A GIS-Multicriteria Approach to Analyzing Noise and Visual Impacts of Wind Farms

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Land-use conflicts in facility siting can trigger public opposition in communities. A negative public perception, such as the Not-in-my-backyard (NIMBY) attitude, is a planning issue that is strongly associated with some types of siting decisions. After the Feed-in-Tariff (FIT) program through the Green Energy Act was introduced in Ontario in 2009, a large number of wind farm developments were proposed and implemented. Public concerns regarding the noise and aesthetic impacts of wind turbines have created public resistance and caused project delays. More importantly, the wind farm siting decision making process is a top-down process, which overrides the power of municipalities and ignores public concerns towards wind farms.

In this thesis, a Geographic Information System (GIS)-based multi-criteria decision analysis (MCDA) siting approach has been developed, which is capable of representing the potential noise and visual impacts caused by wind turbines in a wind farm siting process. After identifying a sample of feasible sites in Southern Ontario, the noise and visual impact assessment approaches were applied to estimate the affected-population by wind farm sites. The changes of suitability levels within each feasible site can be determined after the integration of noise and visual criteria with the common siting criteria, which include physical, environmental, planning and economic factors. This siting approach is generalizable, which means it can be applied to other facility developments that have potential noise and visual impacts to the public. The results illustrate the spatial changes of suitability level before and after introducing the noise and visual criteria into the siting process. Planners and decision makers could potentially apply this siting approach to address public concerns in the future wind farm siting decisions.

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Dedication

To my mom & dad, who have been giving me life, love, happiness and the courage to pursue my dreams!

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Chapter 1 Introduction

Spatial conflicts in facility site selections can potentially trigger public concerns within local communities. Waste sites, nuclear power plants and wind farms are examples of facilities that have contributed to the rise in local opposition towards these types of developments. Specifically, negative public attitudes toward large-scale wind farms in close proximity to nearby residents and on valued landscapes, have become a planning issue. Negative attitudes towards wind energy also has been recognized as a major barrier to achieving the targets of electricity generation and in some cases has been a contributing factor in delaying the project developments (Devine-wright, 2007). In 2009, the province of Ontario introduced the Feed-in-Tariff (FIT) program through the Green Energy Act (GEA), which provides incentives to renewable energy projects (Ontario Power Authority, 2014a). The intention of the Ontario FIT program is to create an effective way to promote the renewable energy market development (Pirnia, Nathwani & Fuller, 2011). The large scale of wind turbine implementations in the communities of Ontario has also resulted in negative impacts, including noise and visibility on the residents who live within the vicinity of a wind farm. As the municipalities in Ontario do not have control over the wind farm decision-making process, public opinions and concerns towards developments are usually overridden, which has led to social conflicts (Baxter, Morzaria, & Hirsch, 2013). As a result, local residents have started to question the fairness of the siting decision process (Bidwell, 2013).

A *Wind Farm* is “an area of land with a cluster of wind turbines for driving electrical generators” (Merriam-Webster’s online dictionary, n.d.). Studies on wind farm selection have been conducted in other areas such as Lesvos, Greece, Northwest Ohio, Sierra de Pela and Northern California (Chias & Abad, 2013; Gorsevski et al., 2013; Rodman & Meentemeyer, 2006; Tegou, Polatidis, & Haralambopoulos, 2010). As a number of wind turbines were implemented in the communities of Ontario after the FIT program, public concerns including turbine noise and landscape visibility were presented (Baxter, et al., 2013). However, there is a general lack of studies on wind farm site selections in Ontario. In a typical wind farm siting process, physical, environmental, planning and economic factors are the most commonly used siting criteria (Baban & Perry, 2001; Tegou et al., 2010). On the contrary, public concerns that affect the public acceptance towards wind farm projects, such as aesthetic and noise effects, are not often integrated as siting criteria in the siting process. The noticeable structure, the height of wind turbines to the surrounding landscape, and the location of wind turbines can significantly affect people who live within their vicinity (Wolsink, 2007). Another impacting factor is the noise generated by wind turbines, which can lead to health issues and annoyance-induced stress to surrounding residents (Horner, Jeffery, & Krogh, 2012).

Mourmouris & Potolias (2013) and Christidis & Law (2012) stated that social constraints are important factors in determining optimal wind farm locations. It is worthwhile for planners and decision makers to note that some of the wind farm siting processes lack a decision making process of tackling spatial siting conflicts and resolving public concerns (Heagle, Naterer, & Pope, 2011). A decision process that addresses the public concerns toward wind farm siting could help decision makers to gain public support (Bell, Gray, & Haggett, 2005). As a result, a generalizable spatial siting approach that can identify potential noise and visual impacts of wind farm facilities is needed.

A Geographic Information System (GIS)-based multi-criteria decision analysis (MCDA) siting approach that combines the common wind farm siting criteria with noise and visual concerns, which have not been adequately considered before, should be integrated into wind farm site planning process. GIS applications have been widely applied to different planning practices, particularly in wind farm developments (Baban & Parry, 2001; Christidis & Law, 2012; Karakostas & Economou, 2014). GIS is also a powerful technique that can be used in analyzing spatial information and examining the impacts of noise and aesthetic factors of wind farm developments. GIS-based MCDA is a group of techniques that are designed to compare decision alternatives and integrate geographic data with decision maker's preferences (Malczewski, 2011). It is a collaborative tool that can help involve public opinions and concerns in the decision process at the very early planning stage (Gorsevski et al., 2013).

In this research, a wind farm siting approach was designed with the integration of estimated turbine noise and visibility into the siting decisions. Overall, the results of the siting approach can help decision makers to visualize and identify the optimal locations within each feasible wind farm site. The noise and visual impact siting approaches were developed to spatially represent and estimate the populations affected by wind farm facilities. The siting approach could assist decision makers to incorporate the potential impacts of wind farms in order to alleviate spatial conflicts in land-use planning. Moreover, this siting approach can also be generalized to be applied to other types of facility developments as a profound significance in promoting the integration of noise and visual factors into a siting decision making process.

1.1 Research Objectives

Three research objectives that will be explored in this study are:

1. To develop a siting approach for determining the affected population by potential noise and visual impacts of wind turbines.

2. To visualize and identify the changes of suitability level within feasible wind farm sites by integrating noise and visual criteria with other siting criteria including physical, environmental, economic and planning.

3. To provide recommendations for the integration of noise and visual impacts of wind farms into future siting decisions.

1.2 Organisation of the thesis

This thesis includes five chapters. Chapter 2 presents the current literature related to spatial conflicts in infrastructure planning, especially with respect to wind farm developments. The Ontario Feed-in-Tariff (FIT) program and the associated planning issues are discussed. Major concerns such as noise, aesthetic and environmental effects of wind farms are also discussed. This chapter also compares different facility siting methods to address the importance of using GIS-based MCDA approach in a wind farm siting decision process.

Chapter 3 describes the method of developing a GIS-based MCDA wind farm siting approach, with a specific focus on Southern Ontario. A detailed discussion on the criteria and constraints of site screening process, and the spatial approaches that estimate the affected population of noise and visual impacts are presented. This chapter also discusses the Entropy Information method, which is an objective weighting method that generates weights for criteria. The global Weighted Linear Combination (WLC) and local WLC standardization techniques will also be presented in this chapter.

Chapter 4 presents a sample of feasible areas to build wind farms in Southern Ontario. The population affected by noise and visual impacts of wind farms in Dufferin County and Chatham-Kent is also calculated and presented. The changes in suitability level within each feasible site before and after the noise and visual criteria have been incorporated are also discussed.

Chapter 5 concludes by summarizing the findings, contributions and limitations of this research. This chapter also provides recommendations to the integration of noise and visual impacts of wind farm site selection into future siting decisions.

Chapter 2 Literature Review

This chapter outlines and summarizes the major concepts that are related to the objectives of this research. Section 2.1 identifies the spatial conflicts that are often encountered in infrastructure planning. Section 2.2 discusses the challenges of wind farm developments as well as the relevant policy and planning issues. Section 2.3 outlines major public concerns toward wind farm developments, such as aesthetic effects, environmental concerns and noise effects. Section 2.4 investigates the role of GIS-based MCDA in wind farm site selection and explores a number of facility siting methods that were proposed in literature. Section 2.5 provides a conclusion of this chapter and introduces the objectives of Chapter 3. Figure 2.1 illustrates the structure of this chapter and its relevant topics.

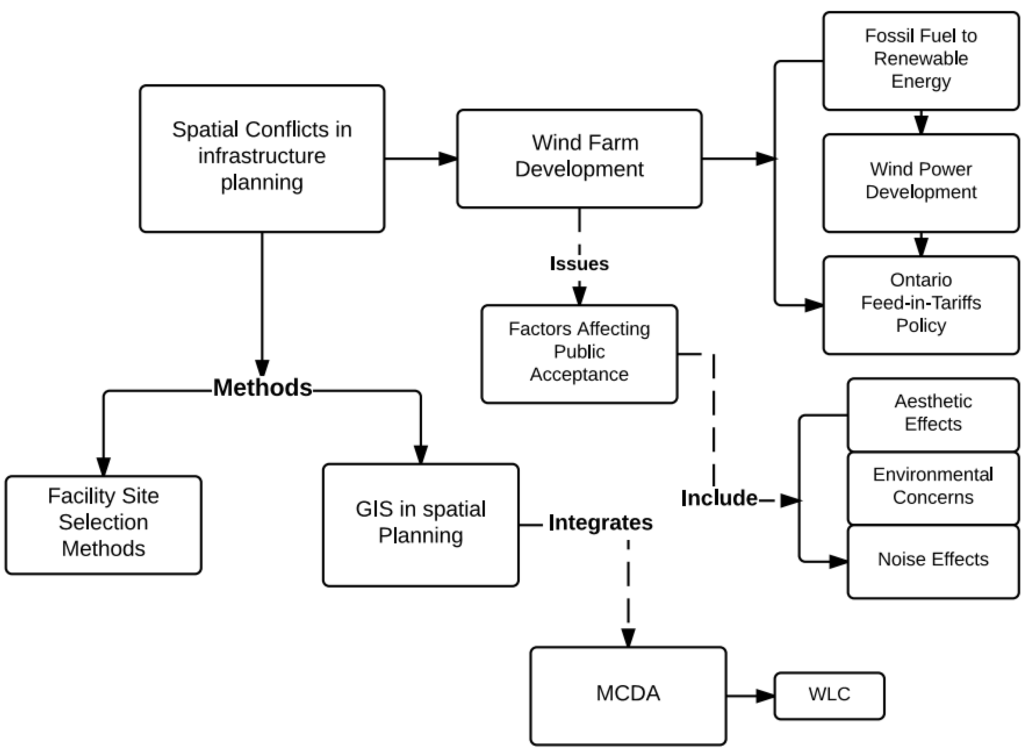


Figure 2.1. Literature Review Structure Flowchart

2.1 Spatial Conflicts in Infrastructure Planning

The term "*Infrastructure*" refers to facilities that support the public services (Goodman & Hastak, 2006). It requires a large amount of capital investments with a tangible economic gain from the developments, some examples are transportation systems, power generation systems and solid waste disposal facilities. The common characteristic of these developments is that large parcels of land are required to build these facilities (Goodman & Hastak, 2006). *Land-use Planning* is "a type of planning for physical environment that provides the focus to the endeavor we call community planning" (Hodge, 2003, p.121). A significant issue that planners should pay attention to, when a new development is introduced to a community, is the spatial impact of the facilities, which is strongly related to the location of the project (Hodge, 2003).

Local opposition often arises when industrial facilities are proposed to be developed, especially the hazardous and risky developments, such as nuclear power plants and waste sites (Lesbirel & Shaw, 2005). Public opposition toward infrastructure siting and the associated impacts on area values have become a major barrier to the implementation of many projects (Kaldellis, Kapsali, Kaldelli, & Katsanou, 2013; Wolsink, 2007; Young, 1998). For instance, Young (1998) highlighted the issues related to unjustified hazardous industrial siting issues in the State of Massachusetts in 1981. More than 20 communities joined a local opposition group called "Stop it" to express concerns related to the environmental impacts from the risk of spills, incineration, and the danger of explosions. Another example is the Fukushima Daiichi Nuclear Power Plant disaster, which was a result of the Tohoku earthquake in Japan in 2011, had a significant impact on public acceptance of nuclear energy (Kato, Takahara, Nishikawa, & Homma, 2013; Visschers & Siegrist, 2013). By comparing the results of the study between 2010 and 2011 conducted by Visschers & Siegrist (2013) after the Fukushima incident, a strong decline in public support of nuclear energy was found. Wind farms, another example of industrial developments also trigger a great public opposition, mainly from the atheistic and noise impacts to the community (Devine-wright, 2007; Baxter, et al., 2013; Gross, 2007).

Siting conflicts often occur when a local community perceives an unequal allocation of costs and benefits from facility development of wind farms (Lesbirel & Shaw, 2005; Pepermans & Loots, 2013). Developers and the government gain economic benefits from the developments, but the local residents have no choice but to accept the associated impacts and burdens (Lesbirel & Shaw, 2005). *Not-in-my-backyard (NIMBY)* is "an oppositional attitude from local residents against some risk generating facility that they have been chosen to host either by government or industry" (Hermansson, 2006, p.23). Wolsink (2007) highlighted that many studies have viewed this attitude as selfish in nature; however, a lack of equality and fairness in the siting process does contribute to this attitude. Policymakers often mistakenly blame public opposition on NIMBYism, where people are not willing to accept a wind farm near their residence for selfish or short-sighted reasons (Baxter, et al., 2013). The NIMBY concept has been criticized in the literature and many have argued that this behavior does not fully explain the human motives and the actual reasons associated with the social and political factors (Bell, et al., 2005).

Distance decay and coverage are the key concepts in infrastructure planning. The term *Distance Decay* is defined as “the attenuation of a pattern or process with distance” (Farhan & Murray, 2006, p. 280). For example, the closer you live to a potential facility, the higher level of noise and aesthetic impacts you will likely to perceive. *Coverage* is referred to as the negative impact zone of the facility (Farhan & Murray, 2006). In a nuclear facility study, Jun, Kim, Jeong, & Chang (2010) suggested that the majority of the opposition came from the local populations, who lived in the coverage of the existing or proposed facilities.

The scale of the project also plays an important role, as the local residents are more likely to oppose large-scale facilities near their homes (Boholm & Löfstedt, 2004). The presence of physical, environmental and social externalities of large-scale facilities has been highlighted in different studies (Khalili & Duecker, 2013; Locatelli & Mancini, 2012; Pepermans & Loots, 2013; Swofford & Slattery, 2010). People who opposed to wind farm developments often report the impacts of noise (Swofford & Slattery, 2010), as well as the visible structure and environmental impacts of wind turbines (Briassoulis, 1995; Wüstenhagen, Wolsink, & Bürer, 2007). The traditional goal of wind farm siting is merely focused on a single aspect, such as maximizing the economic gain from infrastructure developments (Terouhid, Ries, & Fard, 2012). Nonetheless, as more aspects associated with the facility developments were identified, much literature has addressed the fundamental role of sustainable development in integrating multiple criteria into siting decisions (Terouhid et al., 2012).

Suitable site selection plays an important role in resolving siting conflicts, which can minimize not only the potential environmental and ecological issues (Aydin, Kentel, & Duzgun, 2010; Basnet & Raine, 2001; Moeinaddini, Khorasani, Danehkar, Darvishsefat, & Zienalyan, 2010), but can also address the social concerns (Young, 1998; Zeiss & Lefsrud, 1996). According to Lesbirel & Shaw (2005), the site screening process is a typical siting procedure to identify the best locations by gradually excluding unfeasible areas based on a set of siting criteria. If different stakeholders each with their own interests are involved in a siting process, a consensus needs to be reached among them (Lesbirel & Shaw, 2005). After decision makers have reached a consensus, spatial models need to be built to represent alternative solutions (Malczewski, 1999). Finding the optimal locations for a wind farm facility is an example of a complex decision process, which involves a spatial interaction between location and allocation. The suitable area to build certain facilities needs to be identified before the optimal alternatives can be selected from the suitable area (Malczewski, 1999).

Zeiss & Lefsrud (1996) demonstrated that one of the siting principles is to develop an effective siting framework, which is capable of addressing the siting factors and outcomes. Involving public concerns toward facility siting is also a foundation for gaining support and trust from local residents. Jun et al. (2010) noted that the public acceptance can be altered by delivering information that raises public awareness. As a result, a facility siting approach, which represents the perspectives from the public, is essential to address the public concerns and tackle spatial siting conflicts.

2.2 Wind Farm Development and Planning Issues

2.2.1 Shift from Fossil Fuel to Renewable Energy

Fossil fuel, a dominant energy source in North America and worldwide, has a significant impact on the climate. Burning fossil fuel is associated with environmental issues such as anthropogenic Greenhouse Gas Emissions (GHGs) and global warming (Höök & Tang, 2013; Leggett & Ball, 2012). According to Höök & Tang (2013), fossil fuels contribute to 80% of the world's energy generation and the remaining 20% is generated from waste and biomass, nuclear energy and hydroelectricity. In addition, according to the results of global GHG emissions in 2008, there were approximately 30 billion tons of CO_2 emissions from fossil fuel combustion in 2008, which doubled the consumptions of those during the 1970's (Höök & Tang, 2013). As the price of fossil fuel keeps rising on the market, it is essential to shift fossil fuel to renewable energy (IPCC, 2007). Peñuelas & Carnicer (2010) have stated that there is an urgent need for societies to promote non-carbon energy sources and improve energy technologies in order to gain economic advantages and deal with future energy crisis.

2.2.2 Wind Power Development

Alternative energy sources provide a solution to generate low carbon or carbon free electricity. The implementation of renewable energy, including solar, wind, biofuels, wave and geothermal, is growing worldwide (Devine-Wright, 2011). As the price of renewable energy continues to fall, the global deployments of renewables such as wind, solar and biomass are projected to be "the big three" alternative energy sources in 2050 (Tollefson, 2011). By integrating advanced technologies, wind turbines have become a more efficient and reliable energy source (Ertürk, 2012). People are starting to view wind energy as a green solution to accomplish the goal of the Kyoto Protocol and minimize the negative impacts of global warming (Munda, 2008). Warren & McFadyen (2010) noted that the global installation capacity of wind farms has increased significantly from 17 to 200 Gigawatts (GW) between the year 2000 and 2010. Taking Ontario as an example to provide a general idea of GW, a household of 4 people normally generates 800kWh (kilowatt hour) per month (Ontario Ministry of Energy, 2014b). 1kW equals to 0.0011MegaWatts (MW) or 1.1×10^{-6} GW.

In a typical wind farm development, the physical location is the key for power distribution. Building wind farms requires a smooth surface instead of hilly terrain; wooded areas and buildings need to be avoided (Baban & Perry, 2001). The number of turbines varies among projects (Rowlands & Jernigan, 2008). In Southern Ontario, Amaranth wind farms, a large-scale wind farm development in the Township of Melanchthon, 45 General Electric (GE) wind turbines of 1.5 MW with total electricity generation capacity of 67.5MW were installed in 2006. The length of each turbine blade is 37 meters and there are 3 blades per turbine. The Kingsbridge wind farm on the shore of Lake Huron has a total number of 22 turbines, which started operating in 2006. Each turbine has 1.8MW capacity with a total amount of electricity generation capacity of 39.6MW (Rowlands & Jernigan, 2008). The annual wind speed at the hub height of 60 meters varies from 4m/s to 7m/s (Gipe & Murphy, 2005). Typically, wind farm turbines require a separation distance of 3 to 10 Rotor Diameters (RD), which approximately equals to 180 to 600 meters, for a 1.3 MW turbine with a diameter of 60 meters (North Ireland Planning Portal, 2014).

In the European energy market, large-scale wind farm developments have become a “key” to the regional power system for more than ten years (Hiroux & Saguan, 2010). Due to the fact that large-scale renewable developments can significantly contribute to the electricity markets, however they tend to be more costly than conventional energy generation; therefore, incentives were provided to encourage new developments and lower integration costs. The most commonly used support mechanism in Europe is the Feed-in-Tariff (FIT), which offers developers a better market price for electricity generated by renewable sources over electricity generated by non-renewable sources. Countries such as Denmark, Spain, Germany and France, as well as non-European nations such as Turkey have all adopted the FIT supporting scheme to promote wind energy generation (Hiroux & Saguan, 2010).

2.2.3 Ontario Feed-in-Tariff Policy

In 2009, the province of Ontario introduced the Feed-in-Tariff (FIT) program to provide provincial incentives to renewable energy projects through the Green Energy Act and implemented by Ontario Power Authority (Pirnia, et al., 2011; Yatchew & Baziliauskas, 2011; Zhu & Venkatesh, 2010). According to Table 2.1, both large (greater than 10 kilowatts (kW)) and small (less than 10kW) renewable energy programs are invloved in the Ontatrio FIT program.

Table 2.1. Ontario FIT Program and Price (Ontario Power Authority, 2014c)

Renewable Fuel	**Type**	**FIT Program (Projects over 10 kilowatts) -Price (¢/kwh)**	**Micro-FIT Program (Projects 10 kilowatts or less) - Price (¢/kwh)**
Solar PV	Rooftop	i). >10≤100kW 34.3 ii). >100kW 31.6	≤ 10 kW 38.4
	Non-Rooftop	>10kW ≤ 500 kW 27.5	≤ 10 kW 28.9
Wind	On-shore	≤ 500 kW 12.8	All Size 12.8
Water	Waterpower	≤ 500 kW 24.6	All Size 24.6
Bioenergy	Renewable Biogas	≤ 500 kW 17.5	All Size: 17.5
	On-Farm Biomass	≤100kW 26.3	100≤250kW 20.4
	Biogas	≤ 500 kW 16.8	All Size 16.8
	Landfill Gas	≤ 500 kW 17.1	All Size 17.1

Ontario's goal is to generate 10,700 MW of electricity from non-hydroelectricity sources such as wind, solar and bioenergy by 2018 (Ontario Ministry of Energy, 2012). Ontario currently pays fixed prices to renewable energy developments, which is a common form of FIT (Pirnia et al., 2011). The FIT program promotes a green economy, which in turn reduces the negative impacts of fossil fuels. In 2014, Ontario received 1,982 applications to build renewable facilities, including solar, wind, waterpower and bioenergy (Ontario Power Authority, 2014d). As a large number of renewable energy projects have been proposed and implemented in Ontario, they have triggered public concerns from the spatial siting conflicts (Knopper & Ollson, 2011).

2.2.4 Planning Issues in Wind Farm Development

Although wind energy provides an alternative way to electricity generation, planning issues related to wind power, such as social acceptability and spatial land-use conflicts were raised after a number of turbines were implemented in local communities (Heagle et al., 2011; Munda, 2008; Wolsink, 2007).

In Ontario, the Green Energy Act (GEA) itself has allowed a large deployment of wind farms, which had led to an increased amount of public opposition due to the lack of collective benefits gained from wind energy by local residents. The GEA also has significant inequality underlined in the decision-making power between the provincial and municipal governments, since the municipal governments have no authority to approve or deny any green energy projects (Heagle et al., 2011). The policy-making process is a top-down approach that overrides the power of municipalities, which can lead to social conflicts. According to the Ontario Planning Act, it states that "A by-law or order passed or made under Part V (Land Use Controls and Related Administration) does not apply to a renewable energy undertaking. 2009, c. 12, Sched. K, s. 3"; "A regulation or by-law made or passed under section 70.2 (Development Permit System) does not apply to a renewable energy undertaking. 2009, c. 12, Sched. K, s. 3." (Ontario Planning Act, Sub 62.0.2 (6) & (7)). These statements clearly indicate that municipalities do not have the authority to control land-use plans and development permits of renewable energy developments. The Green Energy Act clearly overrides the power that municipality has on wind development decisions. More importantly, decision makers should also consider the future developments and potential changes in the community, meaning that municipalities need to have a critical role in planning wind farms with the provincial government to address the potential land-use changes. The Minister of Energy, Bob Chiarelli described the plan in 2013 as successful, in terms of increasing local and municipal involvement in the future renewable energy projects, by providing priorities to the development plans proposed by municipalities (Timmins, 2013).

In addition, according to the Ontario Ministry of Energy (2014c), local municipalities should support and encourage the local developers, to use local resources in wind farm developments. The locals have no power to influence the decision making process, except to allow developers to use local resources as a "free-rider" (Toke, 2002). People who have high objections to wind farms do not target wind turbines themselves, rather they are mainly against the hierarchical planning and the policy-making process (Wolsink, 1996). As opposition from smaller groups of people are normally ignored in a decision making process, the authorities often think that the opposition group may not necessarily represent the entire population, and often assume the participants who remain silent in the meeting are supportive of the decision (Wolsink, 1996). In order for the development process to become more socially acceptable, the wind farm developments need to integrate public concerns into the siting decision making process. When the projects are first introduced to the community, it is essential to gain and maintain a positive public attitude towards wind farms for any infrastructure developments.

Ontario, in particular, has experienced a significant change in public support toward renewable energy developments (Baxter et al., 2013). According to IPSOS Reid (2010), Ontarians had a high support rate of 89% to renewable energy and the Central and Northern regions of Ontario had relatively higher support rate than other areas; 86% of the residents encouraged the local municipalities to promote wind energy developments. However, ever since the government of Ontario had encouraged developers to implement a large number of wind turbines, local wind farm opposition/resistance groups have grown (Baxter et al., 2013; Ontario Wind Resistance, 2014). Residents are protesting in different local communities, and expressing their concerns about social, environmental and health issues such as drinking water safety, noise and landscape impacts resulted from the wind farm developments (Ontario Wind Resistance, 2014). Bell et al. (2005) identified social gaps for the dramatic changes in social support rate between the public poll survey and during actual planning application and implementation process. The *social gap* describes “the gap between the high public support for wind energy expressed in opinion surveys and the low success rate achieved in planning applications for wind power development” (Bell, et al., 2005. p.461). Bell et al. (2005) have also identified a different type of gap called “*individual gap*”, where the public may support wind farm developments in general, but only oppose to certain wind developments. More importantly, most of the public opinion surveys, only ask if the residents support wind farms in general, without providing further details to allow the residents to consider the potential impacts that wind turbines might contribute to the landscape or environment (Bell et al., 2005). Thus, in order to alleviate spatial conflicts and increase support rates, social and individual gaps need to be narrowed at the planning stage. The public also needs to be well informed about the potential impacts of wind farms.

Eltham, Harrison, & Allen (2008) stated that the public support towards Carland Cross wind farm increased from 74% to 82% from the year 2001 to 2006 in Cornwall, UK. The residents fully participated in the planning process and expressed their concerns. Warren & McFadyen (2010) stated that developers built an excess of onshore wind farms, which had negatively affected the landscape view of the local communities, in the south-west of Scotland. On the other hand, in Gigha, Scotland, a bottom-up participation approach was used, in which public engagement was encouraged in developing community wind farms. The bottom-up approach is the opposite from the traditional top-down developer perspectives in Kintyre (Warren & McFadyen, 2010). By the year 2000, about 80% of wind farms in Northern European countries were community-owned (Bolinger, 2005). Figure 2.2 shows that wind capacity in Germany and Denmark were mostly generated from community-owned wind farms.

	Total wind capacity (MW)	Community-owned wind capacity (MW)	Percentage of community-owned (%)	Number of household investors
Germany	6161	~5400	88	~100,000
Denmark	2268	~1900	84	~175,000
Sweden	240	~30	13	~15,000
The UK	414	~3	1	~2000
Total	9083	7333	81	292,000

Figure 2.2. Community ownership wind farm development in selected European Countries (Bolinger, 2005, P.559)

In the US, several states such as Minnesota, Massachusetts, Iowa and Wisconsin provide incentives to wind farm developments, aiming to support community wind farm projects and promote wind energy (Bolinger, 2005). However, there are limitations and challenges behind this community ownership concept. The interest groups may only consider the benefits and the amount of electricity that they can share, and fail to actively engage or participate in the public consultation process (Nolden, 2013).

Hodge (2003) discussed the Arnstein's Ladder of Citizen Participation in detail (see Figure 2.3), the lower the rung on the ladder, the lower the decision power citizens hold. Hodge summarized that on top of the ladder is the Citizen Power, which includes Citizen Control (citizen govern the project), Delegated Power (citizen has a dominant role in decision making) and Partnership (sharing responsibility with planners and politicians). In the middle of the ladder is Tokenism, referring to minimal power, which is given to the public in the decision process such as Placation (advisory role in decision), Consultation (citizen can express their opinion during a public meeting or survey) and Information (inform the public through media). The lowest level is Nonparticipation, which includes Therapy (educate the public) and Manipulation (persuade the public to accept a decision).

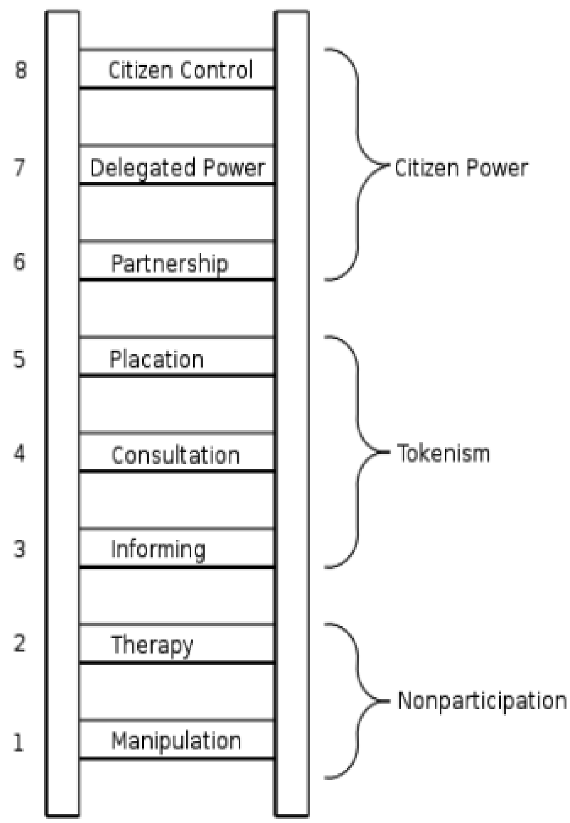


Figure 2.3. Arnstein's Ladder of Citizen Participation (Arnstein, 1969)

Hodge (2003) argued that due to legal and practical reasons, it might not be the best practice for citizens to hold power in the decision making process. The NIMBY attitudes present a lack of public participation and the citizens often see themselves as "Tokenism" who are only being consulted (Hodge, 2003). In a wind farm siting decision process, the consultation or workshop usually takes place after the plan has been announced. It drops the public participation level to Manipulation, as the residents have no choice but to accept the decisions. It is significant for planners and politicians to understand that "the citizens are the primary source of information about the problems that are being experienced by the community, about the impacts of proposed solution, and about the values and aspirations of community members" (Hodge, 2003, p.334). Thus, public concerns towards facility siting are valuable information that needs to be collected and analyzed in the site selection process to resolve planning issues.

