Ruhr-Universität Bochum

Dissertation

Optimizing the visual impact of onshore wind farms upon the landscapes – Comparing recent planning approaches in China and Germany

---

Submission to the

Ruhr-Universität Bochum, Faculty of Geosciences

For the degree of

Doctor of natural sciences (Dr. rer. nat)

Submitted by:

Jinjin Guan. MLA

Date of the oral examination:	**16.07.2020**
Examiners	**Dr. Thomas Held** **Prof. Dr. Harald Zepp** **Prof. Dr. Guotai Yan** **Prof. Dr. Wolfgang Friederich** **Prof. Dr. Harro Stolpe**

Keywords

Onshore wind farm planning; landscape; landscape visual impact evaluation; energy transition; landscape visual perception; GIS; Germany; China.

Abstract

In this thesis, an interdisciplinary Landscape Visual Impact Evaluation (LVIE) model has been established in order to solve the conflicts between onshore wind energy development and landscape protection. It aims to recognize, analyze, and evaluate the visual impact of onshore wind farms upon landscapes and put forward effective mitigation measures in planning procedures. Based on literature research and expert interviews, wind farm planning regimes, legislation, policies, planning procedures, and permission in Germany and China were compared with each other and evaluated concerning their respective advantages and disadvantages. Relevant theories of landscape evaluation have been researched and integrated into the LVIE model, including the landscape connotation, landscape aesthetics, visual perception, landscape functions, and existing evaluation methods. The evaluation principles, criteria, and quantitative indicators are appropriately organized in this model with a hierarchy structure. The potential factors that may influence the visual impact have been collected and categorized into three dimensions: landscape sensitivity, the visual impact of WTs, and viewer exposure. Detailed sub-indicators are also designed under these three topics for delicate evaluation. Required data are collected from official platforms and databases to ensure the reliability and repeatability of the evaluation process.

Friedrich-Wilhelm Raiffeisen Wind Farm in Germany and Zhongying Wind Farm in China have been studied and compared through the LVIE model. The case studies are applied in GIS with digital landscape models. The evaluation results can be quantitatively calculated and visualized to provide definite and clear guidelines for planners and other stakeholders in decision-making. The results in the LVIE model have been validated through questionnaires and analysis of variance (ANOVA) in the Chinese case. The validation aims to verify whether the results of the LVIE model fit the real situations or not, and adjust the recommendations for planning implementation.

Recommendations concerning the planning procedures, mitigation, and compensation measures, are proposed based on the evaluation results of the LVIE model for the optimization of the planning procedures of onshore wind farms. The evaluation results on the three dimensions complement existing forms of information in a meaningful manner that can be provided for various planning departments, in particular, strengthen cooperation between them. The comprehensive result of visual impact reveals that flexible buffer distance dependent on the visual impact degree is more suitable than fixed buffer distance in compact land use areas. A communal fund is recommended to manage and operate the compensation payment that can optimize public participation and local support. Finally, the limitations of the LVIE model are discussed and suggestions for future research in this area are developed.

Kurzfassung

In dieser Dissertation wird ein interdisziplinäres Modell zur Bewertung der Auswirkungen auf das Landschaftsbild erarbeitet, welches die bestehenden Konflikte zwischen dem Ausbau der Windenergie an Land und dem Landschaftsschutz lösen soll. Ziel des Modells ist es, die Auswirkungen von anlandigen Windparks auf das Landschaftsbild zu erkennen, zu analysieren und zu bewerten. Anschließend werden Maßnahmen vorgestellt, welche diese Auswirkungen in Planungsverfahren wirksam minimieren sollen. Basierend auf einer Literaturrecherche und Experteninterviews wurden Windparkplanungssysteme, Gesetze, Richtlinien, Planungsverfahren und Genehmigungen in Deutschland und China miteinander verglichen und hinsichtlich ihrer jeweiligen Vor- und Nachteile bewertet. Dabei wurden relevante Theorien der Landschaftsbildbewertung wie die Landschaftskonnotation, die Landschaftsästhetik, die visuelle Wahrnehmung, die Landschaftsfunktionen, und bereits vorhandene Bewertungsmethoden erforscht und in das LVIE-Modell integriert. Die Bewertungsgrundsätze, Kriterien und quantitativen Indikatoren sind in diesem Modell in der folgenden Hierarchiestruktur organisiert. Die Faktoren, die die visuelle Wirkung beeinflussen können wurden in die drei Dimensionen Landschaftsempfndlichkeit, visuelle Wirkung von Windkraftanlangen und Exposition des Betrachters eingeteilt. Für die weitere Auswertung dieser drei Dimensionen wurden detaillierte Teilindikatoren entwickelt. Um die Zuverlässigkeit und Reproduzierbarkeit des Bewertungsprozesses sicherzustellen, wurden die erforderlichen Daten nur von offiziellen Plattformen und Datenbanken extrahiert.

Für diese Arbeit wurden sowohl der Friedrich-Wilhelm Raiffeisen Windpark in Deutschland als auch der Zhongying Windpark in China untersucht und anhand des LVIE-Modells verglichen. Beide Fallstudien wurden in GIS mittels digitaler Landschaftsmodelle simuliert. Die Evaluationsergebnisse können quantitativ berechnet und visualisiert werden, um Planern und anderen Projektbeteiligten bei der Entscheidungsfindung eindeutige und klare Leitlinien zu liefern. Im Falle des Zhongying Windparks wurden die Ergebnisse des LVIE-Modells durch Fragebögen und Varianzanalysen validiert. Die Validierung überprüft ob die Ergebnisse des LVIE-Modells der tatsächlichen Situation entsprechen, und dient dazu, die daraus abgeleiteten Empfehlungen entsprechend anzupassen.

Auf Grundlage der Evaluationsergebnisse des LVIE-Modells werden Empfehlungen zu Planungsverfahren, sowie zu Minderungs- und Ausgleichsmaßnahmen zur Optimierung der Planungsverfahren von anländigen Windparks vorgeschlagen. Die Evaluationsergebnisse anhand der drei Dimensionen ergänzen bereits bestehende Informationsformen sinnvoll, und können den verschiedenen Planungsabteilungen bereitgestellt werden um insbesondere die Zusammenarbeit untereinander zu stärken. Das umfassende Ergebnis bezüglich der visuellen Wirkung zeigt, dass eine flexible Festlegung von Pufferzonen in Abhängigkeit vom Grad der Auswirkungen auf das Landschaftsbild in kompakten Landnutzungsgebieten besser geeignet ist als ein fester Puffer. Es wird empfohlen einen kommunalen Fonds aufzusetzen, um eine angemessene öffentliche Beteiligung zu ermöglichen und maximale lokale Zustimmung zu erreichen. Schlussendlich werden die Limitierungen des LVIE-Modells diskutiert und Vorschläge für zukünftige Forschung in diesem Gebiet erarbeitet.

Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided and independent work. No unauthorized outside help was used. I have not used other than the declared sources, resources, or programs. I have explicitly marked all material that has been quoted either literally or by content from the sources used. Furthermore, I declare that the submitted electronic version of the thesis is identical to the written version. This thesis was not previously presented to and graded by another examination board and has not been published. The digital illustrations are processed based on the original data with correct citation. No commercial mediation or consultation was used in this thesis.

Ich versichere an Eides statt, dass ich die eingereichte Dissertation selbstständig und ohne unzulässige fremde Hilfe verfasst, andere als die in ihr angegebene Literatur nicht benutzt und dass ich alle ganz oder annähernd übernommenen Textstellen sowie verwendete Grafiken, Tabellen und Auswertungsprogramme kenntlich gemacht habe. Außerdem versichere ich,dass die vorgelegte elektronische mit der schriftlichen Version der Dissertation übereinstimmt und die Abhandlung in dieser oder ähnlicher Form noch nicht anderweitig als Promotionsleistung vorgelegt und bewertet wurde. Digitale Abbildungen nur die originalen Daten enthalten Bildbearbeitung. Keine kommerzielle Vermittlung oder Beratung in Anspruch genommen wurde.

Signed: Jinjin Guan

Date: 14. April 2020

Jinjin Guan

Curriculum Vitae

Personal Data

Name	Jinjin Guan
Date of birth	08.01.1991
Institute	Faculty of Geosciences, Geography Institute, Ruhr University Bochum

Education

Since 10/16	Faculty of Geosciences, Geography Institute, Ruhr University Bochum, Germany Ph.D. student, Supervisor: Dr. Thomas Held, Prof. Harald Zepp, Prof. Guotai Yan
09/13 – 06/16	Department of Landscape Architecture, Tongji University, Shanghai, China Master of Landscape Architecture, GPA: 88.14/100, Supervisor: Prof. Guotai Yan
09/09 – 06/13	Department of Landscape Architecture, Tongji University, Shanghai, China Bachelor of Science, College of Architecture and Urban Planning, GPA: 4.32/5.0 (88.15/100)

Research Focuses

Focuses: Landscape planning, Energy transition, Environmental impact assessment, Wind energy planning procedures, Renewable energy policies, Landscape visual impact evaluation, GIS analysis, Social acceptance of renewable energy.

Title of Dissertation: Optimizing the visual impact of onshore wind farms upon the landscapes – Comparing recent planning approaches in China and Germany

Publications

1.Jinjin Guan. Westerly breezes and easterly gales: A comparison of legal, policy and planning regimes governing onshore wind in Germany and China, Energy Research & Social Science. 2020, 67, 1-12. (https://doi.org/10.1016/j.erss.2020.101506)

2.Jinjin Guan, Harald Zepp. Factors affecting the community acceptance of onshore wind farms: A case study of the Zhongying Wind Farm in eastern China, Sustainability. 2020, 12, 6894. 1-19. (doi:10.3390/su12176894)

3.Jinjin Guan. Lessons from German On-shore wind farm planning. 2018. Journal of Physics: Conference Series, Volume 1102, conference 1. (DOI: 10.1088/1742-6596/1102/1/012029）

4.Jinjin Guan, Nannan Dong. Integrating wind energy planning into the Chinese spatial planning system, Renewable & Sustainable Energy Reviews. (Under review)

5.Landscape aesthetic evolution under the background of landscape transition（In preparation for publishing）

6.Jinjin Guan Conflict and integration of renewable energy and landscape planning - Taking wind energy as an example (In preparation for publishing)

7.Jinjin Guan, Guotai Yan. The Eco-effectiveness of Country Parks in Metropolis – An example of Shanghai Qingxi Country Park. Chinese Society of Landscape Architecture. Urbanization and Landscape Architecture. Peking: China Building Industry Press, 2014: 311-314.

8.Jinjin Guan. The Investigation and Introspection of Chinese Classical Garden - Wangshi Garden. Urban Construction Theory Research. 2012. (21): 46-47.

Journal Review

Review for SCI Journal Energy Policy (Impact Factor 4.88)

Review for SCI Journal Energy Strategy Reviews (Impact Factor 2.63)

Academic Communication

1.08/20 2020 International PhD Academic Colloquium on "National Spatial Planning and Urban Governance Optimization", Peking University, Beijing, China. Oral Presentation: Integrating Wind Energy Planning into the Spatial Planning System – Taking Chinese Spatial Planning Reform as a Case.

2.05/20 2020 Young Scholar Forum-Landscape Architecture Sub-Forum, Tongji University, Shanghai, China. Oral Presentation: Landscape Visual Impact Evaluation and Restoration under the Energy Transition Background.

3.12/19 the 2nd Young Scholars International Forum on Design Innovation Agenda, Jiaotong University, Shanghai, China. Oral Presentation: Landscape ecological evaluation and restoration under the energy transition background.

4.06/19 the 7th World Congress and Expo on Green Energy. Barcelona, Spain. Oral Presentation: Correlation Study of indicators on landscape visual impact evaluation in on-shore wind farm.

5.06/19 the 3rd World Congress on Wind & Renewable Energy. Barcelona, Spain. Oral Presentation: A Duel-standard System of Landscape Visual Impact Threshold in wind farm under Social Constructivist Perspective.

6.12/18 The 6th annual meeting of Deutsch-Chinesisches Zentrum für die Förderung der Umwelt und Energie e.V. Nürnberg, Germany. Speech: Landscape Protection and Planning under Energy Transition.

7.11/18 Chinese Scholars' Academic Forum. Münster, Germany. Speech: Renewable Energy and Environmental Impact.

8.09/18 Wind Europe 2018 International Conference. Hamburg, Germany. Poster Presentations: 1)

Lessons from German on-shore wind farm planning. 2) Landscape visual impact evaluation in on-shore wind farm planning

9.06/18 Geography Institute of Ruhr University Bochum, PhD Colloquium. Bochum, Germany. Oral Presentation: Wind turbines——Their impact on the visual landscape.

10.12/17 the 142nd Rhine Academic Forum e.V. Bochum, Germany. Speech: Landscape Assessment and Protection under Energy Transition.

Awards and Honors

2016	Chinese Government Scholarship, Chinese Scholarship Council, China
2014	Guanghua Scholarship, Tongji Univeristy, Shanghai, China
2013	Excellent Undergraduate Thesis Award of Tongji University, Shanghai, China
2012	Gold Prize in 2012 East-Asian Architecture & Urban Design Workshop of Pusan National University, Pusan, Korea
2010	Gold Prize of Huacheng Architecture Design, Tongji Univeristy, Shanghai, China

Language level

Chinese (Native speaker)

English (IELTS 7.5)

Software Skill

Design: CAD, Adobe Photoshop, In-Design, Illustrator; Sketch Up; Rhino; 3D-MAX, Lumion

Analysis: GIS, BIM, SPSS

Acknowledgments

The completion of this research is inseparable from the help of many people and organizations.

First, I am grateful to my supervisors, my principal supervisor Dr. Thomas Held and second supervisor Prof. Dr. Harald Zepp, from Geography Institute at Ruhr University Bochum and my external Professor Guotai Yan from Tongji University in China. Their professional knowledge reserve, dedicated spirit, great patience, and insightful criticism have considerably inspired and supported my research. I especially want to thank my supervisor, Dr. Thomas Held, for his inexhaustible patience and continuous interest in my research topic, and regular and inspiring discussions with me about the themes, methods, and writing skills of my thesis.

I would like to appreciate the Chinese Scholarship Council for funding my Ph.D. program (No.201606260045).

I thank Prof. Weiding Long, Dr. Luis Inostroza, and Dr. Dennis Edler, for their academic communication and inspiration. I thank Prof. Nannan Dong from Tongji University for his criticism on the thesis and discussion with me.

From May to July in 2017, my supervisor Dr. Thomas Held, Dr. Martina Grudzielanek and I did our fieldwork respectively in Hamburg and in Bad Neustadt to investigate the wind farms. I would like to thank them for their kind support. I would like to thank Ms. Andrea Guetschow, who formerly worked in Senvion German Company, Ms. Meike Wellmanns from PROKON Regenerative Energien eG, Mr. Martin Vollnhals from JUWIi Energy Project Company, Mr. Jonas Feja from CUBE, Dr. Lujun Wang from Zhejiang University, Prof. Weiding Long from Tongji University for receiving my interview about wind farm projects and energy transition. I thank them for their kind assistance, the fruitful discussion, and providing useful information about various topics related to my field of research.

During my four years of study in Germany, I have received warm friendship from Dr. Fang Xie, Dr. Dingding Zhang, Dr. Liwei Fu, Ms. Mengjun Jiang and Ms. Anqi Chen. Their friendship and accompany gave me great motivation in research and life.

Finally, I would like to thank my family, my husband Jun Xiong and my parents Zhiqiang Jin and Zhihong Guan, and my parents-inlaw, Dehua Xiong and Jinmei Yuan.

Contents

List of Figures

List of Tables

List of Abbreviation

WT	Wind turbine
LVIA	Landscape Visual Impact Assessment
LVIE	Landscape Visual Impact Evaluation
LVRS	Landscape Visual Resource System
LEVA	Landscape Environment Visual Assessment
EIA	Environmental Impact Assessment
DEM	Digital Elevation Model
DSM	Digital Surface Model
ELC	European Landscape Convention
FOV	Field of View
TVZ	Theoretical Visibility Zone
AVZ	Actual Visibility Zone
EFL	Electricity Feed-In-Law
EJ	Exajoules
Mtoe	Million tonnes oil equivalent
UVPG	Umweltverträglichkeitsprüfungsgesetz (Environmental Impact Assessment Law)
HFV	Human Field of View
GIS	Geographical Information System
RPM	Revolutions per minute
OIT	the Internet of Things
ANOVA	Analysis of variance
CNDEC	Chinese National Development and Reform Commission
CNEA	Chinese National Energy Administration
BauNVO	Baunutzungsverordnung (Building Use Ordinance)
BauGB	Baugesetzbuch (Federal Building Code)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
ROG	Raumordnungsgesetz (Regional Planning Act)

1 Introduction

1.1 Research background

1.1.1 Wind energy industry development

1.1.1.1 Global energy transition

With the rapid growth of population and urbanization, the global energy demand has risen dramatically with the primary energy increasing by nearly a factor of 20, from 28 exajoules (EJ) in 1850 to 566 EJ in 2017 (Araújo, 2014; Edenhofer et al., 2011; BP, 2018), and with a 10-year annual growth rate of 1.7 % (2007 to 2017). Heating (or cooling), transportation, and electricity constitute the three main pillars of energy consumption. Among them, the electricity generation grew by 4 % in 2018 to reach over 23000 TWh, which ensures electricity increase as a continuous development driver of energy demand with a 20 % share of the total world energy consumption (IEA, 2019).

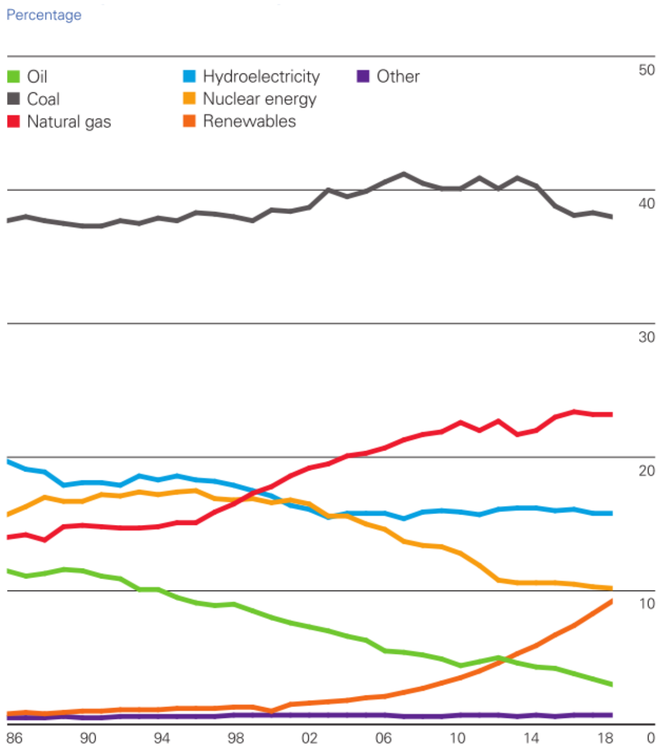


Fig. 1 Share of global electricity generation by fuel (BP, 2019)

As the mainstream energy sources (80 % of the total primary energy supply in 1999), fossil fuel gradually loses its dominant position, while a multi-consisted energy system, as a substitute, becomes dominant shortly. Among all the electricity generation resources, renewable energies are the major contributor, accounting for nearly half of the growth in the last decade. In 2018, the global total energy consumption reached 13864.9 Mtoe (Million tonnes oil equivalent) with a growth rate of 2.9 %, in which renewable energies accounted for 4.05 % with the amount of 561.3 Mtoe with a growth rate of 14.5 % (BP, 2019). In 2015, 186 countries signed the “Paris Agreement” to reduce the greenhouse gas emission and to control the increase of the global average temperature within 2°C compared to the pre-industrialization level. There has been a trend in recent decades that the global energy structure is generally changed by the rapid growth of renewable energies (Fig.1). Renewable energies are looking forward to being effective alternatives to fossil fuels, as well as being a proper solution for the conflicts between energy consumption and environmental protection. Most countries have reached a consensus on promoting energy transition. Energy transition, based on a national or a global scale, is a process of new energy sources appearing and replacing fossil energy sources (Sovacool, 2016; Miller et al., 2015; Hirsh & Jones, 2014; Fouquet & Pearson, 2012). The whole process includes energy sources, technologies, and the attached services comprehensively (Araújo, 2014; Pasqualetti & Brown, 2014).

Despite the significant improvement of renewable energy, its growth rate is far below that required to meet the targets set by the Paris Agreement. It is urgent to take practical actions to address complicated issues involving environmental pollutions, energy shortage, and climate change. A win-win situation, which aims to keep the light on, keep the cost down, and reduce the ecological footprint simultaneously, should be set as a goal for the global energy transition.

1.1.1.2 The advantages of wind energy and its achievements

Renewable energies (e.g., wind, solar, biomass) enjoy high popularity with their cleanness, sustainability, and low-carbon emission characters (Sovacool & Brown, 2011). Moreover, recent research shows that renewable energies have a positive effect on extending human life (Luderer et al., 2019). Among them, wind energy has its own advantages: a worldwide distribution with abundant wind resource, mature technologies, comparatively low-cost, and long-term utilization period (Leung & Yang, 2012). It occupied the first place among renewable energies except for hydropower with the installed capacity of 591GW at the end of 2018 (GWEC, 2019) (Fig.2). Furthermore, wind energy makes a significant contribution to environmental improvement, especially in de-carbonization. According to the prediction (IRENA, 2019), the wind energy could deliver one-quarter (or nearly 6.3 gigatonnes) of the annual CO_2 emission reductions needed by 2050.

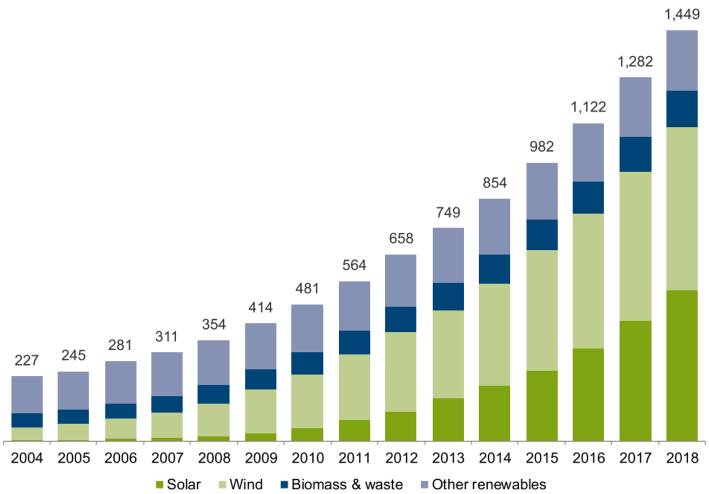


Fig. 2 Global renewable energy capacity, 2004-2018 (GW) (UN Environment, Frankfurt School-UNEP Center, 2019)

Note: "Other renewables" does not include large hydro-electricity project over 50 MW.

Wind energy, also frequently called wind power, is a kind of renewable and clean energy. Although the history of wind energy utilization can be traced back to ancient Egypt and the Middle East 3000 years ago ((Golding, 1976) in Heier, 2016), it is since the 1970s that the modern wind energy industry has been developed accompanied by the oil crisis. When it comes to the 21st century, with the public's awareness of environmental protection and de-carbonization, wind power, together with other renewable energies, becomes the mainstream to fuel the global economic growth and enhance energy security (Ackermann & Söder, 2002; Xu et al., 2010).

1.1.1.3 Wind energy industry prospect

Wind energy has a promising prospect due to the tremendous energy demand, pressure from environmental protection, and support policies from governments. Till 2018, wind energy has been installed worldwide in over 90 countries and areas with a total capacity of 591 GW (including 23 GW offshore wind energy) (GWEC, 2019). The International Renewable Energy Agency (IRENA, 2018) predicts that the renewable electricity production will rise from 24 % in 2015 to 85 % in 2050 of the global electricity generation (wind energy accounting from 1 % to 36 %), far beyond fossil fuels (Fig.3). Indeed, despite such a positive scenario, the production can still be affected by various factors such as policy, economy, and technology. However, the tendency of occupying more spaces both onshore and offshore for wind turbines (WTs) installation obviously persists. Due to the compact land use status for onshore wind farms, further technological development will focus on offshore wind farms and distribute low-speed onshore wind farms with a growing height of turbines, and develop special forms of wind farms such as kite wind farms and floating wind farms.

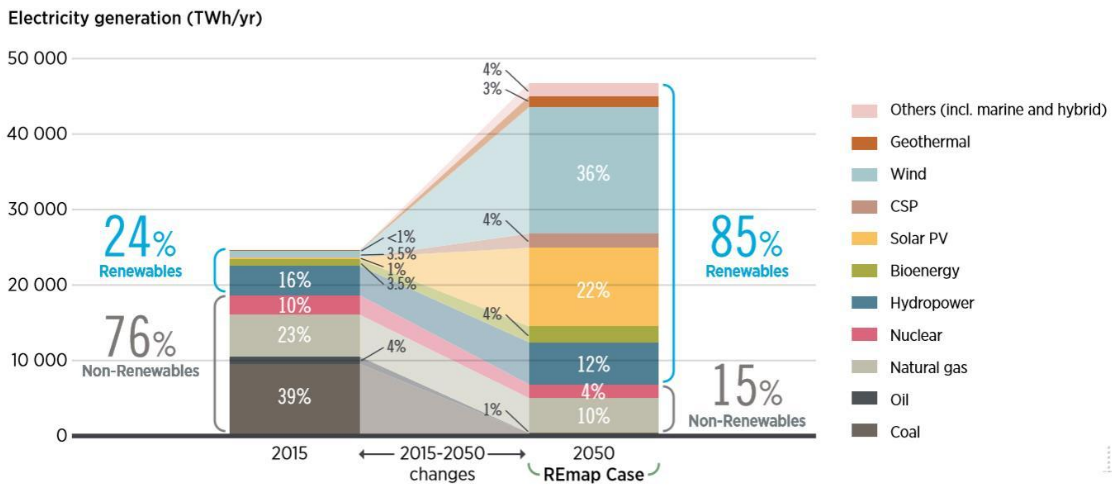


Fig. 3 Share of global electricity generation (IRENA, 2018)

1.1.2 The landscape changed by the energy transition

Although environmental impacts caused by wind energy are much fewer than by conventional energies, the installation of large-scale wind farms has gradually generated the conflicts between environment and wind energy development. Most physical impacts (e.g., noise, shadow flicker, soil erosion) can be mitigated with the advancement of the manufacturing technologies of WTs and the improvement of project management. However, the landscape visual impact, frankly speaking, is getting more and more significant as the number and height of WTs grow (see Fig. 18 in section 2.3.1). Meanwhile, the landscape visual impact receives universal public attention, since it affects extensively people’s daily life in a spatial area ranging from 5 to 7 km (Bishop, 2002). In Germany, 26,000 WTs were erected in 2015 and sacrificed the visual experiences of the natural landscape in exchange for a 16 % increment of wind energy production (Argyropoulos et al., 2016). With the energy transition undergoing, new technologic-identified elements（e.g., WTs）have dominated the original host landscapes and caused irreversible changes in the cultural identity of the landscape, as well as how people define, recognize, and manage the landscape. Meanwhile the advancement of landscape theories, research methods, and administrative management has also changed the connotation of landscape (Kühne & Bruns, 2015).

1.1.2.1 Evolution of landscape theories

The development history of landscape science can be examined by reference to recognition methodology, which consists of three approaches: ***Essentialist***, ***Positivist***, and ***Constructivist*** arguments (Chilla et al., 2016b). ***Essentialism*** (from the Latin essentia, essence) sees the landscape as observer-independent "wholeness", which concerns problems such as what landscape is and what the landscape constitutes. The essence and its properties decide the character of the landscape (Albert, 2005). The ***Positivist*** approach can be understood as a scientific and cartographic method, which defines the landscape as measurable and visible distributions of objects. This approach is still dominant for planning today because of cartographically presented information and analytically oriented with clear research goals (Burckhardt, 2006; Kühne, 2008). The ***Constructivist*** approach has a different understanding of landscape compared with the above two theories as a “result of social negotiation processes”, and it is not based on objective indicators but on what people refer to as a landscape (Kühne & Weber, 2017). It focuses on the approach of how the society generally recognizes, describes, evaluates, and analyzes landscapes, and sheds more light on processes (regionalization) rather than on conclusions (landscape). Over the past few years, more and more international literature adopts the constructivist perspective to understand space-related developments through discourses, institutions, path dependencies, and power struggles (Chilla et al., 2016a; Amin, 2004; Allmendinger et al., 2015). The development of landscape science has also shifted from systematic theoretical research in the 20th century to social science research concentrating on regional and cultural aspects, bridging the gap between traditional landscape disciplines, geography, social sciences, and humanities. In general, the theories of landscape recognition are enriched, and the content, methods, and concerns of landscape impact evaluation are also experiencing tremendous changes.

