An expert system for sustainable planning in the renewable energy sector

Thesis submitted in accordance with the requirements of the

UNIVERSITY OF LIVERPOOL

for the

Degree of Master of Philosophy

by

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September 2017

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1 INTRODUCTION

The development of renewable energy generation has increased the requirements associated with commissioning wind turbines, solar panels and other structures across various location in the UK & EU. The initial and vital process in such commissioning is sustainable planning. This involves identifying all potential constrains which could possibly hinder the development of these structures. The application of Geographical Information system (GIS) in such planning processes allows the identification of these constrains using visual mapping. The flexibility in these applications allows them to be implemented in the planning process of renewable energy sector. The tools available in these applications allow the visualisation and subsequent highlighting of all constrains at varying spatial scales. But, the use of these applications in renewable energy sector planning requires a more unique and flexible framework than planning constraints alone.

Entrust professional limited an SME partner of this research with experience over 200 projects in renewable energy sector outlined an initial requirement to increase the efficiency in the planning process for renewable energy. These requirements led to the scope of this research, which is to develop a framework for a desktop, based GIS application for sustainable planning in renewable energy sector. The framework for such GIS application should consist of methodologies to evaluate the potential of wind energy based on the Wind data, estimation of economic feasibility and capacity factor in the location. The flexibility to apply, create and organize the potential constrains database from the various organisations MAGIC partners, ANPA, MoD, CAA, NATS, SNH, Ofcom, RSPB and etc. The planning procedure implemented in them, which will be varying depending upon locations and respective council authorities are to be organised and updated. These planning procedures include the cumulative effects and buffer zones. The implementation of socio-economic constrains in the GIS framework is an innovative addition to the software. The socio-economic constraints will be based on the Index of Multiple Deprivation (IMD) for England. Within a research context these socio-economic data will be used to empirically demonstrate social and economic impact of wind turbine developments on an area. A currently, unanswered and highly controversial topic within the renewable energy sector

1.1 Aim & objective

The aim of the research is to develop an expert planning framework and GIS system for renewable energy sector which considers socio-economic profile along with other planning constraints, especially for wind turbine developments in England. The objectives of this thesis are therefore:

1. To understand the distribution of existing wind turbine development based on area settlement characteristics (rural/ urban) (A in flowchart)

2. To examine whether these developments are in socio-economically deprived areas (A in flowchart)

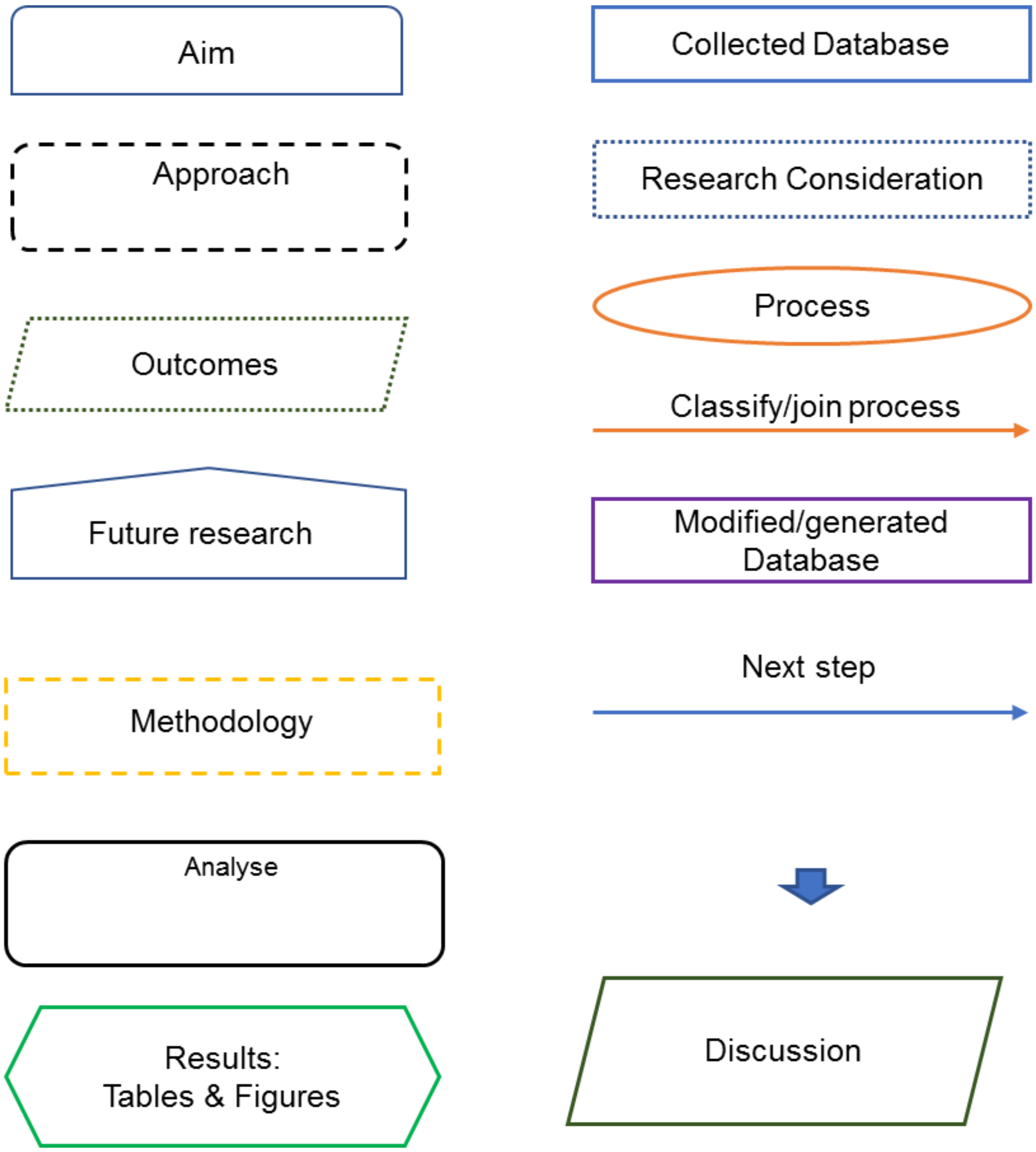
3. To analyse the impact of these developments on the socio-economic profile of the surrounding areas (B in flowchart)

4. To collect, generate, design & develop a framework for identifying potential wind energy development locations in England given current planning constraints (a, b, c in flowchart)

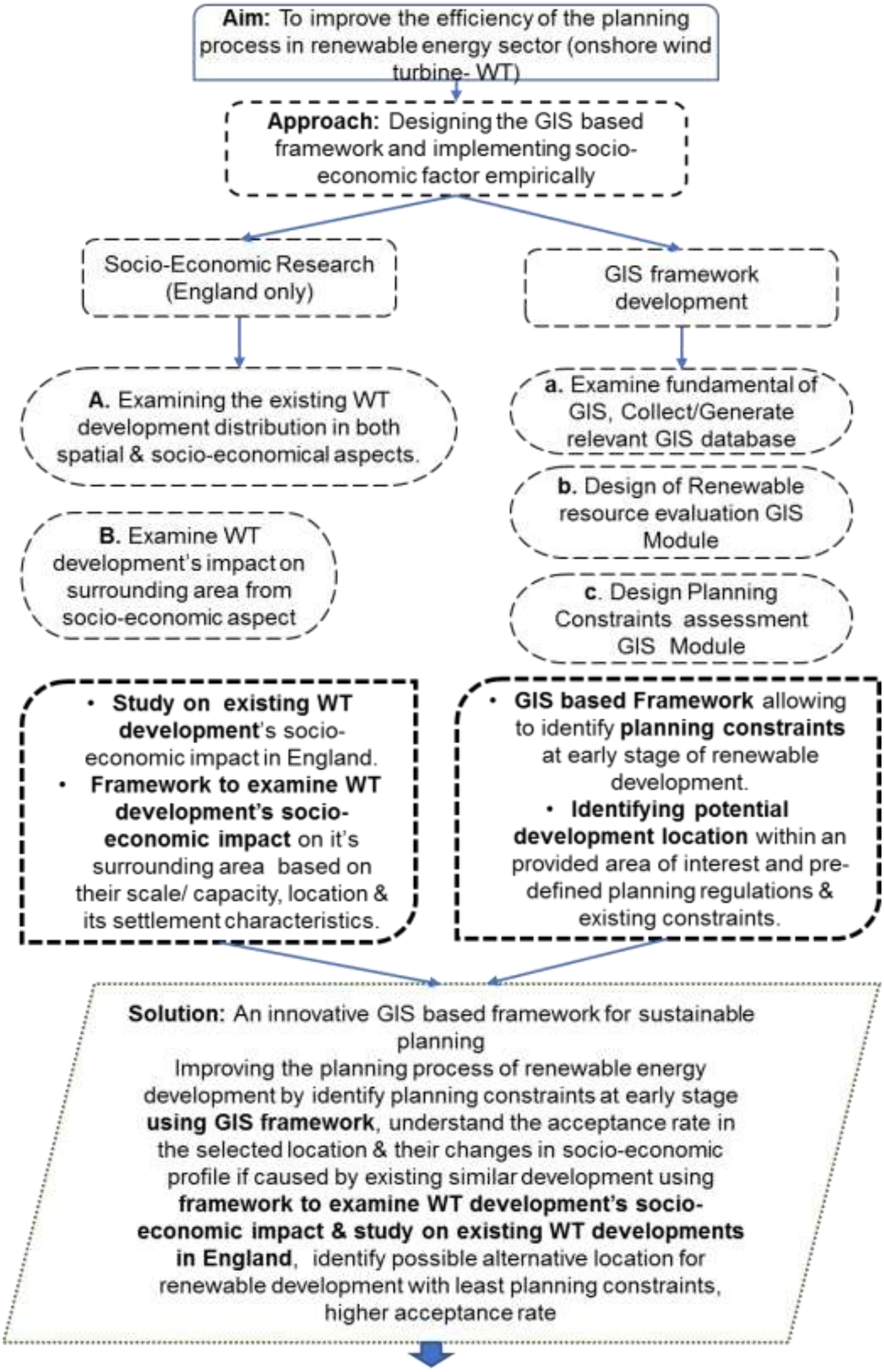
5. Implementation of the above framework as a GIS Desktop and web-based system that may be used in both an office and on-site planning locations

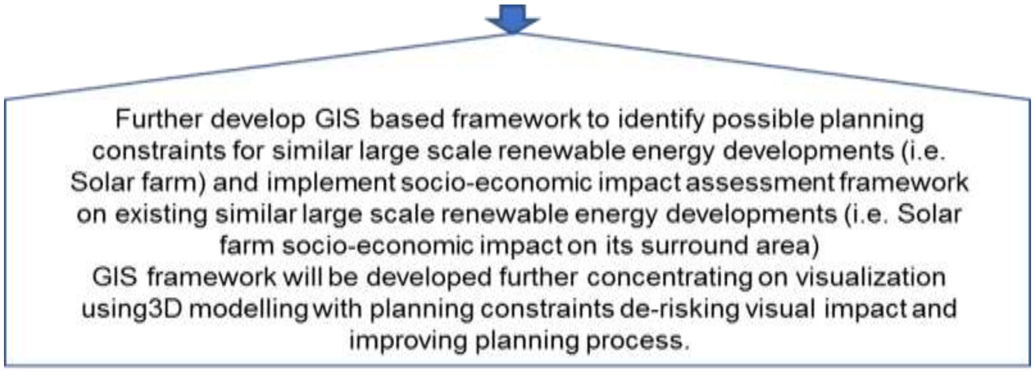
Towards achieving these outcomes, a strategical approach was required in defining what is the overall aim, what type of approach and how the outcome could be interpreted and implemented in to the renewable planning sector. Flowchart 2 Overall Research's Flowchart shown after the Flowchart 1 Legend/Key for flowchart briefly explaining the overall structure of this research's approach and its outcomes.

Flowchart 1 Legend/Key for Flowchart



Flowchart 2 Overall Research's Flowchart





Structure of thesis

To explain this research clearly, this thesis is organised into 5 chapters which are briefly explained as follows and table 1 shows which sections of the chapter addresses the objectives of this research.

Chapter 2 provides an overview of the literature on electricity generation from the early discovery of electricity, to its current production and uses. Literature on greenhouse green emissions and the role of renewable energy in meeting environmental targets is offered.

Chapter 3 details all the datasets considered in this research including, geographical boundaries, renewable planning statistics database, commercial wind turbine planning status database, Socioeconomic profile dataset (index of multiple deprivation), Rural urban classification datasets and planning related constraints for renewable energy development.

Chapter 4 outlines the methodologies implemented to define the impact of wind turbine developments using Geographical Information System(GIS), statistical method including propensity score matching and spatial approaches in weighting the deprivation for analysis and the renewable development planning framework.

Chapter 5 provides an overview of the analysis undertaken as part of this research. An analysis of the socioeconomic impact of wind turbine developments to their surrounding areas is offered. Outcomes and feedbacks from the implementation of the renewable development planning framework with the research industrial partner is also discussed.

Chapter 6. offers a brief set of future research ideas given the outcomes of this research.

Table 1 Chapter titles and associated research objectives

Chapter	Objectives
5.2 Linking onshore wind turbine development and ocio-economics through the index of multiple deprivation 5.2.1 Examining the distribution of onshore wind ırbine developments in England	1 & 2
5.2.2 Examining the socioeconomic impact of the VT developments through index of multiple deprivation.	3
4.8 Renewable energy development planning ramework	4
4.9 Building GIS system 5.3 Developed GIS system for commercial use	5

1.2 Outcomes from thesis

1. Single Wind turbine developments are more likely to get positive planning permission in England, most of these developments are located in rural areas and also in areas deprived by housing affordability, homelessness and access to services. Wind turbine proposed in areas more deprived trend have get positive planning permission when least deprived areas show high negative acceptance. There is no significant socio-economic

impact observed in long-term by these developments to its surrounding areas in England.

2. Presentation at annual graduate conference 2013, University of Liverpool "An expert system service for sustainable planning in the renewable energy sector" -explaining the basic understanding of the planning and GIS application in planning as tool for renewable development planners.
3. Presentation at annual graduate conference 2014, University of Liverpool "GIS for sustainable planning in the renewable energy sector" – outlining the developed desktop GIS framework for sustainable in the renewable developments focusing on the user intractability with conventional system and demand of innovative yet simple interface. Explained the ground work involved in the socio-economic impacts analysis for wind turbine developments.
4. Presentation at 43rd Annual Conference Regional Science Association International – British and Irish Section 2014, Aberystwyth "Why Socio-economic analysis is important in wind farm pre-planning" -outlined the attempt to analysis socioeconomic impacts of wind turbine and methodology to be implemented in pre-planning assessment to help planner structure community benefit from the renewable energy development planning
5. Presentation at 4th Annual Colloquium Regional Science Association International – British and Irish Section, 2014, Aberystwyth. "The socio-economic impact of wind turbine development in small area level" - Discussed the overall idea of this research, gathered feedback which

were considered towards developing the renewable planning framework and socioeconomic analysis.

6. Presentation at annual graduate conference 2015, University of Liverpool "A GIS approach in exploring the relation between large scale wind turbine development and housing price in North West England" – outlined a housing price analysis approach considering GIS methodologies to analyse the impact by large scale wind turbine development.
7. Presentation at Centre of Global Eco Innovation project showcase presentation- Xi'an Jiao Tong-Liverpool University, 2015, China – "Expert system for sustainable planning in renewable energy sector" – showcased the developed sustainable planning framework and discussed the commercial implementation of these research outcomes.
8. 44rd Annual Conference Regional Science Association International – British and Irish Section, 2015, Dublin, Ireland. "An interdisciplinary approach: Does major renewable energy development like wind turbine bring significant impact on house pricing in UK?" – Outlined the dataset created for the housing price analysis from the various GIS methodologies (i.e. visibility analysis).

2 LITERATURE REVIEW

2.1 Introduction

The discovery of electricity as an energy source revolutionized the world and laid the foundation for numerous other inventions during the second industrial revolution of the 19th century(Rosenberg 1998). Electricity a luxury good among rich minorities in 19th century, became an everyday requirement in 20th century and is now seen as a human right in 21st century(Tully 2006). Numerous events like the development of improved and efficient incandescent light bulbs in 1882, perfected metal filament light bulb widely available in 1911, the Electricity (supply) Act in 1926 by PM Stanley Baldwin forming Central Electrical Board (C.E.B) to standardize the electricity generation and evenly distribution across UK, women's involvement in promoting and educating the benefits of electricity for homes through Electrical Association for Women (E.A.W) and an improvement in the overall economy, all led to the increased demand for electricity.

This rapid increase in demand for electricity led to the construction of larger power plants using, electricity from thermal energy by burning fossil fuels, using nuclear controlled fission reaction, hydroelectricity from constructing dam and using water flow's potential energy, using renewable energy sources solar, wind, geothermal, wave and tidal. The fossil fuel power plants proved to be more efficient and sizable, compared to hydro power plants that depended on water flow from the highlands to lowland and required a larger area. But, compared to the nuclear power plants efficiency in terms of fuel source economy, the fossil fuel power plants are less efficient and have higher Green House gas (GHG)

CO_2 emission. The risk involved in the failure of the nuclear power plants leading radiation to the environment and no permanent solution radio-active waste disposal, makes nuclear power plants not be sustainable. The renewable energy sources like solar, wind, geothermal, wave and tidal were the only solution that proved to be sustainable and replenishing in nature. But, considering the long record of proven technology in electricity generation, wind and solar energy trends be well recognized, scalable and economically feasible renewable energy sources. This chapter details the evolution of electricity to the implementation of the renewable energy power plants, particularly with regards to wind turbine, which is renewable energy source of interest to this thesis.

The structure of this chapter as follows: Section 2.2 briefly reviews the history of the electricity evolution and the series of events in 19th century that made electricity as one of the human basic needs in 21st century. The electricity generation power plants and their various energy sources are introduced. Fossil fuel power plant, the conventional electricity generation is detailed in the following section. Its history, development, social, economic and natural impacts are reviewed. Similarly, in section 2.4 nuclear power plants are detailed and their impacts are briefed. The impact of fossil fuel on climate change is detailed and requirement of sustainable and renewable energy is explained. The various types of renewable energy technologies will be explained. The following sections 2.6.1, 2.6.2, 2.6.3, 2.6.4 and 2.6.5 explained in-depth about each renewable energy technologies. The wind energy section 2.6.5.3 details further about the various positive impacts these developments could towards the environment and economy. It also explains the various negative impacts from their developments that are being resolved.

2.2 Overview of electricity's evolution

The history of electricity originates back to 1600 AD. Discoveries were made in attempt to understand the unexplainable phenomenon and in search of solutions for the circumstantial necessities. However, it took a further 200 years for humans to make the electric charges, which are now the basics of the electricity. Table 2 outlines the notable discoveries, which led to the science of electricity we see today.

Table 2 A Brief evolution of electricity (The Discoveries)

Year	Brief evolution of electricity -The Discoveries
1600	Pulling force by electric charge was created by friction of different material and the awareness of the difference between static(non-flowing) electric charge and magnetism from Magnetite was discovered by William Gilbert, he derived the word 'electrica', from Latin term electricus, meaning to "to produce from amber by friction"
1660	First static electricity generator was built by Otto Von Guericke, it was a hand rotating glass rubbed against a cloth.

1709	Francis Hauksbee created light from adding mercury and evacuating the air from the Von Guericke's generator.
1747	Benjamin Franklin Introduced the existence of positive and negative charge in electric forces to the world and this led him to develop many terms which we use today like battery, conductor, condenser, charge, discharge, uncharged, negative, minus, plus, electric shock, and electrician
1792	Alessandro Volta, an Italian scientist, invented the first electric battery based on the observation from another Italian professor of medicine, the dead frog leg twitching experiment. This led a new kind of discovery that said electricity can flowed like steady current of water. The unit of electrical potential flow was named after him as volt.
1803	The British scientist, Sir Humphry Davey, demonstrated the arc light by using the electric battery and two carbon rod. The arc light was form when the two-carbon rod were separated to certain distance but, the electric current is still jumping on air from one rod to the other. This was first time light was produced from steady flow of electricity.

1820	A Danish Scientist, Hans Christian Oersted discovered the relation between electricity and magnetism, led a whole new science known as electromagnetism. A French scientist, Andre Marie Ampere in same year further formulated and introduced governing laws for the electromagnetism, resulted in invention of unit of current, the amp which was derived from his name.
1827	The electromagnetism was further explored led into discovery of resistance in the electricity flow. The German physicist, Georg Simon Ohm derived a law which showed the relation between unit of current (amp), unit of electrical flow (volt) and resistance.

The evolution in understanding and harnessing nature led to numerous inventions in 19th century. One such invention is the practical everyday light bulb by Thomas Alva Edison (Jones 1907). This commercialized the distribution of electrical current through cables from power generators to light bulbs in homes and offices. Table 3 represent the breakthroughs in humankind that changes the electricity from being laboratory experiment to everyday practical solution. These events also show the extensive raise of electricity demand and the need for larger power plants.

Table 3 A Brief evolution of electricity (The big breakthroughs)

Year	Brief evolution of electricity -The big breakthroughs
1831	The English Scientist, Micheal Faraday enthused by the invention of electromagnetism worked towards finding the possibility of creating electricity from magnetism. This let the development of generator with potential to create steady flow electricity by rotating copper wire between magnets. This led into numerous other inventions like motor and power generators for industries later.
1837	Samuel Morse invention of electrical telegraph in 1831 came into practical use when he used supply of electricity with a battery alongside with telegraph. The codes used by the electrical impulse in the telegraph was later referred as famously known "Morse Code".
1866	Sir Charles Wheatstone, Werner von Siemens and Samuel Alfred Verley invented independently the first electrical generator (dynamo) capable for delivering power for industries.
1879	Thomas Edison patented his carbon filament lamp (incandescent bulb) that provided both brightness and long

	lifetime. The demand of the electricity was extensive after this invention. This led into the birth of electricity industry.
1881	The lead-acid accumulator (battery) is introduced, having the ability to be recharged by the newly developed direct current (DC) generator, thus giving a supplementary supply of heavy currents.
1882	First electricity steam engine power plant in Lower Manhattan, New York was built by Thomas Edison to supply DC electricity for the use of light bulb and other DC supply using inventions. It powered only one square mile of the city due to the incapability and losses from the long-distance transmission.
1889	Nikola Tesla discovers the principle of alternating current (AC), which changes in opposite directions fifty times a second - 50 Hertz, and develops an alternating current generator and induction motor. AC current proves more suitable for electricity transmission over long distances
1890s	AC transmission allows the electricity system to cover larger geographical area, generation plant no longer needing be located close to sources of demand, bringing

	into play the possibility of electricity generation from more remote sources, e.g. hydroelectric power
1890s	Electricity applications expand from lighting to electric motors for street railways, trams and for stationary electric motors in factories
1893	Both AC and DC inputs were accepted but, transmission were strictly only AC. The universal system allows the interconnection of existing systems and their power stations and drives the expansion of electricity supply over wider areas to more customers.

2.3 Fossil fuel power plants

Fossil fuel are basically the organic residues of long term geological processes, which is non-renewable by nature. The use of fossil fuels has longer history than its usage for electricity generation in power plants. In 1850, Britain was responsible for 60% for global CO_2 emission from fossil fuel combustion, making it the birthplace for fossil fuel economy(Malm 2013). The fossil fuel like coal were used in steam engine and heat generation purpose for a long period. In 1882, the first commercial electricity power station, Pearl street station at New York used fossil fuel (coal) as its power source for its reciprocating steam engine to rotate the electricity generator. But, the development of steam turbine in 1884 by Sir Charles Parson revolutionized fossil fuel power plants to produce cheap and plentiful electricity. 90% of world's fossil fuel power plants still use steam turbine technology for electricity generation(Wiser 2000).

The working of all fossil fuel power plants basically using the internal combustion of different fossil fuels like Coal, natural gas, crude oil and petroleum. This combustion produces large pressure drives the turbine to generate electricity(Renneboog 2013). Compared to other fossil fuel like natural gas, crude oil and petroleum, coal had established in long usage in industrial and commercial requirement(Malm 2013). The abundance of coal compared to other fossil fuel allowed it to be the major contribution as fuel for these power plants. The fluctuation prices for oil and natural gas also made coal fired thermal power plant economically attractive(Souza 2012). The oil crises in 1970s showed industrialized countries, that disruptions in oil supply not only affect transportations but, also electricity generation(Morse 2012). This made coal to be more attractive for electricity generation than other fossil fuels.

Coal based power plants work under Rankine Thermodynamic cycle(Wiser 2000). The initial method is collection of the fossil fuels coal; these involve transportation of coals from various mining locations to the plant. Due to the irregular dimension of the coal as extracted from mining, they are stored and pulverized into very fine powder through rotation grinders. These pulverized coals are air blown into furnace and fired rapidly turning the water passed through pipes inside the furnace into high pressure steam. The further heating of these steams allows them to reach to superheated form at 540'C. Turbine designed to runs based on these steam produces electricity allowing the steam to loss its pressure and temperature to condensate back into water after passing through natural draft cooling towers. The following figure 1 and table 4 shows the schematic and parts of typical coal power plant.

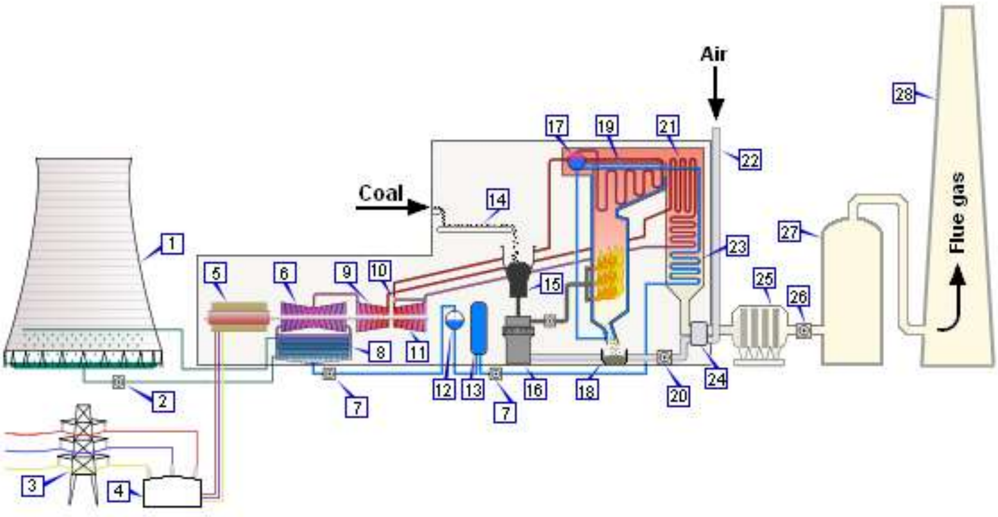


Figure 1 Schematic of typical coal power plant. Source (Milton Beychok)

Table 4 typical coal power plant schematic parts name

1. Cooling tower	10. Steam governor valve	19. Super heater
2. Cooling water pump	11. High pressure turbine	20. Forced draught fan
3. Transmission line (3-phase)	12. Deaerator	21. Re-heater
4. Unit transformer (3-phase)	13. Feed heater	22. Air intake
5. Electric generator (3-phase)	14. Coal conveyor	23. Economizer
6. Low pressure turbine	15. Coal hopper	24. Air preheater
7. Boiler feed pump	16. Pulverized fuel mill	25. Precipitator

8. Condenser	17. Boiler drum	26. Induced draught fan
9. Intermediate pressure turbine	18. Ash hopper	27. Chimney Stack

Fossil fuel power plants has its own advantages apart from power generation, several industrial usable by-products like unused steam for neighbouring industries through underground pipe line, gypsum in the fly ash from burnt coals with slurry process (Mohapatra et al. 2010) and pure nitrogen with selective catalytic reduction from furnace exhaust gas(Phananiramai et al. 2011) are produced helping various other industries. In early 1900s the favour of coal's highest energy density made fossil fuel power plants to use coal directly increasing the growth of coal mining industries, in turn increasing its availability(Renneboog 2013). The reliable technology of coal fired power plants had proved to satisfy the requirement of base power (constant supply) load in electrification. According to pro-coal American coalition for clean coal electricity report (THE SOCIAL COSTS OF CARBON? NO, THE SOCIAL BENEFITS OF CARBON, January 2014), benefits of carbonized fuel, like coal, to society are 50 to 500 times greater than its production cost. This report also concludes that life expectancy had more than doubled and incomes have increased, all by part of increased energy production and delivery at low cost, which would have not been possible without fossil fuels like coal. Although fossil fuel power plants provide the power requirements for the increasing economic growth, the environmental pollutions from these power plants are substantially higher.

2.4 Nuclear power plants

The electricity generated from the capturing the heat energy from the fission reaction of Uranium fuel in a reactor vessel is the principle behind nuclear power plants. The development in atomic energy during Second World War (1939-1945) led the path towards nuclear as energy source. The world's first self-sustaining nuclear fission reactor was built beneath a stadium at Chicago University in 1942. After the war, the solution from the self-sustaining fission reactor led the research in US towards the first experiment breeder reactor (EBR-1) at Idaho in 1951. The USSR were the first country to develop the nuclear reactor to produce electricity and supply to grid by 1954. The world's first commercial nuclear power plant was opened in 1956 at Sellafield, England with a capacity of 50MW. The successful commercialization of Sellafield allowed increasing projects towards nuclear energy(Mladjenovic 1992). The construction of these power plants was expected to solve the increasing demands of electricity, environmental issues from fossil fuel power plants. The oil crises in 1970s favoured the demand of nuclear power plants, but short-lived by 1974 as oil embargo ended and compared to abundant cheap oil to the increased cost of construction and safety in nuclear power plants(Association 2010). Figure 2 shows the schematics of typical nuclear power plant.

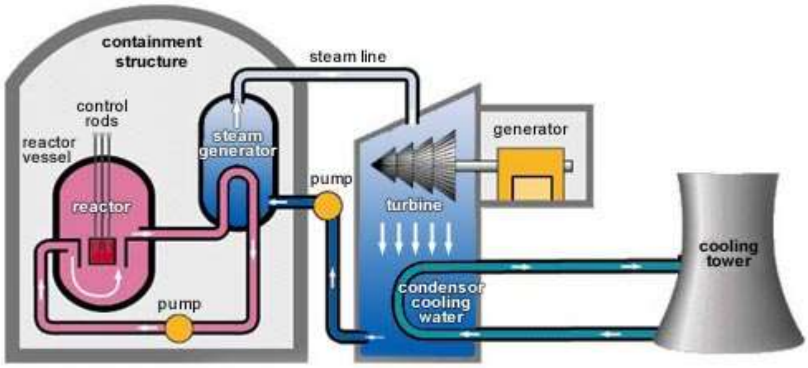


Figure 2 Schematic of typical nuclear power plant. Source (cameco)

The working principle in the nuclear power plants is similar to coal power plants where, however coal is replaced with uranium-235. The complexity involved in these types of power plants are controlling the nuclear chain reaction of the uranium with neutron and cooling down of the whole process. Unlike coal the Uranium 235 is an extracted from high concentration uranium ore. When Uranium 235 absorbs a neutron, which is introduced in the reactor it undergoes nuclear fission reaction. In this process, the nucleus of the uranium 235 splits into lighter nuclei releasing radioactive elements and more neutrons. These neutrons future collide with the lighter nuclei forming chain reaction. The control rods introduced to absorb neutrons reduce and stop the reaction. The heat emitted from this reaction is the source used to steam and pressurize the water which is later fed into turbine for generation of electricity. These power plants utilize large amount of water in-order to cool down the unused steam or excessive generated heat.

The carbon footprint throughout the lifecycle of nuclear power plants is small compared to fossil fuel power plants(Lee et al. 2013). The advantage of nuclear power plants is the immediate impact towards the environment as their no emission of CO_2. The nuclear power plants trend to have overall small cost advantage in life cycle, given that even when coal fuel cost been steady and uranium fuel cost increasing(Jones 1980), proving the overall advantage of nuclear power plant compared over fossil fuel power plants. The amount of fuel used in nuclear power plant is lower than fossil fuel allowing it to have the advantage of using low cost for transportation of fuel. The nuclear power stations have the capacity to produce base load of electricity as fossil fuel power plants with the advantage towards lower GHG emission, lower cost and highly efficient in performance.

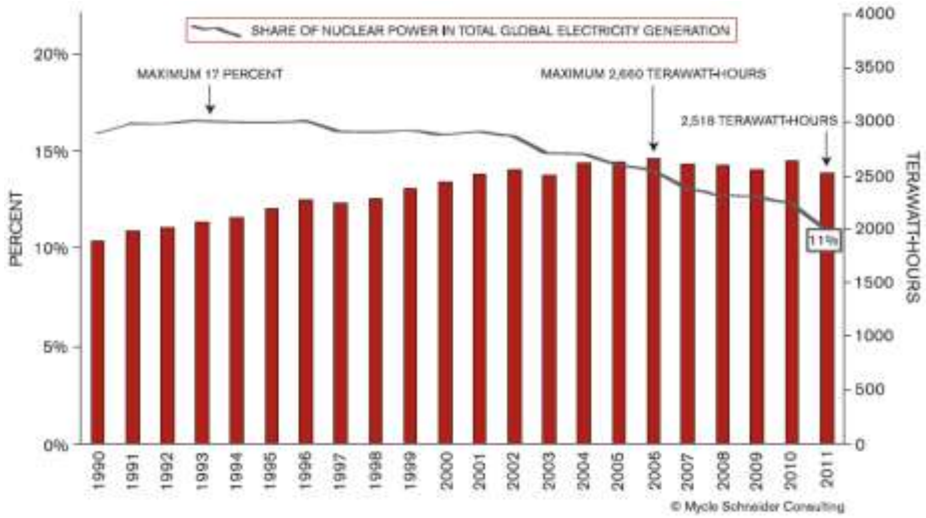


Figure 3 Nuclear power's share in world electricity generation. Source (Schneider and Froggatt 2012)

However, because of radioactive elements as by-products of this nuclear fission reaction, construction of the power plant requires high evaluation of safety, economics and the environment (Wongkhomton, Chantachon and Wongjunta 2011). The accidents involved in nuclear power plants due to natural disasters and human handling errors throughout history, have led to high regulation in the sector and maintenance becoming economically unviable (Cooper 2012). The first major nuclear incident 1979, the Three Mile Island's nuclear partial melt down. The aftermath of this incident showed that combination of human intervention, human carelessness and poor trained technicians lead the cause of this accident. The scientific community agrees that the automatic safety procedure in the plant would have prevented this accident(Stephens 1980). The second major accident was Chernobyl in 1989, were the aftermath revealed that the causes were due to poor operation and bad reactor design. This disaster caused radiation spread about 4300 square kilometres in modern day Ukraine, Belarus and Russia to become uninhabitable to human life(Bailey 1989). The recent major disaster in 2011, the Fukushima Daiichi nuclear power plant exploded radioactive elements due to the cooling system failure by the enormous earthquake followed with tsunami. This natural disaster affected 30Km radius around the plant and 20Km within was considered no go zone(Visschers and Siegrist 2013). These incidents change the peoples trust, their perspective of benefit and risk towards the nuclear power plant and its developments. The sustainable deposition of the radioactive by-products brings an inevitable issue for environment and reducing its share in global electricity generation (Schneider and Froggatt 2012). The inevitable hazards involved in the nuclear reactor have always brought the question of sustainability to people's awareness, proving nuclear power plant's undeniable limitation.

2.5 Impacts of fossil fuel on climate change, Increasing need for Sustainability and Renewable energies

Climate change is one of most serious environmental issue faced in 21st century threatening public health(Özdem et al. 2014) and likely to be the greatest threat for global economic security and social stability(Fouquet and Pearson 2012). Understanding climate change needs understanding the climate itself. Climate is defined as "The general or average weather conditions of a certain region, including temperature, rainfall and wind. On Earth, climate is most affected by latitude, the tilt of the Earth's axis, the movements of the Earth's wind belts, the difference in temperatures of land and seas, and topography, Human activity, especially relating to the depletion of the ozone layer, is also an important factor" (American Heritage Science dictionary, 2014). Whereas the weather itself is a condition of the atmosphere at particular location and time, including winds, clouds, precipitation, temperature and relative humidity. Radiation from sun, ocean currents and atmospheric circulation weave together in a chaotic manner to produce our climate. The Earth's atmosphere is composed primarily of gases N_2 (78.084%), O_2 (20.946%), Ar (0.9340%) and remaining are the trace gases which play the crucial role in Earth's radiative balance(Seinfeld and Pandis 1998). These trace gases are consisting of Carbon dioxide (Co_2) and Methane (CH_4) which are also Green House gases. The carbon dioxide is one of the highly affected GHG by anthropogenic activity. The increase in the concentration of these gases, change the behaviour of the earth radiative balance causing climate change(Seinfeld and Pandis 1998).The intergovernmental panel on climate change (IPCC) is responsible for the scientific analysis of anthropogenic climate change at a global scale. CO_2 emissions are the output of fossil fuels usage.

In the electricity generation through traditional fossil fuels and nuclear reaction both releases CO_2 leading into an unsustainable environment for the present and future. Following figure 4 shows the share of GHG emission by humans.

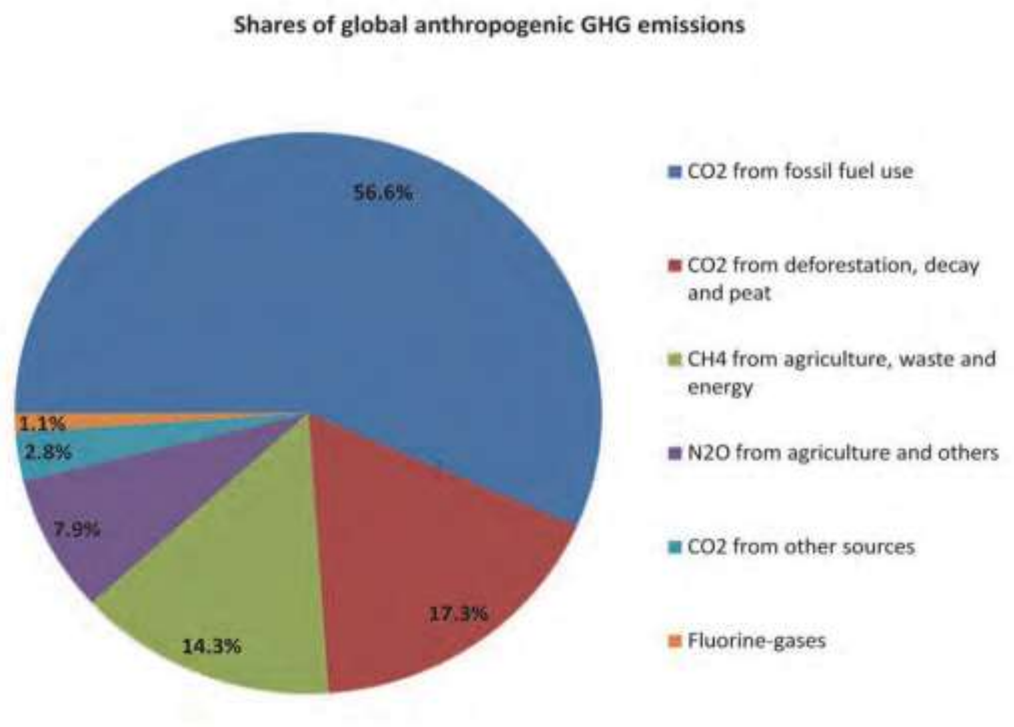


Figure 4 Share of global anthropogenic GHG emissions by origin(Höök 2011)

CO_2 emissions in 1973 compared with 2010 have doubled. Further usage may increase the global climate change above 2 degrees which results in global warming and related hazards. The UK government had targeted a reduction in its carbon dioxide (CO2) emissions of 20% by 2010, as compared to 1990. This target allowed UK to achieve 19% below 1990 level in 2009. The Government's step towards further reduction is through a drafted programme ‘Climate Change Programme’. The key function of this programme is produce electricity from renewable resources.

2.6 Renewable energy

There are numerous definitions for renewable energy. For example, United States Environmental Protection Agency (EPA) defines that “renewable energy are the resources that rely fuel sources that restore themselves over short periods of time and do not diminish. Such fuel sources include the sun, wind, moving water, organic plant and waste material (eligible biomass), and the earth's heat (geothermal)”. The Natural Resources Defence Council (US) states that “renewable energy comes from natural sources that are constantly and sustainably replenished”. The International Energy Agency defines renewable energy as “energy derived from natural processes (*e.g.* sunlight and wind) that are replenished at a faster rate than they are consumed. Solar, wind, geothermal, hydro, and some forms of biomass are common sources of renewable energy”. The Energy saving trust (UK) considers renewable energy to be “energy from any source that is naturally replenished when used”. All these definitions for renewable energy resolute commonly that energy generated from a source that is sustainable in nature.

Renewable energy comprises a heterogeneous class of technologies. They are basically everything that exists around the Earth, like hydropower, geothermal energy, ocean energy, solar energy and wind energy. These various types of renewable energies can supply electricity, mechanical energy and also produce fuel that satisfies multiple energy service needs. These renewable energy technologies are capable for deployment in centralized large energy network and also decentralized standalone energy network, based on rural, urban and industrial requirement (ref IPCC special report renewable energy sources and cc). These renewable technologies are capable for scalability allows developing further in the future to meet the increase demand of energy needs.

Hydropower harnesses the energy of water moving from higher to lower elevations, primarily to generate electricity. Hydropower projects encompass dam projects with reservoirs, run-of-river projects and cover a continuum in project scale. Hydropower projects exploit a resource that varies temporally. However, the controllable output provided by hydropower facilities that have reservoirs can be used to meet peak electricity demands and help to balance electricity systems that have large amounts of variable RE generation. The operation of hydropower reservoirs often reflects their multiple uses, for example, drinking water, irrigation, flood and drought control, and navigation, as well as energy supply. Hydropower technologies are mature. Over exploitation of this technology since, long period had proven to have increasing environmental impacts.

Geothermal energy utilizes the accessible thermal energy from the Earth's interior. Heat is extracted from geothermal reservoirs using wells or other means. Reservoirs that are naturally sufficiently hot and permeable are called hydrothermal reservoirs. Once at the surface, fluids of various temperatures can be used to generate electricity or can be used more directly for district heating or cooling applications based on geolocation. Hydrothermal power plants and thermal applications of geothermal energy are mature technologies, but geographically restricted.

Ocean energy derives from the potential, kinetic, thermal and chemical energy of seawater, which can be transformed to provide electricity, thermal energy, or potable water. A wide range of technologies are possible, such as barrages for tidal range, submarine turbines for tidal and ocean currents, heat exchangers for ocean thermal energy conversion, and a variety of devices to harness the energy of waves and salinity gradients. Ocean technologies, with the exception for tidal barrages, are at experimental stage. Further research and development are improving these technologies more economically feasible.

Solar energy technologies harness the energy of solar irradiance to produce electricity using photovoltaics (PV) and concentrating solar power (CSP), to produce thermal energy (heating or cooling, either through passive or active means), to meet direct lighting needs and, potentially, to produce fuels that might be used for transport and other purposes. The technology maturity of solar applications ranges from R&D (e.g., fuels produced from solar energy), to relatively mature (e.g., CSP), to mature (e.g., passive and active solar heating, and wafer-based silicon PV). Many but not all of the technologies are modular in nature, allowing their use in both centralized and decentralized energy systems. Solar energy is variable and to some degree unpredictable. But, based on profile of solar energy installations in some cases, they satisfy the energy demands without any issues.

Wind energy harnesses the kinetic energy of moving air. The primary application of relevance to climate change mitigation is to produce electricity from large wind turbines located on high wind favouring region. Wind energy technologies are already being manufactured and deployed on a large scale. Wind electricity is both variable and, to some degree, unpredictable, but experience and detailed studies from many regions have shown that the integration of wind energy generally poses no insoluble technical barriers.

The following chapters outline the hydropower, geothermal, ocean and solar renewable technology's principle, advantages and disadvantages. The wind energy is detailed in depth about its technological advantages and disadvantages, economic and environmental positive impacts.

2.6.1 Hydroelectric Energy

Hydropower existed in form of waterwheel in many parts of Europe and Asia for some 2000 years, used as sawing and grinding mills(Paish 2002). In 1086, based on earliest censuses, Domesday, England had 5000 watermills(Research 2005). The invention of hydro turbine in France 1830, originated the first hydropower generation(Research 2005). Demonstration of the hydropower transmission at Munich Exposition of 1882 using DC electricity over the distance of 59Km to Miesbach, Germany proved the world that future for hydropower electricity generation and supply. Towards the end of 19th century, the focus were towards exploiting the hydroelectricity (Egré and Milewski 2002) for large scale supply(Paish 2002). These large-scale generation power plants were more reliable and efficient than fossil fuel thermal power plants.

The over exploitation of this technology produces increasing environmental impact(Hennig et al. 2013). The construction of dam for large hydro power plants lead into numerous other impact factors like resettlement, biodiversity impact, geological effect, sedimentation, downstream effect and Methane GHG emission. Furthermore, the shortage of rainfall in some locations, restricts the complete dependence on hydropower and limited expansion. Alternatively, other renewables like solar and wind power plants were having the advantage over the independency of the water resource and scalability.

2.6.2 Ocean energy

Tidal current energy, the well-recognized form of ocean energy has a longer history than hydro electricity generation. Especially in Europe showing utilization of such tidal energy from tidal mills dated back to middle ages. Oldest excavated tide mill dated back to 619 AD and Doomsday book record shows nearly 200 tide mills in Suffolk alone(Alonso del Rosario et al. 2006). The working principle behind this technology has remained the same. The tidal current is created when two connected bodies of water trying to level their differences, flowing water from area of high pressure to low pressure. During the high tide, water from sea flow towards estuary crossing the wall construction with water flow troughs (sluice) inlet. During the low tide water flows into sea via outlet where mechanical rotation force is generated using waterwheels or turbines. In middle-ages these rotational forces where used to grind flours while in twentieth century they were used to produce electricity with generators. During same period range of tidal barrage plants were constructed around the world, due to economic feasibility, huge civil engineering cost and availability of cheaper alternative led this technology to be less attractive. La Rance barrage in France was the first tidal barrage built in 1966 proved that this technology is possible and not been disastrous impact on environmental as feared by many ecologist(Owen 2014). Similar to hydroelectric energy this technology is restricted with geographical locations and feasibility issues.

2.6.3 Geothermal Energy

Geothermal energy is the heat energy found in the interior of the earth. This heat generally moves from interior towards surface where it dissipates energy as steam or hot water (depending on location), proving geothermal gradient exists at rate of 30 degree C per Kilometre (Barbier 2002). Geothermal hot water found on the surface was utilized from ancient periods in locations like Rome, China and Japan for bath, washing and heating homes. It was on early twentieth century this geothermal steam was used to generate electricity in the Larderello region Italy. Geothermal well were drilled in Beppu, Japan in 1919 and Geysers, California in 1921(Rasmussen and Bengtson 2015). The process behind converting electricity using steam remains same as coal/ nuclear power plants, but extraction process of the steam makes them differ and sustainable. Deep wells are drilled to extract the geothermal energy; this process do cause some environmental impacts during the development and initial phase. This includes construction for access impacts, possible mixing of drilling fluid with aquifers intersected by the wells, dissolved gases like carbon dioxide, hydrogen sulphide and methane in geothermal fluid, chemicals like boron chloride, sodium, mercury, arsenic in the geothermal water, change in ambient water temperature due to release of thermal water into surface water bodies like steam and ponds and finally the noise pollution. These impacts can be addressed using costly measures increase the higher initial cost compared to similar plants to run in conventional fuel. This geothermal energy is still restricted geographically due to uneven distribution, seldom concentration and often found in greater depth to be exploited industrially.

2.6.4 Solar Energy

Solar energy is one of the oldest known energy source used by mankind. Drying of food for preservation, Yielding salt from sea water were oldest known applications of solar energy(Dibben et al. 2007). Around 200BC, burning of Roman fleet in the bay of Syracuse by Archimedes using mirrors was known as the earliest and largest application of solar energy. But, it was believed as myth as no technology was available at that time to manufacture mirrors. During eighteenth century, the very first practical application of solar energy refers to use of concentrating collectors, which are polished glass lens and mirrors to make solar furnaces. The first large scale solar furnace was built by French chemist Lavoisier around 1704 which reached temperature of 1750 degree C using 1.32m lens plus secondary 0.2m lens(2004). During 1878, solar energy was used to produce steam that helped drive printing machines. In 19th Century solar energy was mostly used towards producing thermal energy from concentrating collectors and later converted it into various other applications like pumping, generating electricity and even directly for industrial thermal applications. Photovoltaic (PV) effect discovered in 1839 by Becqurerel in selenium allowed converting solar energy directly into electric charge(2004).

PV cells are packed into modules that produce specific voltage and current (electric charge) when exposed to photons, Photons are particles of light in the energy from sun that reaches earth merely after 8 mins and 20 seconds. Sun emits total of 3.8 X 10^{20}MW energy every second, 1.7 X 10^{11}MW reaches earth outer atmosphere(Wise 2014). This energy is then converted into electricity of specific voltage and current by connecting each PV modules either in series or parallel forming PV solar panels. The output of the panels depends on each PV cell's efficiency to the convert from solar energy to electric energy. In 1958 the conversion efficiency of 11% was achieved with the developed "new" silicon cells with cost prohibitively high. It was only considered in space applications. Later in research other PV materials like amorphous silicon (a-Si), cadmium telluride (CdTe), gallium arsenide (GaAs), compounds of cadmium (CdS), cuprous sulphide (Cu_2S) was created. These technological developments reduced manufacturing cost and increasing the possibility of large-scale electricity generation from solar energy. In current 21st century efficiencies of commercial PV cells are achieved around 15%. Compared to other renewable energy like Ocean and Hydro energy, solar PV is considerable new and fast-growing technology. The efficiency and advancements of this technology is still far behind wind energy.