2.3 Factors Affecting Public Acceptance of Wind Farm

A number of studies discussed the spatial proximity, which has a direct influence on public acceptance (Devine-Wright, 2005). Pepermans & Loots (2013) highlighted that spatial, political, and social distances are the three main factors that affect the public acceptability towards wind farm developments. In the region of Flanders (Belgium), it was found that the spatial distance not only refers to the physical distance, but also the increasingly polarized landscape of cost and benefit distribution between developers and local populations. The massive infrastructure developments took away many residential areas and transformed them into industrial or commercial zones. The consequences of these spatial planning decisions have caused the landscape in Flanders to become fragmented. The political distance refers to the “distance” between decision makers and the public, where minimal power was given to the public during the siting process. The social distance represents the social gap between developers and local communities. Pepermans & Loots (2013) noted that the public is normally engaged after the proposal or plan has already been drafted, so the public starts to feel that their rights are not protected and question the reliability of the siting process. In order to raise the public acceptance towards wind farm implementation, decision makers need to be aware of these important factors including spatial, social, and political distance that affect public acceptability in the planning process.

Three types of major public concerns: aesthetic impacts, environmental concerns and noise effects will be discussed below. Baxter highlighted that noise annoyance and visual impacts are the main reasons behind the public opposition towards wind farms (Baxter, et al., 2013).

2.3.1 **Aesthetic Effects**

Visual impacts are one of the major concerns among residents. Wind turbines are unavoidable structures on the surrounding landscape, which may affect the public attitudes toward wind farms. Wüstenhagen et al. (2007) stated that wind turbines are controversial because their visibility to the landscape is more obvious to local residents than the traditional fossil fuel and nuclear energy facilities, which are normally out of sight.

The impact on urban landscape of wind farms is one of the main driving forces of the public concerns (Pepermans & Loots, 2000). *Viewshed* is “the natural environment that is visible from one or more viewing points" (Merriam-Webster's online dictionary, n.d.). Torres Sibille, Cloquell-Ballester, & Darton (2009) & Ladenburg, Termansen, & Hasler (2013) highlighted that the level of visual impact varies depending on the viewshed. In their study, the onshore wind farm viewshed effects in Ladenburg and Dahlgaard were measured by conducting a questionnaire. The results of their study demonstrated that the residents' attitude towards onshore wind turbines is negative when turbines were already implemented within their viewshed. Pasqualetti (2012) noted that there are other forms of aesthetic concerns such as the reaction to motion and shadow effects. The motion of wind turbines could be perceived by human brains as an annoyance. The shadow flicker effect of wind turbines may also cause potential physical and psychological health impacts (Knopper & Ollson, 2011; Pepermans & Loots, 2013). The height and blinking lights of wind turbines can also change the visibility of the sunlight (Pasqualetti, 2012).

Aesthetic effects are closely related to how people perceive their physical landscape. "Social landscape values are collective perceptions about places and locations that reflect land-use aspirations and potential conflicts" (Brown & Brabyn, 2012, p. 84). The potential locations of social landscape values such as aesthetic, economic, ecological and historical criteria can be illustrated on the map by conducting a landscape classification based on their spatial proportions (Brown & Brabyn, 2012).

Belflore, Montesi, Fernetti, Naidoo, & Mercer (2012) also noted that turbine height, size, number and colour can affect the landscape. In the meanwhile, Molnarova et al. (2012)

conducted a study on visual assessment at the region of the Czech Republic by conducting a survey questionnarie with 18 photographs of landscapes with and without turbines. The results of their study indicated that although wind turbines have negative visual impacts, the impacts can be minimized by avoiding the attractive landscapes or implementing fewer number of turbines. Belflore et al. (2012) also discussed that visual impacts can be minimized in the design stage by changing the size of the turbine and the direction of turbine blade rotation.

Torres Sibille et al. (2009) summarized multiple visual indicators, such as visibility level, color, and fractality. These indicators were collected and measured by conducting literature review and photographs in the region of Cuenca in the Spanish Inland. For instance, the visibility impact of a turbine begins to increase when 15% of a turbine can be seen from the surrounding residences. Also, the bigger the difference between the color of the turbine and that of the surrounding background, the higher the visual impact. The visual indicators in Torres Sibille et al. (2009)'s study were created by incorporating experts' options and non-professional public knowledge. Nevertheless, the aesthetic effects can be objective and vary among different study areas (Pasqualetti, 2012).

2.3.2 Environmental Concerns

Most of the negative impacts on ecosystems revolve around the potential lethal effects on birds from their sensitivity to noise and infrasonic vibrations of the turbine blades and getting hit by the blades during the onshore wind farm operation (Lozano-Minguez, Kolios, & Brennan, 2011). Transmission lines that are connected to either the onshore or offshore turbines can cause serious injuries or deaths to migrating birds (Drewitt & Langston, 2006). Punt, Groeneveld, van Ierland, & Stel (2009) emphasized the importance of considering biodiversity and ecosystem in the siting process, which can minimize the negative ecological impacts on birds and fish, and maximize the revenue from identifying the optimal locations. More importantly, the lethal effects on birds can be strongly related to the turbine locations. Avoiding the migrating routes and their natural habitats in the siting decisions is vital to prevent further collisions.

2.3.3 Noise Concerns

The noise generated from the turbine blades have been recognized as a new source of community disturbance that is strongly associated with visual impact, especially when people can see turbines near their dwellings (Horner, Jeffery, & Krogh, 2012; Pedersen & Larsman, 2008).

Horner et al. (2012) argued in 2008, the public health unit of Chatham-Kent reported that noise level, perceived from wind turbines was relatively lower than that of the construction and traffic. In the following year, a medical officer in Chatham-Kent reported that the noise level of turbines may cause annoyance-induced stress and associated health issues (Horner et al., 2012). In 2012, Health Canada initiated research to evaluate the potential health impacts of wind turbines' noise on residents who live within a 10 km vicinity of a wind farm through a survey questionnaire (Health Canada, 2013).

Noise impacts of wind turbines have been studied not only in Canada, but also in the United States and the United Kingdom. Noise exposure from wind turbines could possibly affect children's hearing ability at a low sound level (Bronzaft, 2011). Pedersen & Larsman (2008) conducted a study in southern Sweden to measure the public attitudes toward wind turbines. Questionnaires were sent to local residents who live in the vicinity of wind farms to collect information on level of noise annoyance they have perceived. In the UK, Taylor, Eastwick, Lawrence, & Wilson (2013) also conducted survey questionnaires to measure noise intrusion from small wind turbines to obtain information on the public attitudes. They found a strong correlation between the public attitude towards wind developments and the noise perception, the higher the noise level, the stronger the negative attitude presents among the local residents.

2.4 Facility Site Selection Methods

Finding optimal locations of facilities is essential for infrastructure planning. For example, in a typical wind farm site selection process, it often requires several major steps. The first step is to collect information and data, and then develop datasets on siting criteria and constraints (van Haaren & Fthenakis, 2011; Baban & Perry, 2001). The second step is to determine the feasible sites in a study area, by excluding unfeasible areas through a site screening process, based on the pre-determined criteria and constraints (Lesbirel & Shaw, 2005). In order to compare the feasible sites, the corresponding weight for each criterion and suitability score of each site need to be calculated (Gorsevski, et al., 2013). The last step of the siting process is to present the results through cartographic visualization to assist decision makers in understanding the data. There are several facility site selection methods that have been discussed in the current literature, including qualitative methods: Delphi approach and case studies; as well as quantitative methods: Mixed-integer linear programming (MILP), Decision-making trial and evaluation laboratory (DEMATEL), GIS and MCDA.

2.4.1 **Delphi Approach & Case Studies**

The Delphi approach is defined as "a group process used to survey and collect the opinions of experts on a particular subject" (Yousuf, 2007, p. 1). The Delphi technique has become a well-known approach in environmental planning and solving complex siting issues (Zakaria, Abdullah, Ramli, & Latif, 2013). It is a qualitative way that "recognizes human judgment as a legitimate and assumes that testimony of experts can provide useful inputs in generating forecasts" (Hishamunda, Poulain & Ridler, 2009, p. 3). Using a hazardous waste facility site selection as an example, the Delphi technique was selected to collect siting criteria based on a survey questionnaire generated by experts (Zakaria et al., 2013). There are three basic steps involved in the Delphi approach (Yousuf, 2007). First, questionnaires are conducted to ask a panel of experts a list of questions, the answers are based on their judgments. After a collective list of information such as siting criteria has been collected from those questionnaires, the experts need to weigh the level of importance among the siting criteria on a second questionnaire. In the last round, a third questionnaire that includes the criteria list and weight will be sent to the participating experts for discussion (Yousuf, 2007). However, the Delphi approach is strongly dependent on group opinions such as experts, which tend to be case specific. In a wind farm suitability siting process, multiple perspectives are required. Merely relying on experts' judgments can limit the perspectives of the problem (Yousuf, 2007). As a result, the Delphi technique is not a sufficient approach to collect siting criteria and compare feasible sites for this study.

Besides the Delphi approach, analyzing case studies is another qualitative method for siting facilities. In a waste siting study, ten different case studies in Canada were analyzed to identify the project characteristics and make suggestions for potential waste site selection (Lawrence, 1996). Although case studies can provide a general idea about the characteristics of a site, it is not the ideal approach to determine feasible sites for a specific study area. The contextual difference among case studies makes it difficult to provide a generalizable siting approach (Lawrence, 1996).

2.4.2 **Optimizing Approach based on Linear Programming and Diagraphs**

Quantitative facility siting methods are also reviewed in this study. Mixed-integer linear Programming (MILP) is a mathematical model that has been applied in identifying the suitable locations of facilities. In the wind farm siting study, the MILP model was utilized to identify the ideal locations of wind turbines based on calculating the optimal layout of the turbines within a wind farm (Archer, Nates, Donovan & Waterer, 2011). The MILP approach was also used in biomass and power-plant site selection to determine the cost-efficient locations (Cattafi, Gavanelli, Milano, & Cagnoli, 2011). However, the MILP model is often applied in a siting process where the emphasis is on wind turbine design, such as optimizing turbine layout and size to reduce the costs of the development, rather than emphasizing on site screening process and dealing with multiple siting criteria and constraints.

Decision-making trial and evaluation laboratory (DEMATEL) is another approach that has been applied in determining the optimal facility sites. This method has been applied to rank the importance of siting criteria for a substation site selection in India and to select optimal alternatives in sustainable developments (Baruah, Raj, Ray, & Chakravorty, 2012; Vinodh & Girubha, 2012). DEMATEL analytical technique is a mathematical model that is often applied to evaluate criteria and provide relationship among multi-criteria based on diagraphs (Baruah, et al., 2012; Shieh, Wu, & Huang, 2010; Sumrit & Anuntavoranich, 2013). The diagraphs allow the users to group criteria into cause and effect, and transform the problem into a structural model (Baruah, et al., 2012). Due to the fact that this technique is more focused on providing information on the relationship and the level of importance among criteria, rather than comparing alternatives of feasible wind farm locations. The cause and affect categories in DEMATEL are also not a suitable way of collecting wind farm siting criteria.

2.4.3 **Geographic Information System (GIS)**

As a wide range of data is required to evaluate the optimal locations of wind farm facilities, GIS can be used as an efficient tool, which allows the data to be integrated, analyzed and visualized. Malczewski (1999) noted that the definitions of GIS are divided into technical and problem-solving aspects. The technical part of the definition emphasizes the functionality of the tool itself (Malczewski, 1999). GIS is defined as "a system of hardware, software and users that manage, analyze and display geographically referenced data" (Belflore, et al., 2013, p. 3). From a problem-solving aspect, the function of GIS system plays an important role in solving spatial problems and providing solutions to decision makers. According to Malczewski (1999), the structure of a GIS includes 5 parts: data input, data output, data manipulation and analysis, data storage and management, and user interface (see Figure 2.4).

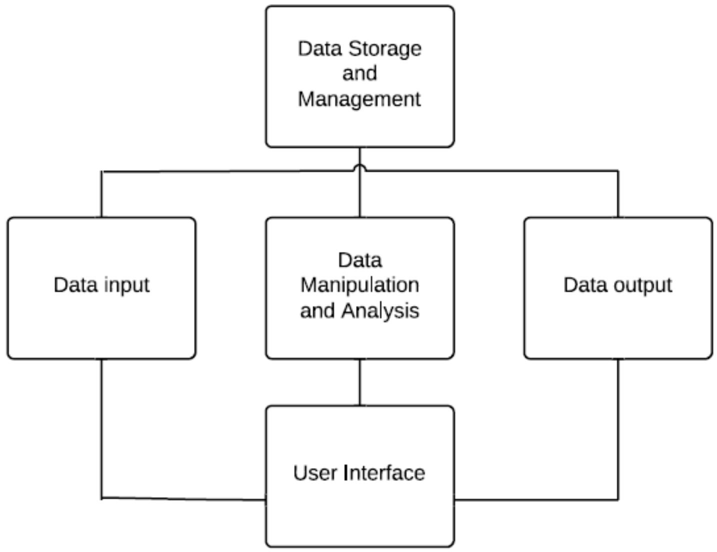


Figure 2.4. The Structure of GIS (Malczewski, 1999, p.17)

Cromley (2012) addressed three important functions of GIS, which are managing spatial database, visualizing spatial data and analyzing spatial data. The database management systems of GIS can store and retrieve data stored in a database. GIS also provides a means to visualize and transform spatial data into maps and graphs, and it supports various analytical functions such as topological and network analysis (Cromley, 2012).

GIS is a powerful tool in terms of providing spatial decision support in solving different planning issues, such as transportation, energy, land-use and infrastructure site selections. GIS-based decision support systems can assist planners in managing and solving spatial conflicts (Baban & Parry, 2001). The functionality of GIS offers numerous opportunities and potential to planners by providing an effective and efficient way of visualizing and storing data (Innes & Simpson, 1993). Aydin et al. (2010) suggested that GIS techniques can be used to conduct energy potential maps and identify suitable locations during the site selection process. The application of GIS is also widely used in wind farm site selection (Christidis & Law, 2012). Sliz-Szkliniarz & Vogt (2011) pointed out the reason for choosing GIS in estimating the impact of wind farms is that it provides a logic solution to analyze spatial data. The multi-objective spatial model created using GIS software can also assist planners to locate the optimal locations for wind farms (Karakostas & Economou, 2014; van Haaren & Fthenakis, 2011).

Although GIS is an effective tool in data analysis and visualization, it can only provide few options in dealing with multiple alternatives and considering different aspects of a problem (Feick & Hall, 2004). MCDA method can be combined with GIS as an extension to allow decision makers to compare and rank feasible alternatives (Feick & Hall, 2004).

2.4.4 **Multi-criteria Decision Analysis (MCDA)**

The terms MCDA and MCDM (Multi-Attribute Decision Making) are interchangeable (Malczewski, 1999). GIS-based MCDA is "the framework integrates the GIS capabilities of MCDM techniques for addressing the geographic data and the decision makers' preference into uni-dimensional values of alternative decisions" (Malczewski, 1999, p. 81). The Department for Communities and Local Government (2009) stated that "multi-criteria analysis established preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved" (p. 20). One of the important roles of MCDA is to assist decision makers in setting up criteria and determining the relative criteria weight by mathematical equations (Department of Communities and Local Government, 2009). The criterion refers to objectives and attributes related to the decision problem, and the weights of the criteria represent the importance of each criterion (Malczewski, 1999).

In a spatial planning process, both expert and non-expert stakeholders may be involved in the decision making process (Hodge, 2003). In order to reach a consensus among different stakeholders, a collaborative tool is needed. MCDA can handle ranking alternatives and solving conflicting criteria in complex decision problems in different research areas, such as environmental, energy management and urban planning (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010). Sustainable planning and management are essential solutions to tackle spatial conflict issues and MCDA is the most commonly applied technique that is used for environmental policy and sustainable management applications (Munda, 2008).

Steps in MCDA

Figure 2.5 illustrates the framework of MCDA. Malczewski (1999) summarized a detailed MCDA framework in his book as follows. Once the decision problem has been established, criteria that are related to the decision problem need to be determined. The evaluation criteria can be selected from the current relevant literature, government documents and survey studies. In a GIS-based MCDA analysis, each criterion contains geographic information with attributes, which are capable of providing GIS analysis and data visualization. A constraint represents the limitations or rules for the criteria, which are used to exclude the unfeasible values and attributes of the criteria. *Alternatives* are also called attributes in the Malczewski's book, which has been defined as "information source available to the decision maker for formulating and achieving his or her objectives" (p. 341). Alternative decisions are also used to measure the performance. The criteria weight is often determined by decision makers' preferences to assign a relative weight of each criterion. After the criteria, alternatives and criterion weight have been identified, the decision matrix can be created to outline the decision outcomes. Decision rules provide a way to aggregate the weighted criteria scores and rank the alternatives. *Sensitivity Analysis* (SA) is a "procedure for identifying the effects of introduced small changes in the inputs (geographical data and the decision maker's preference) on the outputs (ranking alternatives)..." (p.348). At the end of the MCDA process, SA needs to be performed to test the robustness of the ranking and to help decision makers to increase awareness of how the overall results can be affected from the changes of an input value (Malczewski, 1999).

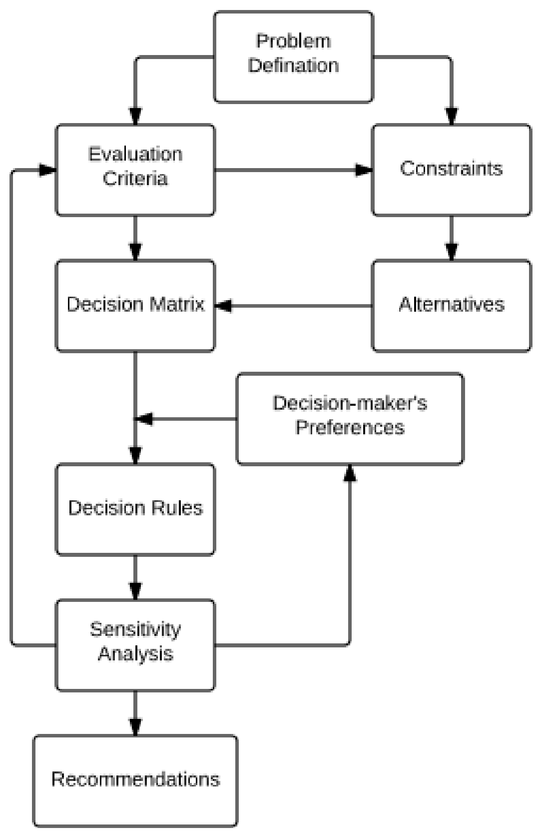


Figure 2.5. MCDA Framework (Malczewski, 1999, p.96)

After reviewing different studies on site selection, GIS-based MCDA was selected as the most appropriate method for this research based on the following reasons. First of all, current literature has suggested that GIS-based MCDA is the most popular and effective approach for solving facility siting problems, such as wind energy projects (Dudukovic, Stanojevic, & Vranes, 2005; Gorsevski et al., 2013; Taha & Daim, 2013). It is also a commonly used technique for decision makers to collect criteria, identify and compare the alternatives of a set of wind farm feasible sites (Tegou et al., 2010; Gorsevski, et al., 2013). Secondly, a wind farm siting process is a complex decision process, which usually involves a large number of siting criteria. MCDA method is capable of solving complex decision problem with multi-conflicting criteria (Barfod, 2012). In order to solve complex spatial facility siting problems, GIS-based MCDA can assist decision makers to structure the siting problem and identify the suitable locations. Thirdly, GIS-based MCDA has been identified as the appropriate approach in dealing with multiple criteria, for this research, it can incorporate and quantify important criteria including economic, environmental and social values into the decision making process (Herath & Prato, 2006).

2.4.5 **Weighted Linear Combination (WLC)**

WLC is the most common and straightforward MCDA technique (Malczewski, 2000, 2011; Moeinaddini, et al., 2010). The WLC is an ideal MCDA method to overlay and aggregate the siting criteria, and to conduct suitability change analysis in the raster environment. WLC is referred to as a simple additive weighting method, which is a popular MCDA technique (Malczewski, 1999). Malczewski (2000) & Baban & Parry (2001) highlighted the importance of WLC in providing spatial solutions to land-use and wind farm siting issues.

A number of studies have applied the WLC method in choosing suitable locations and resolving spatial conflicts. In a waste management study, Moeinaddini et al. (2010) combined both the WLC and Analytical Hierarchy Process (AHP) - pair wise comparison method as selected methods for landfill sites in Karji, Iran. The combination of the AHP and pair-wise comparison was used to calculate the eigenvalues from a pairwise comparison matrix in order to obtain weights and determine the ranking of a set of alternatives (Marinoni, 2004). Another study on Municipal Solid Waste (MSW) management also applied WLC with other MCDA methods, such as AHP, to create suitability maps for the Ariana Region in Tunisia (Aydi, Zairi, & Dhia, 2012). A number of studies on wind farm site selection had also chosen the GIS-based WLC model to overlay the weighted suitability maps (Baban & Parry, 2001; Gorsevski et al., 2013). In the wind farm selection in the UK, Baban & Perry applied the index overlay approach in a raster GIS to create a suitability map, to assist decision makers in identifying optimal wind farm locations.

Global WLC is the conventional WLC, it is a technique that combines decision alternatives and corresponding criterion weights (Malczewski, 2011). The global WLC can be applied to measure the impacts for the whole study region. However, the global WLC and all other MCDA methods are not ideal for generating local context information, as they assume spatial homogeneity over the overall study region and ignore the value of local contents. The local WLC method was proposed by Malczewski (2011) to provide a solution that overcomes the obstacles of the global WLC.

Table 2.2 describes the 6 steps required for the method. The first step of WLC is to set up evaluation criteria, which can be displayed as map layers in GIS. Next, each criterion map needs to be standardized; it can be performed in the raster GIS environment. *Standardization* is a key procedure in the WLC method, it is defined as "A procedure for obtaining comparable scales" (Malczewski, 1999, p.349). There are different ways to perform a standardization process. The approach that Malczewski (2011) applied to standardize criteria is shown in Equation 2.1. The range value was calculated by subtracting the maximum and minimum values. When a higher criterion value is preferred, the standardization value can be calculated by subtracting the minimum value among all the criteria values from the actual criteria value, and divided by the range value. When a lower criterion value is preferred, the standardization value can be calculated by subtracting the actual criteria value from the maximum value among all the criteria values, and then divided by the range value. After all the criteria are standardized, the weight should be assigned to each corresponding criterion to calculate the overall scores. In the end, suitability scores for every criterion need to be combined to rank the alternatives.

Table 2.2. WLC Method Procedure

Source: adapted from Malczewski (1999, p. 199)

Step #	**Description**
1	Set up evaluation criteria and alternatives
2	Criteria standardization
3	Define weight for each criterion
4	Calculate the overall scores by multiplying weights and standardized criteria
5	Aggregate the weighted standardized criteria for overall scores
6	Rank alternatives based on the overall scores; the higher score represents the better alternative

Equation 2.1. MCDA Standardization Process (Malczewski, 2011, p. 442)

$$v\left(a_{ik}^{q}\right)=\begin{cases}\dfrac{a_{ik}^{q}-\min\limits_{i,q}\left\{a_{ik}^{q}\right\}}{r_{k}^{q}}, & \text{for the } k-\text{th criterion to be maximized}\\[2ex] \dfrac{\max\limits_{i,q}\left\{a_{ik}^{q}\right\}-a_{ik}^{q}}{r_{k}^{q}}, & \text{for the } k-\text{th criterion to be minimized}\end{cases}$$

Figure 2.6 presents an example of WLC method. There are 4 cells in both criterion (A & B), each cell value is converted to a standardized value by applying Equation 2.1. The weighted standardized values are calculated by multiplying a weight of 0.55 and 0.45 as an example. By overlapping and aggregating the weighted standardized scores, the overall score for each cell can be calculated. The overall scores can be ranked according to scores from high to low.

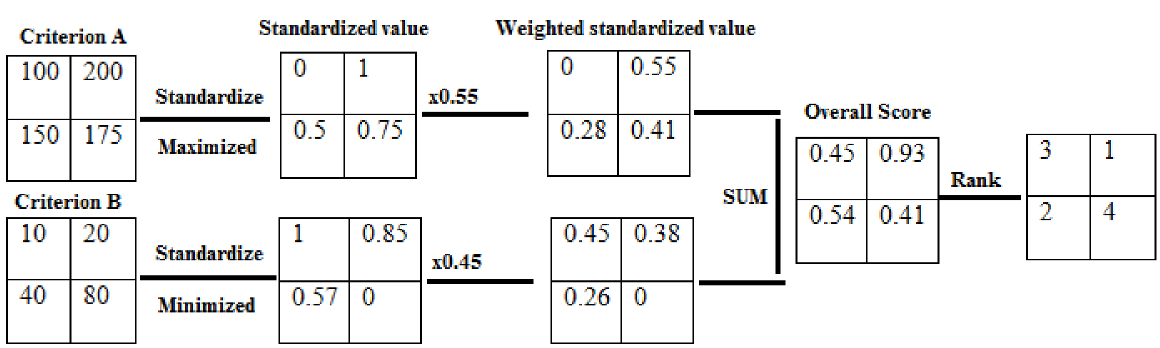


Figure 2.6. WLC Method Example

Source: Adapted from (Malczewski, 1999, p.203)

2.5 Conclusion

This chapter explored and summarized the important concepts and findings of the current literature that are related to this research. The generic spatial siting conflicts in different infrastructure planning, particularly the planning issues of wind farm developments that are embedded in the FIT program were discussed. Public concerns toward wind power, such as aesthetic, environmental and noise impacts were reviewed. Different wind farm site selection methods were also discussed in this chapter. Chapter 3 describes the selected criteria, constraints, and GIS-based MCDA siting method that is used in identifying sample feasible wind farm sites in Southern Ontario. Meanwhile, siting approaches provide an estimation of affected population by turbine noise and visibility, are proposed. The rationale of choosing the Entropy Information weighting method for this study is also discussed.

Chapter 3 Methods

In this chapter, a wind farm suitability siting method is proposed to address public concerns of potential visual and noise impacts of wind farms. Section 3.1 describes the research background, work-flow and the major steps of this research. Section 3.2 describes the study area and rationale behind choosing it. Section 3.3 discusses the utilized software, and Section 3.4 demonstrates how the siting criteria and constraints were selected. Section 3.5 presents the siting analysis and screening process, in which unfeasible areas within the study region are excluded. Section 3.6 explains the procedures used to create visual and noise criteria. Section 3.7 explains the criteria standardization values by using both global and local Weighted Linear Combination (WLC) techniques. Section 3.8 describes the multi-criteria weighting method that is used to generate the weight for each criterion. Section 3.9 presents four scenarios that will be applied to determine the suitability level within the selected feasible sites. Section 3.10 summarizes this chapter.

3.1 Research Steps

This section describes the major research steps of the wind farm siting approach in this research. After the feasible locations to build large wind farms in Southern Ontario have been identified, GIS-based siting approaches that estimate the localized affected-population by turbine noise and visibility are developed. In addition to physical, environmental, planning and economic criteria, potential noise and visual concerns are also integrated into the suitability siting approach, aiming to resolve spatial land-use conflicts.

Figure 3.1 illustrates the method that includes four major steps of identifying feasible sites, creating standardized criteria, weighted criteria and producing overall suitability maps. In this study, the siting criteria and constraints are based on the current literature, the Ontario Approval and Permitting Requirements Document for Renewable Energy Projects (2009) and currently available datasets.

In the second step, the selected criteria are divided into two groups, which are: a) common siting criteria such as physical, economic, environmental, and planning and b) noise and visual criteria. After the results of the potential noise and the visual impacts of wind farms have been obtained, these results can be combined with the results of the common siting criteria. The standardized score of each criterion is calculated by applying the weighted linear combination (WLC) standardization technique.

In the third step, the Entropy Information method is used to generate weights for each criterion. In this study, this weighting method was selected to generate objective criterion weights, which are calculated based on the actual standardized values of each criterion.

Lastly, the suitability levels within feasible sites are illustrated on the overall suitability maps. The spatial changes of suitability level can be determined by comparing the differences of suitability scores before and after the integration of noise and visual impact criteria. Different weights and criteria combinations were applied to present the changes of suitability level within each site.

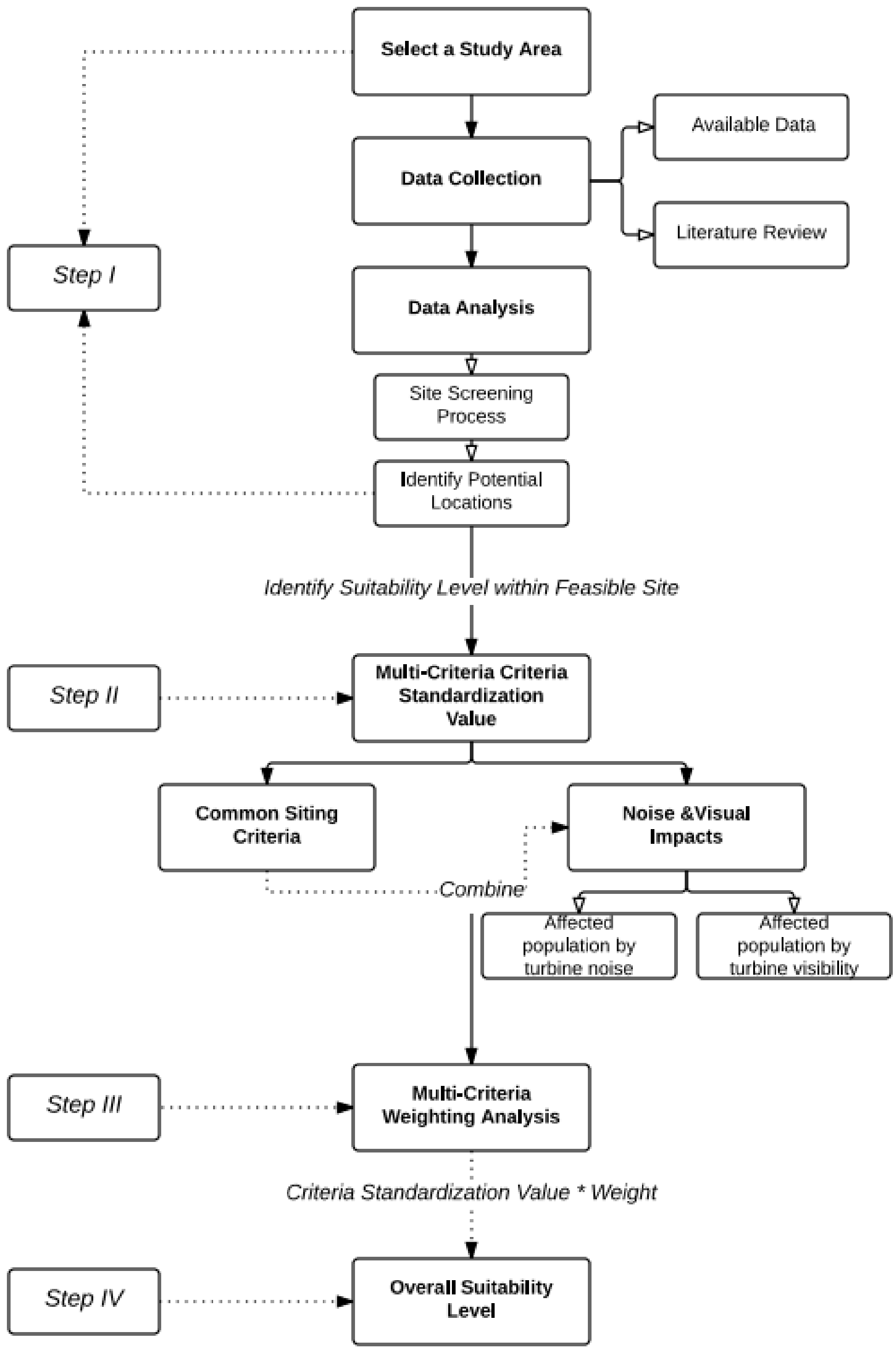


Figure 3.1. Wind Farm Suitability Siting Procedure

3.2 Study Area

The study area of wind farm site selection covers nearly 46,500 km^2. It is located in the south-west region of Ontario, which encompasses 22 census divisions, including Brant, Bruce, Chatham-Kent, Dufferin, Elgin, Essex, Grey, Haldimand-Norfolk, Halton, Hamilton, Huron, Lambton, Middlesex, Niagara, Oxford, Peel, Perth, Simcoe, Toronto, Waterloo, Wellington, and York (see Figure 3.2).