1.1.2.2 Consummation of legislation

The legislation is also adjusted to cope with landscape changes under energy transition in related laws, regulations, and planning guidelines (see Fig. 14 in section 2.2.1.2). In Germany, the Renewable Energy Sources Act (ErneuerbareEnergien Gesetz), Regional Planning Act (Raumordnungsgesetz), and Federal Building Code (Baugesetzbuch) constitute the legal basis of wind farm planning. The Federal

Pollution Control Act (Bundesimmissionsschutzgesetz), Environmental Impact Assessment Law (Umweltverträglichkeitsprüfungsgesetz), and Federal Nature Conservation Act (Bundesnaturschutzgesetz) have laid a solid foundation for landscape protection under wind energy development. According to the amended Federal Building Code in 1998, the wind farm is categorized as “privileged project” and a permit should be granted before construction (IREA & GWEC, 2013). 98 % of Germany's total surface areas are restricted for wind energy, and the rest 2 % of areas have been tested for their permissibility with spatial and regional planning and been further classified into priority areas and suitable areas. 6.3 % of German areas are nature reserves and 26,1 % belong to landscape conservation areas, as well as areas of particular cultural and historical value, which are recognized as pure exclusion areas. Furthermore, each federal state and municipality has the legislative power to restrict wind farm planning in areas with special landscape value by publishing specific regulations, provisions, and procedures as implementation at the state level (LANUV, n.y.). In China, the legal framework for landscape protection in wind farm planning is limited to the basic law, while the specific regulations are still under preparation (see section 2.2.2).

1.1.2.3 Evolution of methods and instruments

The landscape research methods are continually improved and updated. Cartographic and descriptive data can be collected and processed on a “big data platform” in favor of a comprehensive interdisciplinary analysis of obtaining more accurate, reliable, and objective conclusions. There is a tendency that unified data processing standards and discipline-recognized analytical models make landscape research easy for wide-area of analysis and comparisons. With the visualization of spatial data analysis and simulation software like GIS, the parameters and dynamic models of landscapes can be obtained, and the development trend and protection scope can be predicted.

1.1.2.4 Public participation

The popularity of the Internet and Multimedia has increased the opportunities for public participation in wind farm planning and landscape protection. From the perspective of law, the Federal Information Act ensures the right to know for every citizen (BMJV & BFJ, 2019a). Through planning project websites, municipal information platforms, and even communication software, citizens are able to access relevant information as soon as possible. The procedures and implementation of public participation are also widely discussed in the landscape literature to improve transparency and justice in planning procedures and ensuring the progress of the project (Wolsink, 2007). Public participation has increased the complexity of projects and is a major topic in future landscape planning.

Generally speaking, both of the two developing domains, wind energy industry and landscape theories promote the reorganization and reconstruction of the knowledge framework for Landscape Visual Impact Evaluation in wind farm planning procedures.

1.2 Research questions

The expansion of onshore wind energy needs more space, which causes severe visual impact in the broader space and arouses widespread public attention. Germany and China are chosen to make a comparison under this topic for the following reasons:

Firstly, both China and Germany are the leading countries in the renewable energy industry with their advanced technologies, large markets, high efficiency, and excellent yields (REN21, 2018). Regarding wind energy, the cumulative installed wind capacity reached 591.55 GW worldwide by the end of 2018. China ranks first with the highest wind capacity of 211.39 GW, accounting for 35.73 % of the global production (Dai et al., 2018). Germany ranks third with a total of 59.56 GW wind capacity and has advanced legislation system and planning regimes to guarantee the nature protection under onshore wind energy expansion (Guan, 2020). They respectively represent two typical development patterns in developed countries and developing countries, which provides insight for other countries in the energy transition.

The second reason is that with the strategic decision for the transition of wind energy in countries with different development paths. In China, wind development transfers from North China to Southeast China, which is famous for its complicated topography and dense population. China will meet the same problems as those of Germany. Since the compact land use constrains onshore wind energy expansion, more standardized and scientific planning procedures are required to reach a compromise between various land use and avoid environmental impact.

The key question in this thesis is how to evaluate and mitigate landscape visual impact caused by onshore WTs by optimizing the wind farm planning procedure in a comparative study between Germany and China.

To resolve the key question, several sub-questions are to be answered:

1. What are the concept and value of the landscape? Is there a difference in the German and Chinese concept of landscape? How to perceive and recognize the landscape visual impact and evaluate the visual impact of the landscape?

2. How severely do WTs cause the visual impact? Which components and features of WTs intensify the landscape visual impact? How can the influences of spatial range, duration, and the intensity of landscape visual impact be detected and evaluated? Is there any additional impact on social, cultural, and aesthetic aspects?

3. Do the viewers' position and demographic characteristics influence the visual impact? How can these related indicators be included in a systematic and quantitative evaluation model?

4. How to take advantage of the outcomes of landscape visual impact evaluation in wind farm planning to improve the site selection as well as landscape protection? How to mitigate the visual impact with planning instruments?

1.3 Research objectives

1.3.1 Establishment of a Landscape Visual Impact Evaluation (LVIE) model for wind farms

Due to the rapid expansion of onshore wind energy, landscape visual quality suffers from severe impairments. The first objective of this thesis is to develop a theoretical framework for evaluating the landscape visual impact caused by WTs. An interdisciplinary LVIE model is expected to be established, which consists of general principles, criteria, and measurable indicators that can be obtained from official data sources. The theory and methods of landscape evaluation will be clarified, including the landscape connotation, landscape aesthetics, visual perception, and evaluation theory. The indicators will be selected through literature research to present the subtle and slight changes in landscape visual quality. Through the establishment of the LVIE model, landscape visual qualities can be evaluated and compared among various proposed sites, and their different status before and after the construction of the wind farm can also be compared.

1.3.2 Application of the LVIE model in German and Chinese cases

The LVIE model is applied in GIS to realize the visualization of evaluation results through modeling and 3D simulation. Moreover, the evaluation of the landscape visual impact requires an implementation guideline that allows for the flexible application in different wind farm sites. In order to evaluate the visual impact caused by WTs, a digital landscape model is established. Selected indicators are put into the model to calculate the degree of the visual impact of each spatial unit. This application aims to implement the theoretical model in practice and to provide recommendations for wind farm planning.

1.3.3 Validation of the evaluation in the Chinese case through questionnaire

The effectiveness of the results of LVIE is validated through questionnaires and ANOVA in the Chinese case. The aim of the validation is to verify whether the results of the evaluation fit the real situations or not, and adjust the recommendations for planning. Although the LVIE is quantitatively conducted based on considerable geographical and demographic data, a slight deviation is possible in the results. Integrating theories with public evaluative reaction would constitute an important step towards the holistic approach of landscape visual impact evaluation.

1.3.4 Recommendations for wind farm planning procedures

Based on the results of the LVIE in two cases and the validation of the Chinese case, appropriate recommendations are proposed for optimizing the planning procedures for onshore wind farms. The recommendations offered can help planners mitigate visual impact during the site selection and layout of the wind farms. The recommendations are expected to bridge the gaps between wind energy development and landscape visual quality protection through flexible implementation methods.

1.4 Research methodology

1.4.1 Methodology

Methodological approaches vary with different research targets, research conductors, regions, and scales. The selection of specific approaches is constrained by political and cultural backgrounds (Gulinck et al., 2001). As a term with abundant connotations, the research on the landscape should be limited within specific logical and conceptual frameworks. In this thesis, a set of theoretical foundations and logic of inquiry will be introduced for further research methods selection, together with a critical evaluation of alternative research strategies and methods.

The research on landscape visual impact is related both to ontological and epistemological methodologies. On the one hand, the landscape elements and spaces are based on physical and material objects, which belong to the perspective of ***ontology***.

The perception of the landscape is continuously enriched by incorporating many cultural construction meanings like ethics, morality, political constitutions, customs, gardens, and paintings (Han, 2006). The extended meaning of the landscape increases the difficulty of selecting a method for the landscape visual impact evaluation and performs empirical research. Human value systems and attitudes towards WTs more rely on the use of landscape geography, urban planning, epistemological, cultural, and psychological levels instead of merely ontology.

However, ***ontology*** and ***epistemology*** cannot be stripped. Ontology defines the origin and characteristics of the physical landscape. Epistemology interprets the dynamic process of socially constructed landscape imagery and meaning. These two aspects are unified by dialectic materialism, a belief that there is a material reality, while it is continuously changing and new properties continually evolve (Potter, 1996). This thesis is based on the Dialectical Materialism Methodology (Ridenour & Ruth, 2014) and empirical research, taking the multiple values as theoretical background. Furthermore, it makes full use of landscape, geography, urban planning, ecology, sociology, psychology, environmental behavior, environmental impact assessment, statistics, operations research and other related disciplines to build a comprehensive system for evaluating landscape visual impact and managing landscape visual resources.

1.4.2 Methods

1.4.2.1 Literature research

Literature research can increase clarity, enhance collective understanding of specific topics, and limit research scope. Without such a limitation, the research will be characterized by ambiguity, inconsistency, or a lack of comprehensiveness. Through literature research, a comprehensive and complete knowledge framework can be shown as the theoretical foundation for further research and avoid repeated work. For the comparative approach in the present study, it is particularly important to clearly explicate the meanings of the term “landscape” and “onshore wind farm planning procedures" in two countries, as well as the aesthetics theories, landscape visual perception theories, and landscape evaluation methods.

1.4.2.2 Expert interview and questionnaire

Besides literature research, expert interviews were conducted to collect first-hand information of the wind farms, as well as the direct impression of visual impact and common problems in wind farm planning, which laid the foundation of the establishment of the LVIE model. Based on the theories and implementation skills of the interview, the interviewees and interview content were designed (Meuser & Nagel, 1991; Bogner et al., 2002; Flick, 2016). A total of 6 interviewees were invited to attend this interview. The interview consisted of 4 parts: 1) a brief introduction containing the research background and research target; 2) personal information; 3) educational background; 4) work experiences; 5) open-ended questions about the detailed wind farm planning procedures and practical problems met in projects. Based on the first-round interview, further questions were designed for each interviewee to get specific knowledge. The information offered by those experts (the local attitudes, planning regulations, procedures and compensation measures for wind farms, etc.) guides the research from the practical perspective.

Questionnaire (Yuan et al., 2015; Jobert et al., 2007; Jones & Eiser, 2010; Friedl & Reichl, 2016; Caporale & Lucia, 2015) is the most commonly used method for obtaining public evaluative reaction to the local energy facilities. The questionnaire was designed to validate the LVIE model. It aims to check whether the results of LVIE meet the results of questionnaires, that is, the distribution of visually impacted areas remain similar from both two results. The potential factors affecting local acceptance of wind farms were assembled based on literature research. Distance, socio-demographic features (gender, age, educational level, and length of residence) and environmental impact factors (noise, landscape visual impact, ecological impact, soil erosion, water pollution as well as quality of life and health) were investigated through questionnaires. The questionnaire was conducted in March in 2019 near Zhongying Wind Farm, Zhejiang, China. It consisted of four parts: the first part collected socio-demographic data of the interviewees. The second part concerned the individual perception of environmental impacts. In the third part, the attitude towards the local wind farm was investigated with an 11-point Likert-type scale (i.e., 0: strong opposition, 10: strong support). The interviewees were asked to provide a score regarding their acceptance of wind energy. An open-ended question to obtain additional, intuitive feedbacks about influencing factors was added at the end of the questionnaire.

The expert interview and questionnaire are attached in the appendix. The interview reports and collected 169 questionnaires are presented in digital version of this thesis.

1.4.2.3 Analysis of variance (ANOVA)

The collected data from questionnaires were processed through the ANOVA. Firstly, the data collected by questionnaires were processed by dividing them into groups under various factors:

distance factor and socio-demographic factors (e.g., age, gender, educational level and length of residence). One-way ANOVA between each factor (independent variables) and local acceptance (dependent variable) was executed to distinguish the differences between the mean values of two or more groups and the mean values within groups (Caporale & Lucia, 2015). The result of ANOVA can reveal the correlation between influential factors and local acceptance and validate the adequacy of the result of LVIE.

1.4.2.4 Spatial analysis and visibility simulation with GIS

The implementation technology aspect of this thesis utilizes spatial-data analysis such as GIS, CAD, and 3D-simulation. With the various computer-aided analysis methods and data sources such as Digital Elevation Model (DEM) and Digital Surface Model (DSM), the simulation of the landscape scene can be built as vividly as possible. The visibility of WTs and the influenced proportion of settlements and passersby can be quantitatively calculated and visually demonstrated through the spatial analysis in GIS.

1.5 Thesis structure

This thesis is formed by three parts (Fig.4): pre-study, evaluation framework, and planning implementation.

The first part is pre-study, including Chapter 1, Chapter 2, and Chapter 3. Chapter 1 gives a brief introduction of global wind energy development and the evolution of the landscape theories. The key question of the thesis is then put forward based on a discussion of research objectives and methods. Chapter 2 compares wind energy development and onshore wind farm planning between Germany and China. Chapter 3 researches the connotation of the term landscape and addresses the difference in the meaning between Germany and China. In addition, the target of LVIE in onshore wind farm planning is formed based on the knowledge framework made up of landscape perception, landscape aesthetics, and landscape functions.

The second part contains the establishment of LVIE model, its application and validation, which consists of Chapter 4 and Chapter 5. Chapter 4 sets up the theoretical framework of LVIE (Fig.28) based on the discussion of the principles of evaluation, basic steps, indicators selection, and evaluation process introduction. Chapter 5 selects two case studies respectively in Germany and China and implements the LVIE by the landscape digital model in GIS. The results of LVIE are verified through questionnaires and ANOVA in the Chinese case.

Chapter 6 and Chapter 7 constitute the third part on recommendations for onshore wind farm planning. Chapter 6 focuses on discussions on the advantages and constraints of the implementation of LVIE in GIS, as well as the difference between LVIE model and current evaluation methods, the practicable suggestions for planners. Chapter 7 summarizes the contents of this thesis, its contribution to knowledge and implication.

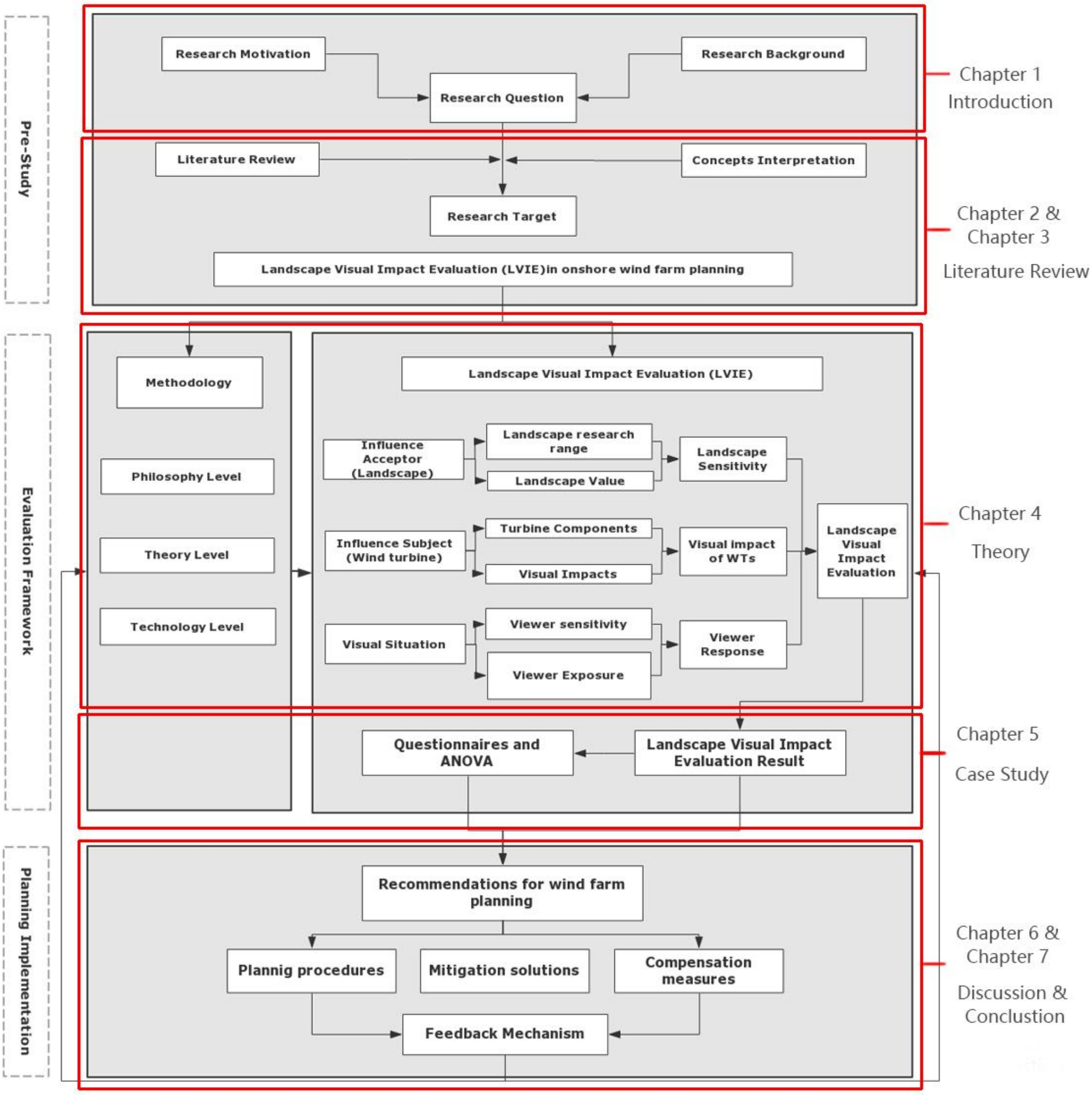


Fig. 4 Thesis structure

2 Comparison of wind energy development and planning in Germany and China

2.1 Wind energy introduction

2.1.1 Wind energy industry origination

Wind energy, frequently also called wind power, is a kind of renewable, clean energy, which takes advantage of the airflow through WTs to generate electrical power. The utilization of wind power can be traced back to 3000 years ago in the Middle East ((Golding, 1976) in Heier, 2016) and Ancient Egypt (Heier, 2016). Currently, the reliable sources that have been unearthed are the vertical windmills in Afghanistan and Persia built from seventh century to tenth century (Fig.5). Till the Middle Ages, Mediterranean developed sail-windmills to pump water and grind grain, and these windmills are still visible today in traditional areas such as Crete in Greece (Fig.6). In Europe, the coastal plains of the North Sea first took advantage of wind energy in 1180 by constructing wooden windmills, the so-called “Bockwindmühlen” (Tacke, 2004).

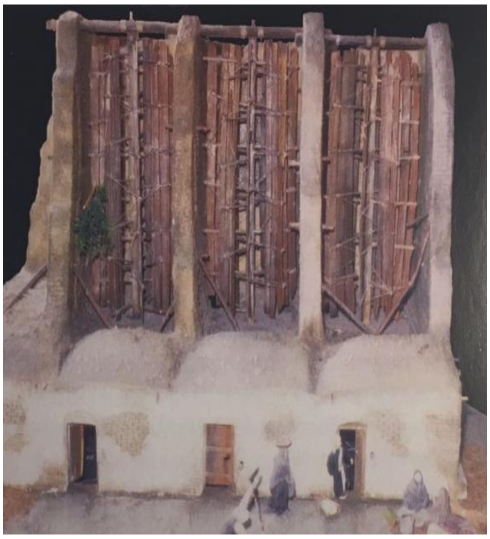


Fig. 5 Persian Windmill (Heier, S., 2017)

Fig. 6 Sail Windmill (Heier, S., 2017)

The wind electricity production has more than 130 years of history. James Blyth (1839-1906) first began to use windmills to generate electricity in Scotland in 1887 (Fig.7) (Price, 2005). Afterwards, Kurt Bilau and Betz invented a modern vertical-axis windmill design with aircraft airfoil in 1920 (Hau, 2016). The general utilization of wind energy was after the invention of horizontal axis WT, which was aimed at supplying the electricity in remote areas which the power lines cannot reach. With the development of aerodynamics theory and aircraft technology, the modern three-blade WT has been improved to increase power production efficiency.

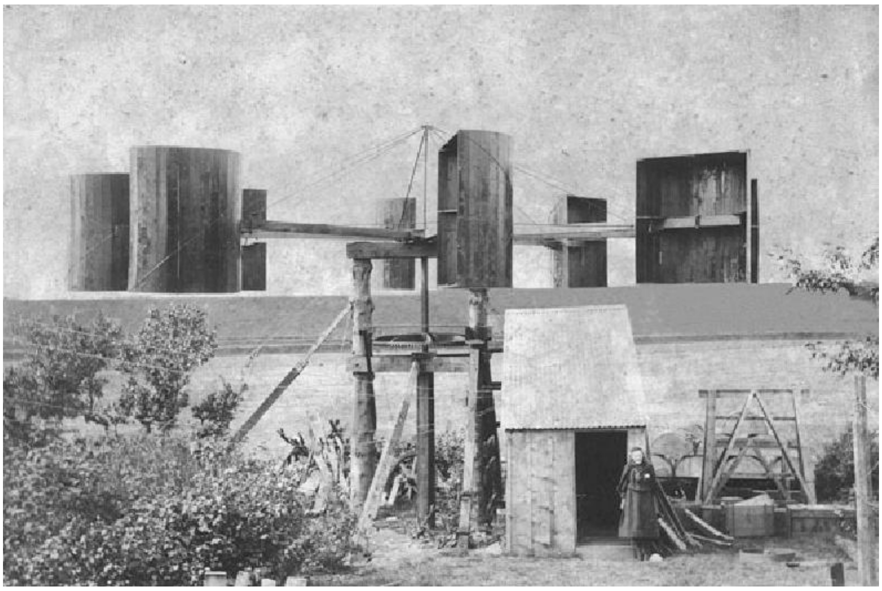


Fig. 7 James Blyth's "windmill" at his cottage in Marykirk in 1887 (Price, 2005)

The development of wind technology has always fluctuated with oil prices. Wind energy welcomed its first technology innovation during the 1970s when there was an oil crisis (Leung & Yang, 2012) while it declined afterward (Ackermann & Söder, 2002). When it comes to the 21th century, with the public's awareness of environmental protection and decarbonization, wind energy has ushered in an explosive growth with the capacity doubled approximately every three and a half years for meeting the demand of global economic growth and securing energy security (Ackermann & Söder, 2002; Xu et al., 2010; GWEC, 2019).

2.1.2 Current design and growing height of WT

According to the direction of the axis, the WTs can be divided into horizontal axis and vertical axis WTs. In addition, there are some special-shaped WTs requiring further research. The “kite” wind generator is researched in its experimental stage by several technological companies like KPS and KiteGen. The bladeless wind generators are also under development with the vortex oscillation principle (Vortex Bladeless, 2019). Two- and even one-blade types are also being tested. These profiled turbines remain in the research stage without enough technical production ability. However, they enrich the types of WTs and people’s imaginations of green energy.

Currently, the majority of WTs are the horizontal axis 3-bladed turbines on a steel tower with a mature industrial process and stable yield. However, at the same capacity level, the horizontal axis WT has more substantial visual interference than other types due to its larger blade swept area. Landscape visual impacts caused by 3-Blatt WTs are also a critical issue in this thesis.

From the first groups of WTs for electricity generation, the size of turbines has grown several times. Figure 8 shows the tendency of the growing size of the WT in several decades. The most advanced onshore WTs have already reached a total height of over 300 meters.

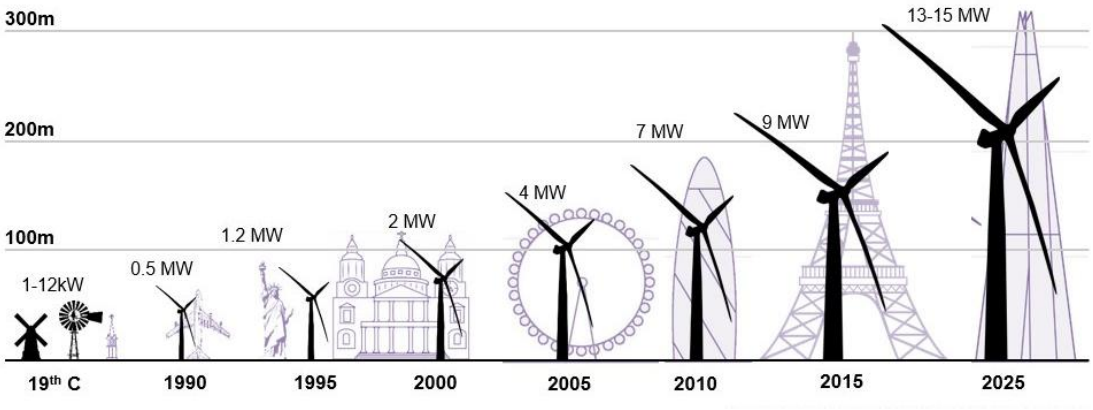


Fig. 8 Evolution of wind turbine heights and output (Liebreich, 2017)

2.1.3 WT components

A conventional wind farm consists of WTs, transformers (substations), and transmission systems. Among them, the components and properties of WTs exert decisive visual impacts on the environment and landscape. The main visible components of a WT include the rotor blade system, nacelle, tower, and foundation, as shown in Figure 9. The transformer can be installed inside or outside the tower according to different turbine types. In addition to WTs themselves, some infrastructure facilities in typical large wind farms are required as follows:

1. Road access to the site, especially for large heavy-duty cranes.
2. A temporary site for storing the main components of WTs.
3. A hardstand near each WT for cranes during turbine erection.
4. One or more anemometer mast(s) to monitor wind direction and speed (Cornwall Council, 2013).
5. A building for daily operation and monitoring.

Fig. 9 The main visible components of a wind turbine (Foto: taken from Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale by the author)

2.1.4 Wind energy resource

The efficiency of wind energy production significantly depends on the abundance and regional distribution of wind energy resources. Wind energy utilization needs to meet the following characteristics:

1) Continuously steady wind with speed over 5 meters per second can effectively generate electricity. Wind energy resources with dramatic fluctuation in wind speed increase the load on the grid.

2) Stable prevailing wind direction can guarantee the safety and efficiency of wind energy production.

3) The wind energy resource should be close to the electricity consumption regions to reduce losses during voltage conversion and electricity transmission.

4) Because of the current form of WTs, the erection of WTs must meet the demand of constructional safety and avoid conflicts with nature protection and landscape conservation areas.

Thus, the utilization of wind energy, especially initial wind resource exploitation and site selection, has a close relationship to geography and climatology. Wind energy is generated from the airflow, which mostly depends on the characteristics of atmospheric circulation globally and regionally. Due to solar radiation, the atmosphere produces differences in temperature, which causes the flowing air, namely, wind. On a global scale, the earth rotation, centrifugal force, and the distribution of ocean and continent as well as mountains all have impacts on the global wind field and generate atmospheric circulation (Fig. 10). In small-scale areas, factors such as the roughness of the surface (usually depending on the type of land use), landmarks, elevation, and micro-topography affect the magnitude and stability of the wind resource.

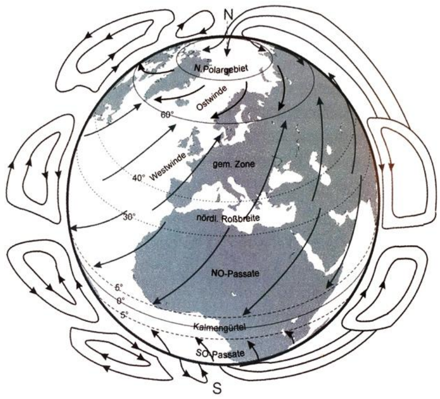


Fig. 10 Global atmospheric circulation (Heier, 2016)

The wind farm, which is also called wind park, should be planned and constructed reasonably according to the atmospheric circulation and local wind direction. Detailed wind resource surveys and wind speed measurements should be conducted at the destination site. With the growing height of the WT and hub, the requirements for wind resource measurement have also become higher. Currently, technologies such as calibration system IEC61400-12, Schalenstern-anemometer, ultrasonic anemometer, remote measurement and LIDAR (Light Detection And Ranging) are usually used to measure wind speed, direction, and distribution by generating a complex computational fluid dynamics-model (Heier, 2016).