2.6.5 Wind Energy

2.6.5.1 History

Harnessing the energy from wind is one of the oldest technical innovations known to human. The earliest form of such harnessing were from sailing, seen through the representation of ship under sail appeared in painted dated 5000 and 5500BC(Carter 2006). Another way of harnessing such wind energy was by use of wind rotors and windmills. Wind rotor had vertical axis rotation, considered to be originated from Sistan region (modern-day eastern Iran) around 200BC(Singer and Raper 1954). Windmills had horizontal axis rotation, existed in Europe during 12th century. The well documented case of the illegal building of windmill recorded in the Chronicle of Jocelyn de Brakelond (AD 1191) and numerous reference of windmills were noted in records of 13th century Europe(Fleming and Probert 1984) confirms their existence. It was the Dutch engineers who pioneered in initiating and improving the windmills, wind-pump for extensive use of their geographical land development (draining marshes).

During the mid of 1700s, John Smeaton, a civil engineer from West Yorkshire, United Kingdom worked on experimenting with various models of windmills, that lied the fundamental principles underlying the design and performance of windmills, wind powered machines and water pumps. This also set the foundation for an aerodynamic theory of wind turbines(Smeaton 1759). The wind energy technology in that period were highly popular, approximately 10000 wind powered machines were found in UK and Germany(Fleming and Probert 1984). But, as coal steam engine became popular, these numbers were rapidly reduced. During the 19th Century the perfected wind energy system like multi-bladed small windmills in United States were rapidly deployed for usage in farms. These small turbines relatively start rotating with low wind speed and produce high torque which was important for pumping water in farms. Till that period wind turbines were always used in the pumping of water, increasing use of electricity in early 20th century influenced wind energy technology to evolve for generation of electricity. In 1891, the Dane Pour La Cour developed the first direct electrical output windmill rotor using the aerodynamic design principles which was practical for electricity generation. Several hundreds of these windmills were installed during 1910 as they produced 5 to 25KW (Kilo-Watt) output and powered several villages around Denmark with 100 to 300 Ampere batteries to meet the high demand even for 10 consecutive windless days. But, the cheaper and larger fossil-fuel power plants soon put these windmill power operators out of business(DM 2006).

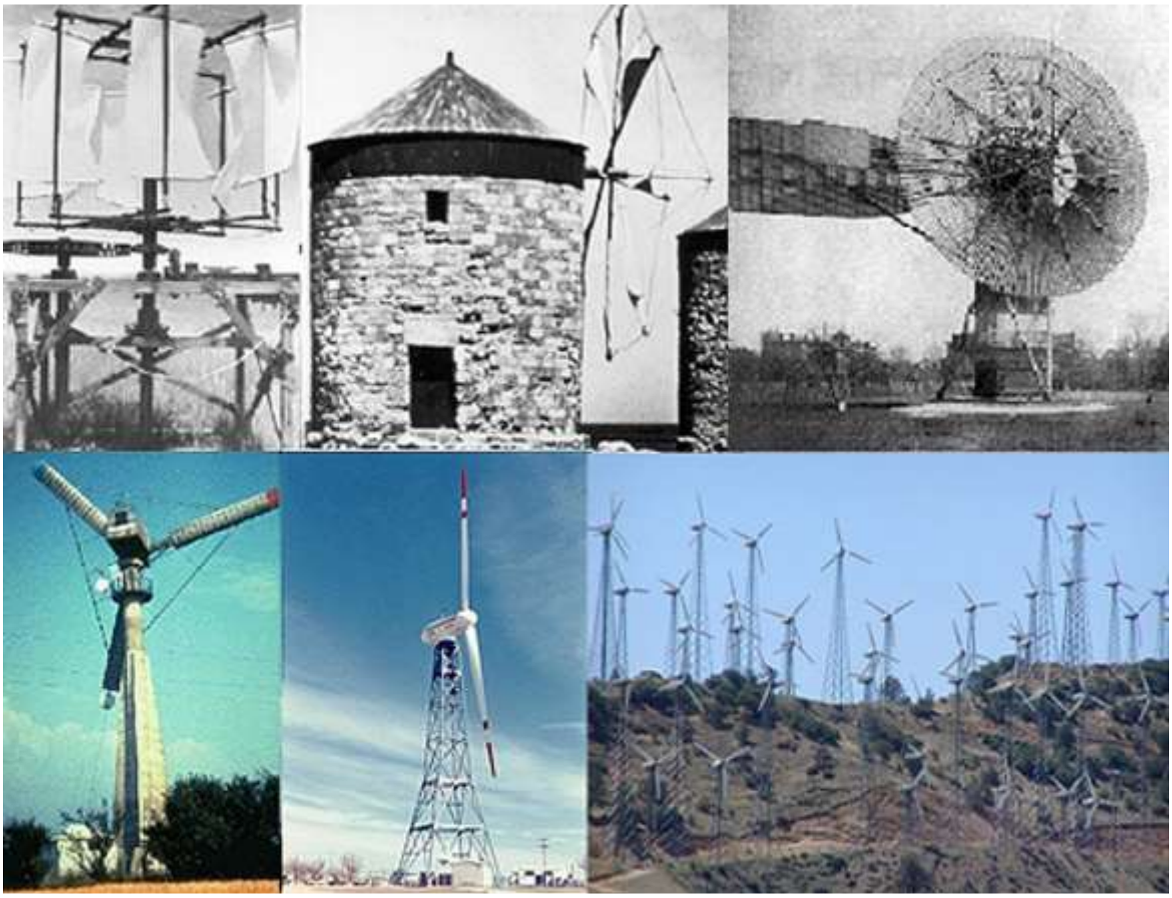


Figure 5 from the early stages of wind energy exploitation to the outbreak of California Source (20th Century Developments-telosnet.com/wind)

In end of First World War, US investigated towards the use of aerofoil from aircraft wing design in the horizontal axis wind turbines, since then many wind energy development researches were trailed the similar pattern and achieved significant improvements in the wind turbine performance. In 1930, USSR's extensive wind research program were the first to develop a large scale three bladed wind turbine, connected to the existing electricity grid and produced about 279 Mega Watt Hour (MWh) in a during of one year. Numerous research towards wind energy had evolved during mid 1900s like, 1940 Grandpa's Knob two bladed large-scale wind turbine constructed during 1935 at Green mountain, 10 miles from Rutland, US researched and analysed for further development and Electrical Research Association (ERA) extensive wind programme from 1945-55 in UK. All these researches were result of the Post Second World War potential interest towards wind energy because of key reasons, like fuel shortage and increasing electricity demand, economic and political problems raising countries to become more independent from imported energy source, realization of fossil fuel reserves limitations and increasing knowledge of aerodynamics. Such programmes were technically successful while, failed to lead commercial exploitation. Post 1973, the two main reasons that led wind turbine research to get higher importance are, understanding of the economic and safety limitations of the nuclear energy, the impact on the economy by the sharp raise on oil price and finite existence of fossil fuel reserves. The awareness of climate change by IPCC panel on 1990s and their carbon emission evaluation as discussed on chapter 3.1.4, led various nations to realize the importance of the implementation of renewable energy. In order to increase the implementation of renewable structures, Feed-in-tariffs, renewable obligation incentives and other subsidies were promoted. In UK, wind energy is considered to be potential renewable source. It was important to understand the working of the wind turbine for optimized siting and performance.

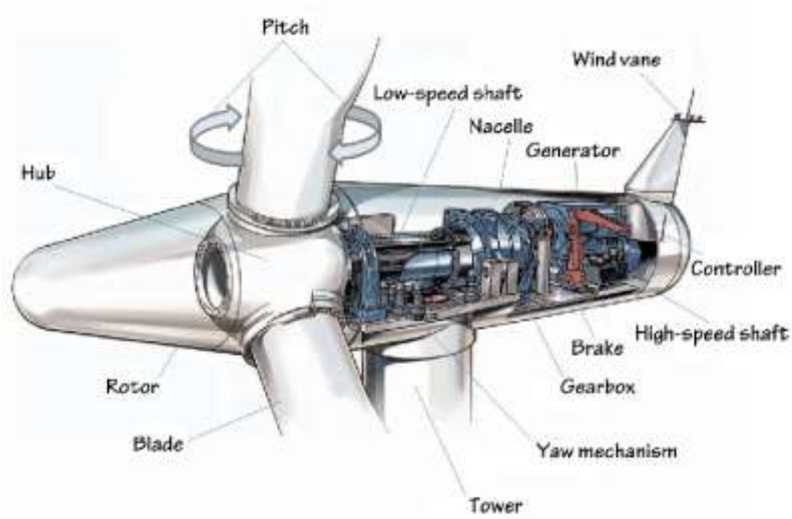


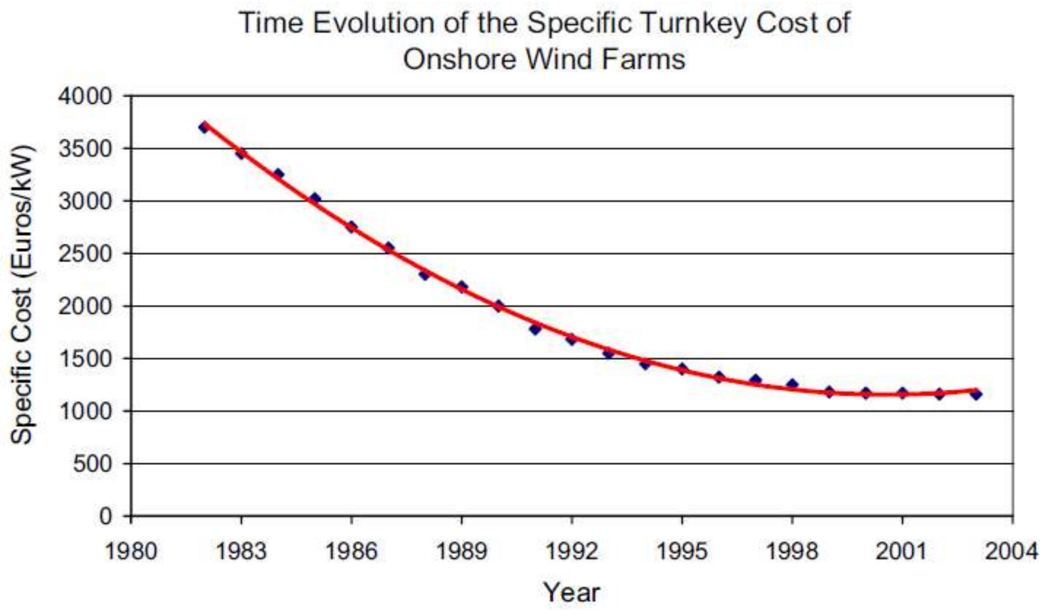
Figure 6 Major components of Wind turbine. Source (Duke University)

2.6.5.2 Working Principle

Wind turbines are the most technologically advancements of windmills. Both share the same working principle in conversion of wind energy into mechanical and then to electrical current. Windmills used drag force from wind for the rotation while, wind turbine uses lift force for their rotation. The basic two types of wind turbine, horizontal and vertical are defined by the rotational axis of wind turbine blades. The wind passing over the aerodynamically designed blades, creating the pressure difference on its surface. Thus, lift force created over the surface of the blade make them push against gravity in horizontal axis and against wind itself in vertical axis. This lift force acting from tip to hub of blade surface creates rotation motion due to rotor configuration. Typical large wind turbine blade rotates at 100 revolutions per minute (rpm). The rotor connected to gears inside the hub increases the rotational speed to several 1000rpm, which in turn rotates the connected electric generator. In horizontal axis wind turbines, digital anemometer in the hub detects the wind direction and rotates the hub and rotor blades to face them. This mechanism working simultaneously increases the efficiency of electricity generation from wind. While, vertical axis doesn't require this mechanism as, they will be facing the wind in 360 degree allowing them be more efficient. The development of horizontal wind turbine is however, more efficient in large scale compared to vertical axis due to structural feasibility. The towers of horizontal axis turbine are high around 100m allowing the enormous huge rotor blade to face less turbulent wind producing more energy than vertical axis turbine which has no tower and blades low height starts near ground level.

2.6.5.3 Economy, Issues and Considerations

The economics of wind energy trends to grow as technological advancements are helping towards reducing the specific investment cost per kilo Watt (kW) of installed wind power capacity(Junginger, Faaij and Turkenburg 2005). Considering the specific cost of 3500 Euro/kW at 1980s gradually reduced to 1400 to 1000 Euro/kW depending on the geographical location can be in figure 8 (Kaldellis and Zafirakis 2011). These reductions of cost and experience in operation of wind energy, energy production cost from wind energy found to be comparable with respective to conventional fossil fuel generation and shows clear economic advantage in future seen in figure 7 (Kaldellis and Zafirakis 2011)



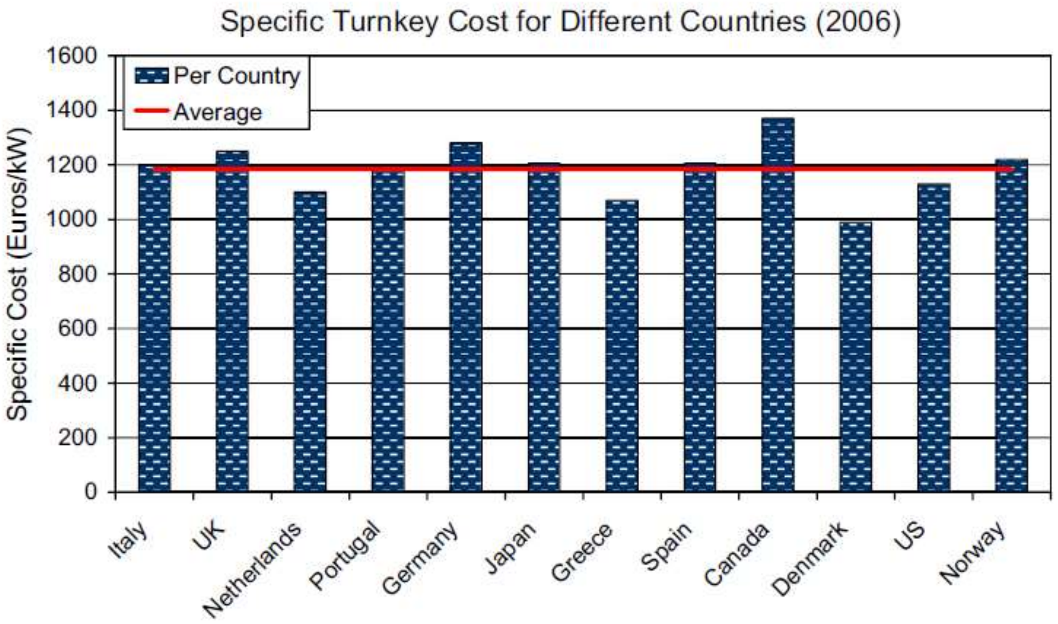


Figure 7 Time evolution of specific cost of wind turbine development

Source

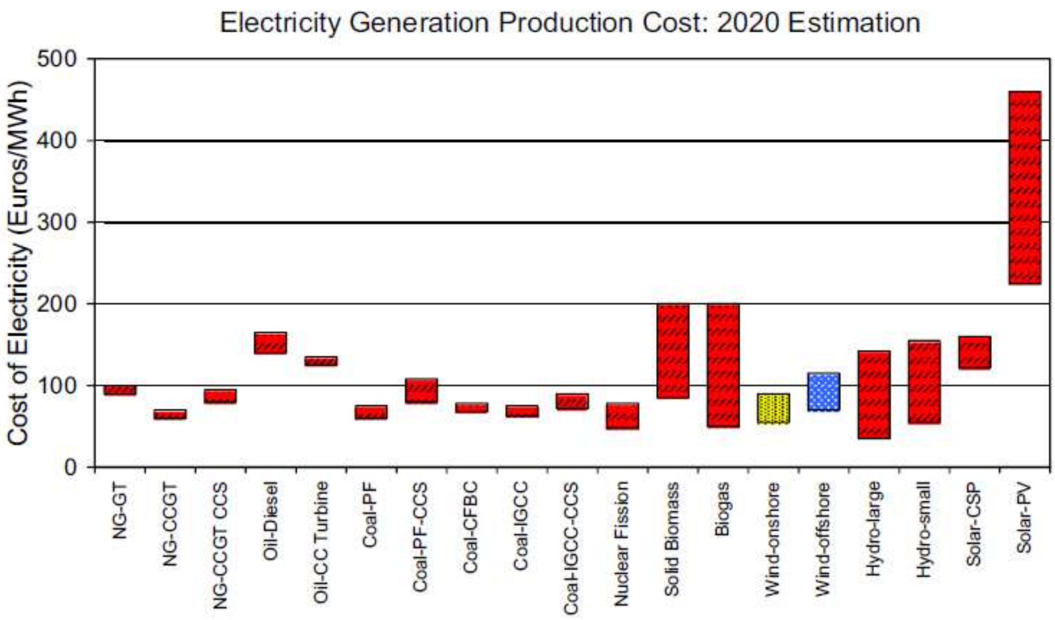


Figure 8 Estimated cost of electricity generation by various sources by 2020 Source (European Commission, Strategic energy technologies information system, Production cost of electricity 2020)

Although wind turbines are considered clean energy source, large wind turbine do have some environmental impacts such as visual impact, noise impact and impacts on bird. Most of these impacts are not perceived to be myths rather that considering as impacts.

Considering the visual and land use impact, large infrastructure developments can always change the landscape properties. Considering the local community opinion was the most efficient solution for this impact, their recognition for the wind turbine varying based on individual level giving no general and static conclusions. But research on these visual impacts relate, distance of the viewer, atmospheric effects of the location (cloudy, clear sky, rainy and mist) and sitting of the turbines are the factors that influences the visual impact assessment. System like GIS, photomontages and interactive augmented virtual reality allows solving these issues in pre-planning of those large infrastructures(Corry 2011). Research also suggests that response of the community could become less negative to a moving turbine than static, explained through two possible reasons, where first considering moving turbine seen as being ‘at work’ and producing energy, while stationary turbine shows no purpose of their development and second to be subtle that, these turbine are quintessential landscape reminding that environment is more than visual experience(Bishop and Miller 2007).

Considering the noise impact from these turbine, there exist two forms of noise impact, first is the noise generated from internal mechanical moving parts. These are found an earlier turbines where, the technological advancement have resolved this use with acoustic insulation in the turbine housing, anti-vibration support footings near the tower and turbine hub, most of this still exist in small turbine which are highly found in urban area(Shamshirband et al. 2014), which could also possible for people’s perception towards existence of such noise in large turbines. Second type is caused by rotation of the blades with wind causing aerodynamic noise, computer generated aerodynamic noise model are always the solution that resolved this issue(Rodrigues and Marta 2014). These model help generating, optimized distance for least level of audible noise from turbines. The distances for the turbines are varying, depending on blade rotor size, landscape properties and also the additional constraint distance like

500metres from residential considered by the local planning authority. These methods followed by the wind turbine developers have proved that wind turbines have least noise impact to the local habitats.

Impacts on bird population by wind turbine are due to improper environmental impact assessment in the earlier stage of the development. The considerations given to estimate the bird mortality from wind turbine development compared to other fatality cause are higher. Numerous research were done towards the impact of wind turbine on birds population (Erickson et al. 2014), (Korner-Nievergelt et al. 2013),(Eichhorn et al. 2012) compared to other factors like car collisions, high tension electricity lines, buildings and communication towers. Figure 9 (Kaldellis and Zafirakis 2011) shows that impact from wind turbine are less compared to other factors. The exist of weak relation between risk assessment studies and recorded bird mortality from wind farms gives an unreliable solution for this impact, further research at individual wind turbine sites and specific species level would resolve this issue(Ferrer et al. 2012).

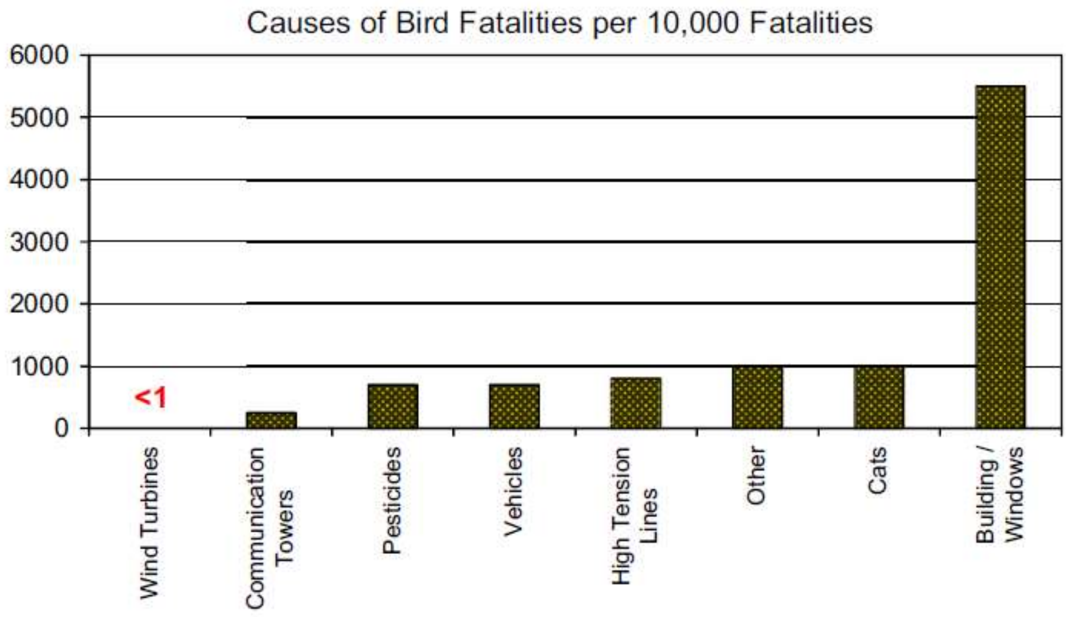


Figure 9 Bird Fatalities due to impact of wind turbine compared to various other structures

The impacts on local economy from wind turbine developments have shown more positive than negative factors. Considering the positive factors that development of large scale wind turbine project leads local new employment opportunities(Tampakis et al. 2013). They also promote educational benefit for local universities towards wind energy. Local community benefit fund of minimum £1000 per installed MW is provided to local communities in UK based on renewable UK's community protocol(Evans 2012). Cheaper electricity for community around the wind turbine, this is provided by the turbine developer by discount on the communities' monthly electricity bills. Local energy efficiency initiatives are provided from the developers through energy efficiency measures for community building like improving insulation levels and heating efficiency measures, small level building mounted renewable structures.

The visual impact of wind turbine is considered to affect the housing prices of properties, indirectly affecting the local economy. This negative impact is highly dynamic, varying depending on the geographical parameter and can't be generalized as negative impact. Study on visual impact of wind turbine over lesser scenic landscape showed to have a positive effect(Lothian 2008) which could be helping to promote the property value. The future development around wind turbine will need to be considering shadow flickering of the blades that may affect the lighting of those developments; this may reduce the property value of the location around wind turbine. Considering the development of various screening methods available in current technology to avoid shadow flickering during the early planning period of those developments. Considering all the economic and environmental positive impacts, wind energy technology is the currently most advanced and sustainable energy generation solution for the future.

3 DATA CHAPTER

3.1 Introduction

This chapter reviews the datasets, including Geographical census boundaries, socioeconomic datasets and planning constraints for renewable development planning, used in this research. Section 3.2 outlines the geographical boundaries which underpin the statistical analysis in this thesis. Section 3.3 details the renewable planning databases contain information on existing wind turbine development in England. Section 3.4 details the datasets considered for the analysis of socioeconomic impact by wind turbine developments, it explains in detail the index of multiple deprivation data and the rural/urban classification used in this thesis. Section 3.5 outlines the wind speed dataset used to characterize locations based on their available wind resource. Section 3.6 explains the planning constraint geographical information system (GIS) datasets, which will be utilized in the planning framework.

3.2 Geographical and census boundaries data

Geographical boundaries provide structure for collecting, storing and aggregating statistical data. The Office of National Statistics (ONS) is responsible for collecting, publishing statistics related to economy, population and society from local to national scale uses various geographical boundaries (administrative, health, electoral, census etc.). These boundaries are provided in geographical information system (GIS) compatible format shape-files (.shp). The lowest geographical level for statistical data is the Output Area (OA). The OA was created specifically for the 2001 census. Super Output Area (SOA) boundaries are similar boundaries designed to improve the reporting of small area statistics, built up from groups of OA. The SOAs are either Lower Super Output Area (LSOA) or Middle Super Output Area (MSOA). Administrative boundaries at local authority districts and regions level are related to local and national government are provided by ONS. All the boundaries are available under the terms of Open Government Licence.

3.2.1 Output Area

OAs were designed to reflect the characteristics of an area through census data taken on 2001 and 2011 in England. All OAs are similar in population size and socially homogenous as possible. They consist either urban or rural postcodes entirely. Their boundaries align with local authority boundaries. They are required to have minimum population size of 100 persons and 40 households to maintain the confidentiality of data (ONS Output Area (OA), 2015). OAs boundaries align with local authority boundaries. OAs boundaries are temporal as they split and merged to maintain the minimum and maximum population in the boundaries based on the census data. An OA is split if population fell below 100 people or 40 households and merged if exceeds 625 people or 250 households. There were 175,434 OAs based on 2001 census increased to 181,408 based on 2011 census in England (171,372) and Wales(10,036). Each output area is assigned with Office of National Statistics (ONS) code beginning with E00 in England.

3.2.2 Super Output Area

Lower and Middle Super Output Areas were released on 2004 for England. They are built by grouping OAs allowing to disseminate statistics at lowest reporting level without risk of disclosing information about an individual person or household. LSOAs have a minimum population of 1000 and maximum of 3000 or minimum household of 400 and maximum of 1200 (ONS Super Output Area (SOA), 2015). MSOAs have a minimum population of 5000 and maximum of 15000 or minimum household of 2000 and maximum household of 6000 (ONS Super Output Area (SOA), 2015). The boundaries of the SOAs varied along with variation of OAs. There were 34753 LSOAs based on 2011 census compared to 34378 LSOAs from 2001 census in England and Wales. Both LSOAs and MSOAs are assigned with ONS code respectively, LSOAs ONS code begins with E01 and MSOA begins with E02 in England.

3.2.3 Local authority districts and region boundaries

The local authority district (LAD) boundaries are administrative boundaries of their respective local authorities. The local authorities had responsibilities for local planning, housing, local highways, buildings, environmental health, refuse collection and cemeteries (OSN Counties, Non-metropolitan Districts and Unitary Authorities, 2015). Regions (Former Government office regions (GORs)) were number of government department working together with local governments to maximise prosperity and quality of life within the area. After March 2011, regions were closed and only considered for regional level statistics purpose (ONS Regions, 2015).

3.3 Renewables statistics (Onshore Wind Turbine) data

In an effort to understand the effects of onshore wind turbine developments at the small area level, a database of existing wind turbine development locations, power generation capacities, installed turbines, turbine heights and development status were required. Any development in UK is obliged to undergo planning by their consent local or national government authorities. Onshore wind turbine development also share the same obligation(Toke 2005). Only in some cases micro-scale domestic wind turbine will not require planning permission under the permitted development rights. Every planning application being documented by their respective planning authorities and under the Town & Country Planning Act it will be available for public view. Any planning applications of onshore wind turbine development above micros-scale must be available to public. Data on planning applications from local authorities therefore identify all the existing onshore wind turbine developments in UK.

In order to understand the local changes brought about by renewable energy developments the locations of existing onshore wind farms and individual wind turbines are required. According to the Commons library standard note "Planning for onshore wind farms" reference number SN/SC/4370, any wind turbine development above 50MW are considered to Nationally Significant Infrastructure Projects (NSIPs). The decisions for these developments are taken by Governments Ministers with recommendations from the Planning Inspectorate, allowing the information of them to be available at national level. local planning authorities decide any onshore wind development below 50MW. The availability of information onshore wind turbine developments below 50MW are held at local authority level (Local Councils) and only developments with appeals and local controversies where dealt by national level planning inspectorate. Collecting and collating wind turbine development data below 50MW at national level required alternative datasets.

The renewables statistics provided by Department of Energy & Climate Change (DECC) is a potential data source for onshore wind turbine developments below 50MW. The DECC renewable energy monitoring provides the various renewable energy development from 10KW turbine capacity and above. This data is updated on monthly basis and provides further information about the planning status of the developments from planning application submission to approval and operation. The easting(longitude) & northing(latitude) provided by this database allows one to plot the various onshore wind turbine developments around the UK based upon their capacity, number of turbines and approximate turbine height. The data provided in this database is for all renewable structures, leading to further requirement of specific database for onshore wind turbine developments.

Renewable energy planning database

The DECC created the renewable energy planning database (REPD). The REPD is updated on monthly basis and all data is available to the public. REPD tracks the progress of all renewable planning application in UK as they move through the different planning stage from initial assessment to construction and generation. Eunomia research and consulting limited manages the database on behalf of DECC. The REPD includes details about existing onshore wind turbine developments and also numerous other renewable technologies like, biomass, hydro, tidal, landfill and offshore wind. Following table 5 details the attributes of the DECC's REPD.

Table 5 attributes available in the DECC's REPD

Heading	**Explanation**
Old Ref. ID	The old reference ID associated with a project in a previous version of the database
Ref. ID	Project reference ID number in REPD database
Record Last Updated	Date a project record was last updated or checked
Operator (or Applicant)	Name of operator or applicant
Site Name	Name of development site
Technology Type	Type of technology (e.g. solar photovoltaics, offshore wind etc.)
Installed Capacity (MW_{elec})	Installed electrical capacity in megawatts (MW)

CHP Enabled	Is the project capable of combined heat and power output
Wind Turbine Capacity (MW)	For windfarms, the individual capacity of each wind turbine in megawatts (MW)
No. of Wind Turbines	For windfarms, the number of wind turbines to be located on the development site
Height of Turbines (m)	For windfarms, the height of the wind turbines in metres (m)
Mounting Type for Solar	For solar PV developments, whether the PV panels are ground or roof mounted
Development Status	**No Application Required** - A project that does not require planning permission has been announced by the developer **No Application Made** - A project that previously submitted a scoping application (or published information about a development) but is no longer intends to submit a formal planning application. **Planning Application Submitted -** Planning application validated by planning authority **Planning Application Withdrawn** - Planning application has been withdrawn by the applicant **Planning Permission Granted** - Planning permission granted by planning authority **Planning Permission Refused** - Planning permission refused by planning authority

	Appeal Lodged - An appeal has been lodged by the applicant following a refusal of planning permission **Appeal Withdrawn** - An appeal against a refusal of planning permission has been withdrawn **Appeal Refused -** An appeal has been refused (dismissed) by the planning inspectorate, such that the original refusal remains **Appeal Granted -** An appeal against a planning refusal has been granted (upheld) and planning permission is therefore granted **Secretary of State - Called In** - A planning application has been called in by the Secretary of State such that the Secretary of State will determine whether planning will be granted or refused **Secretary of State - Refusal** - The Secretary of State has refused planning permission after calling-in a planning application for review **Secretary of State - Granted** - The Secretary of State has granted planning permission after calling-in a planning application for review **Under Construction** - A project is under construction **Operational** - A project is operational **Decommissioned** - A project has been decommissioned and is no longer operating

	Abandoned - Project has been abandoned by developer
Development Status (short)	This is a description of the current status of the development in a more succinct form. For example, where a facility has obtained planning permission either directly from the Local Planning Authority, through an appeal, or from the Secretary of State, it is classified here as 'Awaiting Construction'. Where a development has been refused planning permission, either directly from the LPA, following an appeal, or from the Secretary of State, it is classified here as 'Application Refused'.
Address	Site address of the development
District	District the development site is located within
Region	Region the development site is located within
Country	Country the development site is located within
Post Code	Post code of the development site
X-coordinate **Y-coordinate**	X & Y coordinates for development site in British National Grid (or Irish National Grid for Northern Irish projects)
Local Planning Authority	The relevant local planning authority for the project
Planning Application Reference	The reference number associated with the planning application
Appeal Reference	The reference number associated with an appeal

Secretary of State Reference	The reference number associated with a Secretary of State Intervention
Type of Secretary of State Intervention	The type of Secretary of State of Intervention. This can be one of three types: recovery, call-in, or holding direction
Judicial Review	The latest date of when a legal challenge has been launched to review the lawfulness of a planning application and/or appeal decision
Planning Application Submitted	Date planning application was submitted
Planning Application Withdrawn	Date planning application was withdrawn
Planning Permission Refused	Date planning permission was refused
Appeal Lodged	Date an appeal was lodged
Appeal Withdrawn	Date an appeal was withdrawn
Appeal Refused	Date an appeal was refused (dismissed)
Appeal Granted	Date an appeal was granted (upheld)
Planning Permission Granted	Date planning permission was granted by the planning authority
Secretary of State - Intervened	Date of a project that is 'Called in' by the Secretary of State
Secretary of State - Refusal	Date planning permission was refused by the Secretary of State

Secretary of State - Granted	Date planning permission was granted by the Secretary of State
Permission Expiration Date	Date a planning permission expires (as per the planning decision)
Under Construction	Date construction on site has begun
Operational	Date a project become operational

The REPD was contains data for all renewable technologies specifically for tracking renewable electricity projects. However, detailed information about the number of wind turbines, turbine types and turbine heights have been largely under documented. For example, the REPD published in May 2015 had only 7% of wind turbine height details out of 1929 onshore wind turbine developments. The minimum installed capacity of onshore wind turbines development included in REPD is 1MW. The missing data and limitation of installed capacity in the REPD means that a more reliable database of onshore wind turbine developments is required.

VentusAR cumulative data

Onshore wind turbine planning process involves cumulative impact assessment as part of environmental impact assessment in UK(Masden et al. 2010). Scottish Natural Heritage (SNH) requires cumulative and visual impact assessment as part of planning for onshore wind turbine development. Increasing demand for cumulative impact assessment requires detailed information on existing onshore wind developments on same scale. VentusAR is a software development company that has created a cumulative database of onshore wind turbines in UK. It is the UK's first on-demand database of on-shore wind turbines and contains data on 28,000 individual turbines. The database contains planning information for each individual turbine, which allows identifying most of the onshore wind turbine developments in UK. The commercial database was purchased for the purpose of this research. The following table 6 details the cumulative information available in this dataset.

Table 6 Attributes available in VentusAR cumulative WT database

Heading	Explanation
Application Number	The reference number of the planning application from the respective planning authority
Site Address	Site address of the development
Decision	Current decision status of the planning application
Submission Date	Date of the planning application submitted to respective planning authority
Decision Date	Date of the respective planning authority taken and released the decision of that planning application
Appeal Decision Date	Date of the respective planning authority taken and released the appealed decision of that planning application
Proposal	Brief information about the planning application
Lat.	Latitude of the turbine location

Lon.	Longitude of the turbine location
Hub Height	Wind turbine's hub height
Blade Length	Wind turbine's blade length
Tip Height	Wind turbine's tip height
Turbine Type	Type of wind turbine and its name
Notes	Additional notes for reference
Local Authority	Name of the local authority involved in the planning

Wind turbine tip height and hub height is provided in the VentusAR cumulative data and allows the visibility of each wind turbine based on the terrain of the location to be calculated using geographical information system (GIS). The database has no restriction over the minimum scale of the development. Therefore, it covers most of the onshore wind turbine developments in UK. Planning application reference number provided allows researching detailed information about the development from the respective local authority planning online portals. VentusAR cumulative database is updated every 60 days, providing latest changes in the planning decision status and new planning applications for onshore wind developments.

3.4 Socio-economic data for wind turbine development impact

To understand the socio-economic impact of onshore wind turbine developments geo-referenced data is required. To directly link WT developments to the socio-economic profile each dataset needs to be available at the lowest possible geographical level LSOA, considering these factors, the following datasets will be used in this research.

3.4.1 Index of Multiple Deprivation data

The Index of multiple deprivations (IMD) is an area-based measure of deprivation level for every LSOA (2001 & 2011) in UK. In 2000, the first index of multiple deprivation was created by the Social Disadvantage Research Centre (SDRC) at the department of Social Policy and Social Work at the University of Oxford. The initial index was created at the ward level. Significant changes in the methodology to produce the IMD were observed between 2000 and 2004. The Communities and local government (CLG) has produced the index since 2004. The IMD has been produced for 2004, 2007, 2010 and 2015 at the LSOA level. Each of these indexes include seven domains; Income, Employment, Health and disability, Education skills and training, Barriers to Housing and Services, Living Environment and Crime. There is a time lag observed for each of the domains. For example data for the IMD 2004, related to 2001 (2004) and similar approach were observed in the IMD 2007 related to 2005, IMD 2010 related to 2008 and IMD 2015 related to tax year 2012/13. The following sections outline the data used to compile each domain.

Income deprivation domain measures the proportion of the population in an area that live in income deprived families. The definition of income deprivation adopted here includes both families that are out-of-work and families that are in work but who have low earnings. This domain is based on indicators:

- Adult and children in Income support families (IMD 2004, 2007, 2010 and 2015)
- Adults and children in income-based Jobseeker's Allowance families (IMD 2004, 2007, 2010 and 2015)
- Adults and children in Pension Credit (Guarantee) families (IMD 2007, 2010 and 2015)
- Asylum seekers in England in receipt of subsistence support, accommodation support, or both (IMD 2004, 2007, 2010 and 2015)
- Adults and children in Disabled Person's Tax Credit households whose equalized income (excluding housing benefits) is below 60% of median before housing costs (IMD 2004)
- Adults and children in income-based Employment and Support Allowance families (IMD 2007, 2010 and 2015)
- Adults and children in Child Tax Credit and Working Tax Credit families, below 60% median income not already counted (IMD 2004, 2007, 2010, 2015[modified])

Employment deprivation domain measures employment deprivation conceptualised as involuntary exclusion of the working age population from the world of work. The employments deprived are defined as those who would like to work but are unable to do so through unemployment, sickness or disability. This domain is based on following indicators:

- Recipients of Jobseekers Allowance (both contribution-based and income-based) for men aged 18–64 and women aged 18–59. (IMD 2004, 2007, 2010 and 2015)
- Participants in the New Deal for the 18–24s who are not in receipt of JSA (IMD 2004, 2007 and 2010)
- Participants in the New Deal for 25+ who are not in receipt of JSA (IMD 2004, 2007 and 2010)
- Participants in the New Deal for Lone Parents (after initial interview) (IMD 2004, 2007 and 2010)
- Incapacity Benefit recipients aged 18–59 (women); 18–64 (men) (IMD 2004, 2007, 2010 and 2015)
- Severe Disablement Allowance recipients aged 18–59 (women); 18–64 (men) (IMD 2004, 2007, 2010 and 2015)
- Claimants of Employment and Support Allowance (those with a contribution-based element) women aged 18-59 and men aged 18-64 (IMD 2010 and 2015)
- Claimants of Carer’s Allowance, aged 18-59/64 (IMD 2015)

Health deprivation and disability domain measures premature death and the impairment of quality of life by poor health. It considers both physical and mental health. The domain measures morbidity, disability and premature mortality but not aspects of behaviour or environment that may be predictive of future health deprivation. This domain is based on following indicators:

- Years of potential life lost (IMD 2004, 2007, 2010 and 2015)
- Comparative illness and disability ratio (IMD 2004, 2007, 2010 and 2015)
- Acute morbidity (IMD 2004, 2007, 2010 and 2015)
- Mood and anxiety disorders (IMD 2004, 2007, 2010 and 2015)

Education, skills and training domain, shows the extent of deprivation in education, skills and training in the area (LSOA). The domain is constructed using two sub-domains. The sub-domain for education of Young people/ Children measures their attainments from Key Stage 2, 3, 4 and higher educations. This sub-domain is based on following indicators:

- Key stage 2 attainment: average points score (IMD 2004, 2007, 2010 and 2015)
- Key stage 3 attainment: average points score (IMD 2004, 2007 and 2010)
- Key stage 4 attainment: average points score (IMD 2004, 2007, 2010 and 2015)
- Secondary school absence (IMD 2004, 2007, 2010 and 2015)
- Staying on in education post 16 (IMD 2004, 2007, 2010 and 2015)
- Entry to higher education (IMD 2004, 2007, 2010 and 2015)

The sub-domain for skills are measured with proportion of adults between 25-54 with low or no educational qualifications and language proficiency, based on two indicators:

- Proportions of working age adults (aged 25-54) in the area with no or low qualifications (IMD 2004, 2007, 2010 and 2015[modified])
- English language proficiency, aged 25-59/64 (IMD 2015)

The Barriers to Housing and Services domain measures the both physical and financial accessibility of housing and key local services. Suitable housing(affordability) and local amenities are significant determinant of quality of life(McLennan et al. 2011). People who cannot afford own house, live in overcrowded homes or are classed as homeless are deprived of the safety and stability of a home that is appropriate to their household’s needs. Individuals who have to travel long distances to key local services are also disadvantaged(McLennan et al. 2011). This domain measures such deprivation based on two sub-domains, geographical barriers measuring physical and wider barriers measuring financial accessibilities. The physical accessibilities include the geographical distance to various basic conveniences. This geographical barrier sub-domain is based on following indicators:

- Road distance to GP premises: A measure of the mean distance to the closest GP surgery for people living in the LSOA. (IMD 2004, 2007, 2010 and 2015)

- Road distance to a supermarket or convenience store: A measure of the mean distance to the closest supermarket or general store for people living in the LSOA. (IMD 2004, 2007, 2010 and 2015)
- Road distance to a primary school A measure of the mean distance to the closest primary school for people living in the LSOA. (IMD 2004, 2007, 2010 and 2015)
- Road distance to a Post Office: A measure of the mean distance to the closest post office or sub post office for people living in the LSOA (IMD 2004, 2007, 2010 and 2015)

The Wider barrier sub-domain considers housing financial accessibilities, this includes the following:

- Household overcrowding: The proportion of all households in an LSOA which are judged to have insufficient space to meet the household's needs (IMD 2004, 2007, 2010 and 2015).
- Homelessness: The rate of acceptances for housing assistance under the homelessness provisions of housing legislation (IMD 2004, 2007, 2010 and 2015).
- Housing affordability: The difficulty of access to owner-occupation, expressed as a proportion of households aged under 35 whose income means that they are unable to afford to enter owner occupation (IMD 2004, 2007, 2010 and 2015).

Living Environment domain measures quality of the immediate environment in both inside and outside the house of an individual in the area(LSOA). This includes two sub-domains, indoor and outdoor environment. Indoor sub-domain is based on the following indicators:

- Housing in poor condition: Proportion of social and private homes that fail to meet the decent homes standard (IMD 2004, 2007, 2010 and 2015)
- Houses without central heating (IMD 2004, 2007, 2010 and 2015[modified])

The Outdoor sub-domain is based on the air quality & road traffic accidents indicators.

- The air quality indicator shows the proportion of four pollutants (nitrogen dioxide, benzene, sulphur dioxide and particulates (IMD 2004, 2007, 2010 and 2015).
- The road traffic accidents indicator measures the reported death or personal injury on the road for pedestrians and cyclist in the area(LSOA) (IMD 2004, 2007, 2010 and 2015).

Crime domain measures the rate of four major types of crime. This domain shows the effect of crime on individual and community level deprivation. This domain is based on four indicators which represents the four major crime types: Violence, Theft and Criminal damage represented as rate of crime per 1000 at-risk population and Burglary as rate of crime per 1000 at-risk properties.

The above detailed Indicators and sub-domains for respective domains were combined with aim to straightforward interpret the deprivation of the domain in meaningful units (i.e. proportion of people or households experiencing the form of deprivation), but this was observed only in income and employments domains as their indicators were based non-overlapping counts of deprived individuals. In other domains, the indicators were on different metrics. These indicators were standardised by ranking, transformed to a normal distribution and appropriate weights were used and combined to form the domains scores. In domains with sub-domain, the indicators are first combined into respective sub-domains and then combined to form overall domain scores. The following details the methods used for the respective domains as referred from the technical report for The English Indices of Deprivation 2004 and 2010, Though in this research only the domain scores are considered and not their indicators, the following shows the construction method of individual domain scores, overall indices of multiple deprivation (Shrinkage estimation, Factor analysis technique and exponential distribution procedures are not detailed in this research but can be referred from the technical report(McLennan et al. 2011)):

Income domain, the indicators were summed to produce a non-overlapping count of income deprived individuals at LOSA level. The overall count is then represented as proportion of the total population in the LSOA. Shrinkage was applied to construct the overall Domain score.

Employment domain, the indicators are summed to form an overall seasonally-adjusted count of employment deprived people per LSOA and expressed as proportion of the working age population (women aged 18-59 and men aged 18-64) in the LSOA. Shrinkage was applied to construct the final domain score.

Health Deprivation and disability domain, Indicators were standardised by ranking and transformed into normal distribution. Factor analysis technique was used to create weighs for each indicator, Years of potential life lost (0.27), Comparative illness and disability ratio (0.30), Acute morbidity (0.19), Mood and anxiety disorders (0.24). These weighs were applied and combined to construct domain score.

Education, skills and training deprivation domain, the sub-domains indicators are first combined. The relevant indicators in children and Young people sub-domain were standardised by ranking and transformed to normal distribution. Factor analysis technique was used to weights for following indicator, Key stage 2 attainment: average points score (0.17), Key stage 3 attainment: average points score (0.19), Key stage 4 attainment: average points score (0.20), Secondary school absence (0.17), Staying on in education post 16 (0.10), Entry to higher education (0.17). Combing the indicator based on these weighs the sub-domain scores were constructed. In skills sub-domain, Shrinkage was applied to indicators. The sub-domain scores are then standardised by ranking, transformed to an exponential distribution and combined using equal weighs to create overall domain score.

Barriers to housing and services domain, the relevant indicators within each sub-domain were standardised by ranking and transformed to a normal distribution and combined using equal weights. The sub-domains scores are then standardised by ranking, transformed to an exponential distribution and combined with equal weights to create overall domain score.

Living Environment domain, the indicators in each sub-domain are standardised by ranking, transformed to a normal distribution, and combined using equal weights. The sub-domain scores are then standardised by ranking and transformed to an exponential distribution. The overall domain scores are constructed by combing weights of indoor as two third and outdoor as one third based on the patterns of 'indoor' and 'outdoor' time use within the UK time Use survey 2000.

Crime domain, the four indicators were standardised by ranking and transformed to a normal distribution. Weights from Factor analysis technique was used for each indicator: Violence (0.28), Burglary (0.22), Theft (0.26) and Criminal damage (0.24) were combined forming the overall Crime deprivation score. The scores of each domain being obtained, to create the Index of multiple deprivation the domains scores needed standardisation. This was achieved by ranking the scores of each domain and then transformed to an exponential distribution in order that when the domains are combined, appropriate control over cancellation and facilitation of the identification of the most deprived LSOAs can be achieved(McLennan et al. 2011). The transformed domains are combined using appropriate domain weights. Initially these weights for IMD 2000 and 2004 were principally based on theory with additional though given to the robustness of data. Further research was commissioned to explore empirical derivation of the weights. Since there existed no direct empirical method three indirect method (survey, revealed preference and discrete choice experiment) were approached and mean weight using these approaches were recommended (Dibben et al. 2007). The following table 7 shows each domain weights followed in IMD 2004, 2007, 2010 and 2015. Combing these transformed domains with weights provides the overall Index of multiple deprivation scores. The ranks based on these scores were created for each LSOAs showing LSOA with 1st rank being the most deprived and last rank being the least deprived. In this research, scores and ranks of IMD including seven domains from CLG IMD database for respective years (2004, 2007, 2010, 2015) are only considered. It must be noted that mid-year population of 2002, 2005, 2008 and 2012 were used in IMD 2004, 2007, 2010 and 2015 respective, later in this research this population estimates will be used in assigning weights to LSOAs.

Table 7 Index of Multiple deprivation domains and their respective weights

Domains	Weight
Income deprivation	22.5%
Employment deprivation	22.5%
Health deprivation and disability	13.5%
Education, skills and training deprivation	13.5%
Barriers to Housing and services	9.3%
Living environment deprivation	9.3%
Crime	9.3%

3.4.2 Rural Urban Classification data

Rural urban classification considered in the research is based on the revised 2011 version of the rural urban classification(RUC) developed by the Department of Communities and Local Government (DCLG), the department of Environment, Food and Rural affairs (Defra), the office of National statistics (ONS) and the welsh Government(WG). This classification categorises the lowest statistical area OA on basis of physical settlement and their related characteristics. RUC itself doesn’t contain any statistical data but provided a categorical attribute to the OAs. There are 10 categories in which 4 represents various urban settlements and 6 represents rural. The urban domain is defined based on population of 10,000 or more while, lower population falls within rural domain. Aggregated RUC categories at LSOAs level shows settlements to be more homogeneous, narrowing into 8 categories which will be considered in this research.

Table 8 shows the distribution of this classification at the LSOA level in England and Wales. RUC take no explicit account of land cover but categories the physical character of the settlements within which may indicate little about the land cover. In the research, RUC is considered as category for matching LSOAs allowing it to be applicable.

Table 8 rural urban classification and its frequency in England and wales

LSOA Rural Urban Class	Frequency
Urban: Major Conurbation	33.2
Urban: Minor Conurbation	3.5
Urban: City and Town	45.3
Urban: City and Town in a Sparse Setting	0.3
Rural: Town and Fringe	9.2
Rural: Town and Fringe in a Sparse Setting	0.6
Rural: Village and Dispersed	7.2
Rural: Village and Dispersed in a Sparse Setting	0.9

3.5 Wind speed data

The wind speed data considered in this research is based on national wind speed database commonly known as NOABL, the Numerical Objective Analysis Boundary provided by the (now defunct) Department of Energy and Climate Change (DECC). The wind speeds at 10m, 20m and 45m are above ground are presented as a 1km grid. NOABL uses an air flow model to estimate the effect of topography on wind speed, without considering the effect of local winds such as sea, mountain or valley breezes. The NOABL(NOABL 2015) wind speed database is used as the base value for referencing wind turbine assessment along with commercially available Met office reports(Wrate and Eftekhari 2010, Dutton, Halliday and Blanch 2005). The mean wind speed at height above 45m is applied to each LSOAs in the England allowing to match LSOAs with similar wind speed. Figure 10 shows the average wind speed at 45m above ground level at LSOA level.

