The use of objective measures of response also didn't allow for explanation of any differences in the responses to the videos of photorealistic and simulated wind-turbine landscapes.

Study 3 was designed to address some of the shortcomings of the first two studies. It used an online survey to assess visual preferences for wind turbine extension options, which allowed for a larger sample of participants. This method also allowed for the collection of subjective data to explain the factors that affected participants' visual preferences. Lastly, it allowed for a comparison of ratings of the photorealistic and computer-simulated images.

2.5 Summary

Visual representations of landscape have a long history in research and as part of environmental impact assessments. Various different methods have been used, including; wireframe models, photomontages, scaled 3D models, as well as 3D computer simulations. Most of the research comparing these methods to each other or to real site visits show photomontages and 3D computer simulations to be the most representative of the real landscapes (Berry et al., 2011; Meitner, 2004; Oh, 1994). However, the findings have been somewhat mixed with positive and negative aspects to both methods. Further, with respect to wind farms, the movement of the turbine blades is particularly important and something that is frequently overlooked by researchers (Bishop & Miller, 2007; Bishop, 2002)There is also an over reliance on survey data and a pervasive use of static 2D photomontages, which may objectivity and realism respectively. Some of these issues could be addressed by using 3D computer simulations to systematically assess the complex interactions of physical characteristics (Devine-Wright, 2005a; Lange, 2011).

While the flexibility of 3D simulations would be ideal for assessing the visual impacts of wind farms, it is important to have an objective measure of the realism and validity of such simulations. To test for real-world validity, physiological responses to the simulation could be compared with responses to a video of a real wind turbine landscape. EDA could be used to check to see whether participants react similarly in both conditions, while eye tracking can be used to analyse their visual attention. If the analysis shows that participants have similar physiological reactions in both cases, using 3D computer simulations as a tool to assess CLVI would be justified. If not, then dynamic photomontages may be a better tool for this assessment.

3 Physiological Responses to Wind Turbines in a UK Landscape

3.1 Introduction

Chapter 1 outlined the importance of visual impact in guiding planning applications for wind turbine developments. While there are several important factors that contribute to opposition towards wind farms, including; wildlife impacts, noise levels, community-developer trust, the landscape and visual impacts are consistently cited as one of if not the most important factor for opposition to proposed developments (Molnarova et al., 2012; Pasqualetti, 2011; Saidur, Rahim, Islam, & Solangi, 2011; Tsoutsos et al., 2009). With regards to the planning process, any wind farm proposal must include a landscape and visual impact assessment (LVIA) as part of its environmental impact assessment (EIA), usually including photomontages of the proposed development from representative viewpoints, as well as a map showing the zone of theoretical visibility (ZTV) of the wind turbines (Entec, 2008; Scottish Natural Heritage, 2006). This highlights the importance placed on the landscape and visual impact of proposed wind farm developments in the planning process.

The potential landscape and visual impacts are the predominant reasons for community opposition, and thus why developers' applications for wind farms are denied (Molnarova et al., 2012; RenewableUK, 2014; Wolsink, 2007b). Given the importance of these impacts for community opposition and, in turn, planning application refusal, further research into the factors that affect and contribute to the landscape and visual disamenity is warranted. As such, a greater understanding of the landscape and visual impacts of wind farms could help to inform future wind-farm developments so as to minimise the disamenity created, thus increasing the chances of approval.

Chapter 2 discussed the various methods that have been used in previous research into the visual impact of wind turbines on the landscape. The methods used in previous research have included interviews (e.g. Jerpåsen & Larsen, 2011; Pedersen, Hallberg, & Waye, 2007), surveys (e.g. Jones & Eiser, 2009; Ladenburg, Termansen, & Hasler, 2013), as well as different methods of visual representation. Most of the studies using visual representations have used static photomontages (e.g. Molnarova et al., 2012; Tsoutsos et al., 2009), or static computer simulations (e.g. Berry, Higgs, Fry, & Langford, 2011; Kokologos, Tsitoura, Kouloumpis, & Tsoutsos, 2014). Several studies have tried to assess the validity of using these methods to represent landscapes in general (e.g. Bishop & Rohrmann, 2003; Dupont, Antrop, & Van Eetvelde, 2013; Sevenant & Antrop, 2011), while others have focused in particular on representations of wind turbines in the landscape (e.g. Berry et al., 2011). Bishop and Rohrmann (2003) found that while certain aspects of a 3D computer simulation park were valid, in several ways responses to the simulation did not correspond with that of the real park. Dupont, Antrop, and Van Eetvelde (2013) suggest that panoramic photos of landscapes are more valid than other types of photos, while Sevenant and Antrop (2011) conclude that standard photos appear to be more realistic than other photos.

Berry et al. (2011) used a survey to assess the several methods of representing a wind farm (ZTV, wireframe, photomontage, and GIS-based 3D landscape visualisation). Participants in the study consistently ranked the photomontage the highest on a range of metrics, e.g. clarity, effectiveness, and accuracy. This was followed by the computer simulation (either animated or still) on all of the metrics.

Maehr et al. (2015) used skin conductance response (SCR) and questionnaires to assess participants' emotional responses to photomontages of wind turbines and three other manmade objects (pylons, power plant, and church). Participants rated wind turbines as pleasant as churches, though less calming. They also rated the pylons and power plant as significantly less pleasant than the wind turbines. While this study used SCR to try to objectively measure participants' emotional responses to wind turbines and other manmade structures, the use of static photomontages may affect the ecological validity of any findings. Also, as the authors acknowledged, they used a small sample of approximately 20 students in their study, which resulted in large margins of error.

Dupont et al. (2013) used eye-tracking to examine the effect of photographic properties on landscape characteristics and found that people visually process landscapes differently depending on the type of photo used (e.g. panoramic, wide angle, standard, zoomed). However this finding is contradicted by earlier research carried out by Sevenant and Antrop (2011), which supports the use of standard photos in studies into landscape preference and perception. The current study used standard videos which pan across a wind turbine landscape, which may allow for a good compromise between the two. Further, the movement of the videos, in particular the movement of the wind turbine blades should be more naturalistic than static images, and therefore allow for greater ecological validity. The ecological psychology approach to visual perception highlights the importance of movement for perceiving and understand our environment (Gibson, 1986). Bishop (2002) also states that moving wind turbines are perceived as being between 10% and 20% larger than if they are stationary.

This study uses psychophysiological measures (eye tracking, and skin conductance response) in conjunction with videos of a real wind-turbine landscape with moving turbines. The use of films to elicit an emotional response and measuring that response using psychophysiological measures is a common approach in psychological research into emotion (Fernández et al., 2012; Gross & Levenson, 1995; Stephens et al., 2010). This study aims to use a similar approach to address some of the weaknesses of previous research into the landscape and visual impact of wind turbines. This will be done in two ways; 1) naïve participants are presented with videos instead of static photos, which should result in a more naturalistic response, and 2) the use of eye-tracking and skin conductance response should give a more objective measure of the visual impact of the wind turbines, and people's emotional response to that impact, than static images.

3.2 Methods

3.2.1 Participants

Participant consisted of 75 psychology students from the University of Sheffield. The mean age of participants was 19.77 (SD = 3.27), with 80% of participants being female. Participants were given course credits for taking part in the study. The sample size in this study was determined largely by resources available. These include the cost of materials and running the experiment, as well as the availability of facilities and equipment used. However, the number of participants in this study compares favourably with published research that has used eye-tracking, physiological measure, or both. When carrying out a review of the literature, the number of participants in these studies ranged from 11 to 60 participants, with most being between 20 and 30 (Codispoti & De Cesarei, 2007; Felmingham et al., 2011; Foulsham et al., 2011; Gu et al., 2012; Kimble, Fleming, Bandy, Kim, & Zambetti, 2010; Maehr et al., 2015; Nummenmaa, Hyönä, & Calvo, 2006; Pan et al., 2004; Risko et al., 2012; Van Orden, Jung, & Makeig, 2000; Wieser et al., 2009).

3.2.2 Design

This study used a between subjects design, with participants being grouped according to their wind-turbine preference, as measured by a pre-screening questionnaire, comprised of 10 items commonly found in the UK landscape, including a question on wind turbines. The two main dependent variables assessed in this study are wind turbine fixation time (secs)/size (pixels), as well as the mean number of skin conductance responses (SCRs) while watching videos of wind turbines.

Data cleaning: Three participants were removed from the eyetracking analysis, as their eyetracking data was unusable due to inaccuracies (n = 72). Eleven participants were removed from the SCR analysis due to non-responses (n= 64).

3.2.3 Apparatus

1) **Video presentation & Eye Tracking**

SR research experiment builder was used to create and present the experiment. The videos were presented to participants on a 19" CRT monitor that was a distance of 50cm from the head mount used to keep participants' heads stable. An SR research Eyelink 1000 was used to track participants' visual focus while watching the videos of the landscape. The eyetracking was monocular (predominantly the left eye) with a sample rate of 1,000 HZ. Pupil threshold values were maintained between 70 and 120, and corneal reflection thresholds were between 200 and 240. Participants went through a 9-point calibration and validation process before beginning the experiment. During the validation process, error values were maintained at < 0.5° average and < 1.0° maximum. These settings were recommended by the SR Research in their user manual and at a workshop on using eye tracking with dynamic stimuli (SR Research, 2008, 2015).

2) Electrodermal Activity

Biopac's Acqknowledge 4.1.1 software and a Biopac MP36R were used for the acquisition of the electrodermal activity data. Biopac EL507 pre-gelled snap on electrodes were placed on the participants' index and middle fingers on the first phalanx, and the electrodes were connected to the MP36R system using an SS57L electrodermal activity lead. To sync the data with the videos, the experiment computer was connected to the MP36R with a serial port cable and a transistor-transistor logic (TTL) pulse was used to mark the start and end of each video.

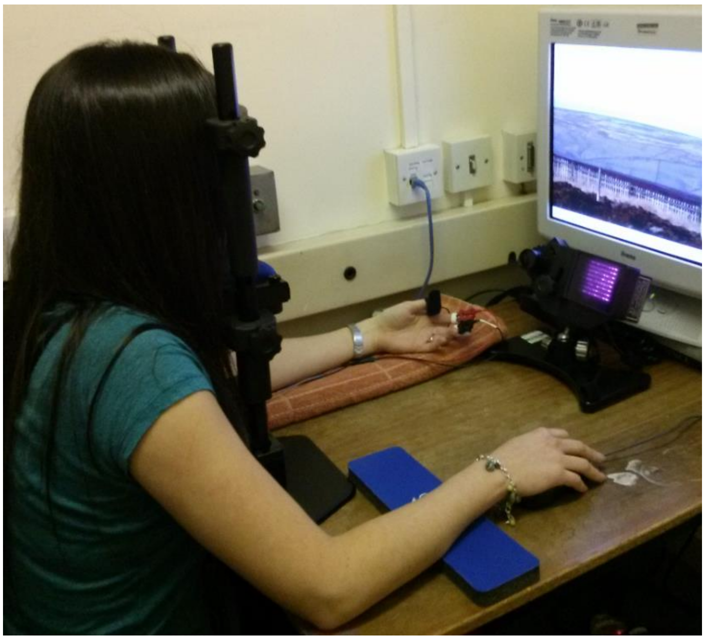


Figure 3.1: Experimental Setup

3.2.4 Materials

Participants completed four different questionnaires as part of this experiment. These are; 1) A pre-screening questionnaire on items in a landscape 2) The Revised New Ecological Paradigm (NEP), 3) The Positive and Negative Affect Schedule, 4) Survey on attitudes to wind turbines

1) **Pre-screening questionnaire**

   This consisted of ten items that are commonly found in the UK landscape, five of which were manmade (stone wall, electricity pylon, fence, telephone pole, and wind turbine) and five of which were natural (tree, hedgerow, heathland, grazing sheep, grass field). The responses to the 'wind turbine' item was used for grouping the participants. All of these items were contained within the video that was presented to participants. Participants rated the extent to which they liked the items on a 5-point Likert-type scale from 'Dislike' to 'Like' (see Appendix A for full text of the survey).

2) The Revised New Ecological Paradigm (NEP)

This is a 15-point scale that assesses people's ecological world view. Originally published in 1978, the present studied used the revised version from 2000 (NEP, Dunlap, Liere, Mertig, & Jones, 2000). The 15 items asks participants the extent to which they agree with statements about the relationship between humans and the environment, and is generally used as a unidimensional measure of environmental attitudes (Hawcroft & Milfont, 2010). The eight odd-numbers items are worded so that agreement indicates a proecological world view, while the even-numbers are the opposite. Participants rated the extent to which they agree with the items on a 5-point Likert-type scale, from 'strongly disagree' to 'strongly agree'. The revised NEP scale was validated using a representative sample of 676 Washington State Residents. A principal-components analysis showed that all 15 items loading heavily (.40 to .73) on the first unrotated factor, with a Cronbach's alpha of .83. Responses to items on this scale were coded from 1-5, with '5' representing the highest level of agreement (with the even-numbered items reverse coded). These scores were then summed for each participant, giving a range of 15 to 75. The full survey is listed in Appendix A.

3) The Positive and Negative Affect Schedule (PANAS)

This is a 20-item measure of positive and negative affected developed in 1998 (PANAS, Watson, Clark, & Tellegen, 1988). The PANAS consist of two 10-point scales that are used to measure positive affect (PA) and negative affect (NA). The 10 descriptors for the PA scale are: *attentive, interested, alert, excited, enthusiastic, inspired, proud, determined, strong, active*, and the 10 descriptors for the NA scale are: *distressed, upset, hostile, irritable, scared, afraid, ashamed, guilty, nervous, jittery*. The scale was validated using undergraduate psychology students at Southern Methodist University, with a Cronbach's alpha ranging from .86 to .90 for PA, and .84 to .87 for NA. Items on the PANAS are measured using a 5-point Like-type scale from 'Very slightly or not at all' to 'Extremely'. These responses were scored

1-5 and summed for PA and NA, with a score range for each of 10-50. The PANAS is a widely used measure of affect and has been validated with a UK adult population (Crawford & Henry, 2004). The full survey is listed in Appendix A.

4) **Survey on Attitudes to Wind Turbines**

This is a 15-item questionnaire that assessed participants' attitudes to wind turbines. The items included were based on what previous research found to be predictors of wind turbine acceptance (see chapter 1). The survey was composed of questions on three sections; wind turbine characteristics, experience and beliefs, and landscape quality/type, with five question in each section. The full survey is listed in Appendix A.

During the experiment, participants were shown two videos that pan across an area near Stockbridge, UK (see figure 3.2. below). Each video was 1280x720 pixels, 30 frames per second and approximately three minutes in duration, with one video panning left-to-right and the other right-to-left. The presentation of the videos was counterbalanced to avoid any order effect.

Figure 3.2: Still from Video Presented During Study 1

3.2.5 Study Area

The study area is located at the edge of the Peak District National Park, near Stocksbridge, UK (Latitude: 53.505513, Longitude: -1.735582). The chosen study area contains three wind farms: 1) Hazlehead, 2) Blackstone Edge, and 3) Royd Moor. Hazlehead has 3 x 2MW turbines with rotor diameters of 82m and a tip height of 100m, while Blackstone Edge has 3 x 2.5MW turbines with rotor diameters of 80m and a tip height of 101m. Royd Moor, the oldest of the three wind farms, has 13 x 0.45MW turbines with rotor diameters of 37m, and a tip height of 54m. The combination of three different wind power projects of different ages, wind turbine designs and rotor sizes, combined with the close proximity to the Peak District National Park, make this location ideal for the assessment of people's responses to the CLVIs of wind power projects. See Figures 3.4, 3.5, 3.6 and 3.3 for views the three wind farms from the video recording site and a map of the study area. Figure 3.7 shows a scale model of the sizes of the wind turbines used in this study.

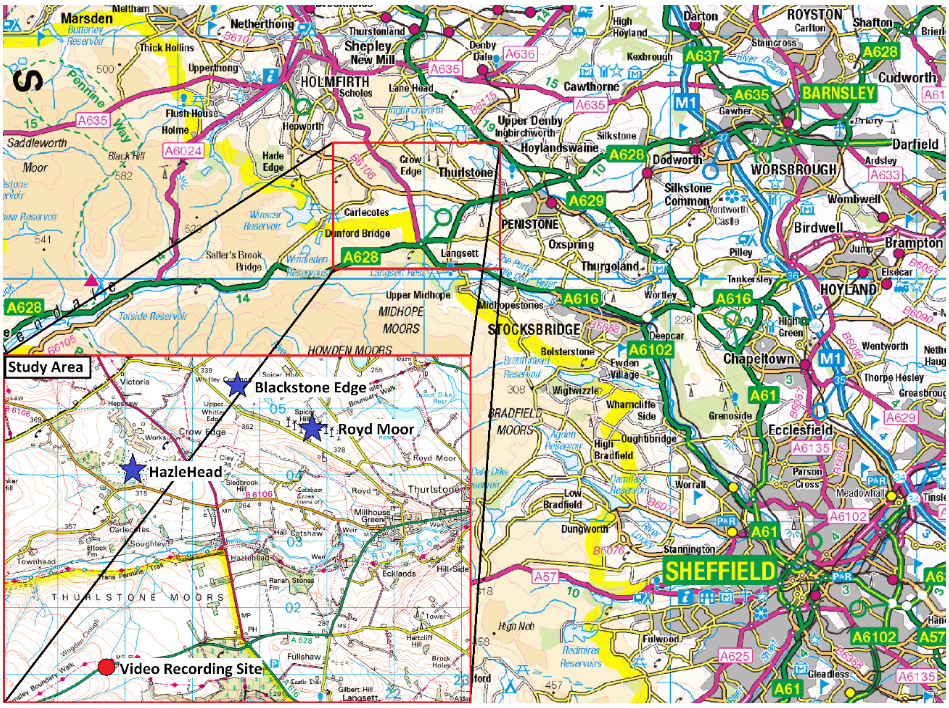


Figure 3.3: The Locations of the Video Recording Site and Wind Farms

Figure 3.4: View of Hazlehead Wind Farm from the Recording Site

Figure 3.5: View of Blackstone Edge Wind Farm from the Recording Site

Figure 3.6: View of Royd Moor Wind Farm from the Recording Site

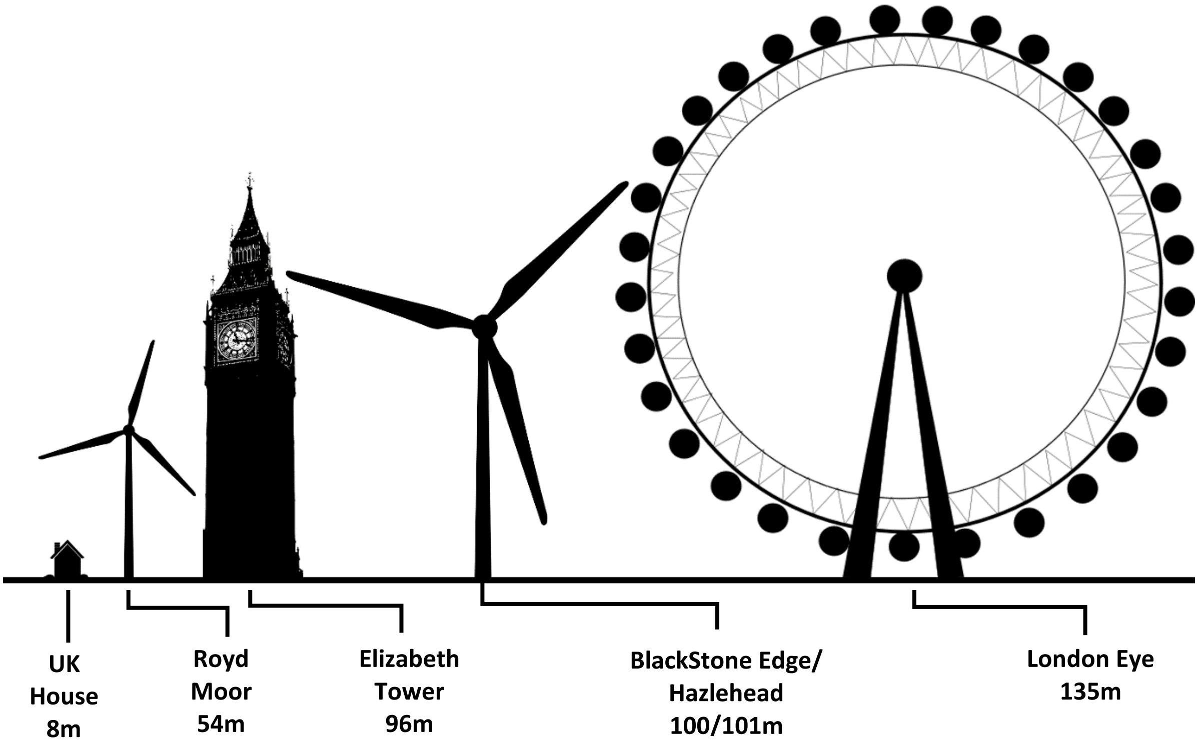


Figure 3.7: Scale of Wind Turbines used in Study

3.2.6 Procedure

Participants completed an online pre-screening questionnaire that asked them to rate the extent to which they like/dislike 10 items commonly found in a UK landscape, using a five-point Likert-type scale. Half of these items were man-made, e.g. stone wall, electricity pylon and half were natural e.g. tree, hedgerow (for a list of the items, see Appendix A.) Participants were then invited to take part in an experiment in a controlled laboratory situation at the University of Sheffield. Participants were not informed that the experiment was assessing responses to wind turbines in the landscape, but rather that it was more generally assessing their responses to the landscape.

In the first part of the experiment, participants completed the new ecological paradigm (NEP) questionnaire, as well as the positive and negative affect schedule (PANAS) to assess their emotional state and control for any influence on their electrodermal activity (EDA) (see Appendix A). Participants then watched the landscape videos with their heads in the eyetracking head mount and their left arm placed on the desk with the electrodes connected to their fingers (see figure 3.1). After the setup and calibration process, participants were instructed to stay as still as possible and to simply watch the videos. At this point the experimenter left the room and the participants started the first video with a mouse click. Participants had the opportunity for a short pause after the first video (but were instructed to keep their head in the same position. Once ready, participants started the second video with another mouse click.

After watching both videos, participants were asked to compete the PANAS again. Once completed, participants were informed of the true focus of the experiment and then asked to answer the final questionnaire. Participants were given the opportunity to ask any questions they wished before and after completing the final questionnaire and informed that they could withdraw at any point.

As the final questionnaire asked participants about their attitudes to wind turbines, it was felt that it was best to inform them of the true nature of the study beforehand. In a review paper on the use of deception in psychological experiments, Hertwig and Ortmann (2008) analyse the potential impact of deception on experiments. Based on the findings from previous studies on deception, they argue that it is possible for deception to breed suspicion among participants, which in turn impairs the experimental control and has the potential to negatively impact the research outcomes. In the present study, it was believed that asking them to complete a questionnaire about their wind turbine preferences without revealing the nature of the experiment may have bred suspicion, and ultimately impacted the research findings.