The study area was selected for the following reasons. After the FIT program was introduced to Ontario in 2009, a large number of wind farm developments were proposed and implemented. The high volume of wind turbines triggered public opposition in communities, where residents continued to express their concerns regarding the environmental, social and health issues (Ontario Wind Resistance, 2014; Baxter et al., 2013; Heagle et al., 2011). The study area includes areas where wind farms have been built and there are reasonable grounds to think that more wind farms will be proposed in the near future. Southwest Ontario is close to areas of demands, it has physical properties that lend itself to southern wind farm developments and has had localized instances of public concerns regarding wind farm impacts. For example, two large wind farms in Dufferin County, Melancthon Phase I & II have caused local public opposition (Ward, 2014). Additionally, there are few studies in the literature that have explored and addressed this essential spatial wind farm siting issue, such as potential noise and visual impacts, within the context of Ontario. Therefore, a suitability siting method is deemed necessary to tackle the siting problems and to identify feasible wind farms in Southern Ontario.

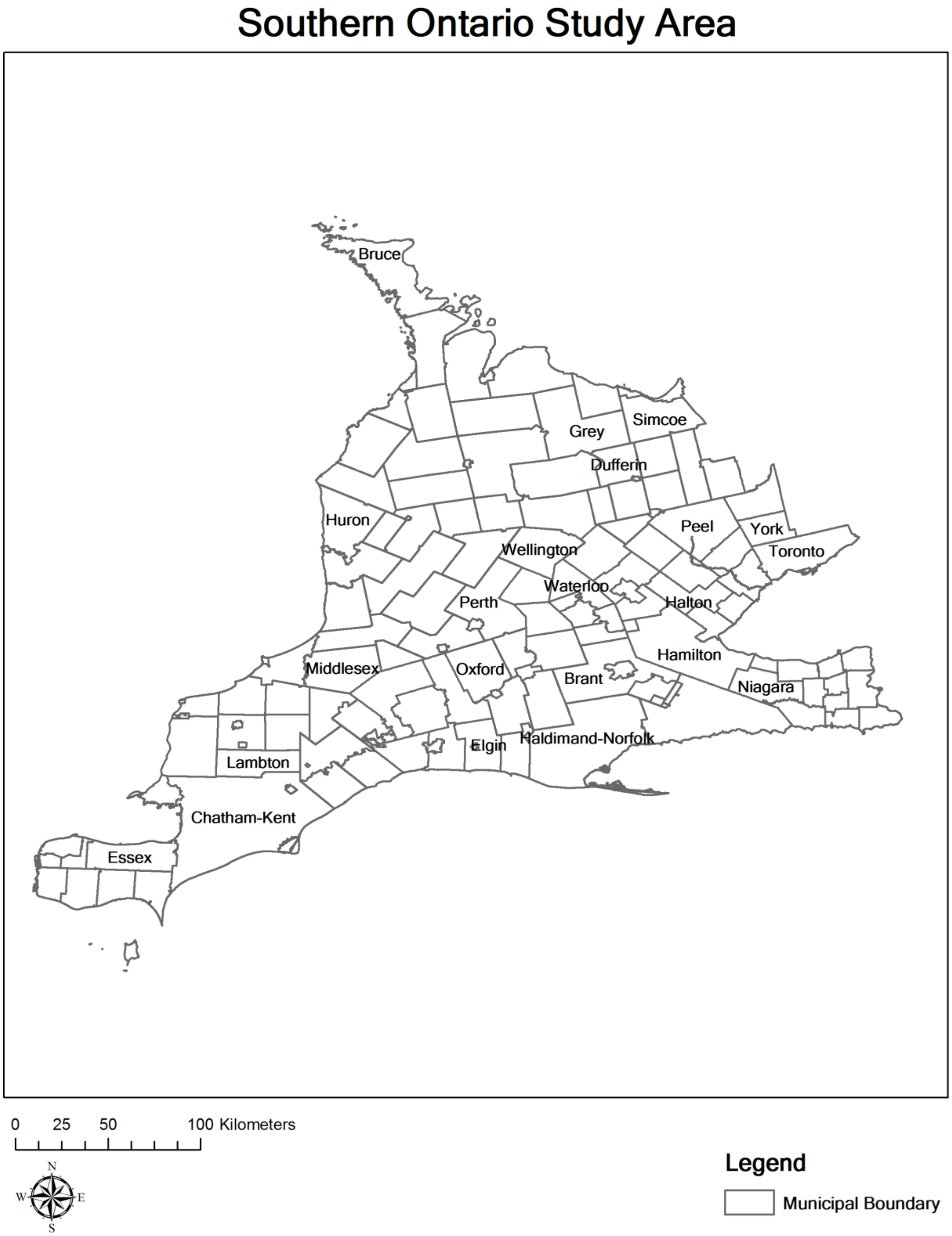


Figure 3.2. Map of Southern Ontario

A site screening process was applied to the Southern Ontario study area to identify potential feasible areas that are greater than 85 acres to build wind farms. As per the results of the study conducted by the Center for Sustainable Systems, University of Michigan (2013), large wind farm projects that generate greater than 20 MW require a minimum land cover of 85 acres (≈ 343,983 square meters). According to Rowlands & Jernigan (2008), the power generated from the selected large wind farms in Southern Ontario were all greater than 20 MW; thus, 343,983 square meters was chosen as the minimum size of the feasible sites for this study to exclude smaller feasible land areas.

Sample sites in Dufferin County and Chatham-Kent were chosen to incorporate potential noise and visual impacts along with other common siting criteria, including planning, economic, physical and environmental. There were several reasons behind selecting these sites. First of all, after reviewing the survey results of Christidis (2012) of Dufferin County and Chatham-Kent wind farm studies, local residents have expressed concerns regarding vibration noise, sound and visual impacts of wind farms, including visual domination of the landscape and flicker. Secondly, many wind turbines have already been installed in Dufferin County and Chatham-Kent. According to the Ontario Power Authority (2014b), there were 45 turbines installed in Melancthon I Wind Plant in 2006, which generated 67.5MW in the township in Melancthon. In 2008, there were an additional 88 wind turbines installed in Melancthon II Wind Plant, generating 132MW in the Township of Amaranth and Melancthon in 2008 (ibid). By 2011, a total number of 9,300 acres (≈37,635,475 square meters) of wind farm developments were implemented, generating nearly 200,000 kWh annually from Raleigh Wind Energy Center of Chatham-Kent (Onatio Power Authority, 2014b). Ontario Power Authority (2014b) also noted that Dufferin County and Chatham-Kent have a relatively higher level of electricity generation than the other commercial wind farm operations in southern Ontario.

A number of wind farms have been implemented and have already caused public opposition in Dufferin County. The suitability level within each feasible site was not identified according to the Dufferin County Wind Power Project Site Plan (Dufferin Wind Power Inc, 2012). Sites in Dufferin County and Chatham-Kent were selected to demonstrate how this method works and presents the spatial variation in suitability levels before and after incorporating the visual and noise criteria. The siting method of this research is not restricted to these selected areas and it can be applied to other feasible areas to spatially represent noise and visual impacts of wind farms.

3.3 Research Tools

Many studies have noted that GIS is a popular and effective technique that has been widely applied in wind farm site selection applications (Christidis & Law, 2012; Janke, 2010; Karakostas & Economou, 2014; McWilliam, van Kooten, & Crawford, 2012; van Haaren & Fthenakis, 2011). GIS has been identified as a powerful tool in land-use planning and suitability mapping (Malczewski, 2004). In this study, ArcGIS is used as a key tool to perform spatial analysis in both raster and vector environments. Raster GIS was used to create the criteria suitability scores and perform global and local Weighted Linear Combination (WLC) standardizations. The vector data is mainly applied in the feasible site selection process. In order to aggregate all the criteria layers and produce output maps, an overlay technique that combines all the weighted raster criteria layers was applied.

In addition, to spatially represent the noise-affected population, the analysis was conducted by utilizing an Interactive Data Language (IDL) programming code in ENVI. ENVI is an imagery processing tool that offers a rapid way to perform a raster analysis by running the IDL code (EXELIS, 2014). More importantly, the raster files in ENVI are interchangeable with ArcGIS, which allows users to visualize raster results and perform additional analysis. Viewshed analysis, a function in ArcGIS, was selected as a tool to calculate the population that was exposed to the visual impact.

3.4 Site Selection Criteria and Constraints

Due to a lack of publicly available studies on Ontario wind farm site selections, the siting criteria need to be reviewed and identified based on the current literature. After reviewing the current wind farm literature, the most commonly used wind farm siting criteria and their corresponding categories have been summarized in Table 3.1. Each criterion will be used as a siting criterion in this research.

Table 3.1. Summary of siting criteria from literature

Category	**Siting Criteria**	**Tegou, et al. (2010)**	**Belflore, (2012)**	**Gorsevski et al. (2013)**	**Kumar & Shaikh (2013)**	**Al-Yahyai et al. (2012)**	**Baban & Perry (2001)**	**Bennui et al. (2007)**	**Rodman& Meentemeyer (2006)**	**van Harren & Fthnakis (2011)**
Physical	Slope	✓	✓		✓	✓	✓	✓	✓	✓
	Wind Speed	✓	✓	✓		✓	✓	✓	✓	✓
Environmental	Wooded Lands &Vegetation Areas	✓		✓	✓		✓	✓	✓	✓
	Water Bodies			✓			✓	✓		✓
	Wetlands	✓		✓					✓	✓
	Environmental Sensitive Areas		✓	✓		✓	✓	✓	✓	✓
	Wildlife Bird Feeding Area/habitat			✓					✓	✓
Planning	Single Dwellings		✓				✓			✓
	Distance to Airport	✓		✓				✓		✓
	Large Settlement/Urban Area	✓	✓	✓	✓	✓	✓	✓	✓	✓
Economic	Distance to Roads/Highway	✓	✓	✓	✓	✓	✓	✓		✓
	Distance to Transmission line	✓	✓	✓			✓			✓

The availability of spatial data can affect the results of the feasible location. In this study, the constraints and siting criteria are based on the current literature and the regulations of the Ontario's Approval and Permitting Requirements Document for Renewable Energy Projects (2009). Due to the fact that the constraints for some criteria in this study are not listed in this regulation document (2009), siting constraints such as slope, distance to airport, large urban settlements and transmission lines are also studied from the current literature. Meanwhile, ideal datasets should include specific information on trout lakes and provincially significant wetlands, wooded areas, wildlife habitat, provincial parks are unavailable. The following sections describe the criteria and constraints that were gathered from currently available datasets.

Physical Criteria

Wind Speed

Wind speed is the most critical factor in the wind farm selection process, in which higher wind speed is preferred for higher efficiency and productivity (Al-Yahyai, Charabi, Gastli & Al-Badi., 2012; Baban & Parry, 2001; Belflore, et al., 2012; Bennui, Rattanamanee, Puetpaiboon, Phukpattaranont, & Chetpattananondh, 2007; Kumar & Shaikh, 2012; Rodman & Meentemeyer, 2006; van Haaren & Fthenakis, 2011). Baban & Parry (2001) and Al-Yahyai et al. (2012) applied 5.0 m/s wind speed as their physical criterion; Rodman & Meenteneyer (2006) used 7.0 m/s as a suitable speed for large wind turbines.

In this study, the physical constraint of wind speed is based on the acceptable feasible wind speed that starts at 6.5 m/s at a height of 80 meters, based on the data from the Ontario Renewable Energy Atlas (Ontario Ministry of Energy, 2014a). The areas with a wind speed that less than 6.5m/s were excluded in this study.

Slope

Slope is another important physical criterion in designing wind turbines, a steady slope is required because "limited accessibility of the cranes needed to lift heavy turbine components" (van Haaren & Fthenakis, 2011, p. 3336). Meanwhile, the slope can also affect the wind power generation since "the sharper changes in slope can also cause turbulences" (Al-Yahyai, et al.,2012, p.83). Baban & Perry (2001) and Kumar & Shaikh (2012) used a slope angle less than 10% in the UK and India studies.

In this study, slope was obtained from Digital Elevation Model (DEM). A slope value of 10%, stated in both Kumar & Shalkh (2013) and Baban & Perry (2001) studies, was applied as a threshold to exclude areas with a slope angel that is greater than 10%.

3.4.1 **Environmental Criteria**

In order to minimize the environmental impacts of wind farms, environmental criteria are essential factors in wind farm siting. Environmental criteria include wetlands, water bodies, environmental sensitivity areas, wooded areas and bird habitats (Al-Yahyai et al., 2012; Bennui et al., 2007; Gorsevski et al., 2013; Rodman & Meentemeyer, 2006; Tegou, Polatidis, & Haralambopoulos, 2010; van Haaren & Fthenakis, 2011).

Water Bodies

According to the Approval and Permitting Requirements for Renewable Energy Projects report (2009), renewable energy projects should not be built within "300 meters of the average annual high water mark of a lake trout lake that is at or above development capacity" (Section 5.2.3.1, p.15). Accordingly, assuming all water bodies are treated as trout lakes, a 300-meter buffer was applied around the water body layer and then the buffered areas were excluded from the overall

Southern Ontario study area. This assumption is made due to the fact that the water body layer does not contain attribute information on natural trout lakes specifically.

Water Courses

In this study, the type of water course data is polyline, which does not contain width information on the water course. According to Upper Thames River Conservation Authority (2008), which is the up-to-date data available regarding the average width of rivers in Southern Ontario, the average calculated width of water stream is approximately 15 meters. Also the setback regulation in Ontario is 120 meters to protect the high water mark of the permanent or intermittent stream (Section 5.2.3.1, p.15). After converting the water courses polyline data into a 15 meters width polygon, the 120 meters setback regulation is applied on the watercourse layer. Then, the buffered water course areas were excluded from the study area.

Wetlands

Rodman & Meentemeyer (2006) emphasized that wetland areas are unsuitable to build wind farms. Wetlands are also considered as one of the constraints in Tegou et al. (2010)'s study.
In Ontario, the renewable energy regulation prohibits the construction "within 120 meters of provincially significant southern wetland" (Section 5.2.3.1, p.15). In this study, the wetland areas were buffered with a distance of 120 meters and have been excluded from the overall study area, according to the Ontario renewable energy regulations. The study assumed that all wetlands are equally important due to the fact that there is no attribute information to distinguish the significance of certain wetlands from others.

Wooded Areas

Refer to the Ontario Approval and Permitting Requirements for Renewable Energy Projects, it states that "No person shall construct a renewable energy testing facility…within 120 meters of a significant woodland" (Section 5.2.3.1, p.15). In this study, a 120 meter buffer has been applied to the woodland areas according to the Ontario regulations for renewable energy, before excluding the buffered wooded areas from the study region. All woodlands are treated as equally important because this is no attribute information to distinguish the significant wooded areas from others.

Parks

A 120-meter buffer has been applied to all parks, according to the Ontario Approval and Permitting Requirements Document for Renewable Energy Projects, with the purpose of protecting the provincial parks. In Ontario, the renewable energy regulation prohibits the construction "within 120 meters of provincial parks" (Section 5.2.3.1, p.15). However, the park dataset does not contain attribute information that can help to identify the provincial parks specifically. Hence, a 120-meter buffer was applied to all the parks in Southern Ontario according to the Ontario renewable energy regulations. Then the buffered areas were excluded from the overall study area.

Environmental Sensitivity Area (ESA)

The ESA belongs to the conservation reserve area group. A 120 meters regulation rule applied before they are excluded from the overall study area, as the Ontario renewable energy regulation stated that “No person shall construct a renewable energy testing facility…within 120 meters of a conservation reserve” (Section 5.2.3.1, p.15).

Wildlife and Bird Habitat

As stated in the Ontario Renewable Energy Approval Document, renewable energy projects should be built 120 meters away from significant wildlife habitat. In this study, a 120 meter buffer was applied to wildlife and bird habitats criterion, according to the Ontario renewable energy regulations. All the habitats were treated as equally important in this analysis, because the attribute does not contain information to distinguish the significant habitats from other data.

Provincially Significant Area of Earth & Provincially Significant Area of Science

The provincially significant areas of earth science were buffered with 50 meters according to the Ontario regulations as “No person shall construct a renewable energy testing facility…within 50 meters of a provincially significant area of natural and scientific interest (earth science) & … within 120 meters of provincially significant area of natural and scientific interest (life science) ” (Section 5.2.3.1, p.15). The provincially significant area of life science was buffered with 120 meters, as stated in the Ontario Approval and Permitting Requirements Document for Renewable Energy Projects. Both buffered areas were then excluded from the study area.

3.4.2 **Planning Criteria**

The planning category is consisted of the following criteria: distance to airports, large urban areas and single dwellings.

Airport

Bennui et al. (2007) noted that a wind farm should be built at a minimum distance of 2000 meters from an airport. According to Boughner (2013), the airport zoning setback regulation in Canada is four kilometers in order to ensure the safety for any developments. In this research, a four kilometer buffer was applied to exclude the unfeasible areas.

Large Urban Areas

In this study, the proximity to large urban settlements is based on Tegou et al., (2010), which suggested a restriction of 1500-meter buffer of construction zones around large urban settlements.

Single Dwellings

Baban & Perry (2001) noted the setback for a single dwelling is 500 meters. van Haaren & Fthenakis (2011) also suggested that wind farms should be kept 500 meters away from single dwellings, to minimize potential noise impacts. The wind farm setback regulation in Ontario is currently 550 meters for noise receptors (Ontario Regulation 359/09). The noise receptors imply single or multiple dwellings as well as buildings (Ontario Regulation 359/09). Therefore, in this study, a buffer distance of 550 meters were applied to all single dwellings, and then excluded from the study area.

Two types of dwelling data are available for this study, polygons and points. However, the information of lot area for each point dwelling is unavailable in the attribute table. In order to obtain the lot area information for dwelling point data, the average size of the available single dwelling polygons was calculated, which is 780 square meters. Therefore, a round buffer with a radius of 15.76 meters was applied, which is equivalent to the size of 780 square meters ($\pi \times 15.76^2$) to covert the point data to polygon.

3.4.3 **Economic Criteria**

Roads and transmission lines are considered as economic criteria, they can help reduce the economic costs of the installation process. On the other hand, a shorter distance from potential wind farms to roads and transmission lines is preferred.

Roads

In this study, the road data obtained from Ontario Ministry of Natural Resources (MNR) is in the form of polyline, which does not contain information about the width. The road data was converted into the average width of roads based on Table 3.2 to represent the Right of Way widths before being excluded from the study area.

Table 3.2. Ontario Right of Way Widths

Adapted from (City of London, Design Specifications & Requirements Manual, 2012, p.3-4)

Category	**Average Width (m)**
Freeway	90
Expressway	60
Arterial (1way & 2way)	31
Collector (Primary & Secondary)	24
Local (Residential & Minor industrial/commercial)	18

<u>Railway</u>

According to the requirements listed in the Standard Respecting Railway Clearance (Transport Canada, 2014), the railway network structure lines were excluded from the study area by applying a 4.27-meter width buffer as the main and siding tracks.

<u>Transmission Line</u>

Gorsevski et al. (2013) highlighted that transmission lines should be as close to potential wind turbines as possible to minimize or avoid the cost of installing new transmission lines. According to Baban & Parry (2001)'s study, the wind farm should not be sited more than 10 kilometers from transmission lines, in order to reduce cost of the wind farm development. In addition, in order to select a suitable distance to transmission lines, a measurement between existing wind turbines in Melancthon Phase I and transmission lines was performed by GIS. The result demonstrates that many existing turbines are located within 10 kilometers of the transmission lines. Another example of the Sydenham wind farm project in Lambton County, Ontario also sited within 10 kilometers of the transmission lines (Sydenham I Project Stantec Draft Site Plan, 2011). Thus, in this study, the distance of 10 kilometers was applied as the distance to exclude areas outside 10 kilometers of transmission lines.

3.5 Siting Analysis and Screening Process

Figure 3.3 illustrates the site selection screening process. After clipping the Southern Ontario study area from Ontario's overall map, the criteria in Step 2 were processed. In Step 3, due to the fact that some feasible sites were isolated or too small, feasible areas that are smaller than 343,983 square meters were excluded. The 343,983 square meters was selected as this study is primarily focused on wind farm facilities that generate greater than 20 MW to exclude small feasible sites. To test how reasonable the feasible wind sites identified in the site screening process, the results of this study will be compared with the current wind turbine map of Southern Ontario, retrieved from Ontario Wind Resistance (2014).

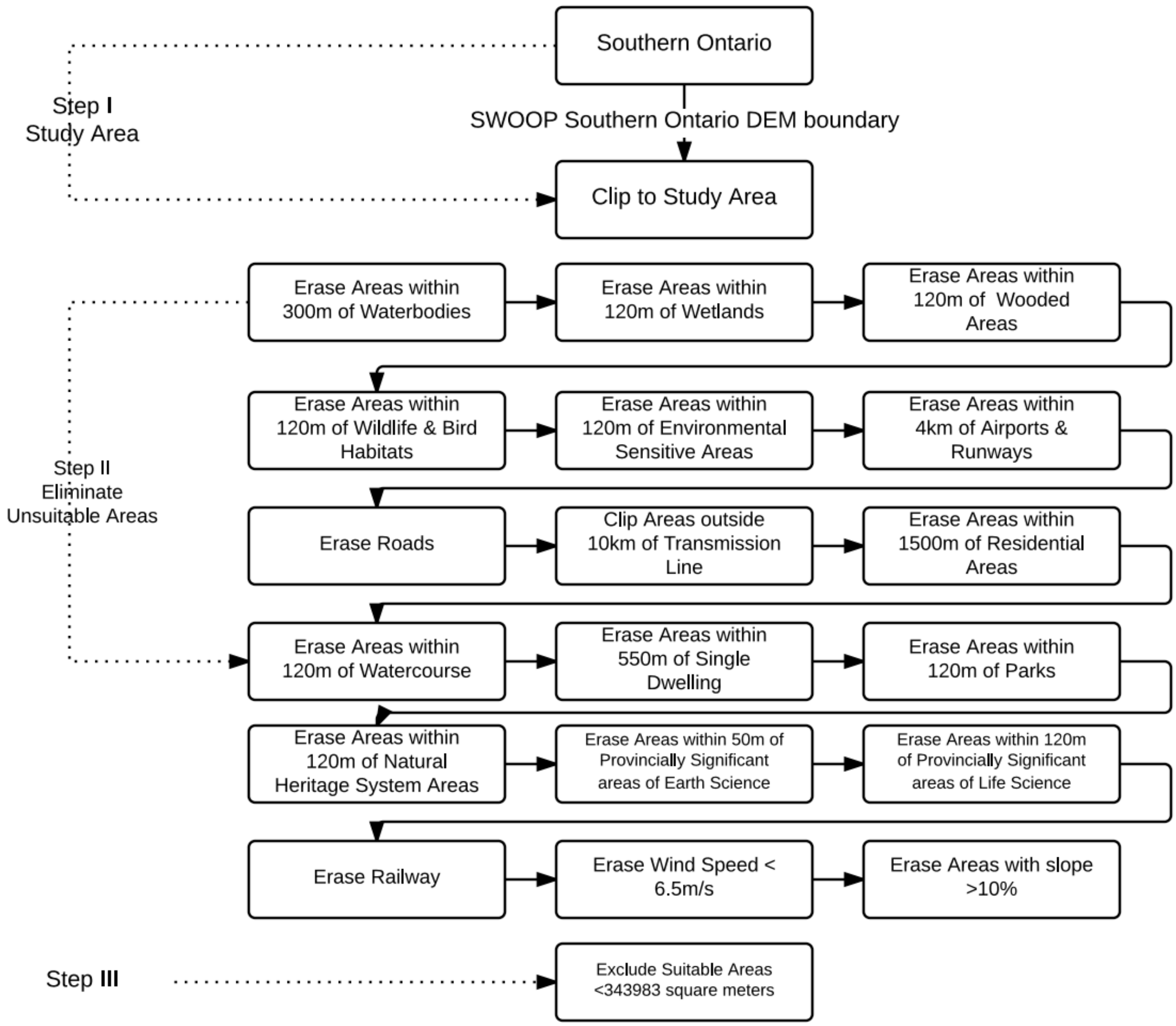


Figure 3.3. Wind Farm Feasible Sites Screening Procedure

Table 3.3 summarizes the siting criteria according to the data type, date, reference, spatial analysis and constraints utilized in this study. These criteria were used to identify the feasible locations to build wind farms in Southern Ontario.

Table 3.3. A Summary of Siting Criteria and Analysis

Criterion	**GIS analysis**	**Description**	**Data Source**	**Year**	**Citation**	**Data Type**
Slope	DEM-Mosaic To Raster- Raster to Slope-Reclassify	Slope less & Equal to 10% -10m resolution	MNR	2009	Kumar & Shaikh (2013) Baban & Perry (2001)	Raster
Wind Speed (spd_80_ont_100mres _geog_nad83)	Raster Reclassify	6.5m/s as an acceptable speed -100m resolution	Ontario Wind Atlas	2005	-Hélimax Energy -MNR	Raster
Wooded Area	Buffer 120m. Erase from study area	No Renewable construction within 120m of significant woodlands	NRVIS-Structured-MNR	2013	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-polygon
Water Course	Buffer 120m. Erase from study area	No construction within 120m of the high water of a lake or permanent /intermittent stream (a) The average width of water stream is around 15m(b)	Ontario Hydro Network (MNR)	2010	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)-(a) Upper Thames River Conservation Authority (b)	Vector-line
Water Body	Buffer 300m. Erase from study area	No Renewable construction within 300 meters of the average annual high water mark of trout lake	Ontario Hydro Network (MNR)	2010	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-polygon
Wildlife and Bird Habitat	Buffer 120m. Erase from study area	No Renewable construction within 120m of significant wildlife habitat	MNR-NRVIS	2008	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-polygon
Parks	Buffer 120m. Erase from study area	No Renewable construction within 120m of significant provincial parks	DMTI	2013	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-polygon

Criterion	GIS analysis	Description	Data Source	Year	Citation	Data Type
Environmental Sensitive Areas	Buffer 120m. Erase from study area	No Renewable construction within 120m of Conservation Reserve Area	MNR-NRVIS	2008	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-polygon
Natural Heritage System Area	Buffer 120m. Erase from study area	No Renewable construction within 120m of Conservation Reserve Area	MNR	2006	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-Polygon
Natural and Scientific Interest Area (ANSI)	Earth Science buffer 50m &Life Science buffer 120m. Erase from study area	No construction within 120m of life science significant area & 50m of earth science significant area	MNR	2012	Approval and Permitting Requirements Document for Renewable Energy Projects (Sept, 2009. P15)	Vector-Polygon
Roads-Road Network	Convert the polyline into the average width of Right of Way	See table 3.2	MNR	2010	Design Specific & Requirements Manual (2012)	Vector-line
Railway Network	-Railway line buffer distance of 4.27m		ORWN	2012	Standard Respecting Railway Clearance (2014)	Vector-(lines & Points)
Airports and Runways	Buffer 4km, Clip to Erased study area		ESRI	2003	Boughner (2013)	Vector-polygon
Transmission Line	Buffer 10km, Clip to Erased study area		MNR	2008	Baban & Perry, (2001) Melancthon & Sydenham wind Projects	Vector-line
Large Settlement/Urban Area	Buffer 1500m, Erase from study area	Residential Areas	DMTI	2013	Tegou et al., (2010)	Vector-polygon
Single Dwelling (a)	Buffer 550m, Erase from study area	Building-to-Scale	NRVIS-Structured MNR	2010	Ontario, FIT Policy (2009)	Vector-polygon
Single Dwelling (b)	Buffer 550m setback and average 780m^2 dwelling lot area	Building-symbol	NRVIS-Structured MNR	2010	Ontario, FIT Policy (2009) Average building-to-scale:780m^2	Vector-point
Ontario Boundary and CSD			Statistics Canada	2011		Vector-polygon
Orthoimagery	Orthoimagery	20cm resolution & 40cm multi-spectral	SWOOP	2010, Spring		Satellite imagery

3.6 Potential Noise and Visual Impacts Siting Approach

One of the objectives of this research is to address potential noise and visual concerns. This section describes the GIS approach that was developed to estimate the potential affected population by turbine noise and visibility. Section 3.6.1 discusses the approach that was used to estimate the affected population as a result of wind turbine noise. Section 3.6.2 describes the method of viewshed analysis that identifies the affected population as a result of the physical presence of a wind turbine.

The population that perceives turbine noise and visibility can represent the impacts of wind farms to the surrounding residents. Qualitative approaches, such as interviews and survey questionnaires are often used to collect opinions of the residents, who live within the vicinity of existing or proposed wind farms (Molnarova, et al., 2012; Taylor, et al., 2013; Pedersen, Hallberg & Waye, 2007). For instance, Taylor et al. (2013) distributed a survey to measure the level of noise impacts of households near wind turbines. However, the disadvantage of this approach is that the information collected from survey questionnaires can only represent the sample populations for a specific sample site within the study area, and each sample site will need to be studied separately (Kelley, Clark, Brown & Sitzia, 2003). For example, in this thesis, a large number of feasible wind farm sites were identified across Southern Ontario study region, and there are contextual differences among different sample sites within a large study area, it is not ideal to use a qualitative approach as a generalizable approach to quantify the noise and visual impacts of wind turbines. Quantitative approaches, such as quantitative estimates is another approach that is often applied in the land use suitability analysis (Malczewski, 2004). It can assist decision makers to analyze the spatial patterns and identify the potential impacts of wind farms in the site planning process. As the intention of this thesis is to develop a generalizable approach to spatially represent potential noise and visual impacts of wind farms, a quantitative siting approach was chosen to estimate the population that can be affected be turbine noise and visibility. The noise and visual criteria that are generated through this study can be combined with the common siting evaluation criteria to make the siting decisions more socially acceptable.

In this thesis, the “affected population” represents the population that can potentially perceive the turbine noise and visibility impacts. The population affected by turbine noise can be estimated by summing the population counts that are estimated to perceive a noise level of 20 dB and above from a turbine location. The affected population with respect to turbine visibility is estimated by aggregating the total population that is located at the visible landscape cells of an 80-meter high turbine. The visible landscape cells are calculated by running the viewshed analysis, which will be discussed in Section 3.6.2. In order to estimate the population affected by a wind turbine, the term “single dwelling cell” is introduced. According to Statistics Canada, single dwellings include single-detached houses, apartments, mobile homes and other movable dwellings that are used for residential purposes (Statistics Canada, 2012). In this thesis, single dwelling data was converted into single dwelling cells in raster format. Due to the fact the population of each single dwelling is unavailable, the population of each single dwelling cell was estimated by dividing the total number of population in each Dissemination Area (DA) by the total number of single dwelling cells in the DA.