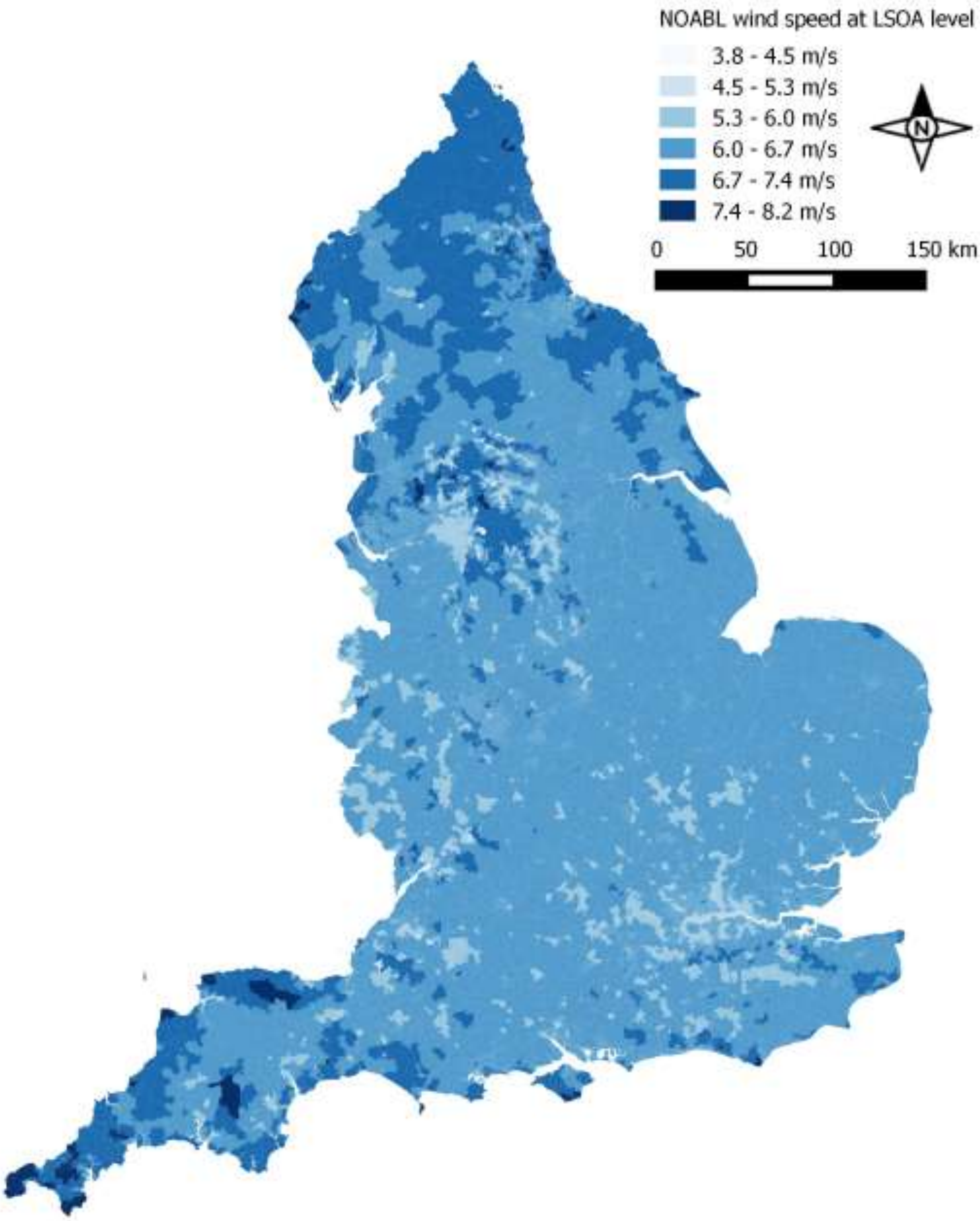


Figure 10 NOABL wind speed at 45m ground level at LSOA level

3.6 Planning Constraints

Planning for wind turbine development in England requires an examination of the surrounding environment like any other infrastructural development. Due to the visual dominance of the wind turbine's height, planning for these developments requires large area investigation and consider various constraints which are not common among other developments. To develop the GIS to examine WT developments required the combination of 30 datasets. These datasets are collected from various government and private agencies including Natural England, Royal Society for the Protection of Birds, English Heritage, Forestry UK and Ordnance Survey. These datasets are categorised into Ecology, Landscape, Heritage, Ministry of Defence (MoD) and others based on their characteristics, which are considered as constraints in term of wind turbine development planning. These datasets are described in table 9.

Table 9 Planning constraint categories, name and brief description

Constraints category	Geographical Constraints Name	Description
Ecology	*Biosphere Reserves*	These are the areas of terrestrial and coastal/marine ecosystems where the conservation of ecosystems and their biodiversity is combined with the sustainable use of natural resources for the benefit of local communities. All three reserves are of importance for both landscape and biodiversity values.

Ecology	*Local Natural Reserves*	Local Natural Reserves are the sites with importance for wildlife, geology, education or public enjoyment. Some are also nationally important Sites of Special Scientific Interest. LNRs are controlled by the local authority through ownership, lease or agreement with the owner. These areas are known for the natural features which make the site special.
Ecology	*National Nature Reserves*	England's National Nature Reserves (NNRs) represent many of the finest wildlife and geological sites in the country. First NNRs emerged in the post-war years alongside the early National Parks, and have continued to grow since then. NNRs were initially established to protect sensitive features and to provide 'outdoor laboratories' for research. Their purpose has widened since those later periods.
Ecology	*RAMSAR*	These are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. Ramsar sites may also incorporate riparian (banks of a stream, river, pond or watercourse) and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands.

Ecology	*SAC*	A Special Area of Conservation (SAC) is an area which has been given special protection under the European Union's Habitats Directive. SACs provide increased protection to a variety of wild animals, plants and habitats and are a vital part of global efforts to conserve the world's biodiversity.
Ecology	*SPA*	A Special Protection Area (SPA) is an area of land, water or sea which has been identified as being of international importance for the breeding, feeding, wintering or the migration of rare and vulnerable species of birds found within the European Union. SPAs are European designated sites, classified under the European Wild Birds Directive which affords them enhanced protection.
Ecology	*SSSI*	A Site of Special Scientific Interest (SSSI) is one of the country's very best wildlife and/or geological sites. SSSIs include some of the most spectacular and beautiful habitats: wetlands teeming with wading birds, winding chalk rivers, flower-rich meadows, windswept shingle beaches and remote upland peat bogs.
Historic	*Ancient Woodlands*	Ancient woodland is land that has had a continuous woodland cover since at least 1600 AD and may be ancient semi-natural woodland (ASNW), which retains a native tree and shrub cover that has not been planted, although it may have been managed by coppicing or felling and allowed to regenerate naturally, or plantation on ancient woodland sites (PAWS) where the original

		tree cover has been felled and replaced by planting, often with conifers, and usually over the last century.
Historic	*Conservation Areas*	Conservation areas are crucial to the conservation of our environment. There are over 600 conservation areas in England, Scotland and Wales. Many were designated in the early 1970s, but some have since been re-designated, merged, renamed, given smaller or larger boundaries and new ones have been added. They can cover historic land, battlefields, public parks, designed landscapes or railways but most contain groups of buildings extending over areas of a village, town or city. To safeguard them for the enjoyment and benefit of future generations any new development should preserve or enhance their varied character without impacting them.
Historic	*Historic Battlefield*	The English Heritage Register of Historic Battlefields is administered by English Heritage under the National Heritage Act 1983. It identifies 43 important English battlefields, with a purpose to offer them protection and to promote a better understanding of their significance. The Register is intended to be the starting point for battlefield conservation and interpretation, identifying the most visually sensitive areas.

Historic	*Listed Buildings*	Listed buildings are the structures with special architectural or historic interest compiled by the Secretary of State for Culture, Media and Sport under the Planning (Listed Buildings and Conservation Areas) Act 1990, on advice from English Heritage. The dataset is being added to regularly and there are approximately 375,000 entries on the list. They are categorized into grades I, II and II*. Planning near these structures requires further investigation.
Historic	*Protected Wrecks*	The Protection of Wrecks Act (1973) allows the Government to designate an important wreck site to prevent uncontrolled disturbance and heritage agencies to develop research, education and access initiatives to raise awareness of, and involvement in, designated wreck sites. English Heritage advises the Government on designations and manages the licensing scheme that enables access to English sites.
Historic	*Registered Park and Garden*	The Register of Parks and Gardens of Special Historic Interest in England is administered by English Heritage under the National Heritage Act 1983. It serves to ensure that the features and qualities that make these landscapes of national importance can be safeguarded. The Register can include other designed landscapes such as town squares, and currently has over 1,600 entries.

Historic	*Scheduled Monuments*	Nationally important sites and monuments are given legal protection by being placed on a Schedule of monuments. English Heritage takes the lead in identifying sites in England, which should be placed on the Schedule by the Secretary of State for Culture, Media and Sport. The current legislation, the Ancient Monuments and Archaeological Areas Act 1979, supports a formal system of scheduled monument consent for any work to a designated monument. The word 'monument' covers the whole range of archaeological sites. Scheduled monuments are not always ancient, or visible above ground. The dataset is being added to regularly and there are over 22,000 entries on the Schedule for England.
Historic	*World Heritage Sites*	World Heritage Sites are described by UNESCO as exceptional places of ‘outstanding universal value’ and ‘belonging to all the peoples of the world, irrespective of the territory on which they are located’. Scotland currently has five cultural World Heritage Sites. Once a World Heritage Site is inscribed, under the Convention, member states have a duty to protect, conserve and present such sites for future generations
Landscape	*Agricultural Land Classification*	Agricultural land classified into five grades. Grade one is best quality and grade five is poorest quality for agriculture. A number of consistent criteria used for assessment which include climate (temperature, rainfall, aspect, exposure, frost risk), site (gradient, micro-

		relief, flood risk) and soil (depth, structure, texture, chemicals, stoniness).
Landscape	*Area of Outstanding Natural Beauty*	These are landscape which have magnificent views and natural beauty. These areas have significant landscape characteristics, recognised as national importance and maintained.
Landscape	*Country Parks*	More than 400 Country Parks exist. They are public green spaces often at the edge of urban areas which provide places to enjoy the outdoors and experience nature in an informal semi-rural park setting. Country Parks normally have some facilities such as a car park, toilets, perhaps a cafe or kiosk, paths and trails, and visitor information. There is not necessarily public right of access, although most are publicly accessible; some charge entry others do not. Most are owned and managed by Local Authorities. Many Country Parks were designated in the 1970s by the then Countryside Commission, under the Countryside Act 1968.
Landscape	*Green Belt*	In United Kingdom town planning, the green belt is a policy for controlling urban growth. The idea is for a ring of countryside where urbanisation will be resisted for the foreseeable future, maintaining an area where agriculture, forestry and outdoor leisure can be expected to prevail. The fundamental aim of green belt policy is to

		prevent urban sprawl by keeping land permanently open, and consequently the most important attribute of green belts is their openness.
Landscape	*National Park*	National Parks are extensive tracts of country that are protected by law for future generations because of their natural beauty and for the opportunities they offer for open air recreation. The parks are living and working landscapes, with an increasing focus on supporting the communities and economic activity that underpin the qualities for which each have been designated. National Parks provide more than 70 million visitors each year (State of the Natural Environment, 2008) with the opportunity to experience and explore some of England's most dramatic and often remote landscapes.
MoD	*Eskdalemuir Seismology Centre*	The Eskdalemuir Seismological Recording Station is located in southern Scotland and has been in operation since 1962, making it the longest-operating steerable seismic array in the world. The altitude of the seismic pits varies from 900ft to 1400 ft. The isolated location ensures that micro seismic interference is kept to a minimum. An 15km radius around this area is restricted for any development
MoD	*Low Flying Zones*	These areas represent where the MOD anticipates construction of wind turbines would result in

		considerable and significant concerns due to their likely effect on the UK low flying system.
MoD	*MET Radar*	These areas as mapped and published for the purpose of offering guidance about locations likely to be problematic regarding planning.
Others	*Public Right of Way*	Public Right of Ways (PROWs) are designated routes publicly accessible to walk (footpath), horse riding (bridleway) and pedal cycling (bridleway) respectively. These routes are mostly used for leisure walking relating them to nature landscape. These PROWs must be considered for planning as visual impact on them by development could affect the planning decision as they are need to be preserved for the landscape views (OS raster map extracts, Open-street maps and local authority council maps)
Others	*Aviation*	Civil aircraft aerodrome including airports
Others	*Railways*	Railway tracks including public and industrial operations
Others	*Electricity*	Gridlines above 110KV operated by National grid
Others	*Waterway*	Includes low level waterbodies to major rivers
Others	*Road*	Included minor streets to Major motorways
Others	*Woodlands*	Vegetation including small forest and patch of large trees

4 METHODOLOGY CHAPTER

4.1 Introduction

This Chapter provides an overview of the methodologies used in this research including the development of WT development database detailed in section 4.2 which is developed combining DECC REPD and VentusAR cumulative WT database. WT development categories are outlined in section 4.3 and a method to define the impact distance of a WT development is outlined in section 4.4. The boundary standardisation of the IMD score is outlined in section 4.5. The assignment of population weights to each LSOA within 2 KM of a WT development is outlined in section 4.6. To examine the impact of WT developments on the socio-economic profile of an areas, Section 4.7 outlines the propensity score match method, which is used to match. Section 4.8 and 4.9 details the commercial outputs from this research and outlines the development of the renewable energy planning framework and method involved in building GIS system for implementing the planning framework.

4.2 Developing a robust onshore wind turbine development(WTD) database

For the purpose of this research, a robust onshore wind turbine development database for the UK was created by merging DECC's REPD and VentusAR cumulative databases. Linking both databases provides information on all existing onshore wind turbine development, both spatially and temporally. The format of the database is comma separated values (csv) that was imported into

GIS using the latitude and longitude coordinates of each turbine. The following table 10 describes the database structure.

Table 10: Overview of the onshore wind turbine development database

Heading	Explanation
Planning Application Number	The reference number of the planning application from the respective planning authority
Site Address	Site address of the development
Installed Capacity	Installed electrical capacity in megawatts (MW)
DECC REPD Development Status	No Application Required/ No Application Made/ Planning Application Submitted/ Planning Application Withdrawn/ Planning Permission Granted/ Planning Permission Refused/ Appeal Lodged/ Appeal Withdrawn/ Appeal Refused/ Appeal Granted/ Secretary of State - Called in/ Secretary of State – Refusal/ Secretary of State – Granted/ Under Construction Decommissioned
VentusAR Planning Application Decision	Current decision status of the planning application
Submission Date	Date of the planning application submitted to respective planning authority
Decision Date	Date of the respective planning authority taken and released the decision of that planning application

Appeal Decision Date	Date of the respective planning authority taken and released the appealed decision of that planning application
Proposal	Brief information about the planning application
Latitude	Latitude of the turbine location
Longitude	Longitude of the turbine location
Hub Height	Wind turbine's hub height
Blade Length	Wind turbine's blade length
Tip Height	Wind turbine's tip height
Turbine Type	Type of wind turbine and its name
Notes	Additional notes for reference
Local Authority	Name of the local authority involved in the planning
Region	Name of the Region in England of the development

4.3 Classification of onshore wind turbine developments

Onshore wind turbine developments vary from a single turbine to large wind farms with multiple turbines. For the purpose of any analysis it is therefore necessary to classify the scale of the wind turbine developments. The scale of wind turbine development can be classified based on the planning framework followed in England. Developments over 50MW are considered as Nationally Significant Infrastructure Projects (NSIPs) and therefore require development consent from the planning inspectorate. The planning inspectorate examines the project and relevant Government Minister takes the final decision.

Developments below 50MW are processed at the local authority level (Planning for onshore wind (House of commons), Louise Smith,2015). Since most of the wind turbine developments are below 50MW, local authorities have been the main body making the decisions on whether a WT is developed or not. Thus, the classification of the scale of wind turbine development followed by local authorities must be considered. Every local authority has different type of classification for scale of wind turbine developments based on planning applications they receive and review, type of physical settlement (rural/urban) and landscape sensitivity. Table 11 provides an overview of the various types of classification defined by five local authority councils; Aberdeen City council, Vale Royal Borough Council, North Somerset, Cumbria and Breckland and King's Lynn & West Norfolk.

Table 11: Wind turbine development classification by local authority councils

Local Authority	Classification	Reference
Aberdeen City council	Single-0.05MW to 3MW; Cluster: 2-3 turbines/3-6MW total; Small: 4-10 turbines/ 6-16MW total; Medium: 11-20 turbines/16-31MW total; Large: 21 or more turbines/ 31MW or more;	Aberdeen local development plan draft supplementary guidance Nov 2012
Vale Royal Borough Council	Single Turbine: a single turbine; Small Group: 2 – 6 turbines; Medium Group: 7-12 turbines; Medium-Large Group: 13-25	Supplementary Planning Document 4 Sept 2007

	turbines; Large Group: over 25 turbines;	
North Somerset	Single: single turbine; small cluster: 2-3 turbines; medium cluster: 6-10 turbines; large cluster: 11-25 turbines; very large farm: 26 and more turbines;	Renewable and Low Carbon Energy Generation: Wind Turbines Jul 2014
Cumbria	Single/twin turbine; small group: 3-5 turbines; large group: 6-9 turbines; small farm: 10-15 turbines; medium farm: 16-25 turbines; large farm: 26 or more turbines; (considered average turbine height 95-102m)	Cumbria wind energy supplementary planning document (part 2) Jul 2007
Breckland and King's Lynn & West Norfolk	Single Turbine; Small Scale: 2-12 turbines; Medium Scale: 13 – 24 turbines; Large Scale: 25 plus turbines.	Wind Turbine Development August 2003 Landscape Assessment, Evaluation and Guidance

Considering the above classifications, in this research wind turbine development are generalized into four groups for WT above 0.05MW and a total capacity of 1MW. This ignores the microscale and domestic wind turbine development which doesn't require planning permission from local authority and not included in DECC's REPD. These groups are:

a. Single turbine (commonly observed in local authority's wind development classification)

b. Medium farm: 2-4 turbines (commonly observed in local authority's wind development classification)
c. Large farm: 5 and above turbines (simplified to generalize large clusters of wind turbines)

4.4 Impact distance of wind turbine developments

Any infrastructural development influence changes on surrounding area, but the intensity of the change itself depends on development type, scale and topography. Considering wind turbines, there are no accurate and standardized method to measure the impact distance as it is completely based on wind turbine height, ownership, environment and topography. Universal acknowledgement of visibility of wind turbine as important influencing impact(Buchan and Heritage 2002), the distance to which wind turbine could be visible was considered as impact distance of wind turbine development. The impact distance from various guidelines on wind development are stated in the following table 12.

Table 12 visual impact distance guidelines referred by various sources

Visual Impact distance & perception	reference
Up to 2 km: Likely to be a prominent feature; 2-5 km: Relatively prominent; 5-15 km: Only prominent in clear visibility (seen as part of the wider landscape); 15-30 km: Only seen in very clear visibility (a minor element in the landscape);	PAN 45 (revised 2002): Renewable Energy Technologies
Dominated the view: 2Km; visually intrusive: 1-4.5Km; Noticeable: 2-8Km; indistinct element: over 7Km	Stevenson & Griffiths (1994)

significant visual effect - upto 5Km; visible only in clear visibility and likely to be minor element in landscape - beyond 15Km;	BWEA & Powergen Renewables
recommended zone of visual impact (ZVI) atleast 25Km-	Scottish Natural Heritage (2001)
ZVI atleast 10Km	Countryside Council Wales (1999)
ZVI must be 20Km	South Norfolk District Council Supplementary Planning Guidance (2000)

Most of these guideline distances are generic and non-specific. In this research we consider the majorly accepted visual impact distance based on these guidelines and also considered the manageability of the data size for processing in GIS and statistical software. The impact distance of wind turbine development is therefore grouped as 0-2 Km, 2-5 Km, 5-10Km and 10-20Km.

4.5 Standardizing index of multiple deprivation score and rank of 2004, 2007, 2010 and 2015 for LSOA 2011 in England

As noted in the Data Chapter, an index of multiple deprivation (IMD) was released for England for 2004, 2007 and 2010 at the lower super output area (LSOA) spatial level. The 2001 LSOA boundaries were used for each of these indexes. In contrast, the IMD released in 2015 although also released at the LSOA level used boundaries based on census 2011 (Changes to Output Areas and Super Output Areas in England and Wales, 2001 to 2011, ONS, A Trait 2012). To compare the change of in deprivation over the time, IMD scores and ranks of the 2004, 2007, 2010 and 2015 need to have the same LSOA boundaries. To adjust the IMD scores and ranks from LSOAs based on 2001 census to 2011 census, the changes in their boundaries were explored. There were 2.5% change in LSOAs in England and Wales, these changes were made to maintain the population size, social homogeneity and to align with changed local authority boundaries (Changes to Output Areas and Super Output Areas in England and Wales, 2001 to 2011, ONS, A Trait 2012)). Examining England, 32482 LSOAs based on 2001 census increased to 32844 with 2011 census. The increase in the LSOAs were based on the following changes:

a. 366 LSOAs were split into 881 LSOAs
b. 293 LSOAs were merged into 145 LSOAs
c. 151 LSOAs had Complex changes, where boundaries of LSOAs are redefined by both merge and split process into 146 LSOAs.
d. Remaining 31672 LSOAs were unchanged.

The methodology used by Public Health England to align the IMD 2004, 2007 and 2010 with 2011 boundaries for LSOAs (reference: document-excel sheet-downloaded from PHE) was used for the purpose of this research. The IMD scores of LSOAs are adjusted based on the type of their changes in their boundaries. Area and population based approach were additionally implemented in LSOA boundaries with complex changes. These adjustments are detailed below:

- Splits: 366 LSOAs were split into 811 LSOAs, the scores of LSOAs to be split were assigned to the each newly split LSOAs.

Example, 2001 census based LSOA with IMD 2004 score 46.43, code E01000047 and name Barking and Dagenham 021A were split into two new LSOAs with assigned IMD 2004 score of 46.43 on both E01033587 and E01033588 equally as shown is following figure 11

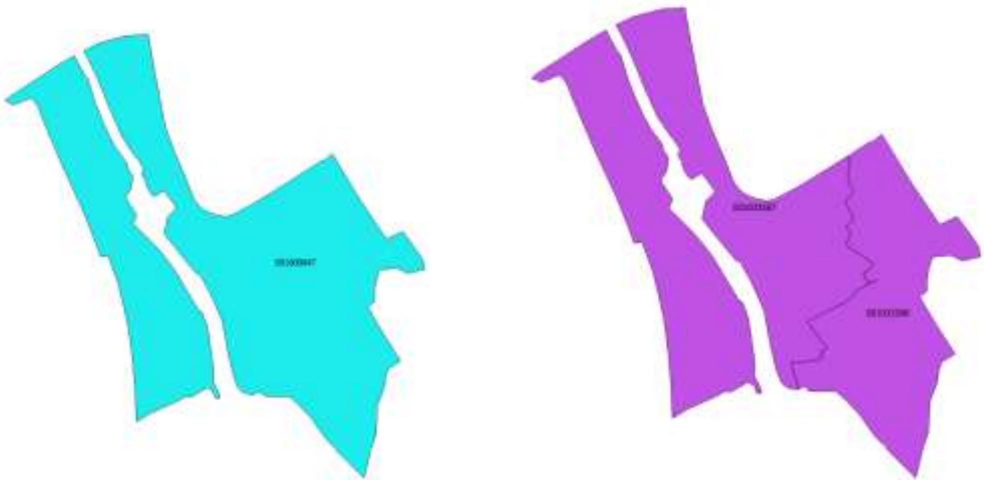


Figure 11 split of LSOA(E01000047) into two LSOAs (E01033587 and E01033588) left (LSOA boundary based on 2001 census) right (LSOA boundaries based on 2011 census)

- Mergers: 293 LSOAs were merged into 145 LSOAs, the scores of the merged LSOAs were based on weighted average population of the unmerged LSOAs, these weighted average populations were based on estimates used in the respective IMD releases.

  Example, 2001 census based LSOA with IMD 2004 score 10.4(name: Aylesbury Vale 001D, code: E01017685, population [2001]: 1560) gets merged with LSOA with IMD 2004 score 9.01(name: Aylesbury Vale 001E, code: E01017686, population [2001]: 1560) forming 2011 census based LSOA with IMD 2004 score of 9.7(name: Aylesbury Vale 001F, code: E01032960) as shown if following figure 12.

Figure 12 merging of LSOAs (E01017685 and E01017686) into LSOA (E01032960) left (LSOA boundaries based on 2001 census) right (LSOA boundary based on 2011 census)

- Complex: 151 LSOAs have complex changes, where they are not simply split or merged but changes include grouping several LSOAs together, ungrouping single LSOA into several LSOAs and boundary changes. To adjust the IMD score for these 151 complex changes weighted average population along with area of LSOAs were considered.

  Example, Census 2001 based LSOA with IMD score 31.23 (name: Coventry 037A, code: E01009545, population [2001]: 1520, Area: 18.234ha) and LSOA with IMD score 14.72 (name: Coventry 037D, code: E01009551, population [2001]: 1530, Area: 26.854 ha) have complex change in boundaries. LSOA E01009545 increased its area by 4.73ha from LSOA E01009551. Ratio of 0.18 (4.73ha) from 26.58ha area of LSOA E01009551 is applied to its population 1530. This rationalized and rounded population of 274 is assigned to 4.73ha area of LSOA E01009551 with IMD score of the same LSOA. The merger methodology is applied to LSOA E01009545 (full population:1520, IMD score: 31.23) with LSOA E01009551(rational population:273, IMD score: 14.72) and assigned to LSOA with boundary based on 2011 census (name: Coventry 037F, code: E01032534, adjusted population [2001]: 1793, IMD score: 28.7). LSOA E01009551, 4.73ha area had been reduced but, IMD score was assigned to LSOA with boundaries based on census 2011 (name: Coventry 037G, code: E01032535, adjusted population [2001]: 1270, IMD score: 14.72) as shown in following figure 13.

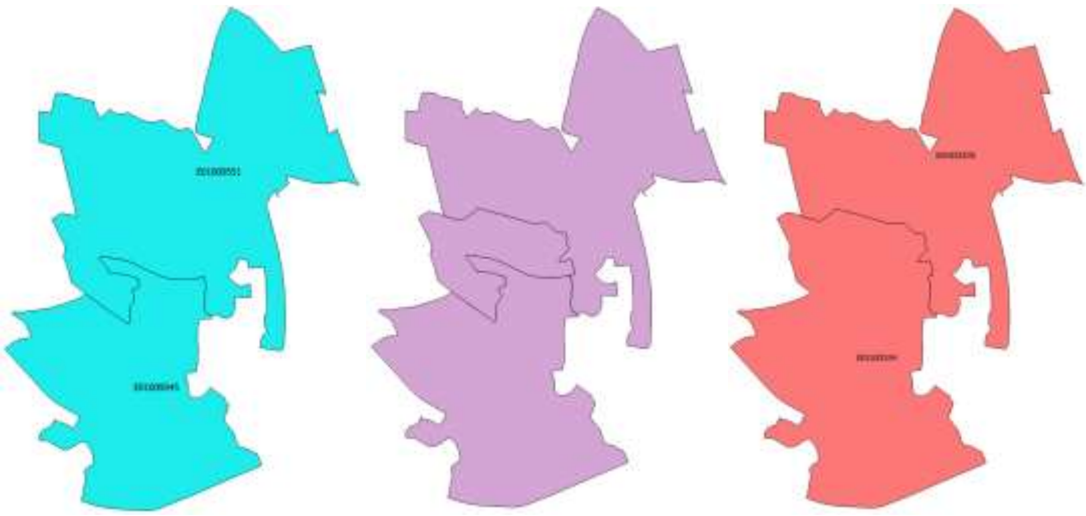


Figure 13 Change in boundaries of LSOAs based on census 2001(E01009545 & E01009551) to census 2011(E01032534 & E01032535), left (LSOA boundaries based on 2001 census), middle (LSOA boundaries shared in adjustment) right (LSOA boundary based on 2011 census)

The above methodology was applied to each of the seven IMD domains for 2004, 2007 and 2010 IMD. The adjusted overall scores along with each domain scores were combined and assigned to the LSOA boundaries based on the 2011 census. The change in the LSOA boundaries also affects the national ranking of LSOAs based on IMD scores for 2004, 2007 and 2010. This effect is resolved by re-ranking the LSOAs with new boundaries based on the adjusted IMD scores for respective years. For the purpose of this research, the IMD 2004, 2007 and 2010 ranking of each LSOA at regional, county and local authority level were required. Regional, county and local authority codes were assigned to each LSOA using a GIS. The ranks for LSOAs based on IMD scores were applied using the STATA rank function. Similarly, percentile, quantile and decile for the LSOAs based on IMD scores were created at National, regional, county and local authority level using the ‘Tile’ function in STATA. The 32,844 LSOAs are now assigned with IMD 2004, 2007, 2010 and 2015 IMD score, rank, percentile and decile. As the IMD scores of the LSOAs cannot be compared across time (i.e. IMD 2004 score cannot be compared to IMD 2007 score of the same LSOA), **the IMD and individual domain percentiles for each LSOA is considered throughout this research.**

4.6 Assigning weights to IMD scores of LSOAs with impact radius of wind turbine development.

To assess the IMD scores to LSOAs within a 2km impact radius of each wind turbine development, a buffer must be applied to the wind turbine point data. The point data is first changed to polygon data by applying the buffer value using QGIS (GIS application), fixed distance buffer tool. The LSOAs in this buffer zone contain attributes of each respective WT development. This buffer is used to clip the OAs and LSOAs in England containing attributes including respective ONS code (LSOA code and OA code) and their area in square metres using the QGIS- Clip tool. These 2km LSOAs and OAs areas are measured using QGIS-attribute area tool and assigned as additional attribute (2km area) respectively. The IMD scores is merged using the LSOA’s ONS code in the 2km LSOAs by QGIS- Join by attribute tool. Merging the IMD to the buffered LSOAs produces a dataset of attributes including ONS code, total area of the LSOA, 2km area of the LSOA, adjusted IMD scores (2004,2007,2010 & 2015), adjusted IMD percentile (national level, regional, county & local authority level).

Small Area population estimates based on 2011 statistical geography hierarchy are also included, this data provided mid-year population estimates from mid-2002 to mid-2013 for OAs and LSOAs in England and Wales. The LSOAs ONS code from this data is joined to 2km LSOA again using QGIS's, join by attribute tool. The population of LSOAs for 2002, 2005, 2008 and 2012 (based on Mid-year population estimates) are also linked to the buffered data, using QGIS's, attribute editor function. To create weights for the IMD scores within the buffered LSOAs, population data at the lowest administrative level need to be considered. Small Area population estimates for 2002, 2005, 2008 and 2012(Mid-year population estimates) at the output area (OA) level are used.

Nesting the appropriate 2011 OAs within each LSOAs, population data at the OA are further joined to 2km buffered LSOAs. Similarly, the ratio of 2km area to total area is created using QGIS's attribute editor function. This ratio is applied to the population of OAs which represents the proportion of population with 2km OAs. This still assumes that population within OAs are equally distributed which remains as a simplification. The dataset now contains attributes including OAs ONS code, LSOAs ONS code, ratio of population estimates in 2km for mid-year 2002, 2005, 2008 and 2012. The 2km OAs grouped based on their LSOA code, their ratio of populations is summed. This grouped 2km OAs are referred as 2km LSOAs population. This grouped 2km LSOA population is joined with the 2Km LSOAs in which the ratio of 2Km OAs summed population and LSOAs total population is considered as weighting factor for the IMD scores within the 2Km

LSOAs. Similar weighing method have been in used to estimate voter turnout percentage for SOAs by (Huby, Owen and Cinderby 2007) and also in analysing socioeconomic impacts of water management actions by(Westling, Lerner and Sharp 2009).

The weighted mean and weighted standard deviation of IMD and each domain scores were estimated for each buffer area with WT development reference based on weighted scores of each 2km LSOAs within the buffer area, this approach is based on (Brunsdon, Fotheringham and Charlton 2002).

$$\bar{x} = \frac{\sum w_i x_i}{\sum w_i}$$

Where $\bar{x}$ = weighted mean score of IMD and each domain of the buffer area

w_i = weight of i^{th} LSOA within buffer area, x_i = IMD and each domain score of the i^{th} LSOA. sd_w = weighted standard deviation of the buffer area.

$$sd_w = \sqrt{\sum (x_i - \bar{x})^2 w_i}$$

This methodology is applied to both operational and refused wind turbine development in England. Each 2km buffer area contains the development reference id, development category, related development period, weighted mean scores of IMD and each domain for respective years and weighted standard deviation of IMD for respective period. Further to relate the IMD scores temporally the mean scores and standard deviations are represented in percentile based respective years minimum and maximum of the IMD and each domain scores.

4.7 Propensity score matching method

In this research propensity score method is used to match LSOAs with a WT development to similar LSOAs without a WT development to ascertain the impact of WT development on the socio-economic profile of an area. These two groups of LSOAs become ‘control’ and ‘treatment’ areas. The control areas are LSOA without a WT development. In contrast, the ‘treatment’ areas are LSOAs with a WT development. PSM is used extensively in evaluation studies to estimate the impact of an intervention (for example a WT development) on an area or group of people. Thus, PSM is common among medical research and observational studies on analysing the effect of the treatment among treated and control group(Nduka et al. 2016), (Sengupta Chattopadhyay et al. 2016). For this research, PSM allows one to match LSOAs with a WT to an LSOA without a WT based on the similarity of their characteristics.

PSM uses the ‘propensity score’ or the conditional probability of participation (treatment group, Y_1) to identify and match a counterfactual group of non-participants (outcome group, Y_0), given a set of observable covariates, X. Matching relies on the assumption of conditional independence. LSOAs with similar propensities are matched and analysed pair-wise, so that given X, the outcome Y is conditionally independent of whether the LSOA received treatment (a WT development). Several PSM methods exist including nearest neighbour, stratification, radius, kernel and local linear regression matching algorithms (von Randow et al., 2012; Abello et al., 2002; Jesmin et al., 2012). While there is no clear rule for determining which algorithm to use pre-estimation, using post estimation results it is possible to examine which algorithm best satisfies the balancing property. This means that observations with the same propensity score must have the same distribution of observable covariates independent of treatment status. This thesis uses nearest neighbour method to match the treated and control LSOAs. The following two section details the use of propensity score matching in this research.

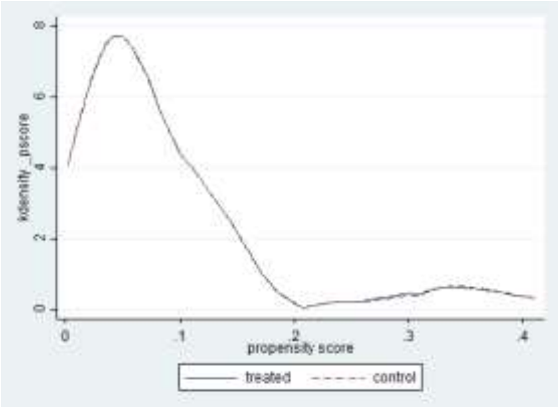
4.7.1 Matching LSOAs within 2km of operational wind turbine development to LSOAs with similar deprivation, physical settlement and topography characteristics

Data on LSOAs within 2km of an operational WT development containing the adjusted IMD scores and percentile, region, county and local authority ONS code of respective LSOAs are linked with the 2km LSOAs containing the population weighting factor (ratio of 2Km OAs summed population and LSOAs total population). This linked dataset contains 32844 LSOAs of England with additional attributes apart from the defined above, treatment attribute showing status of WT development in LSOAs (1 and 0), operational year of WT in LSOAs (2004, 2007, 2010 and 2015), WT development reference id (4 digits numerical) and category of WT development in the LSOA (a, b, c). Rural urban classification of the LSOAs (1-8 categories), average wind speed of LSOA in metre/sec and total area of each LSOA is also included.

To implement the propensity score matching, all the LSOAs with operational wind turbine are considers as treated and all other LSOA are in control group. It must also be noted that matching is performed for each IMD period (i.e. all operational WT development in 2004 period is matched separately to 2007, 2010 and 2015 operational WT development period), this allows the IMD percentile to be also used as covariates. The matching criteria are set as following:

- Region as a categorical variable
- County as a categorical variable
- Rural Urban Classification as a categorical variable
- LSOA area as a continuous variable
- Average wind speed as a continuous variable
- IMD percentile for respective period as a continuous variable
- IMD local authority level percentile for respective period as a continuous variable.

Based on the criteria set the propensity score and matches are generated. To validate the matching, kernel density for propensity scores are plotted for 2004, 2007, 2010 and 2015 periods between matched control and treated group and is observed from the following figure 14 and 15 that the matched groups have similar propensity score.



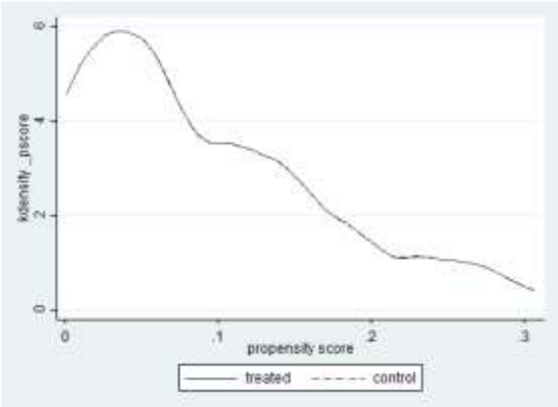


Figure 14 kernel density plot for propensity scores of control and treatment matched 2004 (left), 2007 (right)

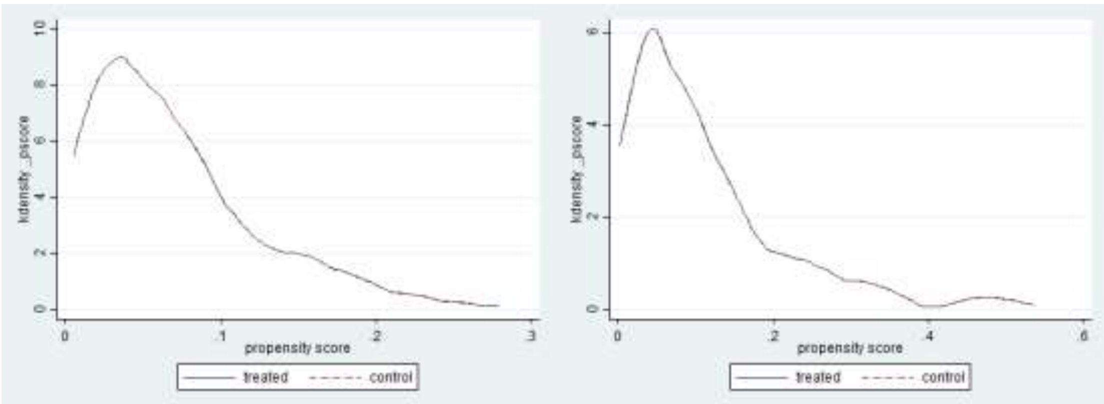


Figure 15 kernel density plot for propensity scores of control and treatment matched left (2010) and right (2015)

The matched dataset is extracted and the LSOAs acting as controls are aligned with the treated LSOAs. This allows the comparison of IMD profiles of LSOAs with WT development with LSOAs without WT developments.

4.7.2 Matching Operational and refused wind turbine developments with similar development characteristics

To gain insight into the socio-economic profile of LSOAs with operational WT versus LSOAs that refused WT developments, PSM is also applied using wind turbine development status as treatment variable in the matching process and refused development sites as the control. Operational developments are treated while refused as untreated. The matching criteria are as follows:

- Region ONS code as categorical variable
- Rural Urban Classification as categorical variable
- IMD period as categorical variable
- Wind turbine category as categorical variable
- Installed capacity as continuous variable.

As we are using a subset of LSOAs (operational and refused) we did not expect each treatment LSOA to be matched to a control LSOA. Based on the above matching criteria 42 operational WT developments were matched to 42 refused WT developments from 337 developments (148-operational and 189 refused). To verify the matching, the kernel density plot for the propensity score between control and treat group was observed to have similar propensity scores. To analyse the levels of deprivation across these matched developments, the 2km area of these development is considered as the impact area and weighted IMD scores are assigned to these 2km area based on the approach outlined in methodology 4.6. The following figure 16 shows the kernel density plot of propensity score of matched operational and refused WT developments.

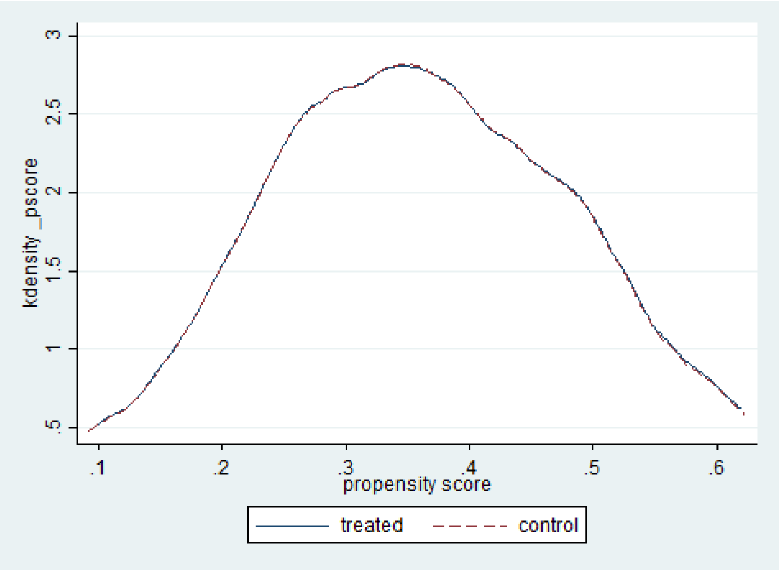


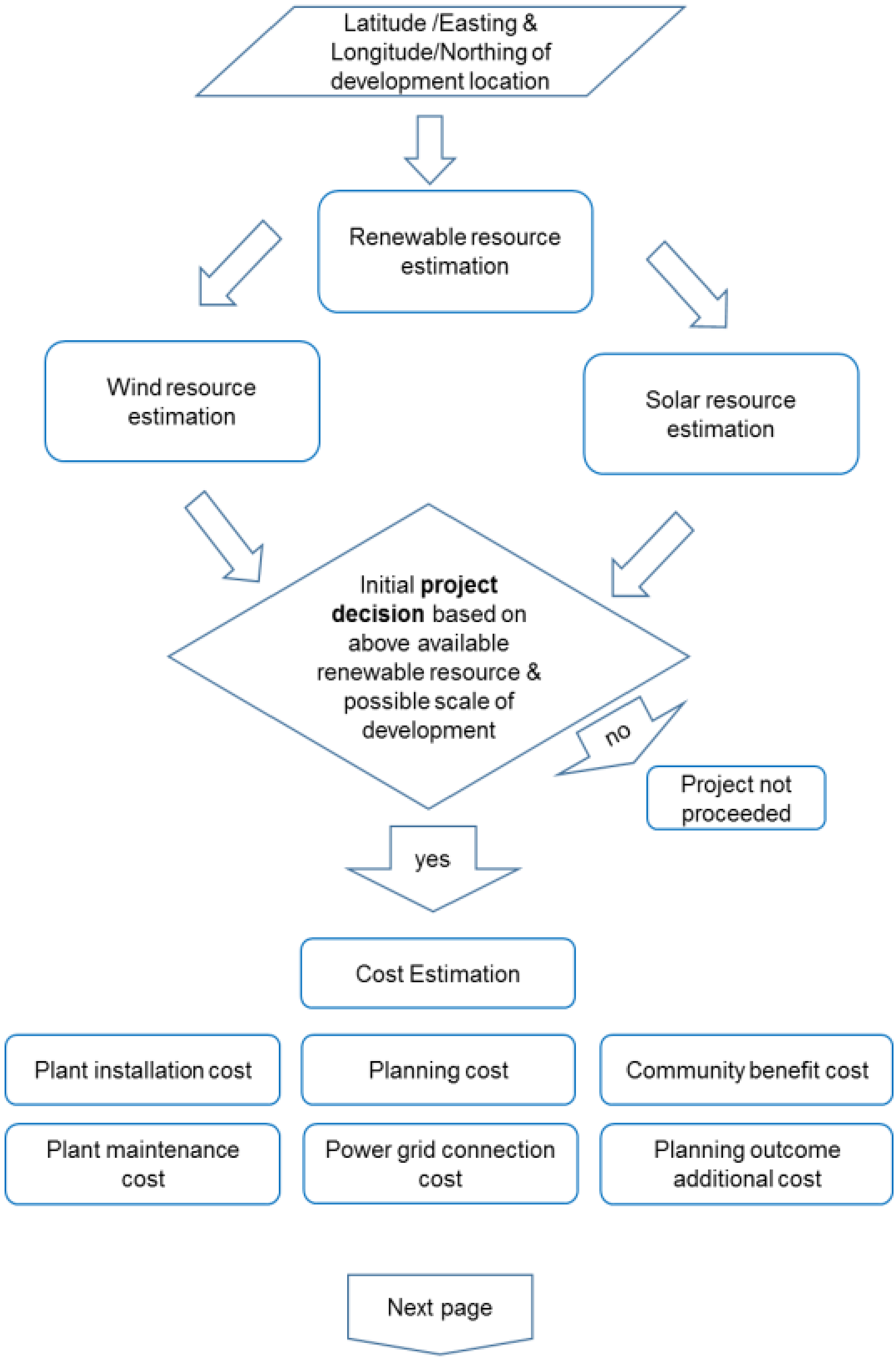
Figure 16 kernel density plot for propensity scores of control (Refused) and treatment (Operational)

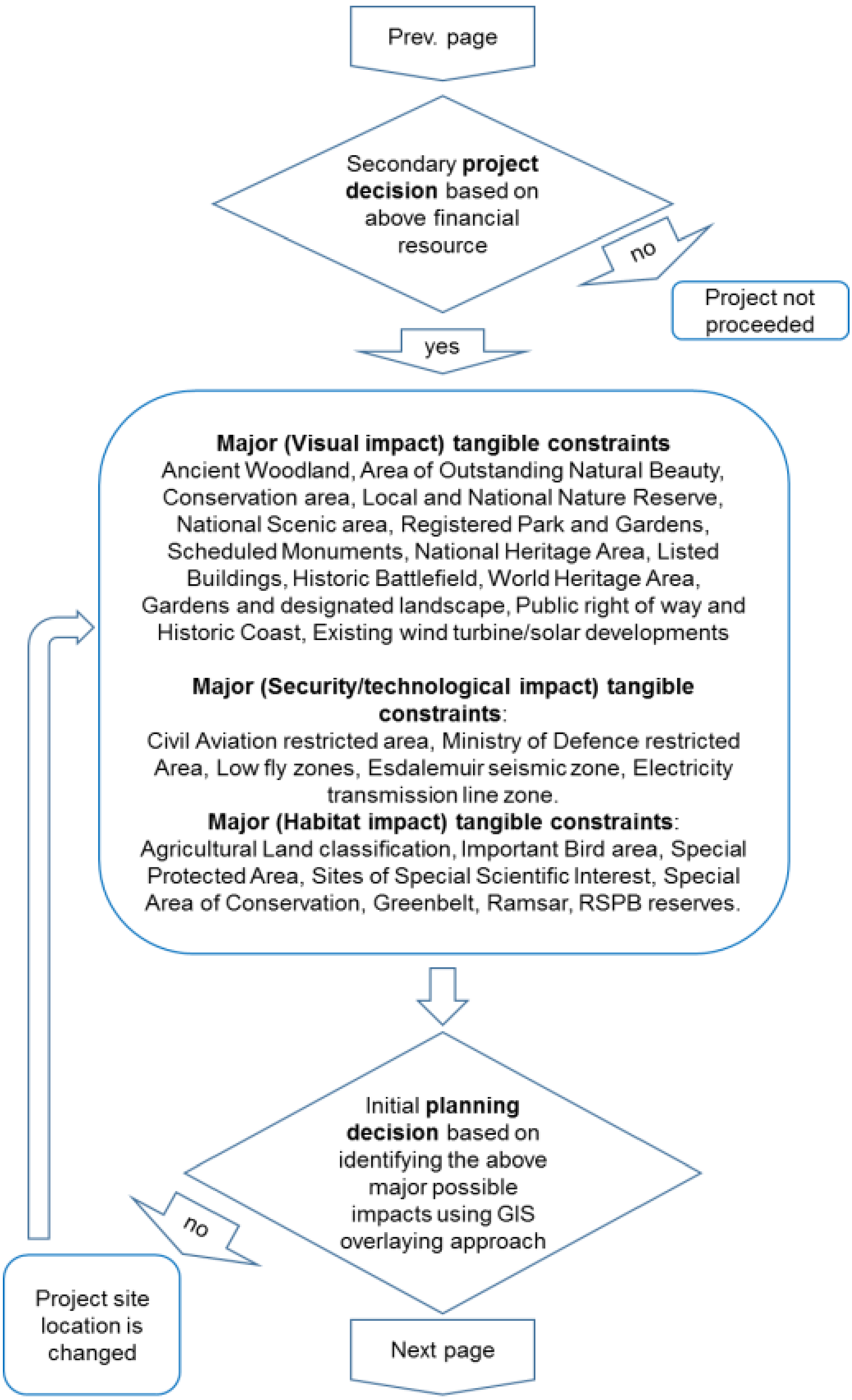
4.8 Renewable energy development planning framework

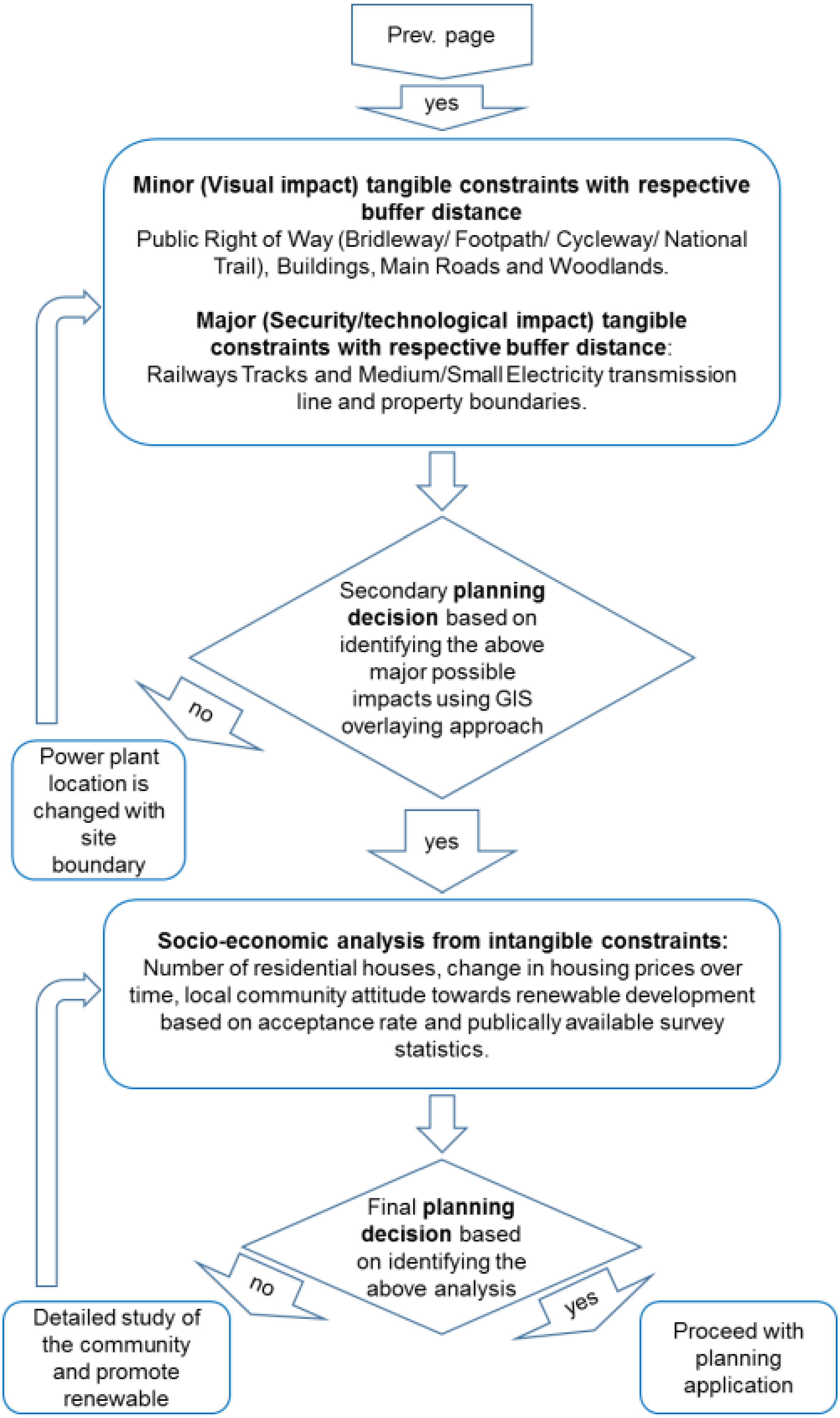
For any infrastructural development numerous assessments of the location must be carried out. However renewable infrastructures, particularly onshore WT developments are a source of on-going controversy at the local level and thus the planning process is highly involved. Within this context, one of the main aims of this research was to develop a GIS to account for both the physical and socio-economic constraints that must be accounted for when planning a renewable development. One of the main considerations in building the GIS was to ensure that the software was able to examine both wind and solar energy. However, it is important to note that this research thesis is focused on onshore wind developments alone. The next Section outlines the GIS process step-by-step.