3.3 Results

3.3.1 EDA Data Processing

Several steps were taken in processing the EDA data in order to assess participants' skin conductance response (SCR), in accordance with guidelines produced by the Behavioural Brain Sciences Centre, University of Birmingham (Braithwaite, Watson, Robert, & Mickey, 2013). These are outlined on the next page.

1) Resample Waveform

The EDA data was recorded at a sample rate of 2000 samples/second. This was resampled to 25 samples/second

2) Digital Filter

A low pass filter was used at 1 Hz to eliminate high frequency noise components of the signal

3) Locating SCR

The settings used for SCR were the following;

- Construct phasic EDA using Smoothing Baseline removal
- Baseline estimation window width: 5 seconds
- SCR Threshold 0.02 umho
- Reject SCRs under 0% of max

Using the TTL signal, the number of SCRs was calculated for the duration of the videos when the turbines were present (approximately 1 minute). The number of SCRs were also calculated for the same duration directly before the presence of the turbines for the video that panned from right to left and directly after for the video that panned left to right, to ensure that there was no order effect. Mean values were calculated for the SCR of participants to both videos for the turbine present and turbine absent conditions.

3.3.2 Eye-tracking Data Processing

SR Research data viewer was used to process the raw eye-tracking data. In order to track the wind turbines as the videos panned across the landscape, dynamic areas of interest were created. Dynamic areas of interest enable a researcher to modify the area of interest in a video on a frame by frame basis to ensure that the object of interest as it moves across the screen (see figure 3.8 on the next page).

3.3.3 Likert scale data vs Like-like data

There is much debate as to how to treat Likert and Likert-like data. Likert scales are composed of multiple items, often containing up to 20 items which are combined to create a score for a trait or behaviour (Wigley, 2013). The NEP and PANAS are examples of Likert scales used in this research, as they are composed of multiple items. Some researchers argue that Likert scales should be treated as ordinal level variables (Hawcroft & Milfont, 2010), however others argue that they can be treated as interval data (Carifio & Perla, 2007). In this study, and the subsequent two studies in the thesis, multi-item Likert scales, such as the NEP and PANAS, are treated as interval data and analysed as such.

However, the responses to the item in the pre-screening questionnaire, on the extent to which participants like wind turbines in the UK landscape, have not been treated as interval level. As it is a single 5-point item, it should be treated the same way as a Likert scale that is composed of multiple items (Carifio & Perla, 2007). Instead, this item is used as a grouping variable, and analyses have been conducted to see if there are any differences between the groups on perceptual of physiological measures.

Figure 3.8: Screen Shots of DAOIs

The total fixation duration was calculated for each of the wind farms; Hazlehead, Blackstone Edge, and Royd Moor. The fixation times were then divided by the size of the areas of interest (number of pixels) to account for differences in the overall size between the wind farms.

3.3.4 Descriptive Statistics

Table 3.1: Descriptive Statistics by Turbine Preference Group

Turbine Preference Group	Really Dislike	Dislike	Neutral	Like	Really Like	All
Number	6	24	15	21	9	75
Age (Mean)	18.333	20.250	19.467	19.857	19.778	19.537
SD	0.516	4.336	2.850	2.496	3.492	2.738
SCR Turbs (Mean)	4.917	2.921	3.179	3.353	4.750	3.824
SD	2.871	1.895	3.434	2.566	2.138	2.610
SCR No Turbs (Mean)	5.833	3.816	3.321	3.176	4.250	4.079
SD	3.401	2.244	3.291	2.325	2.619	2.702
Hazlehead Fix. Dur. (Mean)	0.134	0.055	0.081	0.065	0.095	0.086
SD	0.077	0.023	0.047	0.033	0.052	0.046
Black. Edge Fix. Dur. (Mean)	0.131	0.066	0.067	0.056	0.088	0.082
SD	0.112	0.023	0.031	0.024	0.049	0.048
Royd M. Fix. Dur. (Mean)	0.224	0.164	0.179	0.171	0.230	0.194
SD	0.104	0.037	0.062	0.030	0.046	0.056

3.3.5 New Ecological Paradigm (Revised)

The revised new ecological paradigm (NEP) is a 15-item scale that is used to measure environmental attitudes (Dunlap et al., 2000; Dunlap, 2008). Participants were asked to rate their level of agreement with the fifteen statements on a 5-point Likert scale from strongly disagree to strongly agree. Agreement with the eight odd number items and disagreement with the seven even number items indicates a pro-ecological world view. The mean NEP score for this study was 52.76 (SD = 6.04).

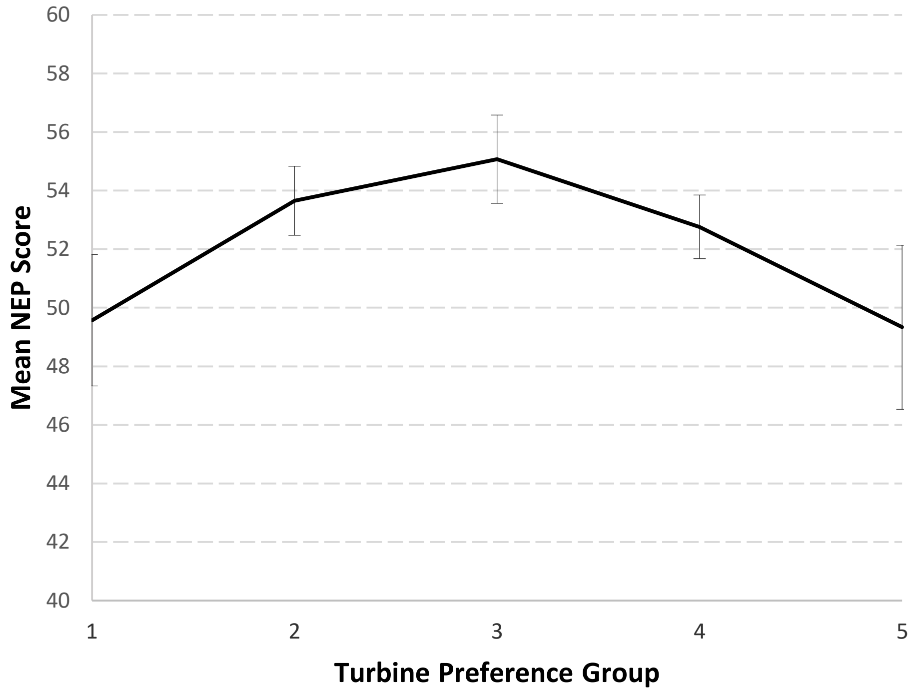


Figure 3.9: Mean NEP Score by Turbine Preference Group

As the data didn't meet the requirements for parametric analysis, due to non-normality of the dependent variable, the data were analysed using a non-parametric test. A Kruskal-Wallis H test showed no significant difference between the five groups on their scores on the new ecological paradigm scale ($\chi^2(4) = 6.322$, $p = .176$). Post-hoc tests using the Bonferroni correction revealed that there were no significant differences between any pair of the five groups ($p > .05$). The results suggest that, although there appears to be a quadratic trend with higher NEP scores for those who neither strongly like or dislike wind turbines, the differences between any two of the five groups is not particularly large. The largest mean score was 55.07 for group 3, and the smallest mean score was 49.33 for group 5. This range shows that all of the participants were moderately pro environmental (Hawcroft & Milfont, 2010).

3.3.6 Positive and Negative Affect Schedule

The positive and negative affect schedule is a 20-item scale that is comprised of two mood scale, to measure positive and negative affect (David Watson, Clark, & Tellegen, 1988). Participants were asked to rate their level of agreement with the twenty statements on a 5-point Likert scale from strongly disagree to strongly agree. They were asked to complete the PANAS scale before and after watching the video. The mean positive affect was 30.01 (SD = 7.23) before watching the video and 27 (SD = 8.56) after. The mean negative affect was 14.32 (SD = 4.65) before watching the video and 14.24 (SD = 5.141) after. These scores are consistent with Watson et al. (1988), who suggest that the normal population should have a mean positive score of 29.7 (SD =7.9) and a mean negative score of 14.8 (SD = 5.4).

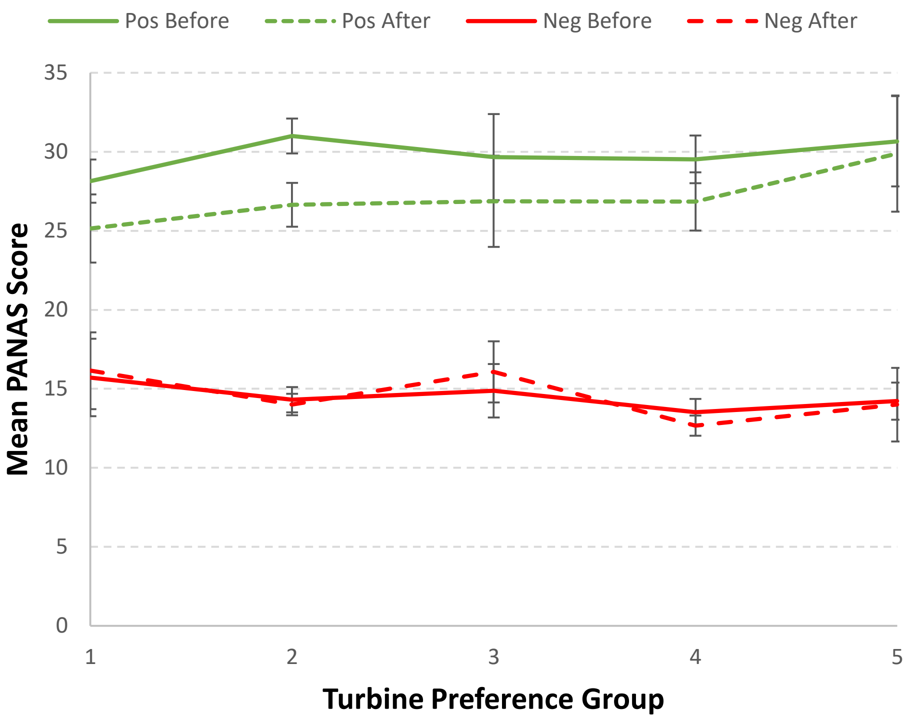


Figure 3.10: Mean PANAS Scores by Turbine Preference Group

As the PANAS scores were not normally distributed, non-parametric analyses were used. Wilcoxon Signed-Ranks tests indicated that positive affect was significantly higher before the experiment than afterwards ($Z = -4.335$, $p < .001$), and that there was no significant difference in negative affect before and after the experiment ($Z = -.694$, $p = .488$). While there was a significant difference in the positive affect of the participants, there appears to be no pattern across the five groups. Therefore, it is possible that this effect was due to fatigue or boredom caused by participation in the test.

3.3.7 Skin Conductance Response

The SCR scores were not normally distributed and therefore a non-parametric analysis was used. A Wilcoxon signed rank test found that there was no statistically significant difference in the skin conductance response (SCR) between when the turbines was present during the video and when they were not ($Z = -1.156$, $p = .248$). Trend analyses showed quadratic trends with large effects size close to statistical significance across the groups for SCR when the turbines are present ($F(1, 63) = 4.013$, $p = .05$, $\omega^2 = .46$), and when the turbines are absent ($F(1, 63) = 3.708$, $p = .059$, $\omega^2 = .39$).

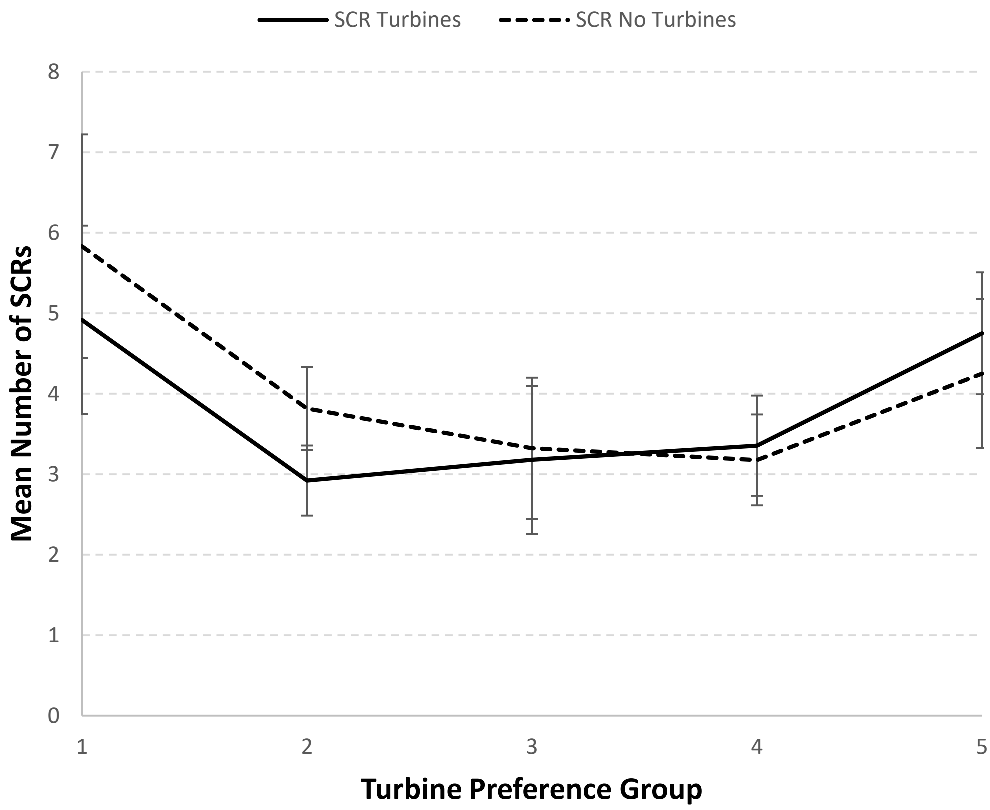


Figure 3.11: Mean SCR Scores by Turbine Preference Group

While there was no significant difference between the SCR while the turbines was present in the video and while they were absent, there are clear quadratic trends for both of these across the five groups. Further, the mean SCR is higher while the turbines are present for the group who really likes them in the landscape, while the mean SCR is higher while the turbines are absent for the group who really dislikes them in the landscape. Given that the participants are not from the area shown in the video, nor are they faced with potential development near their house, the general trend is in line with what might be expected based on the groups' preference (Devine-Wright, 2009).

3.3.8 Eyetracking

A two-way ANOVA revealed a significant main effect for fixation time/size ($F (2, 66) = 77.387$, $p < .001$, $\eta^2 = .701$). Post-hoc tests using the Bonferroni correction revealed that the fixation duration was significantly longer for the Royd Moor wind farm when compared with Blackstone Edge ($p < .001$) and Hazlehead ($p < .001$). Further, there was no significant difference between Blackstone Edge and Hazlehead ($p = 1$). No interaction effect was found between wind farm and turbine preference grouping ($F (8 ,134) = .59$, $p = .785$, $\eta^2 = .034$). As two of the assumption for a two-way ANOVA were violated – normality of the dependent variable, and homogeneity of variance, non-parametric tests were also run, which confirmed the results. A Friedman test showed a significant difference between the fixation times of each wind farm ($\chi^2 (2) = 82.861$, $p < .001$). Post hoc Wilcoxon signed ranks tests with the Bonferroni correction showed that fixation duration was significantly longer for Royd Moor than Blackstone Edge ($z = -7.183$, $p < .001$) or Hazlehead ($z = -7.194$, $p < .001$). Further, there was no significant difference in fixation duration between Blackstone Edge and Hazlehead ($z = -.196$, $p = .844$)

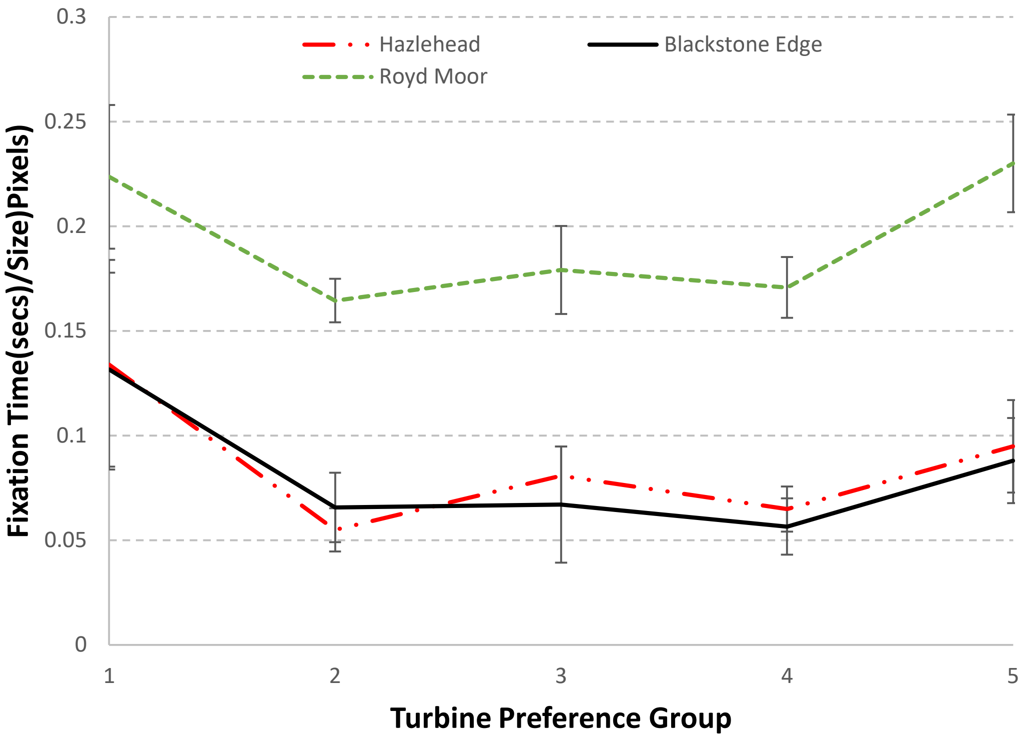


Figure 3.12: Mean Fixation Time/Size of Wind Farm by Turbine Preference Group

The results suggest that participants' visual attention varied according to the type of wind farm that was present in the video. The two wind farms with the large turbines, Hazlehead and Blackstone Edge, drew significantly less attention that the wind farm with a large number of smaller turbines (Royd Moor). Even when accounting for the overall size of the wind farm, it appears that a larger number of smaller wind turbines constitutes a greater visual impact than fewer but larger wind turbines.

3.3.9 Survey on Attitudes to Wind Turbines

At the end of the experiment, participants were informed that the true purpose of the study was to look at people's responses to wind turbines in the landscape. After been given the opportunity to ask any questions or to withdraw from the study, participants completed a 15-item survey on wind farms. There were five items on three different themes; turbine characteristics, experience and attitudes, and landscape quality/type (see Appendix A for a complete list of items).

3.3.9.1 Regression on survey items

A stepwise multiple linear regression was calculated to predict participants' rating of wind turbines in the landscape based on their answer to the 15-item survey. The 'Wind turbines negatively affect the beauty of the rural landscape' item was removed due to multicollinearity, as it had Pearson's correlation scores over 0.7 with several other variables. A significant regression equation was found ($F(1, 71) = 23.265$, $p < .001$), with an R^2 of .396. It was found that 'Wind turbines are too big' ($\beta = -.424$, $p < .001$) and 'I think more onshore wind turbines should be built in the UK' ($\beta = .28$, $p < .05$) were significant predictors of participant rating of wind turbines.

Table 3.2: Multiple Linear Regression on Survey Items as Predictors of Wind Turbine Preference

Survey Items	***b* (SE)**	***B* (T)**	***P***
Turbines are too big	-.413(.111)	-.424 (-3.732)	<.001
More onshore turbines should be built in the UK	.335(.136)	.28 (2.463)	.016
Model Summary: R^2 (Adjusted R^2)			.396 (.379)

3.4 Discussion

Environmental Beliefs

The results from the NEP scale suggest that all of the participants in the study had pro-environmental beliefs, with little variation across groups. The consistent pro-environmental scores across groups may be explained by the fact that this study was carried out using a university student sample. Using data from the British Household Panel Survey, Cotton and Alcock (2012) found that university attendance was positively correlated with a commitment to environmental sustainability. Hawcroft and Milfont (2010) carried out a meta-analysis of 69 studies that used the NEP and found that people from higher socio-economic status (SES) groups scored significantly higher than those from lower groups. The student sample is likely to be skewed in favour of higher SES and this may also help to explain the results. Another possible explanation for the lack of variance in NEP scores across groups is the issue of scale validity. Brennan, Binney, Aleti, and Parker (2014) argue that, while the NEP scale may be reliable, it may not be valid. They conclude that the items on the scale do not accurately reflect individual attitudes towards environment sustainability.

Affective Response

The results from the PANAS were in line with what is expected from the population (Crawford & Henry, 2004; David Watson et al., 1988). While there was a reduction in positive affect (PA) after the experiment, there is no particular pattern across groups. The reduction is likely a result of participant fatigue, as participants had to keep their head still for the duration of the videos. No significant differences were found between negative affect (NA) before and after the experiment. The findings suggest that there was no significant variation in emotion within the sample and that this can be excluded as a possible confounding variable when interpreting the SCR results.

The SCR results show a clear u-shaped pattern, with higher scores at either end. While the findings were not statistically significant, this quadratic trend accounts for a large proportion of the variance both while the turbines are present in the video, and also when they are absent. Further, those who dislike turbines have higher SCR scores when there are no turbines than when the turbines are present. Conversely, those who like turbines have higher SCR score when turbines are present, compared to when there are no turbines, though these differences are not statistically significant. These finding show that those at the extremes (like or dislike) have the greatest affective response to the videos, with response falling towards the more neutral groups. It is possible that the lack of significance is due to the small sample size, so some caution is necessary when interpreting the results. That said, the general trend in the findings may be explained in the context of the 'Green on Green' concept or the biophilia hypothesis.

Biophilia

'Green on Green' describes a situation in which people on opposing sides of an argument could be said to be supporting 'green' or pro-environmental beliefs. Warren, Lumsden, O'Dowd, and Birnie (2005) argue that wind power development is an unusual example of development in the landscape. Most conflicts between development and conversation tend to be focus on socio-economic benefits on the one hand, and environmental costs on the other, with strongly pro-environmental people positioned on the landscape conservation side of the debate. In the case of wind energy, environmentalists could argue in favour of their development as they are a clean, renewable source of energy. Equally, environmentalist could oppose the development of a wind farm on the basis of its impact of the landscape. This interpretation is further strengthened by the findings from the multiple regression, where 'wind turbines are too big' was found to be a significant negative predictor of wind turbine rating, while 'I think more onshore wind turbines should be built in the UK' was found to be a significant positive predictor'.