With the above exploring technologies, the global and national wind energy distribution can be illustrated based on cartography (Fig. 11 and Fig.12). According to the 3rd National Wind Energy Resources Census, the total exploitable capacity of China for both onshore and offshore wind energy reaches around 1000 GW (CMA, 2009), and the German potential available wind energy resources reach 1188 GW (Lütkehus et al., 2013). With the continuously accumulated and updated wind atlas and wind resource simulation data, spatial strategic planning for wind energy and other land use can be implemented on a rational basis. The spatial distribution of wind resources in Germany and China is similar: the wind resource is abundant in the north and insufficient in the south. The spatial planning of wind energy and combination with other energy sources should be considered before the local planning. To summarize, the wind resource is firmly bound to space attributes that decide the average wind speed, wind direction, and the frequency of wind change. On the other hand, the attributes of space also bring constraints to the site selection of a wind farm.

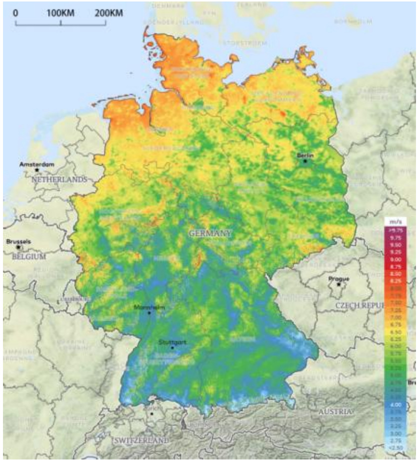


Fig. 11 German Wind Atlas
(Globalwindatlas.info)

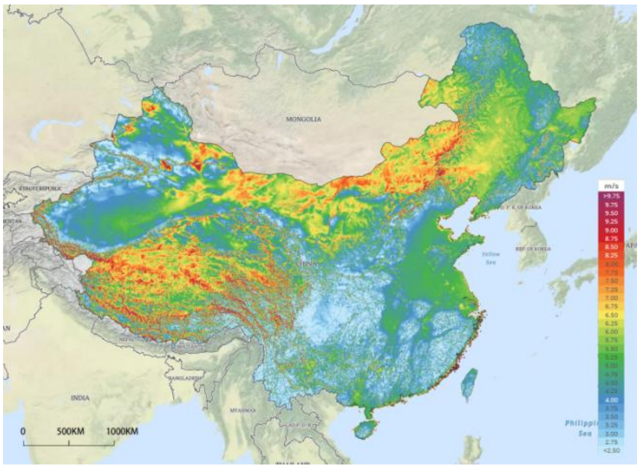


Fig. 12 Chinese Wind Atlas
(Globalwindatlas.info)

2.1.5 Development of wind energy industry

The broad utilization of wind energy electricity began during the oil crisis in the 1970s' because it could be used to supplement scarce energy supplies and to stabilize the energy structure. When it comes to the 21st century, with the growing awareness of environmental protection and de-carbonization, wind energy and other renewable energies like hydro, wind, solar power, and bio-energy occupy an increasing share in the world energy consumption, reducing the reliance on fossil fuels and enhancing energy security (Ackermann & Söder, 2002; Xu et al., 2010; Araújo, 2014; IRENA, 2018). As clean energy, wind energy enjoys a worldwide distribution due to abundant wind resources. Wind energy makes a significant contribution to environmental improvement, especially in de-carbonization. In 2018, the electricity generated from WTs avoided an estimated 200 million tons of carbon pollution. This reduction is equal to roughly 43 million cars' worth of CO_2 emissions (AWEA, 2019).

Furthermore, the advantages of comparatively low-cost and long-term utilization make wind energy a primary energy source in the future (Leung & Yang, 2012; Eichhorn et al., 2019). Figure 13 shows the dramatic growth of cumulative installed wind energy capacity from 2001 to 2018. As a large-scale produced source of electricity, wind power has already been applied in more than 90 countries. Over 29 countries have installed more than 1 GW. Till the end of 2018, wind energy has owned a mature global market with a total installed capacity of 591 GW，568 GW onshore and 23 GW offshore (GWEC, 2019).

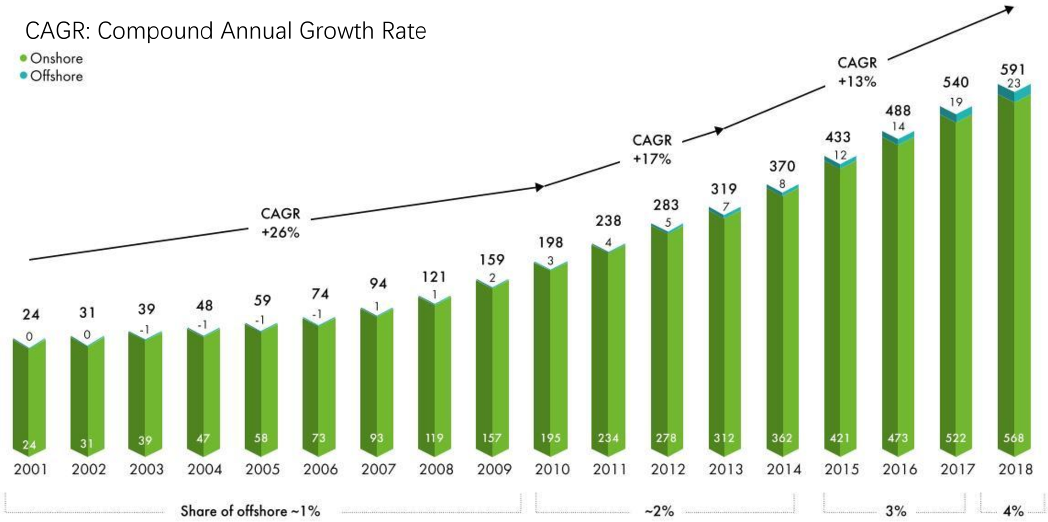


Fig. 14 Global cumulative installed wind energy capacity and compound annual growth rate, 2001-2018 (GWEC, 2019)

Among the top five wind energy countries shown in Figure 14, there are developed countries like USA, Germany, and Spain, which have a stable industrial foundation and strong national financial support, as well as countries like China and India, which have heavy burdens of population and enormous demands of economic development. In the near future, offshore wind farms and energy markets in developing countries will become the main developing points in the wind energy industry (IRENA & GWEC, 2013; European Commission, 2018; IRENA, 2018).

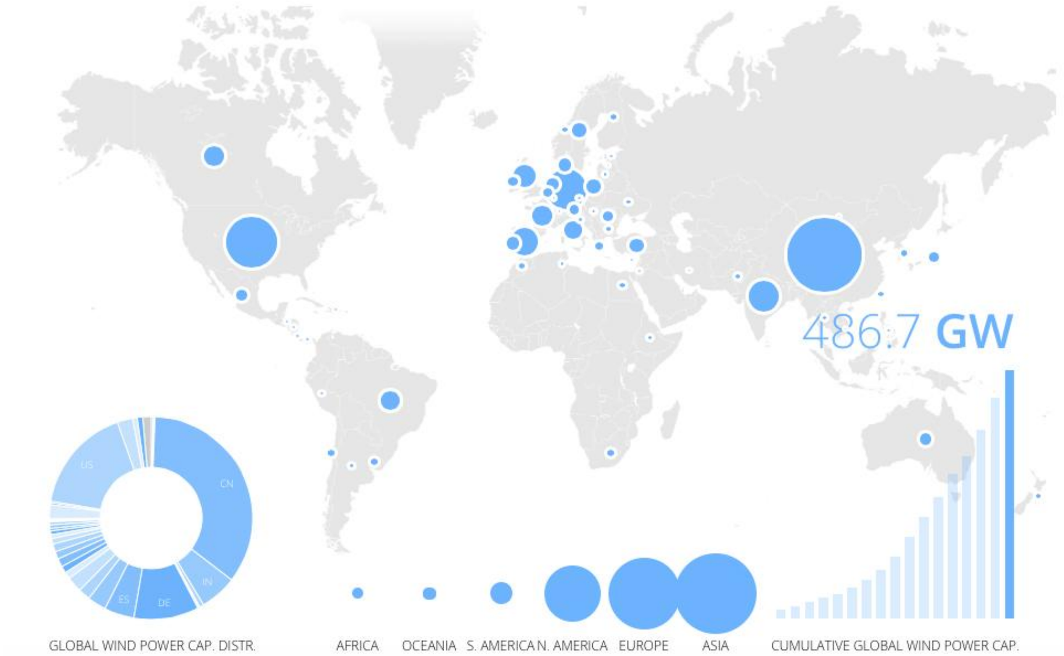


Fig. 13 Global wind energy development and distribution in 2016 (gwec.net)

2.1.6 Wind energy industry comparison between Germany and China

Although Chinese potential wind resources and cumulative installed wind capacity exceed Germany, China lags behind Germany in technological aspects like mechanical technologies, spatial planning, offshore wind energy and grid compatibility. Germany is a leader in the field of wind energy with a solid industrial and technological base. As shown in Table 1, the installed wind capacity of Germany reached 59.56 GW in 2018, in which offshore wind energy accounted for 6.38 GW with a high proportion (GWEC, 2019). Additionally, the share of wind energy consumption of 2017 remained at a high level of 16 %, outperforming nuclear energy (12 %), natural gas (13 %), and hard coal (14 %); it will reach 19 % in 2020, according to the energy transition target of Germany. Wind energy is and will remain the mainstay of the energy transition in Germany. For the long-term energy plan for 2050, in spite of many uncontrolled factors that may influence the target, a conservative prediction of the wind energy capacity is 206 GW given by Fraunhofer Institute (Fraunhofer Institute, 2017) and a radical prediction is 240 GW by GWEC (gwec.net).

Table 1 The comparison of the wind industry in Germany and China.

Comparison Items	**Germany**	**China**	**World**
Installed onshore wind energy capacity till 2018	59.56 GW	211.39 GW	591.55 GW
Newly installed wind energy capacity in 2018	3.39 GW	23 GW	51.32 GW
Growth rate of wind capacity in 2018	5.69 %	10.88 %	8.68 %
Proportion of wind energy generation in domestic energy consumption (2018)	21 %	5.2 %	4 %
Wind energy capacity planned in 2050	82.8 GW	1 TW	4.6-16.9 TW
Proportion of planned renewable energy production in domestic electricity consumption (2050)	80 %	67 %	40 %

Sources：(GWEC, 2019; Pregger et al., 2013; Wind Europe, 2019; CNEA, 2019a; WWA, 2015)

However, currently the wind energy industry in Germany is in crisis due to the burgeoning bureaucracy, ill-fated funding policies and the complaints of citizens. Firstly, the expansion of onshore wind energy is confronted with the problems of few available areas because of the constraints by strict regulations (e.g., Regional Planning Act, Federal Building Code, and the Federal Nature Conservation Act). Theoretically, 13.8 % (49,361 km²) of the German land area can develop wind energy (Lütkehus et al., 2013), while the reality is that only about 1-2 % of land area in each state is available and assigned as concentration zone (Nkomo, 2018). The planning and construction of wind farms have many external constraints, such as environmental protection, land use coordination, construction conditions and financial budgets. Furthermore, the opposition from inhabitants accumulates the intense emotion, forcing authorities to set more strict clearance distance for WTs. Decrees such as the “10 H” regulation in Bavaria (Bayerische Staatsregierung, 2014) and 1500 m clearance rule in North Rhine-Westphalia cause the standstill of the further development of onshore wind energy. The German Wind Energy Association once calculated that with the "10 H" rule and other legal restrictions just 0.05 % of the Bavarian territory can be installed turbines (Bruhns et al., 2019).

The newly amended Renewable Energy Sources Act in 2014 signals a deceleration by controlling the renewable energy expansion from the perspective of the planning agent. Each renewable energy technology has been set a fixed upper limit of annual addition. For onshore wind, the annual construction allowed is only 2.5 GW (Bundesministerium für Wirtschaft und Energie, 2017). Moreover, the amended law in 2017 presents a shift from the Feed-in Tariff model to the tendering procedure, revealing the fact that the renewable energies have been developed mature enough to face the competition on the open market without subsidies any more. The revisions in recent years have controlled the expansion pace of renewable energies and standardized the open market but posed a challenge for reaching the long-term target of climate protection.

Nevertheless, conditions for erecting new turbines have become stringent. One of the factors inhibiting the development of wind energy seems to be the uncertain impact of higher facilities on environments (e.g., noise emission, shadow flicker, threats to wild animals, and annoyance to human beings) and landscapes. The available priority areas are further limited in terms of repowering (Hötker, 2006). Simone Peter, the head of Germany's Renewable Energy Federation, states that about 20 GW of wind capacity in Germany would be retired by 2023 as the turbines would exceed their guaranteed 20-year operational life (Journalism for the energy transition, 2018). The enormous demand for repowering has posed a higher requirement for increasing the share of renewable energy.

The development of the land-based wind energy and repowering projects would probably come to a halt, mainly due to the transformation from Feed-in Tariff to tendering model. Additionally, stricter land use planning, uncertainty of future land-reservations, and a lack of national planning procedures also limit its development. The plan to increase the share of renewable energy in electricity consumption to 65 percent by 2030 is unlikely to be achieved. The focus of the future development lies in offshore wind farms and onshore low-speed wind farms, and the exploitation of more available space.

The advantages of the Chinese wind industry are the large number of potential wind resources and energy consumption, as well as the broad market prospects and a large amount of labor, while in the technology field, China is still in the need of improvement. Since the promulgation of the Renewable Energy Law in 2006, China has accelerated the development speed of renewable energy. China has surpassed the U.S. and maintained the first place of global wind energy since 2010. As shown in Table 1, the total installed capacity of wind energy has reached 211.39 GW in 2018, accounting for over 36 % of the total world capacity (GWEC, 2019). In spite of the giant installed wind capacity, the share of wind energy in domestic electricity consumption remained a low proportion of

4 % in 2018. On the one hand, it is because of the enormous domestic electricity consumption; on the other hand, influenced by a severe "wind curtailment" problem with an average rate of 17.1 % in 2016 (Ye et al., 2019; Li et al., 2018). The wind curtailment means that wind electricity produced out cannot be totally consumed and cause waste. The central and local governments did not pay enough attention to the fact that the power grid was poor and lagged behind renewable energy development (Luo et al., 2016). However, shutting down wind turbines also causes mechanical loss and potential threats to the safety of wind turbines. The waste of resources caused by wind curtailment has severely hindered the future development of the wind energy industry in China.

The "13th Five-Year-Plan" released by the Chinese National Energy Administration (CNEA) in 2016 aims to optimize the spatial layout of wind farms, resolving wind curtailment problems in the north of China and encouraging the construction of the distributed and low-speed wind farms in the south of China. Then the energy generation is close to the consumers, which avoids the energy losses during the long-distance transformation (CNEA, 2016). The total wind capacity will reach 210 GW by 2020, with electricity production of 420 TWh occupying 6 % of total power production, which reflects the commitment made by the Chinese government in the Paris Agreement in 2015 and a foreseeable continuous expansion of the wind industry in China. At the same time, the Chinese wind industry will confront with more challenges in supporting facilities such as high-voltage power transmission, power grid connection, storage technology, distributed power grid as well as land use planning and wind curtailment. The expansion of Chinese wind energy enterprises, such as Goldwind and Envision, and the innovation of wind technologies, make wind energy industry one of the core energy industries.

Because of the smaller population and territorial area compared to China, the total amount of wind energy generation in Germany is not as much as that in China. However, the industrialized manufacture of WTs, offshore WT technologies, and the tariff-in system in Germany are more developed with better system compatibility, more operating hours, and higher gird-connection proportion than those in China. Compared with Germany, China has disadvantages with respect to wind energy planning, management, power grid connection, and power market trading. Besides, the wind power consumption level is far behind the manufacturing and installation level. The severe issue of wind curtailment is partly caused by a lack of careful consideration and spatial planning in the early stages. Some potential environmental impacts are easy to be neglected. For example, the insufficient stamina reflects in the reduction of annual installation in 2016 was resulted from the pre-stage disordered planning. Of course, the vast territory and a tremendous amount of energy consumption also increase the difficulty of improving wind energy proportion in China.

2.2 Onshore wind farm planning

To guarantee the energy transition and meet the demand for wind energy extension, a well-organized planning framework for wind farm is of great necessity both in Germany and in China. With the exploding development of the wind industry in the past decade, the wind energy planning framework should be reviewed and refined for issues and challenges in the new era. Due to different national strategies, laws, administrative systems, and spatial planning frameworks, there are many differences in the onshore wind farm planning procedures between Germany and China. This section compares the legislation, administration, policies, planning and permitting procedures between two countries for learning from each other.

2.2.1 The planning system of Germany

Onshore wind energy offers the most economical expansion potential in the field of renewable energies in the short and medium-term, which makes a significant contribution to the energy transition. In order to find more potential spaces for onshore wind energy expansion, the current administrative and legislative frameworks are constantly adjusting to adapt to the new situation. Based on the principles of ensuring the equality of living environment and resource utilization, a solid foundation of the wind energy industry consists of a complete administrative system, strict legal framework and effective policies is of great necessity both in Germany and China.

2.2.1.1 Administrative framework

The federal government is the highest executive organ of the Federal Republic of Germany, which is responsible for guiding political directions at the federal level, providing leadership, and publishing major plans like the Energy Concept 2050 for the energy transition (Turowski, 2002). Led by the federal government, the spatial planning system, which consists of a vertical structure of federal, state, regional, municipal, and local levels, plays a major role in coordinating wind energy spatial allocation (Fig. 15). At the federal level, the Ministry of Economic Affairs and Energy, Federal Office for Building and Regional Planning, and the Ministry of Economics and Technology take charge of the strategic development plan of renewable energy and sectoral planning. Other departments like the Ministry for the Environment, Nature Conservation, and Nuclear Safety are concerned with nature conservation in wind farm projects. The target put forward by the federal government will be distributed to local spatial planning authorities as strategic development goals. Although the federal government has the highest administrative and legislative power according to the principles of the Basic Law (Pahl-Weber & Henckel, 2008), local decrees differ significantly from state to state because they have their legislative rights, administrative governments, and detailed planning procedures. Decrees, regulations, and guidelines issued by each state are most potent and practicable for planning and permitting procedures of wind facilities, even though they appear to be not formal or scientific enough.

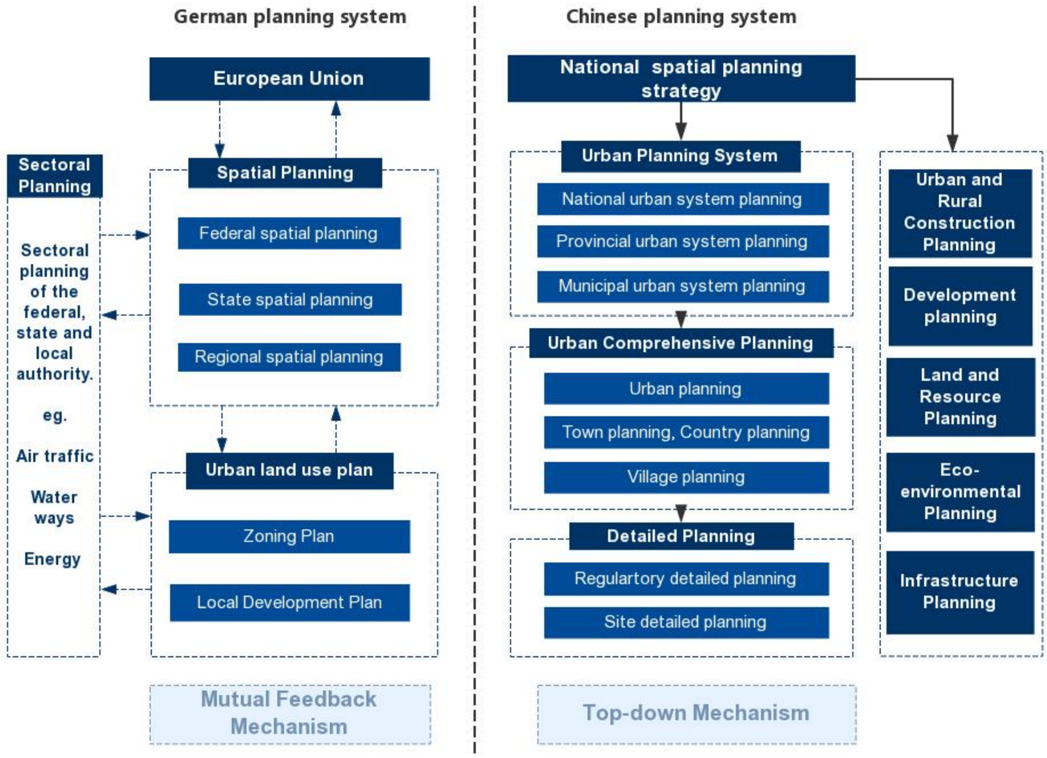


Fig. 15 The planning systems comparison between Germany and China (Guan, 2018)

2.2.1.2 Legislation

Under the German constitutional framework, the Electricity Feed-in Act, the Renewable Energy Sources Act, as well as the Energy Industry Law, coordinate the energy system and ensure that wind electricity has standard grid-in prices and priority for feeding into the grid. The Regional Planning Act and the Federal Building Code balance space and resource utilization by spatial planning instruments. The Federal Nature Conservation Act, The Federal Pollution Control Act, as well as the Environmental Impact Assessment Law, form the legal basis for nature conservation and landscape protection (Fig.16).

	Germany	China
Energy	●Electricity Feed-in Act,-1991 (Replaced by EEG in 2000) ●Renewable Energy Sources Act,-2000 (amended in 2004, 2009, 2012, 2014 and 2017) ●Energy Industry Law, -1998 (amended in 2003, 2005, 2008 and 2011)	● Electricity Law,-1996 (amended in 2009, 2015 and 2018) ●Energy Conservation Law,-1998 (amended in 2008, 2016 and 2018) ●Renewable Energy Law, -2006 (amended in 2010)
Planning	●Regional Planning Act,-2008 (amended in 2009) ●Federal Building Code,- 1987 (amended in 2007, 2011, 2013 and 2017)	●Land Management Law, -1987(amended in 1999, 2004 and 2019) ●Urban and Rural Planning Law, -2008 (amended in 2015 and 2019)
Environment	●Federal Nature Conservation Act,-1977 (amended in 2002 and 2010) ●Federal Pollution Control Act,-1974 (amended in 2002, 2013 and 2017) ●Environmental Impact Assessment Law,-1990 (amended in 2010 and 2012)	●Environmental Protection Law, -1989 (amended in 2015) ●Environmental Impact Assessment Law, -2003 (amended in 2016 and 2018)

Fig. 16 Legislation framework of wind energy planning in Germany and China (Guan, 2020)

2.2.1.3 Policies

Forced by the national strategy of energy transition, which is also called "Energiewende", the federal government and local authorities have published a series of wind energy supporting policies from political, financial, institutional, technological, and social-cultural aspects to guarantee wind energy promotion, as well as environmental-friendly policies to protect nature area under wind energy development.

2.2.1.3.1 Energy Concept 2050

In 2010, the federal government published the "Energy Concept 2050 " for setting long-term targets of the national energy transition (IRENA & GWEC, 2013). This national development policy aims to develop an environmentally friendly and sustainable energy transition roadmap in Germany with some strategies, such as an increment in renewable energies, a reduction in greenhouse gas emissions, and cessation of nuclear power (ForschungsVerbund Erneuerbare Energien, 2010). According to this strategic policy, the share of renewable energy in the domestic electricity supply will reach at least 35 % by 2020, 50 % by 2030, 65 % by 2040, and finally 80 % by 2050 (GWEC, 2016). Wind energy is the most cost-competitive, technologically mature component in this transition.

2.2.1.3.2 Economic incentive policies

Economic incentive policies guarantee the liberalization of the wind energy market, wind energy generation, grid connection, and investment model optimization under the complete legislation framework. The Feed-in Tariff policy ensures the grid access of wind energy with a stable price and obliged utilities purchasing renewably generated energy. More important is, the Electricity Feed Law has opened up the grid infrastructure to private wind energy generators, which encouraged the citizens, cooperatives and communities to join in wind energy investment (Lupp et al., 2014). The remuneration rate is a price adjusting tool for balancing electricity prices between various renewable sources, different scale, capacity and electricity yields by different remuneration rates. Other policy tools like the direct investment in research and development, direct subsidies from domestic, state-owned development banks, government-guaranteed loans also provide stable financial support for wind energy expansion (Nkomo, 2018). The diversification of economic incentive provisions has strengthened commercial feasibility, reduced project risks, increased investors' interests and encouraged diversified investment models, which ensure sufficient financial investment sources and possibilities for wind energy development.

2.2.1.3.3 Repowering

With the EU Directive (Directive 2009/28/EG) and the "Energy Concept 2050" on the promotion of renewable energy share in the energy supply system, the wind energy capacity has also to be enlarged through repowering policies, which means replacing old and smaller WTs with modern and more powerful ones to increase electricity production (REN21, 2017). It is estimated that through repowering, the wind capacity can double and the annual yield triple with significantly fewer turbines deployed. Till 2015, around 6 GW wind facilities in Germany are over 15 years and waiting for repowering (IRENA & GWEC, 2013). The newest onshore WT can reach a height of over 200 meters with a capacity of 5 to 6 MW and bring new challenges for wind energy planning.

New planning procedures are necessary for achieving more efficient wind farm planning in aspects of obtaining approval, height restriction, advanced detection and simulation of wind farm operation as well as predicting the wind yield (Grotz et al., 2012). The permission for repowering projects should be reassessed after 20 years' operation without any exemption. The fast-growing height of new version WTs should be taken into consideration and release the height constraint appropriately. States like Lower Saxony and Schleswig-Holstein with abundant wind resources have amended the decrees of repowering and issued supporting policies for encouraging the election of bigger WTs on the original site with partly simplified approval by local authorities (Bundesverband Windenergie & VDMA Power Systems, 2016).

2.2.1.3.4 Rare species protection policies

In the process of planning, construction and operation of wind farms, a species protection examination, which covers all the "legally related" species and their habitats, is mandatory in the form of the expert report. At the European Union level, "Natura 2000" (§ 31 BNatSchG), which is set up as an ecological network for protecting the core breeding and resting sites for rare and threatened species, plays a crucial role in safeguarding the ecological environment affected by wind farms. Based on "Natura 2000", the Fauna-Flora-Habitat Directive（92/43/EEC）, Bird Directive (2009/147/EC), guidance documents and species protection provisions issued by the European Commission safeguard the wild fauna and flora without threatening of wind projects (Nkomo, 2018).

In Germany, for protecting rare species that are sensitive to WTs, the Federal Nature Conservation Act sets requirements in connection with the prohibition of killing (§ 44 para. 1), interference ban (§ 44 para. 2) and the access ban (§ 44 para. 3), which constitute the critical contents in the approval by local wind farm projects (Dorda, 2018). Further detection of highly wind-sensible wild animals is listed in the Ordinance of Protection of Wild Animal and Plant Species (BMJV & BFJ, 2005). For example, the red kite is more affected by WTs than other birds, which do not need such a large action space (Schaub, 2012). In the Saarland, a guideline on wind-sensible birds and bats protection is published by the State Office for the Environment and Occupational Safety, which is highly concerned with wind project approval (Richarz et al., 2013).

2.2.1.3.5 Opening-up policy

Since the limited priority areas will be used up in some states, new decrees have come into force for exploring newly available spaces for wind farms (MUGV, 2011). The areas under the protection of the Fauna-Flora-Habitat Directive（92/43/EEC）and Landscape Protection Areas can be opened to the wind farms as long as the subject of protection is not negatively affected. However, the permission should be strictly assessed case-by-case as the prerequisite. Additionally, more natural spaces like forest, woodland, and grassland have also been opened to the wind farms with a precondition of avoiding impact on the local ecosystem and landscape (Wagner, 2012a).

These new policies have widened the potentially available priority areas and ensured that protection targets would not be compromised at the same time. However, the opening-up policy is still in a pilot stage and receives fierce criticism from residents. The influence of government attitude may reverse the openness. For instance, the newest Coalition Agreement (2017-2022) of North Rhine-Westphalia has canceled the designated priority areas and forest land for wind farms and increased the buffer distance up to 1500 m to general residential areas (Fachagentur Windenergie an Land e.V, 2017).

2.2.2 The planning system of China

In China, the development of wind energy started later than Germany but with a higher growth rate and cumulative installed capacity now. Represented by the Renewable Energy Law (2006), the complete administration mechanism, systematic legal framework and supporting policies established by the central, provincial, and local governments guarantee the smooth promotion of the wind energy industry (Liu, 2019).

2.2.2.1 Administrative framework

Renewable energy has a complex administration system in China, which is cross managed by both the Chinese National Energy Administration (CNEA) and the Chinese National Development and Reform Commission (CNDRC). These two national-level departments promulgate the development targets and spatial designation of renewable energy in China. Besides, the Finance Ministry is responsible for providing subsidies and funding. The Ministry of Science and Technology, Ministry of Environmental Protection, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture, Administration of Quality Supervision, Inspection and Quarantine are also involved in renewable energy policy-making (Hua et al., 2016).