Since this framework is based on a selected location, the available land area, geographical coordinates (i.e. Easting and Northing or Latitude and Longitude) is required. This allows to one to identify the location. This assessment uses NOABL wind speed dataset(NOABL 2015). Considering both resources in the assessment, the outcome and development scale based decision will be considered. The second planning assessment stage requires information on the development cost, planning cost, community benefit cost, plant maintenance cost, grid connection cost and post planning/pre-development cost. This involves experts from various fields including financial experts, solar/ wind installer and electricity grid assessors. The financial assessment provides initial decision of the development's financial feasibility. The overall located based planning framework is outlined in the following flowchart.

Location based Planning Framework Flowchart




Prev. page
Secondary project decision based on above financial resource
no
Project not proceeded
yes
Major (Visual impact) tangible constraints
Ancient Woodland, Area of Outstanding Natural Beauty, Conservation area, Local and National Nature Reserve, National Scenic area, Registered Park and Gardens, Scheduled Monuments, National Heritage Area, Listed Buildings, Historic Battlefield, World Heritage Area, Gardens and designated landscape, Public right of way and Historic Coast, Existing wind turbine/solar developments
Major (Security/technological impact) tangible constraints:
Civil Aviation restricted area, Ministry of Defence restricted Area, Low fly zones, Esdalemuir seismic zone, Electricity transmission line zone.
Major (Habitat impact) tangible constraints:
Agricultural Land classification, Important Bird area, Special Protected Area, Sites of Special Scientific Interest, Special Area of Conservation, Greenbelt, Ramsar, RSPB reserves.
Initial planning decision based on identifying the above major possible impacts using GIS overlaying approach
no
Project site location is changed
Next page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yes
Minor (Visual impact) tangible constraints with respective buffer distance
Public Right of Way (Bridleway/ Footpath/ Cycleway/ National Trail), Buildings, Main Roads and Woodlands.
Major (Security/technological impact) tangible constraints with respective buffer distance:
Railways Tracks and Medium/Small Electricity transmission line and property boundaries.
Secondary planning decision based on identifying the above major possible impacts using GIS overlaying approach
no
Power plant location is changed with site boundary
yes
Socio-economic analysis from intangible constraints:
Number of residential houses, change in housing prices over time, local community attitude towards renewable development based on acceptance rate and publically available survey statistics.
Final planning decision based on identifying the above analysis
no
yes
Detailed study of the community and promote renewable
Proceed with planning application

If a positive financial outcome is identified, the planning process proceeds to an assessment of the major planning constraints (outlined in Section 3.6). The GIS developed as part of this research considers 24 out of the 30 planning constraints outlined in the chapter 3.6, including the Landscape, Historic, Ecology and MoD categories. A WT development must not be located within these major constraints. However, in some instances in which the development location is within any of the major constraints, the category of the constraints is considered. For example, if they are in historic and landscape category, zero of theoretical visibility (ZTV) assessment is considered to assess the level of visual impact using digital terrain datasets at different resolutions (i.e. Digital Terrain Model (DTM), Digital Elevation Model (DEM) and Light Detection and Ranging (LiDAR)). Based on the topography of the location, a WT development may be potentially hidden from these constraints and the planning process is allowed to further. If ecological constraints are identified, relocation of development site to nearest land without ecological constraints is considered.

Potential developments without any of these constraints proceed to a secondary GIS assessment, and buffer distances to constraints are analysed. to consider buffer distances. The distances vary depending on the local authority and their planning standards. Table 13 outlines the different buffer distance to be considered for wind turbine developments from residential properties.

Table 13 Buffer distance required between WT development and residential properties.

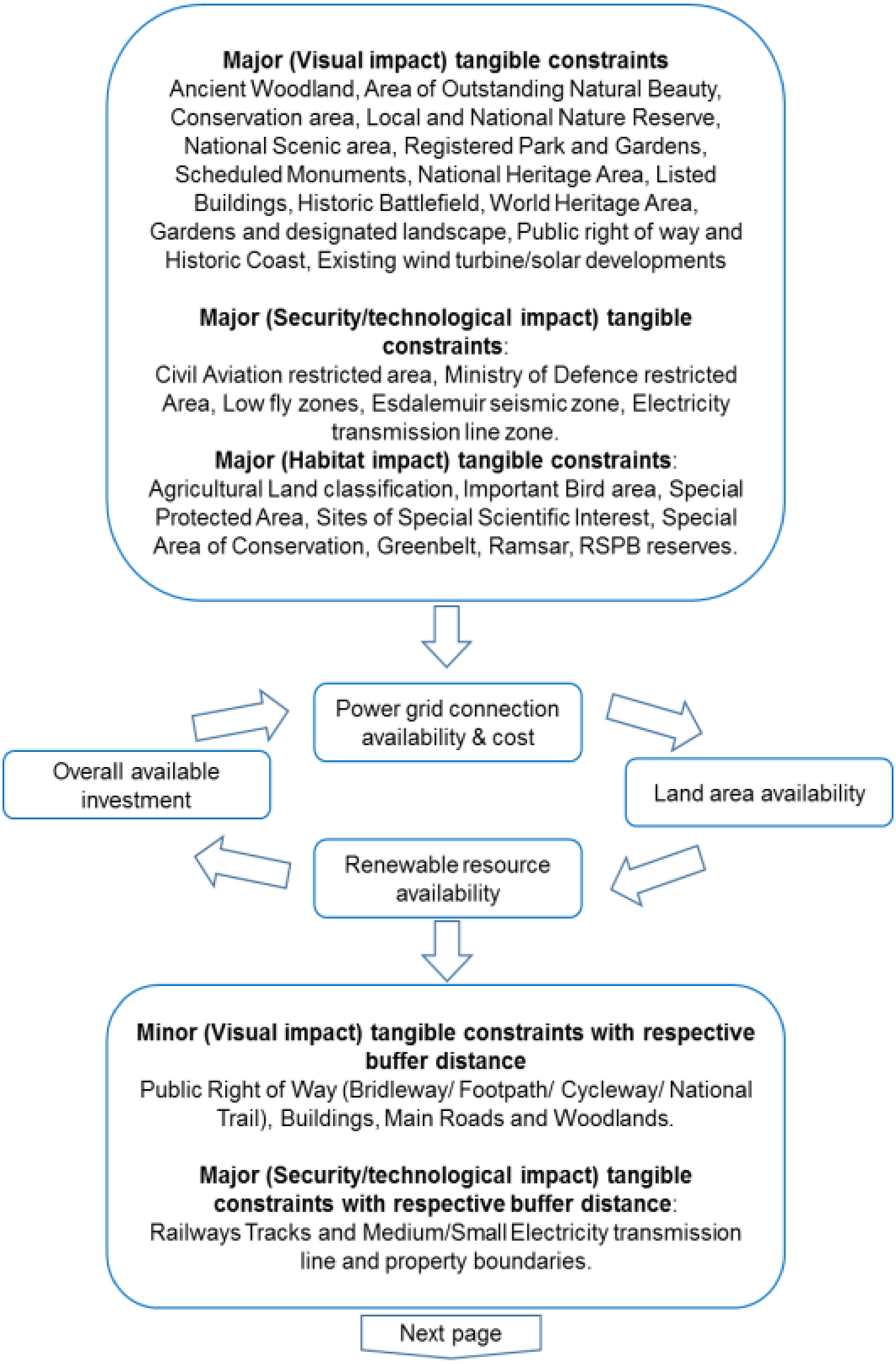
Location/ Planning Authority	Distance	Details
Welsh Assembly	500m	Technical Advice Note 8: Renewable Energy sets out a typical separation distance between turbines and residential property. Flexible approach, and can be refined by LPA
Northern Ireland	10 times rotor radius	Planning Policy Statement: Related to wind farm development proximity to occupied dwellings. Noise related.
Cherwell District Council	800m	Informal planning guidance Recommends separation distances between turbines and settlements/dwellings, based on amenity and other issues such as landscape, noise, heritage, safety and shadow flicker.
Lincolnshire County Council	700m (2Km if there is noise issue)	Wind Energy Position Statement: Distance from residential properties. The county council is not the planning authority.
Wilshire Council	Sliding scale up to 3Km	Policy text within the Wilshire Core Strategy Submission Draft. Sliding scale based on distance from residential property.
Scottish Planning Policy	2Km	Guidance refers to strategic search areas for wind and relates to settlements

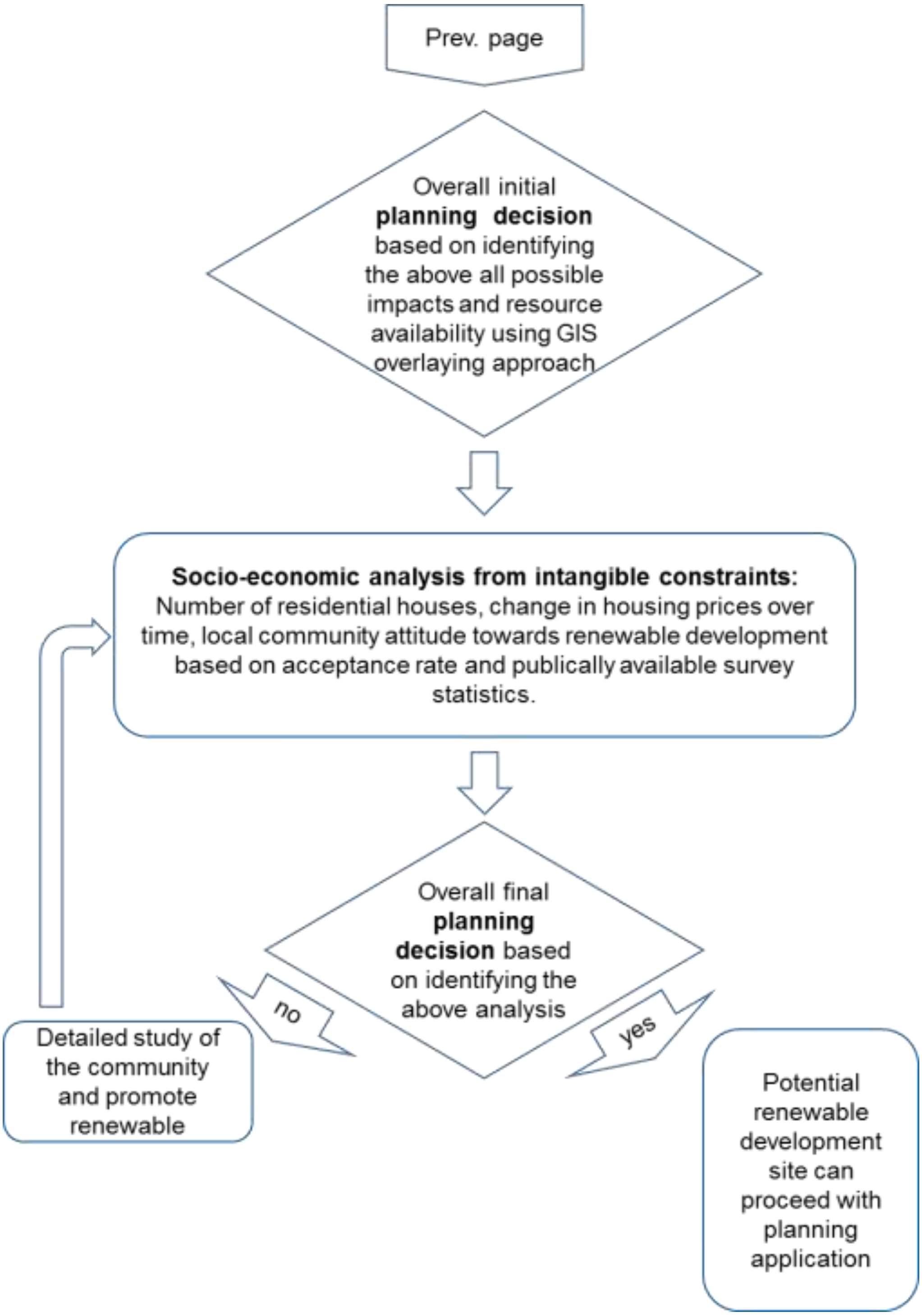
After considering the buffer distances, the development will be micro-sited within the development land boundary, and ZTV will additionally be considered to verify if the topography hides the constraints. The location of electricity transmission lines or railway tracks within the area requires relocating the development.

Large-scale developments need to consider impact radius based on the local authority suggestion and national planning framework regulation. The GIS considers the impact radius at the OA, LSOA and MSOA level. The weighting factor methodology detailed in chapter 4.6 is implemented and assigned to each development to provide appropriate population weights. The GIS allows a brief or detailed assessment depending on the requirements of the planners and developers and the socio-economic component of the GIS can provide insights on the impact of a development to the community.

To GIS therefore can identify potential renewable development locations across England considering the considering 24 major planning constraints, electricity grid availability, development area availability, renewable resource availability and the financial investment required. Meeting the commercial requirements of the project, the GIS is available as both a web-based and desktop application. The methodology of the implementation is detailed in Section 4.9. The identification of potential renewable development sites framework is outlined in following flowchart.

Identifying potential renewable development sites framework flowchart




Prev. page
Overall initial **planning decision** based on identifying the above all possible impacts and resource availability using GIS overlaying approach
Socio-economic analysis from intangible constraints: Number of residential houses, change in housing prices over time, local community attitude towards renewable development based on acceptance rate and publically available survey statistics.
Overall final **planning decision** based on identifying the above analysis
no
yes
Detailed study of the community and promote renewable
Potential renewable development site can proceed with planning application

4.9 Building the GIS system

Towards implementing the location based planning framework and identifying potential renewable development sites the following criterions are considered:

- Planning constraints database are updated by various agencies at different frequencies.
- The database of planning constraints must be updated manually from the sources allowing planners include additional useful information they gathered from planning experiences from different planning authorities.
- The user interface for updating the constraints database should not be different for the using the constraints for planning interface.
- The planning constraints for specific planning must be available both offline and online.
- The constraints database must be shareable among other planners involved in the planning.

The constraints database was centralized and kept as a common GIS format file (shapefile-vector, asc and .tiff-raster) allowing users to update them with open source GIS software. QGIS open source software was used to underpin the desktop GIS system. To build the centralized database, the 30 planning constraints outlines in Section 3.6 were gathered. Spreadsheet document containing the information of these database including, website address, provided format, update frequency and last downloaded date was created and maintaining for future updates. All the collected planning constraints in GIS format were processed for errors and required corrections were applied. These constraints are then geo-referenced to local authority, county and region boundaries from the ONS website. The constraints are further processed into same spatial projection used in England, commonly known as Ordnance Survey National Grid (OSGB) converting latitude, longitude into easting and northing.

Towards managing the size of the data in the planning constraints, they were split by clipping them based on their county boundaries. County planning constraints database were created and incorporated all the 30 planning constraints. If the planning development is in the borders of the county were addressed by increasing the boundaries of the county by 5km. To achieve uniformity in the appearance of the planning constraints in the GIS system, a standard style setting was created for each constraint and their respective attributes. Python scripting QGIS project file was created for each of the 152 counties in England applying the standard style and categories of the planning constraints. The county planning constraints database is used for to identify potential renewable development location framework.

To develop the web-based GIS system, duplicate County planning constraints database was created. This duplicate database is connected to the original database using a two-way sync method. The web-based GIS system required more complex approach as the data size must be at minimum to reduce rendering time without losing vital information. User account based web development was considered which retains the data created and modified by the user with a default time period of 1 year. Entering the coordinates or address of the potential WT development location, one can zoom in on the map and click the centre of the development site or draw the boundary of the development site. On confirming the selection their screen will provide an information of the time required by the website to process the required constraints within their assessment area.

The development of the GIS from the server side begun with collecting coordinates, assessment distance and boundary of the development (if provided) from the user. The process involves analysing the area and its boundary identifying the country, region, county area and local authority. This analysis involves resolving issues when the development share boundaries or the assessment area is distributed between two countries. The outcome from this process is a polygon file, which is clipped and contains information on the respective county ONS code. This clipper using ogr2ogr clip function from Geospatial Data Abstraction library(GDAL)clips all the planning constraints from the duplicate county planning database using the ONS county code. These clipped vector files are re-projected into a web Mercator projection commonly used in web-based mapping applications, converted into SQL database file and uploaded onto the server. Once uploaded the predefined styles were applied to the constraints based on their type. On completion of this process an email would is sent to the user allowing them to directly view the constraints on their browser.

5 ANALYSIS

5.1 Introduction

Renewable energy development such as wind farms is one of the keys solutions for a sustainable future. Though it has the technical favourability of utilizing high winds in England, it was facing high refusal from public on individual development basis resulting in lower rate of deployment of these renewable developments. As scope of this research is to increase the efficiency of planning process in renewable energy sector specially in onshore wind turbine development, with no development have been approved or being under consideration for future development (based on REPD database), it is necessary to understand possible cause of this current state.

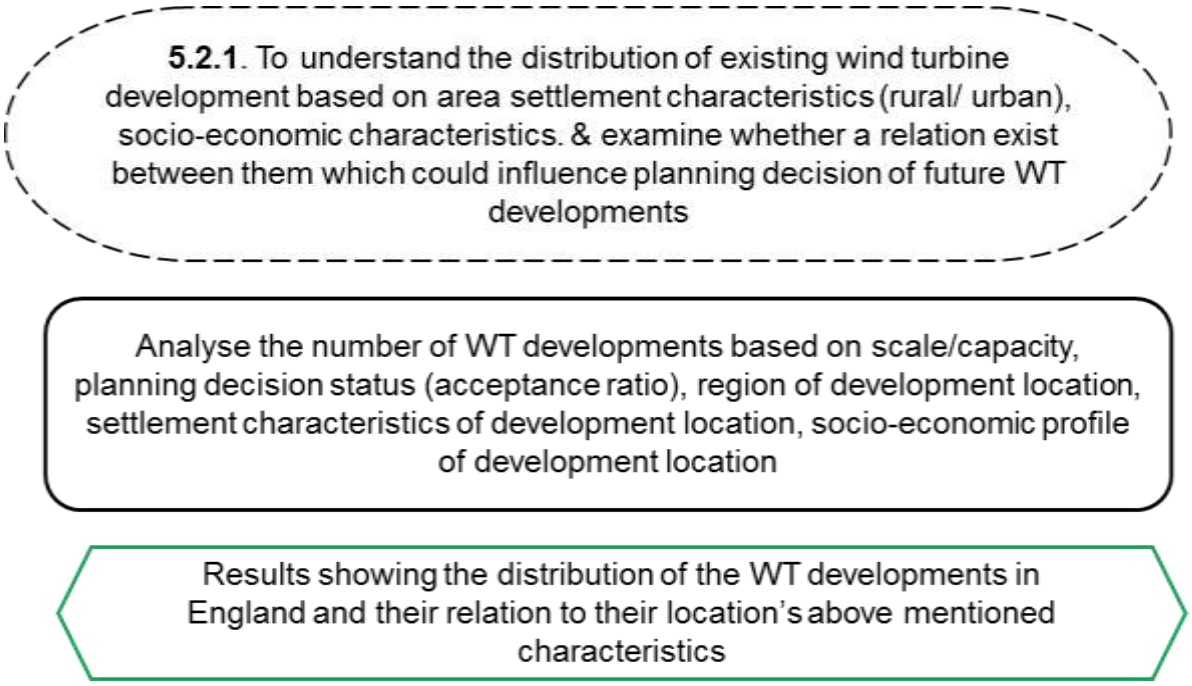
The impacts of developments in renewable energy are often projected through the reduction in greenhouse gas and dependability on fossil fuels. However, developments in the renewable sector will also have impacts on the economy and societal welfare these wider socio-economic impacts are usually not projected. Socio-economic impact assessments (SEAI) are sometime found in large scale wind turbine development as part of planning application projecting the positive impacts the proposed development could bring to the local community often biased by the developers but, no research or literature study empirically shows long term socio-economic impacts that have been caused by existing operational developments. This leads to an important gap in the literature on the socio-economic impact of renewable energy development. In this research, we consider this gap as the fundamental issue and the cause of public’s negative perception increasing refusals of these developments.

Towards addressing this gap, a novel attempt has been made to quantitatively assess the socio-economic impact of existing wind turbine development in England. The impacts of these developments are geographically diverse and include national level, community level and individual level impacts. Towards assessing these impacts, distribution of the existing wind turbine is studied relating scale of these developments and their planning decisions to their location's spatial & socio-economical characteristics by testing the following research questions:

1. Does scale of the wind turbine development have an impact on planning decision?
2. Does wind turbine developments are favoured in particular regions of England?
3. Does location's physical characteristics (i.e. type of area[rural/urban] have any influence on the planning decision of these developments?
4. Does location's socio-economical profile (i.e. type of area[rural/urban]), scale of the development and time period of development have any influence on the planning decision of these developments?
5. Does wind turbine developments are often located in deprived areas?
6. Does wind turbine development bring long term socio-economical changes to their surrounding areas?

In section 5.2 we are answering the above research questions by examining the relation between the spatial and socio-economical profile of these onshore wind turbines development location and further assessing the socio-economical changes these developments would have contributed to their surrounding areas using an Robust onshore wind turbine database, spatial boundary database (OA, LSOA, County, Region, Local Authority),Mid-year population estimates database, Index of multiple deprivation database and methodologies including weighted average, propensity score matching and various GIS techniques (clipping, merging, generating centroid from polygon, adding polygon attributes to points inside them, counting points inside polygons, measuring areas of polygon within clipping area). The following flowchart 3, shows each sub-section aim, approach and expected outcomes of the section 5.2 in this chapter.

Flowchart 3 Overall aim, approach and expected outcomes from Section 5.2



5.2.2. To examine whether there exist a significant impact of the WT development to it's surrounding area through socio-economic perspective using Index of multiple deprivation score as measurement.

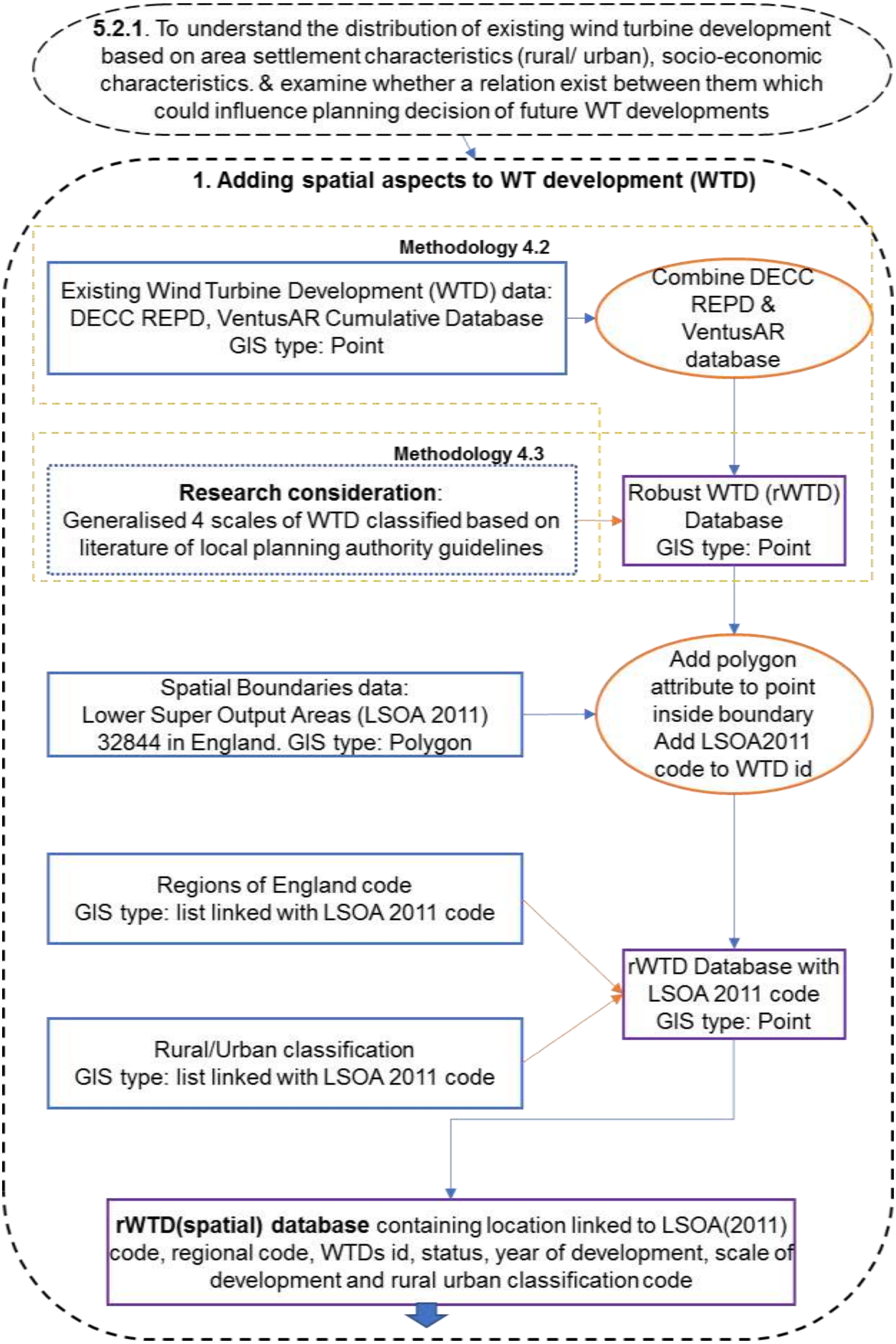
B.1 analysing socio-economic impact of **operational WT** developments on its **surrounding area** (LSOAs within 2Km) based on **capacity/scale using before & after approach on IMD scores in percentile**

B.2 analysing socio-economic impact of **operational WT** developments on its **surrounding area** by **comparing** them to **similar spatial & socio-economic** profiled area **with no WT** developments using before & after approach on IMD scores in percentile

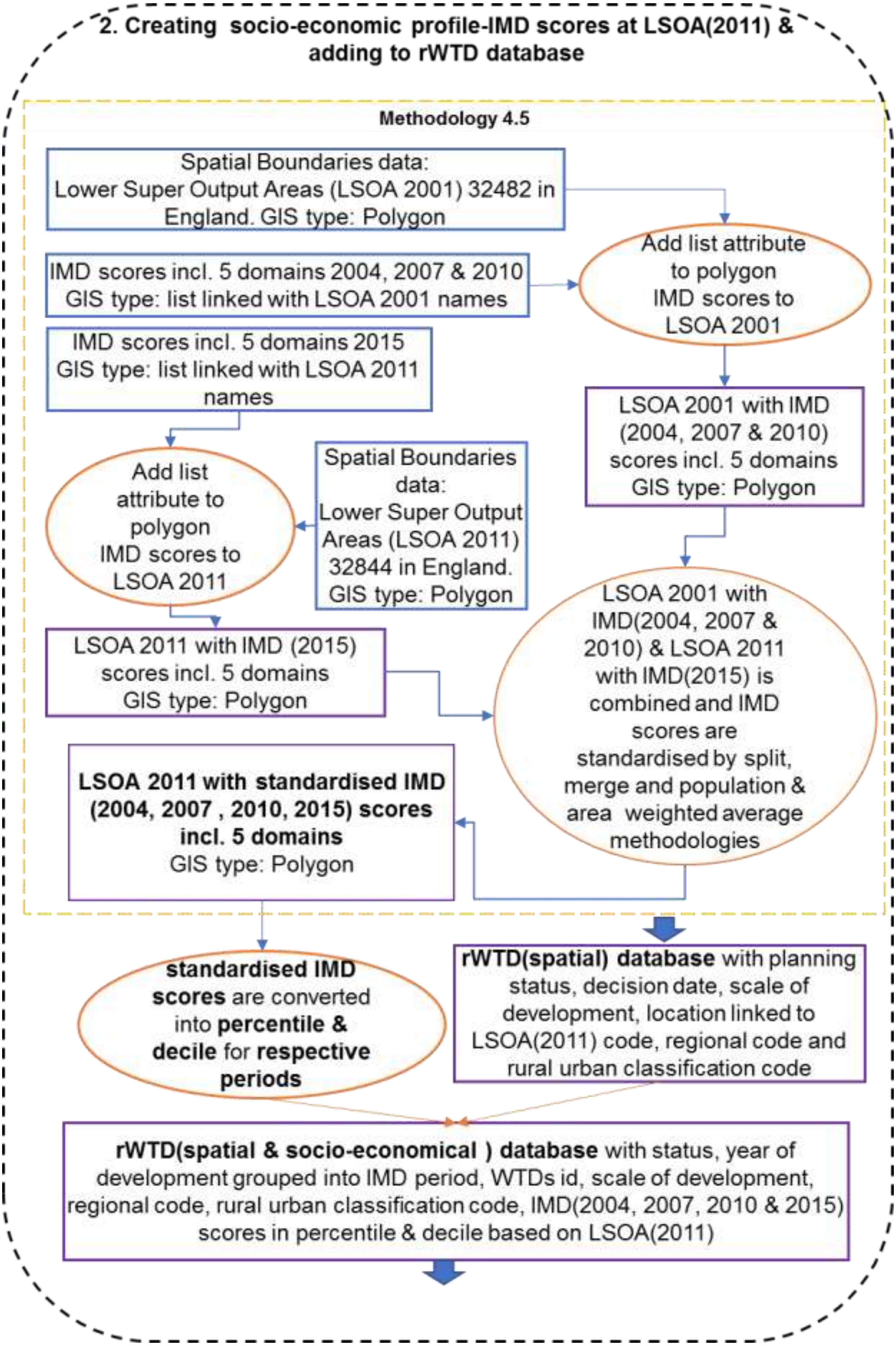
B.3 analysing socio-economic impact of **operational WT** developments on its **surrounding area** by **comparing** them to **similar capacity/scale refused WT** development's **surrounding area** using before & after approach on IMD scores in percentile

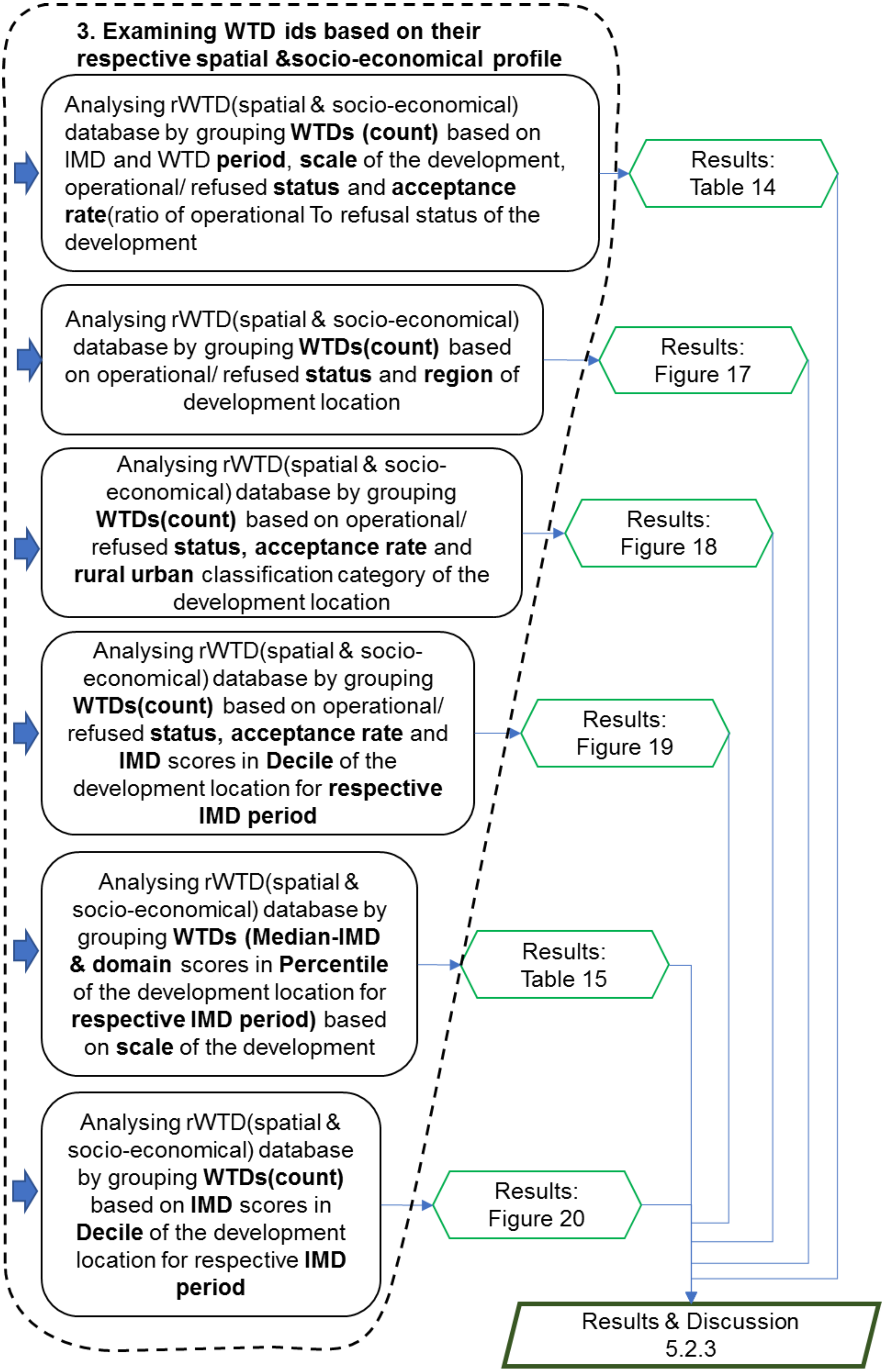
B.4 analysing socio-economic impact of **operational WT** developments on its **surrounding area** by **comparing** them to **similar capacity/scale refused WT** development's **surrounding area** using control impact approach on IMD scores in percentile

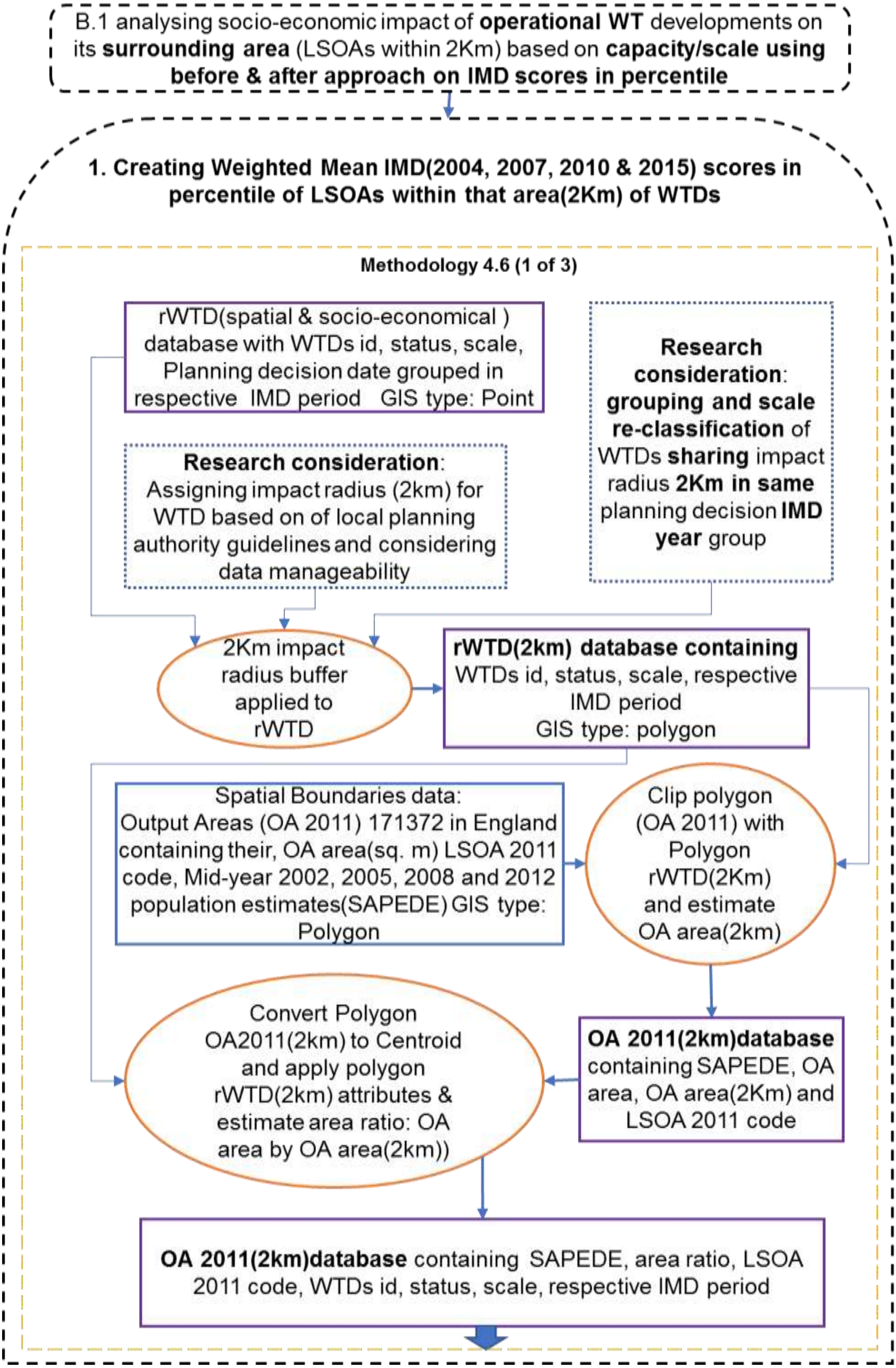
Results showing whether WT developments bring socio-economical changes to its surrounding and to what extent these change have occured.

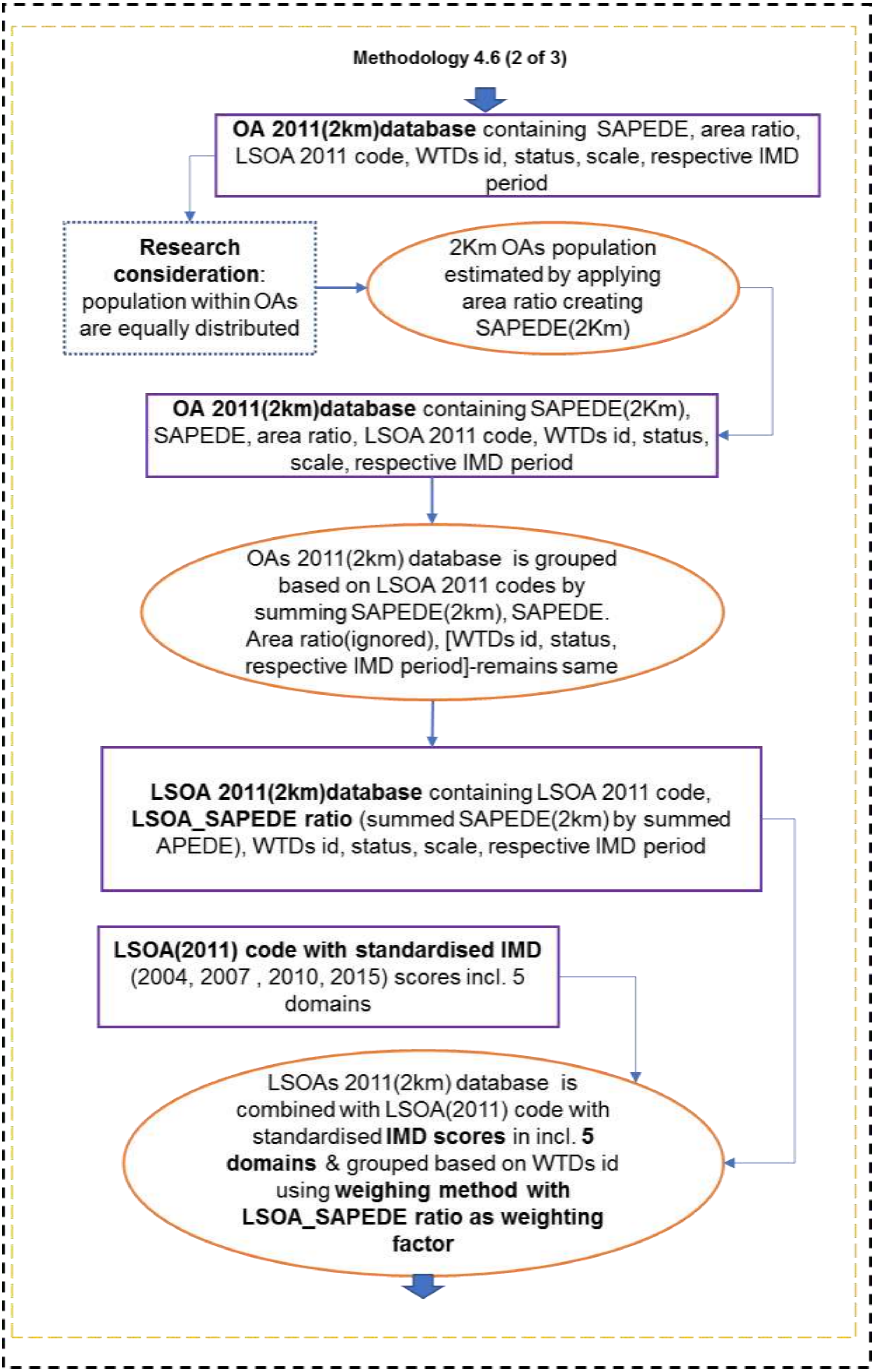


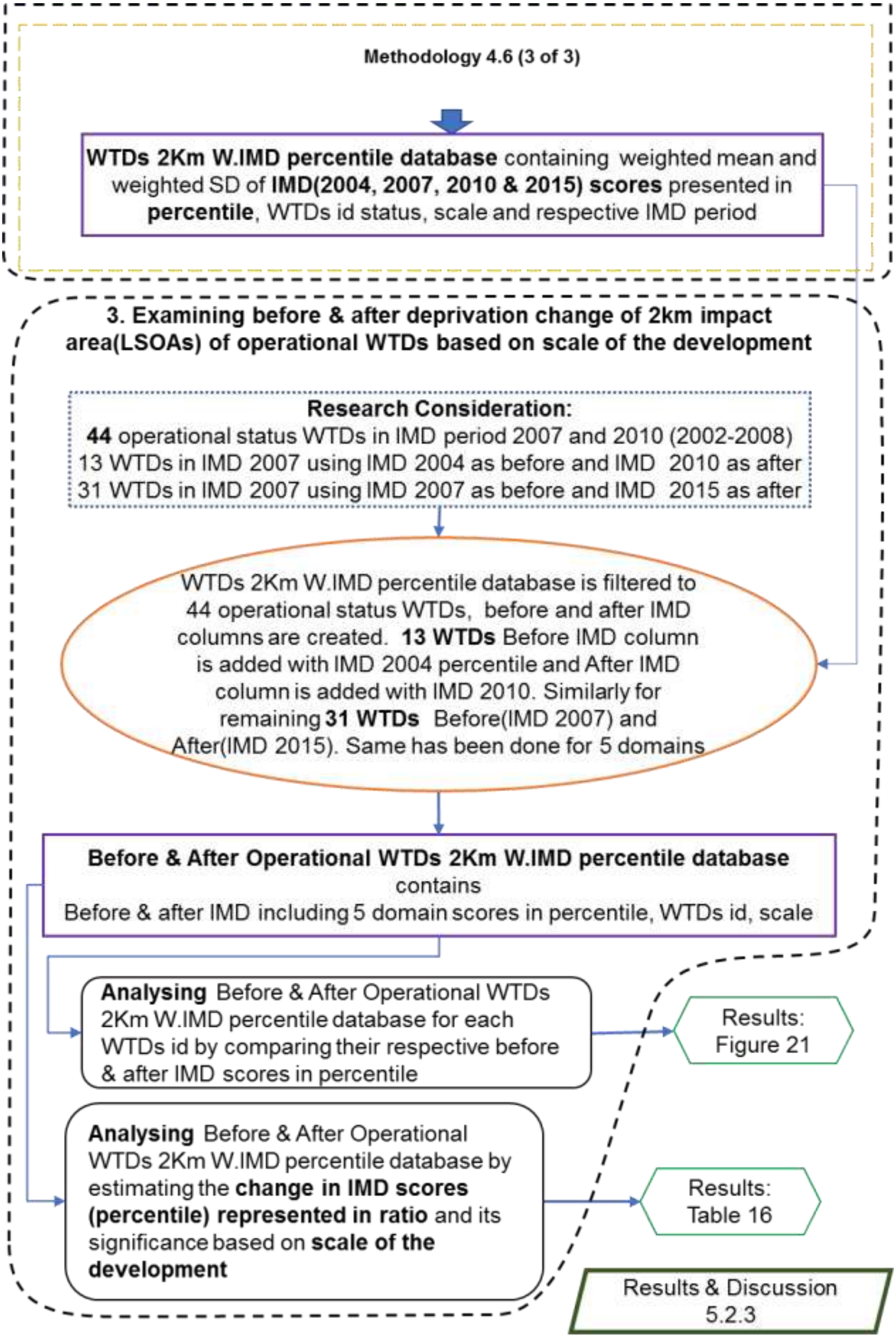
5.2.1. To understand the distribution of existing wind turbine development based on area settlement characteristics (rural/ urban), socio-economic characteristics. & examine whether a relation exist between them which could influence planning decision of future WT developments
1. Adding spatial aspects to WT development (WTD)
Methodology 4.2
Existing Wind Turbine Development (WTD) data: DECC REPD, VentusAR Cumulative Database GIS type: Point
Combine DECC REPD & VentusAR database
Methodology 4.3
Research consideration: Generalised 4 scales of WTD classified based on literature of local planning authority guidelines
Robust WTD (rWTD) Database GIS type: Point
Spatial Boundaries data: Lower Super Output Areas (LSOA 2011) 32844 in England. GIS type: Polygon
Add polygon attribute to point inside boundary Add LSOA2011 code to WTD id
Regions of England code GIS type: list linked with LSOA 2011 code
rWTD Database with LSOA 2011 code GIS type: Point
Rural/Urban classification GIS type: list linked with LSOA 2011 code
rWTD(spatial) database containing location linked to LSOA(2011) code, regional code, WTDs id, status, year of development, scale of development and rural urban classification code