Popularised by Edward Wilson in 1984, the biophilia hypothesis posits that human beings have an innate bond with and preference for life and life-like processes (Kellert & Wilson, 1993). Biophilia is proposed to have evolved in humans due to biophilic responses resulting in a greater likelihood to survive and reproduce. As a result, humans have developed a genetic predisposition to positively response to nature. While there has been some criticism of the hypothesis, e.g. that it is quite broad and not well-defined, findings from several research fields show that people do respond affectively to life-like things such as animals, plants and landscapes. Further, these elements of nature can provide enjoyment and health benefits (Joye & de Block, 2011). Within the framework of the biophilic hypothesis, the higher responses from the like and dislike group could be interpreted as a greater biophilic response. This would explain why the participants respond to both the absence and presence of the turbines. They are responding to the landscape as a whole, with either an increased or decreased response when the turbines are present, depending on their group (i.e. whether or not they like wind turbines in the landscape). While the difference within the groups between the turbine and no turbine condition are not significant, the trend is the right direction if the results are interpreted in the context of the biophilia hypothesis. Further, given that the participants weren't connected to the area in the video, and therefore had no place attachment, as well as being a young pro-environmental sample, a large effect should not be expected.

Visual Impact

The eye-tracking data shows a clear difference in response to the different wind farms. Controlling for the area/size of the wind farms, it is clear that the participants spent significantly longer looking at the Royd Moor wind farm, than Blackstone Edge or Hazlehead. The latter two are quite similar in their layout, both having three turbines of approximately 100m in height, whereas Royd Moor consists of 13 turbines of 54m in height placed closer together (see figures 3.4 – 3.6 for the layouts and figure 3.7 for a comparison of scale).

Although there is a slight trend towards higher fixation times for the really like and really dislike group, no significant intergroup differences were found. It is clear that Royd Moor commanded more visual attention than the other two wind farms, however participants' rating of wind turbines did not appear to influence fixation time. As such, the intergroup differences in SCR can be attributed solely to an increased affective response to the stimuli, rather than increased exposure to the stimuli. Simply put, the increased SCR in the really like and really dislike groups was not caused by looking at the wind turbines for longer than the other groups, but is likely due to differences in their cognitive-emotional response to viewing the turbines. The findings are somewhat different to previous research that looked at the effect of the number of turbines on the visual impact (Ladenburg & Dahlgaard, 2012; Torres Sibille et al., 2009; Tsoutsos et al., 2009), however these studies focussed solely on number or size, rather than the interaction between the number and size of turbines. The results from the current study could be important in the context of the use of zones of theoretical visibility (ZTV) in environmental impact assessments of wind turbine developments.

A ZTV map illustrates the locations where a wind turbine development may be visible (Scottish Natural Heritage, 2006, 2012) and is considered good practice to include as part of a landscape and visual impact assessment (Scottish Natural Heritage, 2009). ZTVs are created using GIS software and map the potential visibility of wind turbines based on their height and the surrounding terrain. As such, larger wind turbines create a larger zone of theoretical visibility. Given the result of this study, a larger ZTV doesn't necessarily mean a larger visual impact on the landscape. If ZTVs were created for the three wind farms used in this study, Royd Moor would have the smallest ZTV dues to the small turbines. However, the eye tracking data shows that Royd Moor attracted considerably more visual attention from participants than the larger wind farms, Hazlehead and Blackstone Edge. These findings would suggest that the size of turbines is not the most important factor to consider when assessing the landscape and visual impacts of wind farm developments.

Strengths and Limitations

This study used novel psychophysiological methods to address the issue of landscape and visual impacts of wind turbines, particular cumulative impacts. The use of videos of a real landscape with real, moving turbines as the stimuli and the use skin conductance response and eye tracking provide objective measures of responses that are lacking in most of the research that has tried to assess the landscape and visual impact of wind turbines.

While the results of this study highlight the insights that can be gained from applying psychophysiological methods to understanding ,the landscape and visual impact of wind turbines, there are some potential weaknesses that need to be discussed. One of the most common issues with experimental psychological research is that the samples used may not be representative of the population of interested, frequently being comprised of predominately well-educated, mostly female, university students (Henrich, Heine, & Norenzayan, 2010). Age has been consistently shown to a significant effect on acceptance of wind turbines (Álvarez-Farizo & Hanley, 2002; Bishop & Miller, 2007; Devine-Wright, 2005a), with younger people tending to be more accepting of wind turbines Another important sample issue is that the participants weren't facing a real development near their home. Previous research has shown the influence that place attachment and equity and fairness have on people's attitude towards wind farm developments (Devine-Wright, 2005a, 2009, Wolsink, 2000, 2007b). It is possible that the results would have been different if the sample was drawn from a group of people in a community with an existing or proposed wind-farm development. While accepting these weaknesses, the methods used address some of the weaknesses in previous research in this area.

Conclusion

Using novel methods, the study has shown that people's ratings of wind turbines in the landscape and the layout of wind turbines appear to have an effect on people's psychophysiological responses to those wind farms. People who really like and really dislike wind turbines seem to show greater affective responses to videos of the wind turbines than do those with a more neutral attitude to wind turbines, though these findings are not quite statistically significant. Further, irrespective of how they rated wind turbines, participants spent significantly longer looking at Royd Moor wind farm that Hazlehead or Blackstone Edge.

The skin conductance response findings can be interpreted in terms of 'green on green' or the biophilia hypothesis, which is also supported by the responses in the attitudes survey. Those who either really dislike or really like wind turbines are both pro-environmental, but for different reasons. The findings from the eye-tracking data have important implications for landscape and visual impact assessments that are created as part of an environmental impact assessment for proposed wind farm developments. Fewer but larger turbines may have less of a visual impact than smaller, but more numerous turbines.

The psychophysiological methods used in this research would lend themselves well to assessing people's reactions to other methods of visualising wind turbines. Several papers have suggested that computer visualisations could be used to model landscapes for interactive design and planning, as well as research (Lange & Hehl-Lange, 2005; Orland et al., 2001; Olaf Schroth, Lange, & Schmid, 2005). While computer simulations provide an ideal way to create and control any variables that may contribute to the visual impact of a development, there may be an issue with their ecological validity. Previous research has asked participant to rate their preference for various GIS-based visualisation tools (Berry et al., 2011). However, the use of psychophysiological methods may help to provide greater insights into how people respond to computer simulations of wind turbine landscapes. Chapter 4 discusses the second study of this thesis, which replicates the current experiment but replaces the video of a real landscape with a video of a computer simulation of the same landscape.

4 Physiological Responses to a Simulation of Wind Turbines in a UK Landscape

4.1 Introduction

In chapter 3, the study looked at participants' responses to a video of a real landscape with wind turbines. This study replicates the first but instead of viewing a photorealistic landscape, the participants watched videos of a simulated landscape with wind turbines. A comparison between the responses to the photorealistic and simulated landscape may help to provide insights into the perceived realism of computer generated simulations of landscapes.

As discussed in the methodological review in chapter 2, there is a long history of using computer generated simulations to represent the landscape, especially potential or proposed changes to a landscape (Sheppard, Shaw, Flanders, & Burch, 2007; Zube et al., 1987). With the continual improvement in computing capabilities as technology advances, and the subsequent improvement in the realism of computer generated simulations, researchers have argued that these simulations could be used for landscape modelling, planning and community engagement exercises (Lange, 2011; Orland et al., 2001; Schroth, Hayek, Lange, Sheppard, & Schmid, 2011). Computer simulations provide several advantages when compared with photomontages; they allow for precise control over what is modelled, and can create 3-dimensional landscapes which allow for multiple viewing angles, and they allow for interaction (Bishop & Stock, 2010).

However, perceived realism of computer simulations is an issue that has been noted by several researchers (Bishop & Rohrmann, 2003; Perkins, 1992). The issue of perceived realism, or ecological validity, is particularly important. If research or community engagement is carried out with simulations then it is important that people respond similarly to the simulations as they would to the completed wind farm development. Otherwise the ecological validity, and thus the entire purpose for the research/engagement, is called into question. There have been several studies which have asked participants to rate different visualisation methods, such as photomontages, wire frames, computer generated visualisations (Berry et al., 2011; Meitner, 2004; Roth, 2006; Sevenant & Antrop, 2011). However, this study seeks to assess people's responses to a computer simulation of wind turbines and to attempt to objectively quantify these responses using eyetracking and skin conductance response.

Computer simulations can range from static 2D images to interactive 3D virtual environments. There are a range of different software programmes which can be used to create the simulations, and the realism, cost, complexity and learning time associated with these programmes can vary considerably (Schroth, 2009). This study will use two programmes to create the virtual environment of the wind turbines in Stocksbridge (the location where the videos were recorded for the first study); these are Google Earth and Sketchup. There are two reasons for choosing these programmes: 1) they are both free and so are available to a wide range of people regardless of financial constraints, 2) they are less complex and less labour intensive than more advanced software such as Visual Nature Studio, so do not require the same high level of expertise. Google Earth covers the world and can be used to create accurate 3D environments of any area (Peterson et al., 2012). Sketchup can be used to create 3D models of wind turbines, which can easily be exported into Google Earth, and is considerably more user-friendly that other industry standard software (Wolk, 2008). Moreover, the programme can be used to create 3D models of any object found in the landscape, e.g. houses, walls, trees, sheep. There is also a large online library of pre-existing models, which can be added to by users of the programme, as well as downloaded for use or modification.

Another key issue which will be addressed in this study is the dynamism of simulations. Several researchers have highlighted the importance of movement in visualisation of the landscape. The movement more closely represents people's natural experience, and thus people respond differently to dynamic simulations (Danahy, 2001; Heft & Nasar, 2000). This study adds movement by using videos that pan across the landscape (as they did in the first study), and by animating the wind turbines in Google Earth. Animating the wind turbines was achieved using KML (keyhole markup language), which can be used to define longitude and latitude, altitude, tilt, heading, as well as a timespan (Honjo, Umeki, Wang, Yang, & Hsieh, 2011; Zhu et al., 2014). Two of the key criteria in choosing the visualisation software were cost and ease of use. Dynamic computer visualisations of wind farms would need to be reasonably straightforward and cost effective for widespread adoption in community engagement. Table 4.1 on the next page includes an overview of the strengths and weaknesses of the different software options that were considered before choosing the combination of Sketchup and Google Earth.

The aim of this study is to try to objectively assess people's responses to a simulated wind turbine landscape through the use of psychophysiological measures. The findings can then be compared to the findings from the previous study to assess whether participants respond in similar ways to videos of a real landscape as to that of a computer simulated landscape. This will provide insight into the levels of realism that can be achieved with Google Earth and 3D models created in Sketchup. It will also help to analyse the suitability of these programmes for creating visualisations of wind farms for use in planning, community engagement, or research.

As such, there are two hypotheses being tested:

H_1: The skin conductance response (SCR) of participants will follow the u-shaped pattern found in study 1, with larger scores for those in the 'strongly pro-turbine' and 'strongly anti-turbine' groups.

H_2: The eye-tracking data will show that, when controlling for size, the smaller turbines of Royd Moor wind farm garner more visual attention than the large turbines of Blackstone Edge and Hazlehead wind farms.

Table 4.1: Overview of strengths and weaknesses of different visualisation software options

Landscape visualisation Software	Learning Curve	Level of Realism	Real-time	Cost
3D Modeller				
Autodesk 3ds Max	+++	+++	No	£1,500 per year
Blender	+++	++/+++	No	Free/Open Source
Cinema 4D	+++	++	Yes	£2,800
Sketchup	+/++	+/++	Yes	Freeware
Digital Globe				
Bing Maps 3D	+	+/++	Yes	Freeware
Biosphere 3D	++	++	Yes	Free/Open Source
Google Earth Pro	+	+/++	Yes	Freeware
GIS & 3D Plugins				
ArcGIS	+++	+/++	Yes	£120+ per year
Erdas Imagine	+++	+/++	Yes	£2,000+
GRASS GIS	+++	+	No	Free/Open Source
QGIS	+++	+	No	Free/Open Source
PhotoRealistic Landscape Renderer				
3D Nature (VNS & Scene Express)	+++	++/+++	No	£2,500+
Terragen	+++	++/+++	No	£500+
Vue	+++	++/+++	No	£1,000

Key: + = Low, ++ = Medium, +++ = High

4.2 Methods

4.2.1 Participants

Participants consisted of 75 students from the University of Sheffield. The mean age was 23.12 (SD = 3.99), with 66.67% of participants being female. Participants were given either course credit or £5 as compensation for taking part in the study. As with study 1, the sample size was determined for the most part by cost and availability of the resources need to run the experiment (see section 3.2.1 for further details).

4.2.2 Design

As with the first study, this study used a between subjects design, with participants being grouped according to their wind turbine preference, as measured by a pre-screening questionnaire, comprised of 10 items commonly found in the UK landscape. Again, the two main dependent variables are wind turbine fixation time (secs)/size (pixels), and the mean number of skin conductance responses (SCRs) while watching videos of a simulated wind turbine landscape.

4.2.3 Apparatus

The apparatus used in this study were the same as the those outlined in chapter 3, including;

- 19” CRT monitor
- Eyelink 1000
- Biopac MP36R & EL507 electrodes

For full details, see section 3.2.3.

4.2.4 Material

The materials used in this study were the same as those used in the previous study, including;

- Pre-screening questionnaire
- The revised new ecological paradigm (NEP)
- The positive and negative affect schedule (PANAS)

- Survey on attitudes to wind turbines

For a detailed description of the above, please see section 3.2.4

The only change in material from the previous study is that this study used a video of a computer simulation of the wind turbine landscape, instead of a video of the real landscape. As with the previous study, the video presented was 1280x720 pixels, 30 frames per second and approximately three minutes in duration. As with the previous study, one of the videos panned left-to-right across the landscape and the other right-to-left, with the order of presentation being counterbalanced to avoid any order effect. Figure 4.1 shows a still from the video used in this study. The study area used is the same area as used in study 1 (see section 3.2.5 for full details).

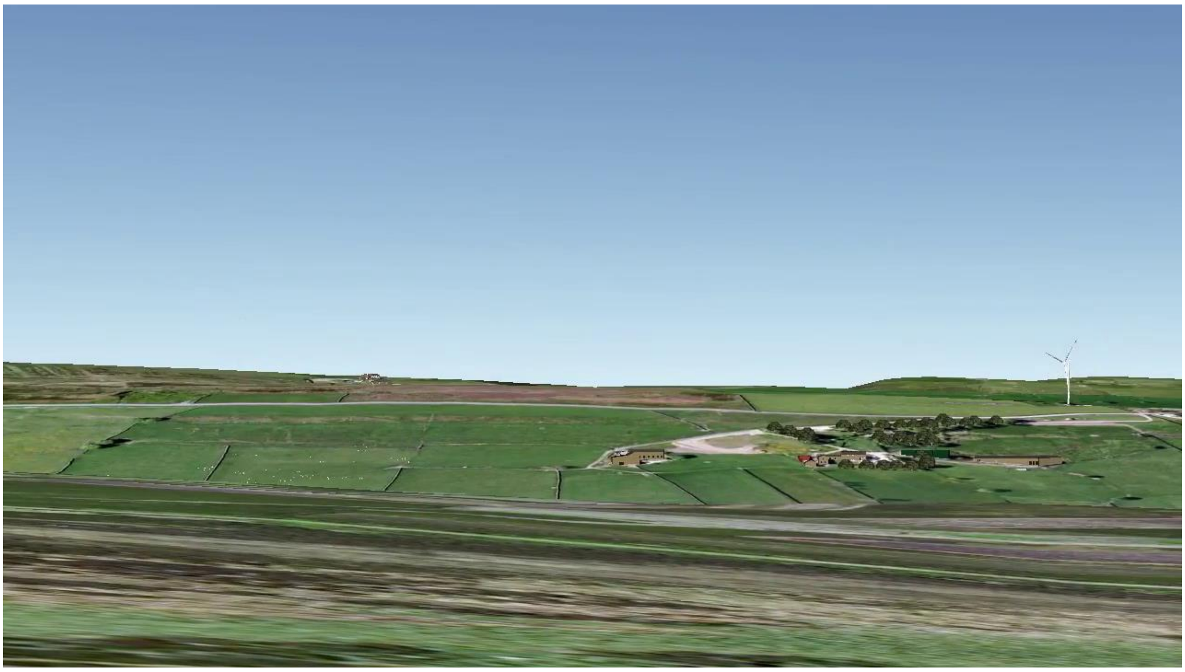


Figure 4.1: Still from Video Presented During Study 2

A 3D representation of the landscape from Study 1 was constructed using Sketchup and Google Earth. The landscape was populated with models of the existing wind turbines and other key physical features (e.g., houses, trees, walls). Keyhole mark-up language (KML) was used to animate the turbines and a screencast (a digital recording of the computer screen output) was made while panning though the landscape to replicate the video from Study 1. KML is a geospatial language that can be used to manipulate objects in google earth (Wilson, 2008).The turbines were animated for Hazlehead and Royd Moor wind farms, but not for Black Stone Edge. This is because the three turbines in the Blackstone Edge farm were not moving on the day the video was recorded for study 1. Full details of the KML coding used to animate the wind turbines can be found in Appendix E. The turbine angles were randomised to ensure that they were not all rotating in sync. This is important as it makes them appear more natural. The code was modified for each turbine to create this effect.

Examples of the models that were used to create the 3D simulation in Google Earth can be found in figure 4.2 below. Figures 4.3, 4.4, and 4.5 show the simulations of Hazlehead, Blackstone Edge, and Royd Moor respectively.