Since the population of each single dwelling cell in this thesis is calculated based on the total number of population and single dwellings in each DA, all single dwelling cells within the same DA hold the same number of population. According to the definition of Statistics Canada (2014), a dissemination area is the smallest standard geographic area among all census data, with a population range of 400 - 700 people. The population of single dwelling cells is different among different DAs, since the total population and the total number of single dwelling cells vary for each DA. Appendix VIII shows an example to demonstrate how the population in each DA is calculated. In this thesis, there are more single dwellings cells in each DA, and the estimated population of each single dwelling cell is varied according to the actual total population of each DA, and the number of single dwelling cells in each DA. In this example, there are three DAs within the turbine impact zone. In DA 1, the total population is 500 and there are two single dwelling cells; thus, the average population of each single dwelling cell is 250 (500/2). The population of the single dwelling in the adjacent DA 3 is 700 (700/1), because the total population in DA 3 is 700, and there is only one single dwelling cell. As a result, for two single dwelling cells that are close to each other, as long as they are not within the same DA, they would most likely have different population as demonstrated in the example above. Unlike an urban area, where the population count of single dwelling cells in each DA can be tested to produce a smooth population surface, rural areas have more spare population and single dwelling cells. Thus, the population count of each single dwelling cell can be higher, in order to represent the total population of each DA.

3.6.1 **Noise Impact**

The spatial approach that was applied to present the noise-affected population will be discussed in this section. In order to perform the analysis, the feasible sites and single dwellings need to be converted into raster cells. Equation 3.1 is used to calculate the sound pressure level at each single dwelling raster cell.

<u>Determine Noise Level</u>

In order to measure the potential noise impact of wind turbines, the potential affected population needs to be determined first. In this study, the noise level of 20 dB was applied as a threshold value to estimate the affected population by turbine noise, that is, the population that perceives more than 20 dB of noise from a potential wind farm will be considered in the analysis. In Canada, there are presently no wind turbine setback requirements for the national or local levels, as in France or Italy, but there are provincial regulations (Haugen, 2011). The 550-meter is the minimum regulated wind turbine setback in Ontario that restricts noise level of 40 dB (CMOH, 2010). However, there are still health concerns when residents perceive a noise level of less than 40 dB. Shepherd, McBride, Welch, Dirks, & Hill (2011) compared different studies and concluded that the exposure to noise level varied in different studies. They stated that 20% of respondents had sleeping trouble with a noise level of 25 dB(A); another study showed that with an even lower noise level of 10 dB, residents still reported disturbances. Bakker et al. (2012) concluded that people who live in quiet areas are exposed to higher annoyance than noisy areas; therefore, the noise threshold differs depending on the study area and the response from residents. 20 dB is selected in this study as the threshold value to collect the population that is affected by a noise level of 20 dB or above; nonetheless, different threshold noise values can be assigned to obtain the potential noise-affected population.

Sound Pressure Level Calculation

Equation 3.1 was applied to calculate the noise level of wind turbines, discussed in van Haaren & Fthenakis (2011). In order to perform this calculation, the inputs of the Sound Noise Level at Source (Lw), Turbine Height (H), Distance between turbine and noise receiver (X), Atmospheric Absorption (α) are required.

Equation 3.1. Wind Turbine Sound Pressure Level

Source: Adopted from (van Haaren & Fthenakis, 2011)

$$Lp\ (dB) = Lw\ (dB\ (A)) - 10\log_{10}(2\pi R^2) - \alpha R$$

$$R^2 = H^2 + X^2$$

Where: Lp (dB) = Sound pressure level
Lw (dB (A)) = Sound noise level at source -102dB
H (meter) = Turbine height at 80m
X (meter) = Distance between turbine and noise receiver
α dB(A)/m= Atmospheric absorption which equals to 0.005dB/m
R (meter) = Square root of H^2+X^2

a. Turbine Height (H)

Refer to Dufferin Wind Power Inc (2012), where the turbines hub heights range from 80 to 85 meters. In this study, a standard 80 meter height turbine is applied as a constant turbine height value across the study area, based on the turbine height used in the Ontario Renewable Energy Atlas (Ontario Ministry of Energy, 2014a).

b. Sound Noise at Source (Lw)

The sound noise at source is presented in a-weighting decibels-dB (A), which is the most commonly used unit to measure the medium intensity sound level to human ears (Rogers, Manwell, & Wright, 2006). According to van Haaren & Fthenakis (2011) and Rogers et al. (2006), the sound pressure level (dB) is measured by calculating the distance from an observation point to the turbines with the consideration of 1000Hz atmospheric absorption. The minimum setback of 550-meter is applied to the noise level of 102 dB (A) at the source with a number of 5 turbines (Environmental Protection Act, 2009). Consequently, 102dB (A) is used to represent the sound pressure level at the source.

c. Atmospheric Absorption (α)

The atmospheric absorption equals to 0.005 dB/m was given in van Haaren & Fthenakis (2011).

d. Distance between Turbine and Noise Receptor (X)

The potential wind turbine location is represented by each 25 x 25 meter raster cell within a feasible site. The noise receptors are the surrounding single dwelling cells of wind farm areas. The distance was calculated by conducting a Euclidean distance, which measures the shortest distance between each turbine site cell and individual single dwelling cells. After all the necessary information for this equation is obtained, the noise pressure level at each site cell location can then be calculated.

Table 3.4 summarizes the noise pressure level of wind turbines associated with the distance at the source noise, by implementing Equation 3.1. Within the coverage of 1800 meters, the single dwelling cells can perceive 19.9 dB (≈ 20 dB) of noise from a wind turbine.

Table 3.4. Calculation of noise impact level at different locations

Noise Pressure Level Lp (dB)	**Sound Noise at Source Lw (dB)**	**Noise Receiver's Distance X (m)**	**Height H (m)**	**Atmospheric Absorption α(dB/m)**	**Square root of H^2+X^2**
36.34	102	550	80	0.005	555.79
28.93	102	1000	80	0.005	1003.20
25.80	102	1250	80	0.005	1252.56
19.90	102	1800	80	0.005	1801.78

Noise-affected population IDL Code Description

The noise-affected population analysis was conducted by running the IDL code in ENVI software and the results were displayed using GIS software. The general logic behind the code is shown in Figure 3.4 and Appendix IV. The potential noise impact is illustrated by creating a continuous raster surface with an input value of the noise level at each location. The noise-affected population is calculated based on a four-step analysis.

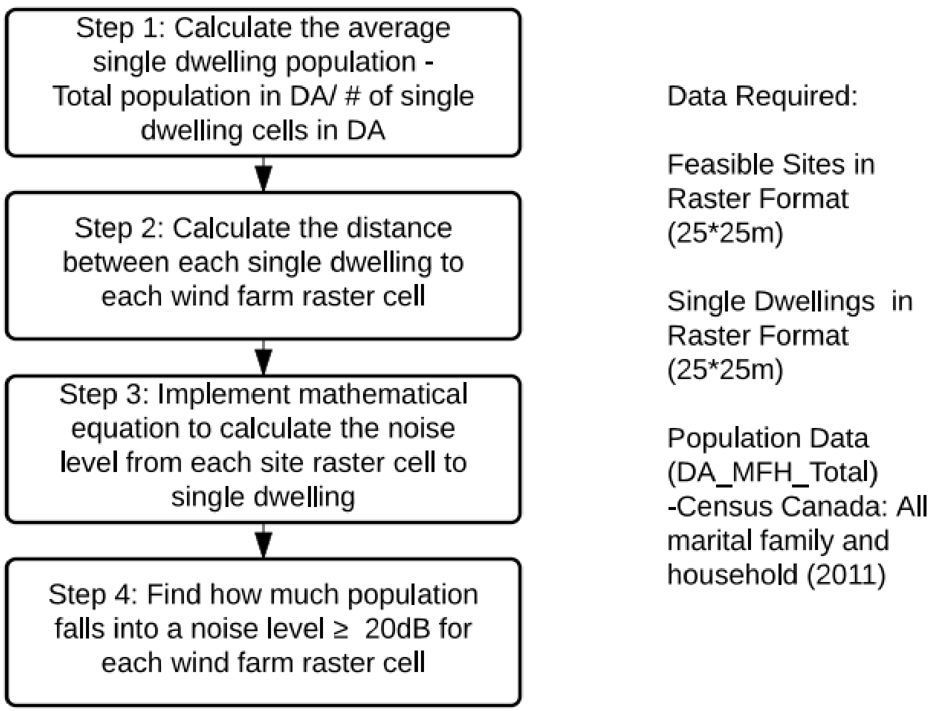


Figure 3.4. Wind Farm Noise-affected Population Calculation Procedure and Data Requirements

Step 1: The population in DA was selected to present the total population in each DA. The average population in each single dwelling needs to be calculated by using the total DA population, divided by the total number of single dwelling cells in each DA.

Step 2: After the average population of each single dwelling is calculated, the distance between each single dwelling cell to every raster wind farm site cell was measured by using Euclidean distance.

Step 3: The potential noise level that each dwelling cell may be exposed to every wind turbine site cell is calculated by implementing Equation 3.1.

Step 4: Calculate the total population that falls into the noise level ≥ 20 dB of each wind farm site cell.

The noise-affected population standardization values are combined with the standardized values of the common siting criteria in order to compare the changes of suitability level within a feasible site.

3.6.2 **Visual Impact**

The aesthetic impact of wind farms is another critical issue that triggers public opposition. In order to illustrate the potential visual impacts of wind farms, ArcGIS viewshed analytical tool was used to create a visual impact raster layer. Figure 3.5 presents how the viewshed analysis is performed and the description of the characteristics of the viewshed analysis is shown in Table 3.5. In this study, a turbine height of 80 meters was applied as the value of Offset A. The Digital Elevation Model (DEM) was also obtained to determine the surface elevation of the turbine. The default settings of viewshed analysis were applied to the rest of the characteristics, including Azimuth 1 & 2, Vertical Angel 1 & 2 and Radius 1 & 2 to consider all the possible visible landscape cells within the horizontal scan angel from 0° to 360°, vertical scan angel from 90° to -90°, and the scan radius distance between 0 to the boundary of the DEM.

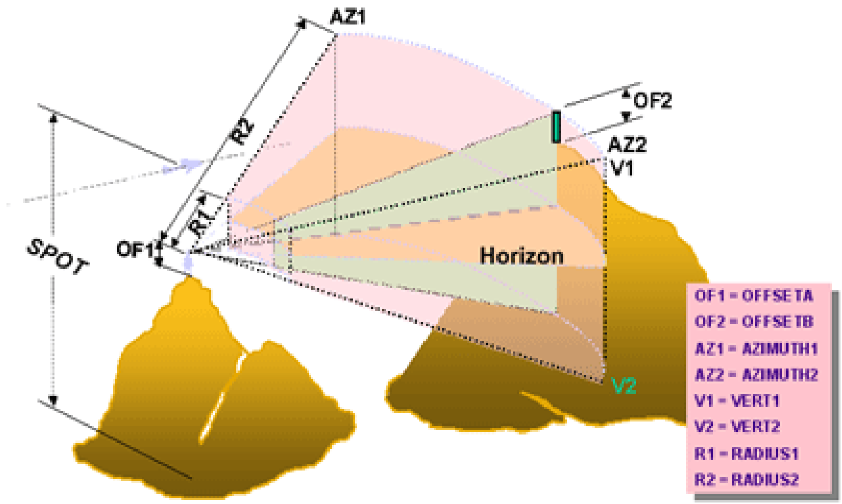
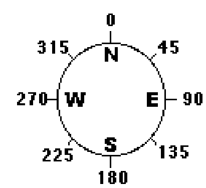
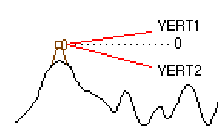
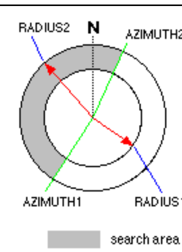


Figure 3.5. Demonstration & Characteristics of the Viewshed Analysis (ESRI, ArcGIS Help, 2012)

Table 3.5. The Characteristics of the Viewshed Analysis ((ESRI, ArcGIS Help, 2012)

Characteristic	Description
Spot	Surface elevations of the tower - Digital Elevation Model (DEM)
Offset A	Offset A: Elevation to be added to the tower (80-Meter Height Turbine)
Azimuth 1 **Azimuth 2**	The horizontal angel of the scan range Azimuth 1: Start angel (0˚ as default) Azimuth 2: End angel (360˚ as default) 
Vertical Angel 1 (Vert 1) **Vertical Angel 2 (Vert 2)**	The vertical angel of the scan range Vert 1: Upper horizontal angel (90˚ as default) Vert 2: Lower horizontal angel (-90˚ as default) 
Radius 1 **Radius 2**	The radius limit the scan distance Radius 1: Start Distance (0 as default) Radius 2: End Distance (boundary of the clipped DEM) 

In this study, based on a standard wind turbine height of 80 meters, the viewshed analysis allows users to identify the visible and non-visible areas of each wind farm site cell. Groothuis, Groothuis, & Whitehead (2008) addressed the term viewshed to determine the compensation for local residents who perceive greater visual concerns. The viewshed analysis also provides results of visibility impacts in a raster landscape environment (Möller, 2006). In order to perform the visual analysis, Digital Elevation Model (DEM) data and potential turbine points with height are required. In this study, the turbine points are created from the centroid of each 25 x 25 site cell of a feasible site with a turbine height of 80 meters.

In a viewshed analysis, the raster landscape is divided into two groups: visible and non-visible. Running a viewshed analysis helps identify which landscape cells are visible from different turbine locations. It is a sufficient way of creating visibility maps and demonstrating the cells on a landscape area that each turbine is exposed to. This can be applied to estimate the population that can be visually impacted by building a wind farm in a particular raster cell. Figure 3.6 illustrates a viewshed example of an observation tower (green triangle). Based on the height of the observation tower and the input surface, an output raster layer is created to illustrate the visible (green) and non-visible landscape cells (red) from the tower. In the viewshed analysis, 29 kilometers was applied to clip the input surface (DEM) raster layer, because beyond that point, wind facilities will not be noticed by observers (Sullivan, Kirchler, Cothren, & Winters, 2013).

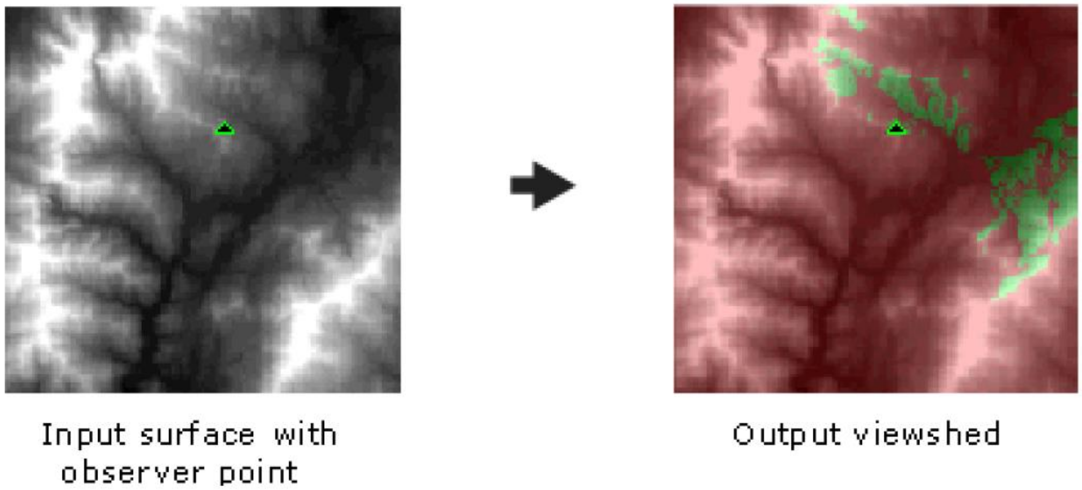


Figure 3.6. Identifying the Visible Landscape Cells from a Turbine by Performing Viewshed Analysis (ESRI, ArcGIS Help, 2012)

The diagram of the visual impact siting approach is shown in Appendix V. After the visible landscape raster cells from each turbine have been identified, the impacted population by the visibility of each turbine can be extracted, based on the overlapped areas of the average single dwelling population raster cells and the visible landscape raster cells. The standardization values of visual impact are combined with the standardized common siting criteria values to compare the difference of suitability level, after considering the potential visual impact within each feasible site.

3.7 Criteria Standardizations

In order to make the siting criteria comparable with one another, it is significant to convert raw data in each criterion into a standardized score on a 0 to 1 range, by applying the linear transformation such as WLC (Malczewski, 1999). After the standardized value for each criterion has been obtained, a weight will be assigned to each criterion. The standardization techniques that are used in this study are both global and local WLC. The global WLC assumes spatial homogeneity within a study region. However, the spatial heterogeneity in a local context is not captured (Malczewski, 2011). The local WLC was introduced by Malczewski (2011), where it considers the variation among geographic spaces within a local scale, and provides spatial sensitivity information about local variations in a feasible site. The global WLC method will be applied to generate information for the overall suitability scores among the selected feasible sites. Noise and visual concerns toward wind farms are localized information; therefore, local WLC method is applied to integrate the noise and visual criteria with other siting criteria.

3.7.1 **Global WLC**

The conventional WLC is referred to as the Global WLC, which is the most commonly used MCDA method (Malczewski, 2011). Refer to Equation 3.2, Equation 3.2a and 3.2b are applied to generate global standardized values for each criterion. The standardized score of k_{th} criteria for i_{th} alternative is calculated by measuring the minimum, maximum and global range values. Equation 3.2a is applied to the scenario where a higher criterion value is preferred, the standardized score can be calculated by the subtraction between the actual value stored in the raster cell and the global minimum value first, and then divided by the global range value. Similarly, Equation 3.2b is applied to the criteria where a lower criterion value is preferred. When a lower criterion value is preferred, the standardized score can be calculated by the subtraction between the global maximum value and actual value stored in the raster cell, and then divided by the global range value. In this study, the global maximum / minimum value for each criterion refers to the maximum / minimum value among all sites. The global range value is the subtraction of the global maximum and the minimum value.

Equation 3.2: Global WLC Standardization

Source: Adopted from (Malczewski, 2011)

$v(a_{ik}) = a_{ik} - \min\{a_{ik}\} / r_k$ ………..Equation 3.2a (k_{th} criteria to be maximized)

$v(a_{ik}) = \max\{a_{ik}\} - a_{ik} / r_k$ ………..Equation 3.2b (k_{th} criteria to be minimized)

Where: $v(a_{ik})$: Standardization score

a_{ik}: Actual value stored in the raster cell

$\min\{a_{ik}\}$: Minimum value among all feasible site

$\max\{a_{ik}\}$: Maximum value among all feasible site

r_k : Range: $r_{(global)} = max_{(global)} - min_{(global)}$

The advantage of using the global WLC is that it can generate the standardization values for the overall study area; however, it ignores the importance of geographic variations among local contexts (Malczewski, 2011). Therefore, the local WLC should be applied to present the spatial changes within each feasible site. In this study, the global WLC was applied to provide information on the suitability level for the overall study areas, by considering common siting criteria such as physical, environmental, planning and economic. In the global WLC analysis, all the common siting criteria will be treated as equally important to generate overall suitability scores and rank among the selected feasible sites. Although different critera weights can be applied to global standardization values, this study is primarily focused on the local context and local weights after the integration of the noise and visual criteria by applying the local WLC standardization. Since the noise and visual impacts vary within each site, the localized criteria weights were generated for all the siting criteria and different criteria combinations in the local WLC analysis. The local WLC method was proposed by Malcewski (2011) to provide a solution that overcomes the obstacles of global WLC.

3.7.2 **Local WLC**

In a local context, Malczewski (2011) noted that local values vary from place to place and the local neighbourhood within the study area needs to be identified in the early stage. In this study, each feasible site was considered as a discrete local study zone. Equation 3.3 is utilized to calculate local criteria standardized values. The local maximum or minimum value for each criterion refers to those values in each individual feasible site. The local range value is the subtraction between local maximum and minimum values. Similar to the global WLC, when a higher criterion value is preferred (Equation 3.3a), the standardized score can be calculated by the subtraction between the actual value stored in raster cell and local minimum value, and then divided by the local range value. When a lower criterion value is preferred (Equation 3.3b), the standardized score can be calculated by the subtraction between the local maximum value and the actual value stored in raster cell, and then divided by the local range value.

Equation 3.3. Local WLC Standardization

Source: Adopted from (Malczewski, 2011)

$v(a_{ik}) = a_{ik} - \min\{a_{ik}\} / r_k$ ………… Equation 3.3a (k_{th} criteria to be maximized)

$v(a_{ik}) = \max\{a_{ik}\} - a_{ik} / r_k$ ………….Equation 3.3b (k_{th} criteria to be minimized)

Where: $v(a_{ik})$: Standardization score

a_{ik}: Actual value stored in the raster cell

$\min\{a_{ik}\}$: Minimum value within each feasible site

$\max\{a_{ik}\}$: Maximum value within each feasible site

r_k : Range: $r_{(local)} = \max_{(local)} - \min_{(local)}$

The local WLC standardization technique can generate outputs that contain the local maximum, minimum and range values by using GIS (Malczewski, 2011). The results can assist decision makers to identify the changes within the local context and potentially resolve local spatial problems. In this study, eight feasible sites in Dufferin County (three sites) and Chatham-Kent (five sites) were selected to demonstrate the suitability variation within a local context by considering not only the physical, environmental, economic and planning criteria, but also the noise and visual criteria.

3.7.3 Site Evaluation Criteria

In this study, raster GIS analysis was applied to calculate the distance between the siting criteria and the feasible sites. A standardization analysis was applied to evaluate each criterion value. The site evaluation criteria are listed in Table 3.6. The evaluation criteria are different than the site screening criteria, listed in Table 3.3. For instance, large urban settlement, railway and water course layers were not considered in the site evaluation process. Since all feasible wind farm sites were already 1500 meters away from the large urban settlements in the screening process, the distance between large urban settlements and feasible wind farms were not considered. In addition, only a few railway lines crossed the feasible wind sites; therefore, railway layer was not included. Water courses including water streams were all close to feasible sites, so this layer was not involved in the standardization process.

Each feasible site is divided into 25 x 25 raster cells, the nearest distance to all of the above mentioned criteria, with the exception of the wind speed and slope, which were calculated by conducting the Euclidean distance analysis and results were stored in each raster cell. Raster cell size is often dependent on the actual spacing between turbines and the size of the study area. In this study, the feasible sites are divided into 25 x 25 meter raster cells to demonstrate the changes within a large feasible site. As mentioned in the literature review, the spacing for wind turbine depends on the rotor diameter of the turbine (Gipe & Murphy, 2005). However, 25 x 25 meter raster cells used in this study is for demonstration purposes to illustrate the changes of spatial suitability level/variation in a smaller area. The cell of the raster feasible site is not restricted to

25 x 25 meters; a different size can be applied depending on users' preferences and the actual rotor diameter of a turbine.

In a wind farm siting process, a higher wind speed value is preferred. A further distance to wetland, water body, park, natural heritage system, wooded area, natural and science significant area, airport, single dwelling, wildlife and bird habitat, and environmental sensitivity areas are also preferred. The standardized values of these criteria were calculated by using Equation 3.2a for the global WLC standardization and Equation 3.3a for the local WLC standardization. On the other hand, a shorter distance to roads, transmission lines and slopes are preferred. The standardized values of the criteria were calculated by using Equation 3.2b for the global WLC and 3.3b and local WLC standardization.

Table 3.6. Summary of Site Evaluation Criteria

Category	Criteria	Description	Analysis	Standardization Preference
Physical	Wind Speed (m/s)	Wind speed for each raster feasible cell	Extract by Mask	Higher value is preferred
	Slope	Slope for each raster feasible cell	Extract by Mask	Lower value is preferred
Economic	Transmission Line (m)	Each cell contains distance value to the closest transmission line	Euclidean Distance-Extract by Mask	Shorter distance is preferred
	Road Network (m)	Each cell contains distance value to the closest road	Euclidean Distance-Extract by Mask	Shorter distance is preferred
Environmental	Wetland (m)	Each cell contains distance value to the closest wetland	Euclidean Distance-Extract by Mask	Further distance is preferred
	Water Body (m)	Each cell contains distance value to the closest water body	Euclidean Distance-Extract by Mask	Further distance is preferred
	Park (m)	Each cell contains distance value to the closest park	Euclidean Distance-Extract by Mask	Further distance is preferred
	Natural Heritage System (m)	Each cell contains distance value to the closest natural heritage system	Euclidean Distance-Extract by Mask	Further distance is preferred
	Wooded Area (m)	Each cell contains distance value to the closest wooded area	Euclidean Distance-Extract by Mask	Further distance is preferred
	Earth Science Significant Area (m)	Each cell contains distance value to the closest earth science significant area	Euclidean Distance-Extract by Mask	Further distance is preferred
	Natural Science Significant Area (m)	Each cell contains distance value to the closest natural science significant area	Euclidean Distance-Extract by Mask	Further distance is preferred
	Wildlife and Bird Habitat (m)	Each cell contains distance value to the closest wildlife & bird habitat	Euclidean Distance-Extract by Mask	Further distance is preferred
	Environmental Sensitivity Area (ESA) (m)	Each cell contains distance value to the closest ESA	Euclidean Distance-Extract by Mask	Further distance is preferred
Planning	Airport & Runway (m)	Each cell contains distance value to the closest airport & runway	Euclidean Distance-Extract by Mask	Further distance is preferred
	Single Dwelling (m)	Each cell contains distance value to the closest single dwelling	Euclidean Distance-Extract by Mask	Further distance is preferred

3.8 Multi-criteria Weighting Analysis

In this study, the Entropy Information method, which is an objective weighting method, was applied to determine the weight of each criterion. According to the Ontario's Integrated Power System Plan by Ontario Power Authority (2006), Ontario offshore wind projects are based on certain ranking factors that consider expertise, professional judgments to rank the suitability level among different sites. Malczewski (2011) discussed the global / local spatial weighting method; however, the local weights are also highly dependent on global weights, which are obtained from the experts' opinions as well.

In a typical wind farm decision process, the experts' judgments are often required in order to assign criteria weights. However, there are several limitations associated with this weighting technique. For example, when a study involves a large number of sample wind farm sites, it is not ideal to merely rely on the experts to assign criteria weights for each individual site, as each feasible site has its own site features, such as topography, proximity to transmission lines and environmental conservation areas (Belflore, 2012). Besides, "the experts" cultural bias can lead to similar answers to some questions which in fact are poorly known" (Yousuf, 2007, p. 5). When dealing with a study area such as Southern Ontario, there are a large number of sample feasible sites, the selected experts may not be familiar with all the feasible sites across the study area to be able to assign appropriate criteria weights for each site. The judgments collected from the group of experts may not be representative and the process can be time consuming (Yousuf, 2007). Zou, Yun & Sun, (2006) suggested that the entropy information method is an effective way for determining the weight for each criterion because it adequately considers all the criteria values. It is an appropriate weighting method for generating criteria weights that are based on the actual criteria values. It is a suitable weighting technique for a study that contains a large number of sample sites, because the criteria weights can be calculated based on criteria values for all the selected feasible sites.

The Entropy Information method was introduced through the concept of information entropy theory, by Shannon in 1949 (Wang & Niu, 2011). This weighting method has been broadly applied in the field of engineering, economic, statistics and decision theory (Zou, et al., 2006, Wang & Niu, 2011). After reviewing the current literature, there is a general lack of studies that have applied this weighting method in the wind farm siting analysis. In order to fulfill this research gap, the Entropy Information method was chosen to combine with the local WLC technique to determine the localized criteria weights of the feasible sites. However, there is also a limitation associated with this method, since this method is only dependent on the variations among the values of each criterion, public perceptions towards wind farms and the actual dominant siting criteria weights may not be captured.

The information entropy indicates the degree of disorder and uncertainty of a system (Wang, et al., 2008; Zou, et al., 2006). In a comparison matrix (see Figure 3.7), when the difference cell values among the same criterion (A_{11} to $A_{1n,}$ A_{21} to $A_{2n...}$) appears to be high, it is an indication that the entropy is low; therefore, a higher weight should be assigned to that criterion (Zou, et al., 2006). In contrast, a smaller difference means a higher entropy; hence, a lower weight is assigned to that criterion (Zou, et al., 2006). By comparing the differences between the index values in the comparison matrix, the weight of each criterion can be generated (Wang, et al, 2008).

$$A = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{pmatrix}$$

Figure 3.7. Entropy Information Comparison Matrix (Wang, et al., 2008, p.1430)

A detailed description of each step of the Entropy Information method is shown in Table 3.7. The first step of the Entropy Information method is to find the best value for each index. When a higher criterion value is preferred, the maximum value needs to be identified. Conversely, when a lower criterion value preferred, the minimum value should be identified. Similar to the standardization process, the purpose of step 2 and 3 is to standardize the criteria value to make the criteria comparable. Step 4 is to calculate the entropy value by summing up the values from multiplication of standardized value and the associated ln value. In Step 5, the weight of entropy value for Hi can be calculated by the equation. After obtaining the weight of entropy value (hi) and information entropy value (Hi), the weights for each criterion can now be obtained.

Table 3.7. Steps of Entropy Information Method
Source Adopted from (Wang et al., 2008, P.1430-1431)

Step	Description
1. Find the best value for each index	Two scenario: a) Higher value is preferred x_i^*=Max (xi_1, xi_2, xi_3.... xi_m), i=1,2,3,....n b) Lower value is preferred x_i^*=Min (xi_1, xi_2, xi_3.... xi_m), i=1,2,3,....n
2. Calculate the proximity degree between x_{ij} to x_i^*	a) Higher value is preferred $D_{ij}=x_{ij} / x_i^*$ i=1,2,.....n b) Lower value is preferred $D_{ij}= x_i^* / x_{ij}$ i=1,2,.....n
3. Normalize the index and calculate the weight for x_{ij}	$d_{ij}=D_{ij}/ \sum_{j=1}^{m} Dij \;\; Where \sum_{j=1}^{m} dij = 1$
4. Calculate entropy value of i_{th} index	$Hi= -\sum_{j=1}^{m} dij\ lndij$
5. Normalize H_i in H_{max} to get weight of entropy value	$h_{i=} H_i/\ln m$
6. Calculate Weight	Wi= (1-h_i) /n-H, i=1,2,3,....n $$Where \sum_{i=1}^{n} hi, 0 \le wi \le 1\ and \sum_{i=1}^{n} wi = 1$$

Figure 3.8 shows an example of how the criteria weights are calculated by applying the Entropy Information method, where a higher criteria value is preferred. Both criteria A & B contains four site cells, and a criterion value has been pre-assigned to each site cell. In step 1, the maximum values within the criteria are highlighted in red. Step 2 is to calculate the proximity degree by dividing the actual criterion value by the maximum value within each criterion. In step 3, the d_{ij} value is calculated by dividing the criteria values in each cell in step 2 by the sum of proximity degrees. The Hi and hi values in step 4 and 5 can be calculated by implementing the equations in Table 3.7. In the end, the weight for each criterion can be generated. Since the variation of cell values in criterion A is higher than that of criterion B's, a higher weight, which is 0.98 will be assigned to criterion A, and a lower weight of 0.02 will be given to criterion B.