2.2.2.2 Legislation

The legislative framework of renewable energy consists of laws from three aspects: energy, planning and environment (Fig. 16). The Electricity Law, the Energy Conservation Law and the Renewable Energy Law form the cornerstone of laws, policies, and practical measures for renewable energy production. The Land Management Law and the Urban and Rural Planning Law guarantee the implementation of wind power from the spatial planning and construction level. The Environmental Protection Law and the Environmental Impact Assessment Law provide a guideline for environmental protection in renewable energy projects. In order to direct wind energy authority management, planning policies and industry operation, more regulations, industry codes and guidelines are enacted, which include national standards, power industry standards and machinery industry standards (see also Tab. 3, p. 32).

2.2.2.3 Policies

In China, wind energy policies are more diverse and flexible than laws, which can be generally divided into four categories: development plan policies, research and development policies, economic incentive policies, and environmental protection policies.

2.2.2.3.1 Development plan policies

The government has issued a series of development plan policies, like Five-Year Plans (CNEA, 2016), the Med- and Long-term Renewable Energy Plan (CNDRC, 2007) that set out guidelines and concrete objects like specific increment or future scenario. These plans were published by central or provincial governments, which can adjust the development targets and sometimes be even more efficient and practicable than the laws (Liu, 2019). However, the flexibility of government-oriented policies is a double-edged sword. On the one side, it can stimulate the expansion of wind energy in the short-term with more flexible implemental instruments. On the other side, the modification of policies in the long-term may not maintain the stability and influence the rights and obligations of stakeholders and may even confuse with the authority of the laws (Chang & Wang, 2017).

However, different planning instruments and objectives can reflect the different stages of development. For instance, the “12th Renewable Energy Five-Year Plan” focused on the rapid increase of installed wind capacity, while the “13th Renewable Energy Five-Year Plan” shifted the target to adjust the layout and improve the wind energy industry (CNEA, 2016). Tracing policy changes can quickly grasp the progress of wind energy development.

2.2.2.3.2 Research and development policies

The Chinese government attaches great importance to the independent research and innovation of wind energy technologies. Different authorities, such as the Ministry of Science and Technology, the CNDRC and CNEA, have promoted various investments and research programs from both academic and industrial aspects. The central government has proposed the “Wind Plan”, the National Science and Technology Research Program, the National High-tech R&D Program (863 Program), and the Wind Power Concession Project for encouraging wind energy technology innovation. Since 2005, the National Natural Science Foundation of China has funded more than 370 wind energy projects, covering various aspects of wind energy utilization. These projects include offshore wind energy, electricity storage, GW-level wind farm operation, wind energy industry standards, testing and certification, and other public service systems.

2.2.2.3.3 Economic incentive policies

Economic incentive policies are the most flexible and adjustable implemented methods for facilitating wind energy deployment and commercialization. The financial incentives are continuously changing with the development phase of the wind industry of China, transferring from direct fund subsidies to multiple market-adjustable mechanisms.

The dramatic growth of wind capacity is based on abundant governmental investments during the 12th Five Year Plan (2011-2015) to facilitate large-scale wind farm construction and operation, especially in northwest China (Wang et al., 2010; Schuman & Lin, 2012). However, direct economic supports were gradually reduced after 2015, replaced by market-based financial instruments (Liu, 2019). For instance, the Feed-in Tariff Scheme promulgated by the Pricing Bureau is an instrument for the government to regulate the energy market. It sets different prices depending on the different energy sources and sizes of generators. The Measures on Supervision and Administration of Grid Enterprises in the Purchase of Renewable Energy Power (SERC [2007] No. 25) (CNERC, 2007) and the Renewable Portfolio Standards, which provides quotas for grid companies, local utilities and large energy-consumption corporations (GWEC, 2019), are mechanisms for promoting open market for renewable energy. They are designated to remove the obstacles to electricity market reform, provide financial incentives and ensure the smooth transition of energy structure and technologies. Additionally, favorable loans, preferential tax policy, exemptions and preferential price policy are commonly implemented to promote industry evolution and adjust the developing pace.

With mature technologies and competitive prices, the wind energy industry is opened to the commercial market. The CNEA announced that all subsidies for onshore wind energy would be removed before January in 2021, transforming the wind energy industry into a market-oriented operation (CNEA, 2019b). The Feed-in Tariff for onshore wind electricity would also be canceled, and the prices of wind electricity in each region would be equal to coal electricity.

2.2.2.3.4 Environmental protection policies

The amended Renewable Energy Law in 2009 has emphasized the importance of environment and ecosystem protection during the planning, construction and operation of wind farms. The Environmental Impact Assessment Law (amended in 2016) has also improved instruments to control pollution, shifting from end control to process control (Zhang, 2017). From 2017, the National Forest Ministry has promulgated two policies, “Interim Procedures for the Administration of Examination and Approval of Construction Facilities in National Nature Reserves” (March 2018) and “Notice on Further Strengthening the Management of National Forest Parks” (December 2017), to forbid wind farm project construction in national nature reserves and forest parks. Compared with Germany, China has yet insufficient policies concerning environmental protection. More complete and standardized regulations and policies at the local level are under draft by learning experiences from advanced countries.

2.2.3 Onshore wind farm planning procedures

2.2.3.1 German onshore wind farm planning and permission procedures

In Germany, onshore wind farm planning involves a hierarchical planning structure. It is closely correlated to the spatial planning system, consisting of state strategic plan, state development plan, regional plan, urban land use plan, zoning plan, and local development plan (Fig. 17) (Turowski, 2002;

Pahl-Weber & Henckel, 2008). Wind farm planning should obey the Regional Planning Act and the Federal Building Code at different planning levels. Site selection is constrained in the concentration zones of priority areas and aims to avoid conflicts with a set of taboo zones (e.g., buffer zones, clearances for species, and areas under protection).

At the federal level, the long-term nationwide strategic development plan "Energy Concept 2050" is promulgated by the central government to set a general target. State governments should obey the targets set at the federal level and publish state development plans according to their resource conditions and varying priorities. A solid proportion (around 2 % of the territory) of the priority area in each state is required in statutory documents.

At the regional level, the main target of wind energy planning is to identify the privileged land use for wind farms (§ 35 Para. 1 BauGB). Regional planning designates the priority areas, suitability areas, and exclusion areas for wind energy in cooperation with other sectoral planning authorities (Pahl-Weber & Henckel, 2008). WTs over 50 m high are recognized as having a significant impact on local development, which should be installed in priority areas with buffer zones (§ 3 Para. 6 ROG). The

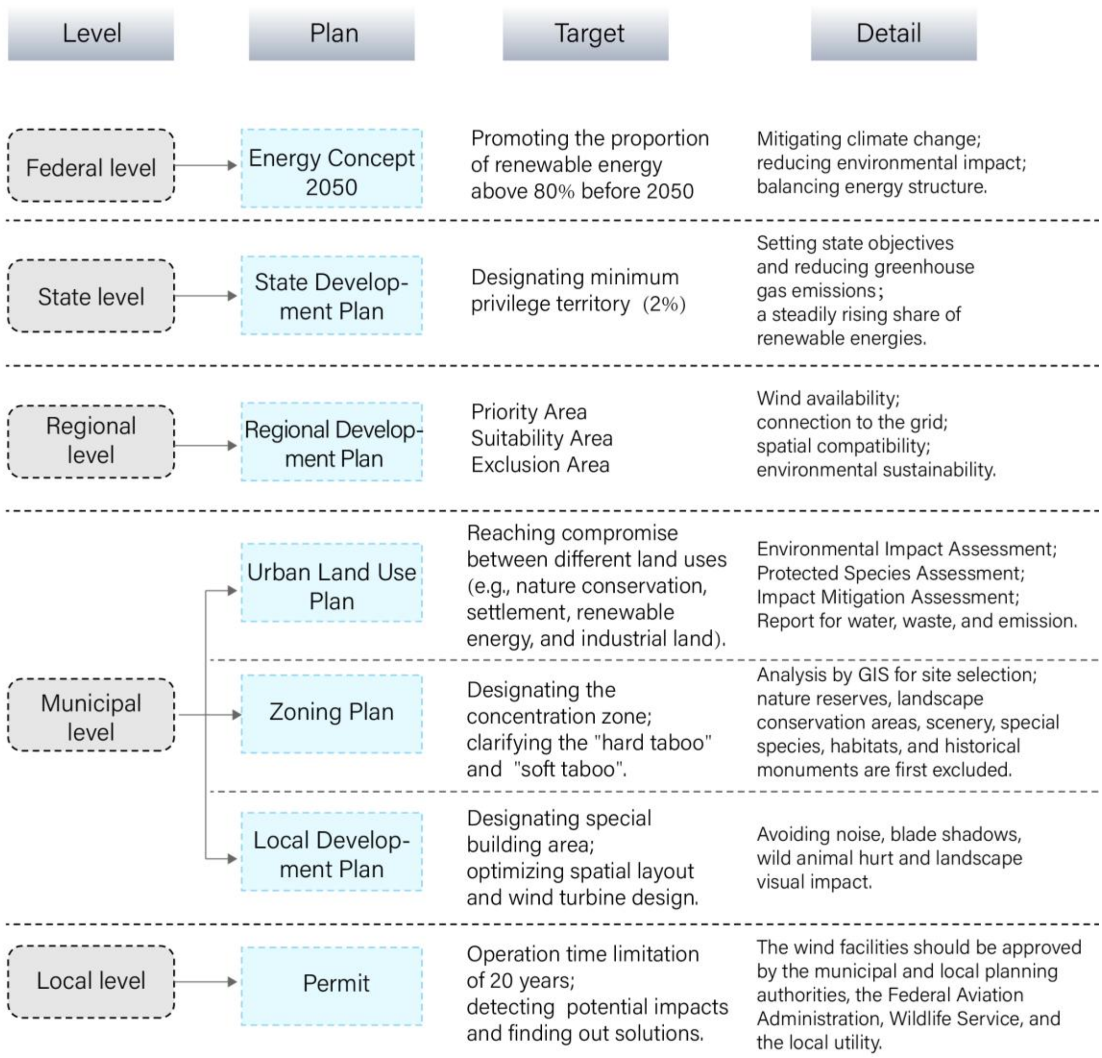


Fig. 17 German wind energy planning and permission framework (Guan, 2020)

national wind resource census and spatial analysis are mandatory for each state to establish a set of criteria for site selection, such as wind availability, connection to the grid, spatial compatibility, and environmental sustainability.

The urban land use plan aims to balance various land uses (e.g., nature conservation, settlement, renewable energies, industrial land) to reach a compromise and make concentration zones legally effective (§ 11 Para. 2 BauNVO). A set of criteria, which designates the precise boundary between priority areas and the surrounding exclusion area, are established during the planning procedures to make the consumption of land more efficient and compact. On the other hand, the land use plan also protects other land uses from wind farm interference. The environmental report is mandatory, including Environmental Impact Assessment, protected species assessment (habitats assessment), European protected species assessment, the Impact Mitigation Regulation and decrees for water, waste and emission (§ 1. Para. 6 No 7. & § 1a BauGB). This phase usually lasts more than two years due to a large amount of consulting work with other specialized authorities. The public participation is included in this phase, consisting of public interpretation, collecting opinions, reinterpretation and announcement of approval (Jami & Walsh, 2014).

The zoning plan designates the concentration zones under the constraint of the priority area (§ 35 Para. 3 Phrase 3 BauGB). Usually, the agricultural land and industrial land are designated as concentration zones. The exclusion area, also called "Hard taboo", refers to the areas, which are "absolutely and permanently unsuitable" for wind energy. Suitability area, that is "Soft taboo", refers to the precautionary area, which can be adjusted in planning consideration. GIS is usually used for site selection by weighing potential areas and comparing conflict land use. Nature reserves, landscape conservation areas, scenery, tourism are first excluded. Other influencing factors like military land, airport land, special species, habitats and historical monuments should be taken into consideration. The analysis result of concentration zones will be legally represented in the formal Land Use Plan document (§ 35 Abs.3 Satz.3 BauGB). Additionally, height restriction regulation is set at the zoning plan level (§ 16. Para. 1 BauNVO).

At the local development plan level, further allocation of special building areas is conducted within the concentration zones with detailed regulations, such as spatial layout and wind turbine design (§ 11. Para. 2 BauNVO). During the wind farm design, the spatial layout of turbines is of great importance to achieve the highest possible energy yield and mitigate the environmental impact. It contains the wind speed assessment and simulation determined from general meteorological data, an examination of the orography of the selected site, the terrain structure, the ground roughness as well as the type and size of the landings of the terrain (Gasch & Twele, 2011). Some environmental impacts, such as noise, blade shadows, wild animal hurt, and landscape visual impacts, will be avoided as much as possible (Dai et al., 2015; Wang & Wang, 2015). Helped with computer simulation software (e.g., WinPro, WAsP), the layout of WTs should be designed most efficiently and economically under consideration of suitable cable laying and feed-in feasibility (Heier, 2018). At the same time, appliances for construction, transportation, safe operation, and soil conservation should be taken into account in the phase of construction (Gasch & Twele, 2011).

Although WTs can only be erected in concentration zones, a permit is still essential before construction (§ 35 Para. 5 Phrase 2 BauGB) (IRENA & GWEC, 2013). When the operation life of turbines expires, WTs should be dismantled, or new permits should be approved for repowering. The requirements of permits are decided by the number and height of WTs in each project (Wagner, 2012b). The approval process aims to detect the potential impact caused by proposal projects and puts forward solutions for mitigation or compensation measures. A great number of laws and regulations have to be taken into consideration at different phases, as listed in Table 2.

Table 2 Laws and Regulations in different aspects of onshore wind farm permission in Germany.

Laws	**Content**	**Remarks**
Federal Building Code/ State Building Code	Clearances towards buildings and property lines	Different between various states
Federal Immission Control Act	Noise	Specific thresholds listed in TA Lärm
	Shade	≤ 30 hours per year, or ≤ 30 min per day
Federal Nature Conservation Act (BNatSchG)	Compensation for Restrictions on use in Agriculture and Forestry	§ 16 BNatschG
	Generally prohibited in nature conservation areas, national parks and core zones of biosphere reserves	§ 23- § 25 BNatschG
	Within landscape conservation areas and nature parks (It depends on the protection targets and the state.)	§ 26, § 27 BNatschG
Natura 2000 (§ 31ff BNatSchG)	Deterioration prohibition	§ 33 Para. 1 BNatschG
	In the case of possible significant impact, an environmental impact assessment is mandatory.	§ 34 Para. 1 BNatSchG
	If there is significant impact, there is the possibility of an exception.	§ 34 Para. 3 BNatSchG
Species protection	It is prohibited to hurt, disturb or kill species	§ 44 Para. 1 No. 1-3 BNatSchG
	Depending on the significance of the risk of the species	
	Setting clearances for different protection objects	/
§ 30 BNatSchG, Biotope protection	Wind turbines are generally prohibited.	/
	Exception if the impact can be compensated	§ 30 Para. 3 BNatSchG
Impact mitigation regulation (§ 14ff	Following the cascade of avoidance, minimization, balancing, and compensation	/

Sources: (Nkomo, 2018; Fachagentur Windenergie an Land, 2019; Wagner, 2012b)

2.2.3.2 Chinese onshore wind farm planning procedures

The wind farm planning procedures are not tightly integrated into the spatial planning system of China, but more project-oriented with the chronological sequence (Fig. 18). At the national level, the Mid- and long-term renewable energy plan (CNDRC, 2007) and Five-Year Plans (CNEA, 2016) are promulgated by the central government as essential strategies for increasing the wind energy capacity up to 1 TW, accounting 26% of domestic energy capacity at 2050 (IEA & ERI, 2011).

At the provincial level, wind energy targets are roughly designated by energy authorities according to the wind resource distribution based on the wind energy atlas. Due to the enormous territory of China, the measurement of accurate wind energy resources covering the entire territory is impossible. The specific project planning and site selection must have exploitation and measurement of wind energy resources for more than one year before the application of the permission. Different from the case of Germany, there are neither priority areas nor suitability and exclusion areas designated for wind energy in China. The Wind Farm Site Selection Technical Regulation ([2003] 1403) stipulates the compromise between wind energy and other land use during site selection (CNDRC, 2003).

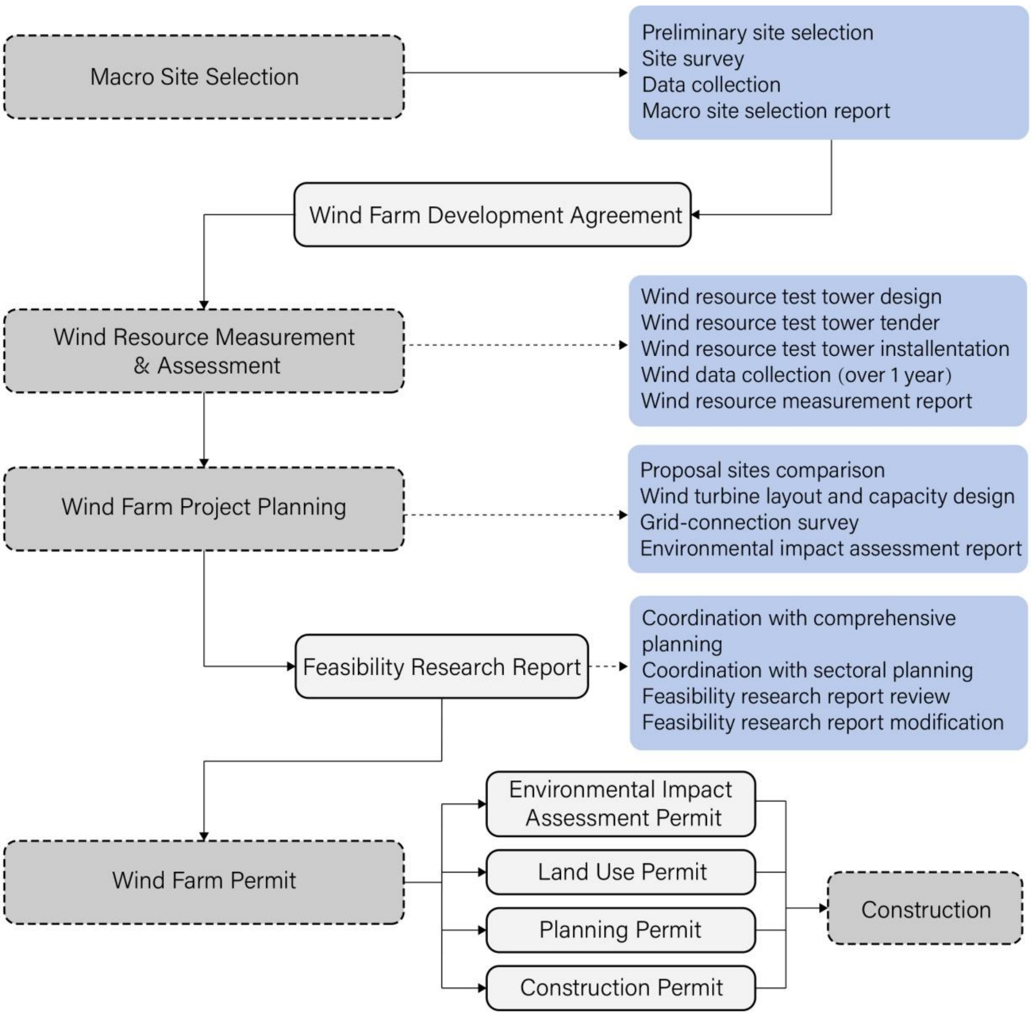


Fig. 18 Chinese wind energy planning procedures and permission (Guan, 2020)

At the municipal comprehensive planning level, wind farm site selection should meet the requirements of land use planning, transportation planning, wind energy planning, and supporting transmission planning according to the Code for Wind Farm Design (GB 51096-2015) (MOHURD, 2015). It should also coordinate with environmental protection, soil and water conservation, airport clearance, military facilities, mineral resources, cultural heritage protection, and scenic area protection. Once approved by the land administration, the designation of wind farm construction land is permanent. However, the operation period for WTs is 20 years. After the operation period, turbines should be demolished or replaced.

At the local planning level, the land use should strictly obey the Land Use Indicators for Power Engineering Projects-Wind Farm (HPDI, 2012) with the precise available area for each power facility. However, there are neither regulations of minimum buffer distance nor height constraint in this standard yet.

The permission process of wind farm consists of environmental impact assessment approval, land use approval, planning permit and construction permit. The planning and permission procedures are regulated by a series of national industrial standards and regulations, as shown in Table 3.

Table 3 Relevant regulations and technical standards of onshore wind farm permission in China.

Wind energy regulations and technical standards	**Management department**
Technical specification of wind power plant design (DL/T5383 2007)	Chinese National Development and Reform Commission
Land use indicators for power engineering projects-Wind farm (ZBBZH/DLFD-2012)	Hydropower Planning and Design Institute
Code for design of wind farm （GB 51096-2015）	Ministry of Housing and Urban-Rural Development
Noise limits and measurement method of wind power plant （DL/T1084-2008）	Chinese National Development and Reform Commission
Code on the operation of wind power plant (DL/T 666-1999)	Chinese National Economic and Trade Commission
Relevant regulations and technical standards	**Management department**
Technical code for environmental impact assessment of wind farm projects (NB-31087-2016)	Chinese National Energy Administration
Guideline for environmental protection design of mountain wind farm in Guizhou (DB52/T-1183-2017)	Guizhou Provincial Bureau of Quality and Technical Supervision
Code for seismic design of electrical installations (GB 50260-2013)	Ministry of Housing and Urban-Rural Development & Administration of Quality Supervision, Inspection and Quarantine
Integrated wastewater discharge standard (GB 8978-1996)	National Environmental Protection Agency & National Bureau of Technical Supervision
Technical code on soil and water conservation of development and construction projects (GB 50433-2008)	Ministry of Construction & Administration of Quality Supervision, Inspection and Quarantine

Sources: (HPDI, 2012; MOHURD, 2015)

Compared to the complete system in Germany, wind energy planning in China is not systematic and complete enough. It has not been integrated with the spatial planning framework, causing overlapped contents and even conflicts with various sectoral planning contents. Additionally, the detailed provisions are missing, such as concentration zone designation, high constraints, clearances, and species protection guidelines.

2.2.4 Landscape protection and wind farm planning

The landscape protection must be taken into account during the planning and approval process of the wind farm. In Germany, comprehensive legislation, the rigorous planning system, as well as compensation measures are the solid basement for both landscape protection and wind energy industry. From the planning perspective, Figure 19 shows the complete planning system concerning landscape and wind farm planning, which regulates the implementation of wind farm planning in each stage (Pauleit, 2017). The task of landscape protection in wind farm belongs to the landscape planning system. As shown in Fig. 19, landscape planning has various levels corresponding to spatial planning, state development program, regional planning, land use planning, and building design. The hierarchy structure of landscape planning is in line with the planning procedures of the wind farm. Landscape planning serves to achieve the objectives and principles of nature conservation and landscape protection both in protection areas and in projects, which can control impairments to the nature and landscape of the planning areas (Turowski, 2002).

§ 1 in the Federal Nature Conservation Act states that one of the aims of the law is to secure the diversity, peculiarity and beauty as well as the recreational value of the landscape. Accordingly, damages to protective regions should be avoided and minimized as far as possible. § 15 in the Federal Conservation Act stipulates that impairments that cannot be avoided must be compensated or replaced. A substitute measure can be conducted by monetary compensation. Each state has the

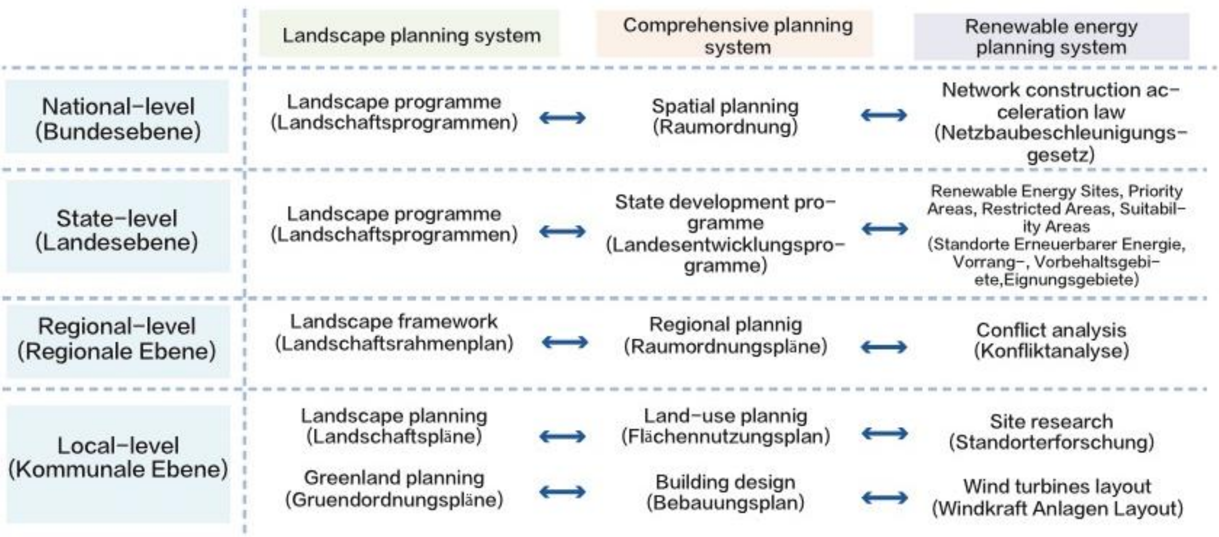


Fig. 19 The planning system of landscape, renewable energy in Germany (Pahl-Weber & Henckel, 2008)

respective right to supply and explain the Federal Conservation Act by the State Nature Conservation Act. The form and level of compensatory measures for interfering with the landscape by wind energy installations can vary among the federal states.

To what extent WTs will affect the landscape aesthetics has a significant influence on the approval of the project. A landscape analysis should be undertaken at the phase of potential wind resource analysis. The visual vulnerability and reliability of the target area, the aesthetic relevance of the intervention by the planned wind farm, and the extent of compensatory measures or replacement payments need to be made in advance for comparisons and far-reaching decisions.

2.2.5 Mitigation solutions for landscape visual impact

In the planning process, there are various flexible measures to tackle the intervention, including the multi-site selection, mitigation measures, the replacement and compensation measures, which can be sequentially conducted.

2.2.5.1 Multi-site selection

There is no doubt that the best solution is to comprehensively take factors from all aspects into consideration in the site selection process as early as possible. According to the development goal and resource advantages of each region, the proposed sites can be selected for the decision-maker to achieve the highest integrative benefits. Several types of area should be excluded first: natural reserve, hard taboo, soft taboo, cultural heritage, military land, and the eco-sensitive area. Under the conditions of abundant land use, it is also necessary to designate extra extended clearance from residential and commercial areas.

2.2.5.2 Mitigation measures

In the intervention steps, foreseeable impairments are to be avoided as much as possible after the macro-site is determined. Mitigation measures incline to adjust the micro-positions of WTs in order to reduce the intervention in the landscape. If necessary, for the mitigation measures, even energy production efficiency can be sacrificed. As a rule, areas of large spatial extent are considered. In this respect, existing digital data must be used. For this purpose, digital elevation models (DHM, data on the height of the earth's surface) and data on land use (official topographical-cartographic information system, ATKIS DLM 25/1) are available in most federal states.

The commonly used mitigation measures are listed as follows:

- Designating the layout of WTs based on existing landscape structures (for example, the edge of the forest, slope foot, road);
- Using vertical surface structures, vegetation, etc. to “hide” WTs;
- Avoiding severe impairments on the significant sightlines;
- Painting WTs into green and gray color for merging into the background;
- Creating a harmonious proportion in the view.

2.2.5.3 Compensation measures

To which degree of impairment in the landscape should be compensated is regulated by various laws and regulations. The German Supreme Court states that the landscape should keep the previously existing state in the most possible approximation. To be more precise, the original peculiarity, essential elements, structure and functions of the landscape should be maintained (Unland & Wittmann, 2016). The Federal Nature Conservation Act (§ 15), the draft of the Federal Compensation Ordinance, and the Wind Energy Decree of each state all set specific requirements for compensation measures. The most common compensation measures are replacement and substitute payment.