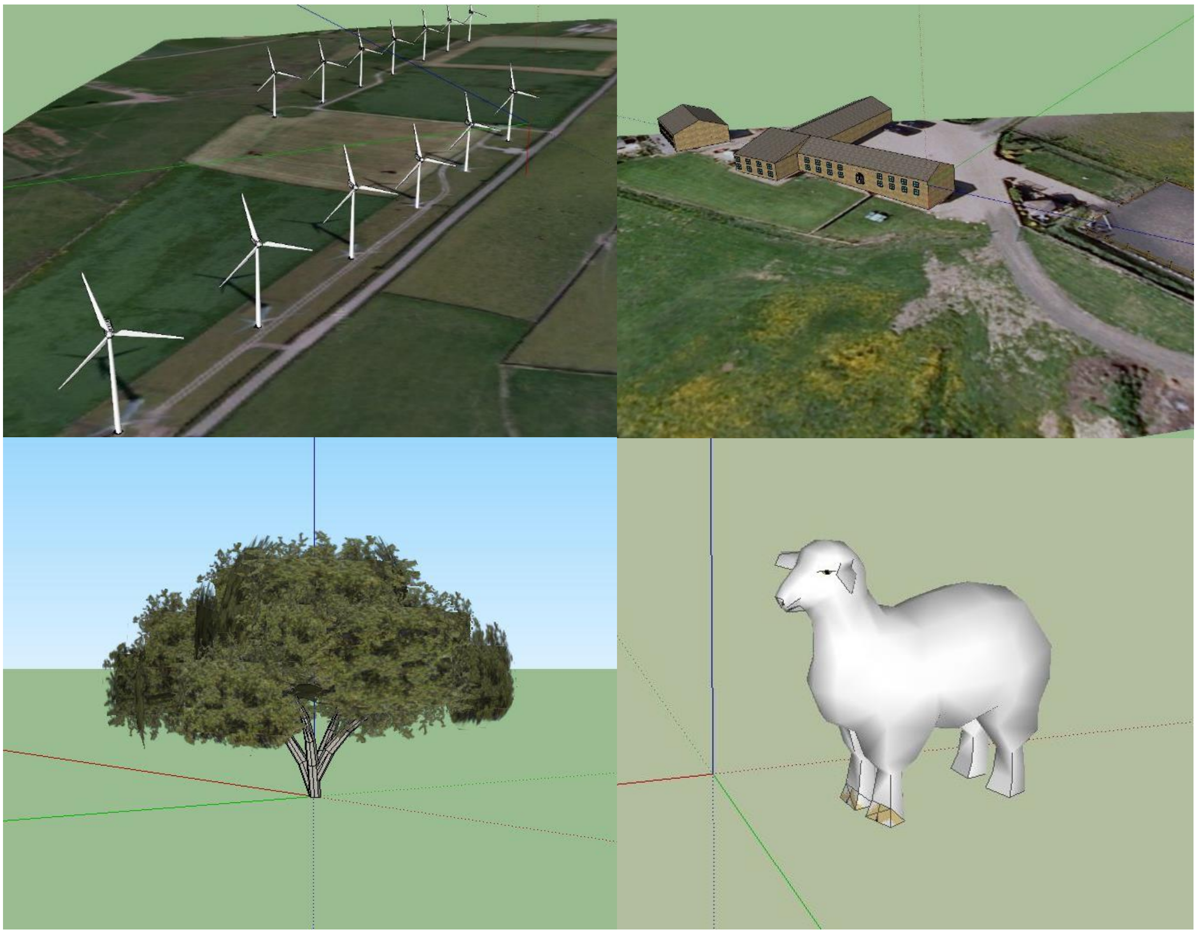


Figure 4.2: Examples of Sketchup Models used to create 3D simulation

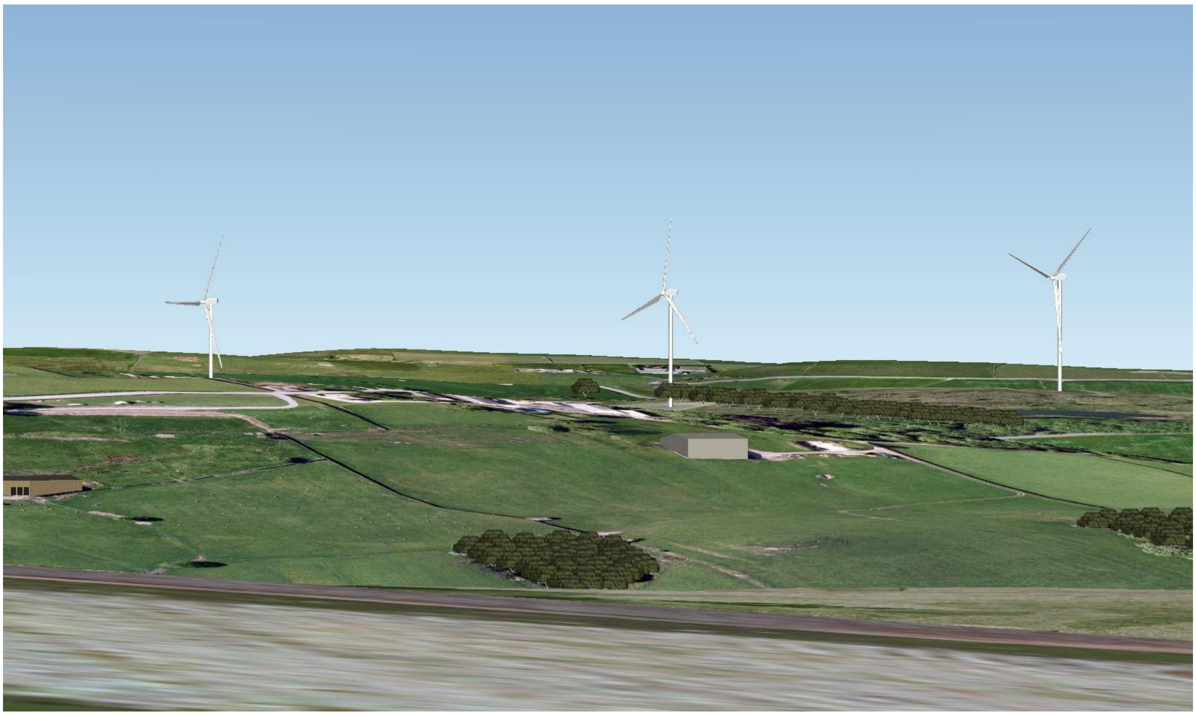


Figure 4.3: View of Hazlehead Wind Farm in Google Earth

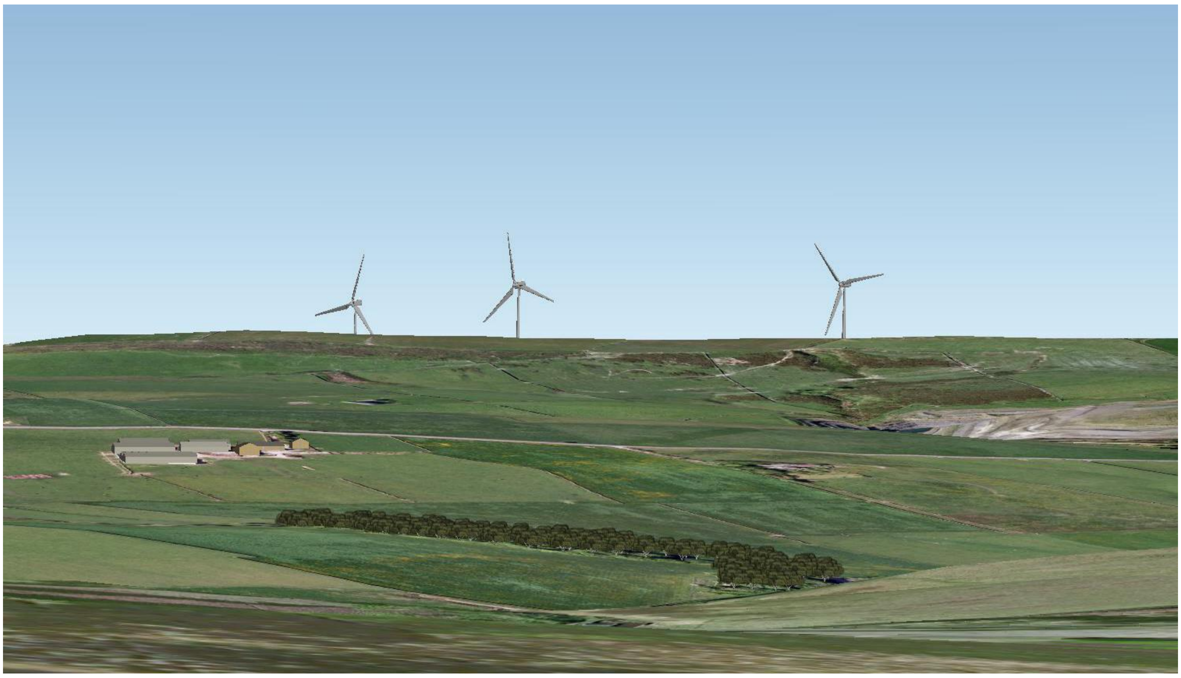


Figure 4.4: View of Blackstone Edge Wind Farm in Google Earth

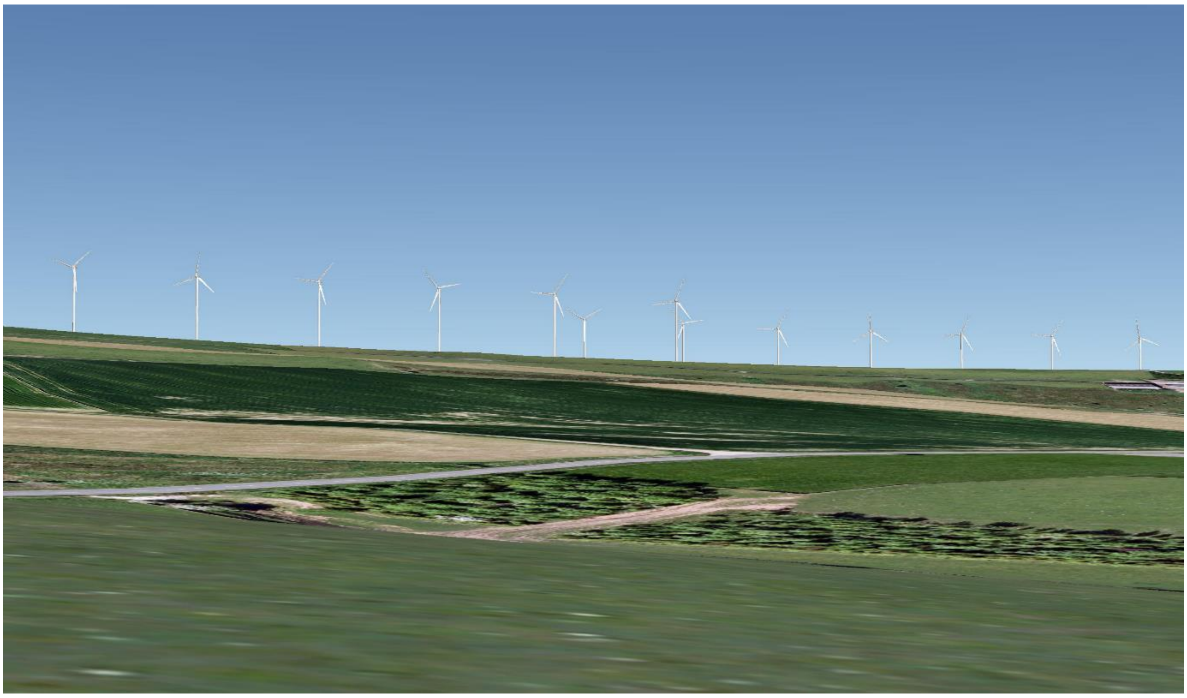


Figure 4.5: View of Royd Moor Wind Farm in Google Earth

4.2.5 Procedure

The procedure for this study was identical to study 1, except for the video. As outlined in the previous section, the video was created using a computer simulation of the landscape. For full details of the procedure, see section 3.2.5 in chapter 3.

4.3 Results

The EDA and eye-tracking data were processed in the say way as in study 1, as outlined in chapter 3 of this thesis (see sections 3.3.1 & 3.3.2).

Data Cleaning: Four participants were removed from the eye-tracking analysis due to inaccurate tracking (n = 71). Three participants were removed from the SCR analysis due to non-responses (n = 72).

4.3.1 Descriptive Statistics

Table 4.2: Descriptive Statistics by Turbine Preference Group

Turbine Preference Group	Really Dislike	Dislike	Neutral	Like	Really Like	All
Number	3	9	26	22	12	72
Age (Mean)	20.333	24.333	23.462	22.500	23.583	22.842
SD	4.041	3.391	4.101	3.635	4.833	4.000
SCR Turbs (Mean)	2.833	3.111	4.231	4.405	3.542	3.624
SD	4.298	1.943	2.028	1.883	2.584	2.547
SCR No Turbs (Mean)	3.333	3.333	4.596	4.357	3.458	3.816
SD	3.944	2.422	1.785	1.808	2.792	2.550
Hazlehead Fix. Dur. (Mean)	0.198	0.184	0.132	0.127	0.167	0.162
SD	0.144	0.116	0.055	0.052	0.084	0.090
Black. Edge Fix. Dur. (Mean)	0.140	0.131	0.115	0.101	0.164	0.130
SD	0.196	0.083	0.038	0.044	0.052	0.083
Royd M. Fix. Dur. (Mean)	0.322	0.263	0.249	0.204	0.332	0.274
SD	0.389	0.107	0.060	0.063	0.102	0.144

4.3.2 New Ecological Paradigm (Revised)

The mean NEP score for this study was 53.34 (SD = 6.49). As the data didn't meet the requirements for parametric analysis, due to non-normality of the dependent variable, the data were analysed using a non-parametric test. A Kruskal-Wallis H test showed no significant difference between the five groups on their scores on the new ecological paradigm scale ($\chi^2(4) = 4.909$, $p = .297$). A trend analysis showed that data were well fit by a quadratic model with the quadratic component accounting for a large and significant portion of the variance $F(1, 67) = 4.253$, $p < .05$, $\omega^2 = .62$). Post hoc tests using the Bonferroni correction revealed that there were no significant differences between any pair of the five groups ($p > .05$). As with study 1, the real difference between groups is not particularly large, with all groups having high scores. The largest mean score was 58 for group 1, and the smallest mean score was 52.85 for group 3 (see figure 4.6 below).

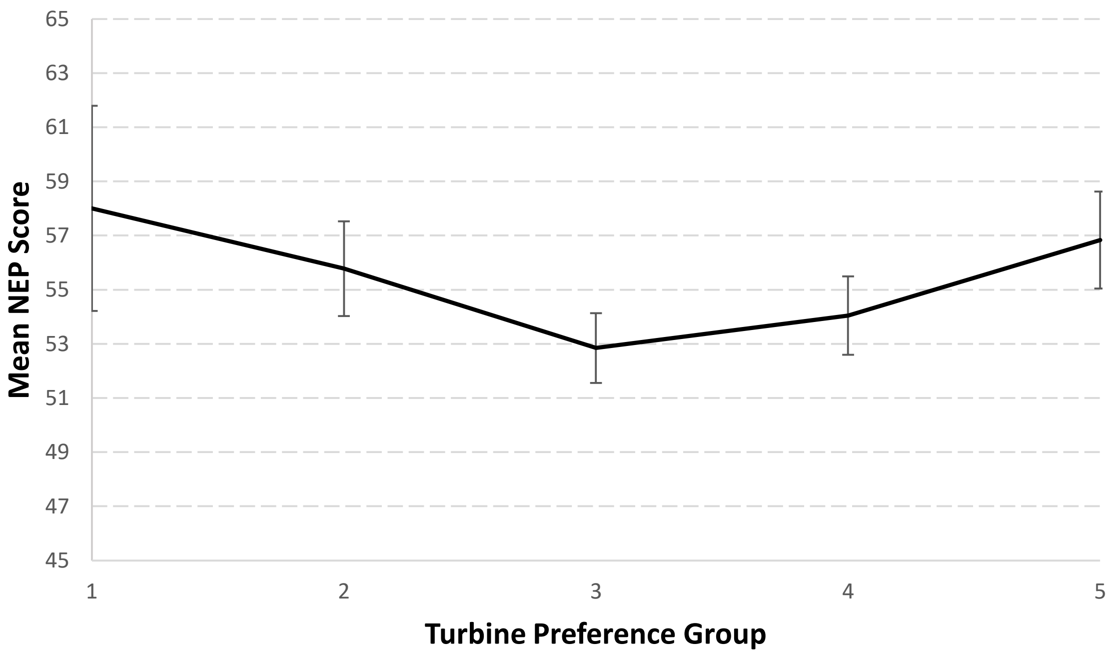


Figure 4.6: Mean NEP Score by Turbine Preference Group

4.3.3 Positive and Negative Affect Schedule

The mean positive affect was 33.61 (SD = 6.29) before watching the video and 32 (SD = 7.815) after. The mean negative affect was 14.73 (SD = 5.33) before was the video and 13.71 (SD = 5.42) after. As with study 1, these scores are consistent with Watson et al. (1998), who suggest that the positive and negative affect score of a normal population should be 29.7 (SD = 7.9) and 14.8 (SD = 5.4) respectively.

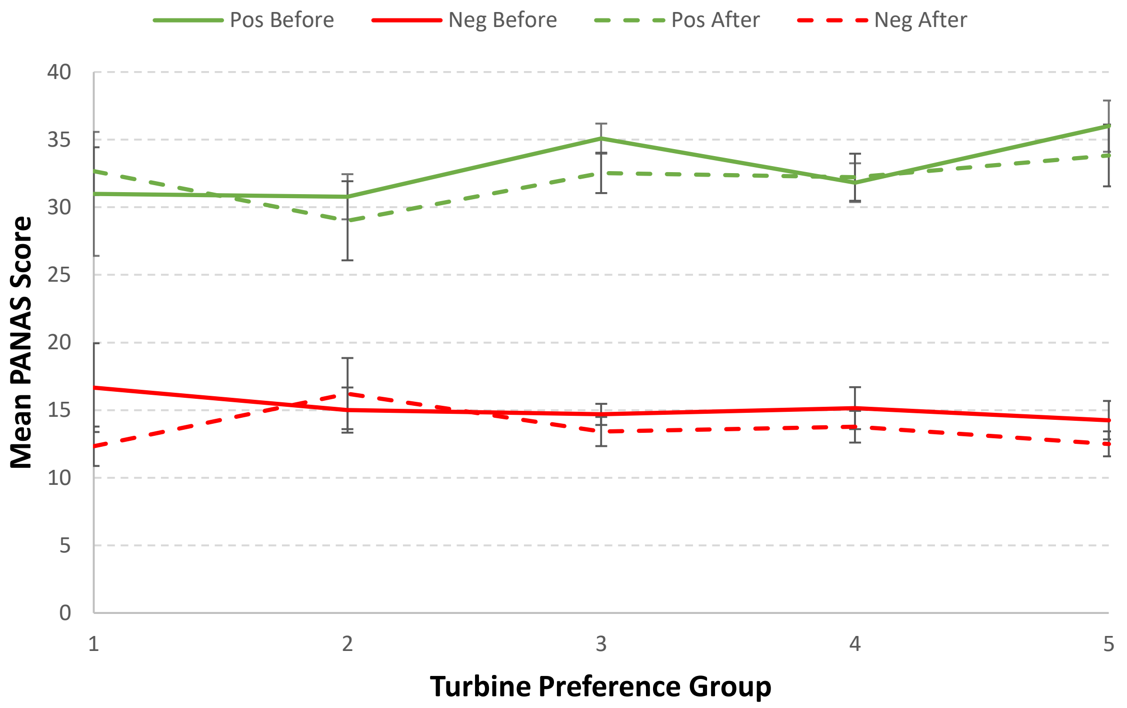


Figure 4.7: Mean PANAS Scores by Turbine Preference Group

As the PANAS scores were not normally distributed, non-parametric analyses were used. Wilcoxon Signed Ranks tests indicated that positive affect was significantly higher before the experiment than afterwards ($Z = -2.378$, $p < .05$) and that negative affect was also significantly higher before than after ($Z = -2.375$, $p < .05$). As with study 1, there appears to be no pattern across the five groups. Again, it is likely that the decrease in positive affect may be due to fatigue or boredom. The reduction in negative affect may be due to participants being less apprehensive after completing the experiment.

4.3.4 Skin Conductance Response

The SCR scores were not normally distributed and therefore a non-parametric analysis was used. A Wilcoxon signed rank test found that there was no statistically significant difference in the skin conductance response (SCR) between when the turbines were present and absent during the video ($Z = -.648$, $p = .517$). Trend analyses showed no significant linear or quadratic trends across groups for SCR when turbines were present or absent ($p > .05$). Figure 4.8 shows that the trend across groups for SCR is almost n-shaped. This is almost the inverse of the pattern that was found in study 1 (see figure 4.9 for a comparison).

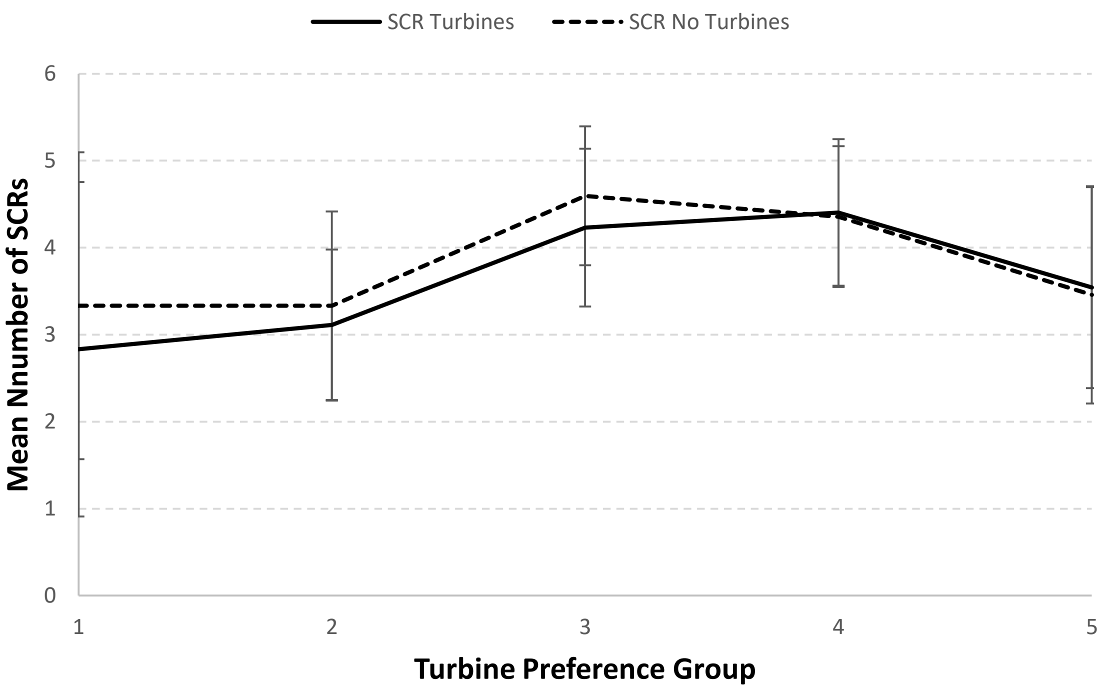


Figure 4.8: Mean SCR Scores by Turbine Preference Group

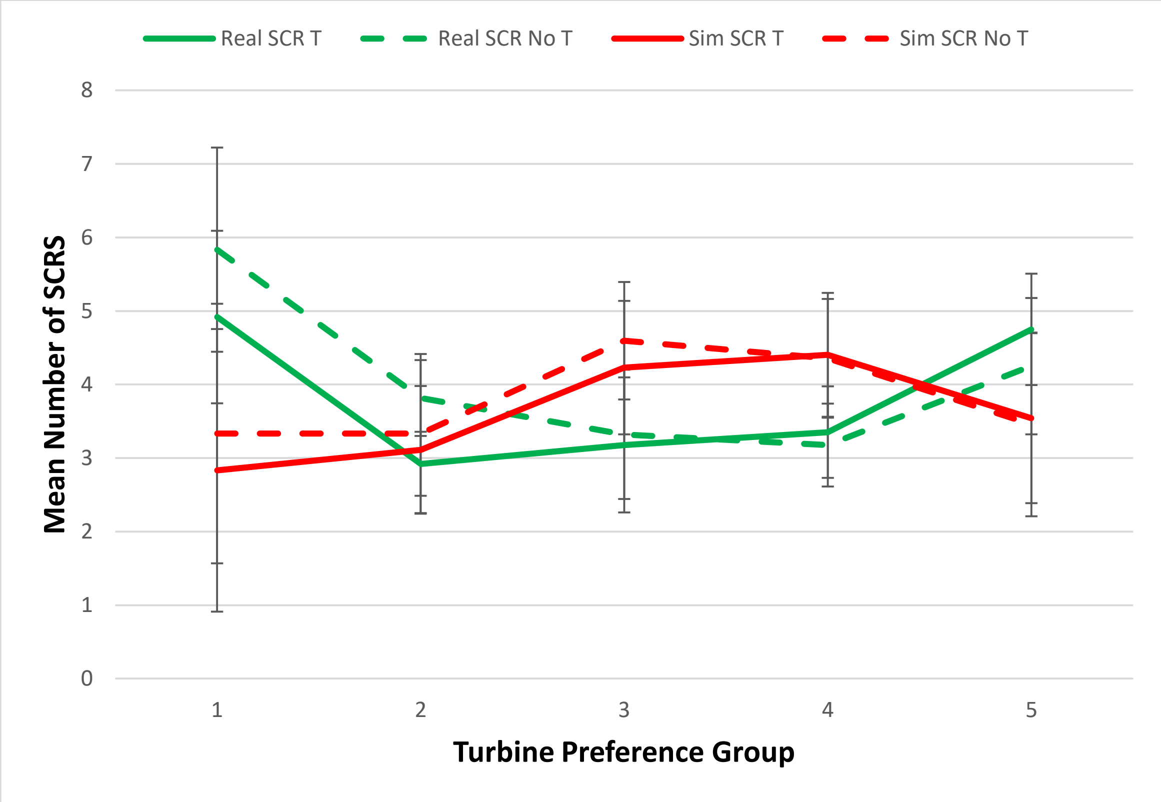


Figure 4.9: Comparison of SCR Scores from Study 1 & 2

4.3.5 Eye-tracking

A mixed ANOVA revealed a significant main effect for fixation time/size (*F*(2, 66) = 39.874, p < .001, η^2 = .377). Post=hoc tests using the Bonferroni correction revealed that the fixation duration was significantly different between all three groups (p < .0167). The order of longest fixation duration to shortest is Royd Moor, Hazlehead, and Blackstone Edge. No significant interaction effect was found between wind farm and turbine preference grouping (*F*(8, 132) = .828, p = .579, η^2 = .048). As two of the assumption for a mixed ANOVA were violated – normality of the dependent variable, and homogeneity of variance, non-parametric tests were also run, which confirmed the results. A Friedman test showed a significant difference between the fixation times of each wind farm (χ^2 (2) = 55.79, *p* < .001). Post hoc Wilcoxon sign ranks tests with the Bonferroni correction showed a significant difference in fixation duration for between Royd Moor and Blackstone Edge (z = -6.645, p

< .001) and Hazlehead (z= -5.962, p < .001). However, no significant difference was found between Blackstone Edge and Hazlehead (z = -2.158, p = .031).