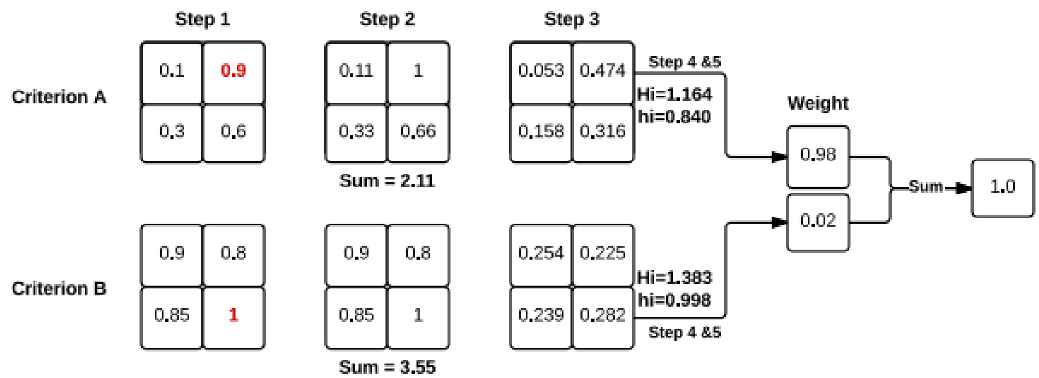


Figure 3.8. Entropy Information Method Example

3.9 Wind Farm Suitability Level

The last step of this research is to create the overall suitability maps for each of the selected wind farm sites. The overall suitability scores are computed by utilizing the weight of each criterion, multiplied by the criteria standardized values. By aggregating the results of all criteria including the noise and the visual criteria, the overall suitability score in feasible sites is calculated. Raster calculator in ArcGIS is the primary function to overlay the overall weighted criteria standardized scores.

The results from the overall suitability maps can assist decision makers to illustrate the suitability level within the feasible sites. The higher the suitability scores, the better the feasible locations to build wind farms. Therefore, the overall suitability scores are the results of this wind farm siting approach, which considers not only physical, environmental, economic and planning, but also the noise and visual impacts criteria.

In order to visualize the spatial changes within feasible sites, criteria weights were generated and different criteria combinations were applied. Four scenarios were applied to determine the changes of suitability level within wind farm sites from altering the criteria weights and criteria combinations:

Scenario (a): combine noise impacts criterion with the common siting criteria

Scenario (b): combine visual impacts criterion with the common siting criteria

Scenario (c): combine both visual and noise criteria with the common siting criteria

Scenario (d): combine noise and visual criteria only

3.10 Summary

This chapter described the research method in detail. After conducting the site screening process, the sample feasible areas to build wind farms in Southern Ontario were identified. The global WLC was applied to rank the overall suitability scores among the eight selected feasible sites in Dufferin County and Chatham-Kent. In addition, the feasibility level within each selected feasible site was identified by applying the standardization technique of local WLC. The spatial approach was developed to estimate the affected population by noise and visual impacts. The changes of suitability level were determined and compared before and after integrating the noise and visual criteria. The next chapter presents and discusses the results that were generated from the method.

Chapter 4 Results & Discussion

This chapter discusses the results of the wind farm site selection process, and the site suitability analysis, with the integration of noise and visual impacts of the sample wind farm locations in Dufferin County and Chatham-Kent. Section 4.1 presents and discusses the results of feasible wind farm locations in Southern Ontario. Section 4.2 and 4.3 demonstrate the estimated affected population by applying the noise and visual siting approach, described in Chapter 3. Section 4.4 displays the changes of suitability level after integrating the noise and visual criteria in the siting process. Finally, Section 4.5 discusses the results and Section 4.6 summarizes this chapter.

4.1 Feasible Wind Farm Locations in Southern Ontario

A fundamental step prior to incorporating the noise and visual criteria into a siting decision process is to identify the sample feasible wind farm sites in Southern Ontario. Figure 4.1 provides an overview of feasible locations for building wind farms in Southern Ontario, conducted in the site screening process discussed in Section 3.4. The map illustrates the sample feasible wind farm sites in each county. Overall, Chatham-Kent has the highest number of suitable sites compared to other counties, with a total land cover of 43.56 km^2. Lambton, located at the north of Chatham-Kent, has the second largest number of feasible sites with a total area of 27.47 km^2. On the other hand, there are very few feasible sites in Dufferin, Elgin, Grey, Oxford and Simcoe.

Figure 4.1. Sample Wind Farm Sites in Southern Ontario

In order to test how reasonable the results of the site screening method are, the wind farm feasible locations derived from this study were compared with the wind farm locations in Figure 4.2. Due to the lack of available information on the current wind farm locations in Southern Ontario from the literature or the Ontario Power Authority, the turbine location map shown in Figure 4.2 was retrieved from the website of the Ontario Wind Turbines (2014). This map provides a summary of the current and proposed wind farm sites in Southern Ontario, presented by the colored polygons based on the Google Map. However, the sites shown in Figure 4.2 are not the exact locations where turbines are installed or proposed, rather, they indicate that there are turbines somewhere in these locations.

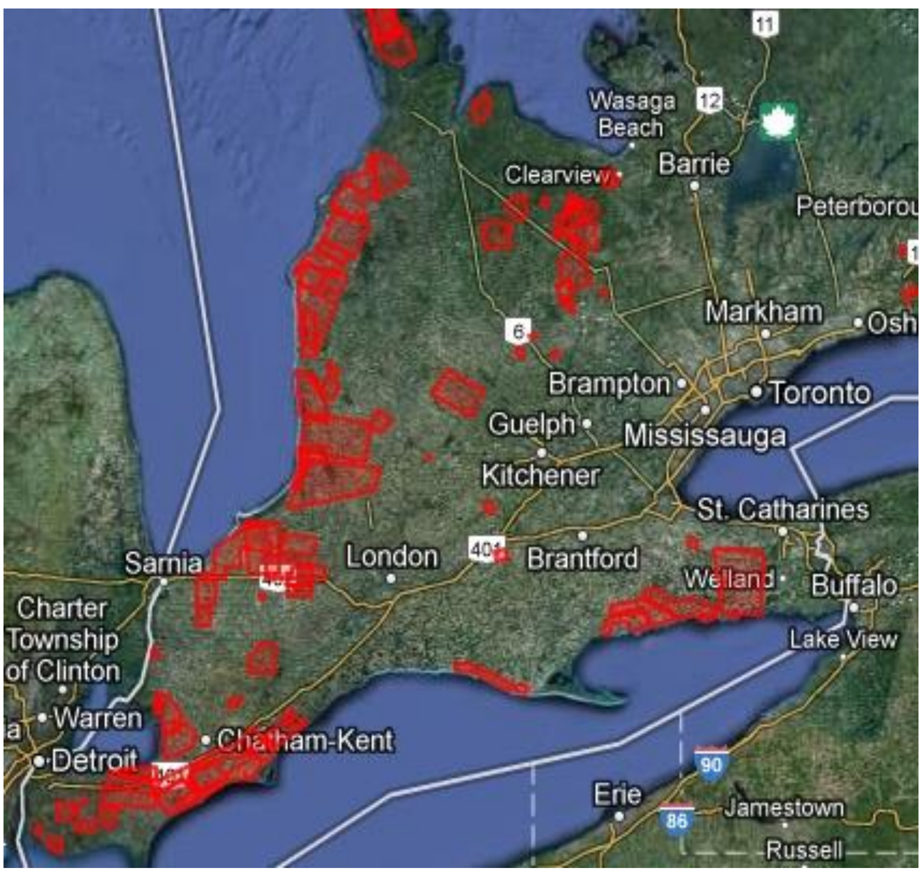


Figure 4.2. Current Wind Turbines in Southern Ontario (Ontario Wind Turbines, 2014)

In general, most of the current wind turbine locations identified in Figure 4.2 overlap with the feasible areas that have been identified in Figure 4.1. There are some discrepancies between the current wind turbine sites and the feasible sites derived from this study, mainly due to the factors such as siting criteria, constraints and the years in which the wind turbines were installed. For instance, the siting constraints for wind turbines installed before 2009 are different from the turbines installed after 2009, since the most recent Approval and Permitting Requirements Document for Renewable Energy Projects was introduced in September 2009. Furthermore, potential wind farm feasible sites with land cover less than 343,983 square meters have been excluded, because this research is primarily focused on wind farm facilities that generate greater than 20 MW.

4.2 Spatial Representation of Noise Impacts

This section presents the noise-affected population of the selected feasible wind farm sites in Dufferin County and Chatham-Kent. A total of eight sample wind farm sites were chosen to demonstrate the results of applying the noise impact siting approach, discussed in Section 3.6.1. There were three feasible wind farms sites in Dufferin County and five feasible sites in Chatham-Kent selected based on diverse geographic locations of the sample wind farm sites to demonstrate the results of the noise impact siting approach.

4.2.1 **DA Population and Single Dwelling Cells**

Figure 4.3 presents the selected feasible wind farm sites in Dufferin County, the total population in each Dissemination Area (DA) and the distribution of single dwelling cells. A total number of three sample wind farm sites (A, B and C) were clustered in two DAs. The single dwelling cells are distributed in each DA, shown in colored dots. The population per single dwelling was calculated by dividing the total population of the DA by the number of single dwelling cells in each DA.

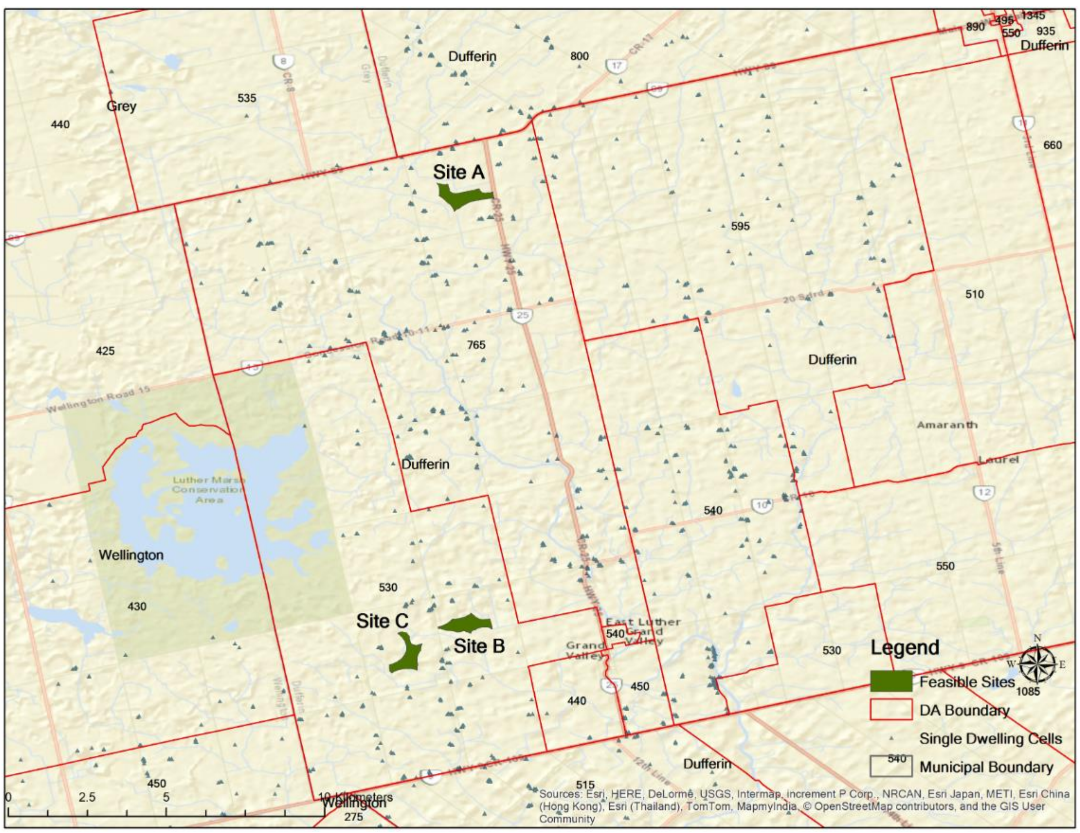


Figure 4.3. Population in each Dissemination Area & Single dwelling cells in the sample wind farm sites of Dufferin County

In Chatham-Kent, five feasible wind farm sites (D, E, F, G and H) were spread out across the study region. Unlike Dufferin County, in which the feasible sites are clustered in two DAs, Chatham-Kent has the highest number of sample suitable sites, with a large land cover. The population of each single dwelling cell is higher than that of the Dufferin County's. These sites were chosen to demonstrate the results of diverse wind farm sites. Figure 4.4 illustrates the sample sites and provides an overview of the surrounding DA population and the distribution of single dwelling cells.

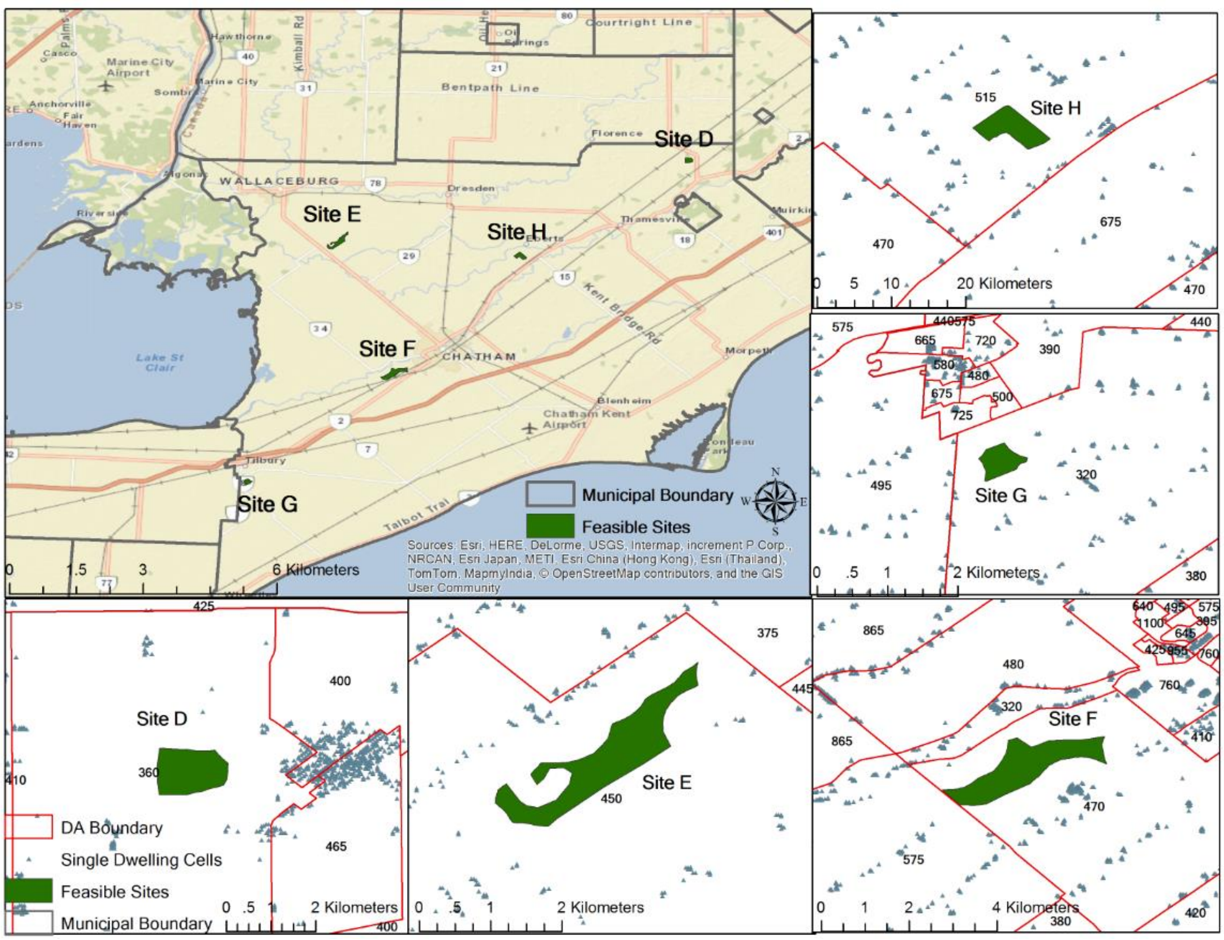


Figure 4.4. Population in each Dissemination Area & Single dwelling cells in the sample wind farm sites of Chatham-Kent

4.2.2 Noise-affected Population

The noise-affected population was generated by implementing the noise impact siting approach, discussed in Section 3.6.1. The estimated affected-population varies within each wind farm site; hence, the manual classification in ArcGIS was applied to divide the affected population into five range groups. The manual classification approach allows users to set the appropriate range groups based on the site-specific data values (ESRI, ArcGIS Resource Center, 2012). The results of the population range groups in each wind farm site were not used for site-by-site comparison, but rather, they are used to compare affected-population within each wind farm site. The diagram shown in Appendix IV demonstrates how the noise-affected population is calculated, also a detailed description was discussed in Section 3.6.1. Each selected wind farm site is divided into 25 x 25 meter raster site cells, each site cell represents a potential location to build a wind turbine within the feasible site. The estimated affected population of each site cell is derived by adding up the population of the single dwelling cells that perceive a noise level of 20 dB or higher.

Figure 4.5 presents the results of noise-affected population of the wind farm sites in Dufferin County, obtained from the noise impact siting approach. Site A contains a site cell that has the lowest noise-affected population, which is 67; and only a few site cells' affected population is greater than 178. In Site B, a large number of site cells can potentially affect population ranging from 220 to 250. There are number of site cells in Site C fall into the affected population range from 250 to 285.

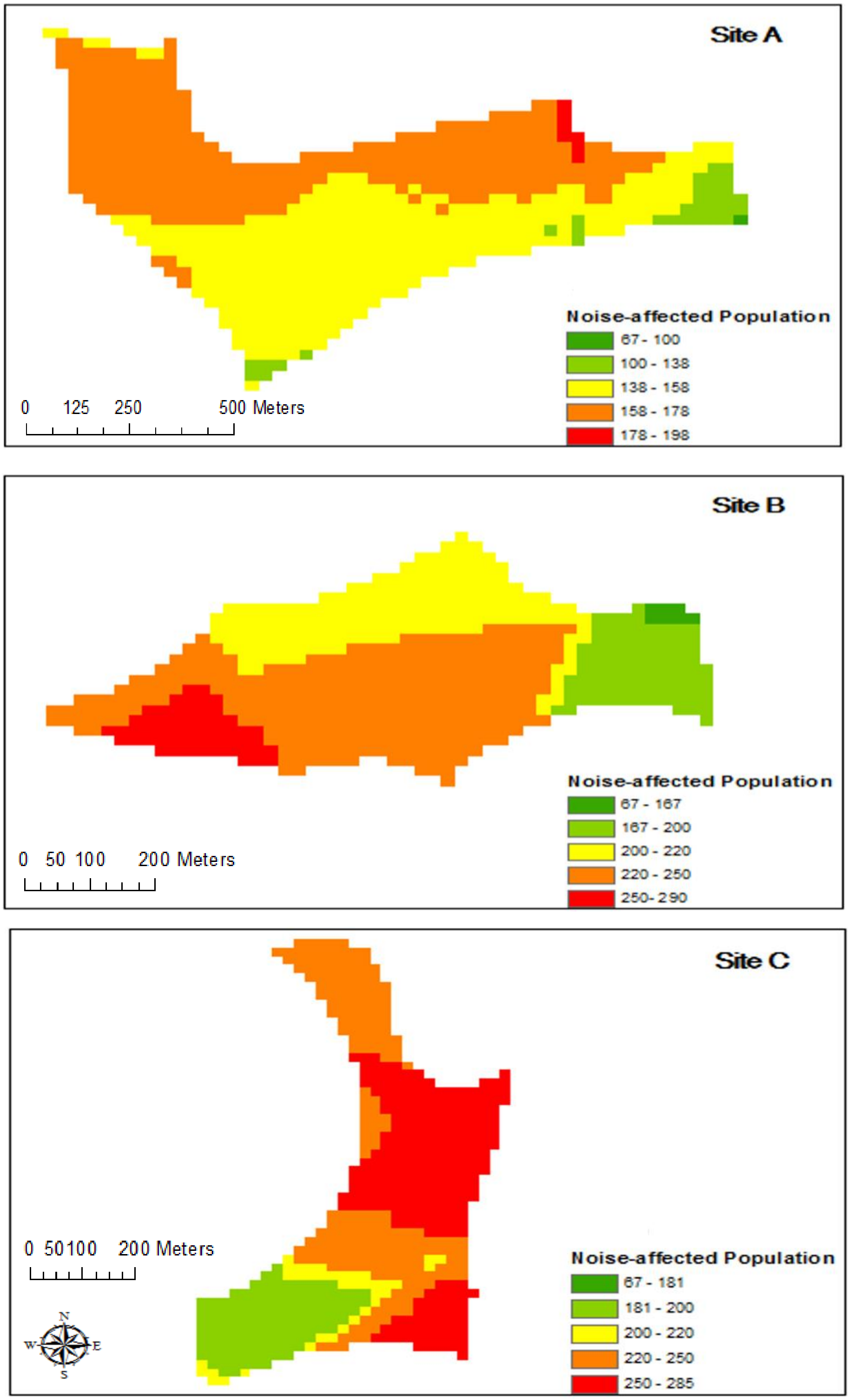


Figure 4.5. Noise-affected population of Site A, B and C in Dufferin County

The noise impact siting approach was also applied to the five selected sites in Chatham-Kent. Overall, the estimated population impacted by the wind farm noise is higher than that of the Dufferin County's, as Chatham-Kent is more populated than Dufferin County. Furthermore, there are more single dwelling cells in Chatham-Kent, the feasible sites could potentially affect a higher number of single dwelling cells; hence, more population may be affected. Refer to Figure 4.6 and 4.7, site cells can potentially affect population ranging from 67 to 1,175 in Site D. Site E and Site H have a lower noise affected population on average, with the affected population ranging from 67 to 104 and 67 to 148, respectively. The impacted population in Site F and Site G is higher than other sites, certain site cells have the highest affected population ranging from 10,000 to 15,545, and 20,000 to 25,675, respectively.

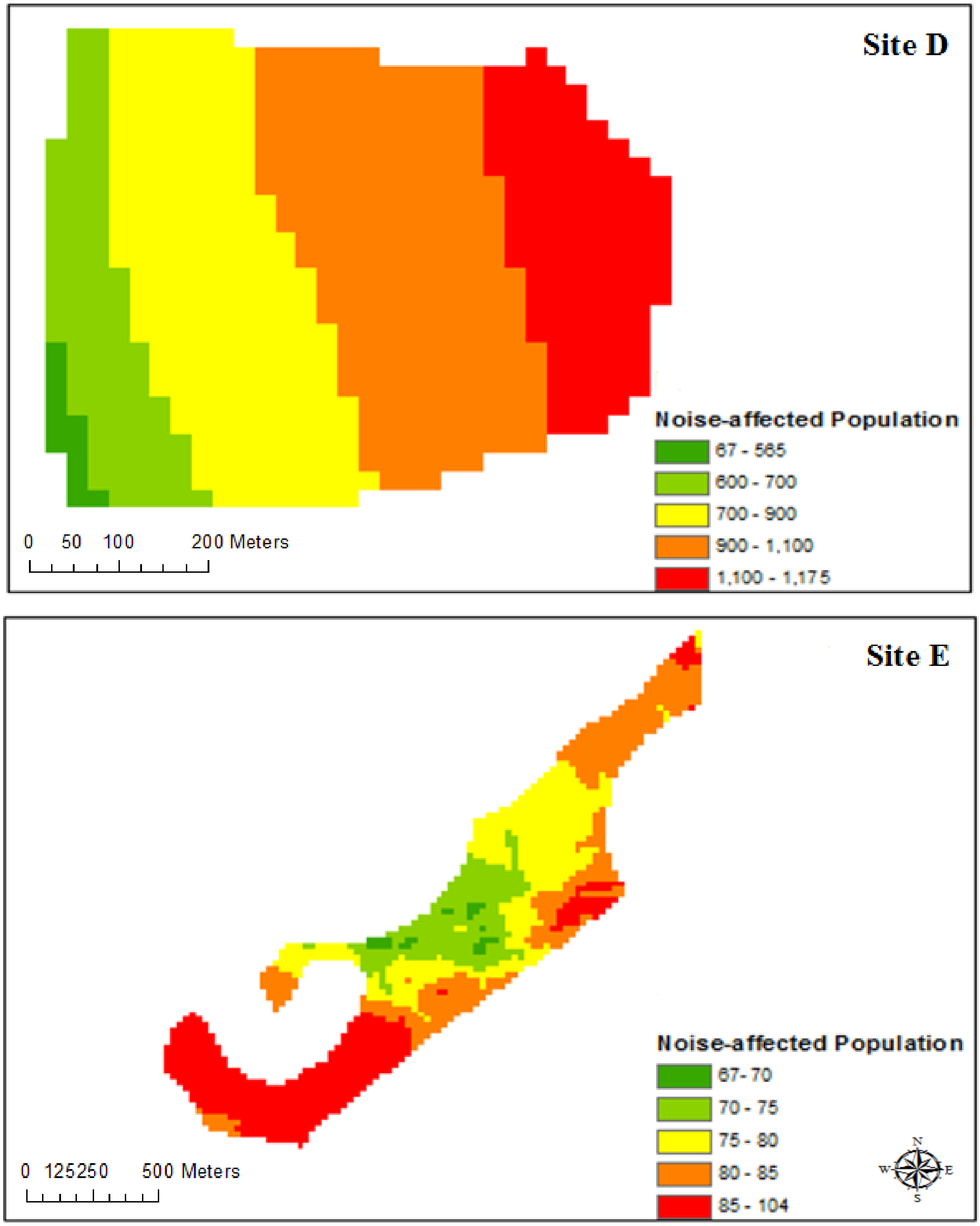


Figure 4.6. Noise-affected population of Site D and E in Chatham-Kent

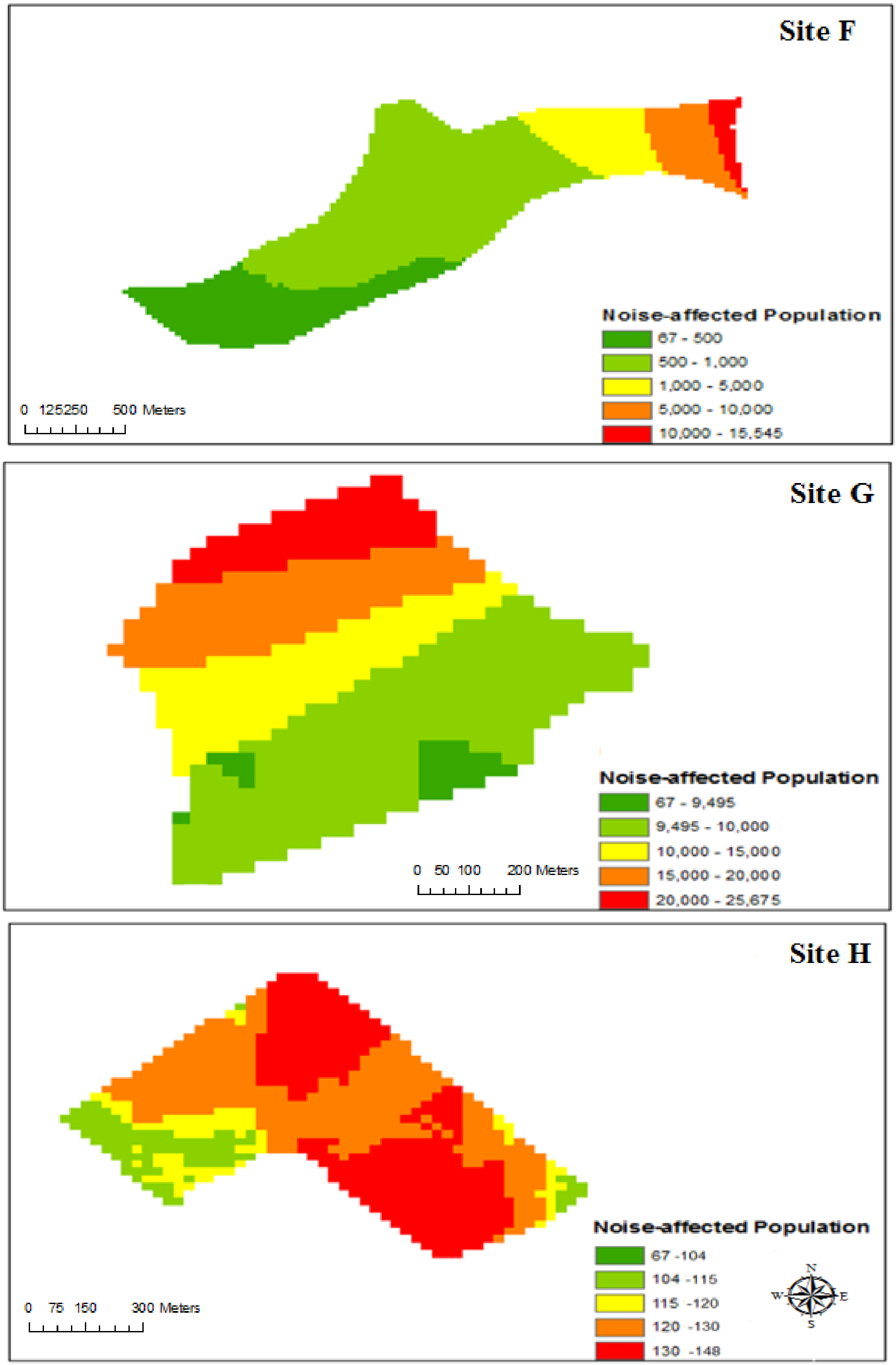


Figure 4.7. Noise-affected population of Site F, G and H in Chatham-Kent

The results of the noise-affected population are strongly associated with the number and geographical distribution of single dwelling cells in each DA, and the total population of each DA. The distance between single dwelling cells and wind farm site cells is also an important factor in this siting approach. This study applied 20 dB as a discrete value, discussed in Section 3.6.1, to estimate the affected population (noise receivers) within approximately 1800 meters of an 80-meter high wind turbine. The results reflect the variations of the affected population within the site. Using Site D in Dufferin County as an example, the areas in red and orange present locations containing a higher impacted-population than others. On the contrary, areas in green are the preferred locations, where the affected population is lower than other locations within the site. This siting approach is a valuable planning tool, as it can assist decision makers in estimating the potential noise-impacted population of wind farm sites. The maps can also provide insights into how to avoid the locations with a high affected population within a site and address the noise impacts in the wind farm siting decision.

4.2.3 **Changes of Suitability Level**

After the noise criterion was created, the suitability level of wind farm sites can be identified. As discussed in Section 3.9, the overall suitability scores were computed by overlaying all the weighted criteria standardized scores on a raster cell-by-cell basis. Different scenarios were applied to test the spatial changes of suitability level within each site, before and after integrating the noise criterion. Performing the comparison analysis offers a beneficial option to evaluate the changes of suitability scores within each site. The results of the comparison analysis are also useful to provide insights into spatial changes within individual feasible sites. This section presents Scenario (a): combine noise impacts criterion with the common siting criteria.

Before combining the noise impact criterion with the common siting criteria, the noise-affected population was first converted into a comparable standardized value on a range of 0 to 1. The standardized values of the noise impact criterion were generated by applying the local WLC standardization technique in Equation 3.3 (b), as a lower criterion value is preferred, the fewer the affected-population, the higher the standardization score. The overall suitability scores were calculated by aggregating the scores after multiplying the standardized value of each site cell and the corresponding criterion weight.