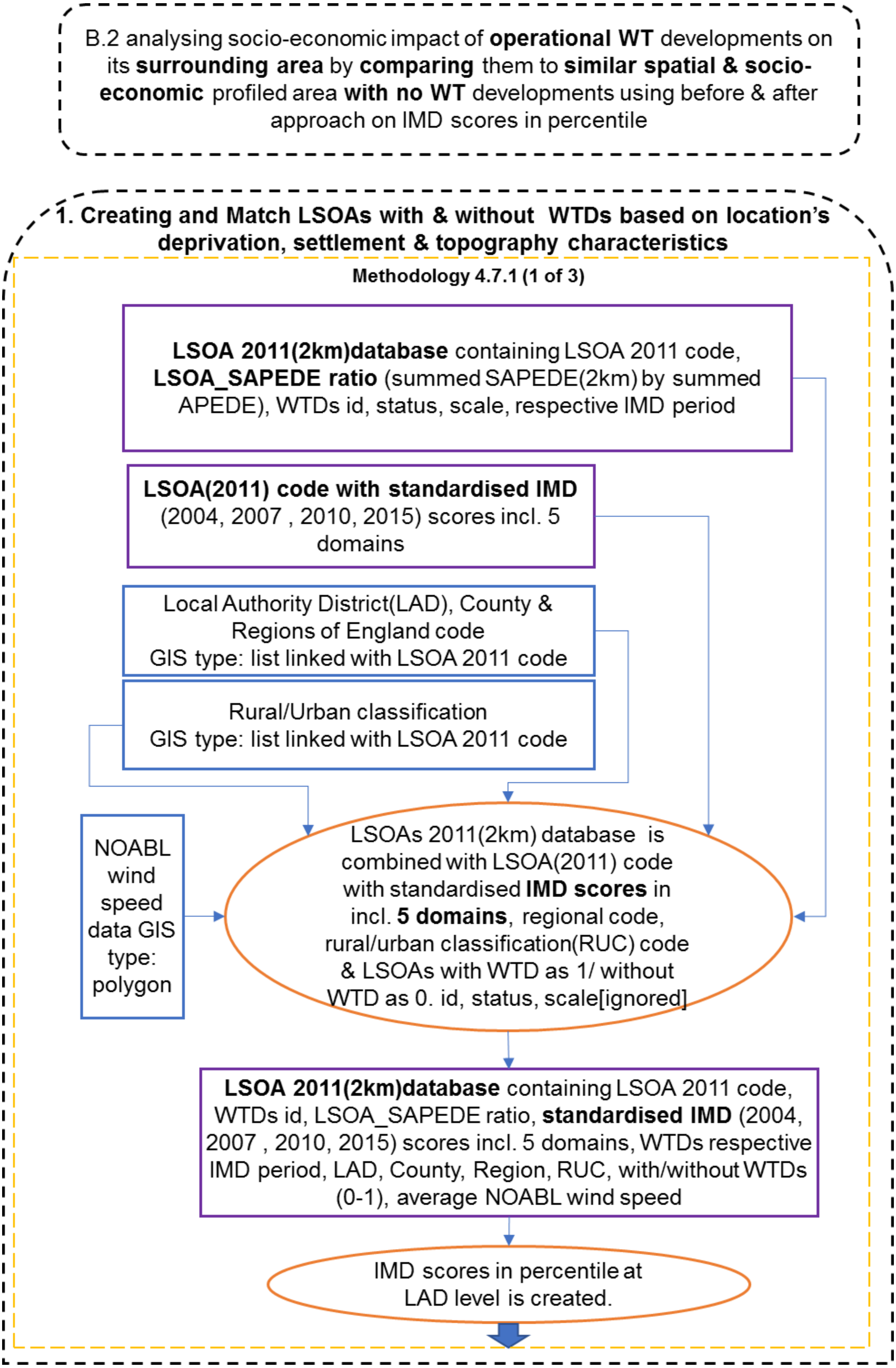

2. Creating socio-economic profile-IMD scores at LSOA(2011) & adding to rWTD database
Methodology 4.5
Spatial Boundaries data: Lower Super Output Areas (LSOA 2001) 32482 in England. GIS type: Polygon
IMD scores incl. 5 domains 2004, 2007 & 2010 GIS type: list linked with LSOA 2001 names
Add list attribute to polygon IMD scores to LSOA 2001
IMD scores incl. 5 domains 2015 GIS type: list linked with LSOA 2011 names
LSOA 2001 with IMD (2004, 2007 & 2010) scores incl. 5 domains GIS type: Polygon
Add list attribute to polygon IMD scores to LSOA 2011
Spatial Boundaries data: Lower Super Output Areas (LSOA 2011) 32844 in England. GIS type: Polygon
LSOA 2001 with IMD(2004, 2007 & 2010) & LSOA 2011 with IMD(2015) is combined and IMD scores are standardised by split, merge and population & area weighted average methodologies
LSOA 2011 with IMD (2015) scores incl. 5 domains GIS type: Polygon
LSOA 2011 with standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains GIS type: Polygon
standardised IMD scores are converted into percentile & decile for respective periods
rWTD(spatial) database with planning status, decision date, scale of development, location linked to LSOA(2011) code, regional code and rural urban classification code
rWTD(spatial & socio-economical) database with status, year of development grouped into IMD period, WTDs id, scale of development, regional code, rural urban classification code, IMD(2004, 2007, 2010 & 2015) scores in percentile & decile based on LSOA(2011)

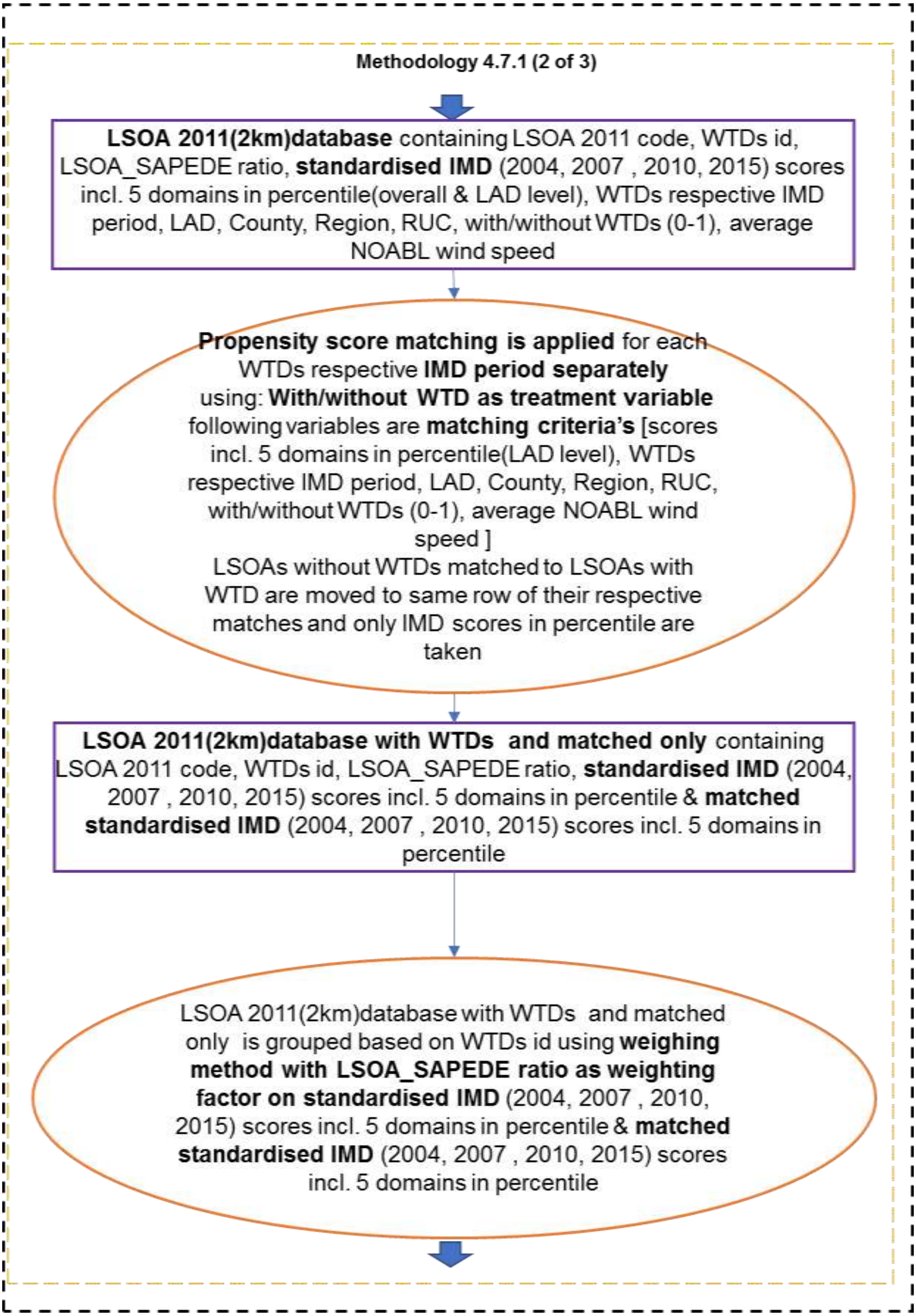

3. Examining WTD ids based on their respective spatial &socio-economical profile
Analysing rWTD(spatial & socio-economical) database by grouping WTDs (count) based on IMD and WTD period, scale of the development, operational/ refused status and acceptance rate(ratio of operational To refusal status of the development
Analysing rWTD(spatial & socio-economical) database by grouping WTDs(count) based on operational/ refused status and region of development location
Analysing rWTD(spatial & socio-economical) database by grouping WTDs(count) based on operational/ refused status, acceptance rate and rural urban classification category of the development location
Analysing rWTD(spatial & socio-economical) database by grouping WTDs(count) based on operational/ refused status, acceptance rate and IMD scores in Decile of the development location for respective IMD period
Analysing rWTD(spatial & socio-economical) database by grouping WTDs (Median-IMD & domain scores in Percentile of the development location for respective IMD period) based on scale of the development
Analysing rWTD(spatial & socio-economical) database by grouping WTDs(count) based on IMD scores in Decile of the development location for respective IMD period
Results: Table 14
Results: Figure 17
Results: Figure 18
Results: Figure 19
Results: Table 15
Results: Figure 20
Results & Discussion 5.2.3

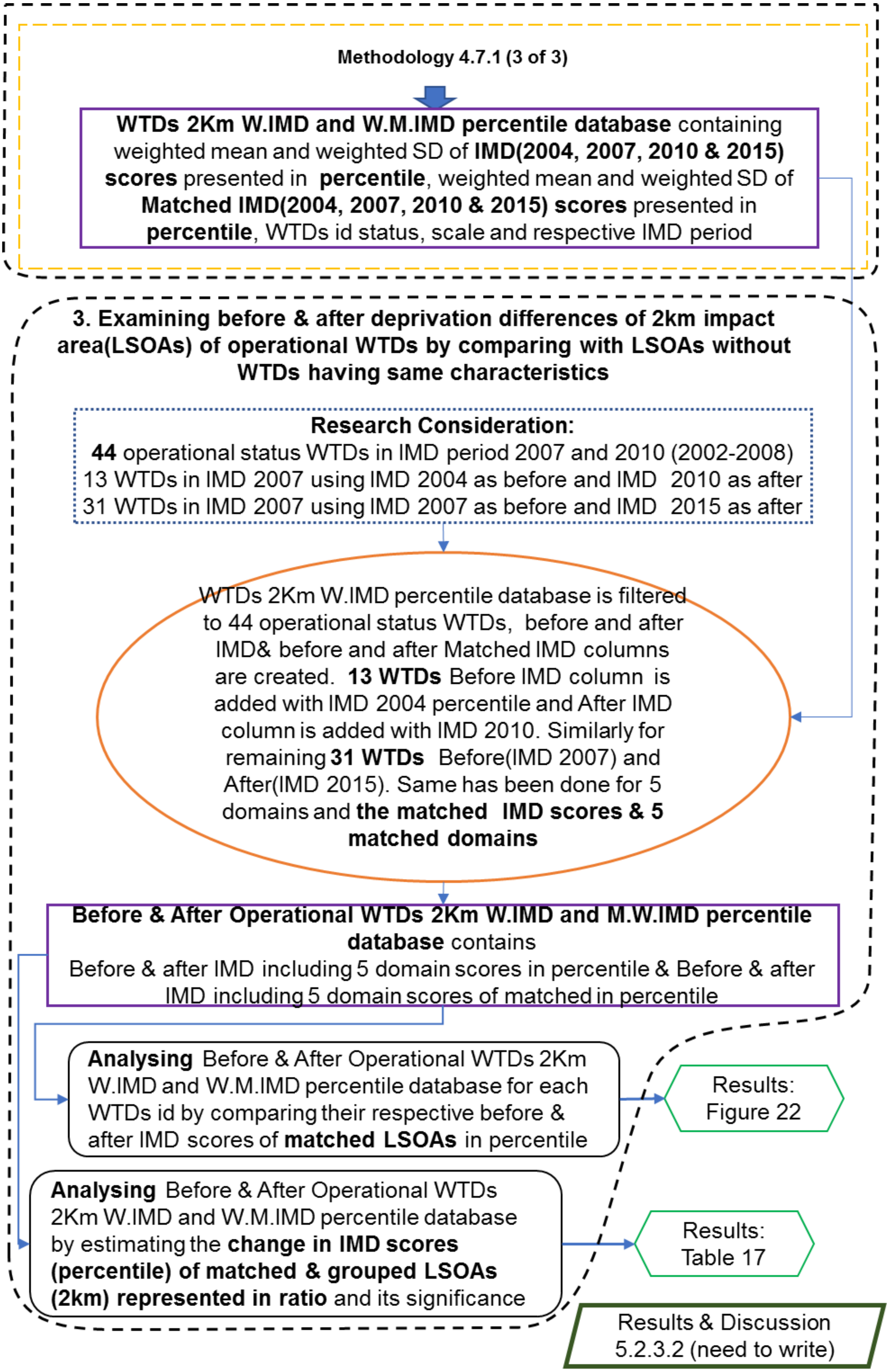

B.1 analysing socio-economic impact of **operational WT** developments on its **surrounding area** (LSOAs within 2Km) based on **capacity/scale using before & after approach on IMD scores in percentile**
1. Creating Weighted Mean IMD(2004, 2007, 2010 & 2015) scores in percentile of LSOAs within that area(2Km) of WTDs
Methodology 4.6 (1 of 3)
rWTD(spatial & socio-economical) database with WTDs id, status, scale, Planning decision date grouped in respective IMD period GIS type: Point
Research consideration: **grouping and scale re-classification** of WTDs **sharing** impact radius **2Km in same** planning decision **IMD year** group
Research consideration: Assigning impact radius (2km) for WTD based on of local planning authority guidelines and considering data manageability
2Km impact radius buffer applied to rWTD
rWTD(2km) database containing WTDs id, status, scale, respective IMD period GIS type: polygon
Spatial Boundaries data: Output Areas (OA 2011) 171372 in England containing their, OA area(sq. m) LSOA 2011 code, Mid-year 2002, 2005, 2008 and 2012 population estimates(SAPEDE) GIS type: Polygon
Clip polygon (OA 2011) with Polygon rWTD(2Km) and estimate OA area(2km)
Convert Polygon OA2011(2km) to Centroid and apply polygon rWTD(2km) attributes & estimate area ratio: OA area by OA area(2km))
OA 2011(2km)database containing SAPEDE, OA area, OA area(2Km) and LSOA 2011 code
OA 2011(2km)database containing SAPEDE, area ratio, LSOA 2011 code, WTDs id, status, scale, respective IMD period


Methodology 4.6 (2 of 3)
OA 2011(2km)database containing SAPEDE, area ratio, LSOA 2011 code, WTDs id, status, scale, respective IMD period
Research consideration: population within OAs are equally distributed
2Km OAs population estimated by applying area ratio creating SAPEDE(2Km)
OA 2011(2km)database containing SAPEDE(2Km), SAPEDE, area ratio, LSOA 2011 code, WTDs id, status, scale, respective IMD period
OAs 2011(2km) database is grouped based on LSOA 2011 codes by summing SAPEDE(2km), SAPEDE. Area ratio(ignored), [WTDs id, status, respective IMD period]-remains same
LSOA 2011(2km)database containing LSOA 2011 code, LSOA_SAPEDE ratio (summed SAPEDE(2km) by summed APEDE), WTDs id, status, scale, respective IMD period
LSOA(2011) code with standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains
LSOAs 2011(2km) database is combined with LSOA(2011) code with standardised IMD scores in incl. 5 domains & grouped based on WTDs id using weighing method with LSOA_SAPEDE ratio as weighting factor

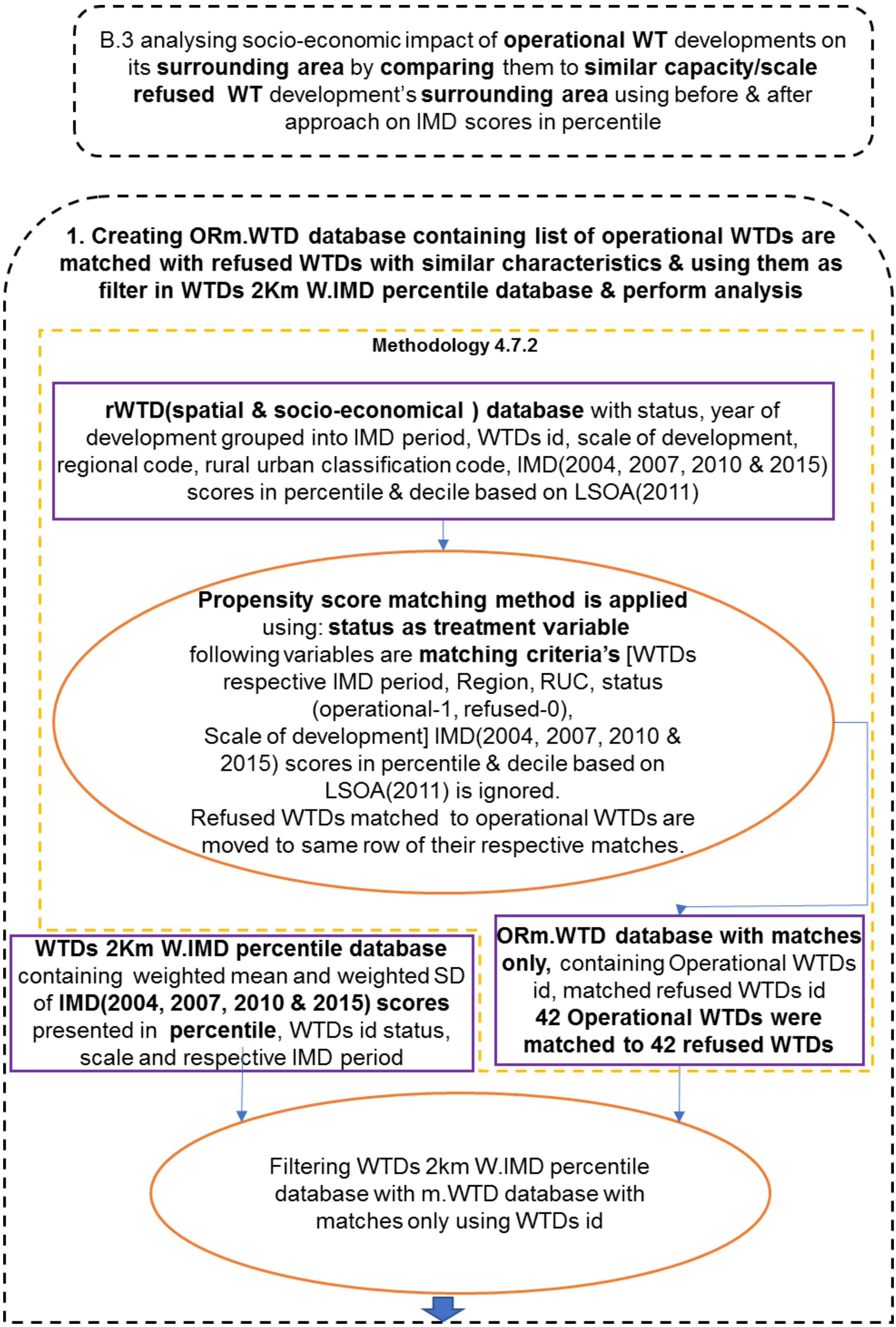

Methodology 4.6 (3 of 3)
WTDs 2Km W.IMD percentile database containing weighted mean and weighted SD of IMD(2004, 2007, 2010 & 2015) scores presented in percentile, WTDs id status, scale and respective IMD period
3. Examining before & after deprivation change of 2km impact area(LSOAs) of operational WTDs based on scale of the development
Research Consideration:
44 operational status WTDs in IMD period 2007 and 2010 (2002-2008)
13 WTDs in IMD 2007 using IMD 2004 as before and IMD 2010 as after
31 WTDs in IMD 2007 using IMD 2007 as before and IMD 2015 as after
WTDs 2Km W.IMD percentile database is filtered to 44 operational status WTDs, before and after IMD columns are created. 13 WTDs Before IMD column is added with IMD 2004 percentile and After IMD column is added with IMD 2010. Similarly for remaining 31 WTDs Before(IMD 2007) and After(IMD 2015). Same has been done for 5 domains
Before & After Operational WTDs 2Km W.IMD percentile database contains
Before & after IMD including 5 domain scores in percentile, WTDs id, scale
Analysing Before & After Operational WTDs 2Km W.IMD percentile database for each WTDs id by comparing their respective before & after IMD scores in percentile
Results: Figure 21
Analysing Before & After Operational WTDs 2Km W.IMD percentile database by estimating the change in IMD scores (percentile) represented in ratio and its significance based on scale of the development
Results: Table 16
Results & Discussion 5.2.3

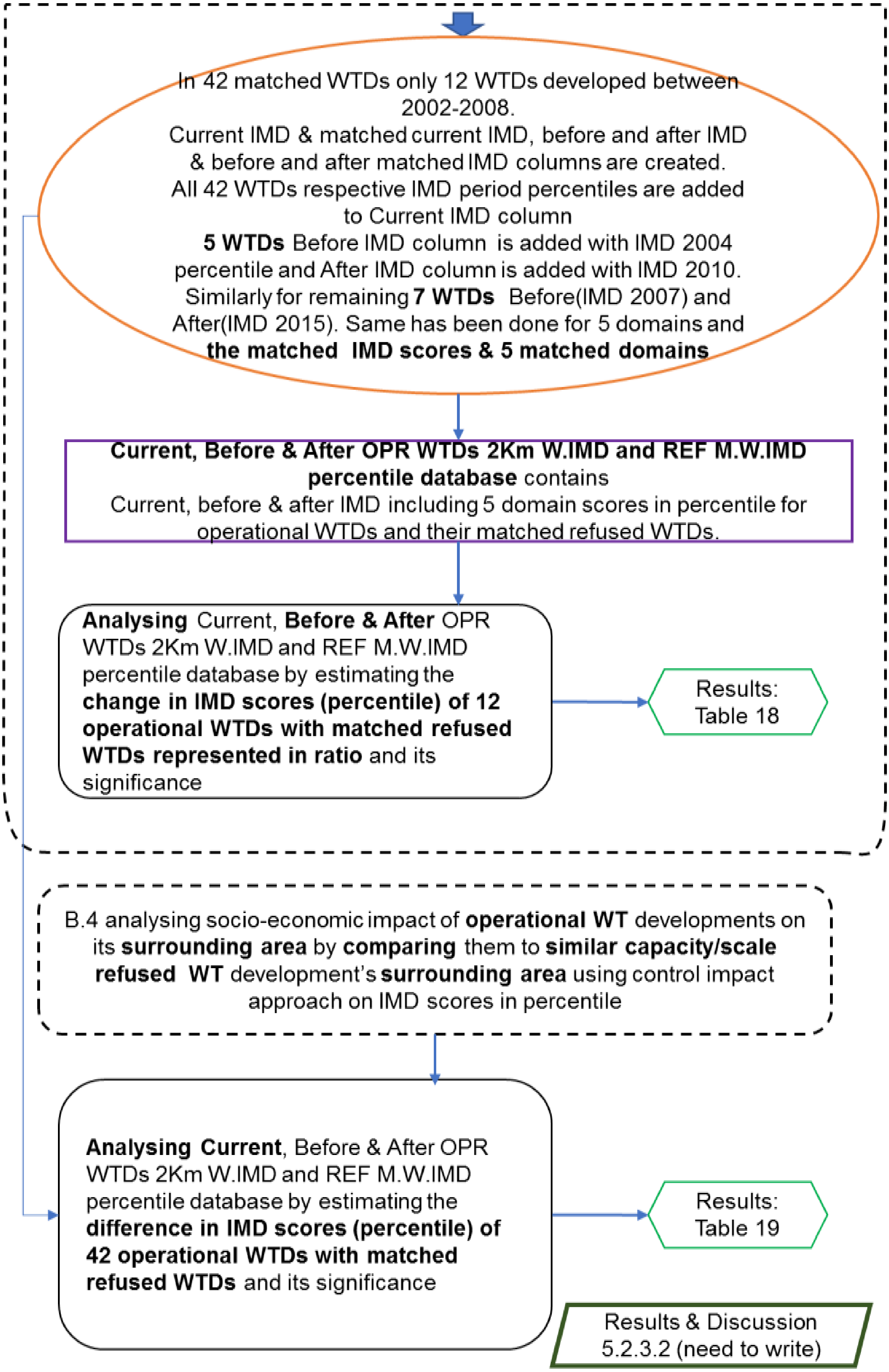

B.2 analysing socio-economic impact of **operational WT** developments on its **surrounding area** by **comparing** them to **similar spatial & socio-economic** profiled area **with no WT** developments using before & after approach on IMD scores in percentile
1. Creating and Match LSOAs with & without WTDs based on location's deprivation, settlement & topography characteristics
Methodology 4.7.1 (1 of 3)
LSOA 2011(2km)database containing LSOA 2011 code, **LSOA_SAPEDE ratio** (summed SAPEDE(2km) by summed APEDE), WTDs id, status, scale, respective IMD period
LSOA(2011) code with standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains
Local Authority District(LAD), County & Regions of England code GIS type: list linked with LSOA 2011 code
Rural/Urban classification GIS type: list linked with LSOA 2011 code
NOABL wind speed data GIS type: polygon
LSOAs 2011(2km) database is combined with LSOA(2011) code with standardised **IMD scores** in incl. **5 domains**, regional code, rural/urban classification(RUC) code & LSOAs with WTD as 1/ without WTD as 0. id, status, scale[ignored]
LSOA 2011(2km)database containing LSOA 2011 code, WTDs id, LSOA_SAPEDE ratio, **standardised IMD** (2004, 2007 , 2010, 2015) scores incl. 5 domains, WTDs respective IMD period, LAD, County, Region, RUC, with/without WTDs (0-1), average NOABL wind speed
IMD scores in percentile at LAD level is created.


Methodology 4.7.1 (2 of 3)
LSOA 2011(2km)database containing LSOA 2011 code, WTDs id, LSOA_SAPEDE ratio, standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains in percentile(overall & LAD level), WTDs respective IMD period, LAD, County, Region, RUC, with/without WTDs (0-1), average NOABL wind speed
Propensity score matching is applied for each WTDs respective IMD period separately using: With/without WTD as treatment variable following variables are matching criteria's [scores incl. 5 domains in percentile(LAD level), WTDs respective IMD period, LAD, County, Region, RUC, with/without WTDs (0-1), average NOABL wind speed]
LSOAs without WTDs matched to LSOAs with WTD are moved to same row of their respective matches and only IMD scores in percentile are taken
LSOA 2011(2km)database with WTDs and matched only containing LSOA 2011 code, WTDs id, LSOA_SAPEDE ratio, standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains in percentile & matched standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains in percentile
LSOA 2011(2km)database with WTDs and matched only is grouped based on WTDs id using weighing method with LSOA_SAPEDE ratio as weighting factor on standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains in percentile & matched standardised IMD (2004, 2007 , 2010, 2015) scores incl. 5 domains in percentile



Methodology 4.7.1 (3 of 3)
WTDs 2Km W.IMD and W.M.IMD percentile database containing weighted mean and weighted SD of IMD(2004, 2007, 2010 & 2015) scores presented in percentile, weighted mean and weighted SD of Matched IMD(2004, 2007, 2010 & 2015) scores presented in percentile, WTDs id status, scale and respective IMD period
3. Examining before & after deprivation differences of 2km impact area(LSOAs) of operational WTDs by comparing with LSOAs without WTDs having same characteristics
Research Consideration:
44 operational status WTDs in IMD period 2007 and 2010 (2002-2008)
13 WTDs in IMD 2007 using IMD 2004 as before and IMD 2010 as after
31 WTDs in IMD 2007 using IMD 2007 as before and IMD 2015 as after
WTDs 2Km W.IMD percentile database is filtered to 44 operational status WTDs, before and after IMD& before and after Matched IMD columns are created. 13 WTDs Before IMD column is added with IMD 2004 percentile and After IMD column is added with IMD 2010. Similarly for remaining 31 WTDs Before(IMD 2007) and After(IMD 2015). Same has been done for 5 domains and the matched IMD scores & 5 matched domains
Before & After Operational WTDs 2Km W.IMD and M.W.IMD percentile database contains
Before & after IMD including 5 domain scores in percentile & Before & after IMD including 5 domain scores of matched in percentile
Analysing Before & After Operational WTDs 2Km W.IMD and W.M.IMD percentile database for each WTDs id by comparing their respective before & after IMD scores of matched LSOAs in percentile
Results: Figure 22
Analysing Before & After Operational WTDs 2Km W.IMD and W.M.IMD percentile database by estimating the change in IMD scores (percentile) of matched & grouped LSOAs (2km) represented in ratio and its significance
Results: Table 17
Results & Discussion 5.2.3.2 (need to write)


B.3 analysing socio-economic impact of operational WT developments on its surrounding area by comparing them to similar capacity/scale refused WT development's surrounding area using before & after approach on IMD scores in percentile
1. Creating ORm.WTD database containing list of operational WTDs are matched with refused WTDs with similar characteristics & using them as filter in WTDs 2Km W.IMD percentile database & perform analysis
Methodology 4.7.2
rWTD(spatial & socio-economical) database with status, year of development grouped into IMD period, WTDs id, scale of development, regional code, rural urban classification code, IMD(2004, 2007, 2010 & 2015) scores in percentile & decile based on LSOA(2011)
Propensity score matching method is applied using: status as treatment variable following variables are matching criteria's [WTDs respective IMD period, Region, RUC, status (operational-1, refused-0), Scale of development] IMD(2004, 2007, 2010 & 2015) scores in percentile & decile based on LSOA(2011) is ignored. Refused WTDs matched to operational WTDs are moved to same row of their respective matches.
WTDs 2Km W.IMD percentile database containing weighted mean and weighted SD of IMD(2004, 2007, 2010 & 2015) scores presented in percentile, WTDs id status, scale and respective IMD period
ORm.WTD database with matches only, containing Operational WTDs id, matched refused WTDs id 42 Operational WTDs were matched to 42 refused WTDs
Filtering WTDs 2km W.IMD percentile database with m.WTD database with matches only using WTDs id



In 42 matched WTDs only 12 WTDs developed between 2002-2008.
Current IMD & matched current IMD, before and after IMD & before and after matched IMD columns are created.
All 42 WTDs respective IMD period percentiles are added to Current IMD column
5 WTDs Before IMD column is added with IMD 2004 percentile and After IMD column is added with IMD 2010.
Similarly for remaining 7 WTDs Before(IMD 2007) and After(IMD 2015). Same has been done for 5 domains and the matched IMD scores & 5 matched domains
Current, Before & After OPR WTDs 2Km W.IMD and REF M.W.IMD percentile database contains
Current, before & after IMD including 5 domain scores in percentile for operational WTDs and their matched refused WTDs.
Analysing Current, Before & After OPR WTDs 2Km W.IMD and REF M.W.IMD percentile database by estimating the change in IMD scores (percentile) of 12 operational WTDs with matched refused WTDs represented in ratio and its significance
Results: Table 18
B.4 analysing socio-economic impact of operational WT developments on its surrounding area by comparing them to similar capacity/scale refused WT development's surrounding area using control impact approach on IMD scores in percentile
Analysing Current, Before & After OPR WTDs 2Km W.IMD and REF M.W.IMD percentile database by estimating the difference in IMD scores (percentile) of 42 operational WTDs with matched refused WTDs and its significance
Results: Table 19
Results & Discussion 5.2.3.2 (need to write)

Section 5.3 provides an outline of many projects in which the developed GIS framework have been implemented by the industrial partner, Entrust Professional limited, from the period 2013 onwards.

5.2 Relating onshore wind turbine development and socio-economics through index of multiple deprivation

The Index of multiple deprivation (IMD) scores are a widely used index to represent the socio-economic deprivation of an area(Morrissey 2015). This allows policy makers to target populations and implement area-based development programmes in a more effective manner. The IMD for England has been used across a variety of cross sectional and longitudinal studies including the geographical analysis of socioeconomic factors in risk of domestic burn injury in London (Heng et al. 2015), the impact of area deprivation on parenting stress(Spijkers, Jansen and Reijneveld 2012), the impact of neighbouring deprivation on mortality(Zhang et al. 2011) and the impact of socioeconomic deprivation on the development of diabetic retinopathy (Low et al. 2015). With regard to environmental issues, Westling examined the impact of river restoration on the deprivation associated with that area (Westling et al. 2009).

The socioeconomic patterning of residential opportunities means that individuals that are constrained financially face limited choices of where to live, and are more likely to reside near major sources of pollution, including roads with high traffic density, industrial facilities, waste disposal facilities, or airports (Gunier 2003; Perlin 1999). A large literature on environmental justice has documented that large infrastructures are often co-located in areas of socioeconomic deprivation(Crocker and Lehmann 2013), (Higgs and Langford 2009), (Higginbotham et al. 2010, Crouse, Ross and Goldberg 2009). While wind turbines are not an environmental hazard the aim of this chapter is to assess whether wind turbines have been disproportionally located in deprived areas in England. Linking the IMD for England from 2000-2015, a further consideration will be the impact of wind turbines on levels of area deprivation over time. Does the locating of a wind turbine or set of wind turbines positively or negatively impact the level of deprivation in an area?

5.2.1 Examining the distribution of onshore wind turbine developments in England

To examine the spatial distribution of onshore wind turbine developments by area level deprivation scores, this Chapter will use the onshore wind turbine database created using the methodology outlined in chapter 4.2. This not only allows one to understand the distribution of wind turbine developments across England, but by mapping the distribution of their status of operationalized and refused at the planning stages, one can also gain insight on whether there is a socio-economic pattern to the acceptance/refusals of WT developments. Considering only onshore wind turbine developments, all onshore wind turbine developments mentioned in this thesis will be there forth referred as WT developments.

Initially each WT developments from the onshore wind turbine development database is categorised based on the classification of WT developments outline in chapter 4.3. Operational and refused wind turbine developments between

1992 and 2013 were considered for this analysis. The dataset contains 148 wind turbine developments that are operational in England, in which there are 21 category-a, 55 category-b and 72 category-c wind turbines. Similarly, there are 189 wind turbine developments, which have been refused, in which there are 25 category-a, 71 category-b and 93 category-c. These classified wind turbine developments are further grouped based on their operational year into 4 periods 1992-2001, 2002-2005, 2006-2008 and 2009-2013, allowed to link them with respective IMD data period for further analysis. The following table 14 detail the distribution of the operational and refused wind turbine developments from 192 to 2013 by their inter-IMD time period. the variables presented in this table are number of wind turbine developments, first column IMD and WT development period shows the 4 periods (2004,2007,2010,2015 & 1992-2013) the developments are grouped into these periods. Second column WT categories represents the scale of the developments into 3 classes (a-Single Turbine, b- 2-4 Turbines, c- 5and above turbines) the developments are grouped based on their scale. Third Column, Number of operational developments represents the count of development with respective scale which got successful planning permission and became operational between the respective IMD and WT development period. Forth Column, Number of refused developments represent the count of development with respective scale which got planning refused, never built whose planning decision was taken between the respective IMD and WT development period. Fifth column, Acceptance rate of development is represented as the ratio of difference between number of development which got planning permission to number of development which got planning refused by total number of development applied for planning permission (i.e. in period

2004 there was total 49 wind turbine development applied for planning permission while only 23 of them got permission to be built while, 26 being refused. The difference of 3 development is 6% of the total 49 developments, negative sign representing negative rate of acceptance.

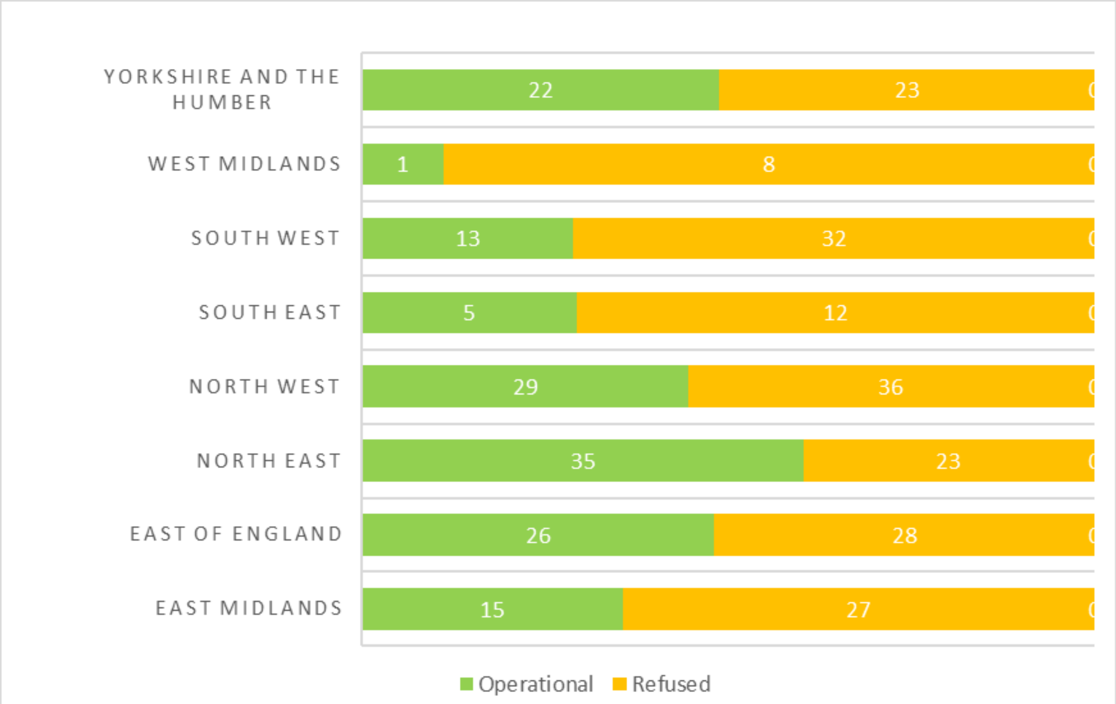
Table 14 Operational and refused wind turbine developments related to IMD period

IMD and WT development period	WT Categories	Number of operational development	Number of refused developments	Acceptance rate of development
2004 (1992-2001)	a	2	7	-56
	b	6	10	-25
	c	15	9	25
		23	**26**	**-6**
2007 (2002-2005)	a	6	6	0
	b	5	7	-17
	c	9	13	-18
		20	**26**	**-13**
2010 (2006-2008)	a	4	4	0
	b	16	8	33
	c	16	23	-18
		36	**35**	**1**
2015 (2009-2013)	a	9	8	6
	b	28	46	-24
	c	32	48	-20
		69	**102**	**-19**
1992-2013		**148**	**189**	**-12**

From table 14, one can see that the overall number of developments in England have increased from 1993 to 2013. It can be seen during the period 2006-2008 there were as positive acceptance of category b (2-4 turbines) wind turbine developments. However, acceptance rates rapidly declined in the following years.

Large-scale category c developments (more than 5 turbines) have seen positive acceptance during early 2000s, which also steadily reduced in following years. Only category A (single turbine) developments have a positive trend in acceptance in England from the early 2000s onwards.

To study the acceptance of these developments spatially, both operational and refused wind turbine developments were grouped based on their respective region of development. The following figure shows the distribution of these developments in the 8 regions of England excluding London, which have only 2 wind turbine developments (category a & b) both of which were accepted. The following figure shows the number of operational and refused turbines in respective regions of England. The green slider represents the percentage of the development which have planning permission and yellow slider represents the percentage of development which were refused from total number of development applied for planning permission. The number of operational and refused developments are mentioned inside those sliders and table below details these numbers, their acceptance rate and percentage of operational developments from total number of development applied for planning permission.

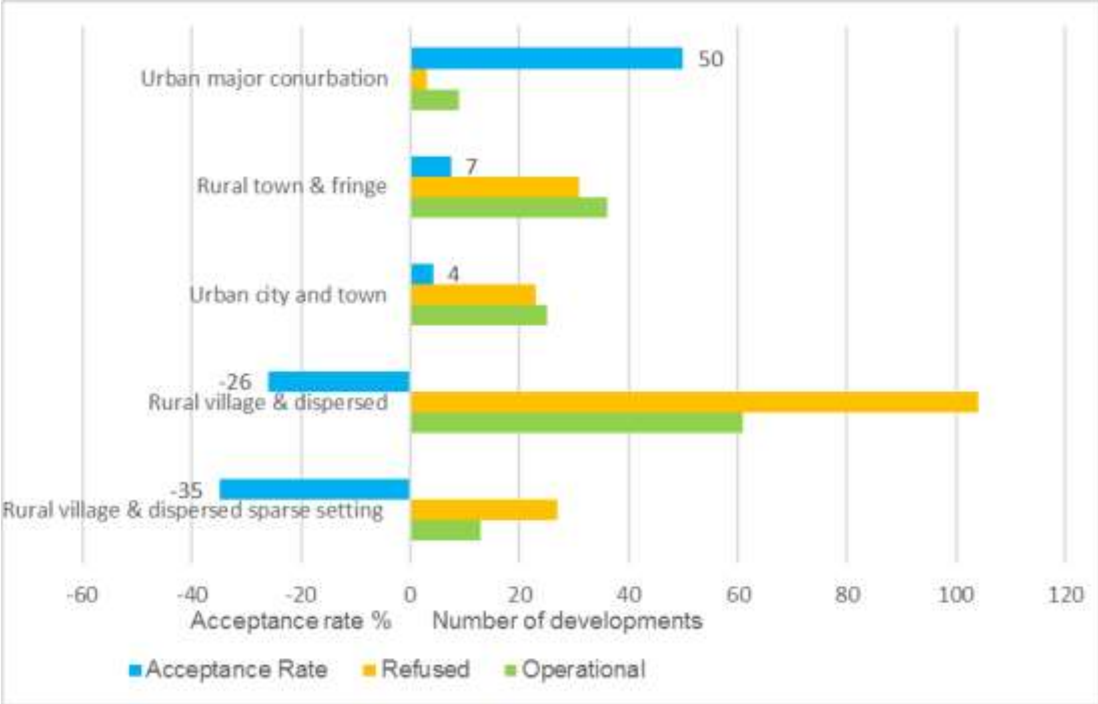


Region	No. of WTD	Oprational	Refused	rate of acceptance	Operational & total ratio
East Midlands	42	15	27	-29	35.7
East of England	54	26	28	-4	48.1
London	2	2	0	100	100.0
North East	58	35	23	21	60.3
North West	65	29	36	-11	44.6
South East	17	5	12	-41	29.4
South West	45	13	32	-42	28.9
West Midlands	9	1	8	-78	11.1
Yorkshire and The Humber	45	22	23	-2	48.9
All	337	148	189	-12	43.9

Figure 17 Percentage of operational and refused wind turbine developments related to Regions of England with table

Figure 17 show that the highest number of WT developments were located in the Northwest region followed by Northeast and then the East of England.

Although the Northwest region recorded the most developments the North-East region had the highest acceptance of WT developments compared to all other regions in England. The West midlands region shares have the lowest acceptance of WT developments, except for category A (single turbine) development. The Yorkshire region has the highest acceptance rate followed by the East of England. The acceptance and refusal of these development could have numerous underlying reasons. For this analysis and to further understand these reasons the physical settlement characteristics of the development's location (i.e. Rural, Urban, Village, Town) were linked to the WT developments. To link the wind turbine developments to their location's physical settlement characteristics, the ONS Rural Urban classification will be considered. The Rural Urban classification dataset detailed in chapter 3.4.2 needed to be linked through LSOAs codes (i.e. E01027447). The spatial boundaries of LSOAs (polygon) with their respective codes as attributes are linked to the operational and refused wind turbine development dataset (point) using a GIS application - System for Automated Geoscientific Analyses (SAGA) Module - Add Polygon Attributes to Points, Author Conrad (2009). This allowed the Rural/Urban classification to be linked to each WT development's location. Figure 18 shows the distribution of operational and refused of wind turbine development in respective to their rural/urban classification. The green slider represents the wind turbine development that are operational with successful planning permission while yellow representing the development which were refused for planning permission. The blue slider represents the acceptance rate in percentage with positive and negative values. The table below shows the values used in the figure.



Area	Developments	Operational	Refused	rate of acceptance
Rural town & fringe	67	36	31	7
Rural village & dispersed	165	61	104	-26
Rural village & dispersed sparse setting	40	13	27	-35
Urban city and town	48	25	23	4
Urban city and town in a sparse setting	2	2	0	100
Urban major conurbation	12	9	3	50
Urban minor conurbation	3	2	1	33
All	337	148	189	-12

Figure 18 Operational and refused wind turbine developments related to their location's rural urban classification with table

From figure 18, it can be observed that the acceptances of these developments are negative in rural villages & dispersed sparse setting and the acceptance of WT developments tended to be urban major conurbation. It can be seen that rural villages & dispersed sparse setting trend to have more negative acceptance with only a few developments, while rural town & fringes have a higher acceptance rate. The greatest numbers of operational wind turbine developments are in rural villages & dispersed (165) areas followed by rural towns (total 48). The least number of operational WT developments are in urban areas. The concentration of operational WT developments in rural areas shows there is disproportional distribution of WT in England.

Further analysis linking the IMD data for these developments allows one to examine the distribution and acceptance of these development based on the locations socioeconomic characteristics.

Examining the socioeconomic characteristics of the locations with WT developments, using the methodology outlined in chapter 4.5 the standardised IMD percentile scores are linked to the LSOA code in the operational and refused wind turbine development dataset. The following figure 19 represents the number of operational and refused wind turbine developments to their respective IMD percentile grouped by deciles. The lowest decile represents the least deprived LSOAs and highest is the most deprived LSOA represented in horizontal axis, while left side vertical axis represents the number of developments and right-side vertical represents rate of acceptance Operational wind turbines are represented using green slider while yellow slider represents refused developments. The dotted lines show the rate of acceptance.

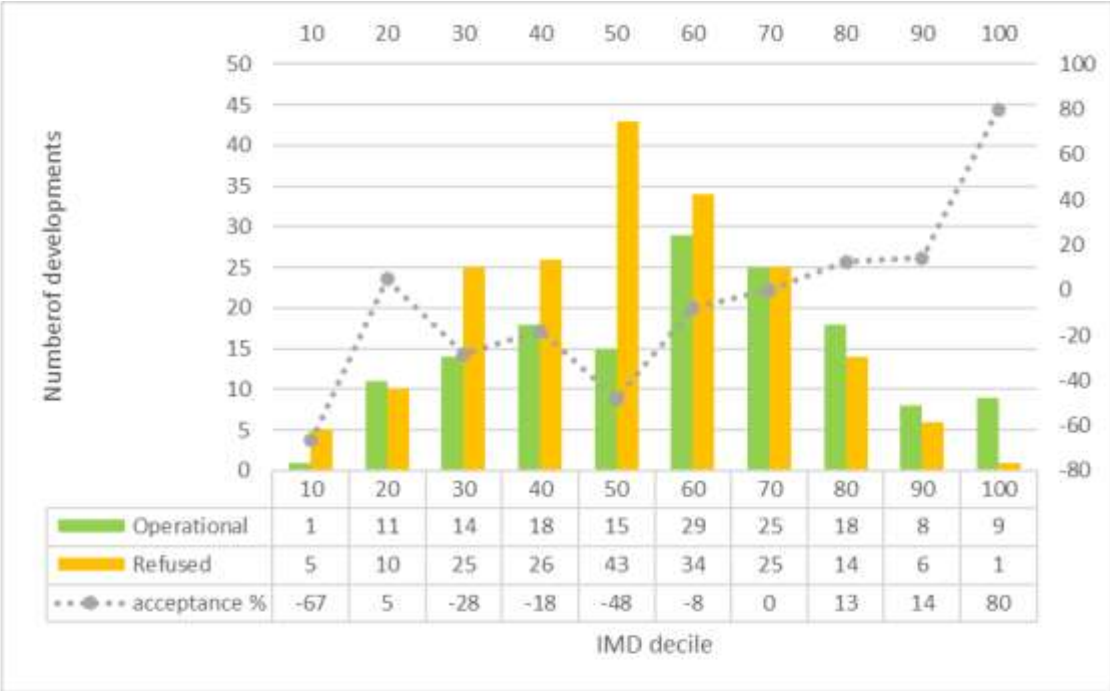


Figure 19 Operational and refused wind turbine developments related to their location's IMD score in decile

From figure 19, one can see that the least deprived areas in England have a negative acceptance rate (70), while the most deprived areas have a positive acceptance rate of WT developments (30). It can be observed that most of these developments are between 50th to 60th percentile of the IMD. The 40th to 50th percentile of IMD shows the most negative acceptance considering they have next highest number of these WT developments. Further examining wind turbine categories and each domain of the IMD, the following table 15 details the relationship between the operational and refused wind turbine development with respective to IMD domains and wind turbine categories. Please note, crime deprivation is ignored in this research. The values presented in the table are the percentiles of the Index of deprivation score(IMD) and individual domain scores. They are grouped together based on Wind turbine development category, their respective year of development and their planning status (operational or refused) This table allows to understand the distribution and acceptance of these developments based on their location's deprivation in percentile at national level. (i.e. all Wind turbine developments in category b (2-4 turbine) which got planning permissions and became operational between IMD period (2002-2005) 2007 are in area which have median deprivation of 71%. These areas are 20% more deprived than national average (50%) deprived areas. Compared to similar wind turbine development which were refused are found at areas with median deprivation of 44% which is below national average deprived areas. This shows that this type of wind turbine developments is proposed in both high and low deprived areas but, refused (negative acceptance) often at areas with lower deprivation and accepted at higher deprived areas.