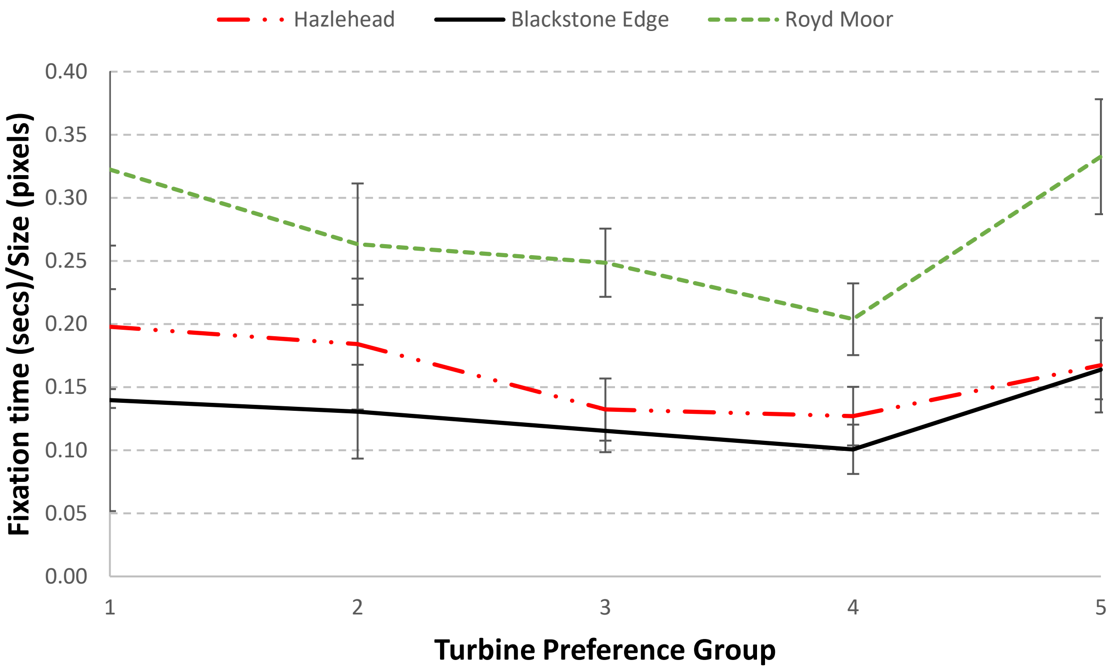


Figure 4.10: Mean Fixation Time/Size of Wind Farm by Turbine Preference Group

The results suggest that, as with study 1, participants' visual attention varied according to the wind farm that was present in the video. Blackstone Edge and Hazlehead drew significantly less visual attention from participants than Royd Moor. This suggests that fewer but larger turbines have less of a visual impact on the landscape than smaller but more numerous turbines. Unlike in study 1, there was a significant difference between Blackstone Edge and Hazlehead using parametric tests, with participants focussing on Blackstone Edge for significantly less time, suggesting that non-moving turbines draw less visual attention than moving turbines. However, when using non-parametric analysis, the difference became non-significant. It is likely then that the difference is due to a type 1 error. Figure 4. 10 shows a comparison of the eye-tracking data from study 1 and 2. While there tends to be higher fixation times for the wind farms in the simulation, the pattern between the different wind farms is similar for real and simulated landscapes.

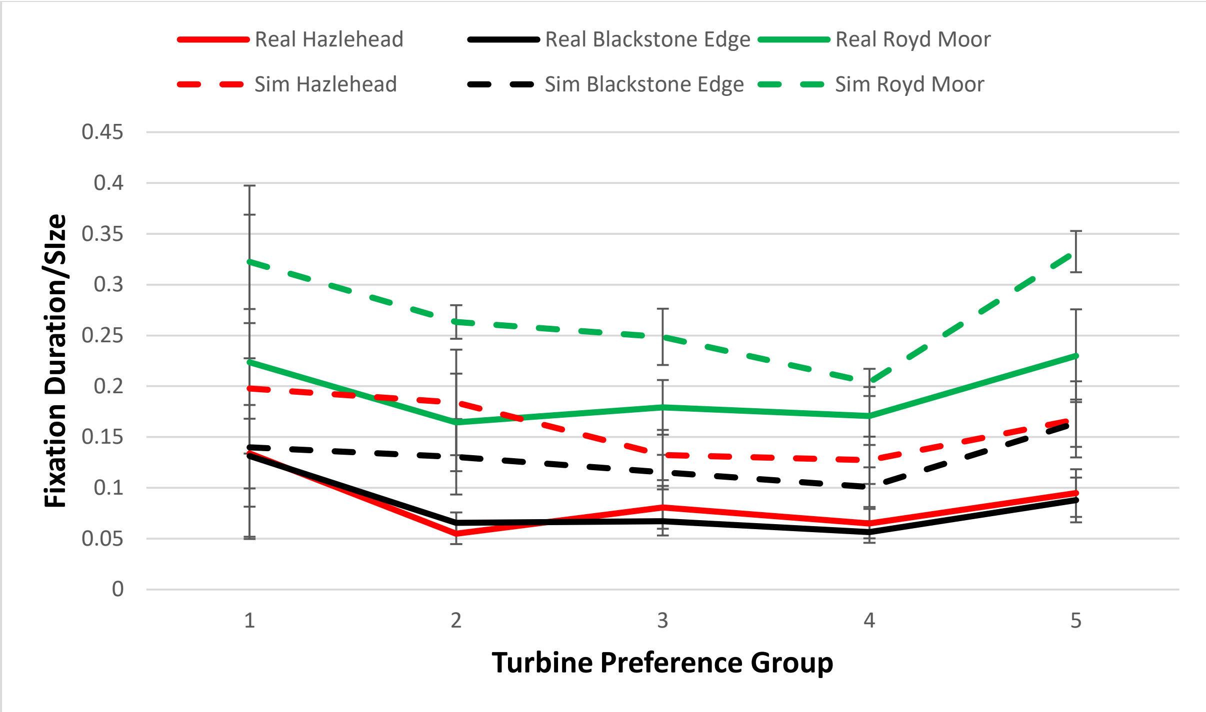


Figure 4.11: Comparison of Eye-tracking Data from Study 1and 2

4.4 Discussion

This study sought to replicate the experiment carried out in study 1, but to use videos of a computer simulated landscape. The aim was to objectively measure, using SCR and eye-tracking, participants' responses to the simulated landscape. The reason for this was to assess whether people responded similarly or different to the videos of the simulated landscapes than real landscapes.

Findings

As with study 1, the participants scored highly on the NEP, with little variation across turbine preference groups, though those in the 'strongly pro-turbines' and 'strongly anti-turbines' groups scored slightly higher. This could support the idea that university students tend to have pro-environmental views (Cotton & Alcock, 2012), or at least those from higher socioeconomic status (SES) groups (Hawcroft & Milfont, 2010). Or, as mentioned in the previous chapter, this may simply be reflective of the scale's lack of validity (Brennan et al., 2014). Given that there was no significant difference across groups in either study, it is possible that the scores on the NEP do not represent the participants' true environmental attitudes. The scores on the PANAS mimicked those of the first study, with broadly similar positive affect (PA) and negative affect (NA) scores before and after taking part in the experiment. In this study, however, there was no significant difference in PA pre and post experiment. It is possible that participants found the computer simulation more interesting than the real landscape and so were not bored by the videos they viewed. There were also no significant intergroup difference in PA or NA. As with the first study, this suggests that there was no significant variation in emotion across groups, nor any change before and after taking part in this study. These findings suggest that the participants' SCRs were not affected by their emotional state during the experiment, and are reflective solely of their affective response to the videos they were shown.

Affective Response

Contrary to the previous study, the SCR scores in this study show a broadly n-shaped distribution across the turbine preference groups. Those with more neutral views towards wind turbines in the landscape scored higher than those who had stronger feelings, positive or negative, though this trend was not found to be statistically significant. As in the first study, participants SCRs were similar when the turbines were present and absent, which suggests that they are responding to the landscape in general, rather than just the wind turbines. In this study, the 'strongly anti-turbine' group had a higher SCR when the turbines were absent, while the converse was true of the 'strongly pro-turbine' group. This is similar to the findings from study 1. The overall quadratic 'n-shaped' pattern is in the opposite direction to the findings from study 1. However, it is important to note that this was not statistically significant, and the differences were smaller than in the previous study. While it initially seemed quite surprising that the results using the video of the computer simulation were almost the inverse of the real landscape, it may make sense in the context of the biophilia hypothesis, particularly if the 'uncanny valley' is taken into account.

If we accept the biophilia hypothesis, that humans have an innate bond with life and life-like processes (Ulrich, 1993), then we would expect participants to respond positively to scenes of a rural landscape such as that shown in the video. In the discussion section in the previous chapter, the biophilia hypothesis was used to explain why the 'strongly pro-turbine' and 'strongly anti-turbine' groups had higher SCRs, to the groups who were more neutral about wind turbines in the landscape. It was argued that participants' in those groups may have had a stronger affinity with the environment. Although on 'opposing sides', those strongly in favour of or against wind turbines could be said to be supporting pro-environmental beliefs. While it might appear strange that the pattern was reversed in this study, the 'uncanny valley' may provide insight into why this might have happened.

Uncanny Valley

Mori (1970) proposed that people's sense of familiarity or affinity with robots would increase as the robots become more humanlike until it reached a valley, called the 'uncanny valley'. This uncanny valley occurs when the robots approach full human likeness but haven't reached 100% likeness (see figure 4.10). This imperfect resemblance results in an uneasy feeling in the viewer due to the mismatch in the expectation of human qualities and the actual experience. It has been found to occur with computer games, 3D robots, and computer-animated characters in films (Ho & MacDorman, 2010; Mitchell et al., 2011; Tinwell, Grimshaw, Nabi, & Williams, 2011). Mori (1970) also posited that movement would result in a magnified uncanny valley effect. He suggested that movement would increase the feelings of familiarity with the robot, compounding the effect of the likeness of the model, and would by extension result in an even more marked drop into an uncanny valley (see figure 4.12 below).

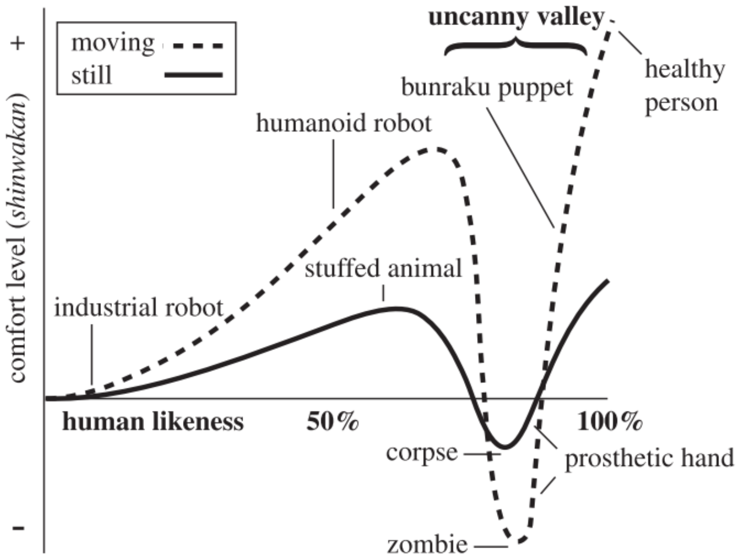


Figure 4.12: Diagram of Uncanny Valley (Source: Mori et al. 2012)

If this idea is extended to the video of the computer simulated landscape that was used in this study, it might explain the near reversal in SCR scores. As was previously mentioned, it is possible that both support and opposition toward wind farms could stem from environmental concerns (Warren et al., 2005). As such, it is possible that the participants in the 'strongly pro-turbine' group and 'strongly anti-turbine' have a strong emotional attachment environment. This could result in an emotional attachment to landscape that might not be shared by those in the more neutral groups. It is possible that this has resulted in an uncanny valley effect when viewing the videos of the computer-simulated wind-turbine landscape. It may have even been exacerbated by the movement of the video and the turbine blades, given Mori's assertion that movement increased the effect. This effect could explain the reduced SCR from people at either end of the spectrum, as well as the increased response from the neutral groups who had a greater reaction to the computer simulation.

Visual Impact

The eye-tracking data produced similar results to the first study, with a longer total fixation duration for Royd Moor than for Hazlehead or Blackstone Edge, when normalised for area. This further supports the notion that smaller, more numerous wind turbines attract more visual attention than fewer, larger turbines. There may be various reasons for this increased visual attention. There were more turbines in the Royd Moor wind farm; it is possible that more wind farms together creates a disproportionate visual distraction the landscape. Previous research has shown that people prefer smaller groups of turbines (Kokologos et al., 2014; Molnarova et al., 2012; Tsoutsos et al., 2009). Alternatively, the smaller, faster moving turbine blades may draw more attention simply because of the speed of movement. Given than blade movement has been shown to increase the visual impact of wind turbines, faster moving blades may increase this impact further (Bishop & Stock, 2010).

Participants spent significantly less time looking at the Blackstone Edge turbines than they did for the Hazlehead turbines, which suggests that non-moving wind turbines might attract less attention than moving wind turbines. This finding should be interpreted with caution. While the difference is statistically significant, the effect is quite small and was not found in the first study with the videos of the real landscape. It is possible that the effect is only found when viewing simulated wind turbines. That being said, the blade movement of wind turbines is consistently listed as something which people find visually intrusive (Landscape Design Associates, 2000; Pedersen et al., 2007; Piper, 2004).

Implications

There are several important implications of the findings from this experiment. First, the eye-tracking data were similar to the first study, further supporting the notion that smaller turbines attract more visual attention than larger turbines, when normalised by area. This could be an important consideration for wind farm developers, and planners. Every planning application for a proposed wind farm development in the UK needs to be accompanied by an environmental impact assessment (EIA) to assess the potential impacts that could results from the wind farm (Cooper & Sheate, 2002; Scottish Natural Heritage, 2009). A landscape and visual impact assessment (LVIA) is a core component of the EIA, particularly in the case of wind farms where landscape and visual impacts are of paramount concern (Scottish Natural Heritage, 2006; The Highland Council, 2010). As discussed in the previous chapter, it is consider good practice to include a zone of theoretical visibility (ZTV) map in an LVIA to assess the extent of the visual impact of a proposed wind farm, which is calculated based on the height of the turbines. Given that Royd Moor would have the smallest ZTV of the three wind farms, yet drew the most amount of visual attention, the findings from this study might be worth consideration from planners and developers.

The findings from the analysis of SCRs may have implications for the use of computer-generated simulations of wind turbines in research, in community engagement, or public consultations. While the patterns of visual attention were broadly similar for the videos of the simulated and real wind turbines, the objective affective responses (as measured by SCR) were very different. These differences in SCR may call into question the ecological validity of computer-generated simulations. If the simulations are not ecologically valid, then it is possible that conclusion drawn from them in research, or community engagement, may not be accurate. While it is clear that computer generated simulations have improved greatly and will do so into the future (Danese et al., 2008; Lange, 2011; Williams, Ford, Bishop, Loiterton, & Hickey, 2007), using Google Earth and Sketchup may lack the realism needed to replicate the real world. This may mean that using computer simulations is not advisable until such as time as the level of realism reaches close to 100%. It is possible that other visualisation software, such as Visual Nature Studio, may provide more realistic simulations but they tend to be costly in terms of finances and time (Schroth, 2009).

Limitations

As is true of the first study, the use of psychophysiological methods, with the more naturalistic panning videos, makes interpretation of the results somewhat difficult. While this study is more ecologically valid than previous studies which have used static photomontages or static simulations (e.g. Molnarova et al., 2012), it is also lacks the tighter experimental control that comes with static images. The results from the SCR analysis highlight this issue. Given that participants responded to the landscape without wind turbines, it can be difficult to tease apart the attribution of SCR. It is assumed that the differences in SCR when the turbines were present or absent was due to the turbines themselves. However, the participants were never asked to give their subjective response to the videos – it is possible, though perhaps unlikely, that they may have given another reason. While the study was designed to try to objectively measure their responses, the lack of subjective responses from the participants does mean that there is greater ambiguity and inference from the results. Similarly, while it is objectively true that participants spent a longer duration of time looking at the smaller turbines of the Royd Moor wind far, we can only infer the reason for this. The smaller turbines could be more visually distracting for a number of different reasons, e.g. faster moving blades, or a greater number together. Equally, they could have been more pleasant to the participants, or there may have been different reasons across the turbine preference groups for the increased visual attention. It may have been beneficial to include some form of subjective analysis, such as a short interview or survey after completing the experiment. Future research may include the objective psychophysiological measures in tandem with more subjective measures, such as surveys or interviews.

The simulation methods used may also have adversely affected the results. As discussed, Google Earth and Sketchup are not the most advanced computer programmes for 3D simulations. They were chosen because they were freely available and do not have extremely steep learning curves, and so are available to a wide range of people, from researchers through to planners and developers. However, the simulations that were created using these programmes may have lacked the realism that better software would have allowed. It is possible that the hypothesised uncanny valley effect would not have occurred if more realistic simulations were created. The study also didn’t assess whether the lack of ecological validity would affect participants’ choices for things such as wind farm layouts, preferences for the number of turbines. While it is important to know that people don’t respond affectively in the same way to the computer simulation, the core question that remains is ‘is this important?’ If participants make the same decisions about a proposed wind farm development, e.g. their preferred turbine layout, or the maximum number of turbines, then the difference in affective response may not be important in practical terms. The next study will seek to address this issue with an online survey.

There are several limitations associated with the sample used. The sample was relatively small, consisting of only 75 participants, though this is relatively large compared to most studies involving psychophysiological measures such as eye-tracking and SCR (e.g. Bianchin & Angrilli, 2012; Calvo & Lang, 2004; Dupont, Antrop, & Van Eetvelde, 2013; Helminen, Kaasinen, & Hietanen, 2011). The sample of participants was not representative of the population, given that it was a sample of university students. This is a common problem with psychological research, with samples tending to be better educated, and richer than the general population (Henrich et al., 2010). There were also an unequal number of participants in each of the five groups, with very few in the 'strongly pro-wind' and 'strongly anti-wind' groups.

Directions for future research

Future research into computer-generated simulations of landscape should, and likely will, focus on virtual reality (VR) and augmented reality (AR). VR has undergone somewhat of a renaissance in recent years, with the largest technology companies (e.g. Google, Facebook, Apple, Samsung, LG) putting their considerable weight behind its development (Webster & Clark, 2015). These various VR would allow for greater levels of immersion than can be achieved by looking at a monitor on a desk. The ability to move your head around to look at a full 360° simulation and to interact in real-time could provide for levels of immersion approaching that of reality. With these companies having already released VR headsets, from the most basic Google Cardboard, through the Oculus Rift, the opportunities for VR in landscape research is increasing. These VR headsets could even be combined with eye-tracking technology to map out what participants are looking at in the 360° virtual world (Stengel, Grogorick, Eisemann, Eisemann, & Magnor, 2015). Similarly, AR could provide greater levels of realism and immersion. Currently, there are companies such as VentusAR (Linknode Ltd, 2016) who create AR wind farms, which can be viewed on a tablet when out in the field. This allows developers, local communities, or researchers to created accurate 3D models of wind farms, which are then superimposed in real-time over the real landscape, as viewed through the camera lens of a computer tablet. It is possible that these can/could be combined so as to use AR on a head-mounted phone, such as Google Cardboard, or Samsung Gear (Hasan & Yu, 2015). The phone's camera could be used to show the real-world around the user while the AR elements could be superimposed onto the screen in real time, allowing for the realism of the real-world with the immersion of a VR headset.

Conclusion

This study has used psychophysiological measures to objectively assess people's responses to a computer-generated wind-turbine landscape. The novel use of a combination of panning videos, animated turbines, eye-tracking, and SCR has provided a more objective assessment of people's responses to a computer simulation of wind turbines. The eye-tracking data from the current study show that people's visual attention patterns are similar while watching a video of a computer-simulated landscape with wind turbines, as they are when they watch a video of the same real landscape. This supports the findings from the previous study, and suggests that wind farms with more numerous but smaller turbines attract greater visual attention than wind farms with fewer but larger turbines. While the reason for this difference is unclear, the findings should be of interest to wind farm developers, planners, or policy-makers.

While the results from the eye-tracking data show consistency between the computer simulation and the real landscape, participants' affective responses appear to be considerably different when watching the video of the computer simulation. The uncanny valley hypothesis may help to explain these differences. It is possible that people's responses to any computer simulations will lack ecological validity until the simulations approach close to 100% realism. Given the limitations of Google Earth and Sketchup, it would be interesting to test whether people would respond similarly to more realistic simulations, such as those created with Visual Nature Studio. It is possible that more realistic simulations, combined with the immersion and interaction of a VR headset, could overcome this uncanny valley and lead to more ecologically valid responses. This is something that future research could address.

Thus far this thesis has focused on two lab-based experiments in an attempt to objectively assess people's responses to wind farms, and to compare the ecological validity of computer simulations with the real world. These studies have two major limitations: they have small samples sizes with 75 participants in each study, and they don't give any insight into why participants responded the way they did. The next study will try to address these two limitations. The next chapter will focus on an online study in which participants viewed animated photomontages or animated 2D simulations, and were asked to assess different hypothetical extension options for Hazlehead wind farm.

5 Assessing Visual Preferences for Wind Farm Extensions using Animated Photomontages and Computer Simulations

5.1 Introduction

The previous two studies have shown two things: that people's emotional responses to videos of simulated and real landscapes of wind turbines are different; and that people's viewing patterns are similar for both the real and simulated videos, with smaller more numerous turbines attracting more visual attention than larger less numerous turbines. Given the results of the first two studies, a core question that remains is whether people answer similarly in terms of preferences when presented with a photomontage or a computer simulation. While it is interesting to note that people's affective responses vary between the videos of real and simulated landscapes, if they make the same decisions with regards to turbine preferences, is the different in response important in any practical sense? Also, while the results from the study one and two showed that people's visual attention patterns were similar, and that Royd Moor farm attracted the most visual attention, it is not clear why this is the case. What characteristics of wind turbines cause the differences in the visual attention patterns?

With this in mind, the present study had three key aims: to assess factors that influence the landscape and visual impact of wind farms; to compare people's responses based on whether they are presented with the animated photomontages or the animated computer simulations; and to compare people's rating of the two different presentation mediums in terms of realism and accuracy. In order to do this, an online study was created in which participants were asked to imagine that they were a member of community being consulted by a wind farm developer about extending an existing wind farm (in this case, Hazlehead wind farm was used). Given the current level of onshore wind farm development in the UK, combined with the increased rejection rate for wind farm development applications, proposals for extensions to existing wind farms are likely to become more common. As such, this study examined a timely issue with regards to people's attitudes to wind farm development.

As discussed in chapter 2, most of the previous research into the factors affecting the landscape and visual impact of wind turbines have used static photomontages or static computer simulations (e.g. Berry, Higgs, Fry, & Langford, 2011; Dupont, Antrop, & Van Eetvelde, 2013; Molnarova et al., 2012). This study used animated wind turbine blades to better represent the visual impact of real, moving wind turbines (Bishop, 2002; Danahy, 2001; Heft & Nasar, 2000). While there has been considerable research into the validity and/or realism of different visualisation methods for landscape representation (Bishop & Rohrmann, 2003; Dupont et al., 2013; Sevenant & Antrop, 2011), there has been little research on the visualisation methods used to represent wind farms, and what effect the visualisation medium might have on people's preferences and decision making.

Berry et al. (2011) provide perhaps the most rigorous examination to date of visualisation methods for wind farm developments, using an online survey. They used a case study of a proposed development of 13 wind turbines in Wales to assess different methods of visualisation, e.g. ZTV, Wireframe, Photomontage, as well as animated and static Computer Simulations. They found that the photomontages were consistently rated the highest in terms of accuracy and realism, followed by the computer simulations. However, there are several limitations of the study that need to be addressed. The photomontages that were used in the study were static rather than animated, which may have affected the results. The study only looked at a single development option (i.e. 13 wind turbines. Also, participants were not asked about what characteristics of the wind turbines affected the visual impact of the proposed development. Lastly, they did not look at the effect of participants' existing attitudes on the visual impact of wind turbines. As was shown in the previous two studies, the extent to which people find wind turbines visually appealing, or not, greatly influences their affective response to wind turbines in the landscape. It is possible therefore that it could affect their ratings of wind turbine visualisations.