Table 4.1 displays the weights of each criterion before and after the noise is introduced as a criterion. All the criteria were grouped based on their category. In both cases, the weights were calculated by using the Entropy Information weighting method, discussed in Section 3.8. As there were 15 siting criteria (without noise criterion), and 16 siting criteria (with noise criterion) considered in this study and the summation of criteria weights equals to 1.0, the weight for each criterion is relatively low.

Table 4.1. Criteria Weights (with/without noise criterion)

Category	Criterion	Weight (without noise criterion)	Weight (with noise criterion)
Physical	Wind Speed	0.04484	0.04204
	Slope	0.04892	0.04587
Environmental	Wildlife and Bird Habitat	0.06681	0.06264
	Environmental Sensitivity Area (ESA)	0.07074	0.06651
	Wetland	0.06099	0.05718
	Water body	0.05980	0.05606
	Natural Heritage System	0.06474	0.06070
	Wooded Area	0.07700	0.07219
	Earth Science Significant Area	0.04944	0.04635
	Life Science Significant Area	0.07026	0.06587
Planning	Park	0.06595	0.06183
	Single Dwelling	0.09401	0.08814
	Airport & Runway	0.06537	0.06129
Economic	Road Network	0.10300	0.09657
	Transmission Line	0.05791	0.05430
Noise	Noise-affected population	0	0.06246
Weight Sum		1.0	1.0

Figure 4.8 illustrates the changes of the suitability level within the wind farm sites in Dufferin County. The process of evaluating the changes of suitability level within the wind farm sites after adding the noise criterion was accomplished, by performing the subtraction of cell values between the overall suitability scores with and without the noise criterion. The noise comparison map (‘suitability score with noise criterion’ – ‘suitability score without noise criterion’) was also presented to illustrate the spatial changes between these two cases. With the intention of identifying and visualizing the spatial changes within each site, the results of the comparison map are transformed into an absolute value instead of using the actual change values. Due to the

low criteria weights, the change of suitability scores in the comparison map are small. Hence, the scores in the comparison map were multiplied by 100 to provide a better visual representation of the change in scores. Refer to the spatial changes of the comparison maps (Site A, B and C), areas with a higher change in scores, which means they are affected the most by adding the noise criterion, are located on the edges of each site.

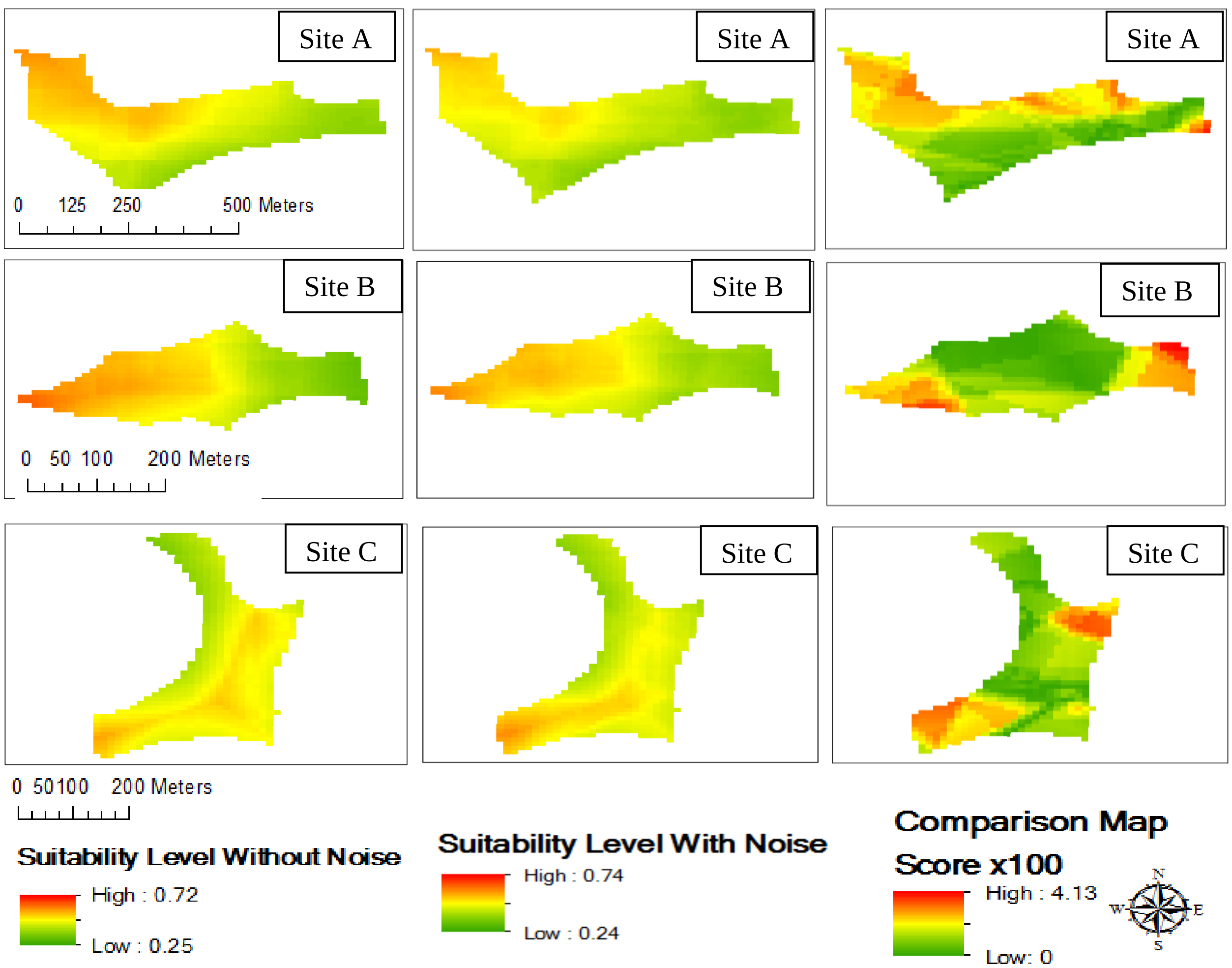


Figure 4.8. Changes of suitability level within the selected sites in Dufferin County before/after integrating the noise criterion

In Chatham-Kent, based on the observations, the change in suitability levels are site-specific within the selected feasible sites before and after integrating the noise criterion, shown in Figure 4.9. In site D, the locations that are highly influenced by adding the noise criterion are located on the eastern and western edges of the site, where in Site E they are positioned in the middle of the site. In Site F, locations with higher change in scores can be found on the north-west side of the site. Respectively, those areas in site G are positioned at the eastern corner of the site. In site H, the locations with a higher change in scores can be found on the edges of the site. The results of these comparison maps indicate that spatial changes are not only occurring on the edges of site, but are also case-specific, depending on the location and value of the noise-affected population. As a result, decision makers can use this approach to identify the locations that are influenced by adding the noise criterion in the siting process, before making a decision on the most suitable areas within the feasible wind farm site. This suitability analysis considers a set of site evaluation criteria, listed in Table 3.6, and slope is one of the important criteria. In order to calculate the slope, digital evaluation model (DEM) is required to calculate the slope for each site cells. There are line features that are presented in the suitability maps of Site (D, E, F, G and H) in Chatham-Kent. The lines are shown on the slope evaluation criterion, which indicate the possible striping artifacts in DEM. Artifacts that may cause from the production of DEMs and elevation errors (Albani & Klinkenberg, 2003). The "stripes" do not represent any spatial patterns, but they are systematic errors of DEMs. The errors can potentially influence the terrain surface, as well as the slope calculation (Albani & Klinkenberg, 2003). Meanwhile, boundary artifacts can often be created when merging the adjacent tiles, and the striated data can cause a problem, which can be shown on the slope criterion (Price, 2006).

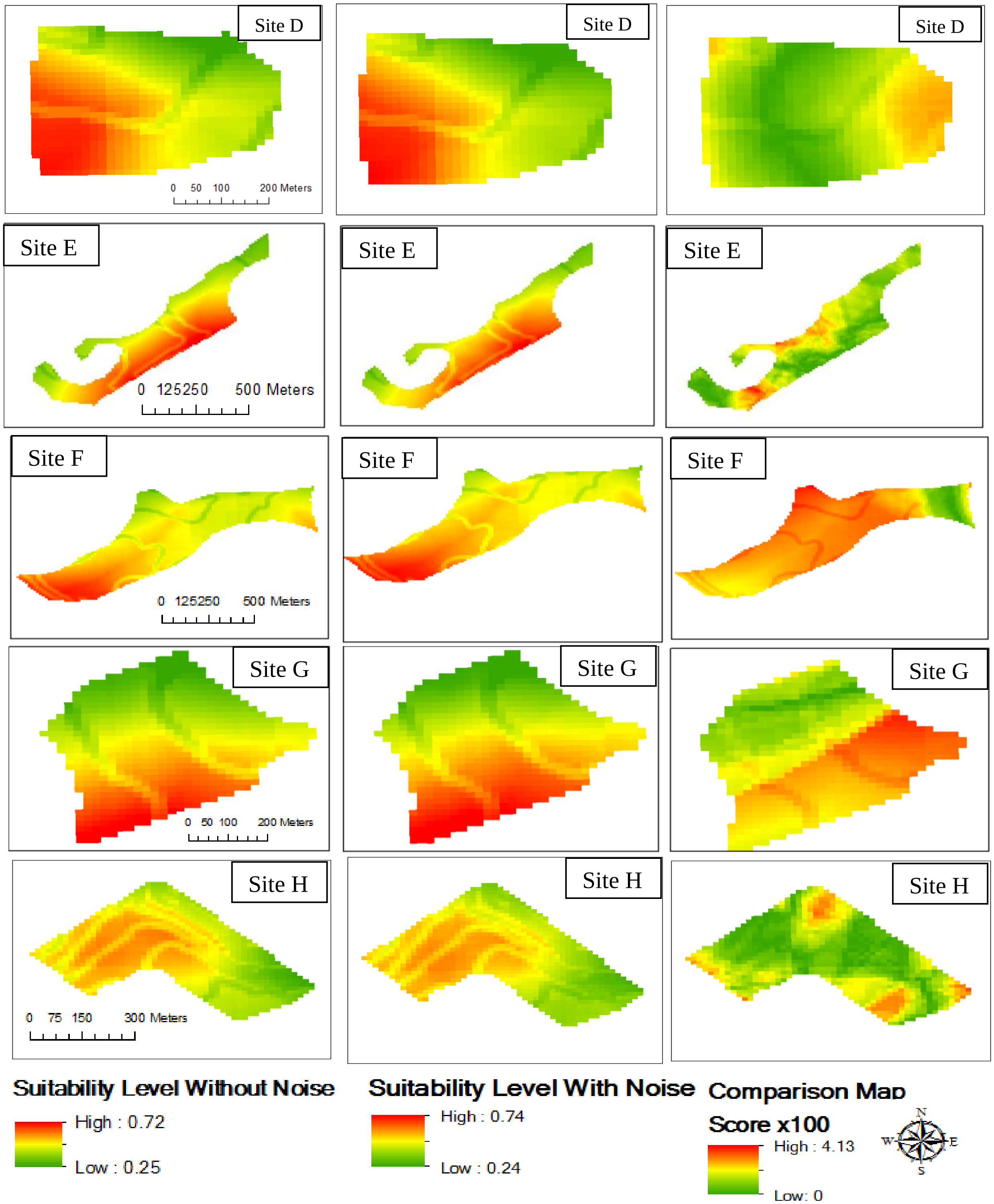


Figure 4.9. Changes of suitability level within the selected sites in Chatham-Kent before/after integrating the noise criterion

4.3 Spatial Representation of Visual Impacts

4.3.1 Visual Impacts

This section presents the results of the estimated affected population by the turbine visibility. Refer to the visual impact siting approach discussed in Section 3.6.2, and a diagram shown in Appendix V, both explain how the affected population was calculated. Performing a viewshed analysis allows users to identify the landscape cells that can be seen from an 80-meter high wind turbine. The feasible site was divided into 25 x 25 meter raster site cells, and the centroid of each site cell was used to represent an individual wind turbine. After the visible and non-visible landscape cells were identified by running a viewshed analysis, the affected-population can be extracted from the overlapping areas between the single dwelling cells and the visible landscape cells. As the affected population varies from site to site, the population was classified into five range groups by using the manual classification to primarily focus on the number within each wind farm site.

It is worth noticing that the affected population by turbine visibility is not only restricted to the population of single dwelling cells within Duffern County or Chatham-Kent. The DEM boundary used in the viewshed analysis is 29-kilometer, which means the single dwelling cells within the adjacent counties that are outside of the Dufferin County or Chatham-Kent boundary were also considered. As long as the single dwelling cells are located at the visible landscape cells of the site cell, the population of those single dwelling cells will be considered as the affected population by turbine visibility. The results of the affected population by turbine visibility can be different for each turbine site cell. Some of the adjacent 25-meter cells have very different affected population. As discussed in Section 3.6, the affected population by turbine visibility is calculated based on three factors, which are the location of visible landscape cells, the distribution of overlapping single dwelling cells, and the estimated population of each single dwelling cell. The estimated population of each single dwelling cell in adjacent DAs can be very different. The turbine location can cause the variation in the visible landscape cells, which ultimately affects the overlapping areas between the single dwelling cells with different estimated population in each DA, and the visible landscape cells. The accuracy of the GIS-based viewshed analysis can also influence the results of the overall population that are affected by turbine visibility. The results of the viewshed analysis may not be precise, since possible errors and quality issues are involved in the viewshed tool itself. The results of the viewshed analysis are highly dependent on the DEM, so any potential database errors in DEM, such as topographic artifacts can have a significant impacts on the accuracy of the visible landscape cells that calculated from the viewshed analysis (Maloy & Dean, 2001; Fisher, 1993). Meanwhile, in this thesis, there are approximately 600 to 800 turbine points presented in each feasible site when converting the sites into 25 x 25 meter raster site cells. As a large number of turbine points are involved in the analysis, mixing pixels of the visible landscape cells can also occur in the viewshed analysis. Thus, these possible errors in the viewshed analysis tool can also potentially lead to a higher affected population count in certain turbine locations.

Figure 4.10 presents the results of the affected population by turbine visibility in Dufferin County. Site A contains an affected population ranging from 0 to 24,206 people. Site B has the affected population between 0 and 1,033 people. Site C has an affected population between 0 and 35,226 people.

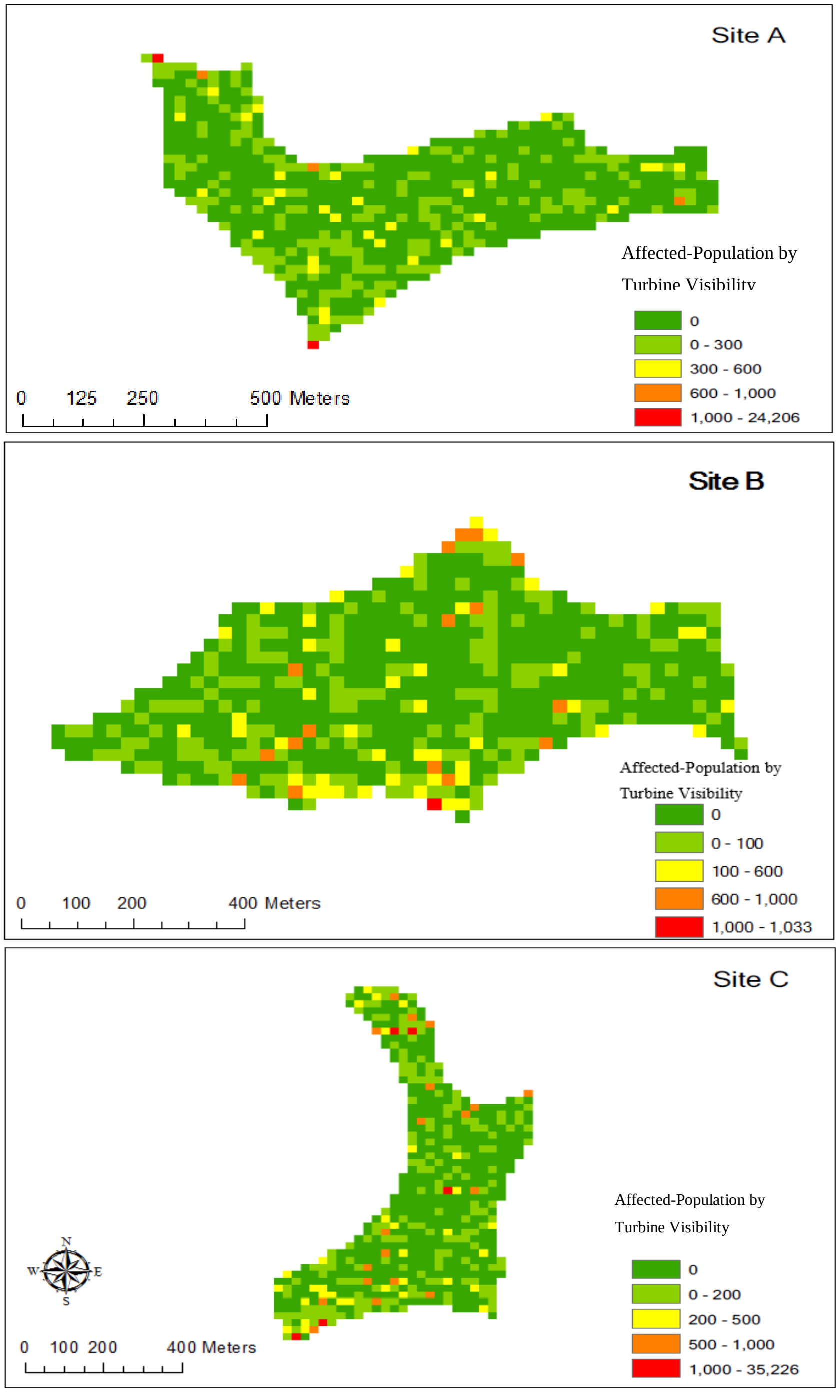


Figure 4.10. Affected Population by Turbine Visibility in Dufferin County

Figure 4.11 & 4.12 present the estimated affected population in Chatham-Kent. The areas with darker green represent the locations that have no visual impact to their surrounding single dwelling cells. The areas with red colour indicate the site cells that have a large number of affected population. The manual classification approach allows users to group cell values that above or below a certain threshold value (ESRI, ArcGIS Resource Center, 2012). It is an appropriate approach for grouping the site-specific affected population, since only a few cells in the selected sites of Chatham-Kent contain population that is greater than 1,500.

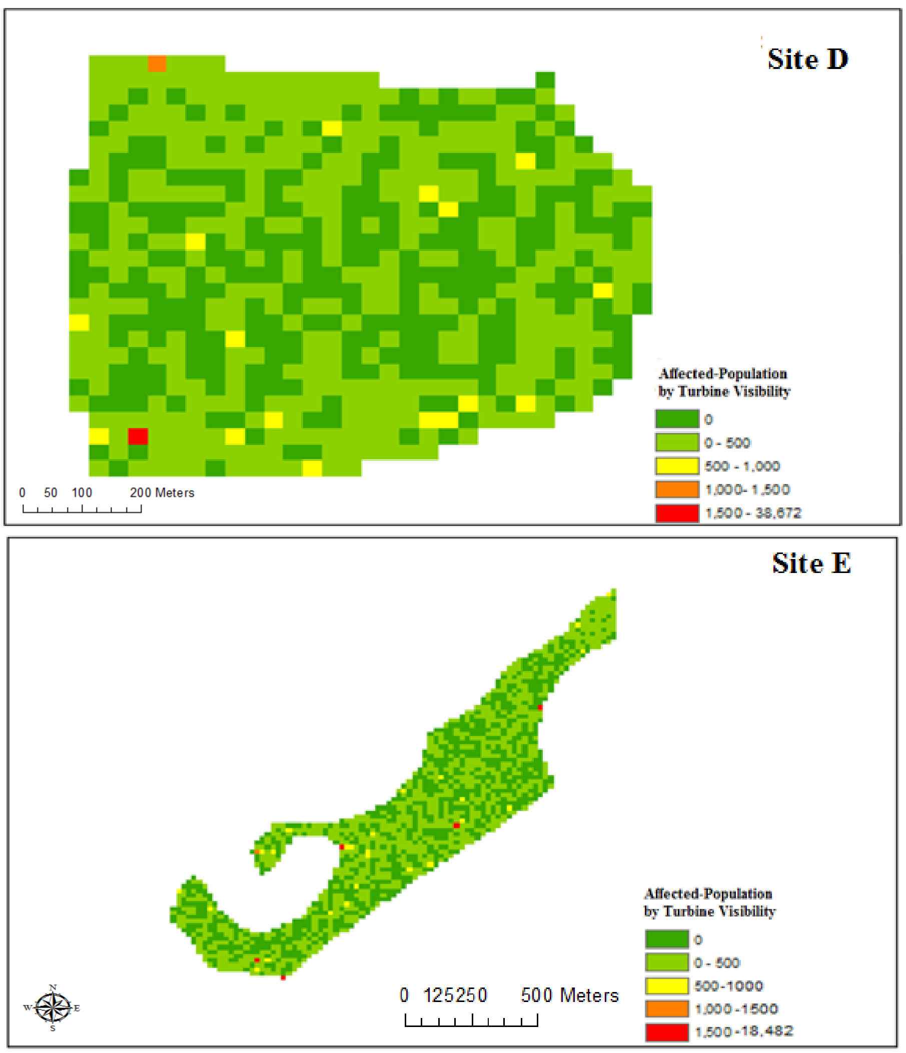


Figure 4.11. Affected Population by Turbine Visibility in Site D & E of Chatham-Kent

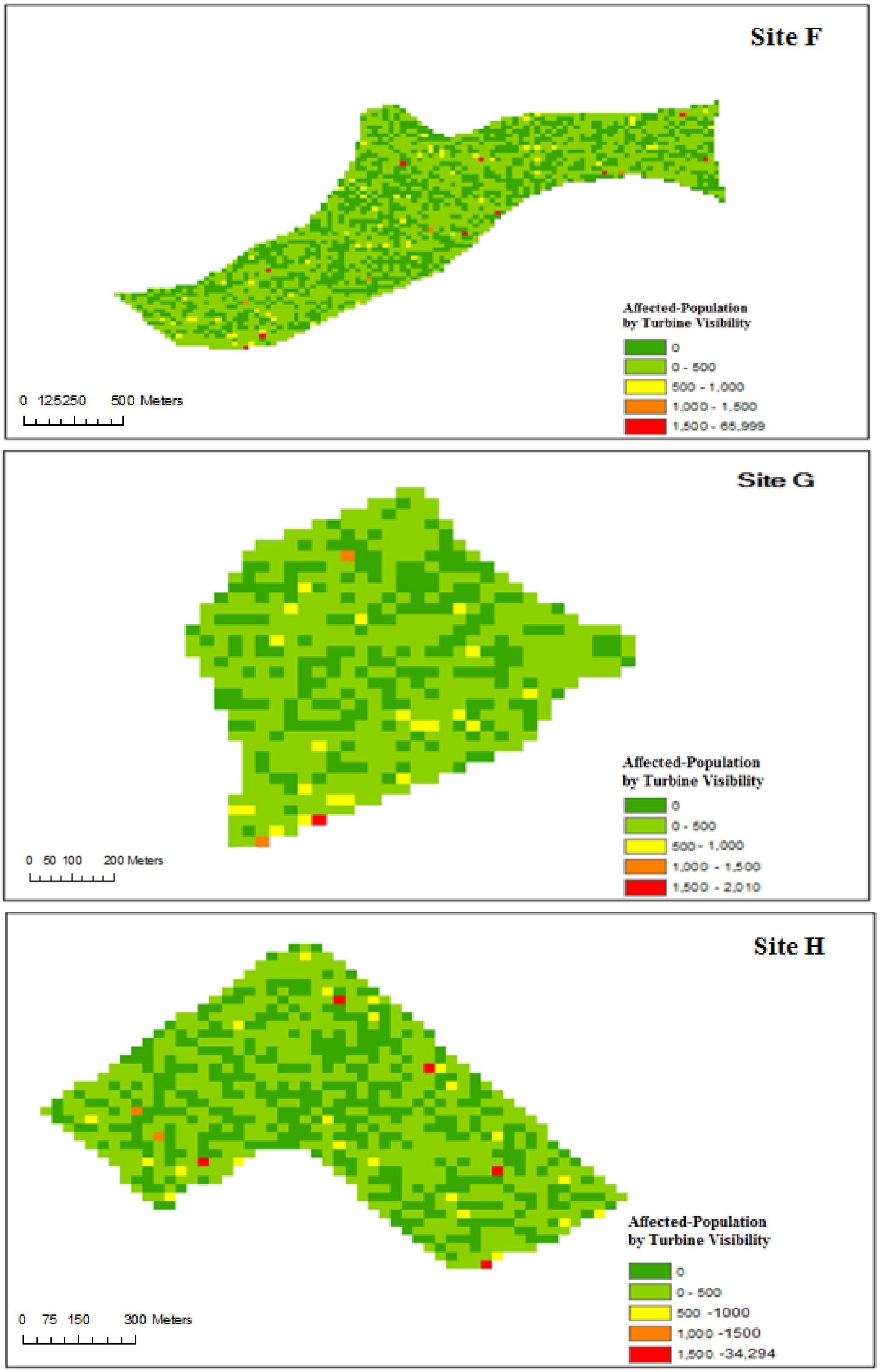


Figure 4.12. Affected Population by Turbine Visibility in Site F, G, and H of Chatham-Kent

The results of the affected population are related to three factors: a) the elevation of the wind farm site and turbine height; b) location of the single dwelling cells and the population of each DA; c) how the viewshed analysis is performed.

As the height of the turbine is directly applied to the surface elevations of the site, it can affect the location of visible and non-visible landscape cells. This study applied an 80-meter turbine, where any change of turbine height will influence the results of visible landscape cells. The height of the turbine determines the distance of the visibility and the potential impact coverage of surrounding dwellings. A greater size of a turbine can lead to a higher aesthetic impacts to the landscape (Torres Sibille et al., 2009). The location of the single dwelling cells and the associated population are also important, as the affected population is calculated by extracting the overlapped areas between single dwelling cells and the visible landscape cells. By comparing the affected-population between Dufferin County and Chatham-Kent, a higher population is presented in certain locations of Chatham-Kent. Performing the viewshed analysis is the key step that determines the number and location of visible landscape cells. As shown in Figure 3.5, it demonstrates how the viewshed analyses is performed, users can control the parameters of the viewshed analysis, discussed in Table 3.5. In addition to turbine height and surface elevation, factors such as horizontal, vertical and radius angel of the scan range can also affect the results of the visible and non-visible landscape.

The visual impact siting approach allows decision makers to determine the estimated affected-population caused by turbine visibility. It is essential to note that some site cells have none or very low affected population than the others within a wind farm site cell. These locations should be promoted as the visual impact is minimal. In contrast, locations with a high affected-population should be avoided in the siting process to minimize the potential visual impacts to the local residents. This siting approach can be applied as a planning tool in representing the aesthetic impacts of wind turbines to address the public concerns of turbine visibility in the siting process.

4.3.2 **Change of Suitability Level**

Identifying the spatial changes of suitability level allows decision makers to visualize the site cells that are influenced by the visual criterion. This section presents the results of Scenario (b): combine visual impact criterion with the common siting criteria. The affected population was converted into comparable values on a range of 0 to 1. The standardized values of the visual impact criterion were generated by applying the local WLC standardization technique in Equation 3.3 (b), since a lower affected-population is preferred, the lower the affected-population, the higher the standardized score of site cell. The overall suitability scores were calculated by aggregating all the weighted criteria standardized scores on a raster cell-by-cell basis. The suitability level was presented from high to low based on the suitability scores of site cells.

Table 4.2 shows a summary of the weights of each criterion before and after the visibility is introduced as a criterion. All the weights were calculated by utilizing the Entropy Information weighting method, discussed in Section 3.8. A total of 15 (without visual criterion) and 16 criteria (with visual criterion) were considered and arranged based on their corresponding category.

Table 4.2. Criteria Weights (with/without visual criterion)

Category	Criterion	Weight (without visual criterion)	Weight (with visual criterion)
Physical	Wind Speed	0.04484	0.04481
	Slope	0.04892	0.04888
Economic	Road Network	0.10300	0.10291
	Transmission Line	0.05791	0.05787
Environmental	Natural Heritage System	0.06474	0.06469
	Wetland	0.06099	0.06094
	Water body	0.05980	0.05975
	Wooded Area	0.07700	0.07694
	Earth Science Significant Area	0.04944	0.04939
	Life Science Significant Area	0.07026	0.07020
	Wildlife and Bird Habitat	0.06681	0.06676
	Environmental Sensitivity Area (ESA)	0.07074	0.07088
Planning	Park	0.06595	0.06589
	Airport & Runway	0.06537	0.06532
	Single Dwelling	0.09401	0.09393
Visual	Affected population by turbine visibility	0	0.00086
Weight Sum		1.0	1.0

Figure 4.13 presents the changes of suitability level within sample site A, C in Dufferin County, and Site D and Chatham-Kent. The results of other sites can be found in Appendix I. The changes were calculated by subtracting the cell values between the overall suitability scores with and without the visual criterion. The comparison analysis (‘suitability score with visual criterion’ – ‘suitability score without visual criterion’) was performed to indicate the spatial changes and the locations that are influenced by adding the visual criterion within each site. Due to the low

weight of visual criterion, which leads to a very small change of suitability level, the results of the comparison maps were displayed in absolute values to primarily emphasize on the changes. The scores in the comparison map were multiplied by 1000 to provide a better representation of change in scores.

The results of the comparison maps demonstrate the changes in suitability level after the integration of the visual criterion. Although it is difficult to determine the changes by only observing the maps before and after adding the visual criterion, the changes can be identified from subtracting the corresponding cell values between the two maps. Overall, adding the visual criterion can alter the suitability scores within each site, and the changes are site-specific. Using Site A, C and D as examples, the locations with the higher change in scores can be found on certain edges of the site, corresponding to the affected-population standardized value. The darker green cells on the comparison maps present the locations with lower change in scores within the site. As a result, turbine visibility is an important factor to be considered in the siting decision-making process, as the overall suitability level can be altered by adding the visual criterion. The visual impact siting approach is a proactive planning tool, as it provides insights into the determination of visible and non-visible landscapes of a turbine and an estimation of the affected population by turbine visibility.