2.2.5.3.1 Replacement

When the landscape suffers impairment, replacement is suggested on the same site or near the proposal project, to recover the whole environmental quality to some extent. Such compensation is not only possible through a similar restoration of the status quo, but also through a "landscaping-appropriate redesign". Landscape redesign is mandatory in the aesthetically significantly impaired space and the immediate vicinity of the intervention site. It is worth mentioning that a slight difference from the original landscape is allowed, as long as the essential features, elements, structure and functions are guaranteed. Specific measures include:

- Restoring vegetation and habitats damaged by project construction and operation, e.g., forests, grasslands, wetlands;
- Restoring damaged landscape structures, such as corridors and green belts, to enhance the overall ecological stability of the landscape;
- Optimizing the functions and peculiarity of the whole landscape, e.g., landmarks, sightlines, and landscape resources with high aesthetic values;
- Restoring cultural-historical landscape elements;
- Adjusting the replacement proposal to match the targets of regional landscape planning (LANA, 1996);
- Redesigning in consideration of sustainability (Nohl, 2010a) and taking into account the landscape carrying capacity for the future energy transition.

2.2.5.3.2 Substitute payment

If the intervention cannot be mitigated or replaced sufficiently, substitute payment may be implemented in the approval process. The essential principle set by the Federal Nature Conservation Act (§ 15) stipulates that the compensation payment is based on the average cost of the unavoidable compensation and compensation measures, at the same time taking the duration and severity of the intervention into account (Unland & Wittmann, 2016).

The impact intensity and compensation amount are evaluated by the respective federal state or the responsible authorities with different calculation approaches. Usually, each federal state sets specific regulations or even displays case studies in the decrees for establishing a uniform and binding methodology of compensation calculation. The calculation methods are mainly based on three criteria: the height of WTs, the number of WTs, and the value of the surrounding landscape. The compensation payment is determined by the number and height of the plant and a compensation coefficient set by the state (lump sum fixed amount per m² of compensation area). In Baden-Wurttemberg and Lower Saxony, a fixed percentage of the planned investment sum is required to submit as a substitute payment. The state laws also regulate to whom and for which purposes the compensation payment has to be paid. The money usually goes to the Lower Nature Conservation Authority and foundation agencies (Unland & Wittmann, 2016). For instance, the State Office for Nature, Environment and Consumer Protection in North Rhine-Westphalia has promulgated a series of compensation regulations for wind energy planning and approval (https://www.lanuv.nrw.de/natur/eingriffsregelung). There is a guideline for the compensation measures with three steps (LANUV, 2016): 1) delimitation of the research area; 2) landscape visual impact evaluation; 3) replacement money determination.

2.3 Visual impact caused by WTs

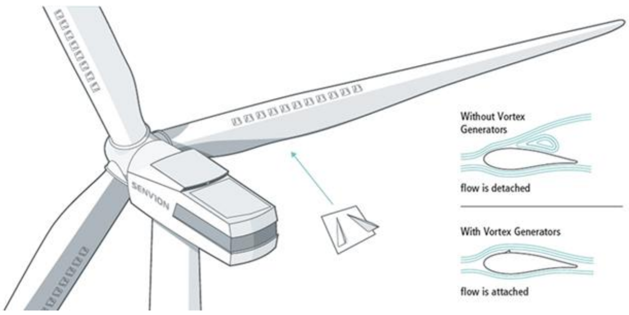
The visual characteristics and impacts related to WT can be further analyzed through components or features. It is accepted that the visual features and sources of visual impacts vary over time. In addition to the visual impacts caused by WT components, the visual characteristics of construction, operation, dismantling, and repowering phases must be taken into account with respect to entirely different physical elements and activities.

2.3.1 The visual impact caused by WT components and features

Table 4 lists the visible components and features of WTs that may cause visual impact.

Table 4 Visual impact relevant components and features of WTs.

Visual impact relevant components/ features	Remarks
1. Location of WTs	Onshore wind farms are divided into four types: the ridge, hills, plains, and desert wind farms. Offshore wind farms are divided into three types: coastal, near the sea and deep-sea wind farms.
Geographic location:	For site selection, the surface roughness and wind shear are vital parameters. Geographic location affects the technology of the foundation construction and materials for the WT, as well as the size and layout of the wind farm.
Distance between supply-side and demand-side:	The wind farms far from demand-side usually have a giant spatial scale and high capacity. The energy transmission depends on long-distance high voltage power lines while wind farms near demand-side are distributed on small scale, close to constructions, and have high visual impacts.

Visual impact relevant components/ features	Remarks
2. Height **Hub height** **Total height**	The most influential feature of WTs is their height. Normally, the height parameters refer to hub height and total height. The height of WTs has a close relationship with the yield and cost. One meter more of height means 0.5 % more electricity production. The average capacity of newly installed onshore WTs is 2.848 MW, with an average rotor diameter of about 109 meters and an average hub height of about 128 meters. All figures are up by 4 % compared to 2015 (GWEC, 2017). The height of a WT will always grow to catch higher wind speed in a higher position. The affected scope and intensity of visual impact will expand with the continuously growing height.
3. Rotor blades **a) Rotor diameter**	Rotor diameter is a crucial parameter for energy production. With the improvement of WT technology, the average length of the rotor blades is dramatically growing. The growing diameter enlarges the area of visual perception and causes more severe environmental impacts.
b) The shape of rotor blades	The design of rotor blades relates to the aerodynamics theory, which aims to improve the ability to capture and transform wind energy into mechanical energy. The shape of blades tends to be slender and flat, while this sharp appearance may cause people's discomfort and insecurity, especially during its rotating.  Fig. 20 The shape of rotor blades (Source: https://energieplus-lesite.be/techniques/eolien6/eoliennes/)
c) Shadow flicker	Theoretically, "shadow flicker" only happens within 10 rotor diameters with specific climate conditions (ODPM, 2004). It belongs to the residential amenity issue rather than landscape visual impact. Many local governments put forward strict regulations of buffer zones for wind farms to avoid this problem.
4. Tower **Structure of the tower**	The essential function of the tower is to support hub and rotor blades. The common forms of towers are steel tubular towers and steel truss towers. They are assembled on-site after prefabrication at the factory.

Visual impact relevant components/ features	Remarks
5. Foundation	The foundation of the WT is a reinforced hollow concrete foundation with a depth of 30 feet or more to avoid the overturning of the tower. The size of the foundation depends on the tower height. It is estimated that per 1,000 kW of installed wind capacity requires approximately 6 hectares (Klaus et al., 2010), causing problems of vegetation destruction and soil erosion.
6. Surface forms and materials (Including color, texture and reflective properties) **a) The material of rotor blades**	Composites are used as the raw material of rotor blades to meet strict demands with high stiffness, high strength, high fatigue resistance, and low weight (Ancona & Mcveigh, 2001). In order to reduce light reflection, the surface-material of blades needs improving.  Fig. 21 The painted bottom of wind turbine mast by Enercon Company (Kletzsch, 2018)
b) Material of tower	The surface material of the tower is non-reflective gray paint. The wind energy company Enercon contributes to painting the bottom of the tower in green to reduce the contrast with the background.
7. Preload and the cumulative effect	The cumulative effect refers to the overlapping visual impact caused by several WTs with respect to the topography and the spatial layout of wind farms (Nohl, 1993). This issue should be considered in the coordination of the site selection of different wind companies.
8. Ancillary facilities	The transformer substation and overhead cables are usually installed on large-size wind farms in connection with the national grid. Since power line planning requires a separate permit, it will not be considered in this thesis.

2.3.2 Visual impact caused in the construction phase

In the phase of construction, there are particular environmental influences different from the usual ones, which should be considered and reduced as much as possible. As listed in Table 5, the visual impacts are different in different periods (pre-preparation, construction, and debugging period). The proposals for the mitigation of those impacts should also take two types of impacts into consideration, that is, the temporary and permanent impacts.

Table 5 Visual impact caused in the construction phase.

Construction phase	Visual impact
1. Prepreparation	Road construction for site access and haulage routes (especially for large heavy-duty cranes), the foundation of WTs, earthworks and other technical support (such as substations and on-site assemble sites) may cause dust, vegetation degradation, soil erosion, and other influences on the landscape.
2. Construction	Construction-related impairments can occur during the construction phase through the use of heavy-duty cranes and machines. For example, noise, vibrations, solid waste, lighting pollution, restrictions on the use of paths are the main impacts during the construction of wind farms. Additionally, enough temporary space has to be spared for stockpiles and heavy-duty crane to assemble the components of WTs, which causes soil compaction.
3. Debugging	In order to ensure operational efficiency and safety, technical adjustments are required in the construction phase to improve the capabilities to fend off risks such as extreme climates, high temperature, and unexpected natural disasters.

Sources: (Heier, 2016; Schöbel, 2012)

2.3.3 Visual impact caused in the operational phase

Generally, the wind farms have the operating license for 20 years (§ 35 Para. 5 Phrase 2 BauGB) (IRENA & GWEC, 2013). For some newly built wind farms, the permission may be prolonged to 25 years. Regular operation and maintenance measures are remotely monitored and controlled through computer-aided systems. As listed in Table 6, the visual impact in the operational phase is derived from the rotating blades, warning lights, shadow flicker, long-term landscape modification, attached with other environmental impact like noise. Nohl (2001a) points out that a large moving object is definitely an "eye-catcher" in the landscape, especially those with noise, shadow flicker, and warning lights.

Table 6 Visual impact caused in the operational phase.

Operation phase	Visual impact
1. Motion status (Static or rotating, rotation speed)	Shang and Bishop (2000) point out that dynamic WTs are about 10 to 20 % larger in their size in visual perception than the size of the static ones. With the tendency of the growing size of WTs, the rotation speed of blades turns down from 30-60 to 10-15 RPM. The reduction of rotation speed can decrease the strong effect caused by the “eye-catcher” and reduce the visual impact. However, some sociologists argue that WTs in the inactive status are recognized as a waste of energy by the public, which may generate negative emotions. The accurate linear relationship between visual impact magnitude and blade rotation speed has not been researched and quantified yet.

Operation phase	Visual impact
2. Warning lights	In the past, warning lighting was required on turbines for aviation safety. Currently, aircraft warning lights can be obscured by a baffle to avoid optical impairments on residents, or solved by other advanced technical solutions that are in the process of development or even already implemented (Cornwall Council, 2013).
3. Noise	Some evidence shows the potential interplay between visual or aesthetic impacts with WT acoustic detection and annoyance (Pedersen & Waye, 2007). Renterghem et al. (2013) find that severe acoustic annoyance increases subjective visual impact, and vice versa. The sound emitted by WTs can be divided into two kinds according to different sources: the mechanical sound from the gearbox, which can be reduced by technological advancements, and the aerodynamic noise created by the rotating blades (Bolin et al., 2011). The continuous noise will constantly remind people of the visual image of the surrounding WTs and aggravate the visual impact. Compared with the decibel level, the low frequency, quality, and characteristics of sounds emitted by turbines are more influential (Haggett, 2012). Infrasound, as a sound below the frequency of 20 Hertz, is identified as an impairment source to the minority of residents on their health (Lenzen-Schulte & Schenk, 2019).
4. Shadow flicker	A parameter "annual impact hours" is introduced to describe the magnitude of shadow flicker (EverPower, 2017). Usually, the influence should not be present over 30 hours per year or 30 minutes per day (Nkomo, 2018). Otherwise, the local government and approval authorities have the right to shut down the wind farm for rectification.
5. Long-term local identity and landscape modification	Regional landscape identity is always changing. Several energy revolutions in human history have driven significant changes in landscape appearance. Linke (2017) proposes that the social construction theory supports the change of landscape with social development. However, excessive development obviously leads to the destruction of landscape, especially the natural, historical, and cultural landscapes. Nevertheless, the process is irreversible, and the loss cannot be measured and compensated. Therefore, the impact of long-term modification cannot be neglected, and it is necessary to pay attention to the protection of regional landscape identity and historical values of the landscape.

2.3.4 Visual impact caused in dismantling and repowering phases

If the WT reaches its technical end of the operation, it must be dismantled or even replaced by a new one in the same location, i.e., repowering. Generally, old facilities like transformers (substations) and transmission systems should be replaced simultaneously. During this phase, the types of visual impacts are similar to those generated in the construction phase. However, the land that has been developed for the wind farm is more likely to be approved for repowering. The new WTs in bigger sizes and of more substantial capacity have more intensive impairments on the surrounding environment.

In practice, some slight and marginal impacts are easily ignored, since only severe and permanent impairments during wind farm planning are mandatorily required for mitigation and compensation. As scientific research, even slight and potential visual impairment should be listed and analyzed comprehensively for further simulation in high accuracy. There are multi-criteria for making the final decision in wind farm planning. In computer modeling, a number of parameters (for instance, the hub height, the wind power density, number of blades, and blade shape) need to be considered in priority for safety and economy benefits before the evaluation of landscape visual quality (Hewitt et al., 2018). The fact is that environmental effects and landscape visual impacts are usually underestimated in the project.

3 Landscape Visual Impact Evaluation - State of the Art

Rather than to exhaustively present the definitions of all relevant terms, the aim of this chapter is to explore and explicate the terms that are of considerable importance in the following discussions. The lexical aspect and the connotation of these terms will be analyzed in detail.

3.1 Theories related to landscape

3.1.1 The meanings of the term "landscape"

3.1.1.1 Distinction between the term "landscape" and "visual landscape"

A exploration of the etymology and meaning of the term "Landscape" and its research context in this paper is the prerequisite for further research. As a subject dealing with land, there is a broad common sense about the term "landscape", which is defined by people in different cultural backgrounds and specific linguistic contexts. An official definition of the term "landscape" is given by the European Landscape Convention (ELC): "an area, as perceived by people, whose character is the result of the action and interaction of natural and human factors" (Council of Europe, 2000). In China, landscape is defined as the overall vision (topography, natural elements and artificial elements) perceived by people in a specific space (Pang, 2012).

Visual landscape refers to the visual expression of the elements, structure, and functions of landscape (Nijhuis et al., 2011). The connotation of "landscape" includes the visual perception of landscape, as well as other sensory and ecologic, economic, and functional aspects of landscape.

The German term for "visual landscape" can be "Landschaftsbild", a compounding word made up of two nouns "Landschaft" and "Bild". It refers to the entire visual perceptible appearance of a landscape perceivable by humans (Schmidt et al., 2018). It is worth clarifying that the literal English translation of Landschaftsbild is "the picture of the landscape". In terms of the same connotation and reference of Landschaftsbild with that of "visual landscape", "visual landscape" is introduced here to correspond to "Landschaftsbild".

3.1.1.2 Evolution and definition of the term "landscape"

The term landscape encompasses an extensive and diverse range of objects, perceptions, and meanings (Table 7). In particular, landscape is the key object of geographic and landscape ecology research as well as landscape planning (Blotevogel et al., 2018). Within the different fields of work and areas of life, there are inconsistent views on the content and use of the term "landscape". Therefore, to define the term "Landscape" is an arduous task, not only because of its integrated meaning containing cultural, social, aesthetic, and historical complexity that exists in different contexts but also due to its continuous evolution (Antrop, 2013).

The earliest meaning of landscape can be derived from the Psalms of the Bible. In Hebrew, the word “Landscape” is etymologically related to “beautiful”, which is used to describe the magnificent overview of the capital Jerusalem with King Solomon's temple, castles, and palaces (Naveh & Lieberman, 1990). From the 15th century, the term landscape appeared as a technical term for painting. Since then, the aesthetic impression of scenery has been always combined with the term landscape. At the beginning of the 19th century, German geographer A. V. Humboldt gave the landscape an scientific definition in the geography domain: ‘Landschaft ist der Totalcharakter einer Erdgegend’, which indicates a twofold meaning of landscape: 1) the synthesis of the visible surface, 2) a limited area (Schönfelder, 2010). 1939, German bio-geographer C. Troll proposed the concept of “Landscape Ecology”. He maintained that terrestrial and biosphere were essential parts of the whole landscape, and advocated the combination of a “horizontal” spatial analysis method used by geographers with “vertical” structural analysis methods used by ecologists. Afterwards, “landscape” has been usually seen as a scale unit in ecological systems. More scholars (Forman & Godron, 1986; Forman, 1995; Turner, 1989; Risser et al., 1984) agree with the importance of landscape in the ecological domain. With the development of landscape branches like cultural geography, social geography, and landscape psychology, the issues such as landscape character, settlement patterns, and social territories have been included as a supplement to the systematic subject “Landscape”. Based on this point, landscape has been integrated as a unique synthesis of the natural and cultural characteristics of a region (Antrop, 2013).

For planning purposes, the term “landscape” in this thesis is defined as a specifically delimited physical area (municipality, region, or federal state/province) related to nature conservation for specific planning at different levels. Landscape is identified as a result of transformation of nature through human creativity and perception, both externally and internally (Fischer, 2013). The customary pair of terms nature and landscape is used in German laws related to planning as a basis of reference. Landscape in the context of planning is an integrated concept that continuously includes newly perceived elements. Currently, the energy transition has led to a revitalization of the discussion on the landscape as identity and home space for the population (Blotevogel et al., 2018).

Table 7 Landscape concepts interpretation.

Landscape meaning in different context	Period	Research content	Related disciplines
Aesthetics	From 19th century	Scenery	Gardening
Geography	From 19th century	Material landform	Natural and human geography
Landscape ecology	From 20th century	Carrier of material exchange	Ecology

Landscape meaning in different context	Period	Research content	Related disciplines
Multidisciplinary	From 21st century	Comprehensive content	Sociology, psychology, behavioral science, etc.
Planning	From 20th century	Planning scales, targets, and approaches	Urban planning and landscape planning

Sources: (Forman, 1995; Turner, 1989; Risser et al., 1984; Naveh & Lieberman, 1990; UNESCO, 1996; Schönfelder, 2010; Antrop, 2013)

3.1.1.3 Differentiation of "landscape" between Europe and China

In German references, the term "Landschaft" initially turned up in the early thirteenth century. Here "Land" refers to a bordered territory with soil, topography, hydrology and other natural components. The suffix "-schaft" in German derives from the verb "schaffen" (to make), which refers to land reclamation and creation. So "Landschaft" as "organized land" is characteristic of the people who make it (Antrop, 2013). In Chinese, "landscape" (景观) can be divided into two parts: "scene" (景) and "view" (观), which combines both the landscape and the viewer.

The origin of landscape has an interesting commonality in Europe and China that it is closely related to nature. Landscape cannot be thought of without nature and is closely related to it. Pursuing landscape reflects the appeal of human beings to their origins and to pursue the essence of life. Different preferences for landscape aesthetics represent different social systems and the pursuit of people in different spiritual levels (Table 8).

In China, the original concept of "landscape" comes from worship of nature in ancient times. The ancient Chinese people believed that the immortal lived in inaccessible, magnificent, mysterious, and beautiful nature as shown in Figure 22. This picture is a part of the famous painting "A Thousand Li of Rivers and Mountains" painted by Ximeng Wang, which reveals the ideal landscape Chinese people pursue. People imagined the dwelling places of the Immortal, imitated the magnificent landscape, and attempted in their pursuit of eternal life. Accompanied by the pursuit of beauty, the emperors built palaces and imperial gardens, which were the beginning of Chinese gardening art. Chinese landscape aesthetics were also displayed in various art forms like Bonsai, poetry and Chinese painting. In its continuous development, art, in turn, influenced the aesthetic of the landscape. For example, the elegant Chinese ink paintings shape the aesthetic preference for the natural and hazy landscape.

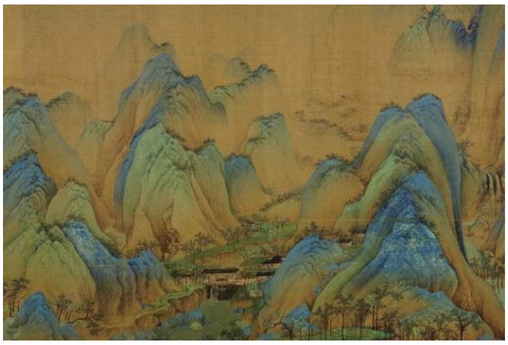


Fig. 22 The imagery of Chinese Landscape
(Wang, A.D.1096-1119, Song Dynasty)

Fig. 23 The imagery of European Landscape
(Hoare II and Flitcroft, 1745-1761)

The landscape origin and development in Germany can be approached by reference to the landscape of the European continent. The landscape concept in Europe is originated from religion. In the Bible, beautiful vision of heaven is portrayed, including magnificent palaces, fountains, flowerbeds, fruit trees, etc. Compared with China, European landscape is entangled with a specific and functional context that transformed from nature to meet the aesthetic and recreational demands of people. Anthropocentrism is rooted in landscape design and formed human-made, regular and axisymmetric styles. Artistic forms, such as oil painting and sculpture, are all modeled on reality. From the Renaissance, scientific ideology has changed the understanding of the landscape. The landscape has become an object that can be studied, deconstructed and built, as shown in Figure 23.

Table 8 The differences in landscape images in China and Europe.

	China	**Europe**
Ideal aesthetic models	Wonderland	Palace and pastoral
Aesthetic origins	Worship of nature	Religion
Associated art forms	Chinese landscape painting, Chinese gardening, poetry	Oil painting, sculpture, European gardening
Art expression skills	Pursuing abstract beauty by leaving blank	Pursuing realistic, regular, axisymmetric beauty, or Baroque style
Implementation modalities	Experience accumulated	Scientific theory system and composition research
Landscape vector	Royal and private gardens (private); Religious gardens (public)	Royal gardens (private); Monasteries, public green spaces (public)

Sources: (Han, 2006; Antrop, 2005)

China and Europe belong to different cultural systems. The meaning of landscape is closely related to respective historical, religious, cultural, and artistic forms. Until the global urbanization and City Beautiful Movement (Bluestone, 1988), landscape has been unified in academic disciplines with standard definitions and scientific research methods. In addition to the disciplinary standards, regional differences and flexibility should be preserved to protect the landscape features and homeland (Heimat) (Weber & Kühne, 2016).

3.1.2 Landscape perception

Landscape perception deals with the critical question of how and what people learn from the landscape environment. The process of landscape perception can be recognized as an interaction between the observer and the landscape. Appleton (1975) notes in *The Experience of Landscape* that: "Beauty resides neither intrinsically in 'beautiful' objects nor 'in the eye of the beholder', but that it is to be discovered in the relationship between the individual and his environment, in short, what he calls experience".

The word “perception” derives from the Latin “perceptiō”, which has the meaning of “being aware” (Oxford English Dictionary, 2019a). Perception is an activity dealing with received information in the brain. It contains objective and factual information, as well as the individual associations, experiences and expectations already in the mind of the beholder (Bell, 2012).

In this thesis, landscape perception refers to a comprehensive sensory system. Visual perception dominates the sensory with 87 % of the sensory information, while the other 13 % (e.g., auditory, olfactory, tactile) is assisted from other dimensions to confirm and reinforce the information (Bell, 2012). Granö (1929) classifies the spatial scope of landscape perception into ‘Nahsicht’ and ‘Fernsicht’. ‘Nahsicht’ refers to the scope people can perceive with all senses (around tens of meters), while ‘Fernsicht’ means a far distance environment that can only be felt with visual sense (several kilometers). Both in terms of information volume and spatial extent, visual perception is the most important sensory source for information, which also influences behavior, preference, and aesthetic in landscape research. It has also become an instrument in landscape protection, monitoring, and planning (Harris & Ruggles, 2007).

Visual perception is itself a complex information processing mechanism related to physiology, psychology and social attributes of human beings (Fig. 24).

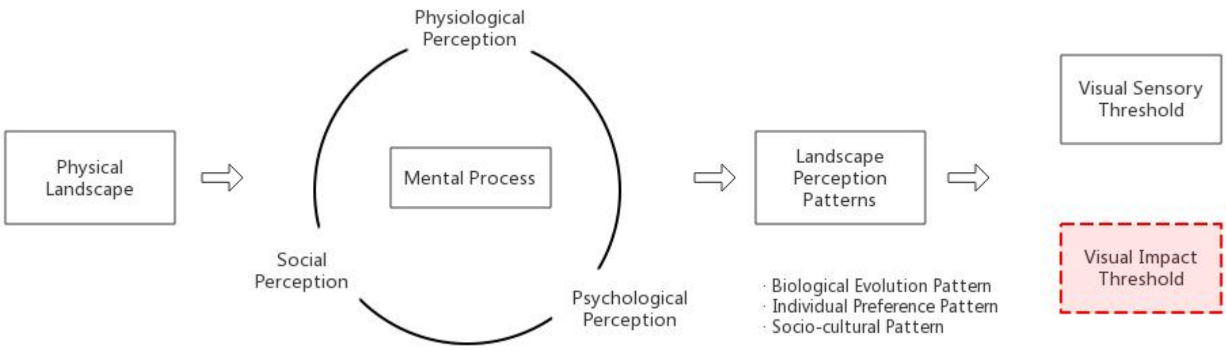
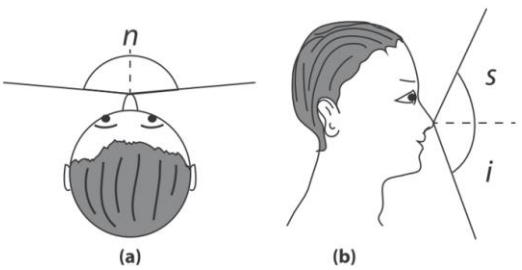


Fig. 24 Visual perception mechanism

The physiology of perception refers to the process of sensation and the mechanism of sight. It also solves problems such as how the human being's eyes work, how eyes receive light, how various patterns can be distinguished, and how the sight limitation can be noticed. According to the Human Field of View (HFV), the physiological mechanism of vision has scientific and objective criteria, as shown in Figure 25 (Joly et al., 2009; Bell, 2012; Sevenant, 2010; Jacobs, 2006; Minelli et al., 2014).



(a) "n" is the nasal angle defining a horizontal plane of 170° from the nose.
(b) "s" and "i" are respectively the superior and inferior angle defining lines extending 65° upwards and 70° downwards from a horizontal line extending from the nose.

Fig. 25 Criteria about "Human Field of View" (Minelli et al., 2014)

When combined, these angles form an ellipse that defines the static HFV. Moreover, the more centrally located in this ellipse, the more visual information is obtained, which is not perceived averagely (Fig. 26).

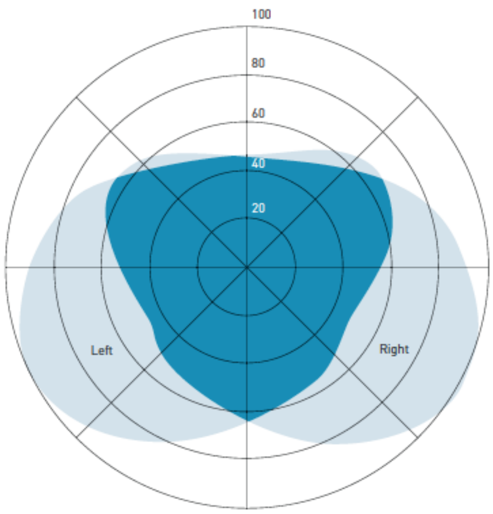


Fig. 26 The Field of View of a person looking straight ahead (Ware, 2012)

The depth of perception, the perception of the contrast between different objects, and the perception of the motion of objects are also affected by the human physiologic mechanism. In general, the vision range depends on these internal physiological limitations as well as external constraints, e.g., weather, air quality and atmospheric scattering (Duntley, 1948; Nijhuis et al., 2011).

The psychology of perception refers to the brain activity that consciously discerns and processes sensory information combined with individual education, experience, emotion, expectation, and cultural background (Kirchhoff, 2014; Hunziker, 2010; Jacobs, 2006). By integrating new information with existing knowledge and experience to assign meaning, define relations, and classify information, the psychological perception process is more derivative, individualized and subjective than physiological perception (Jacobs, 2006; Bell, 2012). The difference in individual psychological perception is the most substantial uncertain variable in landscape perception. Even the same person will give different perceptional impressions in different scenarios. It is necessary to use a large sample size to ensure the reliability and representativeness of the data.

Besides individual physiological and psychological perception capacity, social construction subtly influences the landscape perception preference and information processing. With a set of collective views and habits in cultural background, individual minds will be affected by public expressions and social media (e.g., books, slogans, paintings, videos, body language, et cetera) (Jacobs, 2006). In addition, the social attributes of perception may be used as instruments by the government and mainstream media for orientating public opinion.