This study addressed some of the limitations Berry et al.'s study. The present study used an online survey with animated photomontages and computer simulation to represent several different wind farm extension scenarios, rather than a single development. Participants were asked about characteristics of wind turbines and their effect on ratings of the wind farm extension options. Participants' visual preferences for wind turbines were included in the survey to see what effect they had on ratings of the visualisations. The inclusion of these variables in the current study allowed for a better analysis for the factors that affect the visual impact of wind farms, as well as the effect of visual preference on ratings of wind farm visualisations and wind farm development scenarios.

The first aim of the present study is to assess the factors that influence visual impact of wind farm extensions. Extensions of existing wind farms are likely to become more common as developers look to expand on their wind energy output. There has been little research into the cumulative effects of the extensions on the landscape and visual impacts of the wind farms, though this has been mentioned in previous guidance literature on the visual impact of proposed development (Entec, 2008; Scottish Natural Heritage, 2012). However, questions remain around the impact the size, number, degree to which new turbines match old, will affect the visual impact, and thus people's preferences for different turbine layout options. The present study sought to address some of these questions.

The second aim was to compare how people respond depending on whether they are presented with the photomontages or the simulations. While the psychophysiological data in the previous two studies showed that people's emotional responses vary between the computer-simulated and photorealistic wind turbine landscape, it is unclear what effect this difference might have on preferences/decisions. Whether these psychophysiological differences affect people's decisions about wind farm proposals is an important issue to be assessed, as it could impact upon the methods used in community engagement around wind farm developments. Whether people's preferences for variables such as size, number, and turbine layout are similar or different depending on the visualisation medium are the key questions that will be asked. These are important issues that could have real-world implications for planners and developers with regards to ecological validity and consistency of responses across different visualisation media.

The third aim of this study was to assess people's ratings of the different presentation media. Participants were asked to assess the visualisations in two different ways. They were asked about the realism of the visualisations, i.e. the degree to which the visualisations realistically represented wind turbines in a UK landscape. Secondly, they were asked about the accuracy of the information presented to them, i.e. to what extent the visualisations provided accurate and sufficient information for them to make decisions.

The three research questions are listed below,

Q_1: How do characteristics of wind turbines (size, number, degree of matching with existing turbines, turbine distribution) affect the visual impact of wind farm extensions?

Q_2: Do people show the same visual preferences for wind farm extension layouts when presented with photomontages and computer simulations?

Q_3: How do people subjectively rate the quality of the animated photomontages and computer simulations?

5.2 Methods

5.2.1 Participants

This study included 642 participants. The mean age was 27.77 years old (SD = 9.87), with 53% of participants being female. The size of the sample was not defined in advance of distributing the survey. The goal was simply to collect data from as many participants as possible. Power analyses calculated using G Power with a significance criterion of .05 suggested sample sizes varying from approximately 150 to 750 depending on whether the effect size was small to medium. As such, the sample size is towards the larger end of required sample size.

5.2.2 Apparatus

The survey was created using Qualtrics software (Qualtrics, Provo, UT). This is an online tool for the creation of surveys and collection of data. Participants were instructed to use a laptop or desktop computer with a large screen to complete the survey. Mobile devices were not permitted to be used to ensure that the landscape visualisations were adequately sized. Also, the survey was designed to be completed using a mouse/track pad so would have been difficult to complete on a mobile device such as a smartphone or tablet. If a participant's browser identified their device as a mobile device, they would have been unable to take part in the survey.

5.2.3 Material & Procedure

The online survey consisted of 5 sections. The sections and a brief overview of the content of each section are listed below. For a full list of the survey items, see appendix c.

1) Demographics and General Attitudes

This section consisted of fifteen items relating to demographics: *gender, age, nationality, education-level, homeowner status, whether and for how long they have lived near wind turbines.* It also included 9 statements on participants' general attitudes to wind turbines, including 3 questions on their level of support for wind power development (*support for onshore wind farm development in the UK, support for onshore wind farm development in their local area, support for offshore wind farm development in the UK)*, as well as 6 statements about the impact of turbines on the landscape (*visually appealing, produce low levels of noise, are ugly, have a negative visual impact on a landscape, produce and unacceptable level of noise, enhance the visual beauty of a landscape*). Participants were asked to rate the extent to which they agree with the 9 statements on a 5-point

Likert-like scale from 'Strongly Disagree' to 'Strongly Agree'. The full details of the questionnaire are listed in Appendix H.

2) Wind Farm Consultation Scenario

Participants were instructed to imagine that they lived close to an area with an existing wind farm and that a wind farm developer was looking to extend the development to double the capacity. They took the role of a community member who was being consulted on various turbine layout options for the extension. As such, the participant was being asked to rate the different layout options in terms of visual preference (i.e. which looked best). The location used in this study was the same as study 1 and 2, but only focussed on the Hazlehead wind farm. Participants were shown a picture of the Hazlehead wind farm in its current state (see figure 5.1 below). (See also Appendix H for full details of the survey)

Figure 5.1: View of Hazlehead Wind farm (3 x 101m turbines)

3) Visual Comparison of Extension Options

In this section, participants were presented with the different layout options either as animated computer simulations (created using Google Earth and Sketchup) or animated photomontages (created using VentusAR software). The VentusAR software uses digital elevation models, and wireframes, which were overlaid on the photos to ensure that the wind turbines were accurately represented. Using Adobe Photoshop, animated GIFs were created of each of the layout options by combining screenshots of the wind turbines rotating through 120°. This is sufficient to give the illusion of continual rotation because of the three evenly spaced blades on the wind turbines. For consistency with the simulations, the clouds were removed from the photomontages, and the wind turbines faced south-westerly (the prevailing direction of wind) in both the simulations and photomontages (see figures 5.2 and 5.3 below). The turbine blade angles were also staggered so that they were not rotating in sync with each other. This made for a more realistic representation of real-world wind turbines.

Participants were presented with five different turbine extension options (1 x 195m, 2 x 165m, 3 x 101m, 4 x 100m, and 6 x 97m). These extension options were presented in a random order, each on a single page with the original layout (figure 5.1) presented directly above the extension option for comparison. Each of the animated visualisations was 1060 x 596 pixels in size. Figures 5.2 and 5.3 below show non-moving samples of the photorealistic and computer generated visualisations.

Figure 5.2: Visualisation of Photorealistic Landscape (1 x 195m)

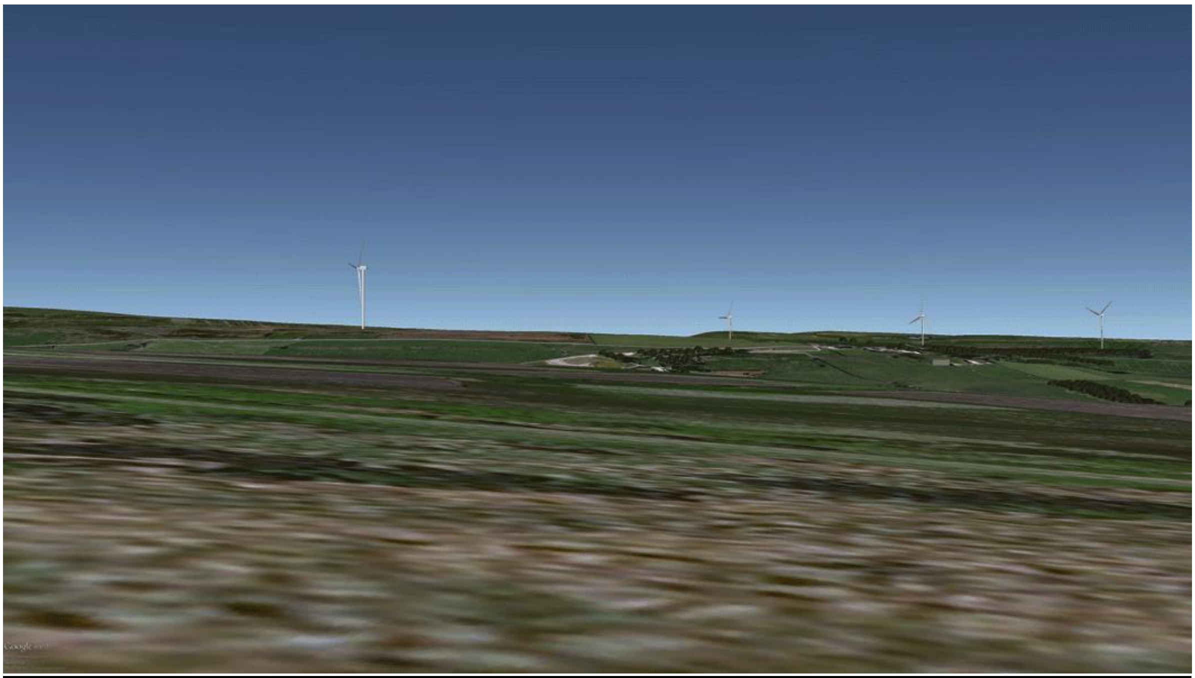


Figure 5.3: Visualisation Using Computer Simulation (1x 195m)

For each visualisation, participants were asked to rate their visual preference for the original layout and the extension option. Participants were also asked to what extent different characteristics (e.g. size of turbines, number of turbines) influenced their decisions (see Appendix H). Once they had completed the five different layout options, participants were asked to rate how realistic and trustworthy they thought the animations were.

4) Order of Preference for Layout Options

Participants were then presented with all five of the layout options, along with the original three-turbine layout and asked to rank them by visual preference. Participants had to drag and drop the animated visualisations in order of favourite at the top to least favourite at the bottom (see figure 5.4 on the next page). The starting order of the visualisations was randomised.

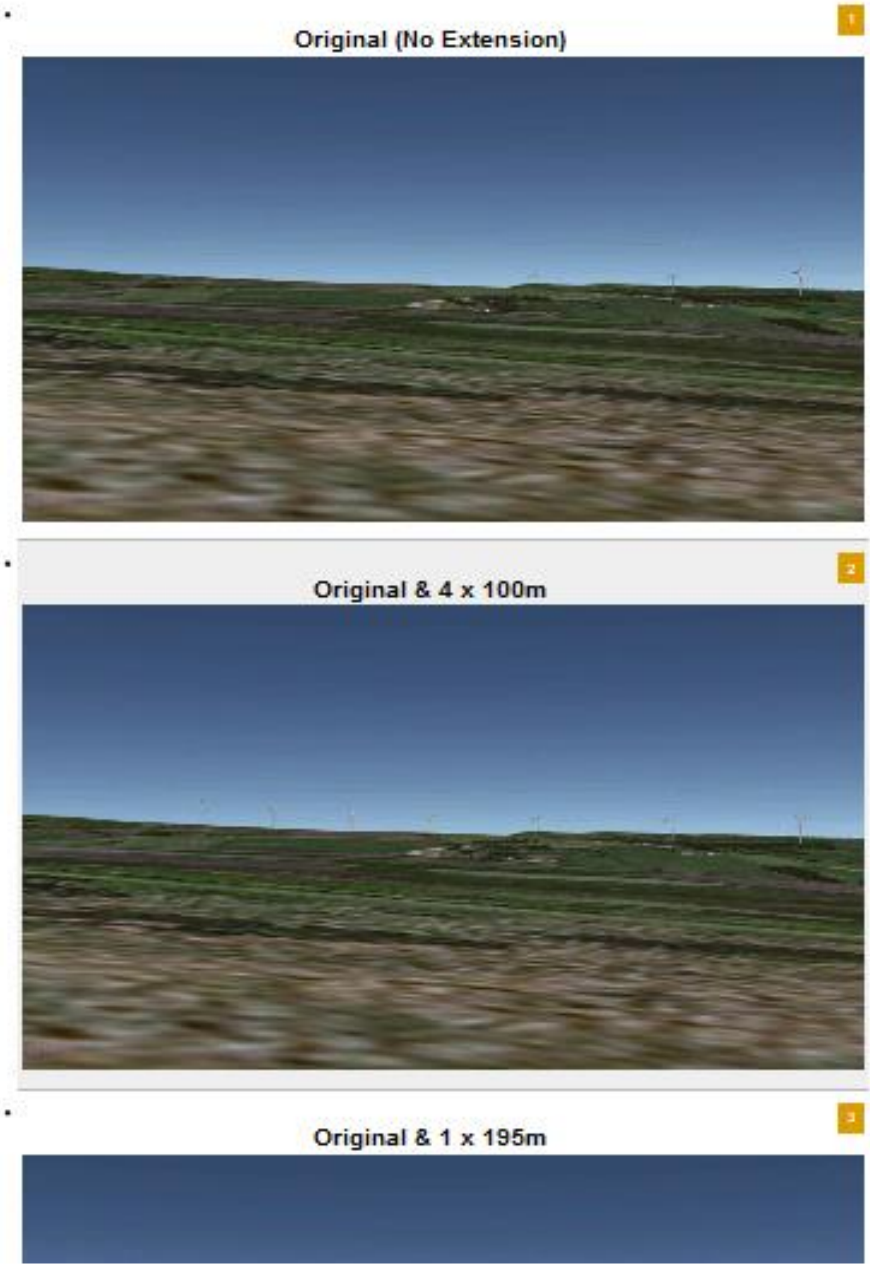


Figure 5.4: Screenshot of Drag & Drop Ranking

5) Biophilic Tendencies

The final section of this study assessed participants' biophilic tendencies. This scale included eighteen items and was modified from a scale by Delavari-Edalat and Abdi (2010). The full list of items is in Appendix H.

5.3 Results

5.3.1 Data Processing

A total of 152 participants were removed from the analysis due to a failure to complete the study. There is a large body of literature that is critical of listwise deletion of participants from a study sample, suggesting various methods of imputation as better alternatives (e.g. Andridge & Little, 2010; Dong & Peng, 2013; King, Honaker, Joseph, & Scheve, 1998; Myers, 2011; Roth, 1994). However, the extent and type of missing data in this study was different to anything discussed in the literature. The imputation methods outlined in the literature are designed for data which are missing at random across participants. In this instance, participants with incomplete data stopped completing the survey at a particular point and any subsequent questions were left unanswered. The mean completion percentage for those who did not fully complete the survey was 33.14% (SD = 26.01%), with 70.4% of those participants only having completed half or less of the survey.

Further, Pearson's chi-square analyses were run on the demographic and attitude questions to compare those who fully completed the survey with the participants who did not. Significant results were found for all but one of the questions, suggesting that there is no difference between those who completed the survey and those who did not (see table 5.1). In this case, listwise deletion should result in a loss of power only, but should not skew the results of the study (Wåhlberg & Poom, 2015).

Table 5.1: Comparison of participants with complete and incomplete survey responses

Question	**Chi-Square**	***df***	**Sig. (2-sided)**
Gender	92.03	4	.000
Age	139.933	47	.000
Country Born In	166.459	56	.000
Education Level	94.783	7	.000
Homeowner	94.582	2	.000
Lived Turbines	95.006	5	.000
Years Near Turbines	10.197	5	**.070***
Support Onshore UK	218.454	5	.000
Support Onshore Local	217.526	5	.000
Support Offshore UK	218.49	5	.000
Visually Appealing	222.639	5	.000
Ugly	224.203	5	.000
Neg. Visual Impact	219.961	5	.000
Unacceptable Noise	220.526	5	.000
Enhance Landscape	220.007	5	.000
Low Level of Noise	219.537	5	.000

5.3.2 Descriptive Statistics

Table 5.2: Descriptive Statistics for the Study Sample

Turbine Preference Group	**Really Dislike**	**Dislike**	**Neutral**	**Like**	**Really Like**	**All**
Simulation						
Number	12	58	88	128	29	315
Age (Mean)	25.250	29.069	27.602	28.156	27.759	27.567
SD	8.125	11.512	8.955	11.363	9.811	9.953
No. Homeowners	1	16	15	24	6	62
Time Lived (Mean)	0.667	1.035	1.000	0.648	1.310	0.932
SD	1.614	1.762	1.531	1.384	1.628	1.584
Photomontage						
Number	14	62	90	127	29	322
Age (mean)	30.786	27.790	27.363	27.380	26.621	27.988
SD	12.583	10.177	9.490	8.557	7.794	9.720
No. Homeowners	1	14	19	24	7	65
Time Lived (Mean)	0.786	0.587	1.083	0.608	0.310	0.675
SD	1.580	1.498	1.393	1.350	0.967	1.358

N Simulation = 315, N Photomontage = 327

5.3.3 Original-vs-New Layout

As the dependent variable was a single Likert-like item, non-parametric analyses were run. A Friedman test found a significant difference between the responses to the different layout type ($\chi^2(4) = 328.5$, $p < .001$). Further, a series of Mann-Whitney U tests showed that there was no significant difference between the visualisation type for each of the layout options: 1x195m ($z = -.317$, $p = .751$), 2x165m ($z = -.02$, $p = .984$), 3 x 101m ($z = -.626$, $p = .532$), 4x100m ($z = -.299$, $p = .765$), ($z= -.813$, $p = .416$).

Figure 5.5 illustrates the effect of the layout on participants' preference for the original or new option. The original option was preferred to the extension option with either one or two large wind turbines, as well as the six small turbines. However, the extension options with either 3 or 4 medium sized wind turbines were preferred to the original layout. This pattern is the same regardless of the visualisation type presented to the participants.

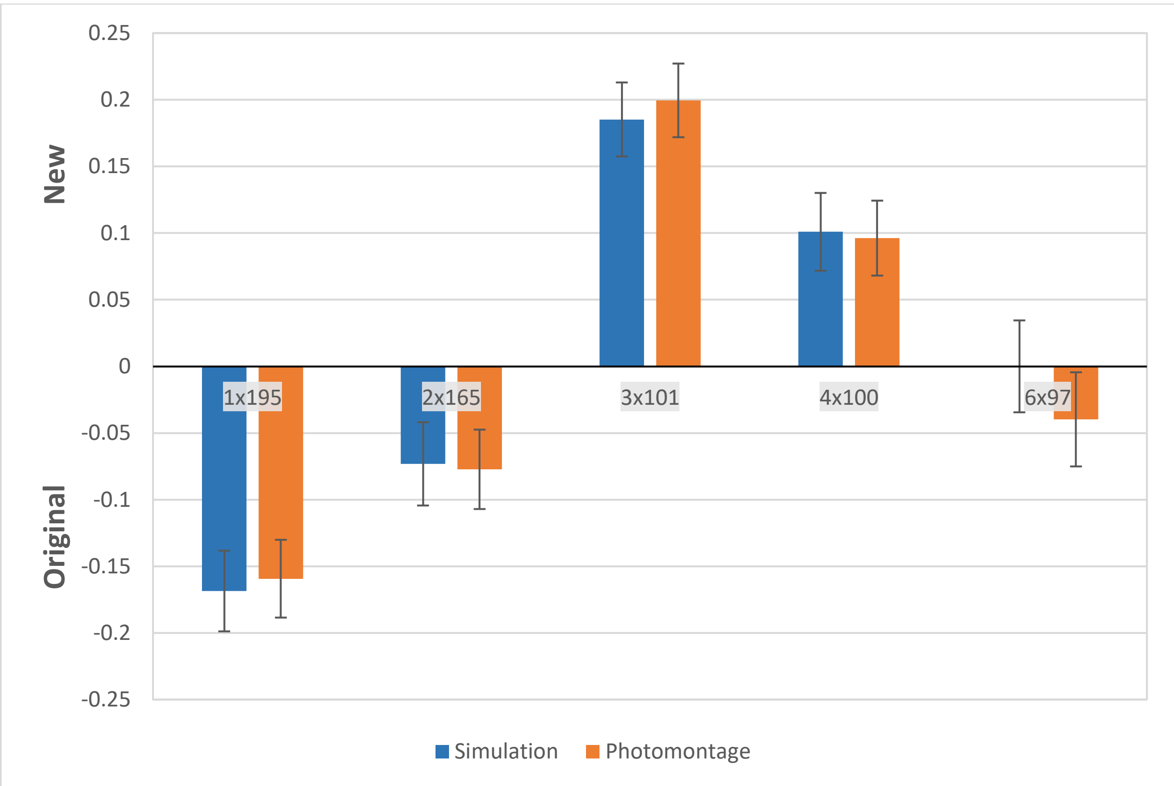


Figure 5.5: Preference for Original-vs-New Layout

5.3.4 Original and New Layouts

As with previous analyses, the dependent variable was a single Likert-like item. As such, non-parametric analyses were also run. A series of Wilcoxon signed ranks tests showed significant differences between ratings of the original and new layout options for four of the five layouts: 1x195m ($z = -14.453$, $p < .001$), 2x165m ($z = -11.754$, $p < .001$), 4x100m ($z = -5.087$, $p < .001$), and 6 x 97m ($z = -9.070$, $p < .001$). There was no significant difference in ratings of the original and new layouts for the 3x101m option ($z = -1.96$, $p = .05$). A series of Man-Whitney U tests showed that there were no significant difference in ratings by visualisation type for any of original or new layout options

Table 5.3 Mann Whitney U Tests on Differences in Ratings by Visualisation Type

Layout Option	**1x195m**	**2x165m**	**3x101m**	**4x100m**	**6x97m**
			Original		
Mann-Whitney U	49492.0	50306.5	51440.0	49981.5	50684.5
Z	-0.895	-0.534	-0.028	-0.679	-0.364
Asymp. Sig. (2-tailed)	0.371	0.593	0.978	0.497	0.716
			New		
Mann-Whitney U	51056.0	50051.5	50062.0	51050.0	50274.0
Z	-0.194	-0.630	-0.631	-0.197	-0.534
Asymp. Sig. (2-tailed)	0.846	0.529	0.528	0.844	0.593

N Simulation = 315, N Photomontage = 327

Figure 5.6 illustrates the main effects for layout option and wind farm option, as well as the lack of an effect of visualisation type. The original wind farm option was clearly preferred across all the different layout options, except for the 3x101m extension option.