Table 15 Operational and refused wind turbine developments related to their location's IMD and their domains percentile (Median)

		IMD		INCOME		HEALTH		HOUSING		LIV ENVI.		EMPLY.		EDU.	
WT cat.	**IMD year**	**Opr.**	Ref.	**Opr.**	Ref.	**Opr.**	Ref.	**Opr.**	Ref.	**Opr.**	Ref.	**Opr.**	Ref.	**Opr.**	Ref.
a		**59**	**44**	**51**	**32**	**62**	**31**	**74**	**83**	**45**	**51**	**64**	**36**	**63**	**31**
	2004	63	40	69	27	56	23	35	87	33	51	73	28	70	24
	2007	67	49	63	47	65	41	45	78	49	41	70	41	77	35
	2010	32	36	27	39	31	30	50	83	49	41	28	23	33	49
	2015	59	45	51	22	65	37	86	89	44	79	64	36	70	28
b		**60**	**45**	**48**	**25**	**55**	**24**	**74**	**91**	**30**	**65**	**55**	**28**	**58**	**43**
	2004	64	38	48	20	66	22	89	91	50	59	68	23	50	18
	2007	71	44	70	50	72	49	74	73	31	57	64	52	74	57
	2010	62	47	50	42	66	25	55	92	12	53	65	28	60	44
	2015	57	46	47	25	50	24	79	92	51	76	49	28	53	36
c		**54**	**52**	**37**	**37**	**48**	**40**	**88**	**91**	**52**	**64**	**40**	**43**	**45**	**48**
	2004	60	64	44	49	47	46	80	81	51	47	58	63	39	56
	2007	67	54	47	42	58	45	98	94	65	50	64	52	71	50
	2010	47	55	36	39	41	41	88	91	46	56	37	46	45	44
	2015	54	49	32	32	47	38	89	92	61	82	36	36	46	0
all		**57**	**48**	**44**	**32**	**53**	**36**	**84**	**91**	**48**	**64**	**49**	**36**	**56**	**44**

From table 15, one can see that all three categories of wind turbine developments focused on in this thesis have a trend towards negative acceptance at lower deprived (wealthier) areas. Examining WT development by IMD domain found that there were differences between accepts and refusals for categories a and b, WT development are accepted at higher deprived areas while refused at lower deprived areas.

Examining WT development by the living environment and housing domains found large different in both distribution and rates of acceptance compared to the other domains. Firstly examining the rate of acceptance in both domains, wind turbine are often refused in areas which are more deprived in housing affordability, living environment quality aspect and accepted in areas which are comparatively lower deprived (i.e. Considering medium scale wind turbine development (category-b) over all IMD periods (2004, 2007,2010,2015) are accepted in areas with 74% deprivation nationally and refused in areas with 91% deprivation). Further examining the distribution of these WT developments from Housing deprivation aspect, it is seen about table 15. All proposed wind turbines in England (both operational & refused) are found in areas with 80% and above deprivation of housing affordability aspect (30% of the most housing barrier deprived areas).

Figure 20 shows the relation between the number of development and their respective IMD domain scores by deciles, the spike in the number of wind turbine developments around 80-100 percentile of the most housing deprived areas visually indicates that the distribution of WT developments has been in areas with high levels of housing deprivation.

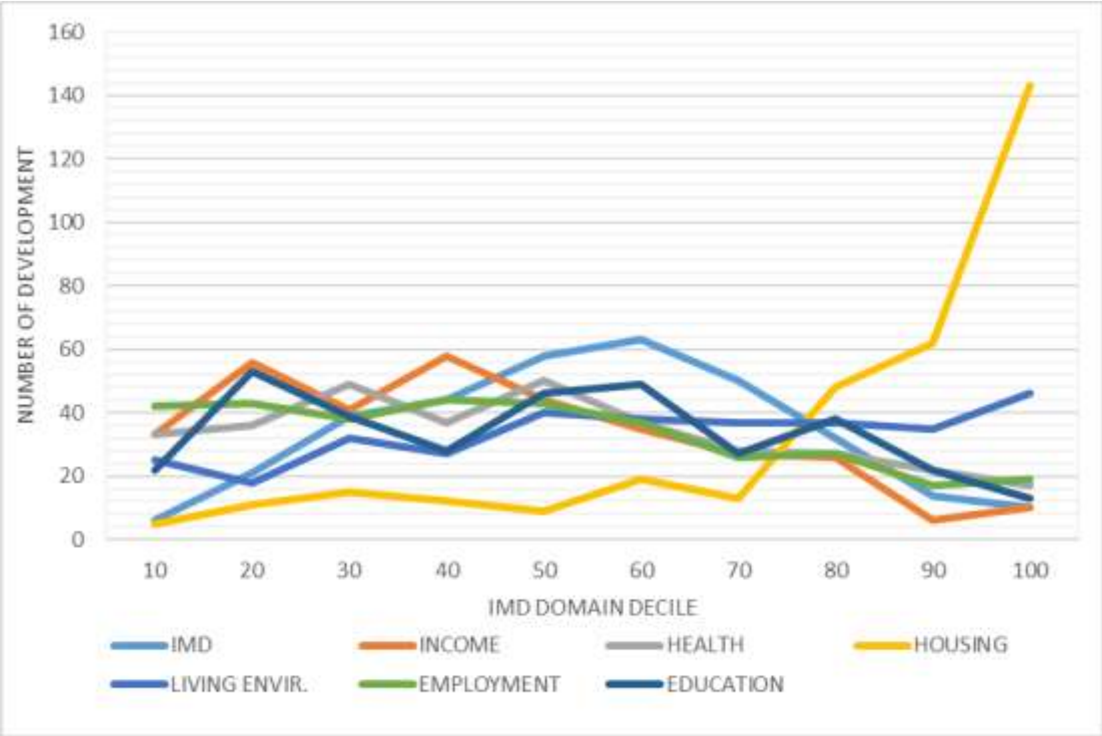


Figure 20 number of wind turbine developments related to IMD domain in deciles of their area

5.2.2 Examining the socioeconomic impact of the WT developments through index of multiple deprivation.

Using descriptive statistics Section 5.2.1 found that WT developments are found in LSOAs(areas) with housing affordability, homelessness and access to services deprived areas. To understand the impact of these development, on the socioeconomic characteristics of an area, it is necessary to perform a before-after analysis using a control impact approach (Osenberg and Schmitt 1996). To begin this analysis, the impact distance of the WT developments is defined based on methodology outlined in the chapter 4.4 and a 0-2km distance from a WT location is considered to have the most impact is defined. A 2km radius for the operational WT developments was created and only LSOAs within this radius will be examined. The WTDs 2Km W.IMD percentile database shown in flowchart 3, section B.1, sub-section 1. Creating Weighted Mean IMD (2004, 2007, 2010 & 2015) scores in percentile of LSOAs within that area(2Km) of WTDs, methodology 4.6 is used in this analysis.

This analysis considers 148 operational WT developments in England, with 56 developments were observed between 2002 and 2008. The developments in these periods are related to IMD 2004 and 2007 periods which allows one to compare the before and after impact of WT developments using IMD 2004 and IMD 2015 respectively. WT developments in the 2007 period uses the IMD 2004 as their ‘before’ IMD reference and IMD 2010 as their ‘after’ IMD reference. Similarly, developments in IMD 2010 period used IMD 2007 as before and 2015 as after development. 12 WT developments required adjustment to consider the impact of more than one development on the same area and same period. The remaining 44 operational WT were considered in this analysis. Figure 21 shows the distribution of the IMD scores of the WT developments, horizontal axis represents the weighted mean IMD scores in percentile of the 2Km area of the WT development before getting planning permission and becoming operational. The vertical axis represents the weights mean IMD scores in percentile of the same 2Km area of the WT development after becoming operational. In both axis, 0 represents the least deprivation score in percentile of the 2Km area and 100 represents the maximum deprivation score in percentile.

(i.e. WTDs id: 3021 is medium class wind turbine development (category b) which became operational between (2006-2008) considered in IMD period 2010. This development has 6 LSOAs within its 2Km area, whose absolute scores of IMD (2004, 2007, 2010 and 2015) and 5 other domains are standardised using weighing factor (ratio of population derived from ratio of the area of Output Areas inside each LSOAs within 2Km).

These 6 LSOAs are now combined into single 2Km area for the WTDs id with standardised scores converted into weighted mean and weighted standard deviation(SD) IMD scores (2004, 2007, 2010 and 2015) and 5 other domains. These weighted means and SD are converted into percentile based on minimum and maximum of IMD and 5 other domain scores for respective period. The weighted mean IMD score in percentile of WTD id 3021 before development is 11.83 (based on IMD 2007) and after development is 12.94 (based on IMD 2015). Point marked in the graph using before and after development IMD scores in percentile with x and y axis respectively. The 1:1 line show the situation in which the deprivation score in percentile has not changed in before and after development, value above this line represents a negative change after in the development and below vice-versa. (i.e. in WTDs id 3021 deprivation score increased from 11.83 percent to 12.94 representing increase of deprivation in LSOAs within the 2Km area of this development). Each point in this graph represents each WTDs (totalling 44 WTDs), red colour shows increase in deprivation will green represents no change or decrease in deprivation.

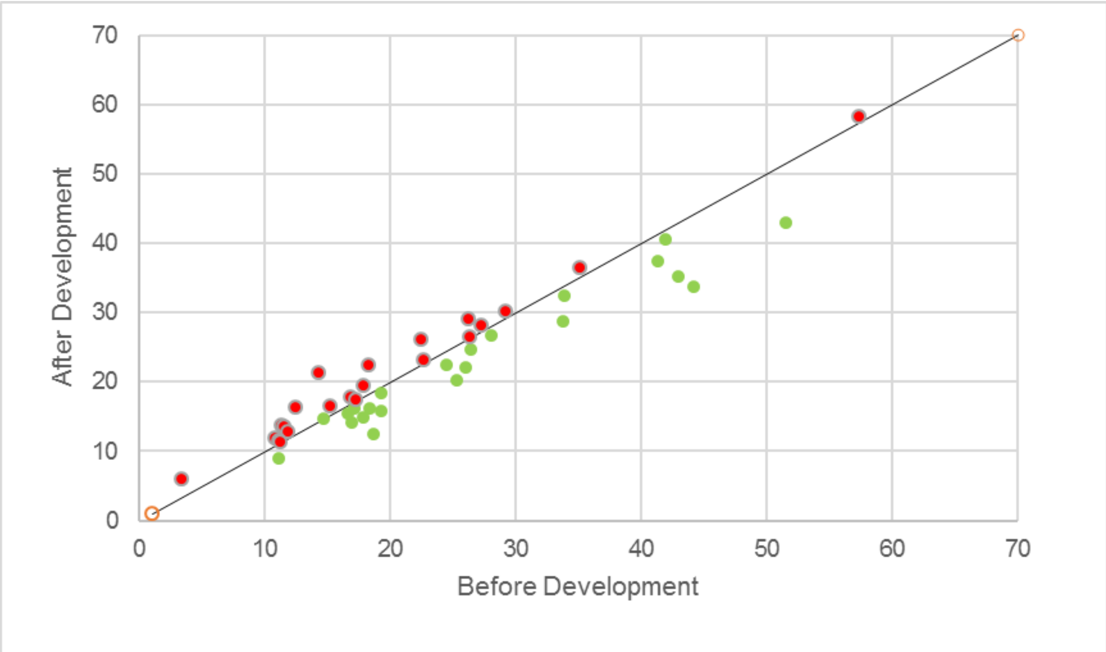


Figure 21 IMD scores of operation wind turbine development before and after development.

From figure 21 the development of WT has little impact on IMD scores over time. Six developments from category b show positive change above 5% (decrease in deprivation) while only one development shows negative change above 5%. 9 developments showed more than 2% positive increase and similarly 9 developments also show negative increase. Further performing t-test on these 44 developments, the Table 16 details the significance of these changes for the 44 developments by each IMD domain. The Before: After (B: A) shows the average ratio of 44 WTDs weighted mean deprivation score (percentile) before and after. (i.e. WTD id 3021 before by after ratio is 11.83/12.93: 0.91, value above 1 shows positive impact and less than 1 shows negative, this WTD evaluated to be contributed negative impact). The significance of the change is represented beside the B: A values. Table 16 also show the before after impact based on the category a, b and c.

Table 16 change in deprivation percentile for each deprivation domains of the developments in respective categories and their significance p= 0.05 (* = significant and NS = not significant)

Deprivation	**2002-2008**	**B: A**	**a**	**B: A**	**b**	**B: A**	**c**	**B: A**
Overall IMD	NS	1.03	NS	0.96	*	1.12	NS	0.99
Income deprivation	*	0.83	*	0.75	*	0.83	*	0.88
Employment deprivation	*	0.85	NS	0.79	*	0.88	*	0.85
Health deprivation	NS	0.99	NS	0.98	NS	1.01	NS	0.98
Education skill deprivation	NS	0.98	NS	0.96	NS	1.10	*	0.85
Housing deprivation	NS	1.00	NS	0.87	NS	1.06	NS	1.01
Living environment deprivation	*	0.75	NS	1.06	NS	0.73	*	0.65

Table 16, shows that the average changes in the IMD scores within 2km of a WT development are positive but these changes are not significant. The Health, Education and Housing domains show a negative impact but also not significant for categories a and b, however category c is significant. The Income and Employment domains show a similar significant negative impact after WT developments except for the employment domains for category b developments. It must be noted that category b development shows an overall positive impact on employment deprivation and is significant. The Living environment domain presents the highest significant negative impact. However, to determine if these changes are related to WT development requires a comparison of similar LSOAs without WT developments over time. To further examine the negative changes in the living environment domain, LSOAS that share similar socioeconomic and physical characteristics need to be compared using a control-impact and before-after combined approach. To identify areas, which have similar characteristics, a propensity score matching (PSM) method was used. The PSM methodology is detailed in the Methodology chapter 4.7.1. Each LSOAs within 2km of the WT development area have their respective development reference id and weighing factor based on the proportion of population and area within 2km. These LSOAs are used as treatment and matched to LSOAs without WTDs id. The Matched LSOAs (without WTD) are combined with weighing factor from its treatment LSOAs (with WTD) and grouped to their respective WTDs id forming matched weighted mean IMD and 5 other domain scores in percentile for each IMD period. The LSOAs with WT developments can now be compared to LSOAs with similar physical settlement, topographical(wind) characteristics having no WT developments. Figure 22 shows the overall IMD distribution of the 44 matched LSOAs, it is observed that 25 out of 44 area trends to show a positive change in IMD score.

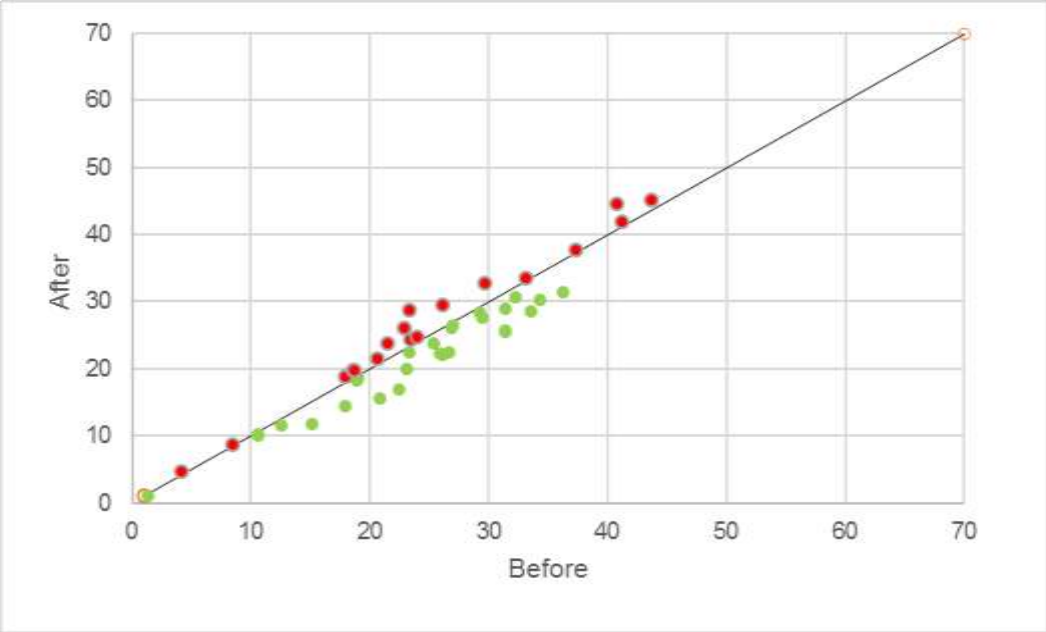


Figure 22 IMD scores of areas matched to wind turbine development areas before and after

However, the overall IMD change observed before and after across the LSOAs with and without WT is not significant as shown in following table 17. Considering the income employment and living environment deprivation in both areas trend to have significant negative change.

Table 17 change in deprivation percentile for each deprivation domains of the developments area versus match area and their significance p= 0.05 (* = significant and NS = not significant)

Domains	2002-2008	B: A	2002-2008 (matched)	B: A
Overall IMD	NS	1.03	NS	1.04
Income deprivation	*	0.83	*	0.82
Employment deprivation	*	0.85	*	0.83
Health deprivation	NS	0.99	NS	0.98
Education skill deprivation	NS	0.98	NS	1.05
Housing deprivation	NS	1.00	NS	1.00
Living environment deprivation	*	0.75	*	0.79

To further examine if the negative changes observed in living environment domain are related to WT developments being operational, the operational WT developments are matched with similar WT development which are refused using similar propensity score matching methodology detailed in chapter 4.7.2. The following table 18 compares the 2km area of the operational and refused WT development. Due to strict matching criteria considered in the matching method only 12 similar wind turbine developments could be used in this comparison in the period of 2002-2008.

Table 18 change in deprivation percentile for each deprivation domains of the operational versus refused development and their significance p= 0.05 (* = significant and NS = not significant)

Domains	2002-2008	B: A	2002-2008 (matched)	B: A
Overall IMD	NS	1.01	NS	1.02
Income deprivation	*	0.79	*	0.83
Employment deprivation	*	0.82	*	0.84
Health deprivation	NS	0.97	NS	1.04
Education skill deprivation	NS	1.01	NS	0.98
Housing deprivation	NS	1.05	NS	1.03
Living environment deprivation	*	0.76	*	0.60

From the table 18, a similar pattern of significance and changes over time is observed in both operational and refused development 2km area. Further significant negative changes are observed in the income, employment and living environment domains. It must also be noted that refused development area trend to have 16% increase in living environment deprivation over time compared to operational development 2km area. Using both before-after and control impact approach in this analysis, it has been observed that operational WT developments in England shows no significant change of overall IMD scores over time on area within their 2km zone. It must be also noted that living environment domain of these areas could increase over time but not conclusively.

On comparing the refused and operational development using only control impact approach, the following table 19 detailed the significance of deprivation score of overall 42 matched operational and refused developments and each deprivation domains over the period of 1993-2013. The percentage difference shows the mean deprivation score (percentile) difference between operational and refused WT developments. The significance of the change is represented beside respective percentile difference. (i.e. category c WTD with operational status in between IMD period 2015 with IMD score in percentile is 44 (based on IMD 2015) for the 2Km area. Its matched category c WTD which got planning refused in between IMD period 2015 has IMD percentile of 27. The difference in percentage between IMD scores is 17)

Table 19 mean difference in deprivation percentile for overall and each deprivation domains of the operational and refused development and their significance p= 0.05 (* = significant and NS = not significant)

Domains	1992-2013	% difference
Overall IMD	*	6
Income deprivation	*	5
Employment deprivation	*	4
Health deprivation	NS	3
Education skill deprivation	*	7
Housing deprivation	NS	1
Living environment deprivation	NS	1

From the table 19, it is observed that WT developments are significantly accepted/planning gets approved in area with more deprivation when compared to the areas where they are refused while consider the surrounding 2Km area. Considering each domain in the IMD; the income, employment and education domains have a similar pattern. It must also be noted that the mean difference between operational and refused turbines are significant, the weighted standard deviation from the IMD percentiles of the each LSOAs within 2km area shows high variability making it inconclusive on the difference of IMD scores between operational and refused WT developments. The following figure 23 shows the distribution of IMD scores in percentile of the matched 42 operational and refused WT developments. In this figure, the horizontal axis represents the IMD score in percentile of the 2Km area of the operational WTDs and vertical axis represents the IMD scores in percentile of the 2Km area of refused WTDs matched to the respective operational WTD. The horizontal line represents the minimum and maximum of the weighed mean IMD scores of all LSOAs inside 2Km area of operational WTD and vertical line represents the same for LSOAs inside 2Km area of refused WTDs matched to the respective operational WTD (i.e. category c WTD with operational status in between IMD period 2015 with weighed mean IMD score in percentile is 44 (based on IMD 2015) for the 2Km area. Its weighed standard deviation is 38.41 which makes the IMD scores(percentage) of LSOAs within the 2Km spread between 5% to 82% while, its matched WTDs 2Km weighed mean IMD score is 27 with weighed standard deviation is 25.89 which make the IMD scores of LSOAs inside 2Km spread between 1% to 53%.)

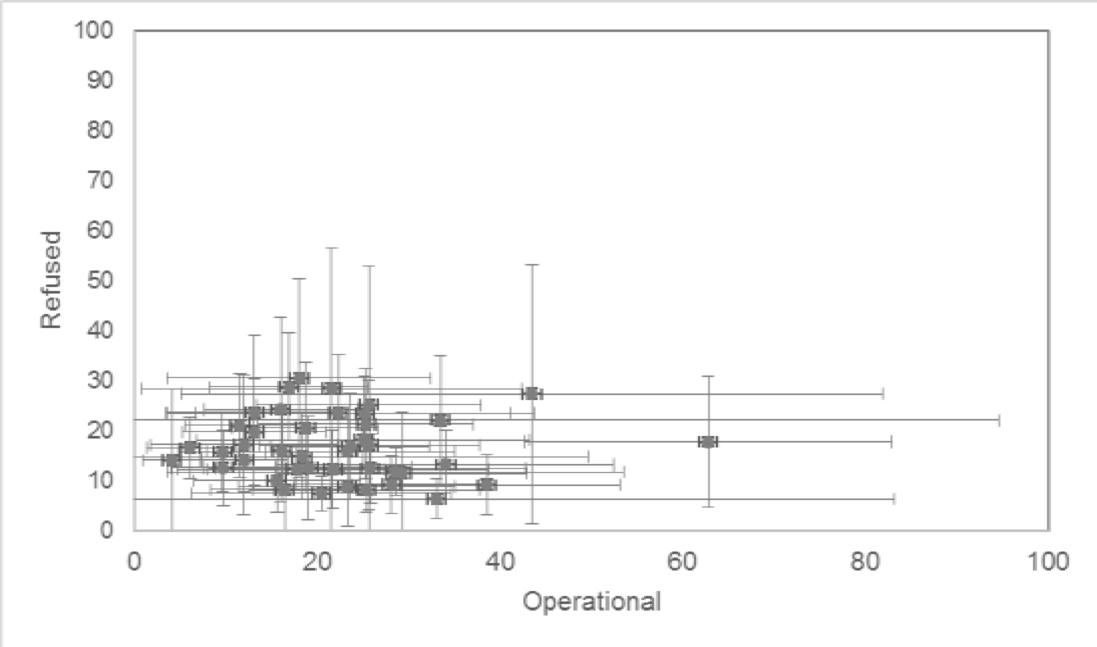


Figure 23 IMD scores and their weighted standard deprivation in percentile of matched operational and refused wind turbine developments between 1993-2013.

5.2.3 Result and Discussion

From quantitative analysis of relating onshore wind turbine development in England to its location's spatial and socio-economical characteristics several observations were made and overall conclusion were derived.

Medium scale and large-scale wind turbine developments are often refused more than Single turbine developments, this is observed from table 14. From Figure 17 Higher number of Wind turbine development were proposed in North West England and followed by North east in which nearly 60% of them were accepted. Yorkshire and the Humber & east of England are the next two regions granting nearly 50% of their wind turbines development applications, concluding that northern and north-eastern parts of England were pro-active for wind turbine developments. Comparing the physical settlement characteristics of WT development areas from Figure 18, it can be observed that there exist a disproportion distribution of wind turbine in England concentrated on rural area, rural village & dispersed areas. 80% of these WT developments are located in rural areas with 68% specifically in rural villages and dispersed setting, suggesting wind turbine development are often in remote areas similar to suggestions from WT development studies on Wales (Munday, Bristow and Cowell 2011) and Scotland (Hanley and Nevin 1999).

Relating the socioeconomic characteristics (IMD & 5 domains) of the location of the WT development, it can be concluded from Figure 20 that most of the WT developments in England are concentrated in 20% of most housing affordability, homelessness and access to services deprived areas. This results correlates with similar finding of Incinerator in deprived areas (Earth 2004) and manufacturing plants(Wolverton 2009). However, unlike these developments, wind turbines don’t bring any known impact on environment. The scale of the infrastructure, availability of the low-cost land and large electricity grid could be the cause for the areas housing deprivation, could be the few reasons of this disproportional distribution. As observed in later in assessing the changes contributed by WT development to its surrounding areas, there is no significant change observed in housing affordability, homelessness and access to services aspect of deprivation.

Relating the socioeconomic characteristics (IMD) of the location of the WT development and assessing rate of acceptance, it can be observed that the acceptance of wind turbine is positive and higher on 30% of most deprived areas in England, but it must also be noted that most number of WT developments are in areas with national averaged deprivation of England by considering only the overall index of multiple deprivations scores(percentile). Areas with overall index of multiple deprivation lower than national average trend to have negative acceptance/refuse of these developments. Using socio-economic characteristics of 2Km impact radius of WT development area similar observation can be noted. From Table 19 showing significant difference between average of all WT developments weighed mean operational/approved WT development's IMD score (percentile) and refused development's IMD score(percentile). From all these observations, we could conclude that WT developments are highly accepted/ planning gets approved when they were proposed in deprived areas in England.

Towards assessing whether these WT developments actually cause socio-economic impact on their surroundings, From Figure 21, 22 and table 16, 27 and 18 using combined control impact and before-after approach operational wind turbine development in England it can be observed that there exist no significant change in overall deprivation over time on areas within 2Km. Living environment deprivation of these areas may increase over time but there is conclusively evidence showing wind turbine development are the actual cause, as this is also observed with non-WT development areas with similar overall deprivation characteristics and also in areas where WT development have been refused. The overall methodology designed to assess quantitatively socio-economic impact of existing WT development is novel attempt bridging the existing gap of assessing and empirically projecting socio-economic impacts of future renewable energy development. This is first of its kind in renewable energy research using Index of Multiple deprivation as index for assessing socio-economic of the development’s location using spatial relation allows this methodology to be implemented in future IMD database and renewable development database making this framework futureproof. It must also be noted for the existing limitation in this methodology as this allows only to analysis the relative change of the deprivation by the comparing two areas with and without WT development, but doesn’t include the possibility of other large-scale infrastructures. The change of deprivation over time is considered based on the availability of the IMD data, which allows us only to observe only the long-term impact of the WT development. Considering this limitation this methodology could be implemented to not only WT developments but, also analysis other large renewable infrastructures including solar farms which is next increasing renewable infrastructure in England.

5.3 Developed GIS system in industrial use

The desktop and web-based GIS system outlined in this thesis have been implemented by Entrust the Industrial partner on this research. The planners were provided with training to use these GIS systems over a period of 1 month. The desktop based system allowed them to identify potential renewable development sites using additional planning experience. The click me file referred in the chapter 4.9 has been particularly useful as their purpose is to provide all available planning constraints at county level. Additional landscape sensitivity maps in raster form were gathered from various local authorities and were overlaid in the desktop GIS system to identify low planning sensitive locations. Data on the electricity grid provided additional information in raster format, which could be included to identify available grid connections.

The desktop system is based on using QGIS platform for interacting with the users. The following shows the approach in identifying potential location for wind turbine development by overlaying planning constraints with buffer distance. These distances depend on the scale of the development, category-a (small: Single turbine), category-b (medium: 2-4 turbines) and category-c(large-5 and more turbines) respectively. These distances were created based on consulting with planning experts from industrial partner with previous experience from handling planning application for wind turbine development. These distances can be varied/modified depending on type and location (local authorities' guidelines) of planning infrastructure allowing this framework to be flexible.

Table 20 Predefined buffer distance in metres considered for WT development in England

Planning Constraints Name	Small	Medium	Large
Electricity Transmission lines	90	162	250
Woodland	65	77	91
Railway track	50	86	131
Public right of ways (Footpath)	50	86	131
Public right of ways (Bridleway)	50	86	131
Public right of ways (Cycle path)	50	86	131
Public Roads	50	86	131
Buildings	400	420	500
Waterways	215	227	241

The Click Me file created for Merseyside county is opened in QGIS software package. On opening the QGIS the file is auto-scripted and all the colours for each planning constraints, pre-defined buffer distance and property boundary with inspire ID will be loaded. Immediately to identify the local planning authority, the boundaries of each local authority is also included. The list of planning constraints and respective grouped layer can be found on the left column with check-boxes allowing user to turn on and off the respective layers that they consider in the search approach. Considering the search for potential wind turbine development, agricultural land classification boundaries can be turned off as the impact of wind turbine development are minimal on land coverage allowing these developments to coexist with ongoing agriculture farms. All the planning constraints will have county names in end of their constraints name, which is part of the system to work efficiently, loading only the constraints within the county boundaries avoid excess data usage and reduce rendering time. The following figure 24 shows the opening screen after loading click me file for Merseyside.

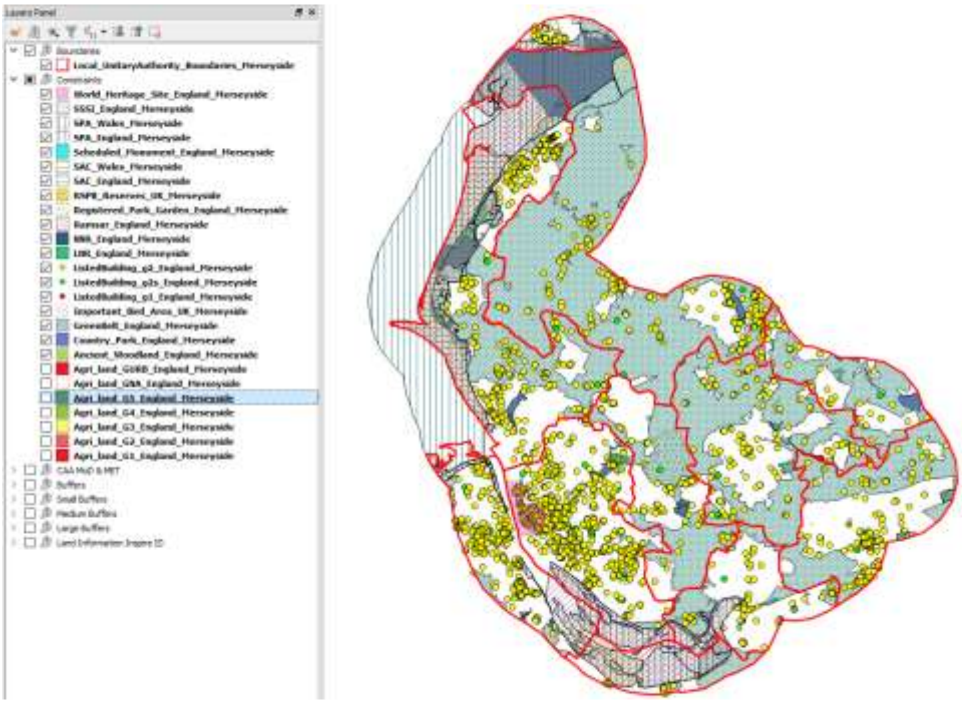


Figure 24 QGIS opening screen with planning constraints loaded for Merseyside with layers detailed in layer panel on left (step-1).

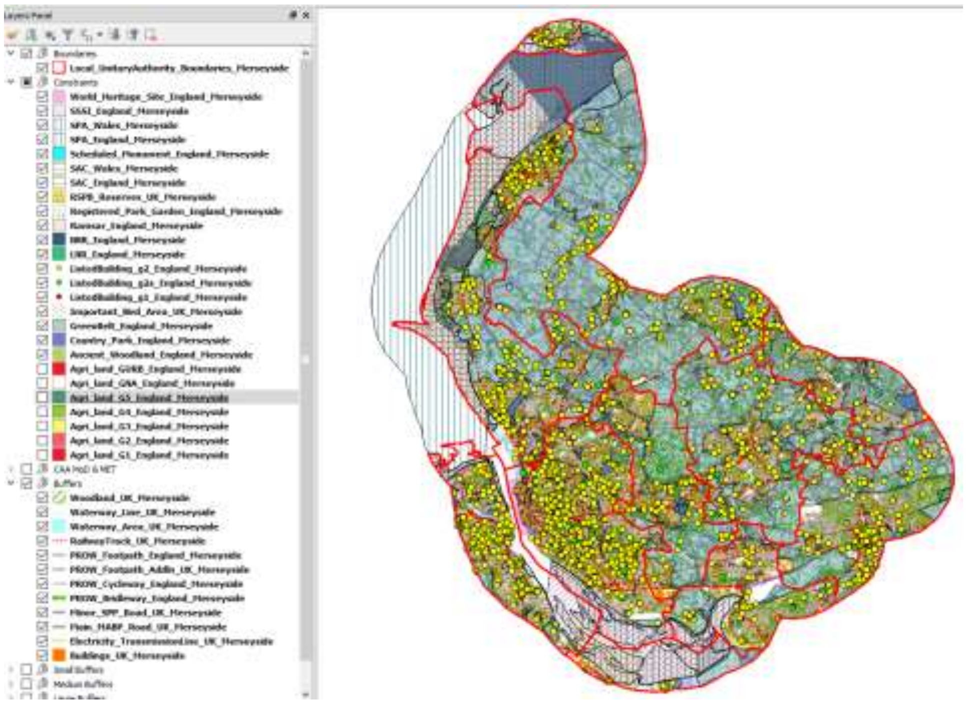


Figure 25 QGIS with planning constraints and buffer (road, Public right of ways, railway track, buildings, major electricity powerlines loaded for Merseyside with layers detailed in layer panel on left (step-2).

The Figure 25 shows both planning constraints and buffer (road, Public right of ways, Railway tracks, buildings, major electricity power lines) overlaid together. It can be clearly observed that all the empty white areas which was available in initial screen got reduced as the buffers loaded. It must be noted that QGIS uses rendering layers based on viewing scale. On zooming in to smaller scale, the size of the layer will get small and more area for potential development could be found. The constraints layers created for each county in this framework usually includes 1Km buffer of the overall county boundaries, this allows users to identify potential location even at the edge of local planning authority/county boundary without needing to open Click Me file for county beside.

Using QGIS tools including merging of all layers and clipping difference on all planning constraints and buffer layers would reveal these potential areas quicker but, visual identification is implemented as the searching approach for potential area for development vary, depending on the scope and scale. In few cases development might be pursued even in location within planning constraints with mitigation solutions pre-agreed with local planning authority depending on case-by-case. The following figure shows the potential locations visually identified (locations with no buffer having white colour by default) using the GIS system considering buffers for large scale of wind turbine development. It must be noted, considering all the planning constraints and buffer distance there was no potential area was available except for areas inside greenbelt. In this search approach greenbelt layer is ignored.

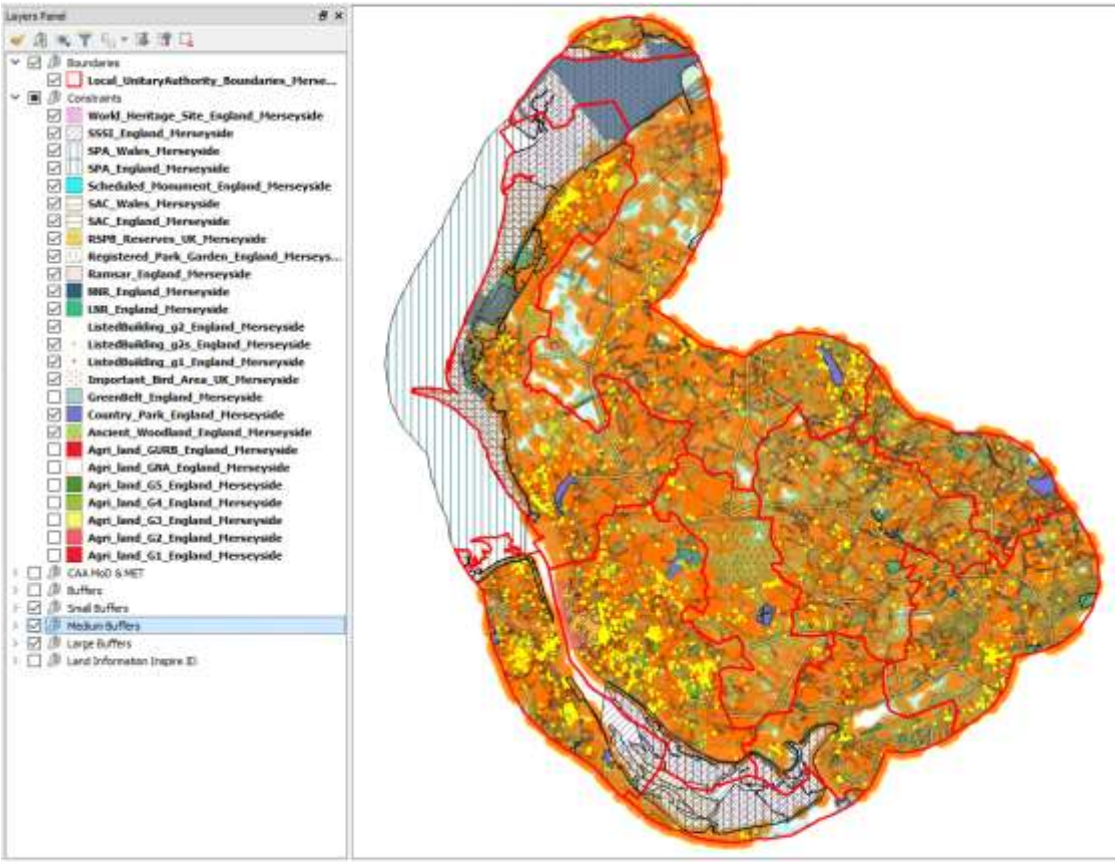


Figure 26 QGIS planning constraints with large scale buffer distance overlaid together allowing to identify potential development location.

The potential of this GIS framework is fully utilized only on interactive approach (using computer) rather than report based approach (identifying sites from printed maps of planning constraints and buffer distances. The Click Me file was generated for all the counties of the England, Wales and Scotland. In this thesis, planning constraints maps generated using the above desktop GIS system for each county (32) of Scotland along with key/legend of those constraints and GIS based site boundary, planning constraints and buffer maps generated for individual renewable energy development (Sample Solar Farm) are included in Appendix to justify the potential outcomes that could be produced by this GIS framework.

Using the desktop system following development had been identified and planning application had been successful.

1. **Development:** Erection of a **single 500KW wind turbine** measuring 77.9m high to tip,50.9m to the hub and associated structure

   Location: Lodge Farm, 255 Narrow Lane, Burton on the Wolds, Leicestershire LE12 6SD.

   Planning application reference: P/13/2506/2 granted on April 2014

   GIS system purpose: ecological category constraints SSSI designation was identified >800m and conversation with local authority whether the proposed development would have a negative impact on SSSI was initiated at early stage of the planning which was resolved before final application.

2. **Development:** Erection of a **single 500KW wind turbine** measuring 40.9m to hub and 67.9m high to tip.

   Location: Land North of Gowdall Broach Farm, Field Lane, Gowdall, East Riding of Yorkshire DN14 0AS.

   Planning application reference: 13/04081/STPLF granted on Sept 2014

   GIS system purpose: MoD category constraints, Civil Aviation Authority Doncaster Airport and NATS 20m were identified, nearest dwelling identified at 450m. These identified constraints were consulted with respective authorities and resolved by micro-siting the turbine.

3. **Development:** Erection of a **single 500KW wind turbine** measuring 77.9m high to tip,50m to the hub and associated structure

   Location: Rainsbutt Farm, Crowle, Scunthorpe DN17 4BJ

   Planning application reference: P/2014/0591 granted on Feb 2016

   GIS system purpose: similar ecological category constraints SSSI designation was identified at 900m, Conservation areas >400m, Listed grade I building >800 and garden and designed landscape 885m were identified. This development was refused on Dec 2014 on the ground of cumulative impact which was addressed using visual impact assessment by identifying key location for visual impact (i.e. conservation areas, listed building grade I)

Implementation of the desktop GIS system with additional planning constraints allows the industrial partner to perform planning assessment for similar large developments. The use of this GIS system has been constantly monitored in this research period and feedback were collected for improving the framework and quoted below for reference.

Kieran Tarpey, Managing Director (chartered Town Planner) stated that desktop GIS system as "The desktop GIS has become an integral part of Entrust's planning appraisal for all proposed infrastructure developments; wind turbines, solar farms, anaerobic digestion and telecommunications masts. The GIS incorporates all the necessary data layers used in conjunction with Entrust's planning expertise for assessing environmental, landscape, ecology, residential amenity, aviation, public rights of way and heritage constraints pertaining to a particular site location anywhere in the British Isles." Regarding required improvements, he stated “It would be useful for the 2 systems to be integrated to allow for switching between the 2 systems. Further refinements such as default buffers for different types of infrastructure developments would enable it to be become more automated and efficient. Also, automatic updating of as many data layers as possible would be very useful.”

Alexander ball, Senior Planning Consultant (member of RTPI) regarding desktop GIS system quoted “The system has been used to identify constraints or show stoppers at the earliest stage of various projects. The desktop GIS system has been used to justify a location for a wind turbine for example, with the planning officer at Ribble Valley Borough Council (ref: 3/2014/1025). It should be noted, that the proposed development was located within an Area of Outstanding Natural Beauty (AONB). The desktop GIS system clearly identified that the site was within a sensitivity landscape designation, and that the applicant was aware at the early stages of the project. In a meeting with the planning officer, we used the GIS maps to clearly demonstrate and justify the reasoning and logic behind locating the wind turbine to a particular location, due to numerous constraints, such as public right of ways, noise levels, and ecology issues.

The layout of the maps with the legend identifying nearby constraints have been used in numerous planning applications, as a tool for planning officers to visually identify all nearby constraints and understand the reasoning for the preferred location of the proposal (wind turbine, solar or telecommunications installation).”

On required improvements Mr. Alexander Ball as quoted “A potential improvement is being able to use postcode searches to find a particular location, as currently the system only uses co-ordinates. In addition, majority of the conservation areas have been uploaded onto the GIS system, however, there are some conservation areas missing.”

Apart from wind turbine and renewable energy development, the web-based GIS system was redesigned for telecom site assessments. It has been implemented in on-going telecom tower power backup generators upgrade planning permission for Emergency Service Network in UK.

Alison Hughes, Senior Planning Consultant (MRTPI) who was been using the web-based GIs system for telecommunication planning assessment stated about web-based GIS as “I use the web based system regularly to assess a particular site’s location in relation to sensitive land designations.” On asking the preference for planning as quoted “My preferred option in assessing a site is the web based system because my work mainly deals with telecommunication base stations and the information I need is whether the site is within a sensitive land designation or near to a listed building.”

Neil Gates, Planning Consultant working on telecommunication planning stated his purpose of web-based GIS system usage. He stated “telecommunications client was in the process of upgrading their apparatus which occasionally was located on buildings. The web-based GIS system was used to ensure that the buildings do not belong within a conservation area. After we had determined whether or not the building was in a conservation area, we then determined whether the upgrades would be A) permitted B) be permitted development under the GPDO, or C) require full planning permission.”.

From observing the feedback collected from the industrial partner in this research, the web-based system as preferred for telecommunication planning while the desktop GIS system was preferred for renewable development planning. The improvements requested from the feedback were stating towards improving the user interface rather than the framework itself. The future commercialization or trailing the GIS system to wide range of planner would give more feedback which could further optimize the planning framework.

The web-based GIS designed part of this GIS framework is used for further analysis on individual site developments especially while interacting with clients and other infrastructures (i.e. Telecom sector) Though the desktop GIS system is superior in flexibility, web-based system is efficient as it is cloud based system allowing multiple user to work together simultaneously on same project and uniquely designed for planner to efficiently identify and micro-siting the proposed infrastructure within the development area. Based on the feedback from desktop GIS system, the web-based GIS system was designed to be simple to interact. The following screenshots from the interface are shown and their feature are detailed.

The opening page of the web-based in designed with log-in page leading into the project menu page. The project menu page loads any previous projects the user has been working in past and give options to create new projects. This system was designed to work with more than one user working on same project. The status of the project is detailed beside their name in project menu, including current active user of the project, synchronisation to server status and available for editing with no active users.

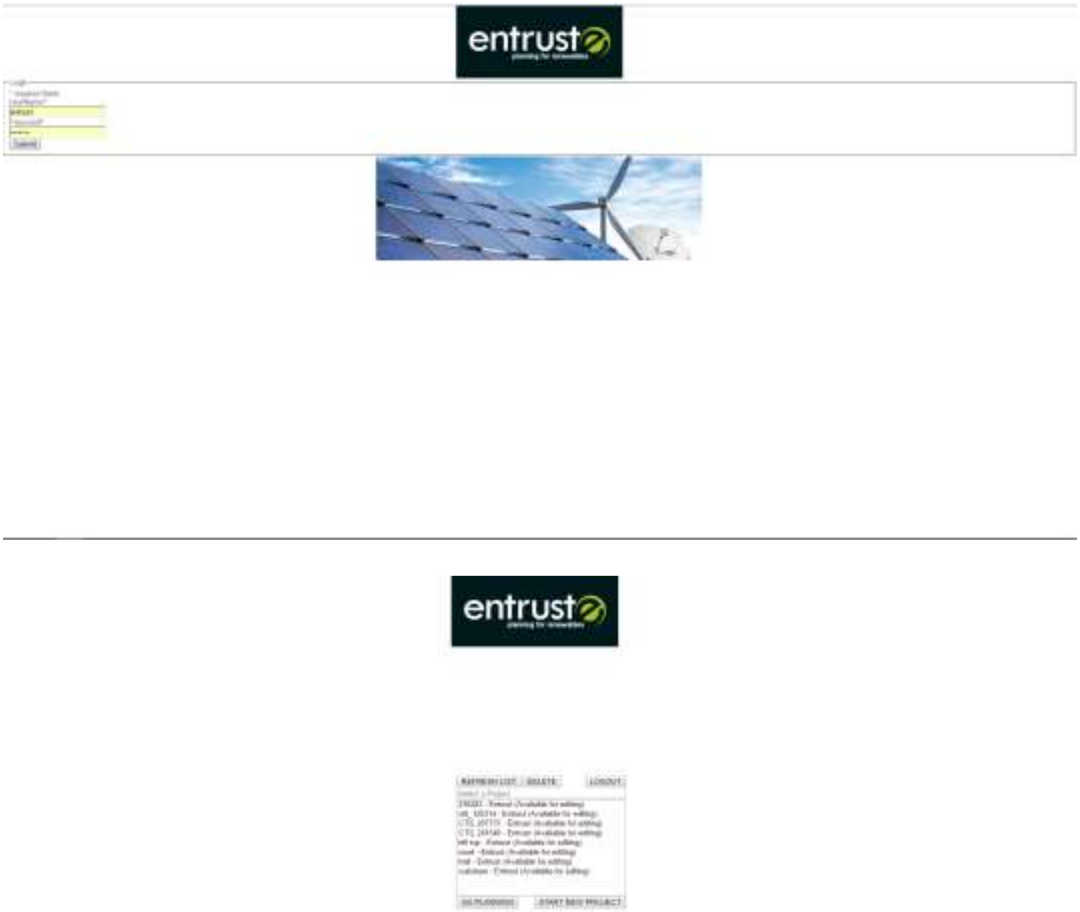


Figure 27 Screenshot of Web-based GIS log-in and project menu page

Once the user chooses to create new project, google maps based page with option to address search bar to locate project location appears. This page allows user to define the development boundary of their project, or simply click approximate centre of their project. The lower left bar allows them to choose the planning constraints consideration radius depending on project scale (by default 5Km radius is provided). Working with multiple sites within 1Km was made available, users can directly upload their predefined boundaries in kml file format (googles' keyhole mark-up language) or shapefile (common GIS vector file) making it easier to start the GIS process and quickly generate the planning constraints. They will be asked to provide project name and their user name as this web-based system was designed to work with multiple users with group log-in and password. Providing the name of user creating project allows tracking for future references.

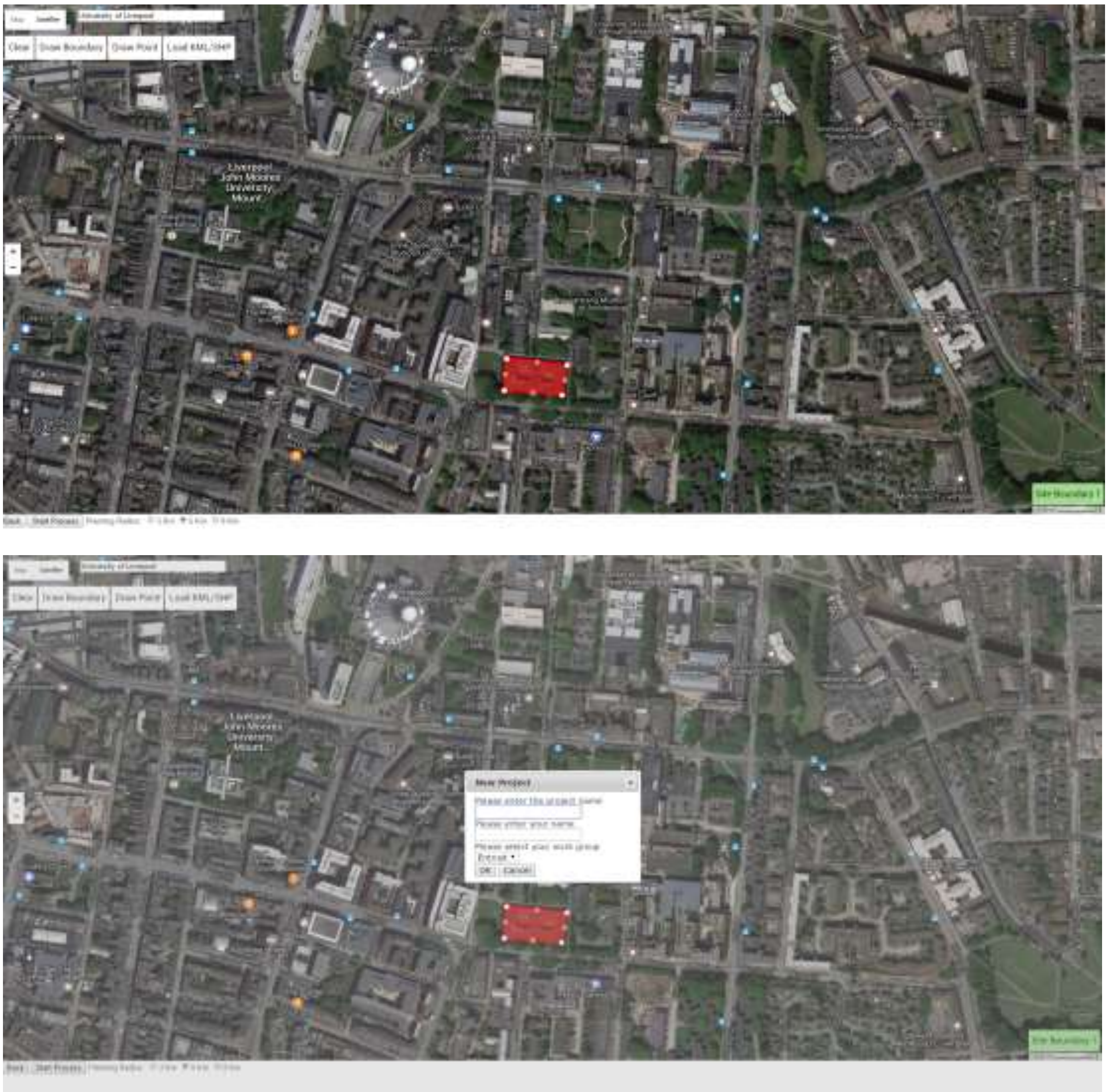


Figure 28 Screenshot of Web-based GIS's project boundary/centre creation page and project name defining menu

The process starts on clicking OK and the server puts the project generation in que. The user will be emailed on completion of the project generation. Depending on the size of the radius selected, location and count of layer this time would vary. Once the project becomes ready they will be in the main GIS map page. This page layout design was based on desktop GIS framework structure to maintain the similarity for user but, made simpler to interact. The layers are listed on left side panel with similar check box to turn on and off a layer. Creating buffer is made simple by providing a buffer button next to the layer. The user can click and enter the desired buffer value for the specific layer. To identify the details of the single point/polygon/line of constraints layer on the map, pop-up menu was designed to display information from constraints layer database only when user selects the layer and clicks the single point/polygon/line on the map.