The physiological, psychological and social perception constitutes the complex process of landscape perception (Fig. 24). Notably, not all perceptional information has an impact, only if it exceeds a certain threshold that depends on the stimulus intensity of the object and the sensitivity of the observer. Viewers' responses can be classified into two types: visual sensory threshold (whether people can see the object) and visual impact threshold (whether people feel themselves being influenced by the object), which are distinguished given different levels of stimulus intensity. The visual sensory threshold (detection and recognition) relies more on viewers' physiological perception capacities, which are measurable as above mentioned, rather than cognitive mechanism (psychological and social perception). The visual impact threshold is more challenging and subjective to obtain, which depends on viewers' subjective judgment criteria and differs largely from person to person, and from society to society (Shang & Bishop, 2000). Specific research methods of visual impact threshold refer to three landscape perceptual patterns: 1) the biological evolution pattern, 2) the individual preference pattern and 3) the socio-cultural pattern (Cosgrove, 1986; Kirchhoff & Trepl, 2009; Drexler, 2010; Hunziker, 2010; Trepl, 2012). They are based on certain preferences and evaluations. In terms of the biological evolution pattern, human beings incline to a natural and safe environment, which can offer the best chances of survival (Hunziker, 2010). The evolutionary pattern has been summarized in the "Prospect-Refuge" theory (Appleton, 1975; Appletion, 1984 in Jacobs, 2006; Ode et al., 2008; Roth, 2012) that human beings prefer the landscape allowing them to hide, as well as to observe the surrounding environment. The individual preference pattern deals with mental dispositions that result from previous individual experiences or differences in personality traits. The socio-cultural pattern determines background, eras, regions, technology and cognitive levels, etc. and is a major premise for the individual's perceived experience. A general conclusion of the visual impact threshold for WTs (h = 200 m) is 5 to 7 km (Molnarova et al., 2012).

The measurement of landscape perception should be conducted under the premise of controlled variables. In the existing landscape visual impact assessment methods, landscape perception is usually assigned as a coefficient by experts (Nohl, 1993, 2001a, 2010b). Paul et al. (2004) state that the perceptional coefficient is proportional to the size (height and width of WTs) and inversely proportional to the square of the distance. However, how and what is perceived is seen as a part of a continual learning process. This paper only discusses the currently feasible coefficient without too much in-depth discussion in perceptional science.

3.1.3 Landscape aesthetics

When the term "landscape" is initially associated with "scene", the connection between land and beautiful scenery is also established. Since the emergence of the term "landscape", aesthetics has constituted an important part of its connotations. The term "aesthetics" originates from Greek with the connotation of sensory perception (Harries, 2012; Archie. L., & Archie. J., 2006), which indicates that beautiful landscape can be perceived by all senses, not only by vision (Linke, 2017). It explains the way how people perceive, experience beauty and entertain themselves with beauty.

Along with architecture, music, sculpture, and painting, landscape is one of the classic objects of aesthetics. The question of how to define and recognize beauty remains a highly related issue in landscape research. Ritter et al. (1997) advocate that landscape aesthetics means the diversity of landscape in a "balanced, harmonious, and beautiful" order. As a significant public resource, the aesthetic landscape is protected by laws and regulations (e.g., Naturschutzgesetz, Raumordnunggesetz, Baugesetzbuch of Germany, and Code for General Planning of National Park of China). Landscape aesthetic preference is of considerable subjectivity and controversy due to the individual-social difference, the era difference, and cultural diversity (Schöbel, 2012). For these reasons, it is difficult to have a precise and definite identification of aesthetic concept in legal cases. Aesthetic preferences of landscape are hard to be sorted and judged without a theoretical framework. This section will describe the evolution of landscape aesthetic theories and give a standard framework for landscape visual impact evaluation in the context of the energy transition.

3.1.3.1 Western classical philosophical aesthetics theories

Human beings have never stopped inquiring into "aesthetics". Although the term becomes more of a universal concept than an academic issue, the essence of aesthetics is first studied in philosophy, and landscape aesthetics is only an extension of this central subject. In the field of western classical philosophy, "aesthetics", as well as "truth" and "goodness", consist of the core value of philosophy (Kühne et al., 2017). Represented by Plato and Aristotle, the classical philosophical school gives a definition that "beauty is eternal, beauty exists in physical characteristics of objects, and the essence of beauty lies in proportion and order". In the Middle Ages, philosophy was closely related to Christianity. Aesthetic theory continued the objectivism of classical philosophy and believed that God creates beauty. Thomas Aquinas, in the thirteenth century, defined "beauty" with three criteria: harmony, completeness, and brilliant color, which can be taken as the representative of the medieval aesthetic theory (Lothian, 1999; Harries, 2012). In the interpretation of the Western Philosophy of Nature, the value of aesthetics is believed as the inherent attribute of the object; it is non-anthropocentric and everlasting. Since the Renaissance, the release of human nature has broadened people's horizons of aesthetics and attracted more attention paid to the role of humans in artistic processes. Kant and Burke believed that beauty is an inherent quality to evoke an aesthetic response or experience in the observer (Lothian, 1999; Harries, 2012; Drexler, 2010). The prevalence of Anthropocentrism made the meaning of aesthetics more complicated and multi-orientated under the perspective of cultural construction.

3.1.3.2 Chinese classical philosophical aesthetics theories

Compared with the Western Philosophy of Nature, the traditional Chinese nature philosophies are "standard cultural philosophies" (Han, 2006), which focus on cultural constructions of human beings, such as ethics and morality, political constitutions, customs, gardens, paintings and so on, rather than a metaphysical ontology. In the ancient era, Chinese developed their unique landscape aesthetic theory based on one essential concept in their view of nature: "Oneness of nature and human beings" (天人合一), which requires human beings to keep harmony and unity with nature. This belief is the opposite of the anthropocentric, subject-object dichotomy that Western Philosophy often assumes as the relationship between humans and nature (Zhou, 1995). Although there are many philosophical schools (the Confucian, the Daoism, the Buddhist, etc.) in ancient China and they follow different beliefs (Han, 2006), they all show the same respect to nature and develop the aesthetic preference of natural landscape (Pang, 2012).

Influenced by the culturally constructed philosophy, landscape aesthetics is more considered as wholeness and a socially constructed ideology in the publics' mind. From the perspective of traditional landscape aesthetics, nature can be recognized as a complex and comprehensive system with elements, which were continually changing and interacting with the properties of "Yin" (阴) and "Yang" (阳). Landscape design and construction must obey the principle of Yin-Yang harmony and transition. This theory spread over the world is known as "Fengshui" (风水) (Geomancy), showing the essence of Chinese landscape aesthetics of "holistic, changing and harmony". In the Ming Dynasty (AD 1368-1644), the landscape aesthetic theories developed to a peak with the flourishing of private gardens. The author of the masterpiece *Yuan Ye* (园冶) (Ji, 1634), a famous garden designer Ji Cheng (AD 1582-c.1642), proposed typical Chinese landscape theories like the utilization of "Empty and Reality" (虚实), "Light and Shadow" (光影), "Artistic Beauty" (意境美) to guide garden constructions, which brought Chinese landscape aesthetics to a specific, detailed, and technological dimension. Chinese Fengshui theory and garden designing as traditional Chinese landscape methodology still guide the site selection, plan, arrangement and vegetation configurations in the contemporary landscape planning of China (Li, 2006).

From the initial ancestor worship to the specific garden construction technologies, the landscape aesthetic of China evolves to a mature phase while always obeys the concept: "Oneness of nature and human beings", Chinese try to gain spiritual detachment through the aesthetic experience of natural landscape. They believe that natural landscape is conductive to spiritual practice, reflection, and self-improvement. The Chinese landscape aesthetics is a holistic, practical and empirical theory without specific standards. Different from Western aesthetics deriving from natural philosophy, Chinese philosophy inclines to conduct the departmentalization analysis of the whole nature and separate the object into separable aspects of the knowledge as specific as possible (Han, 2006). Chinese landscape aesthetics is based on Humanism and cultural background. It is a guideline for living and experiencing life with improved spirit and morality in a beautiful landscape. Therefore, Chinese landscape aesthetic is deeply rooted in cultural constructed imagery and humanism, challenging to summarize and standardize.

3.1.3.3 Scenic aesthetics theories

In modern times, landscape is founded as a subject in the scientific dimension by Frederick Law Olmsted (Kühne et al., 2017). Since that, a large amount of landscape research methodologies and theories have emerged. The topic receiving the most attention is about the meaning of landscape and how to evaluate the landscape quality. Based on the above philosophical aesthetic theories, some classical landscape paradigms and theories derive from the philosophical ontology and extended aesthetic theories of respective society, explaining the landscape perception and preference from the perspectives of biological evolution and cultural theories. The current landscape aesthetic preference is based on human survival needs and historically grown synthesis of culture and nature (Kühne et al., 2017). Generally, a landscape with high aesthetic quality satisfies human biological needs to survive and thrive as a species, and provides abundant information about the cultural-social experience (Tveit et al., 2006). The theories like Habitat Theory of Orians (1980), "Prospect-Refuge" theory of Appleton (1975, 1988), the "Affective-Arouse" theory of Ulrich (1983, 1986) and the "Information Processing" theory of Kaplans' (Kaplan & Kaplan, 1982 ; Kaplan & Herbert, 1987; Kaplan et al., 1989) are more or less related to genetic and cultural influences and summarize the landscape aesthetic patterns from different perspectives (Bell, 2012; Norton et al., 1998). During the period from the 1970s to 1980s, the prosperous period of landscape research, a large number of landscape theories were put forward to explain the landscape aesthetic preference, but most of them remained on the theoretical level without implementing approaches to quantify landscape research.

3.1.3.4 Ecological aesthetics theories

With the development of Landscape Ecology, some ecologists and environmental ethicists have emphasized the importance of ecological principles in landscape aesthetic preferences and advocated the goals of management based on "Ecological Aesthetics". Gobster et al., (1999, 2007) present a sharply polarized and still ongoing debate between the "scenic aesthetics" and "ecological aesthetics". A comparison is conducted between two aesthetics paradigms from both theoretical and practical perspectives. The conclusion is that ecological aesthetics is more scientific-based with more implemental evaluation methods. Howett (1987) asserts that landscape aesthetics cannot be independent of the ecology. What makes a landscape beautiful is often intimately linked to other intrinsic landscape ecological criteria, such as biodiversity and sustainability (Jorgensen, 2011). However, ecological-oriented methods have shortcomings in dealing with cultural and regional attributes.

3.1.3.5 Postmodern aesthetics theories

In the postmodern era, the landscape methodology shifts from essentialism, positivism to social-constructivism, according to which landscape is understood not as a physical object, but as a social construction process (Kühne et al., 2017). Under the processes of the socialization of landscape interpretation, the core issue of landscape aesthetics lies on the following questions: What is the basis of the social judgment of landscape aesthetic quality? How can these social attributes be collected and analyzed and how can these attributes change over time (Kühne et al., 2017)? In Linke's contribution (Linke, 2017), the criteria describing the landscape quality are not from physical characters, but from social-constructed experience. Landscape is recognized more as a reflection and solution media of social conflicts. Along with the characteristics of dynamics and sustainability (Nohl, 2010a), landscape aesthetics has a multi-valued orientation tendency. In addition to beauty, sublimity and ugliness have developed into important categories of landscape aesthetics (Schneider, 2017; Tveit et al., 2006; Lothian, 1999; Rosenkranz, 1996; Seel, 1996). The postmodern change of values thus represents an opportunity for the acceptance of changing landscapes in the future.

3.1.3.6 Landscape aesthetics and WTs

The erection of WTs receives strong opposition at the local level, which is even addressed with a specific term ‘NIMBYism’ (Not-In-My-Back-Yard): An attitude ascribed to persons who object to the setting of something that they regard as detrimental or hazardous in their neighborhood, while they raise no such objections to similar developments elsewhere (Oxford English Dictionary, 2019b). The landscape visual impact ranks first among the rejection reasons, far exceeding the physical impacts like noise, shadow flicker, bird-kill and soil erosion (Kirchhoff, 2014; Bishop & Miller, 2007), which is due to the fact that WTs do not meet the contemporary landscape aesthetic standards (Nohl, 2010a). Residents blame that WTs have destroyed the aesthetic quality of their homeland by generating a disorder in terms of proportion (Kühne et al., 2017). Under the paradigm of social construction, landscape aesthetics is a cultural image set up by the public, which is changeable with the value of wind energy.

Never being static and isolated, landscape aesthetics is a variable, multi-value oriented knowledge framework with a growing number of subjects such as philosophy, scenery, and ecology. The evolution process of landscape aesthetic methods is transferred from essentialism, positivism to social constructivism. In the initial research phase, physical attributes are selected for describing the aesthetic quality of the landscape (***Essentialism***). Then landscape aesthetic preference patterns and evaluation criteria are set up within a scientific and systematic framework of landscape aesthetic theory (**Positivism**). Based on the complete objective theories, more social issues and cultural preferences are added from the social constructivism perspective.

In a concrete planning project, the planning implementation method remains in positivism with objective evaluation indicators describing the aesthetic quality of the landscape. There is an unstoppable tendency that landscape aesthetic preferences are becoming more diverse. The essence of landscape aesthetics is to bring impressive and precious landscape experience to the public.

3.1.4 Landscape functions

According to the principle of "Form follows function" (Chilla et al., 2016a), the beauty of landscape is interpreted as the rational expression of its functional characters (Kirchhoff, 2014), which explains the close relationship among landscape perception, landscape aesthetics, and functional aspects of landscape. The Federal Nature Conservation Act has emphasized the protection target in its first chapter: "Nature and landscape are to be protected on the basis of their own value and as a basis for life and health of the people also in responsibility for future generations in the populated and unpopulated area" (§ 1, BNatSchG), which shows us the main function of the landscape from an official perspective.

3.1.4.1 Ecological function

The ecological function of landscape refers to the whole ecological process, which concerns the value of landscape and nature themselves as well as provides humans with a sustainable survival environment. Specifically, ecological function includes the ability of landscape to retain, utilize, and cycle vital resources such as water and topsoil. The ecological function can be understood as a monitor and service for landscape health status. In addition, the ecological function reflects the fairness of landscape. Landscape not only serves human beings but also safeguards ecosystems for flora and fauna, as well as our future generations. In landscape planning, ecological indicators, which have a solid theoretical foundation and excellent operability, are usually used for monitoring the landscape quality. The ecological function can directly present the landscape qualities through attributes like biodiversity, sustainability, and stability (Křováková et al., 2015). The classical ecology theory, "Pattern-Corridor-Context", has been widely used in landscape analysis (Pickett & White, 1985; Steiner, 2011).

3.1.4.2 Cultural function

Besides biological aspects, landscape has also been examined from the perspective of culture. The cultural function of the landscape manifests itself in the process of landscape formation which always includes the interaction between humans and nature as the foundation of culture. With the same cultural background, people can recognize and analyze the landscape and then perceive and appreciate it. It is highlighted by the European Landscape Convention (Council of Europe, 2000) that landscape is an essential expression of local culture and identity, and a contributing factor in determining the quality of life (Castiglioni et al., 2015; Roca et al., 2011). The cultural function extends the connotation of the landscape by adding deep and symbolic meaning as well as regional identity to landscape under the social constructivism approach (Kühne et al., 2017).

3.1.4.3 Recreational function

The intention of establishing a modern landscape discipline is to provide urban residents with an activity space far away from urban areas usually featured by high population density (e.g., city park, green space). Such a space relates the residents closely to nature and is supposed to be beautiful and comfortable for them to relax (Meeus et al., 1990; Whyte, 2002; Jacobs, 2006). At the beginning of the urbanization process, the recreational function was always emphasized and a large number of recreational zones were built in urban parks and landscape areas (Antrop, 2000, 2004; Steiner, 2011). With the development of environmental psychology, recreation, and sociology, the recreational function of the landscape has been continuously updated and extended. The environment construction of the spaces for all-sensory experience and relaxation relies heavily on the visual landscape quality.

3.2 Landscape visual impact evaluation

3.2.1 The multiple meaning of "evaluation"

The explication of the term "evaluation" is required before the discussion of landscape visual evaluation. Literally, the term "evaluation" derives from "value" and refers to "usefulness of something". Evaluation is a judgment conducted by a subject, to test how the object can meet the demands of the subject (Tang, 2007). Notably, the evaluation method is a set of operationalized standards for reducing interference factors and uncertainty and then drawing reliable conclusions. It consists of a set of evaluation criteria, value assignment principles, weight of criteria, and synthesis rules. The standardization of evaluation procedures can ensure the objectivity and repeatability of the evaluation (Roth, 2012). The evaluation has the following characteristics:

1. Evaluation is inevitably subjective, since it reflects the attitudes, emotions, and will of evaluators.

2. What evaluation reflects is not the objective value of the object, but to what extent the object meets the need of the subject.

3. Evaluation should be based on a set of value standards or guidelines.

4. Evaluation is limited by extrinsic factors such as the era, region, society, technologies, as well as intrinsic factors like culture and morals (Tang, 2007).

The purpose of landscape visual impact evaluation is to protect the nature and landscape environment, which has two steps. The first step is the evaluation of the quality and potential impact of the landscape visual environment; the second step is the establishment of a scientific and reasonable constraint for artificial construction projects, especially highly-impacted projects, to keep the balance between landscape protection and the energy transition.

In describing and judging a specific landscape quality, assessment and evaluation are always linked and confused. There is less "assessment" - "evaluation" distinction in judging the visual impacts of the WTs. The comparison of these two terms will start with the literal meaning of two terms and then the experiences from similar projects (Daniel, 2001). The evaluation focuses on making a judgment about values based on established value standards and guidelines. It is a systematic and objective process of measuring, judging and evaluating the objects. The assessment focuses on collecting data and judging specific objects for improvement in the current situation. It is more process-oriented than evaluation by emphasizing on the whole process of the assessing methodology. In the domain of judging the landscape visual impact, landscape evaluation tries to identify which element makes the landscape better or worse and what kicks the point of this research. In contrast, landscape assessment aims to compare the visual quality of two landscapes by describing and analyzing them (Daniel, 2001). Therefore, the term “landscape visual impact evaluation” is more appropriate for exploring the reasons for landscape visual impact.

3.2.2 Development of landscape evaluation paradigms

3.2.2.1 Legislation

Since the 1950s, many countries successively entered into the state of rapid and complete urbanization and industrialization. Energy, transportation, and economic developments have misappropriated natural resources and even threatened the safety of human beings and ecological safety. Industrial dominance, air pollution, and disorderly planning changed the natural landscape images dramatically and irreversibly. Developed countries like Germany, Britain, and the United States first realized that the visual resources acted the same important role as other physical environments (Tang, 2007). Authorities took active measures to protect landscape visual environment through legislation, research, and environmental management. Since the 1980s, China has also promulgated laws and regulations for the protection of the visual resources.

Table 9 shows a collection of laws initially related to visual resource protection. The targets of the protection involve the forest, water, coast, and other precious natural environment. According to the legislation, potential visual impacts caused by planned projects need to be detected comprehensively and mitigated during the planning phase as much as possible. However, since landscape visual impact evaluation is too abstract and subjective without value standards, there is a lack of reasonable judgment basis in legal cases.

Table 9 Selection of relevant laws for landscape visual resource protection.

Country	Time	Law	Administration
U.S.A	1964	Wilderness Act	National Wilderness Preservation System
	1965	Highway Beautification Act	Federal Highway Administration
	1968	Wild and Scenic Rivers Act	Either a federal, state, or tribal agency, or as a partnership between any government entities and local NGOs
	1969	National Environmental Policy Act	The President's Council on Environmental Quality (CEQ)
	1972	Coastal Zone Management Act	National Oceanic and Atmospheric Administration (NOAA)

Country	Time	The Law	Administration
United Kingdom	1949	National Parks and Access to the Countryside Act	National Parks Commission
	1968	Countryside Act	Countryside Commission
	1981	Wildlife and Countryside Act	Country Council and Environment Agency
Germany	1974	Federal Immission Control Act (BImSchG)	Federal Environment Agency
	1977	Federal Nature Conservation Act (BNatSchG)	Federal Ministry for Environment, Nature Conservation and Nuclear Safety
	1990	Environmental Impact Assessment Law (UVPG)	Federal Ministry for Environment, Climate and Energy Economy
China	1982	Law on Marine Environmental Protection	Environmental Protection Administrative Department
	1985	Landscape and Famous Scenery Provisional Regulations	Landscape and Famous Scenery Management Committee
	1989	Environmental Protection Law	Environmental Protection Administrative Department
	1992	Urban Greening Ordinance	Government of provinces, autonomous regions and municipalities
	1994	Regulation on Nature Reserves	Relevant administrative departments of forestry, agriculture, geology, minerals, water conservancy, oceans, etc.
	2003	Environmental Impact Assessment Law	Ministry of Ecology and Environment

Sources: (Tang, 2007; Zhang, 2017; Nkomo, 2018)

A consensus over visual resource protection must be achieved before further discussing the evaluation of the value of the visual landscape. The generally recognized conclusion of the evaluation can form a solid foundation for land use planning and legal judgment. It is necessary to formulate a unified evaluation methodology and index system for the protection of the landscape visual environment within the legal framework. Both the protection-oriented and the developing-oriented evaluation methodologies should be committed to protecting the current landscape environment as well as the aesthetic rights for the future generation.

3.2.2.2 Planning and management

The improvement of legislation has prompted the planning authorities to pay more attention to landscape visual resources and to upgrade the management systems. The pioneer was the U.S. Forest Service by firstly introducing the Visual Management System in 1974 (Bacon, 1979). Subsequently, various visual management systems have emerged in different planning authorities and resource management departments, as listed in Table 10.

Table 10 The landscape visual resource management systems.

Time	Country	System	Authority
1974	USA	Visual Management System (VMS)	US Forest Service
1984	USA	Visual Resources Management (VRM)	US Land Authority
1978	USA	Landscape Resources Management (LRM)	US Soil Protection Agency
1986	USA	Visual Impact Assessment (VIA)	Federal Highway Administration
1981	Canada	Landscape Assessment and Management System	Forest Service Department

Sources: (Bacon, 1979; USDA, 1974; Tang, 2007)

Since landscape visual resources are not substantial physical spaces, its planning and management must be based on other specific protection objects. In practice, visual resources management should be adjusted feasibly according to different objects. Thus, various guidelines for protecting landscape visual resources are underdeveloped. Wind energy, as a part, is a crucial topic in this thesis. Although the objects are various, the basic framework of each landscape visual resource management system is similar. Moreover, to some extent, they all have the following structure as their components (Fig. 27).

The landscape visual impact evaluation used in planning and management systems is administratively oriented. It requires a straightforward and concise operational framework and data processing methods. There is an inevitable lack of accuracy in visual resources management systems. These visual resource systems from the United States are the representatives of the expert paradigm in subsequent academic studies, also known as a design/formal approach. It features structured quantitative and expert-led methods. More details will be given in the next section.

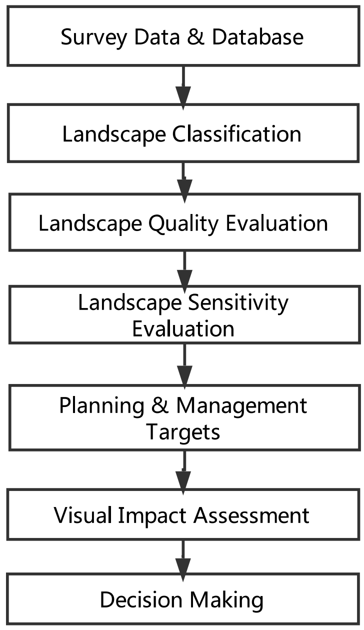


Fig. 27 The framework of landscape visual resource system (Tang, 2007).

3.2.2.3 Academic paradigms

The laws and policies promulgated by governments have stimulated the enthusiasm of academic studies on landscape visual impact evaluation. After years of theoretical research, landscape visual quality evaluation has gradually formed a multidisciplinary field that covers landscape planning, psychology and behavioral science, ecology, geography science, forestry, and other disciplines. It presents a growing trend toward integration and interdisciplinary.

The methodologies of landscape visual quality evaluation have contributed to a diversified classification system after years of practice. The original and most dominant categories were subjective paradigm (Zube, 1974; Kaplan, 1975; Daniel & Boster, 1976; Daniel, 1976; Daniel &

Schroeder, 1979; Herzog, 1987; Herzog & Smith, 1988; Brown & Daniel, 1990) and objective paradigm (Litton, 1972; USDA Forest Service, 1974; Taylor et al., 1982; Daniel & Vining, 1983). S. Kaplan (1975) summarizes landscape evaluation as "Preference Model" and "Surrogate Component Model". Zube, Sell and Taylor (1982) divide landscape evaluation methods into four paradigms: Expert paradigm, Psychophysical paradigm, Cognitive paradigm, and Experimental paradigm. Daniel and Vining (1983) propose five evaluation models: ecological model, formal aesthetic model, psychophysical model, psychological model, and phenomenological model. During the theory development period from the 1960s to the 1980s, discussions about the classification and comparison of evaluation methods and relevant criticism considerably emerged. All in all, different categories have different theoretical bases and value orientations that vary from purely formal beauty to economy, ecology, function, history and culture. Table 11 shows the essential difference in landscape perception and evaluation methodologies within four paradigms.

Table 11 Comparison of four landscape visual quality evaluation paradigms.

Paradigms	Cognition of the landscape value	The role of viewers in evaluation	Attitude towards objective attributes
Expert paradigm	The value of the landscape lies in its formal beauty or ecological significance.	Professional experts conduct the evaluation process.	It describes the landscape quality with formal elements: shape, line, color, texture and the relationship with each other.
Psychological paradigm	The value of the landscape lies in the Interaction of object and subject.	The public aesthetic preferences are used as the evaluation standard.	It describes the landscape quality with physical features: topography, landform, soil, vegetation, and land use.
Cognitive paradigm	The value of the landscape lies in the function of human survival and evolution.	Human survival needs are used as the evaluation standard.	It describes the landscape quality with abstract standards: complexity, mystery.
Experimental paradigm	The value of (subjective) landscape lies in the reflection of the history and background of people.	Emphasize the role of humans (individuals or groups) on the landscape.	It evaluates the landscape quality by including humans as a part of the landscape.

Sources: (Daniel & Boster, 1976; Taylor et al., 1982; Daniel & Vining, 1983; Herzog & Smith, 1988; Brown & Daniel, 1990; Daniel, 2001)

These paradigms are continuously summarized in practical experience to generate evaluation models. Different models have different adaptability to different evaluation purposes and objects and need to be selected according to the characteristics of each specific project. It is noteworthy that there are no conflicts among these four paradigms. They pay different emphasis on evaluation objects and viewers. Currently, common landscape visual quality evaluation models can be divided into three categories: 1) expert paradigm; 2) public preference paradigm; 3) comprehensive quantitative evaluation paradigm.

3.2.2.3.1 Expert paradigm

The expert paradigm emphasizes a modular evaluation structure, uniform evaluation criteria, and an expert-led evaluation process. It is usually carried out by the ecological model and formal aesthetic model. The characteristics of the expert paradigm are listed in Table 12.

Table 12 The characteristics of the expert paradigm.

Evaluation Method	The evaluators are professionally trained experts coming from related disciplines. They evaluate the abstract design parameters related to the aesthetic quality of the landscape and integrate all evaluation indicators to obtain the quality level of the whole landscape.
Characteristic Evaluation Process	1. Select a landscape space unit as the evaluation object 2. Select the evaluation indicators: the formal elements abstracted from the physical landscape environment like line, structure, color, and texture; and the relationship between the above elements like diversity, unity, coordination, and mystery. 3. Experts rate the evaluation object given the indicators respectively 4. The landscape unit can be divided into several quality grades according to the evaluation conclusion. 5. Depending on the grades, experts make suggestions for planning and decision-making.
Theoretical Foundation	The selection of evaluation indicators is in reference to classical aesthetic theory and human aesthetic experience.
Advantages	1. Evaluation procedures are transparent, concise, and easy to operate. 2. The evaluation methodology has a broad universality. 3. Relatively, it costs less time and finance to conduct than other evaluation paradigms.
Disadvantages	1. The conclusion has low accuracy. In this method, there are few quality grades, and most landscapes obtain a medium grade showing an ambiguous attitude. The conclusion cannot efficiently describe different landscapes. 2. Reliability and consistency cannot be guaranteed by expert-led evaluation method for the difference caused by individual experts cannot be ignored.

Sources: (Litton, 1968, 1972; USDA Forest Service, 1974; Taylor et al., 1982; Daniel & Vining, 1983)

3.2.2.3.2 Public preference paradigm

The public preference paradigm takes advantage of the opinions directly from the public through questionnaires and interviews. The collected statistics are analyzed to get a universal conclusion. This method straightforwardly shows the landscape needs of most people. Table 13 lists the characteristics of the public preference paradigm.

Table 13 The characteristics of the public preference paradigm.