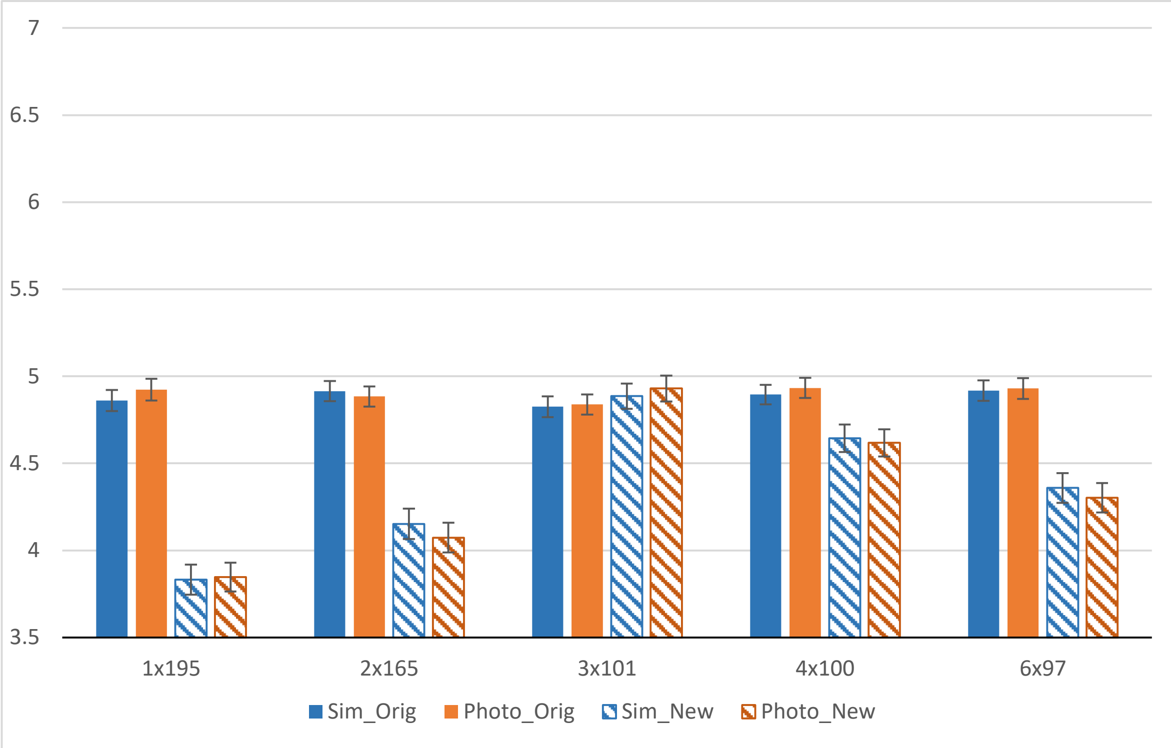


Figure 5.6: Visual Preference Ratings for Original and New Layouts

5.3.5 Importance of Turbine Characteristics

A series of Friedman tests were carried out to assess whether there were any differences in the importance of the turbine characteristics (size, number, visual match, and distribution) across the different layout options. The results showed that there were significant differences across the layout options for all four of the turbine characteristics (see table 5.4). A Series of Kruskal-Wallis tests were also carried out to assess whether there were any differences between the responses from those in the simulation and the photomontage condition. No significant differences were found for any of the turbine characteristics, or for any of the layout options (see table 5.5). Figure 5.7 illustrates the findings from these analyses.

Table 5.4 Friedman Tests on Differences in the Importance of Turbine Characteristics across Layout Options

	Size	Number	Visual Match	Distribution
Chi-Square	254.58	130.82	23.22	65.99
Asymp. Sig.	0.00	0.00	0.00	0.00

N = 642

Table 5.5 Kruskal-Wallis Tests on Differences in the Importance of Turbine Characteristics between Visualisation Type

Layout Option	**1x195m**	**2x165m**	**3x101m**	**4x100m**	**6x97m**
			Size		
Chi-Square	0.716	0.630	0.407	0.780	0.406
ASymp. Sig. (2-tailed)	0.397	0.427	0.523	0.377	0.524
			Number		
Chi-Square	3.791	0.004	0.372	0.685	0.010
Asymp. Sig. (2-tailed)	0.052	0.947	0.542	0.408	0.922
			Visual Match		
Chi-Square	0.023	0.781	7.801	0.478	1.491
Asymp. Sig. (2-tailed)	0.880	0.377	0.180	0.489	0.222
			Distribution		
Chi-Square	0.341	0.013	0.023	0.178	0.046
Asymp. Sig. (2-tailed)	0.559	0.911	0.880	0.673	0.830

N Simulation = 315, N Photomontage = 327

Figure 5.7 shows that all four of the turbine characteristics are consistently rated as important with minimum scores over 4.5. The size of the wind turbines is considered most important for the largest turbine extension option, decreasing in line with the small turbine layout options. The reverse is seen with the importance of the number of wind turbines, with this characteristic increasing in importance for layout options with more turbines. The importance of turbines visually matching existing turbines appears to be fairly consistent across the layout options. The distribution also seems consistently important, though slightly less so for the layout options with one or two large turbines. Lastly, the ratings are similar for the simulation and photomontage groups across layout options and characteristics, with the exception of the number of turbine in the 1x195m layout. In this instance the simulation group deemed the number of wind turbines to be slightly more important in their rating of the extension option.

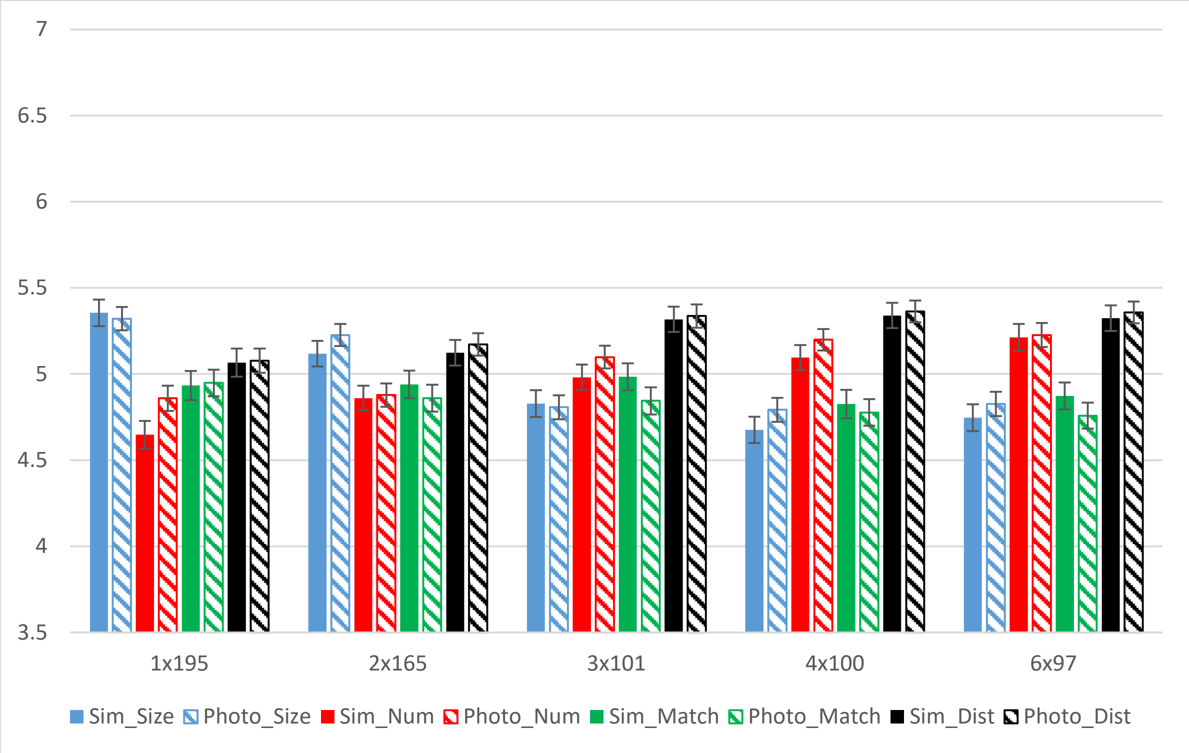


Figure 5.7: Importance of Turbine Characteristics for Layout Ratings

5.3.6 Turbine Attitude Group

A series of Kruskal-Wallis tests were run to analyse the differences across turbine preference groups in responses to the survey items related to the extension options in the wind farm scenario (see table 5.6 for full details). The results show clear differences between the attitude groups in their ratings of the original and new wind farm layouts across all of the extension options. Those in the pro-turbine groups tended to show a preference for the new layout (with the extension) in all the options, except for the 1x195m option, where the preference was only among the ‘strongly pro-turbine’ group. The pro-turbine groups showed this preference most strongly for the 3x101m and 4x100m extension options. Similarly, the anti-turbine groups rated the 3x101m, 4x100m, and 6x97m options more positively than the larger turbine options.

There was no significant difference in the importance of size in participant ratings of the extension options, except in the 1x195m option, where the strongly pro-turbine group rated it as less important that the rest. There was no significant difference across the attitude groups in the importance of number in participant ratings, though ratings were high for all groups in the extension options with larger numbers of turbines. There were significant differences in the across the groups in the ratings of the importance of the visual match in three of the extension options. The neutral and pro/anti-turbine groups appeared to rate visual match as more important the strongly pro/anti turbines groups. Lastly, there was no significant difference across groups for the distribution of the turbines in any of the extension options. It should be noted that all four of these characteristics were considered important to some extent by all of the groups in their ratings of all of the extension options.

Table 5.6: Responses to Wind Farm Scenario by Turbine Preferences Groups

	Attitude Group	Strongly Anti-Turbine (N = 26)		Anti-Turbine (N =121)		Neutral (N =179)		Pro-Turbine (N = 258)		Strongly Pro-Turbine (N = 58)		Kruskal Wallis Test	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	$\chi 2$	Sig.
1x195m	Orig/New	-0.39	0.53	-0.39	0.50	-0.16	0.50	-0.12	0.50	0.19	0.59	54.27	.000
	Orig	3.50	1.66	4.62	1.13	4.87	0.98	5.05	0.95	5.45	0.99	46.99	.000
	New	2.54	1.36	3.13	1.35	3.74	1.35	4.10	1.47	5.05	1.53	88.13	.000
	Size	5.27	1.61	5.67	1.08	5.25	1.27	5.34	1.23	4.93	1.68	11.99	.017
	Number	4.96	1.71	4.80	1.37	4.81	1.26	4.62	1.36	4.98	1.61	6.00	.199
	Vis. Match	4.46	1.75	5.01	1.48	4.89	1.32	5.12	1.39	4.40	1.79	14.81	.005
	Distribution	4.73	1.78	5.12	1.21	5.08	1.24	5.09	1.34	4.98	1.84	1.19	.879
2x165m	Orig/New	-0.58	0.48	-0.36	0.49	-0.11	0.47	0.04	0.51	0.33	0.58	97.85	.000
	Orig	3.50	1.50	4.63	1.07	4.85	0.87	5.09	0.94	5.40	0.94	52.36	.000
	New	2.31	1.32	3.33	1.34	3.99	1.33	4.45	1.40	5.41	1.56	116.49	.000
	Size	5.19	1.23	5.43	0.93	5.17	1.21	5.08	1.27	5.05	1.72	5.35	.253
	Number	5.42	1.17	4.96	1.09	4.90	1.17	4.73	1.22	4.95	1.70	9.06	.060
	Vis.Match	4.27	1.59	4.98	1.35	4.93	1.21	4.98	1.42	4.53	1.81	8.56	.073
	Distribution	5.04	1.66	5.19	0.93	5.21	1.09	5.15	1.29	4.93	1.76	0.51	.973
3x101m	Orig/New	-0.40	0.63	0.00	0.49	0.16	0.43	0.30	0.45	0.49	0.45	77.69	.000
	Orig	3.38	1.44	4.60	1.04	4.75	0.95	5.02	0.95	5.38	0.95	57.52	.000
	New	2.73	1.46	4.23	1.32	4.83	1.12	5.29	1.07	5.86	1.15	125.02	.000
	Size	4.65	1.38	5.04	1.08	4.83	1.26	4.82	1.33	4.36	1.76	6.84	.144
	Number	5.35	1.35	5.15	0.99	5.12	1.11	4.96	1.22	4.79	1.97	3.37	.498
	Vis. Match	4.00	1.55	4.91	1.31	5.01	1.18	5.09	1.40	4.24	1.91	24.08	.000
	Distribution	4.92	1.76	5.45	1.01	5.35	1.08	5.39	1.23	4.91	1.98	3.67	.452
4x100m	Orig/New	-0.44	0.57	-0.12	0.49	0.08	0.46	0.21	0.48	0.38	0.52	69.02	.000
	Orig	3.54	1.45	4.64	1.04	4.82	0.86	5.12	0.94	5.48	0.88	63.57	.000
	New	2.38	1.53	4.00	1.37	4.55	1.18	4.98	1.22	5.66	1.28	111.16	.000
	Size	4.65	1.57	4.82	1.13	4.84	1.20	4.69	1.32	4.50	1.72	1.22	.874
	Number	6.04	0.82	5.31	1.06	5.11	1.09	5.03	1.20	5.05	1.77	22.40	.000
	Vis. Match	3.73	1.59	4.72	1.30	4.82	1.32	5.04	1.35	4.31	1.85	27.06	.000
	Distribution	4.88	1.56	5.39	1.02	5.41	1.07	5.38	1.20	5.17	1.81	4.17	.383
6x97m	Orig/New	-0.35	0.75	-0.21	0.61	-0.09	0.58	0.09	0.59	0.28	0.67	42.24	.000
	Orig	3.58	1.36	4.62	1.08	4.88	0.93	5.09	0.95	5.55	0.99	61.36	.000
	New	2.38	1.70	3.74	1.45	4.18	1.37	4.68	1.37	5.34	1.40	91.55	.000
	Size	5.15	1.16	5.02	1.13	4.71	1.34	4.76	1.31	4.50	1.71	6.16	.188
	Number	6.04	1.00	5.53	1.01	5.23	1.25	5.03	1.33	5.00	1.88	22.64	.000
	Vis. Match	4.38	1.58	4.77	1.30	4.85	1.25	4.95	1.35	4.41	1.82	8.73	.068
	Distribution	5.27	1.48	5.42	0.95	5.37	1.16	5.36	1.22	5.03	1.74	0.94	.919

5.3.7 Order of Preference for Extension Options

A non-parametric Friedman rank test showed significant differences in the ranks for the layout option for the simulations (χ^2 = 227.05, *p* < .001), as well as for the photomontages (χ^2 = 195.02, *p* < .001). Table 5.3 below shows the mean rank scores for the different layout options for the simulation and photomontage groups. Participants in the simulation and photomontage groups agreed for the most part on the order of the layouts, with both groups picking the 3x101m option as their favourite and the 1x195m option as their least favourite. Both groups also agreed that the 2x165m and 6x97m options were their second and third least favourite respectively. However, the groups differed on their choices for 2nd and 3rd favourite option. The simulation group chose no extension for their 2nd favourite option and 4x100m extension as their third favourite, with the photomontage group choosing the reverse.

Table 5.7: Ranks of Layout Options for the Visualisation Groups

	Friedman Test Mean Rank (Rank)	
Extension Option	**Simulation**	**Photomontage**
1x195m	4.37 (6)	4.54 (6)
2x165m	4.02 (5)	3.96 (5)
No Extension	3.14 (2)	3.22 (3)
3x101m	2.46 (1)	2.78 (1)
4x100m	3.20 (3)	2.98 (2)
6x97	3.81 (4)	3.52 (4)

5.3.8 Realism of Visualisations

After completing the layout ranking task, participants were asked to rate the visualisations used in the survey in four ways: the extent to which 1) They presented a realistic depiction of wind turbine in the landscape, 2) They accurately reflected the proposed extensions, 3) They provided sufficient information to form an opinion about the proposed extensions, and 4) They realistically portray the general landscape. A series of t-tests were carried out to see if there were any significant differences between the simulation and photomontage groups on these four questions (see table 5.4 below for the results). On both measures of realism, the photomontages were judged to be significantly better than the simulations, though there was no significant differences in terms of accuracy of sufficiency of information. Further, no significant differences were found in any of the rating metrics across turbine preference group (see table 5.5 below).

Table 5.8: Participant Ratings of Realism of Visualisations

	Simulation		Photomontage		
	Mean	**SD**	**Mean**	**SD**	**t-test**
Realistic Turbines	3.82	.837	4.02	.730	-3.151*
Accurate	3.82	.766	3.85	.801	-.501
Sufficient Info.	3.67	1.00	3.71	.967	-.591
Realistic Landscape	3.60	.940	3.97	.715	-5.615**

*p< .05, **p < .01, N =642

Table 5.9: Participants Ratings of Realism of Visualisations by Visual Preference

Preference Group	**Strongly Disagree (N = 26)**		**Disagree (N =121)**		**Neither Agree nor Disagree (N =179)**		**Agree (N = 258)**		**Strongly Agree (N = 58)**		**Kruskal Wallis Test**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	$\chi 2$	**Sig.**
Realistic Turbines	3.58	1.10	3.88	0.83	3.91	0.78	3.97	0.70	3.97	0.95	4.17	.383
Accurate	3.62	1.02	3.87	0.81	3.77	0.81	3.88	0.70	3.88	0.88	3.93	.416
Sufficient Info.	3.35	1.29	3.60	1.04	3.70	0.93	3.77	0.91	3.64	1.15	3.69	.449
Realistic Landscape	3.35	1.26	3.82	0.85	3.76	0.85	3.85	0.78	3.76	0.94	3.94	.414

5.4 Discussion

This study sought to provide greater insight into the factors that affect the landscape and visual impact of wind farm extensions, and to examine whether the visualisation medium affected participants' preferences. The aims were to examine to what extent the size, number, visual match, and distribution of the turbines affected participants' ratings of the different extension options, whether responses differed between the simulation and photomontage groups, and whether responses differed by participants' visual preference for wind turbines in the landscape.

Layout Preferences and Wind Turbine Characteristics

The findings from this study show that participants rated the original wind farm more highly than the proposed extension in three of the five layout options, the two options with large turbines (1x195m & 2x165m) and the option with six smaller turbines (6x97m). The two options which were considered preferable to the original were the extensions of 3x101m and 4x100m turbines, with the 3x101m the most preferred of the two. These preferences were further supported in the ranking task where the best ranked option was the 3x101m in both the simulation and the photomontage groups, while the second and third ranked option were the 'no extension' option and the 4x100m. Previous research into the physical characteristics that affect the visual impact of wind turbines has shown that the number of turbines is an important factor (Jones et al., 2011; Sustainable Energy Ireland, 2003; Torres Sibille et al., 2009). The research consistently shows that fewer turbines are considered preferable in terms of the minimising the visual impact, though there is some evidence that the visual impact plateaus after six turbines (Ladenburg & Dahlgaard, 2012). The findings from the current study support the idea that the number of turbines is an important consideration, though the options were fewer turbine rated lowest. This is likely due to the interaction of another turbine characteristic, namely the size.

The effect of size or height of wind turbines on visual impact has been examined in several studies with mixed results. Some researchers have suggested that the size of wind turbines does not affect people's preferences for wind farm layouts or the social acceptance of a wind farm (Erp, 1997; Meyerhoff et al., 2010). However, other researchers have found that the size of wind turbines is important in terms of the negative visual impact of a wind farm (Kokologos et al., 2014; Tsoutsos et al., 2009). Tsoutos et al. (2009) found that participants rated a single turbine with a hub height of 120m as having a greater negative visual impact on the landscape than 11 turbines with hub heights of 45m. The findings from the current study support a similar pattern, as participants considered the 1x195m and 2x165m options as having a greater negative impacts than the 6x97m option. It is clear that the size and number of the turbines interact with regards to visual impact. In the case of the Hazlehead wind farm scenario, this interaction is particularly important as the extension options are being add to an existing wind farm with three 101m wind turbines. In this instance, the existing turbines, as well as the size and number of the new turbines interact. This interaction is likely seen in the responses 'visual match' characteristic. The results show that this is rated fairly consistently across the extension options and is likely representative of the interplay of the existing turbines with the size and number of the new turbines. Similarly, the importance of the distribution of the wind turbines is also across the wind farm extension options.

Visualisation Method

The participants rated the photomontages as more realistic than the computer simulations. This was true on both measures of realism, i.e. how realistic the wind turbines were, and how realistic the general landscape was. These findings are consistent with previous research, which has generally found that participants consider photomontages preferable to other methods, e.g. wire frame, or computer simulation (Berry et al., 2011; Bishop & Rohrmann, 2003; Oh, 1994; Rohrmann et al., 2000; Rohrmann & Bishop, 2002). Although photomontages were rated significantly better in terms of realism, there were not considered any different to the simulations in terms of the accuracy and sufficiency of information to make a decision. This would suggest that, in practical terms, the simulations are as good as the photomontages for any decision-making exercise, as is supported by the findings from the wind farm scenario.

There appears to very little impact of the visualisation method on the participant ratings of the layouts, or on the importance of the turbine characteristics in determining visual impact. There were no significant differences between the simulation and photomontage groups in the ratings of the original wind farm and the new layout options, nor in the ratings of the importance of size, number, visual match, and turbine distribution. This would seem to suggest that the visualisation medium does not affect the preferences of people with regards to wind farm developments. However, there was a difference in the order of preference task, with the simulation group rating the 'no extension' option higher than the photomontage group. This would support the contention of many researchers that computer visualisations could and should be used to model landscapes for interactive design and planning (Appleton & Lovett, 2003; Lange, 1994, 2011; Orland et al., 2001; Schroth et al., 2011).

Wind Turbine Visual Preference

Given the differences in skin conductance response between the different turbine preference groups in studies one and two, it seemed important to assess whether these different groups would respond differently to the questions in this study. While participants consistently rated the photomontages as more realistic, there appears to be no difference between the turbine preference groups for any of the four measures of realism and accuracy. There was however a significant effect of wind turbine preference group on most of the questions about the extension options. The participants who were more positive about the visual aesthetics of wind turbines consistently rated the original and the new layouts as more attractive than those who think wind turbines are ugly. Their visual preference grouping also affected participants' ratings of the importance of size, number, and visual matching on the visual impact of wind turbines. These findings are consistent with previous research which has found that people's attitudes to wind turbines has a significant effect on their ratings of the visual impacts of wind farms (Johansson & Laike, 2007; Molnarova et al., 2012).

Implications

While participants rated the photomontages as more realistic than the computer simulations, they rated both types of visualisations similarly in terms of accuracy and sufficiency of information. The results from the questions in the wind farm scenario were also reflected this, with preferences being almost identical. These findings are of practical significance for community engagement and would be of interest to planners or developers who were consulting a community about a proposed wind farm development. If people make the same decisions based on photomontages and computer simulations, then using computer simulations for engagement or decision making about developments could be useful (Bishop & Lange, 2005; Danese, Casas, & Murgante, 2008; Lange, 1994; Sheppard & Cizek, 2009).

The results also provide insight into the visual impacts of wind farm extensions, and the factors that are important in contributing to this visual impact. While wind farm extensions have been mentioned in the literature (e.g. Entec, 2008; RenewableUK, 2014; Scottish Natural Heritage, 2006), there is little academic research into the factors that affect the landscape and visual impacts of these extensions. While this study only used a single wind farm scenario with several layout options, it has provided insight into the importance of factors, such as size, number, visual match, and turbine distribution, in contributing to the landscape and visual impacts of wind farm extensions. This could help to provide insight and guidance to developers about what type of wind farm extension would cause the smallest visual impact on the landscape, and could be incorporated into guidance documents in visual impacts assessment of wind farms (e.g. Scottish Natural Heritage, 2006, 2012).

The findings also show that the wind turbine preference grouping is important. As previous research has shown, people’s general attitudes to wind farms has a significant impact on their ratings of wind turbine developments (Johansson & Laike, 2007; Ladenburg & Krause, 2011; Molnarova et al., 2012).