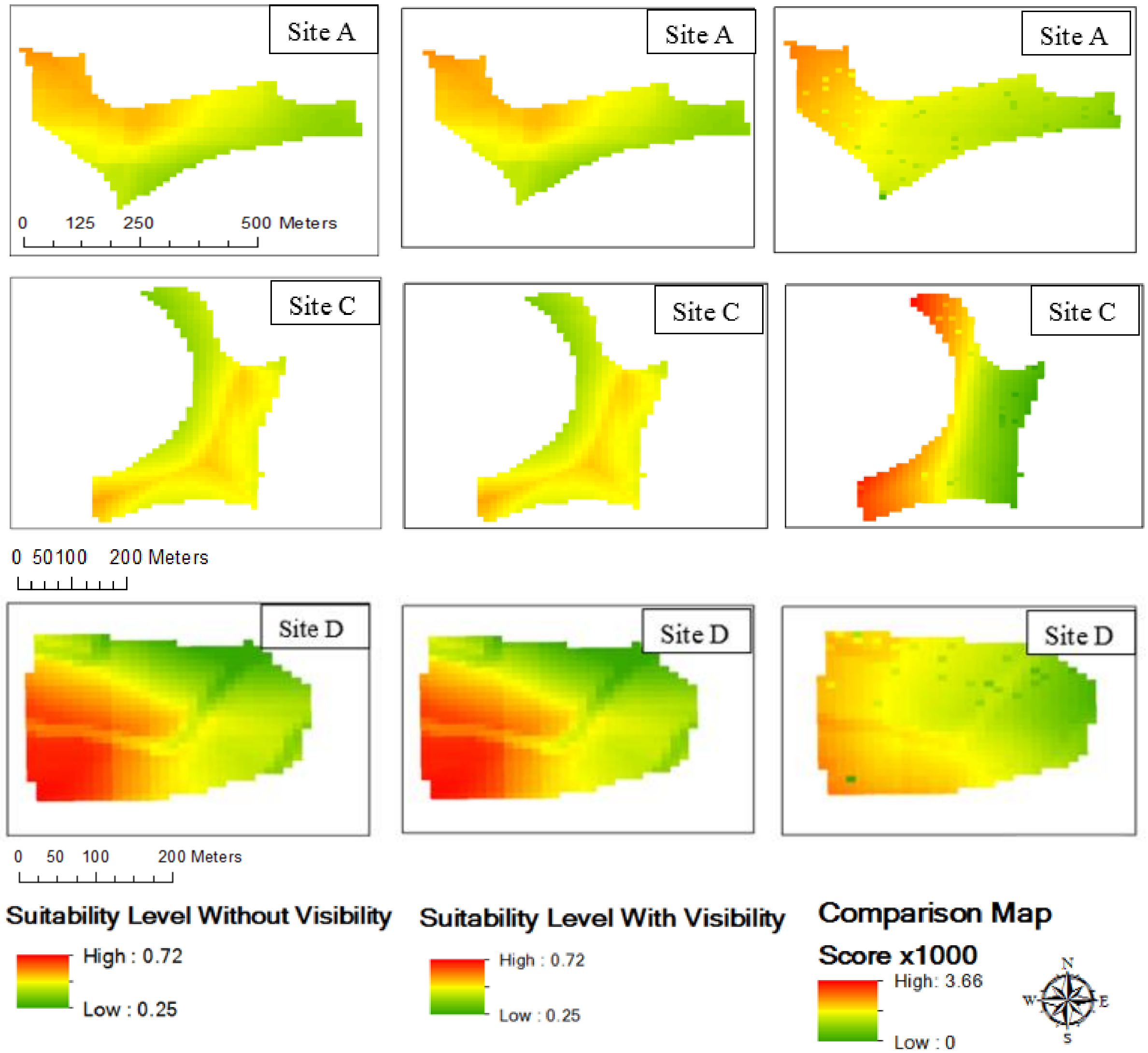


Figure 4.13. Changes in Suitability Level within sample sites A, C and D before/after integrating the visual criterion

4.4 Site Suitability Level Analysis

This section presents the overall suitability scores of each wind farm site and the suitability level within each site after the integration of noise and visual criteria. The global WLC standardization technique was utilized to provide results on the overall suitability scores and rank the feasible wind farm sites. As the affected population by noise and visual impacts is localized information and it varies among feasible sites, the local WLC standardization technique was also applied to capture the local information and determine the changes of suitability level within each feasible site.

4.4.1 Global WLC - Overall Suitability Scores

Table 4.3 displays the overall suitability scores and the ranking among the selected wind farm sites. The standardization technique of the global WLC, discussed in Section 3.7.1 is an appropriate approach in comparing the overall suitability scores among feasible sites, by considering common siting criteria such as physical, environmental, planning and economic. The standardized criteria values were generated by applying the global WLC standardization technique in Equation 3.2 (a) and Equation 3.2 (b). The range of the standardized value is between 0 and 1. As all the 15 common siting criteria are weighted equally in this analysis, the weight for each criterion is 0.0667 (1/15). The overall suitability scores were calculated by aggregating the weighted standardization scores within each site. The higher the overall weighted standardized score, the higher the suitability level of the sites. According to the overall suitability results in Dufferin County, the ranking order of the sites is C<B<A. In Chatham-Kent, the

ranking order of selected sites is G<D<H<E<F.

Table 4.3. Overall Suitability Score & Rank in the Selected Sites

Sites in Dufferin County	**Suitability Score**	**Rank**
A	205.5	1
B	192.5	2
C	178.2	3
Sites in Chatham-Kent		
D	374.5	4
E	920.7	2
F	1263.1	1
G	321.4	5
H	483.1	3

The overall ranking can be used as a reference to assist decision makers to compare the overall suitability scores from one feasible site to another. However, the global WLC is incapable of recognizing the spatial heterogeneity of suitability level within a wind farm site. More importantly, noise and visual criteria are localized information, which means that they tend to vary among feasible sites. Hence, the local WLC technique was performed to collect information on the suitability level within each feasible site.

4.4.2 **Local WLC- Suitability Level within the Selected Sites**

As mentioned in Section 3.7.2, the major advantage of the local WLC over the global WLC technique is that it provides information in a local context. By deploying the local WLC technique in the siting approach, it takes the spatial representation of the localized noise and visual impacts into the site planning stage and allows decision makers to identify the suitability level within each wind farm site. This section presents and discusses the results of Scenario (c): combine both visual and noise criteria with the common siting criteria, and Scenario (d):

i. Combine noise and visual criteria with the common siting criteria

Table 4.4 shows the calculation results of the criteria weights for common siting criteria and combining the noise and visual criteria with the common wind farm siting criteria. All the criteria weights were generated from the Entropy Information weighting method. A total of 17 criteria (with noise and visual criteria) were considered and arranged according to their corresponding category.

Table 4.4. Criteria Weights (with/without noise & visual criterion)

Category	Criterion	Weight (without noise and visual criteria)	Weight (with noise and visual criteria)
Physical	Wind Speed	0.04484	0.04203
	Slope	0.04892	0.04585
Economic	Road Network	0.10300	0.09654
	Transmission Line	0.05791	0.05429
Environmental	Wetland	0.06099	0.05716
	Water body	0.05980	0.05605
	Natural Heritage System	0.06474	0.06068
	Wooded Area	0.07700	0.07217
	Earth Science Significant Area	0.04944	0.04631
	Life Science Significant Area	0.07026	0.06585
	Wildlife and Bird Habitat	0.06681	0.06262
	Environmental Sensitivity Area (ESA)	0.07074	0.06649
Planning	Park	0.06595	0.06181
	Airport & Runway	0.06537	0.06127
	Single Dwelling	0.09401	0.08812
Noise	Affected population by turbine noise	0	0.06244
Visual	Affected population by turbine visibility	0	0.00028
Weight Sum		1.0	1.0

The eight selected wind farm sites were treated individually in a local context. The local maximum, minimum and range were calculated according to the corresponding values of each feasible site. All the common siting criteria were standardized using the local WLC standardization technique in either Equation 3.3 (a) or 3.3 (b). The overall suitability scores were aggregated by overlaying the weighted criteria standardized scores, on a raster cell-by-cell basis.

The results of the comparison maps indicate the changes of suitability level by the subtraction between the two maps ('suitability score with noise & visual' – 'suitability score without noise & visual'). All the changes were presented in absolute values to emphasize primarily on the changes. The scores in the comparison map were multiplied by 100 to provide a better representation of change in scores. It should be noted that the rationale behind integrating the noise and visual criteria in the siting process is to determine and visualize the change in suitability scores within each feasible site. Meanwhile, incorporating the noise and visual criteria ensures the siting decisions to address these dominant public concerns toward wind turbines. In order to evaluate the impacts of adding the noise and visual criteria into a siting decision, decision makers can create comparison maps to identify the changes of suitability level, as a step of choosing the optimal locations to build wind farms.

Figure 4.14 demonstrates suitability level of the selected sites before and after considering the noise and visual criteria. Site C and F were selected as examples to demonstrate the results of the suitability siting approach. The result of the rest of the sites can be found in Appendix II & III. Overall, the integration of noise and visual criteria alters the suitability level within each site. In Site C, site cells located in the middle of the site changes from most suitable locations (orange) to less suitable (yellow) locations, after considering the noise and visual criteria in a siting process. In site F, the locations with high suitability scores are now expended to the middle part of the site. The criterion weight is another contributing factor in the changes of suitability level within the sites. For example, the weight of the visual criterion is relatively low comparing to the weight of noise criterion, the results of the comparison analysis are very similar to the changes of adding noise criterion only.

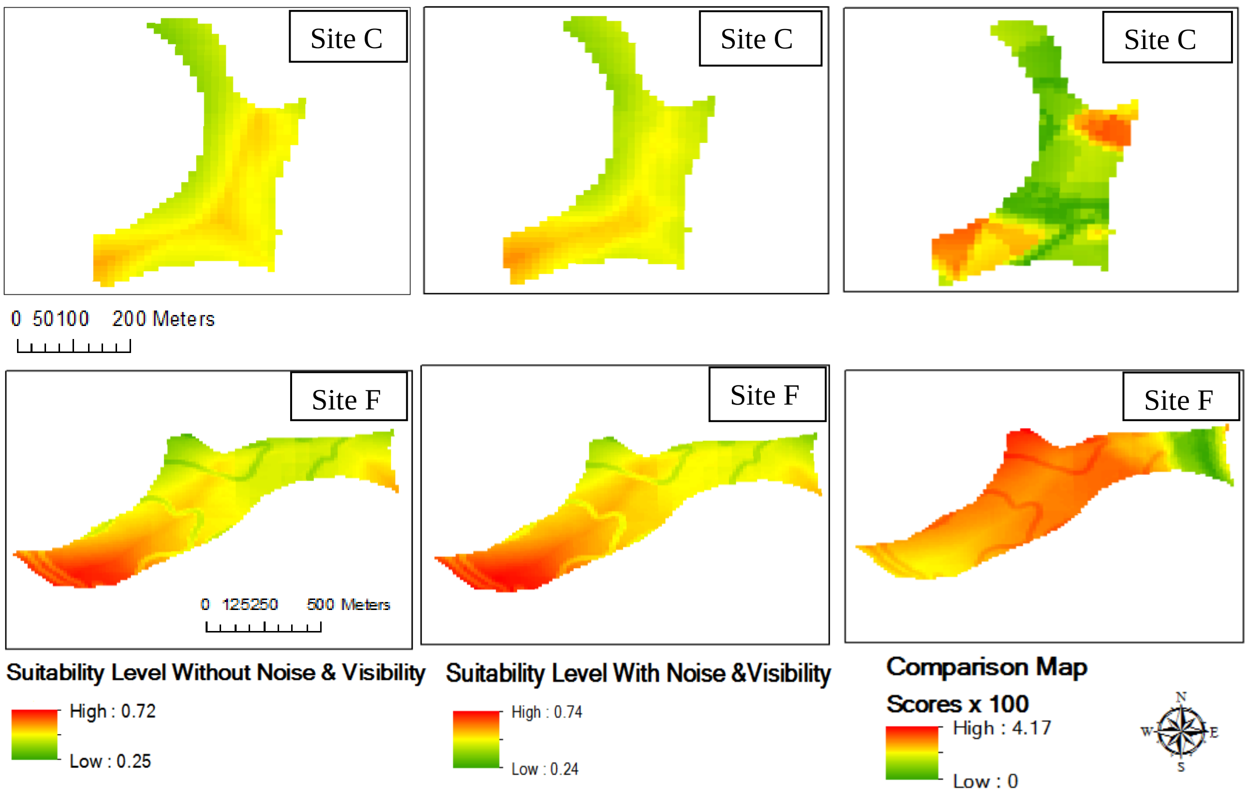


Figure 4.14. Suitability Level within Site C and F before/after the integration of noise and visual criteria

ii). Combine visual and noise criteria only

To further explore the possible impacts of turbine noise and visibility, the results of Scenario (d): combine noise and visual criteria only, are presented and discussed. Four combinations of criteria weights were assigned to determine the suitability level within each feasible site. In Case (a), the criteria weights were calculated by applying the Entropy Information weighting method, discussed in Section 3.8. The criteria weights for Case (b), (c) and (d) were assigned subjectively to demonstrate the change of suitability level within the site by altering the criteria weights.

Table 4.5 shows the criteria weights of the four cases by considering only the noise and visual criteria. The Entropy Information weighting method was applied to calculate the criteria weights for Case (a). Since the variation of the associated criteria values of visual criterion is lower than that of the noise criterion's, as a result, the weight of visual criterion is also relatively low, comparing to the weight of the noise criterion. In Case (b), an equal weight was assigned to both to examine the suitability level by adding an equally weighted noise and visual criteria. Criteria weights of 0.75 and 0.25 were given to Case (c) and (d) to explore the suitability level within the site. A higher weight of 0.75 will be assigned to the dominate factor of either noise or visual criterion.

Table 4.5. Weights for noise and visual criteria

(a)

Category	**Criterion**	**Weight**
Noise	Affected population by turbine noise	0.91556
Visual	Affected population by turbine visibility	0.08444
Weight Sum		1.0

(b)

Category	**Criterion**	**Weight**
Noise	Affected population by turbine noise	0.5
Visual	Affected population by turbine visibility	0.5
Weight Sum		1.0

(c)

Category	**Criterion**	**Weight**
Noise	Affected population by turbine noise	0.75
Visual	Affected population by turbine visibility	0.25
Weight Sum		1.0

(d)

Category	Criterion	Weight
Noise	Affected population by turbine noise	0.25
Visual	Affected population by turbine visibility	0.75
Weight Sum		1.0

Figure 4.15 presents the suitability level of feasible sites by considering only the noise and visual criteria. Site B was selected as an example to demonstrate the results of different criteria weighting combinations. The results of the rest of the sites can be found in Appendix VI and Appendix VII. Based on the results, the alternation of criteria weights can change the overall suitability scores within the site. In Case (a) & Case (c), a higher weight of 0.91556 and 0.75 were assigned to the noise criterion, to represent the situation in which the turbine noise is the dominate concern raised by the public. In Case (d), a higher weight of 0.75 was given to the visual criterion to demonstrate the suitability level when the visibility is the dominant concern in the local community. If both noise and visual concerns were presented equally, an equal weight of 0.5 can be applied to both criteria. With the aim of addressing the public concerns in the siting process, decision makers and planners can apply a similar weighting technique to avoid the locations with high turbine noise and visibility impacts (lower suitability scores) within the site.

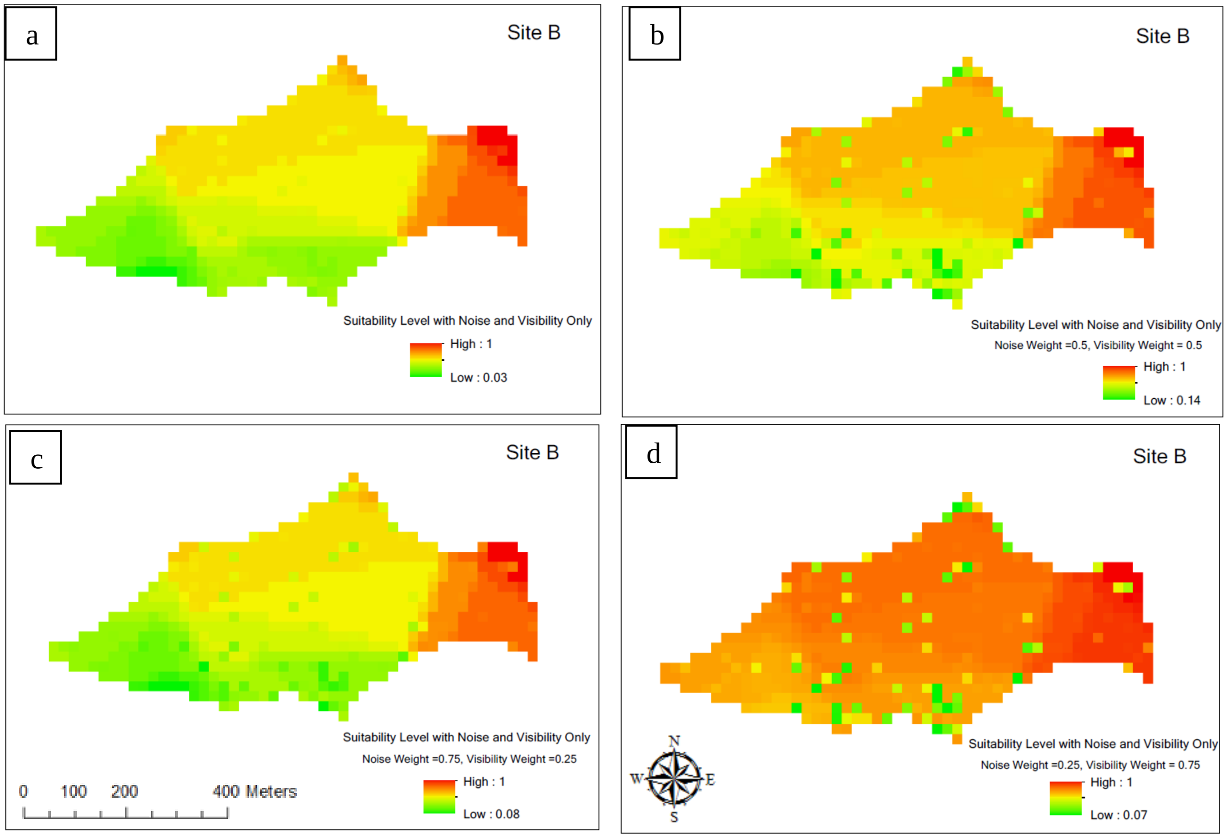


Figure 4.15. Suitability Level within Site B by combining the noise and visual criteria, with different criteria weights

The suitability level within Site B is different in Figure 4.15 from the integration of a set of siting criteria. Refer to Figure 4.16, the first map on the left represents the suitability level of Site B, by considering only the noise and visual criteria. The map on the right shows the suitability level by integrating not only the noise and visual criteria, but also other common siting criteria. The criteria weights in both cases were generated by applying the Entropy Information method. Both the number of criteria and the weight of each criterion can influence the overall suitability level within the site, since the suitability scores are calculated by overlaying the weighted criteria on a raster cell-by-cell basis. The locations with higher suitability scores are only presented on the eastern edge of the site on the first map. However, the second map shows that both eastern and western edges of the site contain a higher suitability score.

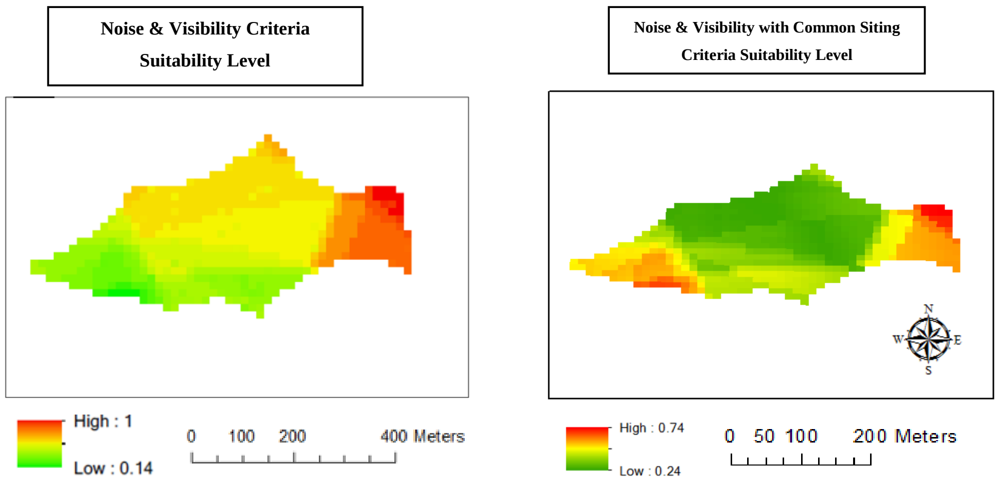
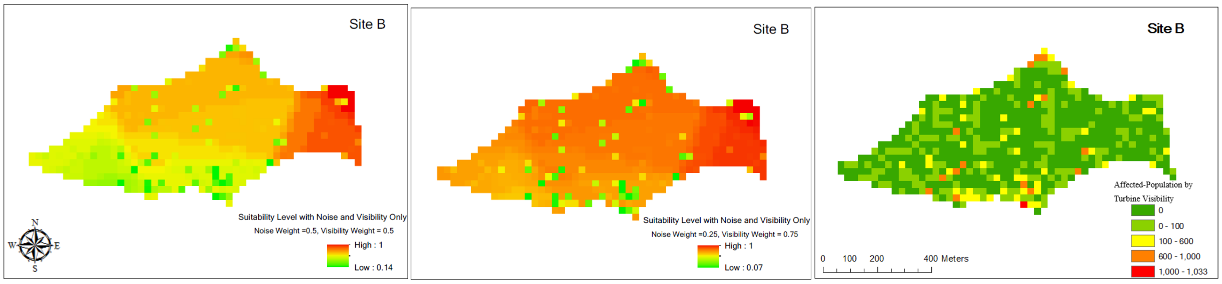


Figure 4.16. Suitability Level of Site B by considering the visual and noise criteria only, and integrating noise and visual with common siting criteria

There are some site cells that contain low suitability scores distributed in the suitability maps of case (b) and (d), Refer to Figure 4.17, the sprinkled cells in case (b) and (d) represent the corresponding locations with a high affected population by turbine visibility, as shown on the affected population map on the right. Based on the site evaluation process, a high number of affected population would result in low suitability scores for those site cells.



Noise & Visibility Criteria Suitability Level (Case b)

Noise & Visibility Criteria Suitability Level (Case d)

Affected Population by Turbine Visibility

Figure 4.17. Suitability Level of Site B by considering noise and visual criteria, and the corresponding affected population by turbine visibility

The results in Figure 4.15 show that the overall suitability scores are sensitive to criterion weight changes. It is necessary for decision makers to apply reasonable criteria weights that can well represent and capture the dominant concerns of the wind farm sites. The criteria weights that are generated by the Entropy Information method in this study only represent the scenario in which the turbine noise is the dominant concern among residents. However, the visual impacts are not well represented, as a lower weight has assigned to the visual criterion. Thus, different criteria weights should be applied accordingly to show the suitability results of different scenarios. According to the literature, both noise and visual criteria are the main driving forces that can trigger public opposition towards wind farms (Baxter, et al., 2013). More importantly, turbine noise can be strongly associated with visibility impacts, when people can see turbines close to their dwellings (Pedersen & Larsman, 2008). As there is a general lack of consideration of noise and visual impacts in the wind farm siting regulations in Ontario, both criteria are recommended be integrated into the siting decisions. As a result, the criteria weights in case (b) are more likely to be represented, where noise and visual criteria are treated as equally important in the siting process. It is also important to note that, the concerns towards wind turbines can also be subjective and case-specific based on the public perceptions of wind farms in different study areas.

4.5 Discussion

The demonstration of the noise and visual impacts siting approach presents the potential for addressing the public concerns in siting decision-making process. Decision makers and planners can apply the siting approach proposed in this study to estimate the affected population of a wind farm site. As previously discussed in Section 2.3, the noise and aesthetic effects are major concerns among residents, which affect the public acceptance and NIMBY attitudes toward wind farm developments. In a typical wind farm siting process, public opinions and concerns are usually not considered, since the municipal governments have no authorities to make the decisions. However, public concerns can be used as a valuable piece of information, which can assist decision makers to solve spatial planning problems. The siting method presented in this study provides a siting approach to represent the noise and visual impacts in the site planning stage, aiming to gain public supports and resolve social conflicts. Distance decay and impact coverage zones are important terms in determining the potential affected population, as the level of noise and visual impacts are strongly associated with the distance to the turbine facilities. At a certain distance, noise impacts can be very minimal to the local residents. It is also important to note that the level of visual impact varies according to the viewshed. In order to reduce the potential visibility effects to the residents, decision makers should select the locations that are not or less visible to the single dwellings within the feasible wind farm site.

However, there are factors that may affect the results of this study. The weight of the criterion is a key factor that influences the overall suitability scores. The visual criterion has a lower weight when compared with other criteria, since the variation among the standardized affected-population by turbine visibility within the selected sites is low, as a property of the Entropy Information method; thus, it leads to very small changes in suitability levels. The weights in this research are generated by the Entropy Information weighting method, which is used to demonstrate an objective method of assigning weights to criteria. However, different weights can be assigned to each criterion based on the user's preferences and expert opinions to address the current siting issues. For instance, if the noise and visual are the main concerns toward the developments, decision makers can assign a relatively higher weight over the others to focus on the locations within a site that have no or minimal impacts of the turbine noise and visibility.

The results of the local WLC standardization within a wind farm site are dependent on the range of data values. Using the affected-population by turbine visibility as an example, the population range in Site F is 0 to 65,999. The standardized value of each site cell was calculated by the subtraction between local maximum value and the actual value stored in the site cell, and then divided by the local range value. The high range value such as 65,999 (65,999-0) can result in an extreme low standardized value across the site. In order to resolve this issue, a threshold for the maximum value can be assigned to provide more accurate standardization results. Due to the fact that the threshold values are often assigned by the decision makers or experts, future studies could collect threshold values by conducting a survey with the experts.

The size of the site cells is another factor that can potentially affect the results of this research. Technically, the wind turbine spacing is highly dependent on the rotor diameter of the turbine (Gipe & Murphy, 2005). The sample wind farm sites in this is study were divided into 25 x 25 meter raster cells for demonstration purposes. Different site cell sizes can be applied depending on the actual spacing of turbines and user's preferences. Using a different cell size can also modify the overall results of the affected populations and the suitability scores within each site.

4.6 Summary

This chapter presented the results and findings from the wind farm site selection approach. The results indicate that the feasible sites for building wind farms in Southern Ontario. The siting approach was designed to represent and determine the potential noise and visual impacts of wind turbines by estimating the total affected population. The suitability levels within wind farms altered after integrating the noise and visual criteria. It is essential for decision makers to evaluate the importance of noise and visual concerns in the siting process with the aim of solving spatial siting conflicts.

Chapter 5 Conclusions & Recommendations

The overall goal of this thesis is to develop a wind farm siting approach that integrates the potential noise and visual impacts into the siting decision making process. This chapter includes four sections. Section 5.1 summarizes how the research objectives are achieved. Section 5.2 discusses the major contribution of this study to the field of land-use planning and wind farm site selection. Section 5.3 outlines the research limitations and Section 5.4 presents the recommendations for future research.

5.1 Research Objective Discussion

The first research objective was to "develop a siting approach for determining the affected population by potential noise and visual impacts of wind turbines". This objective was accomplished by designing the GIS-based noise and visual siting approach to estimate the affected population of turbine sites. The population affected by turbine noise is strongly associated with the estimated population living in the surrounding single dwellings, the distance between single dwellings and turbine site, and the geographic distribution of single dwellings. A noise level of 20 dB was applied in this study to collect the population that can perceive more than 20 dB of the turbine noise. Performing a GIS-based viewshed analysis allows users to identify the visible and non-visible landscape cells of 80-meter turbines. The affected population can be calculated by extracting the overlapped areas between the visible landscape and the single dwelling cells. Turbine heights, elevation of the site, the distribution of population and the setting of the viewshed analysis are factors that can influence the overall results. The maps generated by the siting approach allow the decision makers to identify and visualize the locations with high impacted populations in the planning stage of a site selection. The spatial siting approach not only quantifies the noise and visual impacts of wind turbines, but is also useful as a spatial planning tool for solving siting conflicts and addressing public concerns toward wind farm developments to increase the social acceptability.

The second objective was to "To visualize and identify the changes of suitability level within feasible wind farm sites by integrating noise and visual criteria with other siting criteria including physical, environmental, economic and planning". This objective was achieved by applying a GIS-based MCDA siting approach to present the changes of suitability level before and after the integration of the noise and visual criteria with other common siting criteria. Before integrating the noise and visual criteria, the local WLC standardization technique was performed to calculate the standardize criteria values. The overall suitability scores were calculated by multiplying the standardized values, and criteria weights that were calculated by the Entropy Information weighting method. Sample wind farm feasible sites in Dufferin County and Chatham-Kent, which have been identified by the site screening process, were selected to demonstrate changes of suitability level within each site. The results of suitability scores are sensitive to the criteria combinations and weight changes. This GIS-based MCDA is a well-suited approach for integrating all the siting criteria, performing data analysis and conducting cartographic visualization. The spatial changes within individual sites reflect that both noise and visual criteria are influential in the determination of suitability level of wind farm sites. Suitability maps provide a direct visualization to assist decision makers in recognizing the changes of suitability level after introducing these two new siting criteria. As the noise and visibility are the two dominant public concerns that trigger local opposition towards wind farms, it is essential for decision makers to consider and recognize the importance of the implementation of these two factors into future wind farm siting decision process to minimize potential social conflict.

The third objective of this study was to "provide recommendations for the integration of noise and visual impacts of wind farms into future siting decisions". The use of GIS-based MCDA siting approach provided an effective way to visualize the spatial changes of suitability level and implement these siting criteria into a siting process. As discussed in Section 2.3, noise and visual impacts are the two dominant factors that affect the public acceptance of wind farm developments. The results of this study indicate that these two criteria can alter the overall suitability level within a site. In order to increase the public acceptability toward wind farms and alleviate spatial land-management issues, both criteria are recommended to be taken into considerations in the future wind farm siting processes and regulations. According to the Approval and Permitting Document for renewable energy projects (2009), the current siting regulations are primarily focused on addressing the environmental factors. Siting regulations should also tackle the problematic issues of noise and visual impacts in the early stage of the site planning process. The current literature on wind farm site selection often identify the optimal locations by comparing the overall suitability scores of one site to another. However, it ignores the beneficial insights from evaluating local variations among the sites. It is also important to note that the noise and visual impacts vary across sites. Thus, the local WLC standardization technique is recommended in wind farm siting to examine the local variation within a suitable site and promote efficient land-use planning. As the intention of this study is to develop a noise and visual impact siting approach and illustrate the changes of suitability level of each site, the actual analysis of the spatial change patterns within a site was not conducted. We recommend future research to apply statistical analysis to determine statistically significant site cells within a site and further explore spatial patterns from the change results.

5.2 Contributions

The present thesis has made contributions to the field of land-use planning and wind farm site selection by developing a spatial approach that can estimate the affected population of noise and visual impacts, as well as determine the suitability level of wind farm sites. Although the main focus of this thesis is on wind farms, the spatial approach is generalizable, which means it can be applied to other facility developments to address noise and visual concerns in regards to minimizing the spatial conflicts in facility site selection. This thesis contributes a siting approach and method, aimed to alleviate the spatial siting conflicts and promote efficient land-use for wind farm developments by integrating the noise and visual concerns in the site planning stage.

This work may also make several contributions to the current literature. One of the research gaps in the current literature is the lack of studies on the wind farm siting in Ontario. This study may fill this research gap, and more importantly, the results and datasets of the study could be used as a reference guide for future research in identifying the feasible locations to build wind farms in Ontario. Furthermore, this study extends our knowledge of examining and addressing local variations within wind farms by applying the standardization technique of the local WLC, which is an effective way to provide localized information and determine the suitability level within each wind farm site.