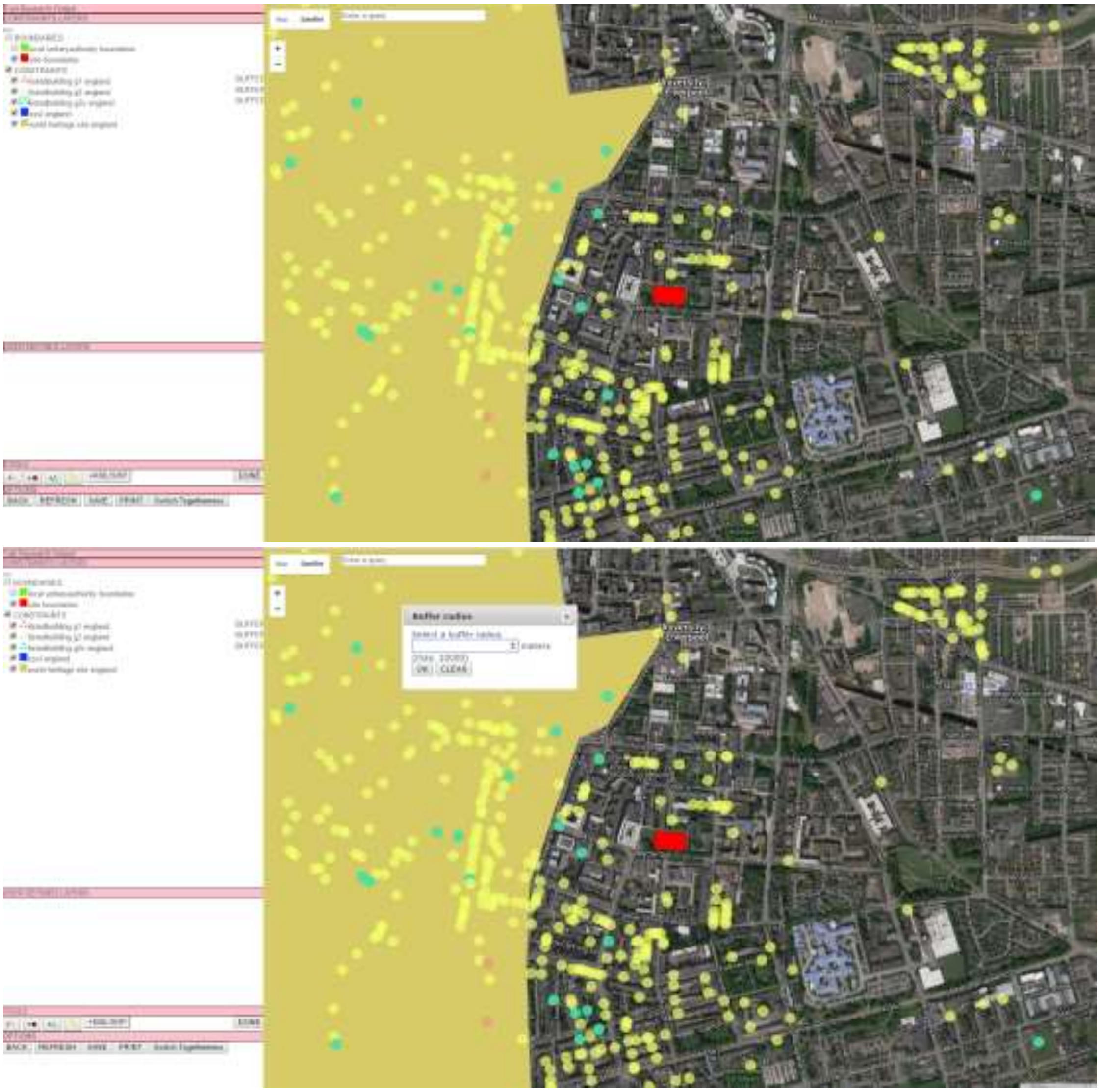


Figure 29 Screenshot of Web-based GIS's main map page and buffer dialog menu

Additional tools including scale, creating new point, polygon and line features were included and can be seen on bottom left panel. User can upload additional relevant GIS data for project in this page. Both KML and shapefile format are accepted by the system. It must be noted that all new information added will be also saved in the server for later retrieval when the project is re-opened. The planning constraints layer legends can be modified using provided colour palette. User can set their desired colour for best suiting visibility and these preferences will be saved and re-applied when re-opening the same project or any future projects loading same planning constraints layer.

Figure 30 Screenshot of Web-based GIS's layer colour palette feature and constraints layer database pop-up menu

The important feature detailed in this web-based GIS system is the feature allowing multiple user to work simultaneously on same project. The open-source java script module togetherness which can be turned on and off using the button on bottom left panel was designed. This allows another online user with provided link, can view and control the project from their PC. The two users can interact through chat and voice chat (restricted only to Mozilla Firefox). This interactive system is still in beta development which will be considered for future development of the web-based system.

Figure 31 Screenshot of Web-based GIS's multiple user interface with control and chat options.

The developed GIS system used in industry as outcome of this research is constantly evolving. The implementation of socio-economics in GIS framework is still restricted with manual inclusion rather than automated. Further development of GIS and well-defined algorithm for automation of the socio-economic assessment based on the user pre-defined project type will be considered. This section overall detailed the implementation of both Desktop and Web-based GIS in the industry which was developed as solution towards improving the efficiency of the planning process in renewable energy sector.

6 FUTURE RESEARCH

The findings from this research provide an innovative insight in understanding the impact of renewable developments on the socioeconomic profile of their area and provides an empirically approach in projecting the socio-economic impact of future renewable energy developments Additionally, the methodology outline above could be implement on other large scale renewable infrastructures like solar farms. The renewable planning framework developed could be further improved based on implementing topography as a default dataset which would allow the use of ZTV instead of the current buffer rings that are used. 3D modelling using GIS constraints would further allow the visualization of the impact on the surround area of the development and give better understanding of the development to the local community.

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APPENDIX

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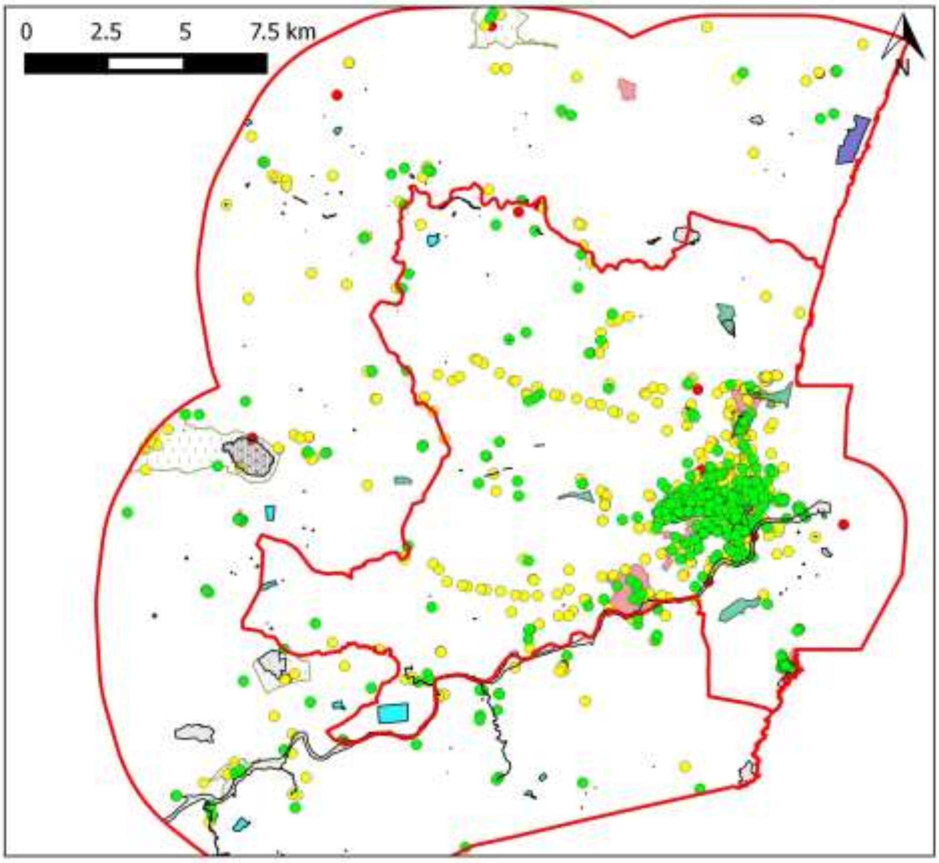
UK County level Constraints Map

County: Aberdeen

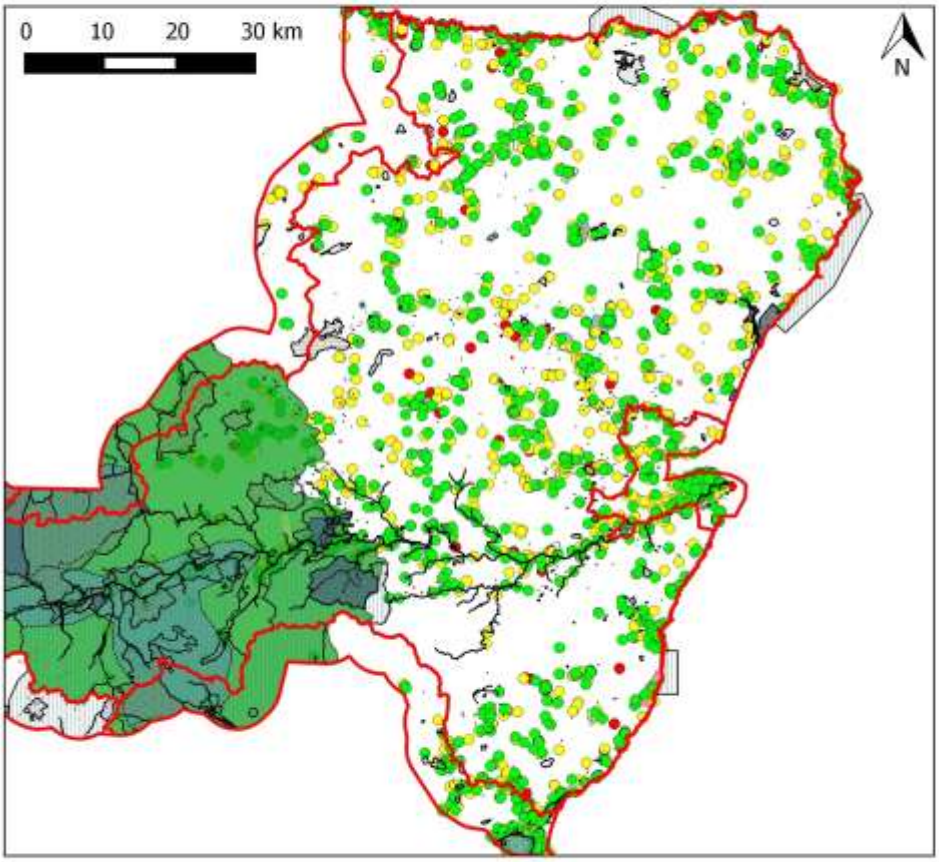
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County: Aberdeenshire

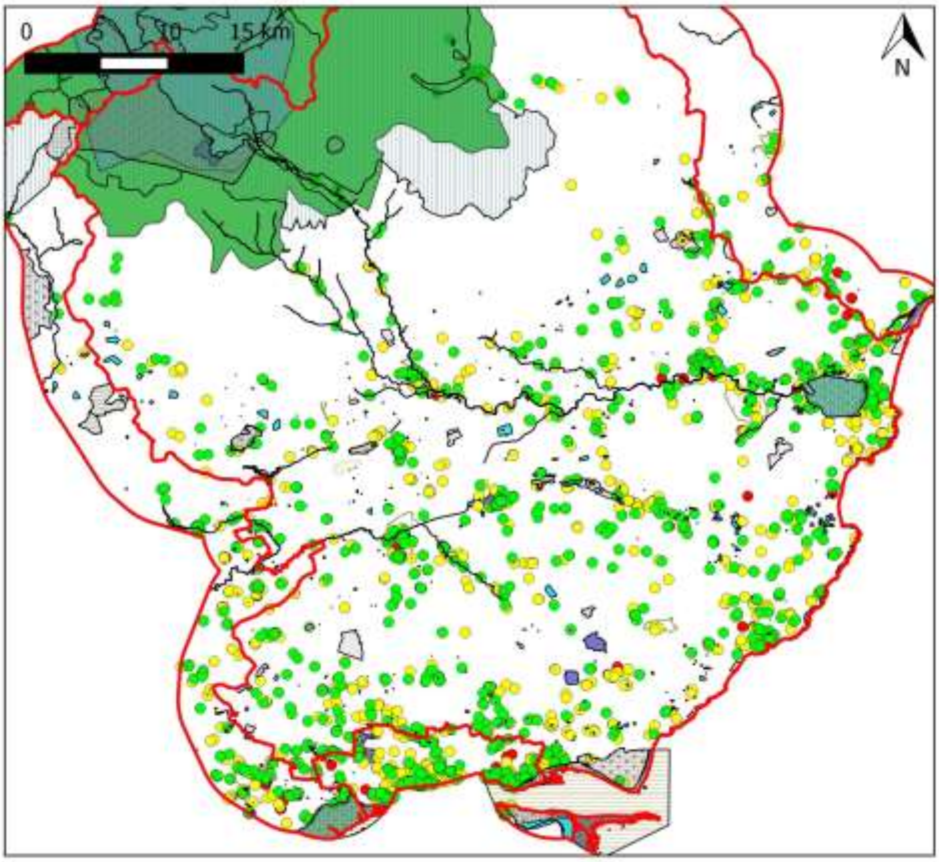
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County: Angus

Please refer section constraints map legends for informations about idenitifying constraints in this map



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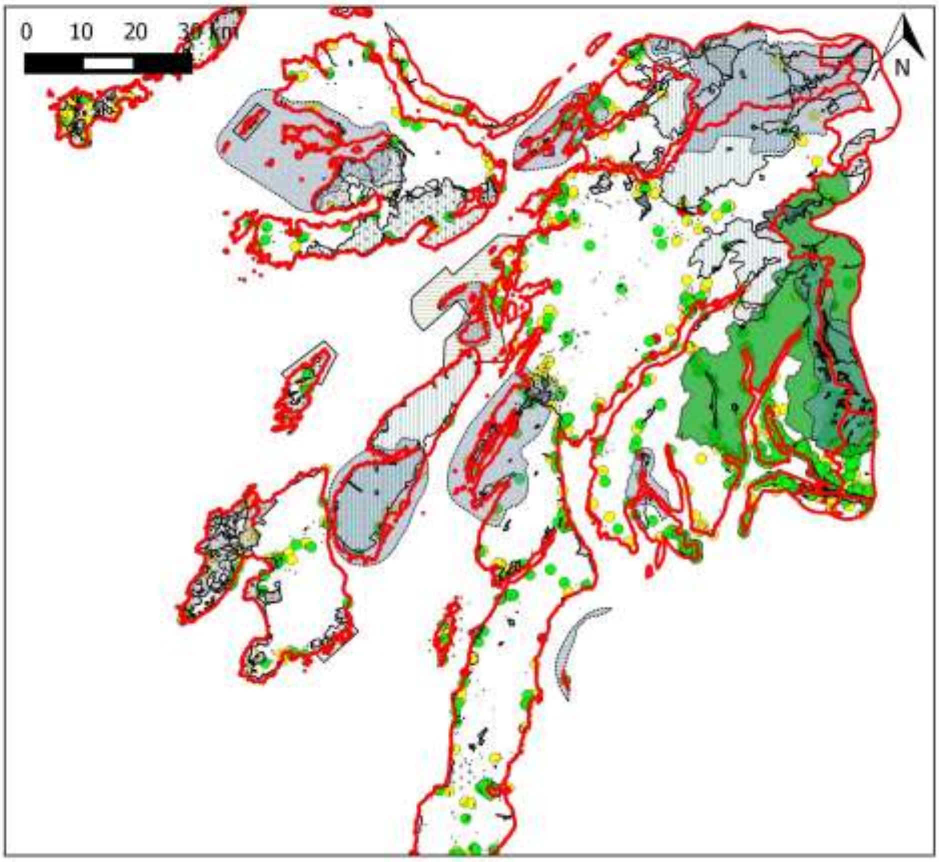
UK County level Constraints Map

County: Argyll and Bute

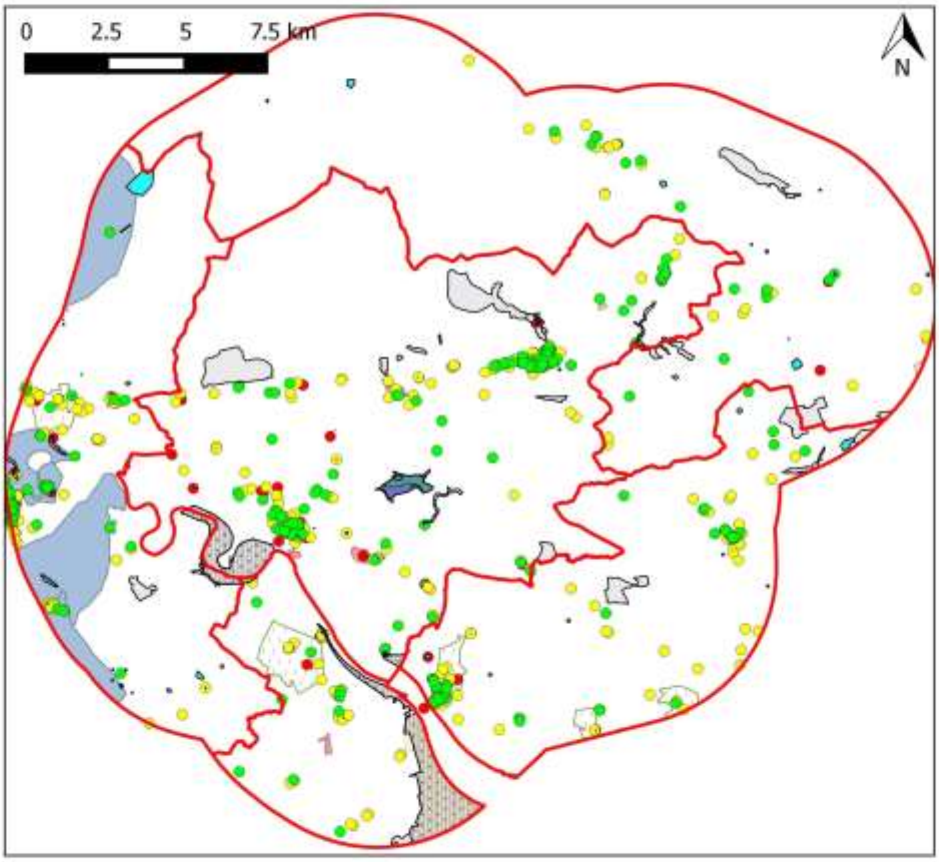
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County:Cackmannanshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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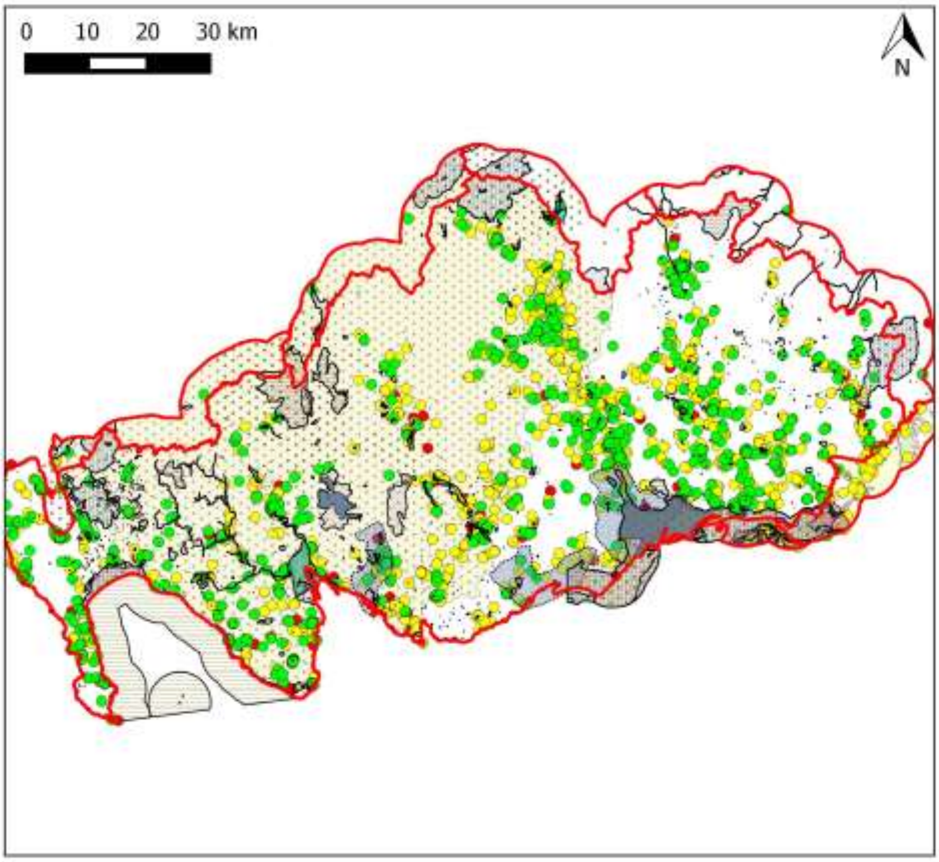
UK County level Constraints Map

County: Dumfries and Galloway

Please refer section constraints map legends for informations about idenitifying constraints in this map



Created For: CGE Project 163 Final Report October 2015
Created by: Yogeswaran Sundara Murthi
Created on: 18/10/2015

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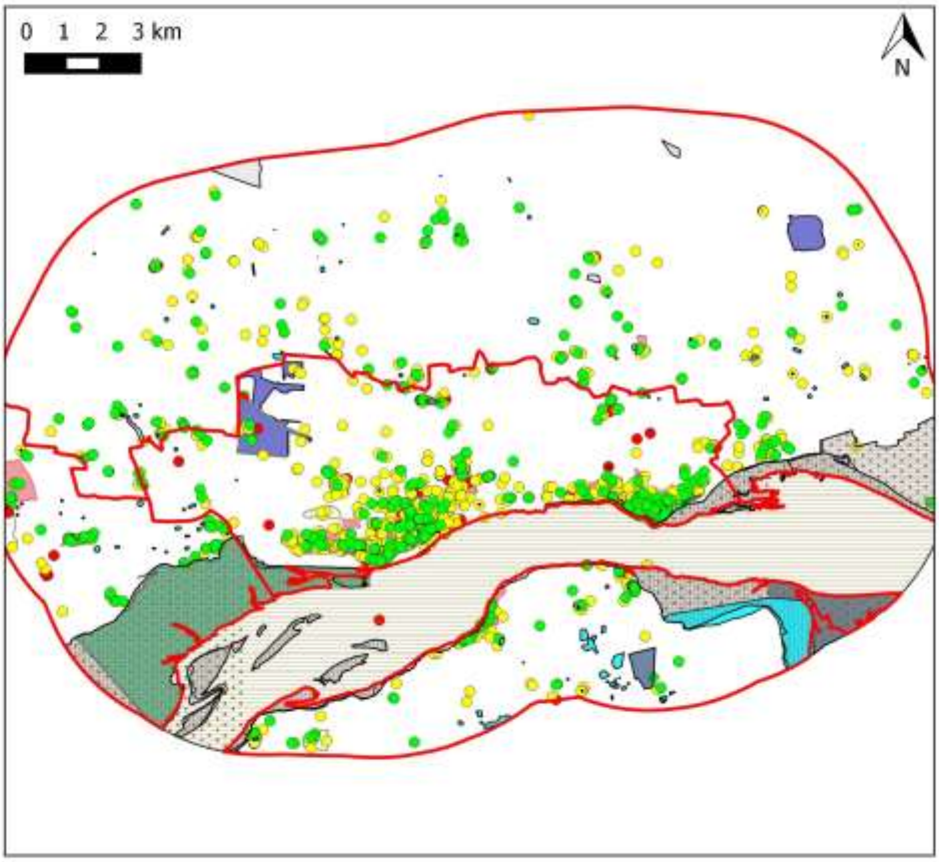
UK County level Constraints Map

County: Dundee

Please refer section constraints map legends for informations about idenitifying constraints in this map



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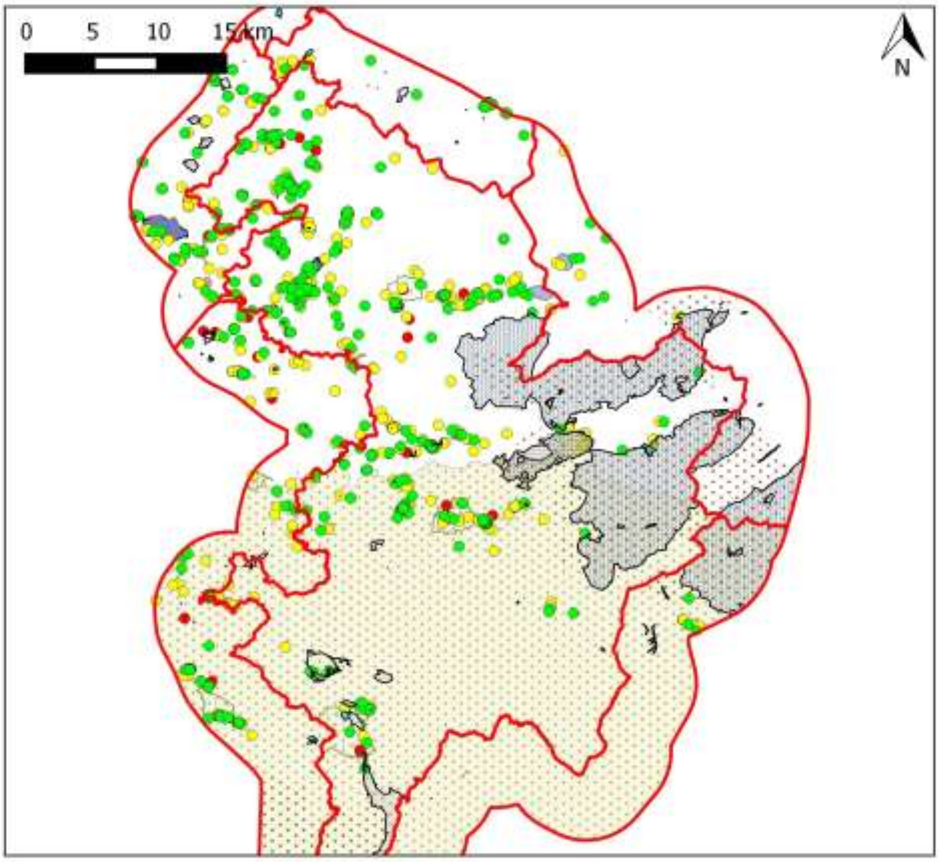
UK County level Constraints Map

County: East Ayrshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



Disclaimer: [illegible]

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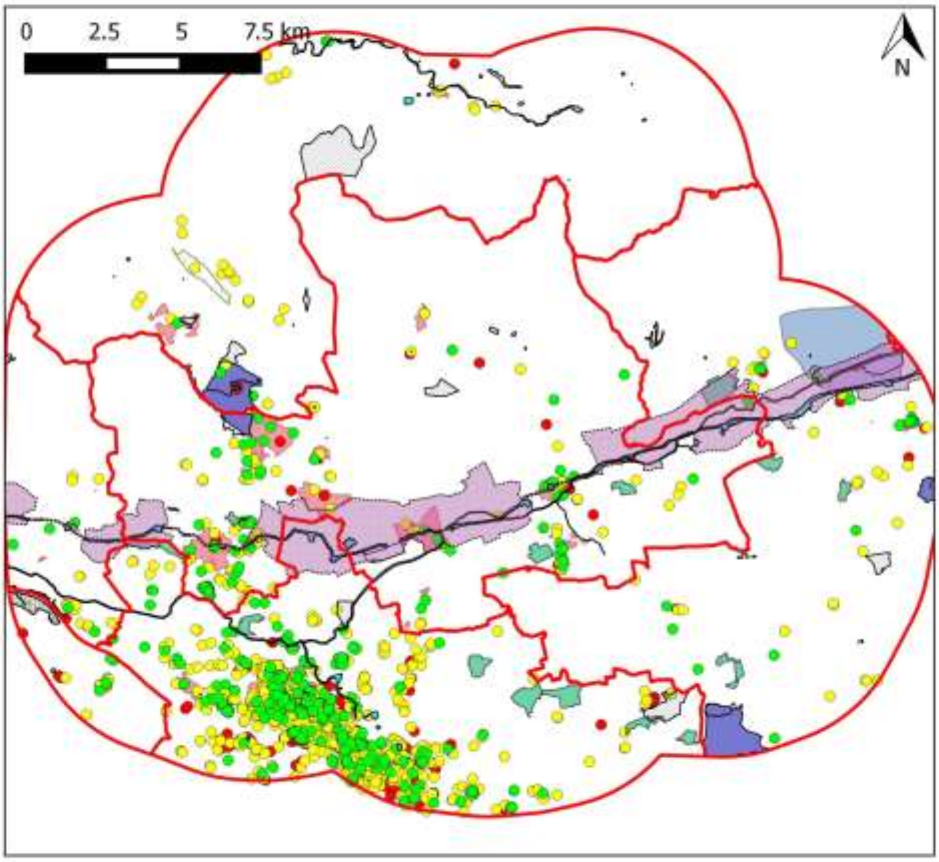
UK County level Constraints Map

County: East Dunbartonshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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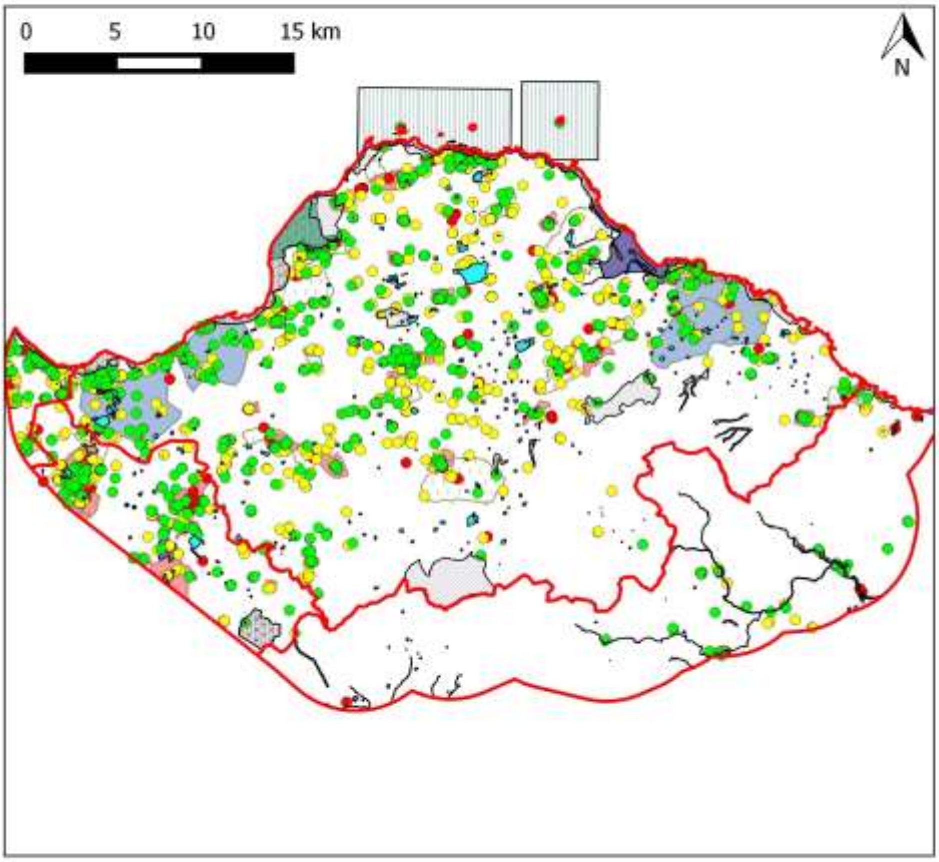
UK County level Constraints Map

County: East Lothian

Please refer section constraints map legends for informations about idenitifying constraints in this map



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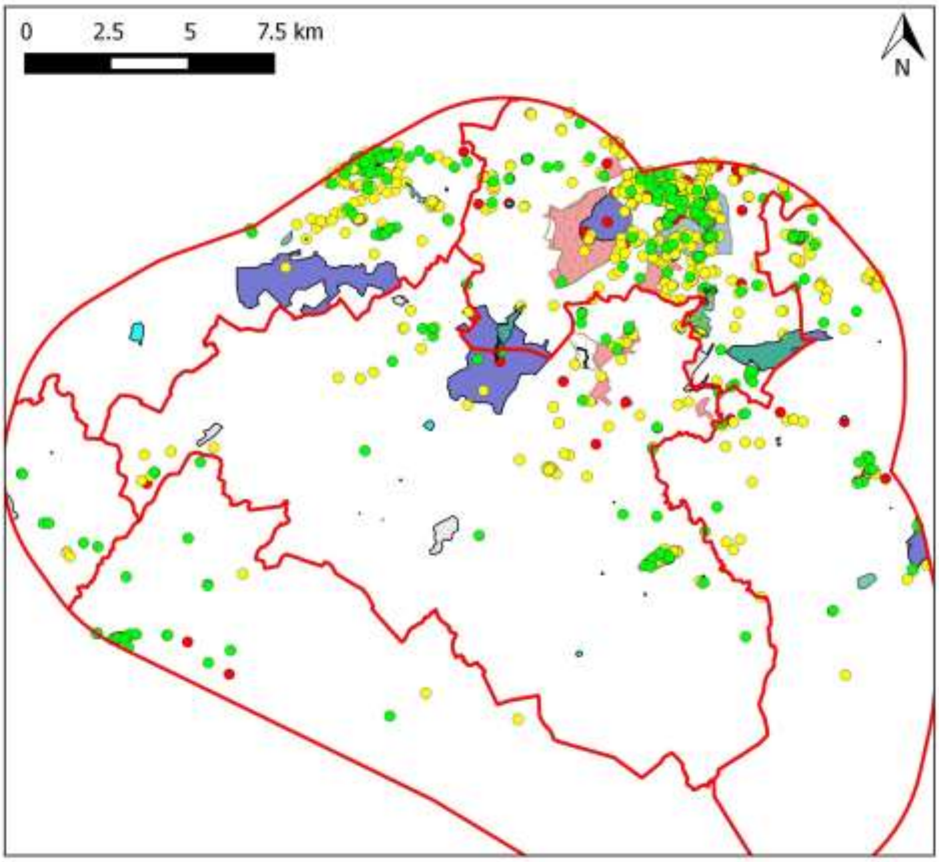
UK County level Constraints Map

County: East Renfrewshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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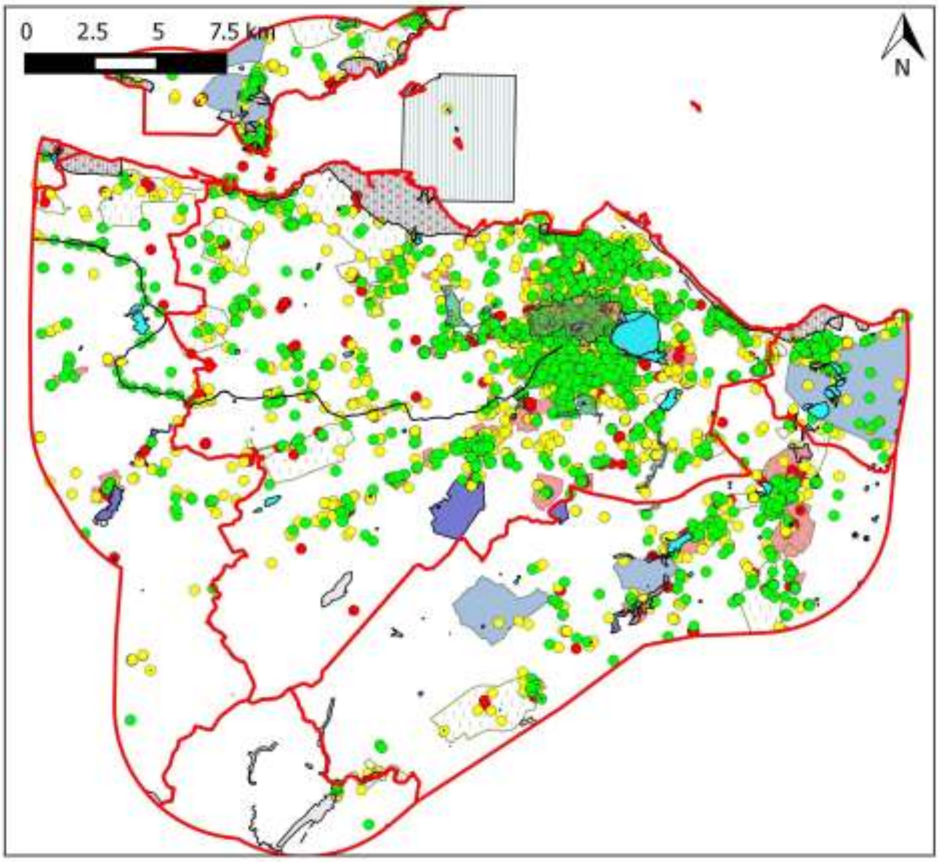
UK County level Constraints Map

County: Edinburgh

Please refer section constraints map legends for informations about idenitifying constraints in this map



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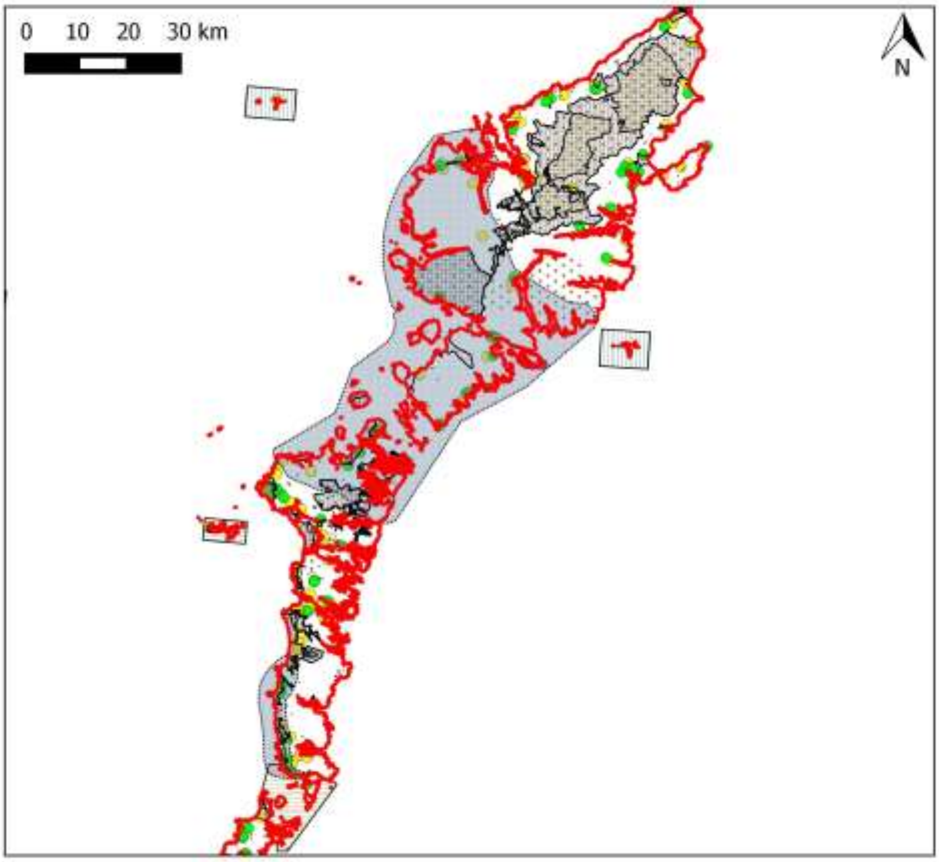
UK County level Constraints Map

County: Eilean Siar

Please refer section constraints map legends for informations about idenitifying constraints in this map



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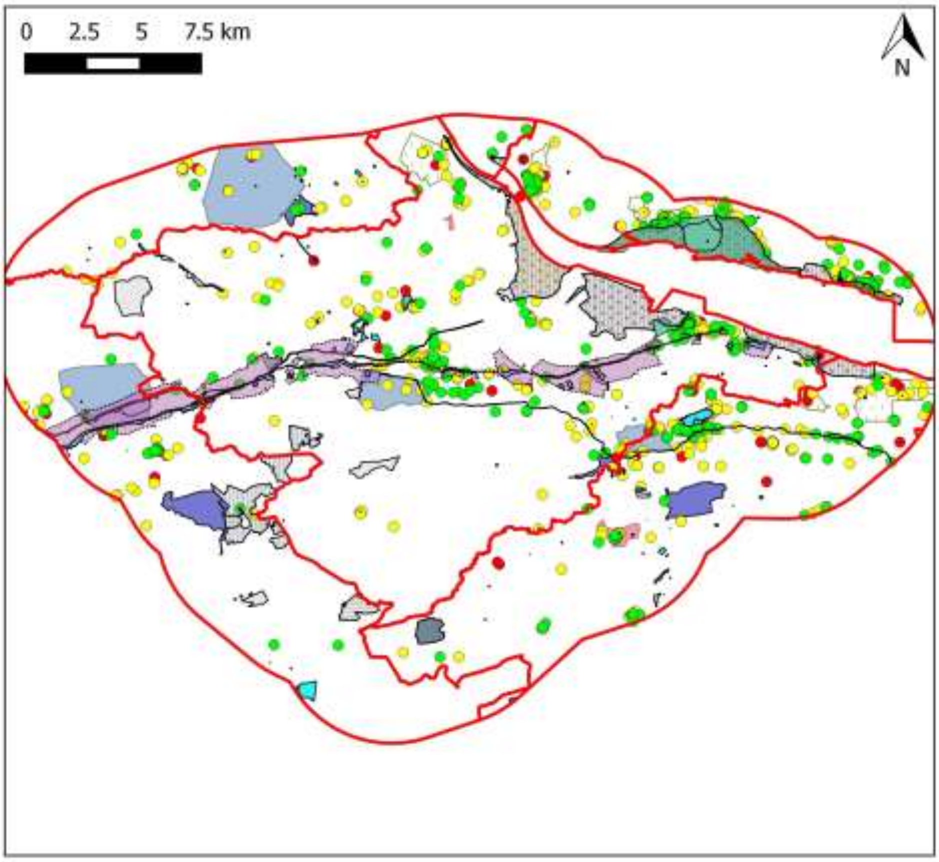
UK County level Constraints Map

County: Falkire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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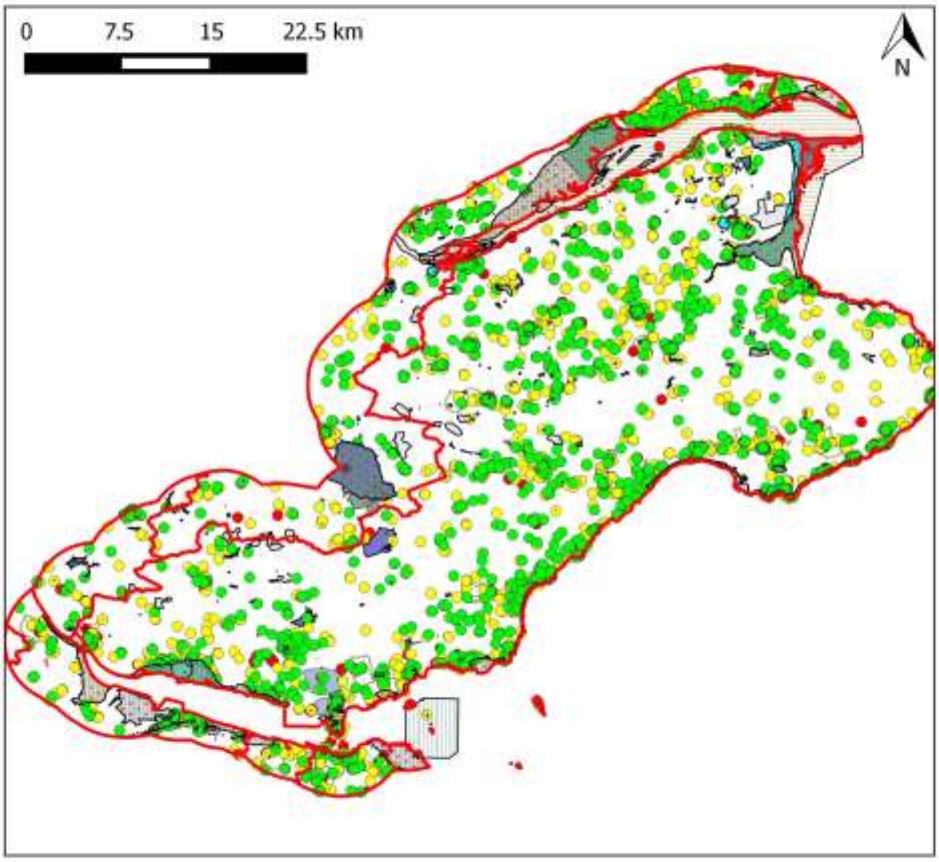
UK County level Constraints Map

County: Fife

Please refer section constraints map legends for informations about idenitifying constraints in this map



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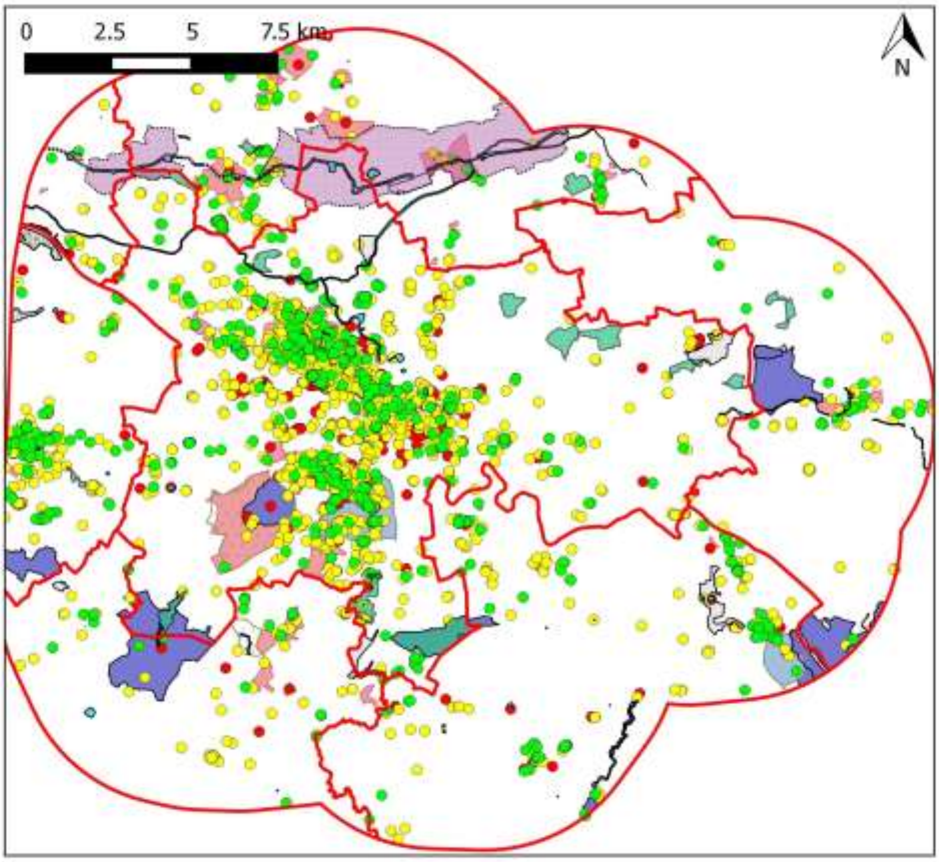
UK County level Constraints Map

County: Glasgow

Please refer section constraints map legends for informations about idenitifying constraints in this map