Evaluation Method	The landscape visual quality is evaluated and ranked by observers according to their direct response to the landscape. Based on landscape ranking and the composition of the landscape, a mathematical model is constructed to obtain the functional relationship between specific landscape elements and landscape quality.
Characteristic Evaluation Process	1. Select the potential landscape observers as the evaluators 2. Assess the landscape visual quality through comparison and ranking grades. 3. According to the analysis of the preferable landscape types combined with the specific demographic date of evaluators, a mathematical model can be built to obtain the public preference landscape model.
Theoretical Foundation	The method is based on subjective philosophy and landscape aesthetics. Some theories like “Protest-Refuge” and “Information Processing” were later put forward to enrich this theoretical foundation.
Advantages	1. The conclusion has high reliability because evaluators give responses directly according to their perception and preference. 2. The method eliminates individual differences and evaluation errors with the big sample size.
Disadvantages	1. This method is time-consuming and labor-intensive. 2. The universality of this method is limited. The number of evaluators should be controlled from five to thirty to ensure the accuracy of the conclusion. 3. Limited by the operational feasibility, the real landscape is always replaced by photos or PPT. The degree of reduction needs to be verified.

Sources: (Zube, 1974; Kaplan, 1975; Daniel, 1976; Daniel & Boster, 1976; Daniel & Schroeder, 1979; Taylor et al., 1982; Herzog, 1987; Herzog & Smith, 1988; Shang & Bishop, 2000; Tveit, 2009; Bell, 2012)

3.2.2.3.3 Comprehensive quantitative evaluation paradigm

The comprehensive quantitative evaluation paradigm combines the expert paradigm and the public preference paradigm.

The expert approach focuses on the practical field of planning and management, while the public preference approach focuses on theoretical research. However, they are based on a consensus that the quality of a landscape visual environment depends on the quality of the landscape material environment and human sensation, both of which are indispensable. The difference of these two paradigms lies in how to abstract the relevant indicators of landscape quality, which actually refers to the selection of landscape quality evaluation indicators.

The comprehensive quantitative method combines the advantages of both paradigms to form a new evaluation model by analyzing the characteristics of these approaches exhaustively. How the landscape visual quality can be presented with specific landscape elements and how evaluators can receive a valid indication by these elements is worth exploring (Daniel, 2001).

Taking the evaluation model created by Schafer as the representative, the public preference approach is applied in evaluating landscape indicators, and the sum of evaluation indicators is the result of the comprehensive quantitative evaluation (Schafer et al., 1969; Shafer & Tooby, 1973; Shafer and Brush, 1977). This model is also called psychophysical evaluation model, which attempts to obtain the mathematical model dealing with landscape physical characteristics (terrain, vegetation, water areas, etc.) and landscape preference by measuring the proportions, characteristics, and the attributes of certain material elements. Such a mathematical model also requires the analysis of the relationship between specific landscape preference and physical characteristics with multiple linear regression equations.

3.3 Critical assessment of present methods of landscape visual impact evaluation in wind farm planning

3.3.1 Overview of existing methods

As wind energy pioneers, Germany, the United Kingdom, and other European countries have developed various approaches to landscape visual evaluation in wind farm planning. Gerhards (2003) discusses the existing methods and classifies them into two paradigms: objective paradigm (or expert paradigm/spatial paradigm) and subjective paradigm (or psychophysical paradigm) according to whether the evaluators influence the evaluation results or not (Table 14). The objective methods are mainly developed by Nohl (1993, 2010a), Köppel et al. (1998), Gerhards (2003), and Roth (2012, 2016), which advocate expert participation, a standardized evaluation process, and quantitative analysis free from any influence from landscape viewers. The subjective paradigm emphasizes on viewers' perception and emotion of the landscape. The analysis methodology can be flexible and individual without being limited by any structured framework or specific criteria and characterized by specific details.

Table 14 Comparison of landscape visual assessment methods.

Classification	Objective methods	Subjective methods
Basic value	Aesthetic and ecological value of landscape	Public preference and landscape perception
Methodology	Multi-Criteria Decision Making (MCDM) framework AHP Contingent Valuation Method (CVM) Fuzzy Analytic Hierarchy Process (FAHP)	Preference model Scenic Beauty Estimation procedure (SBE) Law of Categorical Judgment (LCJ) SD
Paradigm	Expert paradigm	Psychophysical paradigm Cognitive paradigm Experimental paradigm
Representative literatures	(Lewis, 1964; Litton, 1968, 1974; Magill & Litton, 1986)	(Daniel & Boster, 1976； Buhyoff et al., 1978; Buhyoff et al., 1979)
Characteristics	Structural, practical, conscious,	Flexible ,individual, full of specific details

Classification	Objective methods	Subjective methods
Relationship with viewers	Not including	Mainly including the perception and emotion of viewers
Participants	Expert group consists of planners, ecologists, aesthetic experts, etc.	Expert group, community, the local planning authority, public

In practice, objective and subjective paradigms are usually integrated into the Multi-Criteria Decision Making (MCDM) framework, Analytic Hierarchy Process (AHP), and Contingent Valuation Method (CVM) (IPCC, 2011) in site selection. More specific methods, like the Fuzzy Analytic Hierarchy Process (FAHP), are applied to obtain the different weights of the criteria and evaluate the alternatives (Tang, 2007). Sowińska-Świerkosz and Chmielewski (2016) discuss the methods of choosing reasonable indicators for landscape visual assessment; Del Carmen Torres Sibille et al., (2009) approach the wind farm site selection and landscape protection by using a multi-criteria comprehensive assessment method; the planning authorities in the United Kingdom have rich experiences in heritage and landscape protection, and have published specific guidelines dealing with landscape and wind farm planning (Cornwall Council, 2013; LI & IEMA UK, 2005). The following are the three typical methods broadly used by various governments for assessing landscape visual impact in the wind farm projects.

3.3.2 Guidelines based on qualitative analysis

The guidelines based on qualitative analysis are most widely used for the visual assessment of landscapes. For example, the United Kingdom (Swanwick, 2002; LI & IEMA UK, 2005; Beauchamp et al., 2006; Scottish Natural Heritage, 2012; Cornwall Council, 2013), Germany (Oligmüller et al., 2017), Australia (AILA, 2018), and New Zealand (NZILA, 2010) have promulgated guidelines to standardize the process of landscape visual impact assessment for wind farm planning. Laws and regulations of wind farm planning are defined in a general and brief way, and there is no specific discussion and further explanation for the specific operational procedures and some different treatments. Guidelines play a relatively moderate role as planning instruments, giving the wind farm project some flexible suggestions. The suggestions in guidelines are more flexible and subjective than laws and regulations, available for various implementations at the regional level. When compared, guidelines from different regions also have similarities in their content:

1）A brief introduction of the assessment object, including its essential landscape elements and spatial scope (generally for the onshore wind farms near sensitive landscape and nature reserve).

2）The goal of the guideline (protecting the landscape environment of the evaluation area and evaluating the impact level)

3）Basic principles, methods and implementation procedures of the evaluation

4）Detailed evaluation steps

5）Application of specific methods and conclusions

6）Discussion, evaluation and optimization of the guideline itself

The function of a guideline is to guide the implementation in the actual case and analyze different treatments in specific situations. The guideline is relatively more specific, flexible, and practical than other methods, but there is also a disadvantage that it reflects strong local protectionism and is highly accurate. Usually, the local government issues a special guideline for a certain region, including integrated targets for development and protection with many qualitative descriptions. It is impossible to make a quantitative horizontal comparison between cases. Additionally, the evaluation procedures in guidelines heavily rely on the evaluators with a large number of subjective descriptions. Therefore, the reliability and accuracy of the conclusion are under suspicion and received criticism.

3.3.3 Quantitative evaluation method

The quantitative evaluation methods are compensation-oriented planning instruments based on standard processes and objective indicators. Given the Federal Nature Conservation Act (BNatSchG), the erection of WTs must obey the nature conservation and landscape protection requirements. When they intervene in the landscape, effective compensation measures are legally compulsory, which include compensation, restoration, or replacement payments. Since the development of wind projects, several methods for landscape visual impact assessment have been popularized for calculating the compensation area and fees. Among them, the methods put forward by Nohl (1993) and improved by Paul et al., (2004) and Roth (2012) were widely utilized in Germany when the WTs were not as high as the current ones. Nohl aims to solve the landscape visual impact caused by mast-like installations with a quantitative formula with objective indicators:

$$K=F*e*b*w$$

In this formula, “F” refers to the area size of the actual exposure area, “e” is the significance factor, “b” is the compensation area factor, which is assigned by regional planning authorities, and “w” is the perceptual coefficient. The conclusion “K” calculated by this formula is the area that needs to be compensated. The quantitative assessment method transfers the vertical visual impact caused by mast-like WTs into the practical calculation in the horizontal actual impacted areas, which simplifies the wind farm planning procedures with a comparatively objective and conductive conclusion. Compared with landscape visual impact evaluation guidelines, the quantification of both the evaluation process and input indicators enables each project to have a basis for horizontal comparative analysis and a relatively objective and precise evaluation level.

However, due to the limited number of indicators in the formula, the appropriateness of this method is doubtful, as well as the sensitivity of indicators describing the changes of landscape visual quality. For instance, the significance factor “e” is subjective to some extent and assigned by evaluators in specific cases. The accuracy and reliability of the assessment cannot be guaranteed with ambiguous indicator concepts. Moreover, the latest generation of WTs has grown up to more than 250 m, and the influenced spatial areas are expanded exponentially. The original formula and assigned coefficients should be adjusted to adapt to the giant size of WTs. The landscape impairment of wind farms should be analyzed and evaluated in a larger spatial area and longer time duration.

No measures can compensate for a disturbance of the landscape (Blessing, 2017). Landscape intervention caused by WTs is irretrievable, which can cause a continuous and prolong influence on regional identity and landscape character. The derived value of the landscape has not been taken into account by this method.

3.3.4 3D visual simulation analysis based on computer-aided software (GIS)

With the upgrade of the 3D model and animation software, real-world data can be put into the Internet of Things (IOT) to achieve multi-dimensional dynamic analysis, as well as decision-making and real-time supervision. Currently, GIS and 3D graphic software are the most commonly used tools for the selection of the site of wind farms and the analysis of various environmental impacts. For instance, the Spanish method of visual impact evaluation (Hurtado et al., 2004; Tsoutsos et al., 2009) was the earliest case of using GIS to select the site for wind farms and calculate the affected areas. Following the research of Möller (2010, 2006), Rodrigues et al. (2010), and Molina-Ruiz et al. (2011), the spatial analysis assisted by GIS has been used broadly both on national and local level. In addition, the multi-dimensional analysis, such as the study by Manyoky et al. (2016), is a combination of visual-acoustic analysis of the wind farms through visualization and audibility in a computer simulation. Del Carmen Torres Sibille et al.,(2009), Molina-Ruiz et al.,(2011), Minelli et al., (2014), Sklenicka and Zouhar (2018) are committed to set up multi-criteria systems, combining aesthetic knowledge, spatial analysis and statistical methods to achieve more precise and reasonable conclusions of visual assessment. The animation incorporates the temporal dimension into a spatial dimension, and simulates dynamic changes in one day and one year with 4D information, so that the dynamic simulation effect is more realistic (Kokologos et al., 2014; Wrózyński et al., 2016). Moreover, when GIS is combined with other social demographic statistics, such as local population ratio, social acceptance, education level of population, land prices, more interesting findings will be discovered for optimizing the wind farm planning procedures (Kokologos et al., 2014; Gibbons, 2015). Various software and integrated methods have enriched the instruments of wind farm planning, accurately covered potential factors, and led to a more rational and accurate analysis to support the decision-making.

3.3.5 An outlook of a new method based on comparison

An overall methodology combining existing database and planning procedures has not been raised yet. The existing landscape visual impact evaluation methods mainly focus on specific methods and techniques of visual impact evaluation in wind farms. The advantages and disadvantages are listed in Table 15. The research of scientific thought guidance and methodology is not included.

Moreover, there is no interaction and feedback mechanism between landscape planning and wind farm planning procedures. An overall and practice-oriented framework is of urgent necessity in the management of the growing visual impacts.

Table 15 The assessment of the existing landscape visual impact evaluation methods.

Advantages	1. There is sufficient research addressing the impacted spatial range of landscape visual impact. 2. There is theoretical research and validation on the indicator selection for the landscape visual impact evaluation. 3. Some studies focus on the different visual carrying capacities of different landscapes, and their influential factors. 4. There is a classification of landscape visual threshold: visual sensory threshold and visual impact threshold, which clearly explains how landscape visual impact is identified. 6. There is a large number of studies concerning the cumulative effect of the visual impact caused by various WTs.
Disadvantages	1. The contemporary illustrations are mainly the plans based on bird-view, not human perspective. Visual analysis from the human visual angle is necessary. 2. There is a lack of association with existing databases like Digital Elevation Models. 3. The conclusions are too simple, merely showing the quality level or the amount of the compensation. There is no classification of the features. 4. There is a lack of feedback mechanisms that evaluate the landscape visual assessment and proposes amendments.

Sources: (Swanwick, 2002; LI & IEMA UK, 2005; Beauchamp et al., 2006; Scottish Natural Heritage, 2012; Cornwall Council, 2013; Oligmüller et al., 2017; AILA, 2018; NZILA, 2010; Nohl, 1993; Paul et al., 2004; Roth, 2012; Hurtado et al., 2004; Tsoutsos et al., 2009; Möller ,2010, 2006; Rodrigues et al. 2010; Molina-Ruiz et al., 2011)

4 The proposed procedure for Landscape Visual Impact Evaluation (LVIE) of wind farms

4.1 The aim of LVIE

In the context of the global energy transition, the dual tasks of developing renewable energy and protecting the environment should be balanced. How to mitigate the conflict between them and find an effective solution is the critical issue of this thesis. This chapter aims to enrich the knowledge of landscape evaluation with advanced scientific theories and technologies in evaluating landscape visual impacts caused by WTs. More precisely, the target is to set up a theoretical evaluation model with scientific credibility, public acceptance, political and legal viability. Based on this objective, a theoretical framework LVIE is set up, including all potentially related theories, (e.g., landscape concepts, landscape aesthetics, visual perception, landscape evaluation), and organized in a clear structure.

For the validation of this evaluation model, it should meet the following criteria.

1）The evaluation model should have sensible responses to various aspects of changes in visual quality through the utilization of the best available scientific techniques and technologies, and should be accompanied by quantifying measures reflecting the uncertainty in the current situation.

2）The framework for evaluation should be prepared for improvement, being the guidance for future research, within which the indicators are currently not accurate or difficult to be scientifically measured yet.

3）The whole process should be reliable, concise, transparent, broadly explainable and understandable to non-experts.

4）The process and conclusion of the evaluation should be clear to explain and should not risk being viewed by the courts as arbitrary and capricious (Metcalf & Stock, 2015).

5）The evaluation should remain neutral and independent of any political influence.

It has to be admitted that improving precision is a long-term process. Policy-making and uncertainty can coexist. In spite of the uncertainty, the LVIE model can still offer reliable conclusion for decision-making.

4.2 The process of LVIE

A complete process of the LVIE consists of 6 steps. The steps combine the relevant theories (see chapter 2 and 3) and research methods (see section 1.4.2).

1）Establishing the theoretical framework of evaluation: through literature review and expert interview, potential factors causing landscape visual impact are collected and classified into three main factors (landscape, WTs, and viewers) within a theoretical framework. The theoretical framework deals with the relationships among related indicators and interdisciplinary knowledge.

2）Transforming the potential factors into indicators: the process of specification, that is, how to select indicators, needs to combine the theoretical framework with the problems and requirements of planning. The indicators should be sensitive enough to reflect the slight and subtle changes in the evaluation object.

3）Taking legislative and regulatory reference: related legislative and regulative documents should be taken as references for planning at different levels (e.g., BauGB, BauNVO, BImSchG, UVPG, ROG, Luftverkehrsgesez, Landesbauordnung, BNatSchG, conservation acts of the states and the state-specific decrees in Germany and Land Management Law, Urban and Rural Planning Law, Renewable Energy Law, and Environmental Impact Assessment Law in China).

4）Seeking available data sources: only official and updated databases and data collected from planning authorities can be used as input data in evaluation, which aims to ensure the reliability and precision of the evaluation result.

5）Conducting the evaluation: the score of each indicator would be added according to the calculation method (see section 4.5) in GIS to obtain the comprehensive result of evaluation.

6）Verification of the evaluation method: the results of the evaluation need to be verified through questionnaires and statistical analysis.

4.3 Theoretical framework of LVIE

4.3.1 Principles of the theoretical framework

There are various landscape classifications and assessment methods (see section 3.2.2) (Fines, 1968; Litton, 1972; USDA, 1974; Taylor et al., 1982; Daniel & Vining, 1983; Real et al., 2000). They are developed for different research objects and suitable for different management authorities. According to previous experiences, different assessment methods, research objects, technologies, and social backgrounds cause substantial difference in the practice of the landscape assessment process. Although some methods discussed in section 3.3 are typical and broadly used, they cannot be directly introduced for mitigating the visual impact of onshore wind farm.

The socially constructed characteristics of landscape are changing with the development of society and the progress of civilization. Therefore, the landscape classification, evaluation methods, and experimental methods will be further discussed and a new theoretical framework will be established through the introduction of a new research object, WT, and the advanced computer-aided analysis methods.

In 3.2.1, the notion of "evaluation" has already been explained in a way that evaluation is a process for the viewers to judge, whether the landscape visual environment influenced by the newly erected WTs can satisfy the **viewer's tolerance threshold**. In this evaluation, the reference value system is not an absolute value but a changeable value system influenced by the scientific finding and changeable social values deriving from the complex social background and individual experience.

Although the evaluators are inevitably subjective in their ideas, the evaluation procedures can be standardized, which is supported by the rigorous theoretical framework to ensure the objectivity and repeatability of the evaluation.

As a theoretical framework, scientific ethics must first be clarified. According to the European Landscape Convention (ELC), the goal of the landscape protection is that human beings should not only share the equal rights of nature with other animals but also provide a sustainable living environment for future generations. The value system of the evaluaiton should obey this principle. It should be neither excessive humanism that focuses only on humans' requirements nor excessive naturalism that prevents any artificial development. The research must be neutral, free from any political influence, while at the same time it must meet scientific standards and help to mitigate environmental impacts effectively.

In this thesis, LVIE is proposed as an evaluation method for detecting and analyzing the landscape visual quality and the visual impact of the onshore wind farm upon the landscapes. The visual impact is directly related to the visual quality of the landscape and the characteristics of the visual perception of the proposed objects. The LVIE model is based on a comprehensive theoretical research foundation that involves the whole procedure of evaluation such as value orientation discrimination, evaluation scope determination, evaluation indicator selection, available information collection, and the detailed grading of each indicator. The model aims to identify the potential visual impact caused by WTs in specific landscape types and find viable measures to mitigate or reduce the impact. The evaluation method is a practical solution for balancing landscape protection and wind energy development in planning procedures, which can provide a professional judgment on the magnitude of visual impact and the significance of the impact in a logical and objective well-reasoned model. Furthermore, the evaluation conclusion provides a scientific and quantitative reference for the decision whether the site selection of a wind farm can be approved and makes recommendations for the follow-up compensation and management measures.

From the perspective of evaluation objects and elements, the landscape visual impact evaluation can be classified into three parts:

1) The evaluation of landscape visual quality itself, that is, the evaluation of the sensitivity of the landscape visual environment towards the surrounding changes.

2) The evaluation of the visual impact of WTs on the landscape, that is, the evaluation of the invasion of foreign objects into the landscape visual environment.

3) Viewer exposure decides the visual impact from the human-oriented perspective; the visual impact is highly related to the density of the population and the frequency that they see the WTs per day.

In planning practice, the first part is usually used for wind farm site selection at the regional planning level. In a broad spatial scope, the evaluation can afford a rough landscape value analysis for site selection; the second and third parts are more preferred in a project approval process with its accurate and quantified data results for detailed project plans. For different evaluation objects and precision requirements, each evaluation needs to be flexibly adjusted to adapt to different requirements. It is also a means of saving time and labor, and making the conclusions more precise and practical.

The theoretical framework of LVIE model is illustrated in Figure 28, which consists of three interacting bodies: Landscape, WT and Viewer. The process of LVIE can be understood as a process of judging whether the current situation meets the value standards put forward by the evaluator or not. The LVIE theoretical framework involves the connotation of the above three factors and the interdisciplinary theoretical knowledge among these factors as well. In the following part, the potential factors and relevant theoretical knowledge will be discussed and integrated into the LVIE model to construct a multi-dimensional framework with mutually constrained indicators.

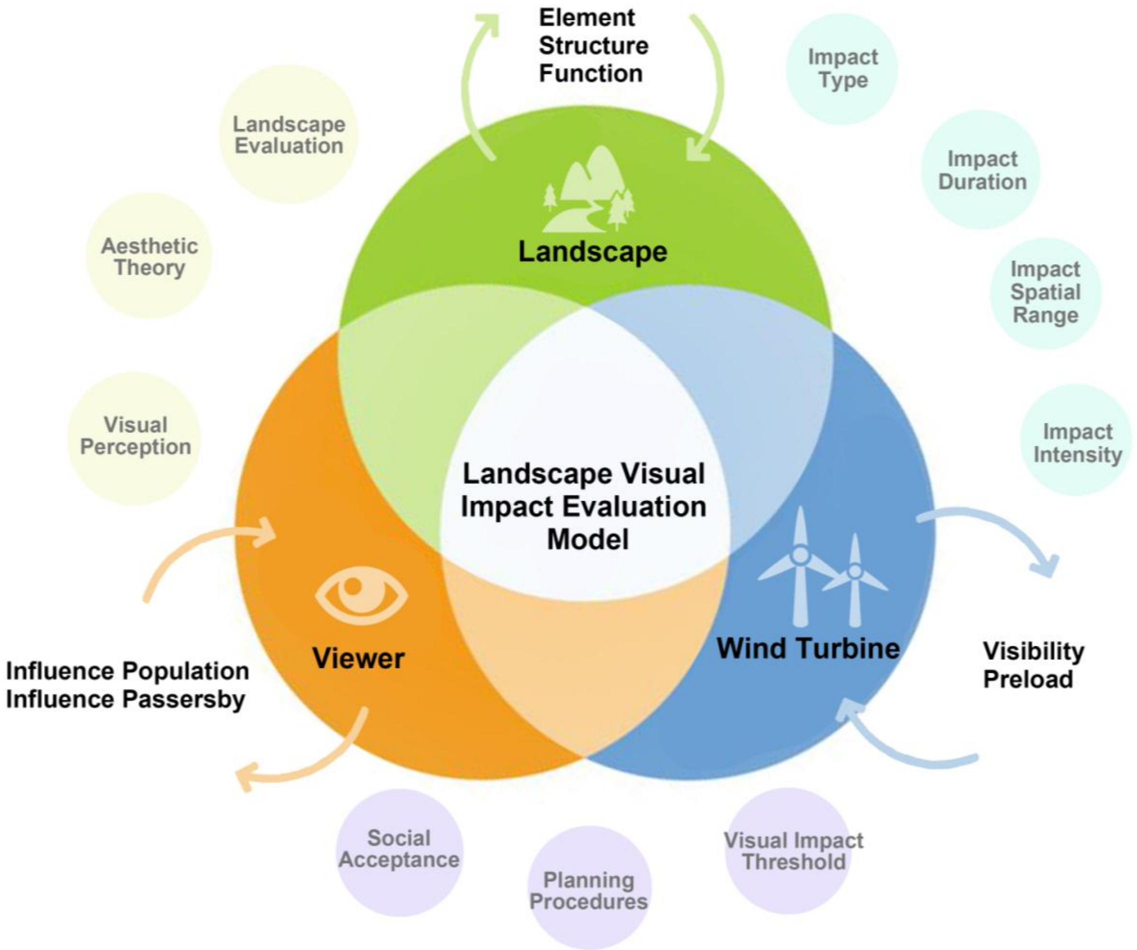


Fig. 28 The theoretical framework of Landscape Visual Impact Evaluation

Source: partly from (Noss, 1990)

4.3.2 Landscape sensitivity

Landscape sensitivity is an indicator representing the capacity of landscapes under the visual impact caused by WTs. It refers to the extent to which the character and quality of the landscape are susceptible to change as a result of wind farm installation with high visual impact. Currently, there is no widely recognized indicator set for evaluating the landscape sensitivity.

The connotations of the term landscape sensitivity and landscape quality are partly overlapping. However, a slight difference should be noticed. The former refers to the ability of the landscape to respond to external stimuli, while the latter refers to the quality of the landscape itself. Therefore, it is not appropriate to directly adopt the evaluation indicators of landscape quality. A set of targeted indicators should be designed based on existing landscape quality evaluation, and such a set demonstrates landscape attributes that are most likely to be affected by WTs (Cornwall Council, 2013). As a prerequisite in wind farm planning, highly sensitive landscape with “outstanding universal value” should be first excluded from the priority area for wind farms (UNESCO, 1996). Natural protection, landscape conservation and wild animal habitats should also be excluded, as mentioned in section 2.2.3.

A large number of studies provide various indicator sets for similar evaluation objects and planning targets. As listed in Table 16, the literature on the landscape quality assessment provides various sets of indicators, most of which are partly overlapping or used similarly. The highly identified aspects of the landscape in Germany are diversity, peculiarity, beauty, and recreational value stipulated by the Federal Nature Conservation Act (BMJV & BFJ, 2019b). As for the monitoring indicators for landscape quality, according to the European Landscape Council, they are diversity, naturalness, and peculiarity. In China, the most authoritative landscape assessment is published in the Code for Scenic Area Planning, which assesses the landscape resources through indicators of natural and cultural categories. Due to the specific landscape theories of China, the natural resource is divided into skyscape, which refers to the scenery connected to the skyphenomena and climate; landscape, which refers to the scenery on the ground; and waterscape, which refers to the scenery related to the water areas.

Table 16 The existing academic research on the indicators of landscape quality assessment.

Author	Year	Evaluation goal	Indicators
B.N. Sowińska-Świerkosz & T.J. Chmielewski	2016	Landscape quality	Land use structure, spatial order, natural values, environmental quality, cultural values and aesthetic values
W. Nohl	2010b	Landscape visual quality	Diversity, nature, proximity and peculiarity
M. Tveit, Å. Ode, G. Fry	2006	Landscape visual character	Stewardship, coherence, disturbance, historicity, visual scale, image ability, complexity, naturalness and ephemera

Author	Year	Evaluation goal	Indicators
C. Swanwick	2002	Landscape Character Assessment (LCA)	Landform, land cover, semi-natural vegetation, field pattern, aspects of settlement and aesthetic characteristics like open skies, long views, or a strong sense of enclosure
H. Gulinck et al.	2001	Landscape quality	Integrity, diversity, construction, aesthetics and ecological qualities
F. Arler	2000	Landscape quality	Biodiversity, atmospheres and characters, pictorial qualities, historical and narrative values
Code for Scenic Area Planning (Chinese)	1999	Landscape resource	Natural resource: skyscape (天景), landscape (地景), waterscape (水景), ecological landscape; cultural resources: gardens, architecture, heritages, local customs
J.F. Coeterier	1996	Landscape quality	Unity, function, maintenance, naturalness, spaciousness, development in time, soil, water and sensory qualities
T. Daniel & R. Boster	1976	Scenic Beauty Estimation (SBE) Method	A dual component model including observer's perception of scenic beauty and his judgmental (esthetic) standards

The selection of sub-indicators of "landscape sensitivity" is based on the research of indicators' theoretical foundation, including a presentation of the possible data sources of the proposed indicators. In order to research landscape quantitatively and objectively, the concept of landscape will be further decomposed. Table 17 progressively decomposes the whole landscape into elements (essentialist approach), structure (positivist approach), and function (constructivist approach) dimensions (Linke, 2017). The table presents the theoretical foundation of the landscape decomposition process, which is also mentioned in section 1.1.2.1.

Table 17 The decomposition of landscape.

Representing attributes of the landscape	Expression formality	Contents	Theoretical foundations
Element	Content and characteristic of elements	Water, soil, air, vegetation, architecture, texture, color, etc.	Its essence and properties decide the characteristics of the landscape.
Structure	Combination form, relationship between elements, and scale of elements	Boundary, relief, shape, density, etc.	Scientific and cartographic method defines the landscape as the measurable and visible distributions of objects.
Function	Description of landscape identity	Diversity, peculiarity, beauty, naturalness, coherence, etc.	It focuses on how society recognizes, describes, and evaluates the landscape.

This section divides the indicator set of landscape sensitivity into a set of sub-indicators: element, structure, and function. The compositional element, structure, and functional aspects of the landscape are interdependent, interconnected and bounded by a larger sphere of concern (i.e., the earth) (Noss, 1990).