5.3 Limitations

Although this study was cautiously designed and the research objectives were successfully fulfilled, there are a number of limitations that could have affected the results of the study. First, due to a lack of data and literature on wind farm site selections in Ontario, it was a challenge to identify and collect siting criteria and constraints. This influenced the overall results of the wind farm feasible areas. Specific information on trout lakes and provincially significant wetlands, wooded areas, wildlife habitat and parks, according to the Ontario Approval and Permitting Documents for Renewable Energy (2009) were unavailable for this research. Assumptions were made in the site screening process that all water bodies were treated as trout lakes, and wetlands, wooded areas, wildlife habitat and parks were all provincially significant. Thus, these limitations may affect the size of feasible wind farm areas.

Another limitation is the spatial representation of noise and visual impacts of wind turbines. The noise equation applied in this study considered the atmospheric absorption, however other possible noise attenuation factors such as from vegetation were not considered in this approach. Trees, buildings and turbine blades were not considered as part of the limitation of the viewshed analysis. The population of each single dwelling was estimated by calculating the total population in Dissemination Area (DA) divided by the number of single dwelling cells in each DA, because the accurate information about the population of single dwellings is unavailable. Similarly, the spatial data for the current wind turbines is also unavailable. The wind farm locations generated by Ontario Wind Turbine (2014) are not the exact wind turbine locations. Thus, this research was incapable of comparing the differences among feasible wind farm sites that have been identified from the research and the current wind turbines in detail.

Since this siting approach was not tested with the surrounding residents, some uncertainties of the actual public concerns toward wind farm developments may not be captured. Although noise and visual are the two major concerns, according to the current literature, other concerns such as health, uneven cost and benefit between locals and developers were not addressed in this research. In addition, the main concerns could be different across the communities and the concerns from each individual can be different as well. This siting approach works the best in the initial site planning stage, which is before wind farm facilities are introduced to the community.

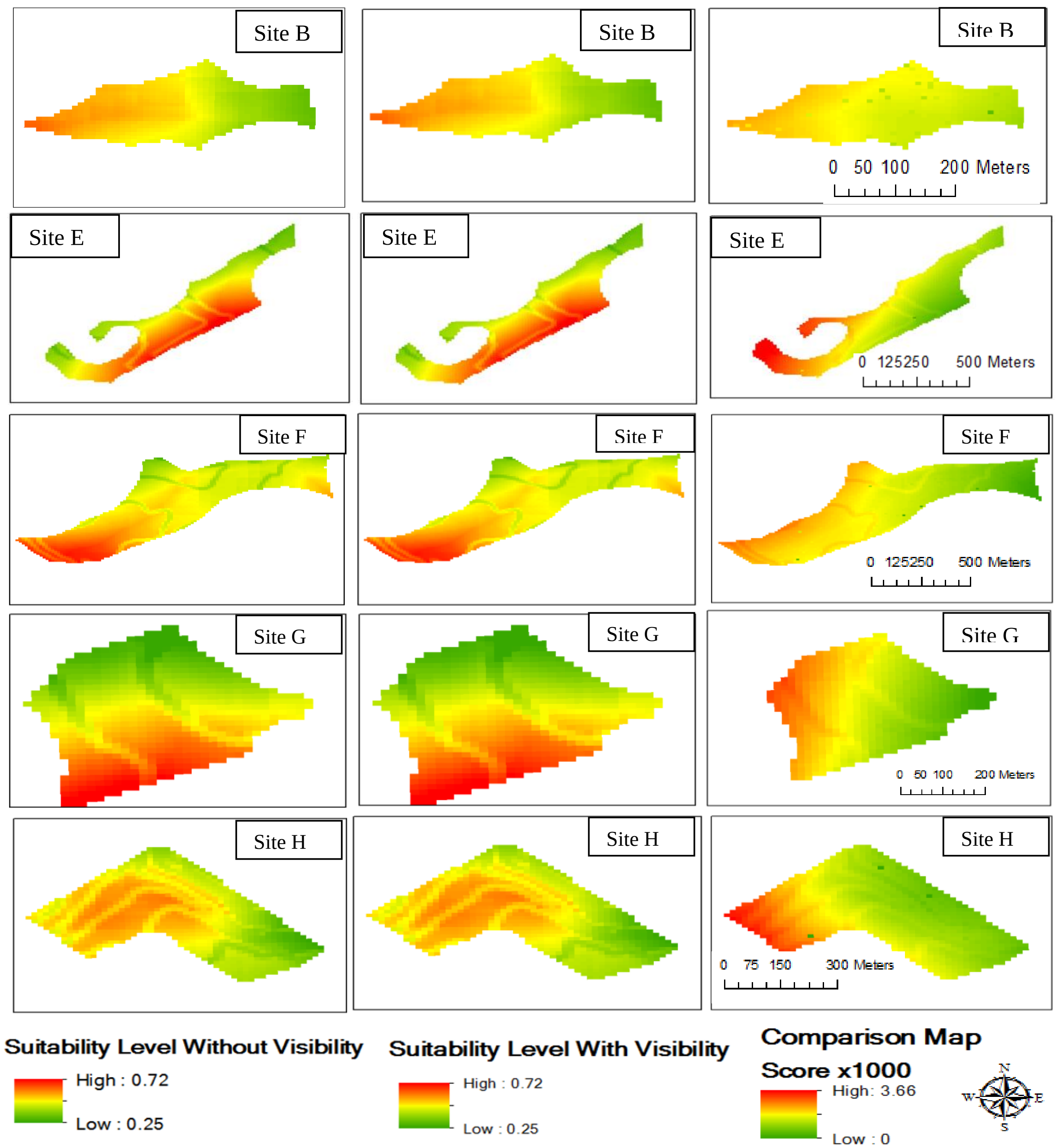
5.4 Recommendation for Future Research

With respect to land-use planning, future research on solving spatial facility siting conflicts could be explored by implementing this siting approach into a web-based interactive mapping application. Designing an interactive mapping application could encourage public participation in the siting planning process to increase the public awareness. After setting the proposed wind turbines on the map, the public will be able to obtain information on how much noise will be perceived from the potential wind turbines by entering the geo-locations (latitude and longitude) of their dwellings. In the meantime, the public will also be able to determine whether they are visible to the potential wind turbines or not.

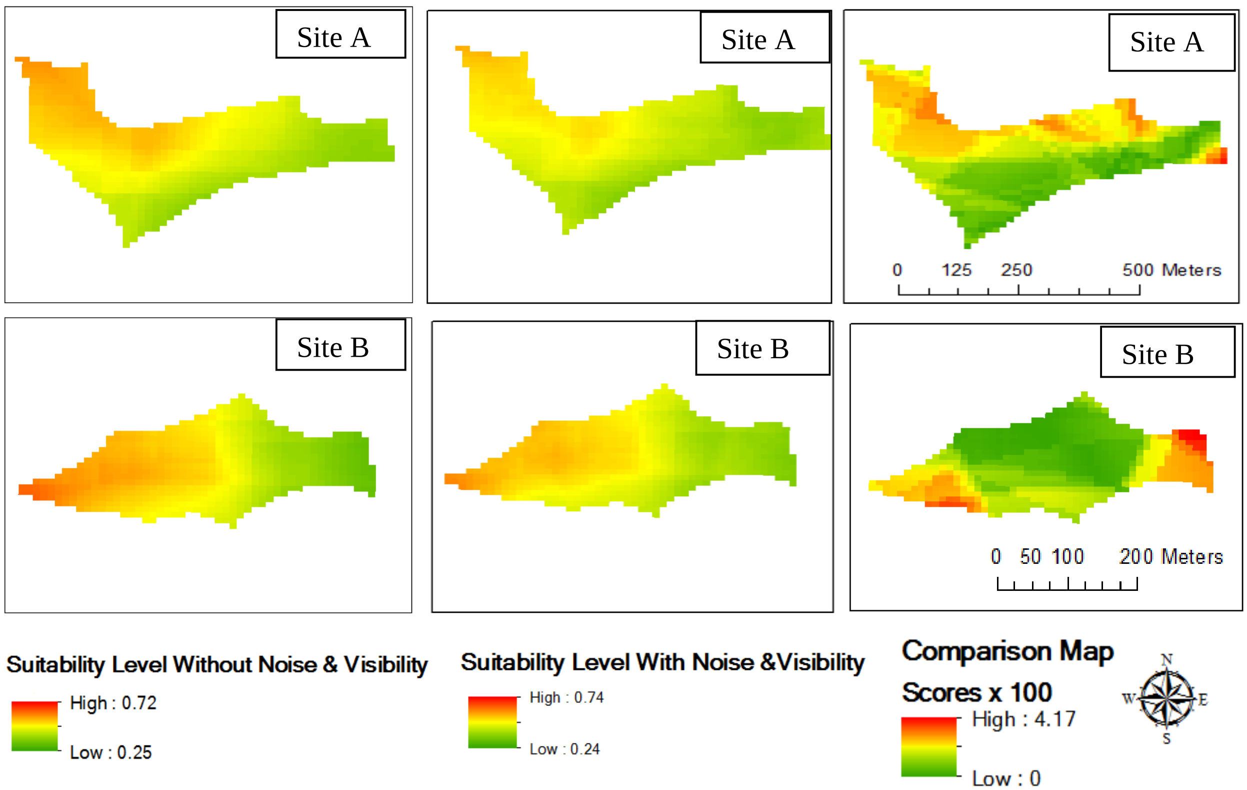
As discussed in Section 5.3, the use of more accurate datasets is essential in identifying more precise feasible wind farm locations in Southern Ontario. Meanwhile, precise data on the population of single dwellings is required to produce more accurate results of the affected populations. We recommend that future studies combine field work data with this siting approach in order to produce more accurate results. This siting approach can be tested with the public during the consultation or public meetings, in order to promote public participation in a wind farm decision making process. Potential concerns among residents who live within the certain vicinity of wind farms can be collected by survey questionnaires. Setting up threshold for the maximum value with experts for the standardization process is beneficial to obtain a more accurate standardized value. The scale of the research can be applied to a national scale across Canada or in a local scale, such as municipalities. Since the siting approach is mainly focused on the wind farm developments, other facilities that have potential noise and visual impacts could apply a similar approach to simulate the noise and visual impacts, and then combine them with other siting factors in the planning process, which would be an effective way to determine the optimal locations.

Appendices

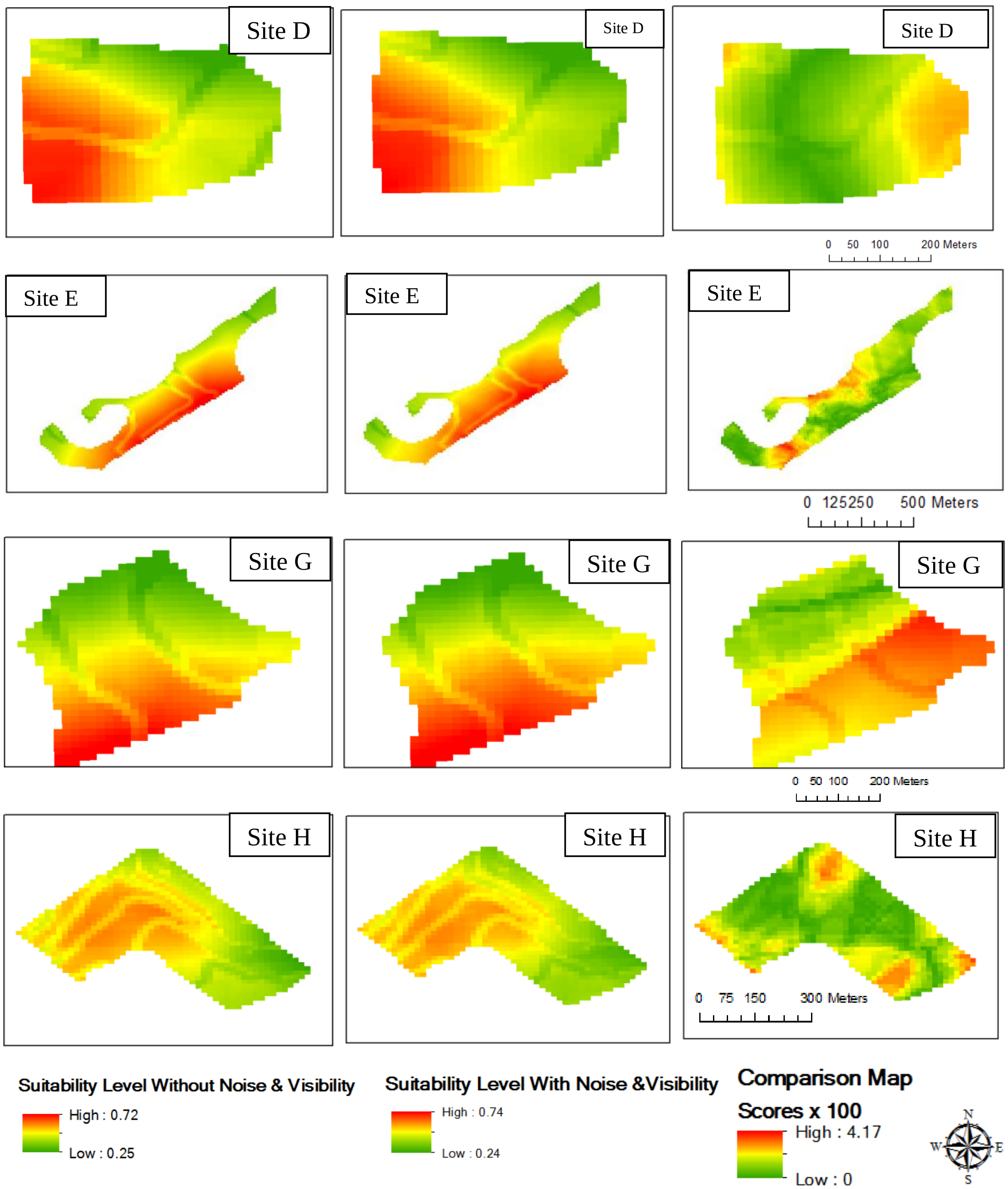
Appendix I. Changes in suitability level within sample sites B, E, F, G and H before/after integrating the visual criterion



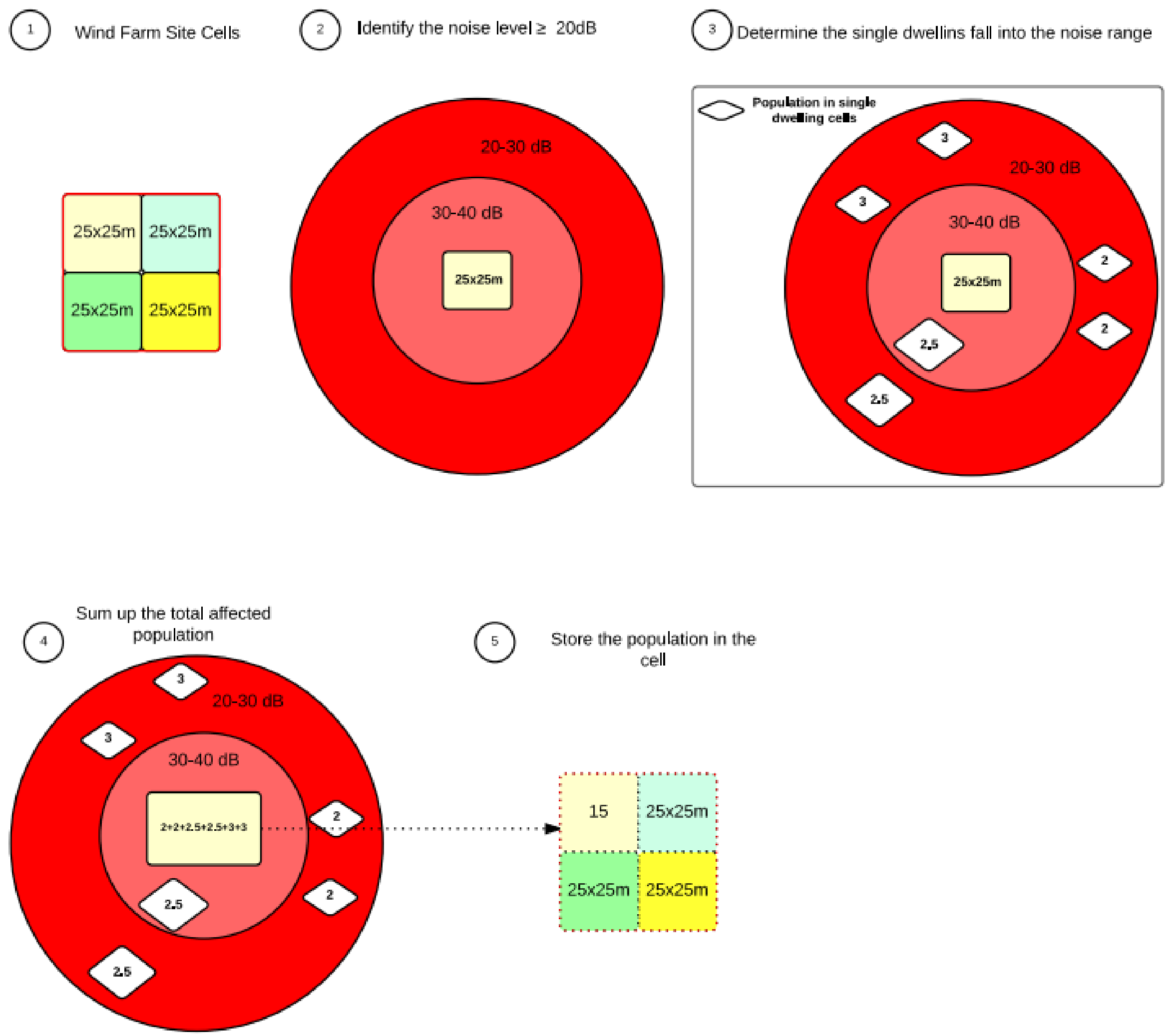
Appendix II. Suitability Level within the sites A & B in Dufferin County before/after the integration of noise and visual criteria



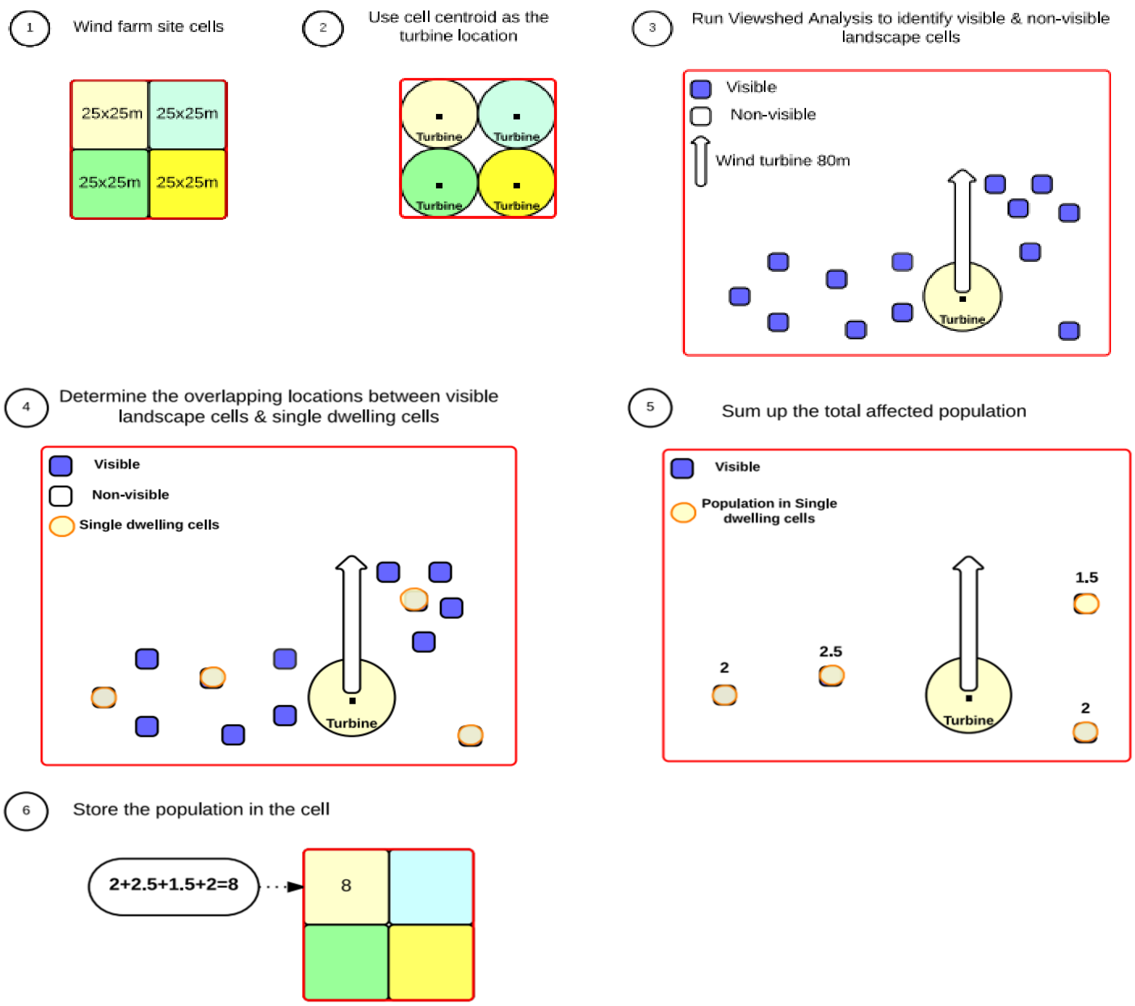
Appendix III. Suitability Level within the sites D, E, G & H in Chatham-Kent before/after the integration of noise and visual criteria



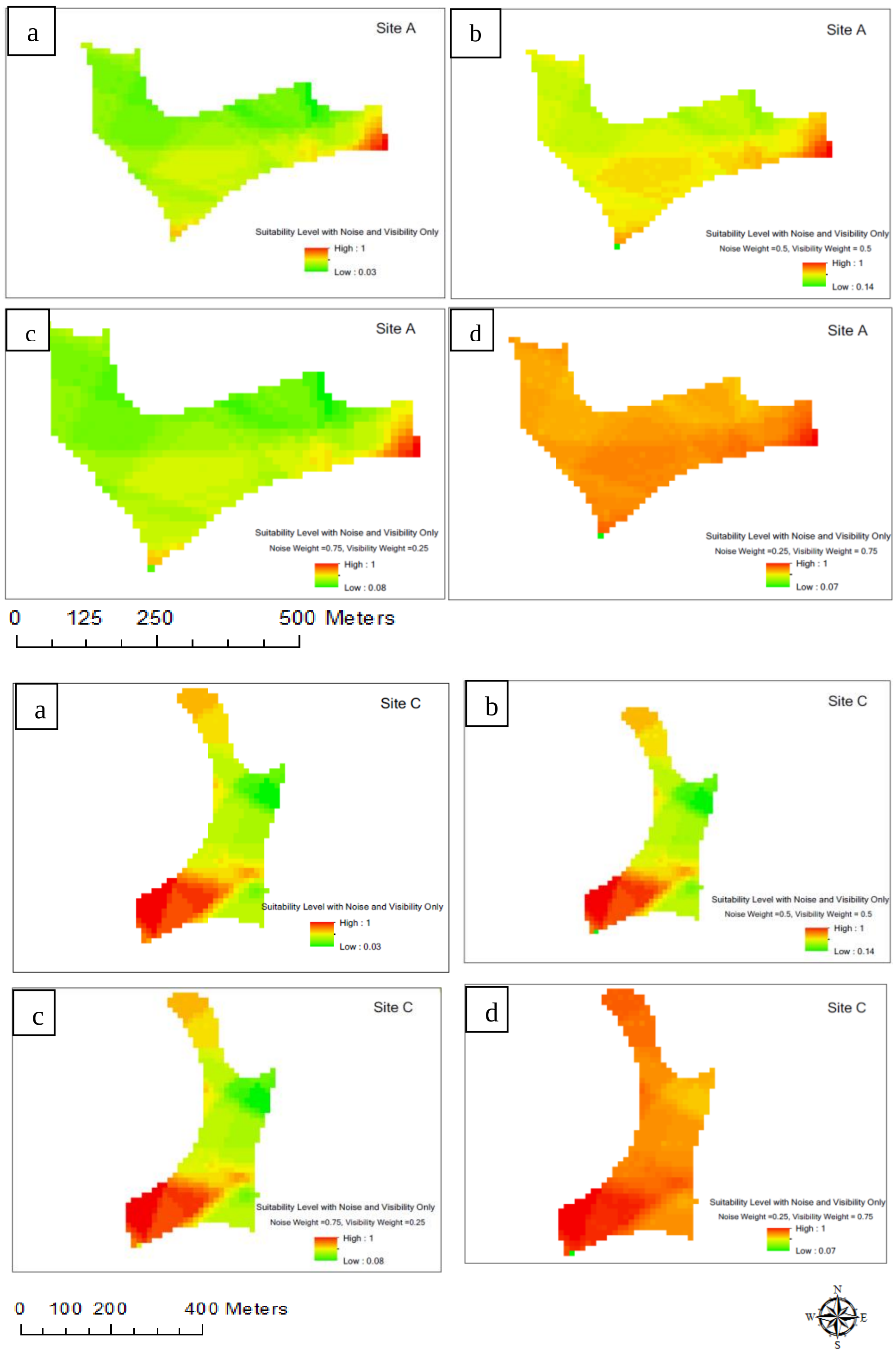
Appendix IV. Demonstration of Noise Impact Siting Approach



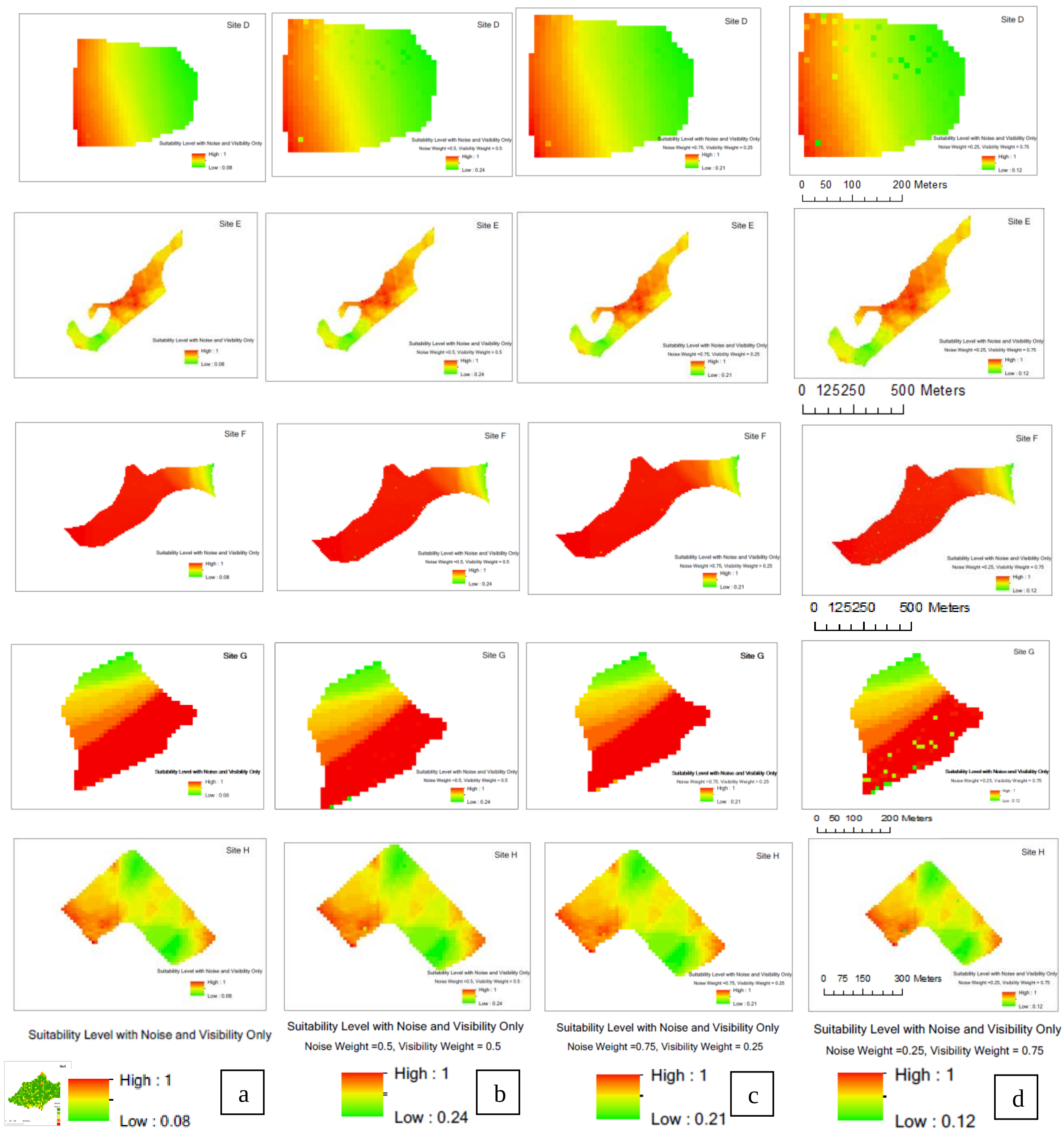
Appendix V. Demonstration of Visual Impact Siting Approach



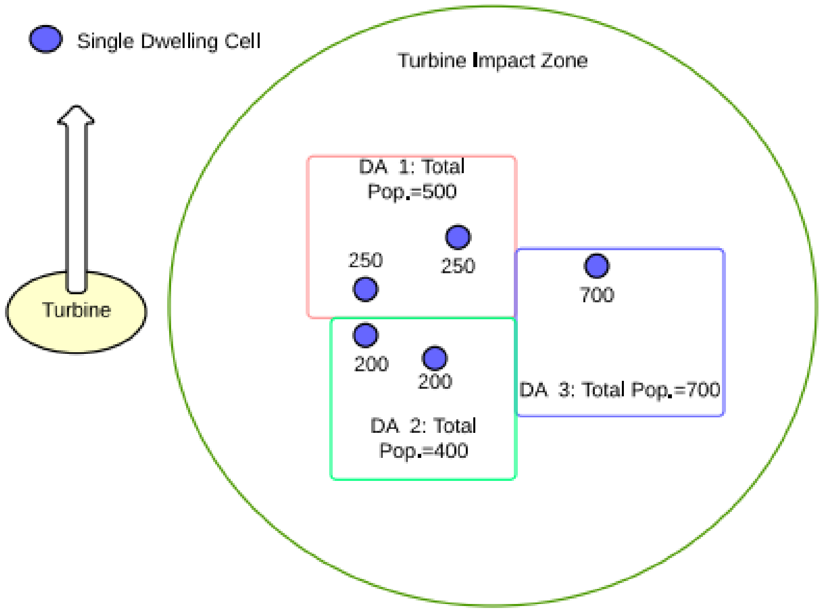
Appendix VI. Suitability Level within Site A & C by combining the noise and visual criteria, with different criteria weights



Appendix VII. Suitability Level within Site D, E, F, G and H by combining the noise and visual criteria, with different criteria weights



Appendix VIII. Example of Population of Each Single Dwelling Cell in Dissemination Areas (DAs)



DA 1 Total pop.=500	# of dwelling cells (2)	Pop. of Single dwelling cell 500/2=250	Pop of Single dwelling cell 500/2=250
DA 2 Total pop.=400	# of dwelling cells (2)	Pop. of Single dwelling cell 400/2=200	Pop of Single dwelling cell 400/2=200
DA 3 Total pop.=700	# of dwelling cells (1)	Pop. of Single dwelling cell 700/1=700	

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