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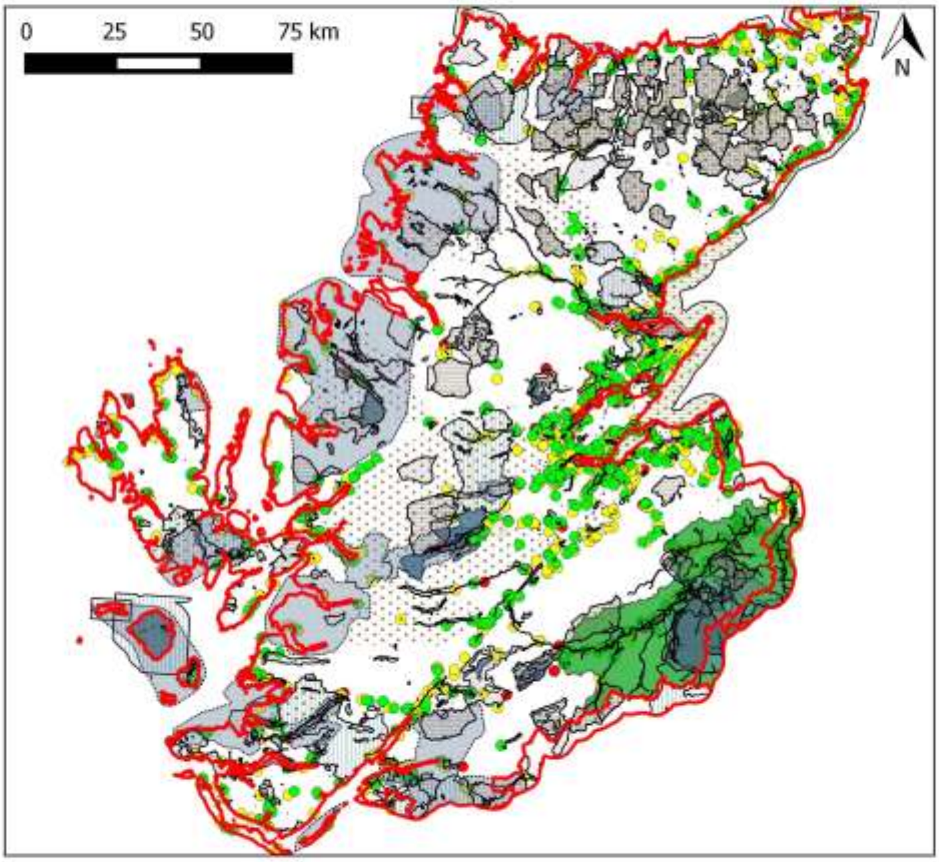
UK County level Constraints Map

County: Highland

Please refer section constraints map legends for informations about idenitifying constraints in this map



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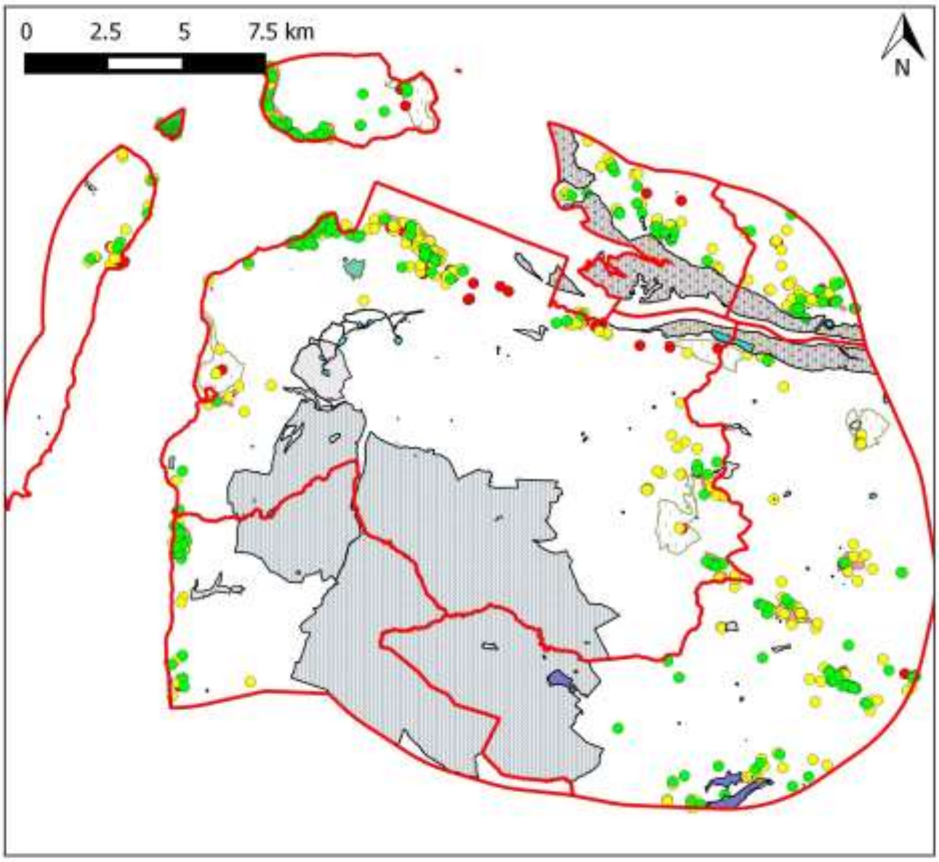
UK County level Constraints Map

County: Inverclyde

Please refer section constraints map legends for informations about idenitifying constraints in this map



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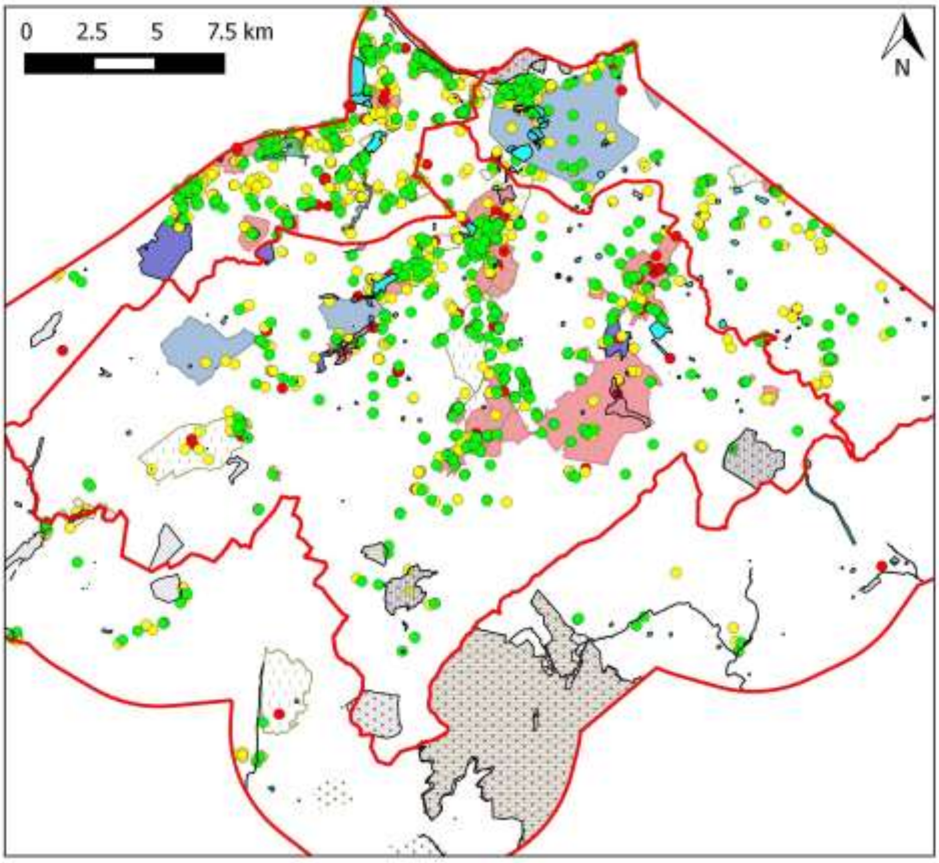
UK County level Constraints Map

County: dlothian

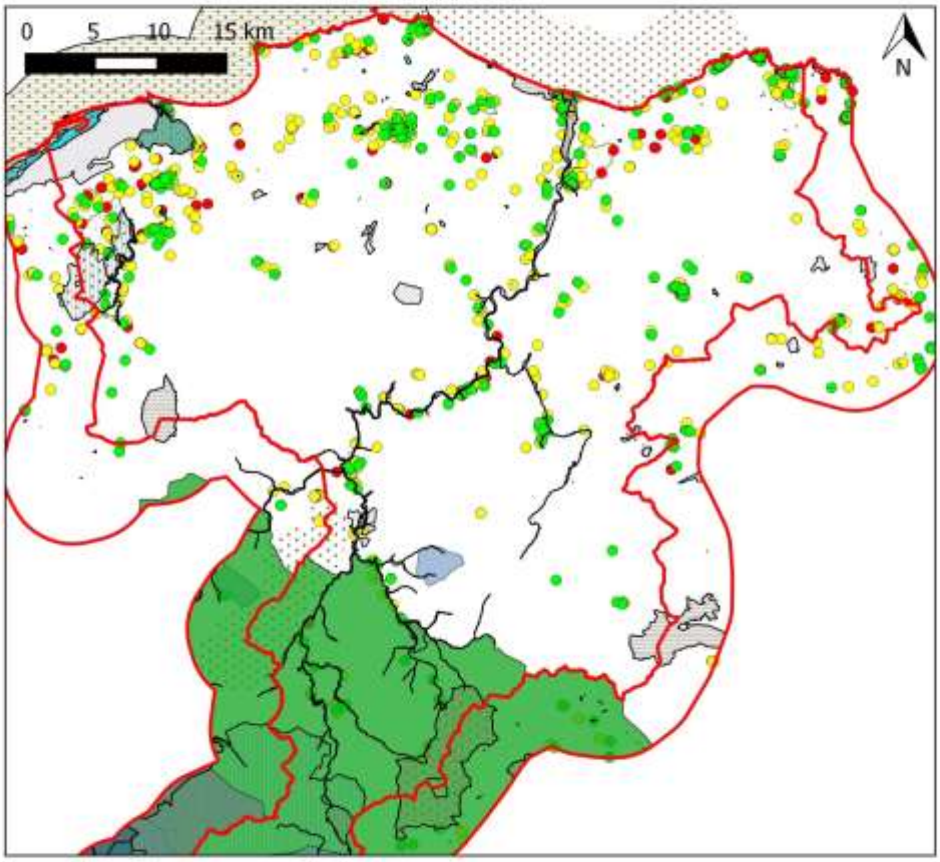
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County:Moray

Please refer section constraints map legends for informations about idenitifying constraints in this map



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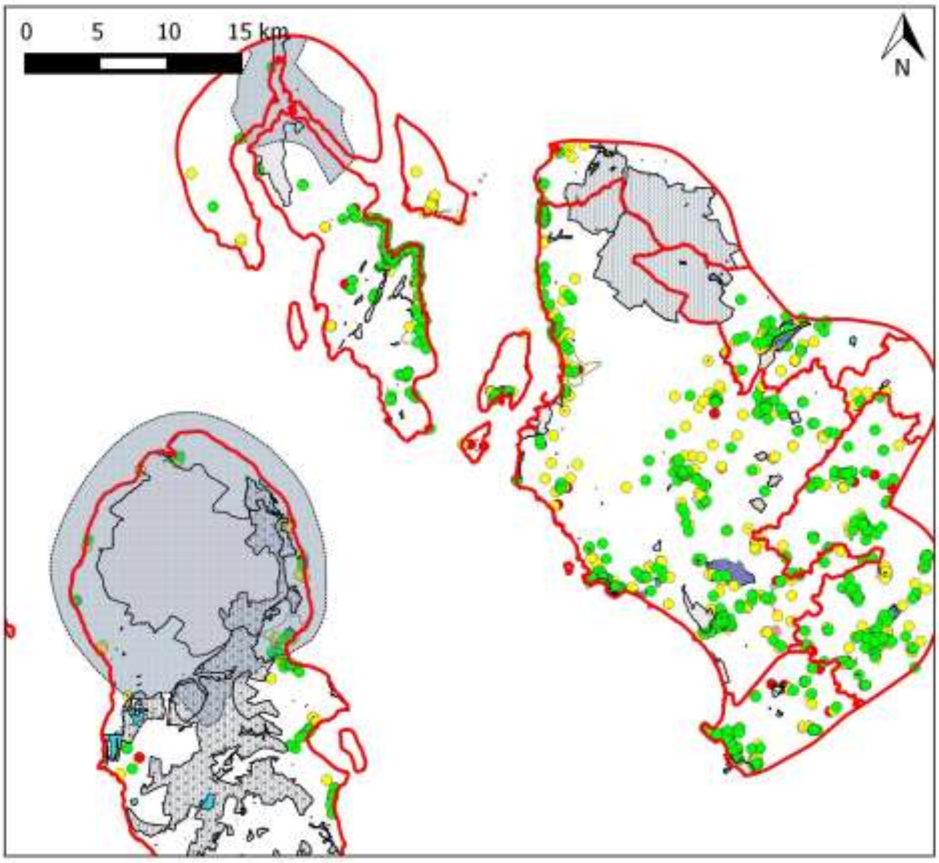
UK County level Constraints Map

County: North Ayshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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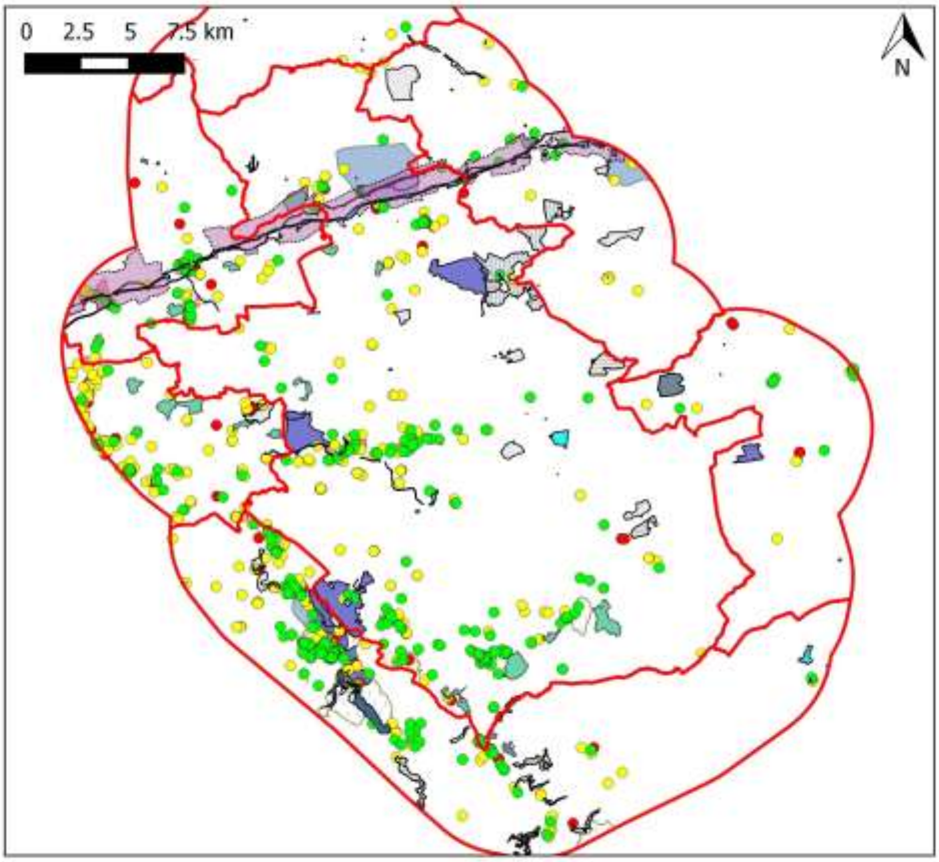
UK County level Constraints Map

County: North Lanarkshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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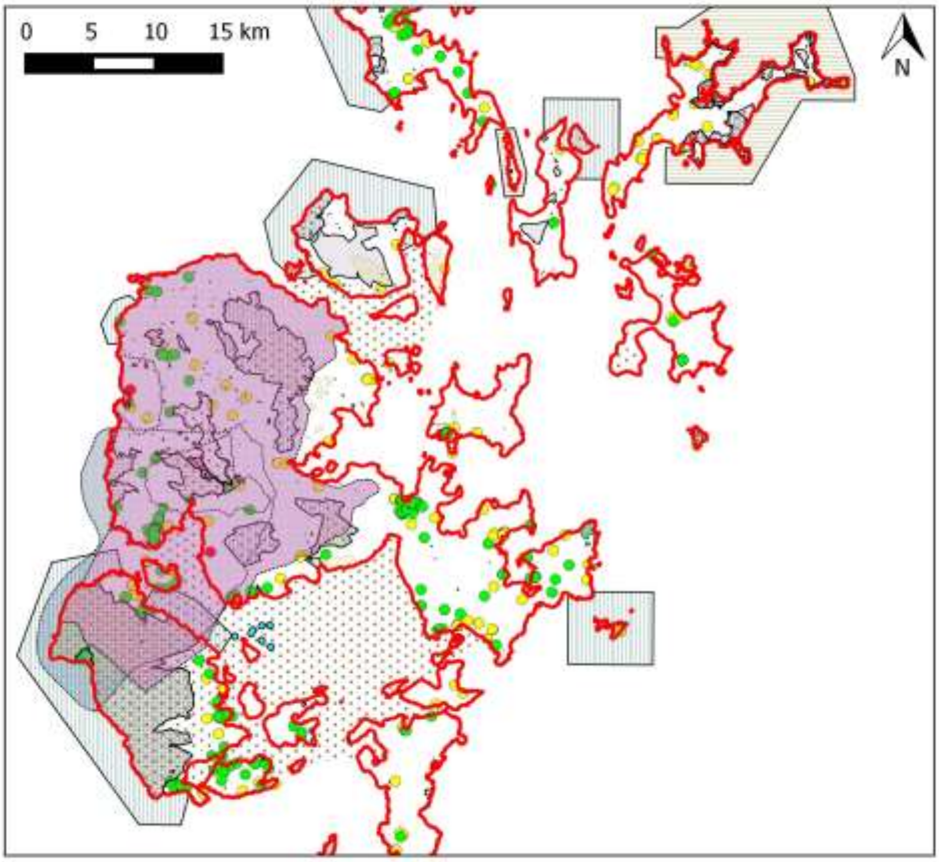
UK County level Constraints Map

County: Orkney Islands

Please refer section constraints map legends for informations about idenitifying constraints in this map



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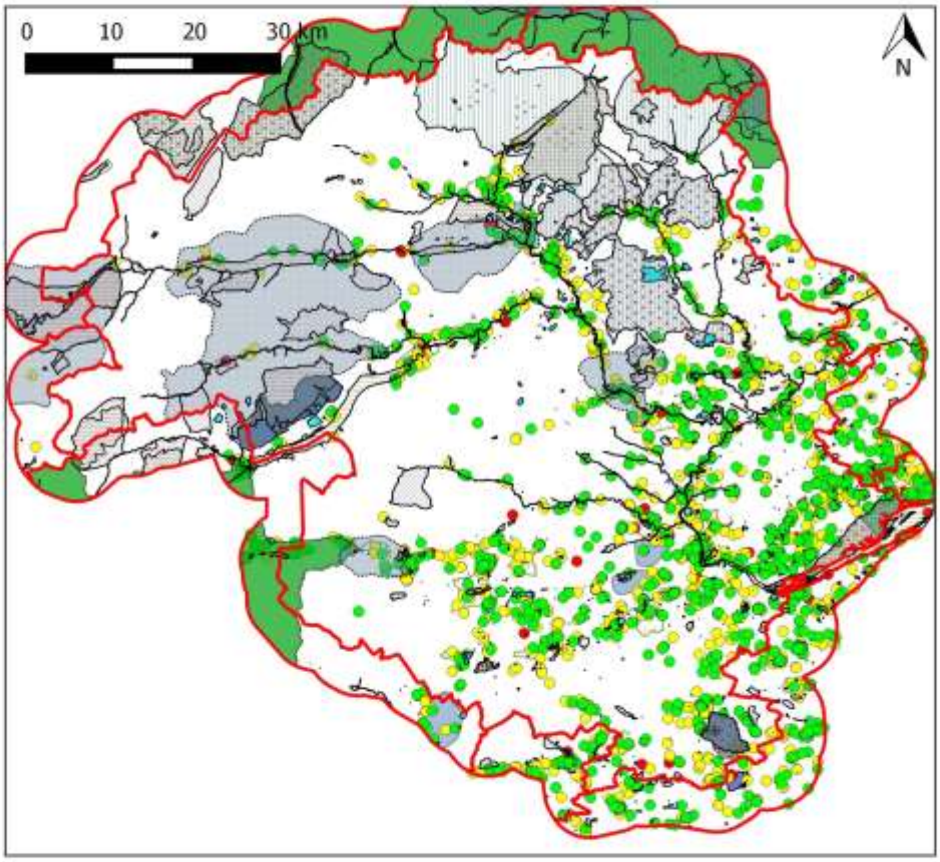
UK County level Constraints Map

County: Perthshire and Kinross

Please refer section constraints map legends for informations about idenitifying constraints in this map



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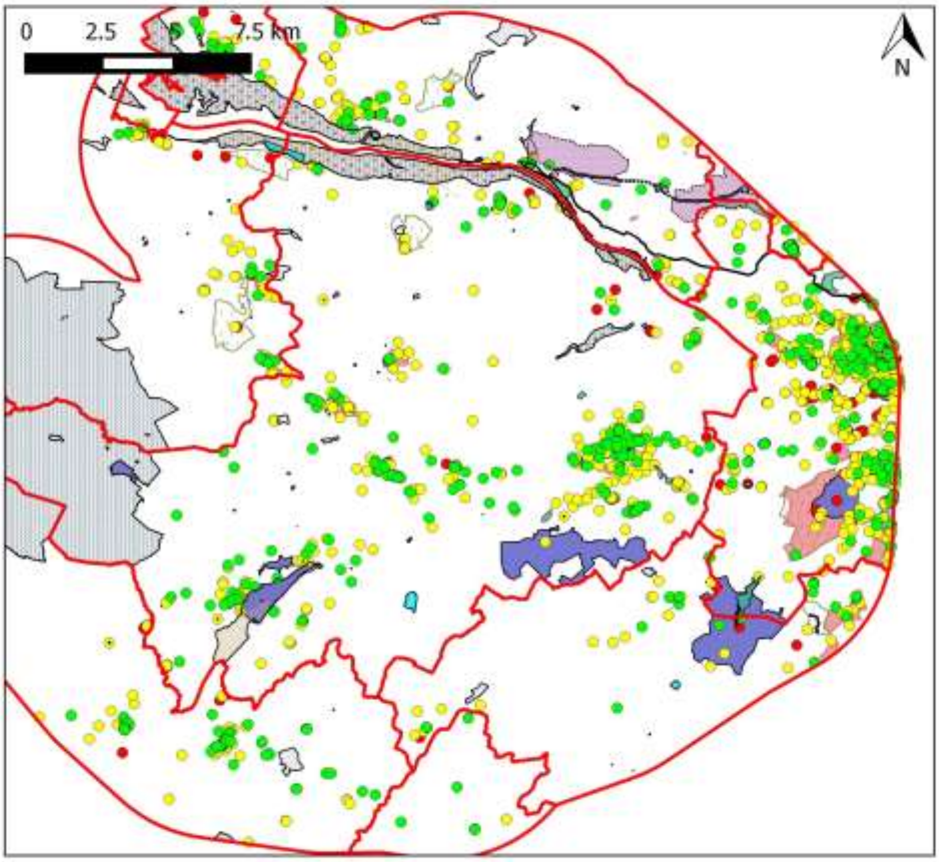
UK County level Constraints Map

County: Renfrewshire

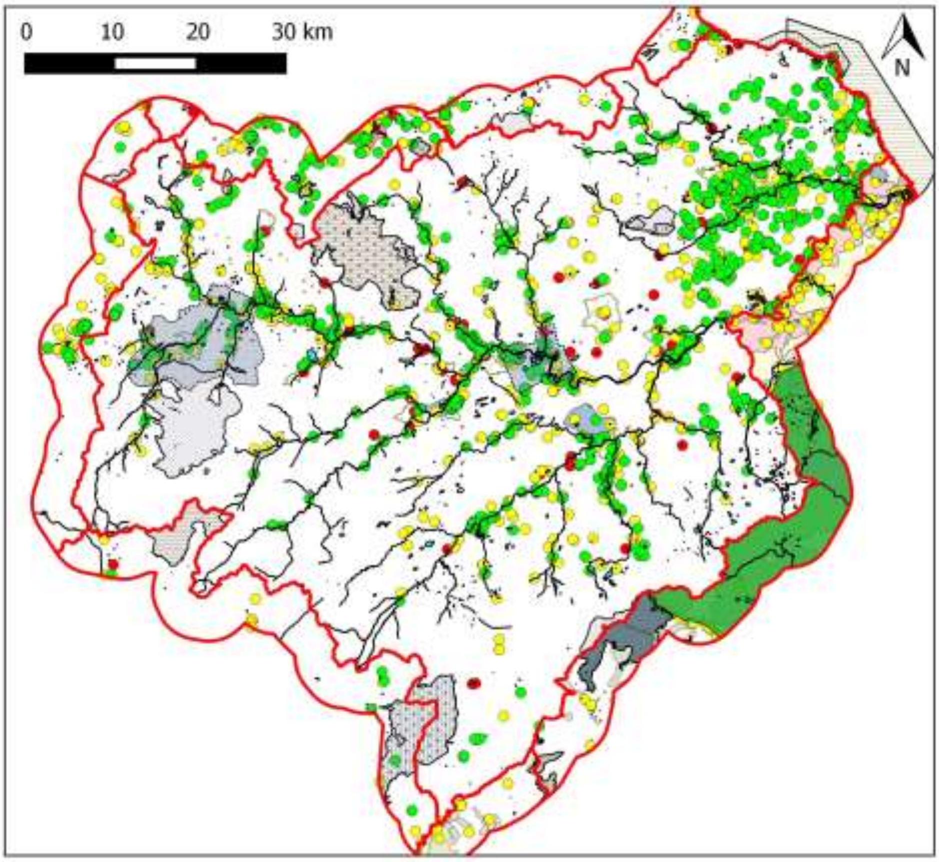
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County: Scottish Borders

Please refer section constraints map legends for informations about idenitifying constraints in this map



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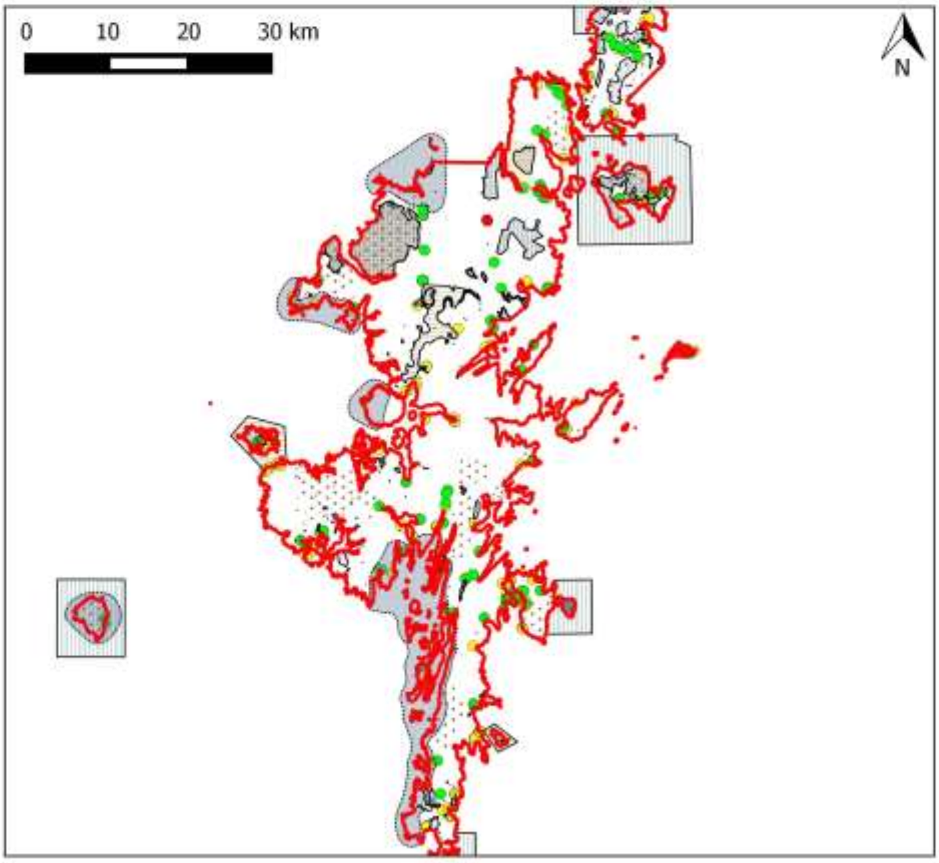
UK County level Constraints Map

County: Shetland Islands

Please refer section constraints map legends for informations about idenitifying constraints in this map



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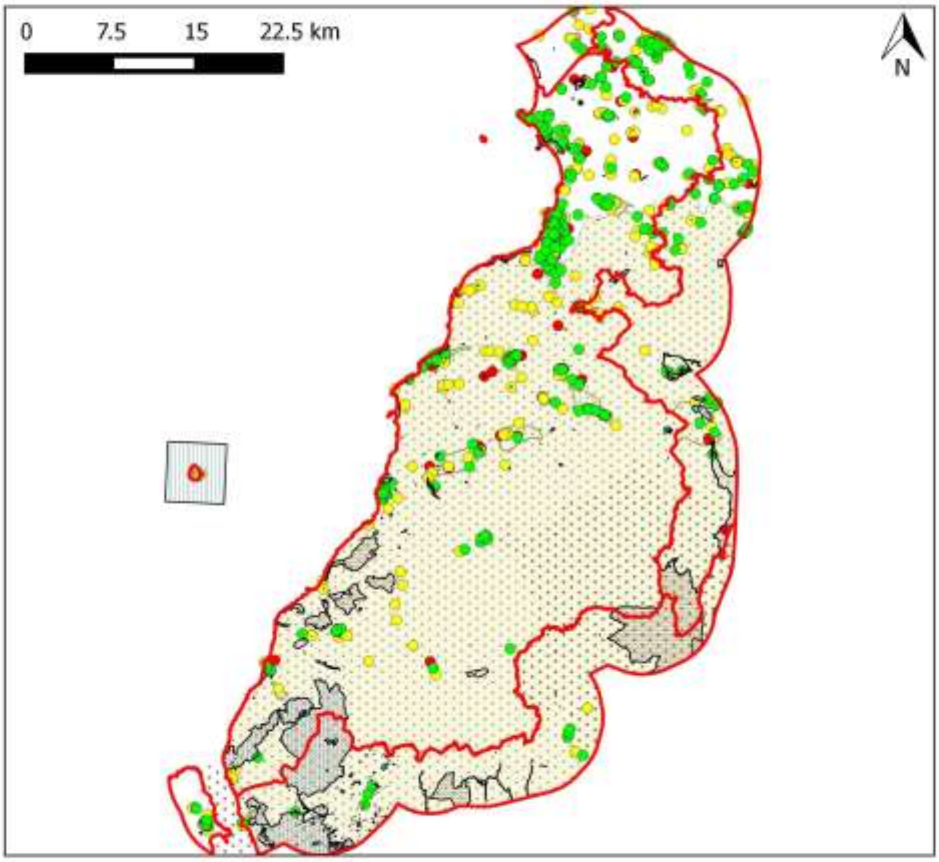
UK County level Constraints Map

County: South Ayrshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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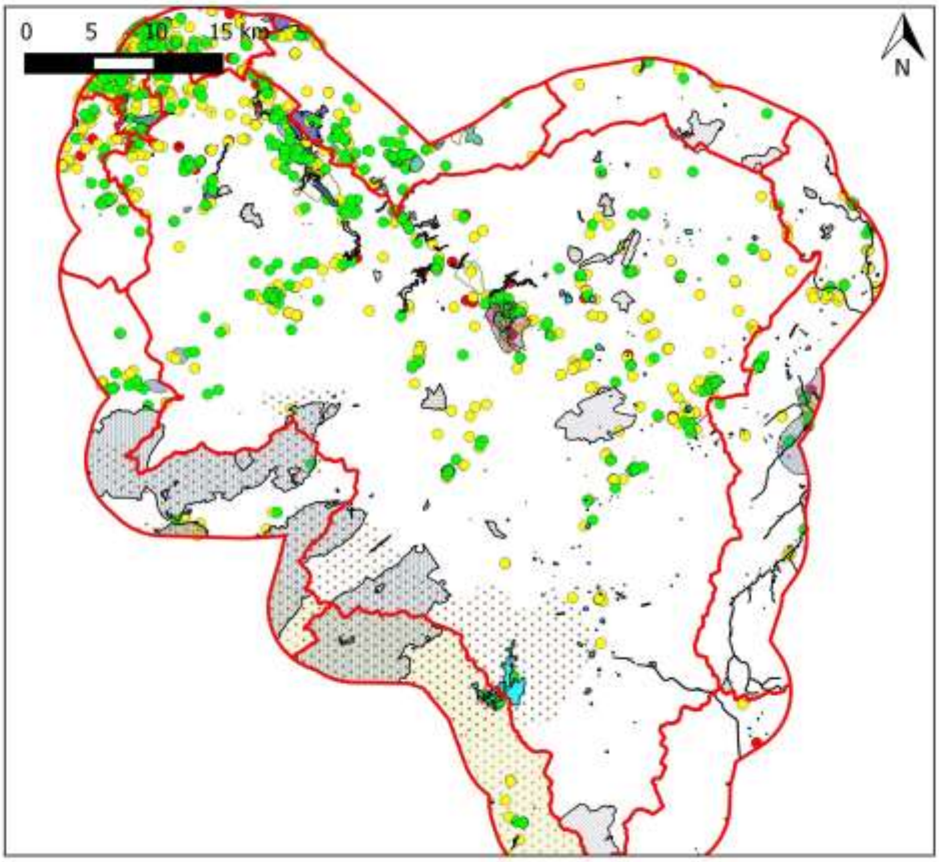
UK County level Constraints Map

County: South Lanarkshire

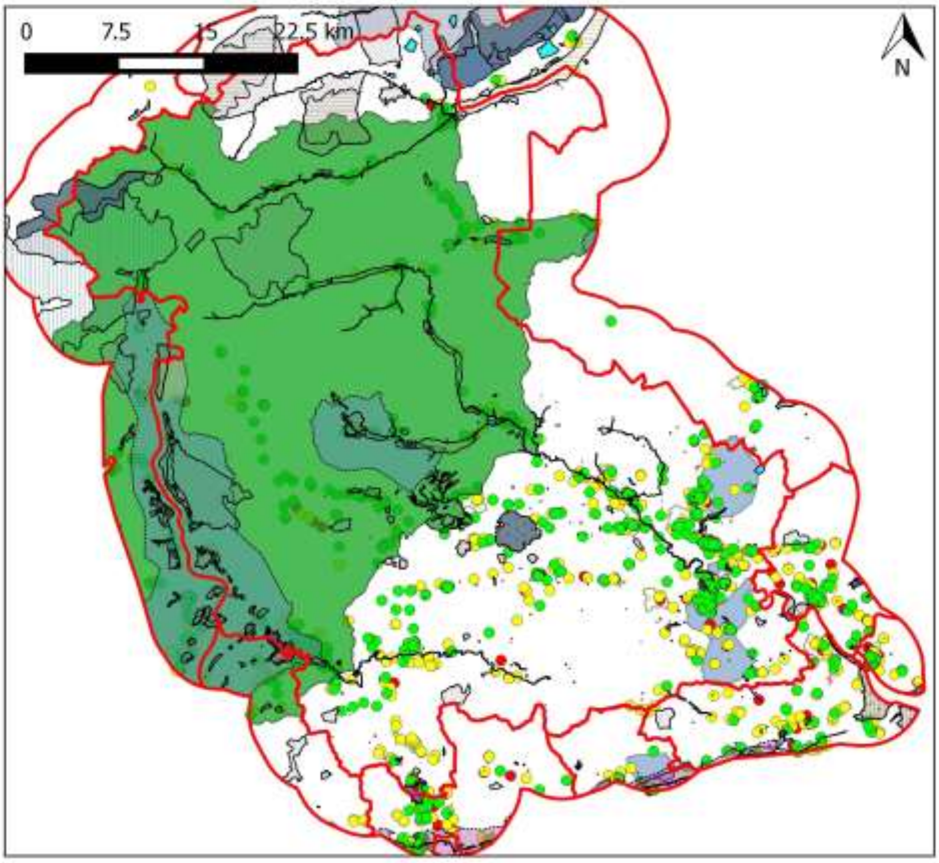
Please refer section constraints map legends for informations about idenitifying constraints in this map



UK County level Constraints Map

County: Stirling

Please refer section constraints map legends for informations about idenitifying constraints in this map



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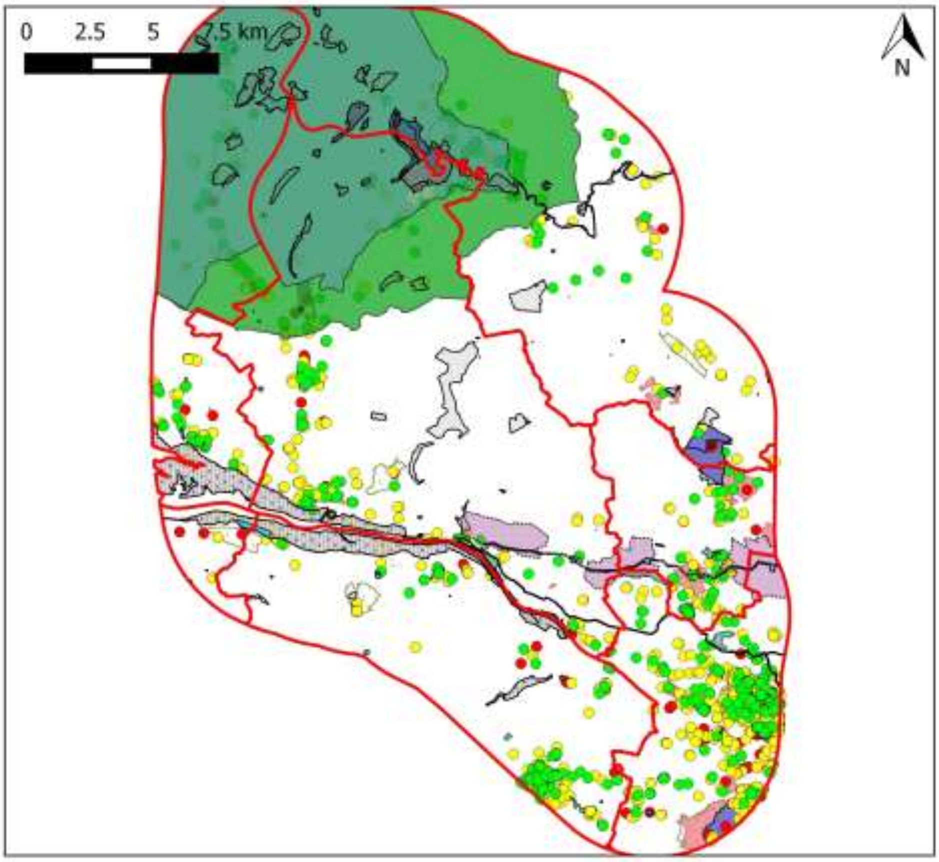
UK County level Constraints Map

County: West Dunbartonshire

Please refer section constraints map legends for informations about idenitifying constraints in this map



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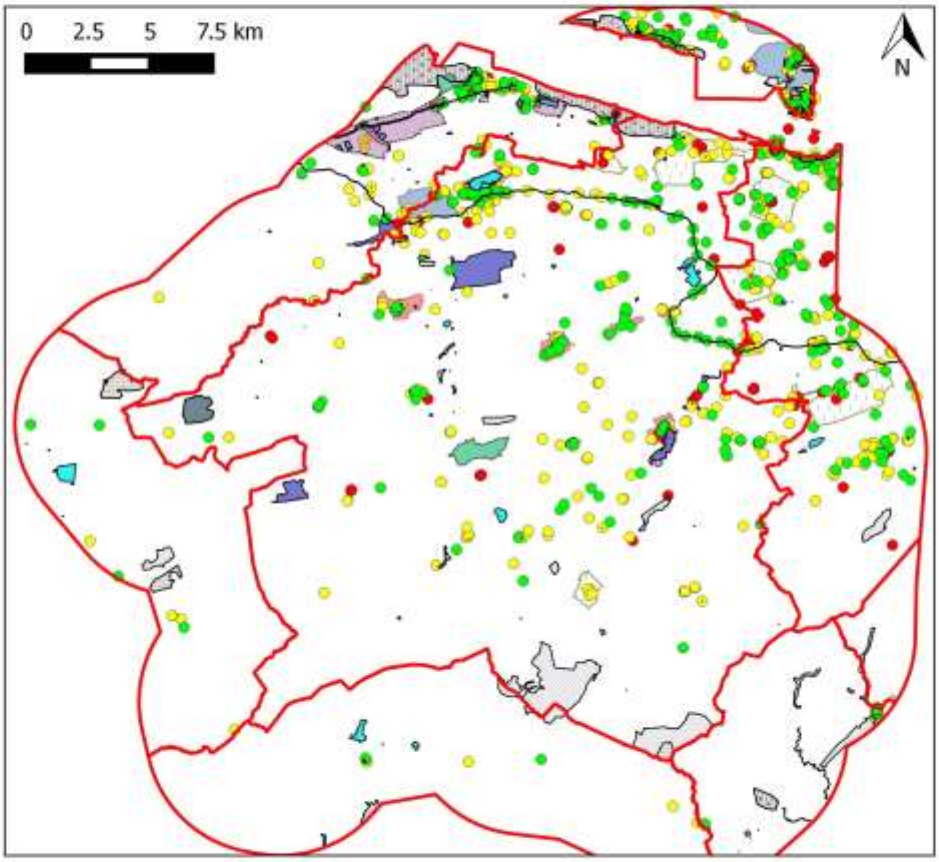
UK County level Constraints Map

County: West Lothian

Please refer section constraints map legends for informations about idenitifying constraints in this map



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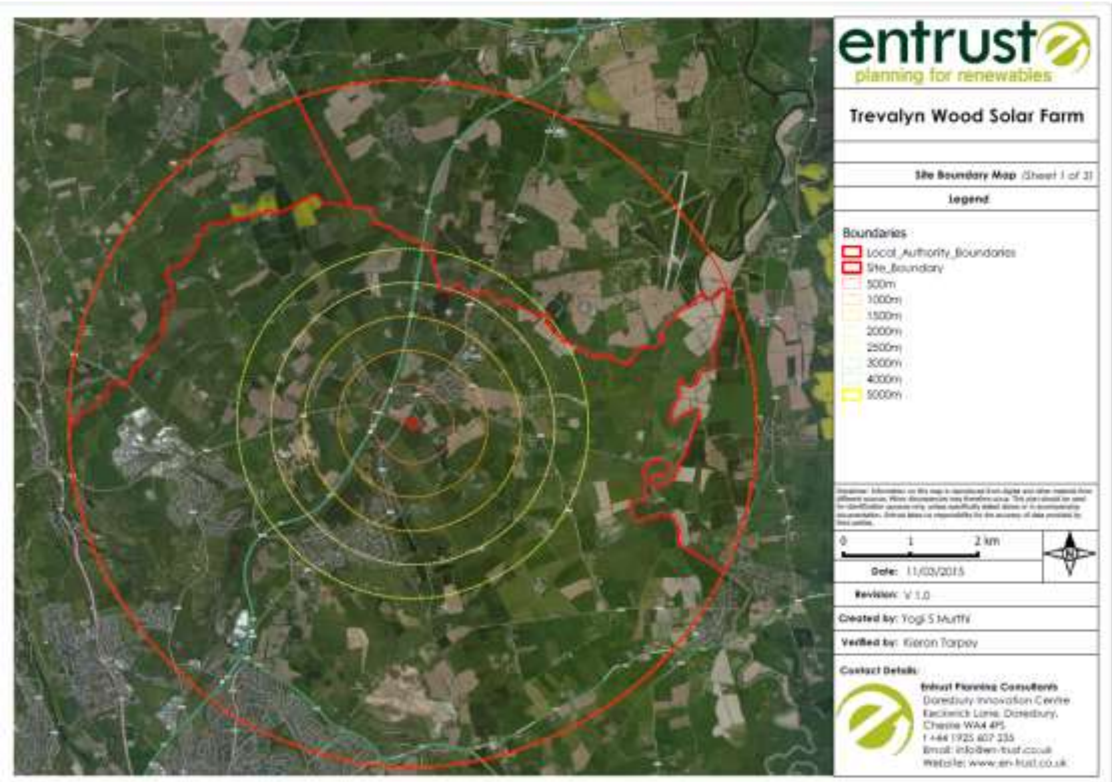
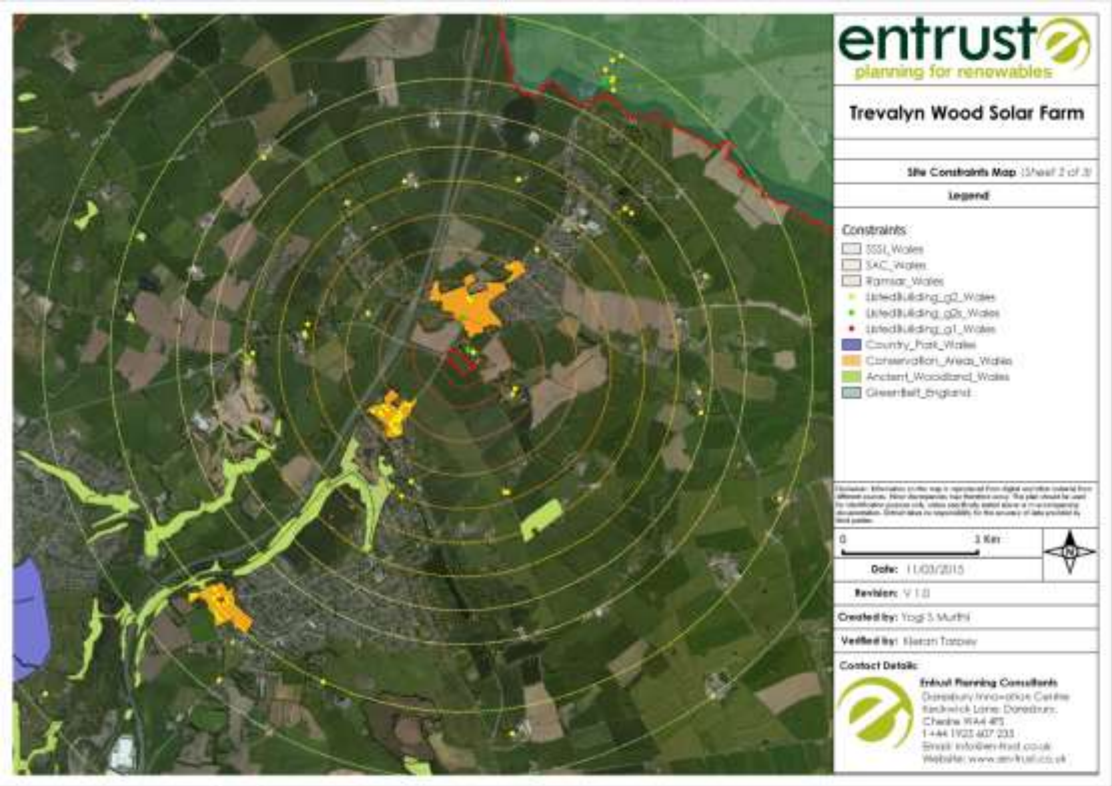
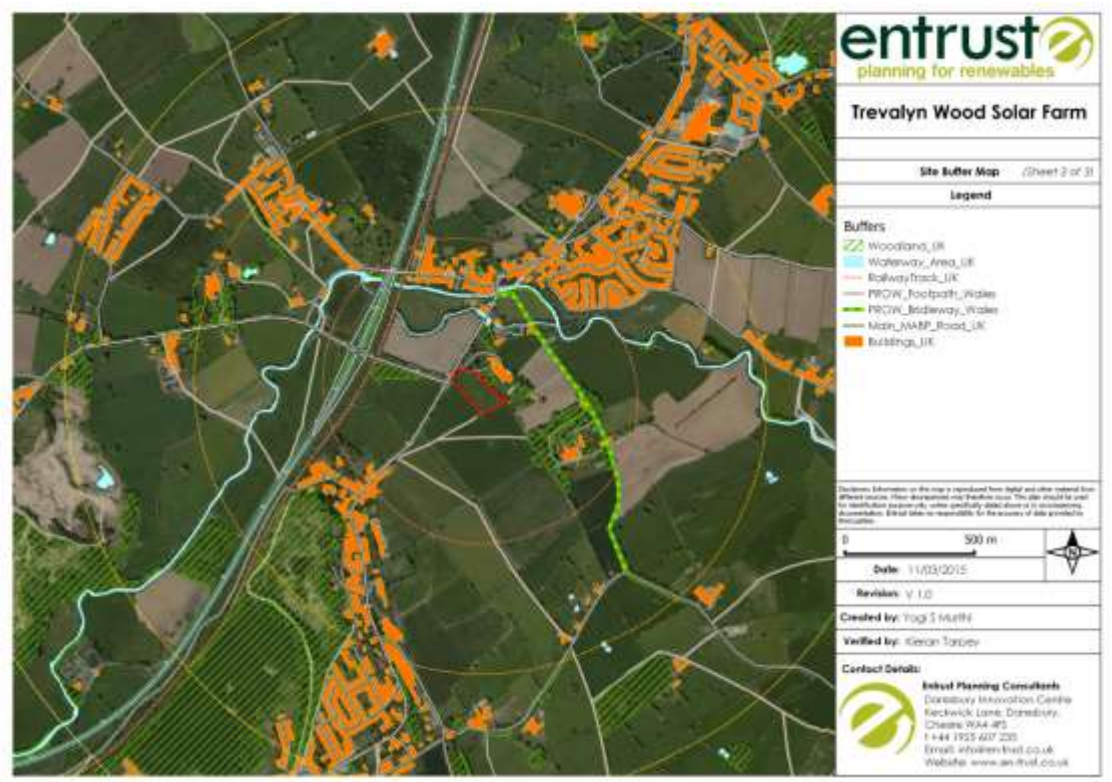


Sample Solar farm development site boundary maps generated using GIS framework.



Sample Solar farm development planning constraints maps generated using GIS framework.



Sample Solar farm development planning buffer maps generated using GIS framework.