It could also be of practical importance in a consultation process to see whether people objecting to a wind farm proposal come predominantly from 'anti-turbine' groups, or if 'pro-turbine' groups are also objecting. This may help to distinguish between those who would be against any wind farm development layout, and those who are objecting to something specific about the wind farm development.

Limitations & directions for future research

There were several methodological limitations of this research that could be addressed in future studies. It may have been helpful to include static versions of the photomontages and computer simulations to assess what effect the dynamism has on people's preferences, as well as ratings of the visualisations. Berry et al. (2011) showed that there may be differences between dynamic and static computer simulations, and it would have been useful to assess this in the current study.

As the study was an online survey, there is likely to be inconsistency in the type and size of computer screens used. While this might not be much of an issue for a text-based survey, it is likely to be important in the current study where participants are viewing images and making decisions based on their perceptions of those images. In an effort to minimise the impact of screen inconsistency, images were displayed at a consistent size (1060 x 596 pixels), and participants were unable to complete the survey on a mobile device, such as a phone or tablet. While the online survey was used as it allowed for a larger sample, future research could try to control for this potential inconsistency. Another methodological weakness is that the amount of time participants spent viewing was not monitored. As such, it is not possible to know the extent to which the participants engaged with the visualisations during the experiment.

While the first two studies provided objective measures of people's responses to wind turbines in the landscape but was unable to provide insight into why people responded as they did, the current study provided the opposite. Given cost and time constraints, it wasn't possible to carry out a study that combined both, it would be interesting to compare the objective physiological responses with people's preferences for different layouts. This would allow a research to examine the relationship between the affective responses and the choices people make with regards to wind farm developments.

As with the previous two studies, this research is skewed towards western, educated, industrialised, and rich (WEIRD) participants. However, the gender ratio was better balanced than the first two studies and the participants were older on average, and weren't exclusively university students. It would be interesting to see if the findings would be the same from a sample that is more representative of the general population. Another sample-related issue is the fact that the participants were not from the area and had no place attachment. Place attachment has been shown to be an important factor in people's opposition to wind farm developments (Devine-Wright, 2005a, 2009). It is possible that participants with place attachment might respond differently to the survey, e.g. people with place attachment may have a more negative response to any wind farm development in their local area. It is hypothesised that those with place attachment have their place-related identity processes threatened by new developments. These new developments could potentially disrupt emotional attachments and so opposition by people with place attachment can be conceived as an act of place protection. Given the lack of place attachment in the study sample, the results may not be reflective of responses to a real-world wind farm development. Further, research has shown a 'social gap' between people's general attitudes to wind farms and their attitudes to wind farms in their local community (Bell, Gray, & Haggett, 2005; Bell, Gray, Haggett, & Swaffield, 2013). This also highlights the importance of studying this issue with a real-world community and the real threat of a local wind farm development.

As was discussed in the previous chapter, virtual reality (VR) and augmented reality (AR) could also be used in future research in this area. Ideally, it would be possible to combine VR headsets with eye-tracking (e.g. Stengel, Grogorick, Eisemann, Eisemann, & Magnor, 2015), as well as using skin conductance response (SCR) and surveys. This would provide a methodological platform that could be used to carry out research into many different aspects of wind farms and their landscape and visual impacts. Further, given the investment and development happing in VR technology (Webster & Clark, 2015), the cost and availability of the technology will no longer be obstacles to its use by developer, communities, or researchers.

Conclusion

This study used a wind farm extension scenario to assess three key issues: the extent to which the characteristics of wind turbines affect the visual impact of wind farm extensions; whether the visualisation medium (simulation or photomontage) affects layout preferences; and how people rate the visualisation media in terms of realism, and accuracy. While participants rated photomontages as more realistic, they showed no difference in ratings of accuracy or information sufficiency, nor did the presentation medium significantly affect their preferences for the layouts. In both cases, participants preferred the extension option that matched with the existing wind turbine in terms of size and numbers. These findings could be of interested to planners and developers, as well as being useful for documents which provide guidelines on landscape and visual impact assessment. Lastly, the findings suggests that, in a practical sense, computer simulations are no different to photomontages, and are as valid to use in a research or community engagement setting.

6 General Discussion

6.1 Justification for Research and Aims of Thesis

With growing concerns about climate change and the threat of its effects to the human population, there has been an increased focus from world governments on decarbonising the energy system to reduce global CO^2 emissions. Given the relative maturity of wind as a renewable energy source and its low cost relative to other sources, wind energy has expanded greatly in the recent years. Electricity generation is the UK's largest single contributor to greenhouse gas (GHG) emissions, and the UK government has committed to building 14GW of onshore wind energy by 2020 in order to help reduce carbon emissions from this sector (Department of Energy & Climate Change, 2012). Since 2000, there has been more than a tenfold increase in the installed capacity of wind energy in the UK, and there would need to be a further doubling of capacity to meet the 2020 targets (Renewable UK, 2015). The increased levels of wind energy development has led to issues around social acceptability and the landscape and visual impacts of wind turbines. In the UK, the percentage of wind farm development applications which have been refused has increased steadily since 2010 (RenewableUK, 2014).

There has been a great deal of research into the factors that affect the social acceptance of wind energy developments. One approach researchers have taken in trying to understand the opposition to wind farms has focussed on community-level factors. Within this approach, some researchers have focused on place attachment and identity and believe that opposition to wind farm developments can be conceived of as a protective action to prevent change (Devine-Wright, 2009, 2011). Others have suggested that planning and procedural processes are key to understanding local opposition, with open and collaborative approaches to planning preferable to existing top-down decision making (Ellis et al., 2009; Wolsink, 2007b). Another approach researcher have taken it to try to assess the characteristics of wind turbines and the attitudes of respondents that contribute to landscape and visual impact of wind turbines. This literature has investigated whether sociodemographic variables, such as age, gender, and income have an effect on people's attitudes to wind farms, with mixed results (Álvarez-Farizo & Hanley, 2002; Ek, 2005; Meyerhoff et al., 2010). This research has also shown that physical characteristics such as the height, number and distance affect the impacts of wind turbines (Bishop, 2002; Jones et al., 2011; Lothian, 2008; Meyerhoff et al., 2010; Molnarova et al., 2012; Torres Sibille et al., 2009; Tsoutsos et al., 2009).

While there is a considerable body of research that has looked at factors that affect the landscape and visual impact of wind turbines, few have looked at the cumulative effects (Jones et al., 2014). While the cumulative landscape and visual impact (CLVI) of wind turbines is noted in guidelines around landscape and visual impact assessment of wind turbines (Entec, 2008; Landscape Design Associates, 2000; Sullivan & Meyer, 2014), it has received very little attention from academic researchers. With the continued growth of onshore wind developments, the factors that contribute to these cumulative impacts need to be better understood. This thesis sought to better understand some of the factors that contribute to CLVI and to take some small steps towards filling this gap in the research.

The second focus of this thesis was on methods used to visualise wind turbines, and the methods used to assess people's responses to wind turbines. Several different visualisation methods have been used to represent wind turbines in practice and in academic research, such as wireframe, photomontage, and computer simulation (Oh, 1994; Rohrmann et al., 2000). There has been some research comparing these different methods, though these studies have used subjective measures such as surveys or interviews (e.g. Berry, Higgs, Fry, & Langford, 2011; Rohrmann & Bishop, 2002; Sevenant & Antrop, 2011). In order to try to objectively assess people's responses to photorealistic and computer-simulated landscapes, psychophysiological measures, i.e. eye-tracking and skin conductance response (SCR), were used. These measures allowed for a novel approach to assessing different landscape visualisation methods and provided new insights into people's responses to the different visualisation methods.

6.2 Findings and Implications

Psychophysiological responses to photorealistic and computer-simulated landscapes

Studies 1 and 2 showed that participants' visual attention patterns were similar for videos of a real landscape with wind turbines and videos of a computer simulation of the same landscape. In both studies, the pattern of fixation duration on three different wind farms was similar. This suggested that the relative visual impact of the different wind turbines was consistent across the photorealistic and computer-simulated landscape. The eye-tracking data provided support for those who suggest that computer simulations could be a useful tool for research, as well as interactive design and planning (Danese et al., 2008; Honjo et al., 2011; Lange, 1994, 2011; Schroth et al., 2011).

The findings from SCR data however showed that participants' affective responses differed between the photorealistic and computer simulated landscape. When looking at the turbine preference grouping, there was a u-shaped pattern that approached significance, suggesting that those who were in the 'strongly pro' or 'strongly anti' turbine groups reacted more than those in the neutral group. The SCR data from study 2 showed that there was a non-significant n-shaped pattern across those groups when they were presented with the video of the computer simulation. In this case, those who were in the 'strongly anti' or 'strongly pro' groups had a reduced affective response when compared with the neutral group, though the difference was not significant. As discussed previously in section 2.3.1, no inferences have been made as to the valence of these affective responses. While it is possible to state that those who were in the 'strongly pro' or 'strongly anti' groups had greater affective responses, it is not possible to deduce whether those response were positive or negative.

The findings from study 1 were explained in terms of the biophilia hypothesis or the 'Green on Green' concept. 'Green on Green' is used to describe and situation in which people on both sides of an argument can be described as pro-environmental. Attitudes to wind energy can be explained by this concept (Warren et al., 2005). Those who oppose wind farms tend to do so because of the effects on the landscape, while those who support wind farms tend to so because they view wind energy as clean and renewable. The biophilia hypothesis could also explain the findings. The hypothesis suggests that people tend to have an affection and preference for life and life-like processes (Joye & de Block, 2011; Kellert & Wilson, 1993). This would explain why participants responded to the videos when the turbines were present and also when they were absent. Participants could be seen to be responding to the landscape as a whole, with increased or decreased response with the presence of the wind turbines depending on their preference grouping. Those in the 'strongly pro' and 'strongly anti' groups could be considered to have greater biophilic tendencies.

The SCR findings from study 2 were explained in terms of the biophilia hypothesis and the uncanny valley. If we assume that those in the 'strongly pro' and 'strongly anti' groups were more biophilic, then we might expect them to have a stronger affective response to the landscape than the neutral group. However, the results were the reverse of what might have been expected. The uncanny valley provides a potential explanation for this seemingly strange result. Within the field of robotics, the 'uncanny valley' is a term used to describe when a humanlike robot approaches but hasn't reached 100% likeness (Mori, MacDorman, & Kageki, 2012). Mori suggested that people's affinity for humanlike robots would increase as the human likeness increased, but that there would be a dip when the likeness was close to but not quite perfect. He also suggested that movement would magnify this effect. The uncanny valley has been found in computer games, animated characters in films, as well as 3D robots (Ho & MacDorman, 2010; Mitchell et al., 2011; Tinwell et al., 2011). If those in the 'strongly pro' and 'strongly anti' groups were more biophilic and had a greater emotional attachment to the landscape, the moving computer simulation in study 2 could have resulted in this uncanny valley effect and led to the SCR data showing an almost reversed pattern to study 1.

Subjective Responses to photorealistic and computer-simulated landscapes

The results from study 1 and study 2 created some interesting questions. The eye-tracking data suggested that participants were reacting in a similar fashion to the photorealistic and computer simulated landscapes, but the SCR data suggested that there was a difference in responses. How would people subjectively rate photorealistic and computer simulated wind-turbine landscapes? And would people's visual preferences be affected by whether the visualisation was a photomontage or a computer simulation? Study 3 set out to answer these questions.

The results from study 3 showed that participants considered the animated photomontages to have a significantly higher level of realism than the animated computer simulation. These findings were similar to previous research which suggested that photomontages were considered to be the most realistic of the traditional visualisation methods (Berry et al., 2011; Oh, 1994). However, on ratings of accuracy and sufficiency of information to make a decision, the participants believed that there was no significant difference between the two visualisation methods. This would suggest that while computer simulations are not considered as realistic as photomontages, they do provide a similar level of information and should result in similar responses to photomontages. This turned out to be the case as the visualisation method appears to have had little to no effect on participant responses. The visualisation method had no significant impact on participants' ratings of the original or new layouts, nor did it affect participants' ratings of the importance of the different turbine characteristics (size, number, visual match, distribution). These findings further support the for using computer simulations for design and planning (Appleton & Lovett, 2003; Orland et al., 2001; Schroth et al., 2011).

There was a slight difference in the layout preference order between the photomontage and the computer simulation group, with regards to the 'no extension' option. If the 'no extension' option were removed from the list, then the order of preference would have been the same for the photomontage and the simulation groups. How important this difference would be in a real-life setting is hard to assess. If a community were being asked to judge several different wind farm layout options, then it would likely be unimportant. It is also possible that this finding is an anomaly and would not be repeated if the study were run again. This is something that requires further research.

Factors affecting CLVI of wind turbines

The eye-tracking data from studies 1 and 2 showed that participants spent significantly longer looking at Royd Moor wind farm than Hazlehead or Blackstone Edge. This would suggest that more numerous smaller turbines attract more visual attention that fewer larger turbines. Previous research has suggested that both size and number of turbines affect the visual impact of wind turbines and the eye-tracking data would appear to support this (Bishop, 2002; Jones et al., 2011; Molnarova et al., 2012). In study two, a small but significant difference in visual attention was found between Blackstone Edge and Hazlehead, with fixation duration being significantly lower for Blackstone Edge. Blackstone Edge had non-moving turbines, which suggests that perhaps static turbines draw less attention than moving turbines. Bishop (2002) has noted how movement makes wind turbines appear larger and the movement of turbine blades is often cited as a key issue with regards to the visual impact of wind turbines (Pedersen et al., 2007; Piper, 2004). This finding should be interpreted with caution as it was not found in study 1 and may be an effect of the computer simulation.

The findings from study 3 gave greater insight into the factors that affect the CLVI of wind turbines. The results showed that all four of the turbine characteristics (size, number, visual match, and distribution) were considered important factors in participants' ratings of the visual impacts of the proposed extensions. The relative importance of size and number varied depending on the extension option. Perhaps unsurprisingly, size was considered a more important factor in the rating of the extension options with the larger turbines, and number was considered more important for the extension options with more turbines. Visual match and turbine distribution were consistently rated as important across the layout options, with no real differences.

Participants rated the single large turbine extension the lowest, followed by the extension option with two large turbines. The highest rated options were the three medium turbines, followed by the four medium turbines options. The extension with six small turbines was rated better than the large turbine options but lower than the medium turbine options. These findings fit with the eye-tracking data from studies 1 and 2. The six smaller turbines are considered to have more of a visual impact than the three medium size turbines. There were no large turbines in study 1 and 2 so it is unclear whether large turbines would attract the greatest level of visual attention. Given that visual match and turbine distribution were consistently rated as important, it may be that these were the most important factors in the decision-making process. The highest rated option visually fit the best with the existing wind farm, and the visual fit is progressively worse the lower the extension rating.

The analysis of the visual preference grouping showed those who were more pro turbines consistently rated the existing turbines and the extensions higher than those in the anti-turbine groups. The grouping also affected participants' ratings of the important of three of the turbine characteristics, namely size, number and visual match. This is in line with previous research which has shown that existing attitudes towards wind turbines affect people's responses to wind farms (Johansson & Laike, 2007; Molnarova et al., 2012).

Summary of Findings

Overall the research suggests that there are clear differences between videos/photomontages and computer simulations. Studies 1 and 2 showed that the affective responses were different, while study 3 showed that the participants rated the photomontages as more realistic. However, the presentation medium didn't affect people's preferences. Studies 1 and 2 showed that participants' visual attention pattern was similar for the photorealistic landscape and the computer simulation. Study 3 supported these findings with participants answering similarly for the photomontages and the computer simulations. The first two studies also showed that participants looked longer at Royd Moor than Hazlehead or Blackstone Edge. Further, the results from study 3 showed that participants preferred the 3x101 option to the 6x97, which could support study 1 and 2, if we assume that the greater length of time looking at Royd Moor was due to the greater negative visual impacts of the smaller turbines. Study 3 also showed that very large turbines were considered to have the most negative visual impact. These findings would suggest that very large turbines or very numerous turbines are not desirable. In the case of wind farm extensions, it is possible that visual match with the existing wind farm is the most important factor in terms of the cumulative landscape and visual impact.

6.3 Limitations of the research

Objective and Subjective Data

Studies 1 and 2 provided an objective psychophysiological assessment of people's responses to videos of photorealistic and computer simulated landscapes. While this approach was novel and provided interesting data, it did not provide much insight into the factors that affected people's responses. So while it was possible to say that people spent longer looking at Royd Moor wind farm, there was no data on why this was the case. It is possible to infer from the results of study 3 that the smaller more numerous turbines had a greater visual impact than the three medium sized turbines of Hazlehead and Blackstone Edge, but it would have been better to ask participants these questions in study 1 and 2. Similarly, the reason for the differences in SCR across turbine preference groups, and between photorealistic and computer simulated landscapes was also inferred. It would have been useful to have included a survey on people's subjective assessment of the videos.

Study 3 tried to remedy some of these limitations by asking people directly about the visualisations. The survey attempted to gain insight into the factors that affect the CLVI of different extension options and to assess the different visualisation methods. However, unlike the first two studies, there was no objective measure of participant responses. This was not possible as study 3 involved an online survey, partly to ensure a larger sample size than the first two studies. While study 3 collected data from a much larger sample, it did not have any form of objective measure of response. Although it would be more costly and time-consuming, a future study could combine the objective and subjective measures. This would provide an interesting comparison between people's objective responses and their subjective assessment.

Sample Issues

Perhaps the most important limitation of the three studies is with regards to the sample. The studies contained predominantly young, western, educated participants, most of whom were Sheffield University students or staff. Although the WEIRD issue is common in psychology research (Henrich et al., 2010), there is a more important issue with the samples used. The samples were not composed of people facing the prospect of a real wind farm development in their community. Devine-Wright's research has highlighted the role of place attachment and its importance in opposition to wind farm developments (Devine-Wright, 2005a, 2009). Wolsink and others have looked at issues of procedural and distributive justice in wind farm opposition, and have argued for the importance of participatory planning (Ellis et al., 2009; Wolsink, 2000, 2007a, 2007b). Researchers have also highlighted the 'social gap' in support for wind energy, with people showing a high level of support for wind energy in general, but a low level of support for wind energy in their community (Batel & Devine-Wright, 2014; Bell et al., 2005, 2013).

The participants in the three studies were not asked about their local community, so the issue of place attachment didn't affect their responses. As it was not a real wind farm development scenario, there were no issues of procedural or distributive justice as there was no real planning process. Finally, the social gap shows that there is a big difference in support for wind development nationally when compared with locally. Given that the participants were not local to the Stocksbridge area, it is possible that their responses are more reflective of their attitudes to wind farm development in general. If this is the case, then it is impossible to know if the findings form the three studies would be replicated with a community facing the real prospect of a wind farm development. Further, as study 3 was a purely hypothetical scenario, the results may not even be reflective of the participants' general attitudes to real wind farm development.

6.4 Future Research

Addressing Limitations

As mentioned previously, future research could combine elements from the three studies to compare objective and subjective responses. This would combine the strengths of the three studies and would eliminate one of the main limitations. Another limitation that could be addressed in future is carrying out similar research with a community that is facing a wind farm proposal, perhaps in conjunction with a wind farm developer. While it may be difficult to get a developer to agree to such a research proposal, the information gather from such a study would be of interest to a number of different audiences, including: planners, developers, and academics.

Another limitation that could be address in future research is the limited number of layout options that were assessed. The wind farm scenario in study three only looked at five different layout option to one existing wind farm. A greater variety of extension scenarios could be created to give greater insight into the factors that affect the CLVI of wind turbines. Moreover, completely different scenarios could be created, such as the repowering of an existing wind farm (Colmenar-Santos et al., 2015; Del Río et al., 2011). Various scenarios could be created to assess the impact of different factors in different situations.

Interactive Online Studies

For online studies, it would be interesting to use images that change dynamically, i.e. hovering over the image, clicking a button, or dragging a slider would change the turbine layout. These were explored as possible ideas for study 3 but proved too difficult to achieve within the timeframe of the thesis. These methods could provide for interesting research designs, e.g. an image could be presented with no turbines and the participants would drag the slider, which would keep adding turbines, until they reached a maximum acceptable number. Conversely, an image could be presented with 50 wind turbines, and the participant could drag a slider to reduce the number until they reach an acceptable number. With more elaborate development, an interactive scenario could be created where participants were asked to create a wind farm of a certain power (e.g. 15MW). They could be presented with an interactive landscape, where they could decide the number and size of turbines and where to place them, as long the final wind farm reached the required power output. This type of scenario could provide insights into the trade-offs between these characteristics in terms of visual impact.

Virtual and Augmented Reality

As discussed in chapter 4, virtual reality (VR) and augmented reality (AR) offer interesting possibilities for future research. Given the active development of VR by large technology companies, such as Apple, Facebook, Google, Microsoft, and Samsung, it offers the possibility of an affordable and immersive technology for research and engagement(Webster & Clark, 2015). VR could be used to created 360° immersive simulations for research or for wind farm proposal. It would be possible for a developer or researcher to create a 3D environment with a wind farm development that could be viewed by anyone with a basic VR headset. In reality this would mean anyone with a smartphone and a cheap VR kit, which can be bought for as little as £20. VR could also be combined with eye-tracking to assess where people are looking in the simulation. AR provides better levels of realism, as it uses the existing landscape and superimposes accurate 3D. VentusAR is software that can be used on tablets to view proposed wind farms on site. AR can be combined with a VR headset to give the realism of traditional AR with the immersion of VR. This can be done using a head mounted kit for a smartphone, using the phone's camera to show the real world with the AR models superimposed on the screen (Hasan & Yu, 2015).

6.5 Conclusion

This thesis set out to improve understanding around the factors that affect the CLVI of wind turbines, and to compare photorealistic and computer-generated visualisation methods. Furthermore, it sought to employ novel methods, such as psychophysiological measures (SCR & eye-tracking), as well as more realistic representations of wind turbines, such as videos and animated visualisations. While there are some limitations of the research, in particular the samples used, the studies created some interesting data with findings that should be of interest to planners, developers, and academics.

SCR and eye-tracking can provide useful insights into people's responses to wind turbines in the landscape, as well to differences between photorealistic and computer simulated landscapes. These methods could be used to study other aspects of landscape visualisation other than wind farms. People's visual patterns are similar but their affective responses are different when viewing videos of photorealistic and computer simulated landscapes. While photomontages were rated as more realistic than computer simulations, this appeared to have no effect on participants' preferences. People's preferences for layout options similar irrespective of visualisation type, though turbine visual preference groups do differs somewhat. With regards to wind farm extensions, similar sized turbines are considered preferable to large turbines or small turbines that do not match with existing turbines, with large turbines considered the worst option.

The new knowledge about psychophysiological methods, visualisation types, and factors affecting turbine layout preferences should be of interest to researchers, planners, developers, or people involved in creating guidelines for visualisation or landscape and visual impact assessment. Future research should focus on populations who are affected by real wind farm proposals, as well as investigating the use of emerging tech such as VR and AR for research and consultation purposes.

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