4.3.2.1 Landscape element

Landscape element refers to the basic materials that make up the overall landscape, e.g., soil, water, air, vegetation, architecture. The elements constitute the research foundation of the landscape. They have both physical and visual perception properties. Their characteristics contribute to the features of the landscape, and their values also affect the overall value of the landscape. Additionally, special elements can represent the identity of the locality, support particular functions, and receive a symbolic value (Antrop, 2005), which is critical in the evaluation process of landscape sensitivity. The content and characteristic of each element can determine whether the WTs can interact with the overall landscape space harmoniously or not.

In the theoretical framework of LVIE, the attributes of landscape elements determine the visual impact carrying capacity in the overall landscape caused by the specific proposed project. For the selection of the specific indicator, the target is to find an accurate indicator reflecting the carrying capacity of different landscape elements for the visual impact of WTs.

4.3.2.2 Landscape structure

The landscape structure is related to the spatial combination, the relationship among elements, and the scale of elements that make up the landscape. For detecting the landscape visual impact caused by WTs, the landscape structure is an important indicator to describe the landscape sensitivity and the key attributes deciding whether the WTs and the host landscape are compatible. The landscape structure can be categorized into two dimensions: vertical and horizontal structure.

The vertical landscape structure determines the visibility, sightline depth and accessibility of WTs. The visibility is mainly influenced by the topographical factors: elevation variation, ridge density and landmarks, which are put forward by Sklenicka and Zouhar (2018). In their study, elevation variation refers to the height variation of the topographical surface. The greater the height variation of the topography is, the smaller the visible area is. Ridge density is a parameter describing the perceived depth of scenery. The high mountain ridge can obstruct the sightlines and restrict the visual impact to a smaller spatial range. Landmarks give a reference to the original landscape scale. The size of the WTs should match the size of the landmarks. Landmarks usually influence traffic accessibility because of their recreational function and hence the attraction to the tourists.

Besides the factor of WT height, the elevation variation determines the visual area at close range (Sklenicka & Zouhar, 2018). Due to the undulating terrain, the complete landscape is divided into small visual spaces. The sightline blocked by the terrain, which affects the visibility of WTs (Klouček et al., 2015) and enhances the contrast between the huge size of WTs and the small-scale of landscape units. Because the size of modern WTs has grown up to more than 250 meters, which is much larger than any natural elements in a traditional landscape, the undulating terrain cannot "hide" the huge WTs. Although the visible area can be reduced in the undulating terrain, the giant size of WTs can have a more intense visual impact on small-scale landscapes. For instance, the visual perception range of a medium-size landscape is about 10-50 meters, which cannot accommodate vertical structures over 200 meters. Uncoordinated structures lead to cognitive dislocations and structural imbalances, undermining the original sense of scale and landscape quality. Moreover, the landscape may lose its own identity and landmarks by inserting obvious technological symbol elements, such as WT.

However, the theoretical visibility zone of WTs may be larger on the plain. WTs up to 200 meters can be recognized at a distance of 20-30 km under good visibility. Without the restriction by topography, the visual threshold of the WT is related to the color contrast between WTs and background, air quality, local climate, and atmospheric scattering (Bishop & Miller, 2007; Shang & Bishop, 2000). On the plain, although the visible area is much bigger than that in the valley, the size of the WT is more adapted to the broad landscape scale. There are no severe visual impacts generated under this circumstance except for an extremely close distance.

From the horizontal structure perspective, the density and diversity of the patches determine the landscape sensitivity (Frank et al., 2013; Lee et al., 2008). Patch density is decided by the size and boundary of landscape patches. In general, the larger the size of the patch is, the higher the landscape stability is, as well as the visual carrying capacity for the WTs. This finding is also confirmed by the ecological theory: if the landscape is fragmented by infrastructure facilities into small patches, it is visually and ecologically sensitive to WTs. The indicator "diversity" has been broadly used in landscape assessment since the highly diverse ecosystems can optimize the suitability and stability of the landscape (Ode et al., 2008; Walz, 2015). Here, we understand patch diversity as the diversity of land use, structures, and forms (Haber, 2008). The indicator representing the diversity of patch structures is essential in landscape sensitivity evaluation. The patch diversity describes the structural characteristics and spatial heterogeneity (Syrbe & Walz, 2012), which is helpful for planners and developers to capture the spatial characteristics of the landscape, avoid construction in highly sensitive regions and set further development goals.

4.3.2.3 Landscape function

The landscape function is highly correlated with the value system in LVIE. The visual impact hampers the specific functions of the landscape and thereby reduces the overall value of the landscape. The decline in value is difficult to measure, while the impact on function can be respectively classified and analyzed. The functional classification itself is a constructed concept of distinguishing different aspects of the landscape that humans need, and sometimes different classifications depending on different purposes. From the ecological perspective, the landscape has the regenerative capacity of natural resources and supplies eco-service for humans; from the cultural perspective, landscape protects the cultural prosperity and establishes local identity; from the recreational perspective, landscape also affords spaces for entertainment and benefits human health. The quality of a landscape is measured by the extent to which it is able to provide these services (Kienast et al., 2013). This section explores which aspects of the landscape function are visually affected by WTs, and which functions are most sensitive to WTs. As discussed in section 3.1.4, for the majority of tourists, the ecological, cultural, and recreational function of the landscape is negatively affected by WTs, except for the case that there is a small part of tourists who are fond of techniques.

As for the ecological function, firstly, the wind farms are prohibited in nature protection and landscape conservation areas. Site selection in natural landscape areas should be approved by Environmental Impact Assessment. WT causes substantial ecological impacts on the landscape in the construction phase and operation phase (section 3.3.3), e.g., vegetation degradation, soil compaction, microclimate change, wild animal hurt (Katsaprakakis, 2012; Leung & Yang, 2012; Dai et al., 2015).

As for the cultural function, the WT brings about more sustained impacts on landscape cultural values (Breukers & Wolsink, 2007). Elements with strong scientific and technological intentions will change the original features of the landscape, especially the historical landscapes and cultural landscapes, since they undermine the overall harmony of the landscape, the regional identification and regional sense of belonging in the long-term (Soini et al., 2011).

There are various kinds of recreational functions performed by the modern landscape, and their sensitivity to WTs varies given specific recreational types. Some all-sensory experience landscape and recreational facilities with the theme of recuperation are particularly sensitive to the visual and other attached impacts from WTs. In extreme cases, large wind farms can even affect the income of leisure resorts and tourist destinations, as well as the land price of real estate (Gibbons, 2015; Geraint & Gianluca, 2016).

4.3.3 Visual impact of WTs

The main factors causing the landscape visual impact are the continuously growing number and size of WTs, as well as their negative visual characteristics. As discussed in section 2.3.2, the visual impact varies from different structures and characteristics of WT components. Meanwhile, visual impact can be subdivided into construction, operation, dismantling, and repairing phases for targeted

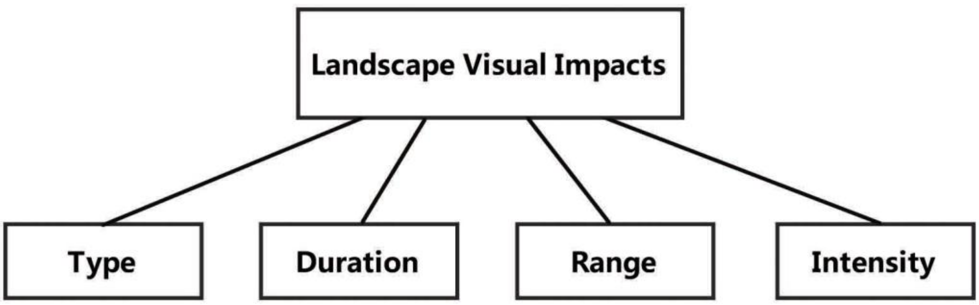


Fig. 29 Four aspects of landscape visual impacts

measures. As shown in Figure 29, there is a more practical category put forward in this section for evaluation process that divides visual impact into four aspects: type, duration, range, and intensity (Gerhards, 2003).

4.3.3.1 Impact types

The influence types are related to the interaction between WTs and the landscape. According to the discussion in section 4.3.1, the impact types are divided into:

1) Changing of landscape elements;
2) Changing of landscape structure (the visual relationship between landscape elements);
3) Changing of landscape function (or landscape character);
4) Changing of visibility.

These four situations depend on both the sensitivity of the landscape background and the extent of visual impairments caused by WTs with their specific appearance features. In the context of wind energy planning, various visual impairment aspects are characterized in the following terms (Nohl, 1993, 2001b; LANA, 1996): loss of the natural environment through introducing of the anthropogenic-technical elements (Adam et al., 1986); changing landscape characters through introducing of the non-local elements; increasing uniformity and monotony through eliminating of the local landscape characters and installing of ubiquitous elements; breaking the horizontal structure through installing of huge vertical constructs; the movement of rotating blades will cause strong visual appeal, which may destroy the sense of stillness and remoteness in the natural landscape; huge WTs may compete with original skylines and existing landmarks; reducing the cultural and historical value of the landscape.

As for the principle of the site selection of wind farms, areas with continuous and stable wind energy resources and fixed wind direction are suitable. However, these suitable sites are generally flat without any protrusion and highly visual exposed such as the plains, ridges, and coasts. Meanwhile, these sites usually have a high landscape peculiarity, biodiversity and are exceptionally sensitive to visual impairment caused by artificial elements. The types of the possible landscape visual impact caused by artificial elements (WTs) can be classified into five levels of visual impact in ascending order as follows, as listed in Table 18.

Table 18 Different impact types in ascending order.

Level	Visual Impact Description
1	The artificial elements are integrated into the original landscape to improve the quality of the landscape through new spatial planning and local environmental remediation.
2	The artificial elements are integrated into the original landscape. The quality of landscape is basically unchanged.
3	The artificial elements are erected in the area with a preload of artificial constructs. With the artificial elements newly erected, the intensity of landscape visual impact gradually decreases.

Level	Visual Impact Description
4	The artificial elements have conflicts with the original landscape character and cause impairment to the landscape and reduce its visual quality.
5	The artificial elements have conflicts with the original landscape character and become dominant in the new landscape.

4.3.3.2 Impact duration

The influence duration can be divided into temporary, long-term, permanent influences and periodic changes.

1) Temporary influences refer to reversible impairments caused by temporary activities, such as installation, demolition and debugging. The noise, dust, vegetation damage, and soil erosion belong to this category.

2) Long-term influences refer to typical visual impacts that emerge with the WTs during their operation of 20 years. Additionally, the visual impact is changing with the wind direction.

3) Permanent influences are abstract and usually unmeasured. As a carrier of culture and emotion, the landscape is closely associated with human civilization and history. The changes in landscape characteristics are permanently irreversible. For instance, the industrialization and urbanization irreversibly change the landscape of certain areas and cause a sense of nostalgia and homesickness. The influence caused by WTs can be permanent since they destroy local identity badly.

4) Temporal elements in landscape visual impacts refer to the periodic changes of the evaluation object, which should be taken into consideration during the evaluation (Roth & Gruehn, 2012). Visual obstructions, like different vegetation foliage states, always change with time. The height and density of vegetation affect sunshine, light, skyline, key viewpoints, etc. Seasonal changes like sunshine, shadows flash and vegetation in summer and winter can be analyzed as extreme cases.

4.3.3.3 Impact spatial range

Compared with other environmental impacts like noise and shadow flicker, the visual impact can cause a negative influence in a broader spatial range. According to theories of visual perception, psychology, landscape aesthetics, etc., landscape visual impact is complicated and difficult to measure, since it is not only related to land cover and vertical constructs on the ground but also decreases with distance nonlinearly. In this section, the research of visual impact can be divided into two parts:

1）Theoretical Visibility Zone (TVZ) and Actual Visibility Zone (AVZ)

For the evaluation of the visual impact, an essential prerequisite is to detect the visible zone of WTs. With computer-aided tools such as GIS, the Theoretical Visibility Zone (TVZ) is easily achieved through the analysis of the Digital Elevation Model (DEM), the coordinates, and the height of WTs. However, the actual situation is far more complicated than the theoretical model, and there are more factors that need to be considered in the reality. For instance, the surface ground is not as flat as a digital terrain model. Any vertical structures (vegetation and artificial constructs) can be the obstacle to the viewing of the WTs. Climate conditions and air quality also influence the actual visibility range. With more advanced technologies and the involvement of new parameters, computer simulation results are getting closer to reality.

2）Visual Impact and Distance Classification

Real visual impacts are not linearly reduced with distance (Nohl, 1993; Paul et al., 2004). The method of distance classification is a combination of human physiological vision, empirical studies and normative prescriptions or conventions. The curve describing the relationship between visual impact and distance is also taken into consideration in this partition (Bishop, 2002). Usually, the visual impact areas are divided into several zones in terms of distance, such as near, medium, and far zones. An overview of the classification of the visual influenced zone is given in Table 19.

Table 19 The researches about the classification of visual influenced zone.

Author(s)	**Proposed delimitation of the visual influenced zones**	**Remarks**
Grauthoff 1991	Visual influences areas are classified into 3 zones: Extremely influenced zone: 0-3H (corresponding to a visual angle of more than 20°)； Dominance zone: 3H- 10H； Visibility zone: 10H - 10 km away or even beyond.	He refers to the height of a small WT, which is a reasonable factor for zone classification.
Hasse & Schwahn 1992	Thresholds are set for the distinction of visibility at 500 m and 3 km.	The classification is based on the investigation of WTs.
Battefeld 1997	Mast-like projects over 30 m high have a visible zone with a radius of about 5 km, and possibly even further in exposed locations.	The height of the WTs needs to be updated in this research.
Breuer 2001	The radius of the seriously influenced zone will reach 15 times the height of the WT. The radius of the visible area will reach 50 to 100 times the height of the WT.	/
Paul et al. 2004	Visual influenced areas are divided into 3 zones: Foreground 0-200 m; Middle ground 200-1500 m; Background 1500-5000 m.	A perception coefficient will be generated relatively with distance grades.
Nohl 2010b	Potentially affected areas are divided into 4 zones: 0-200 m, 200-1500 m, 1500-5000/10000 m. 10000 to infinity. (Negligible)	The classification is based on empirical research on visual impact evaluation of WTs.

Sources: (Gerhards, 2003; Paul et al., 2004; Nohl, 2010a)

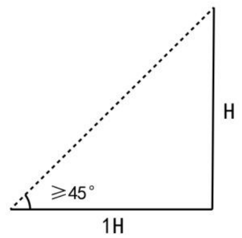
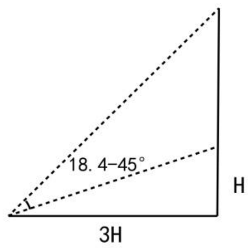
As Table 19 lists, the method of fixed distance has been widely used in the planning implementation. However, it does not consider the growing height of WTs. The method of the multiplying of the turbine height is used again nowadays, which has been first mentioned by

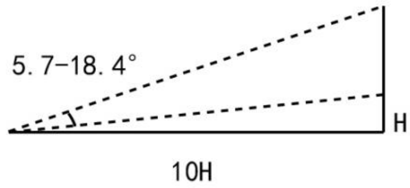
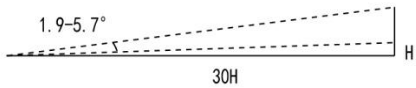
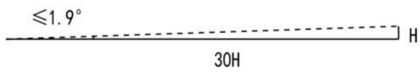
Grauthoff in 1991. Schöbel (2012), Liu and Fan (2013) analyzed the relationship between visual quality and viewing angle (or the proportional ratio between the height of objects and viewing distance), which laid the theoretical foundation for setting buffer according to the multiplication of the turbine height.

In Germany, the requirements for the buffer distance of WTs are strictly listed and vary in different states: Schleswig-Holstein requires a 3H buffer distance between WTs and residential areas, while North Rhine-Westphalia 5H and Bavaria 10H (BayBO, 2007; Fachagentur Windenergie an Land, 2019). The different attitudes toward wind energy depend on local industries, cultural identity, and the supporting rate for wind energy. In China, although the cumulative wind energy capacity ranges the first of the world, related planning regulations and standards have not been completed. Till now, there are no official standards for buffer distance in China. The existing planning regulations are mainly adopted from the experiences of developed European countries.

In order to cope with the ever-increasing height of the WT, the buffer zone of visual impact can be divided into five visual impact levels as listed in Table 20. The method is also consistent with the principle of visual perception and visual impact threshold in section 3.1.2.

Table 20 The visible distance classification for WTs.

Distance	Viewing angle	Remarks	Illustration	
≤1 H	≥ 45°	The WT and background landscape constitute a close space. Within this range, it is suitable for observation and operation. Other functions should be excluded within this distance.		
1-3 H	18.4°- 45°	The WT and background constitute a medium-size space, in which the WT can dominate the landscape feature and bring about a strong sense of pressure. The functions of agricultural, animal husbandry, forestry can be performed in the 3H distance but sensitive to any artificial constructions. Because the noise, shadow flicker, and lighting at night cause physical annoyance for people.		

Distance	Viewing angle	Remarks	Illustration
3-10 H	5.7°-18.4°	The WT and background landscape constitute a large-size space. The controversy about visual impact buffer distance mainly concentrates on this area. In terms of different states in Germany, there are different buffer distance regulations, which are set according to local situations like wind industry development scenario, wind resource distribution, natural conservation and landscape protection areas. For instance, Bavaria revised the buffer distance of WTs to 10H for protecting local landscape visual quality.	 
10-30 H	1.9°-5.7°	The WTs constitute a part of the background but are still clearly perceived by people with a large number of rotating WTs. Wind farms need to avoid areas of high value such as nature conservation, landscape protection areas and cultural heritage sites.	 
≥ 30 H	≤ 1.9°	The possibility of visual interference can be basically eliminated at a distance of above 30 H.	 

Note: The photos are taken from Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale by the author, showing the visual relationships between WTs and landscape, with the hub height of 137 m.

4.3.3.4 Impact intensity

The visual impact intensity can be understood as the superimposed visual perception of both WTs and the external environment, which can increase or reduce the intensity of visual impact because of several factors (preload, cumulative effect, rotation speed, visual angle, and coordination with background).

4.3.3.4.1 Preload

Preload refers to the fact that people have relatively high acceptance when the visual impression is already dominated by technical or industrial structures in the locality. In these areas, which are generally characterized by a relatively low regional identification, newly installed wind farms have no significant negative effect because local people are less sensitive to installed wind farms in constructed areas than those on virgin land, which is already proved by some cases (Schöbel, 2012; Del Carmen Torres Sibille et al., 2009). The concentration of WTs, which causes preload, can reduce the proportion of influenced population and influenced areas in a macro background and protect some precious natural resources, but cause more serious visual impact to overlapping in specific concentration zones.

Fig. 30 Preload in Zhongying Wind Farm (Taken from Zhongying Wind Farm)

From the perspective of the project, preload helps the project to achieve approval quickly. With the preload, the project evokes less protest and requires less compensation compared to the ones constructed on virgin land. However, in terms of aesthetical impact, the visual impact on landscape has not been mitigated in regions with high acceptance. On the contrary, the visual impact is even more significant in "concentration zones" than that on the virgin land, which is opposite to the German constitutional goals for spatial planning, that is, the equality of living conditions between different communities. The landscape visual quality in priority areas should be controlled and meet the statutory requirement. However, different standards should be set for suitability areas and exclusion areas.

4.3.3.4.2 Cumulative effect

The cumulative effect focuses on the overlay visual impact of multiple WTs. Comparatively, preload is a more abstract concept concerning psychological and social-constructional aspects. In the visual sensory experience of human eyes, the intensity of visual impact does not merely increase with the growing size and number of WTs. It is a multi-factor function, interrelated with distance, number, size of WT and their visible parts.

In an ideal case, a wind farm with a regular layout has several rows of WTs. The first row exerts the strongest visual impact, while the visual impact caused by the second row is lower because of the “distance factor” and “partial visibility factor” (Del Carmen Torres Sibille et al., 2009). Paul et al. (2004) propose a “partial visible factor” to describe the arrangement of WTs in an idealized array, which is calculated according to the proportion of the visible part in the total height. It reveals that the visual impact is not proportional to the visible scale, but a logarithmic function. In terms of WTs, the landscape sensitive parts concentrate on the sweeping surface of the blades. The partial visibility does not reduce the visual impact considerably. Mitigation measures for the protection of landscape visual quality should take these factors into consideration and “hide” the total WTs as much as possible.

4.3.3.4.3 Rotational speed

As discussed in section 2.3.3.3, the motion status of WTs can influence the visual impact. More precisely, the visual impact intensifies with the increasing rotational speed of turbine blades (Shang & Bishop, 2000; Möller, 2006). However, speed perception varies greatly from person to person, and can also be significantly improved through training. Thus, it is difficult to quantify the relationship between rotational speed and visual impact. There is a tendency that the growing length of turbine blades can reduce the rotational speed from 30~60 RPM (revolutions per minute) to 10~15 RPM, thereby reducing the visual impact to some extent (Heier, 2016). This is an advantage of the modern, bigger WTs that have slower rotational speed. However, the static turbines will bring the opposite effect because static WTs are recognized as a kind of resource waste (not in use) subjectively.

4.3.3.4.4 Visual angle

The visual impact would be significantly different when WTs are viewed from different angles. The sweeping-surface of a WT contributes the most visual impact. For instance, when the sweeping surface is parallel to the observer's sightline (the visual angle is 0°), only the facade side of the WT would be seen and the visual impact would be minimal. When the sweeping surface is perpendicular to the observer's sightline (e.g., the visual angle is 90°), the observer would see the WT with the largest projected area of background landscape, and the visual impact would be maximal. The visual angle factor can be quantified through the calculation of the projected area of WTs. The visual angle factor can be quantified through the calculation of the projected area of WTs combine with the data of wind direction.

4.3.3.4.5 Coordination with backgrounds

For large scale wind farms, whether the silhouette enveloping a group of WTs coordinates the background line or not also influences the landscape visual quality. Generally, the background is the skyline or the horizon, which depends on the position of the viewer. The background line can be generated in GIS, a 3D model with Digital Elevation Model and land cover. Taking the background line as a reference, the distribution and design of the WTs should have regard for aesthetic factors such as coordination and continuity (Bishop, 2011). Schöbel (2012) lists several layout patterns of WTs, corresponding to different landscape structures and background. Del Carmen Torres Sibille et al.

(2009) quantify the coordination index with fractal theory. Either in the project-oriented method or in the theoretical quantification method, the coordination indicator involves multiple interference factors of psychology and visual perception.

4.3.4 Viewer response

The "viewer response" refers to the subjective response from the viewer based on the perception of the visual information. It mainly depends on how the viewers perceive and judge the landscape visual impact. Viewer response is constrained by two principal factors: viewer sensitivity and viewer exposure (Fig. 31). "Viewer", as the critical participant in the visual impact evaluation, is the most unpredictable factor. There are various factors that can help the researchers to approach the viewer effectively, which can be categorized into subjective features (viewer sensitivity) and objective influence from the outside (viewer exposure).

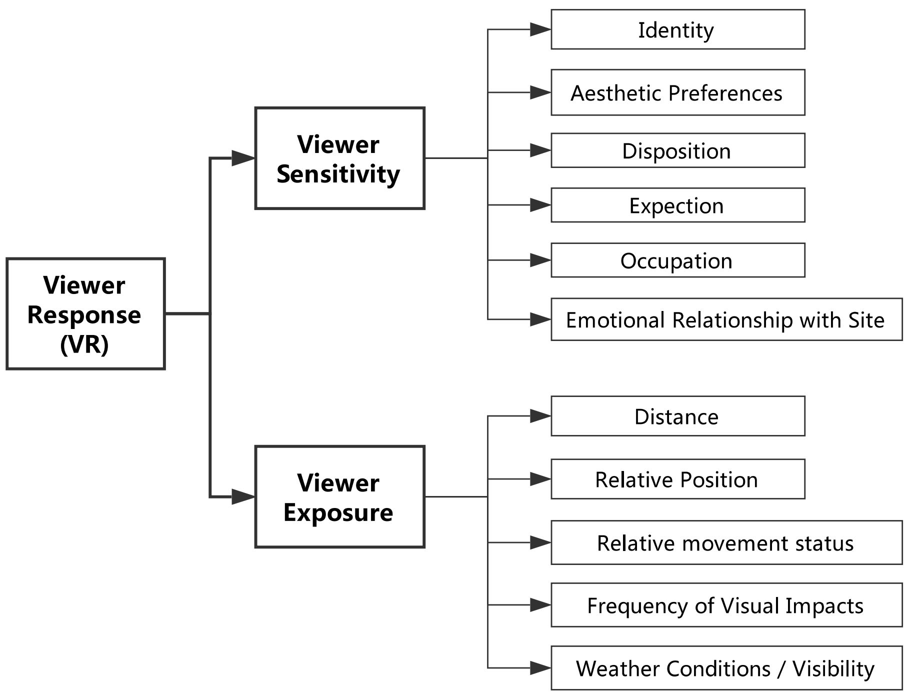


Fig. 31 The factors of Viewer Response in Landscape Visual Impact

4.3.4.1 Viewer sensitivity

Viewer sensitivity refers to various individual subjective aspects like identity, aesthetic preferences, disposition, personal feelings about certain sites, expectation, occupation, personal experiences (Daniel & Boster, 1976; Devine-Wright, 2005; Gobster et al., 2007; Sevenant & Antrop, 2010). Different characters and cultural backgrounds determine various attitudes towards wind farm projects. These individual aspects always change with the surrounding environment.

However, when people experience the landscape, some impressions or emotions, such as pleasure or disturbance, are formed directly in their subconsciousness (Bell, 2012). We cannot distinguish the specific reasons why we like or dislike certain landscape, not to mention quantify the contribution of each reason. The affective response on landscapes can be explained by "landscape preference models" based on qualitative analyses through extensive and empirical social-scientific investigations on site. Preference models can reveal a high level of commonality within cultures and regions.

In the evaluation of viewer sensitivity, personal experiences and individual characters are usually neutralized by large samples. Therefore, individual preference causes little effect on the conclusion in empirical research, even the personal ties to certain sites would not be shown (Wellman & Buhyoff, 1980). The public landscape preference can be attributed to innate human evolution and acquired social construction. It also explains how the models of public landscape preference are formed under both affective and cognitive responses (Bishop, 2011). With relatively consistent affective and cognitive responses to the landscape across the population, some typical models of landscape preference are established for landscape assessment and impact studies. For instance, based on the "Affective-Arouse" theory (Ulrich, 1983, 1986) and "Prospect-Refuge" theory (Appleton, 1975; Appletion, 1984 in Jacobs, 2006; Appleton, 1988), the interdependent factors of different stakeholders can be summarized in simple relationship graphs, demonstrating the similarity or difference in the attitudes towards wind farms.

4.3.4.2 Viewer exposure

Viewer exposure refers to the proportion of the population under the influence of visual impact, which is restricted by external conditions. For instance, the distance, relative position, relative movement status, the frequency of visual impacts and weather conditions (visibility) can influence the visual perception of the viewers (Fig. 31). To some extent, visual exposure is objective and can be quantified for providing references for planners and decision-makers.

1) The influenced proportion of the population

In the research area, the residents who are directly faced with the rotating WTs usually hold the most negative attitude supported by NIMBYism (Not-In-My-Back-Yard) (Wolsink, 2007a; Petrova, 2013). Molnarova et al. (2012) prove that households close to wind farms are the primary victims of visual impact. Their visual experience should be protected or compensated. According to the research of Strumse (1996) in Norway, when the influenced population reaches 30 %, it is not suggested to construct new wind farms nearby. Möller (2006) introduces the data of the population in his research of visual impact evaluation and draws comparative results among several years based on spatial analysis. The common point is that the proportion of the affected population in the research area usually reflects the intensity of visual impacts.

2) The influenced proportion of the passersby

The landscape sightline refers to the sight corridor with high aesthetic value. It contains observation points, appropriate observation distances and viewing targets (Tang, 2007). The aesthetically pleasing sight corridor may be obscured by WTs and the original landscape structure and aesthetic value may be seriously damaged. Not only the residents, tourists and passersby may also suffer visual impacts during their travel. In addition, roads with different traffic flows should be given different weights. Cowell et al. (2012), Latinopoulos and Kechagia (2015) have considered the road access and visual impact during transportation in their research of wind farm spatial analysis.

In summary, the method to quantify "viewer exposure" is to combine different approaches like topography, residential land use, surface constructs as well as counting the exposure of roads to WTs. Rather than calculating the absolute value of exposure degree, this method provides a benchmark for comparison (Möller, 2006).

4.3.5 Limitation of LVIE model

In the actual operation of LVIE model, it will be inevitably affected and constrained by various factors. Figuring out the types and causes of constraints helps to find practical solutions. Generally, constraints can be divided into external and internal constraints (Fig. 32). During the evaluation, evaluators should rationally view the existence of constraints, judging the scope and level of evaluation, and then select appropriate evaluation standards.

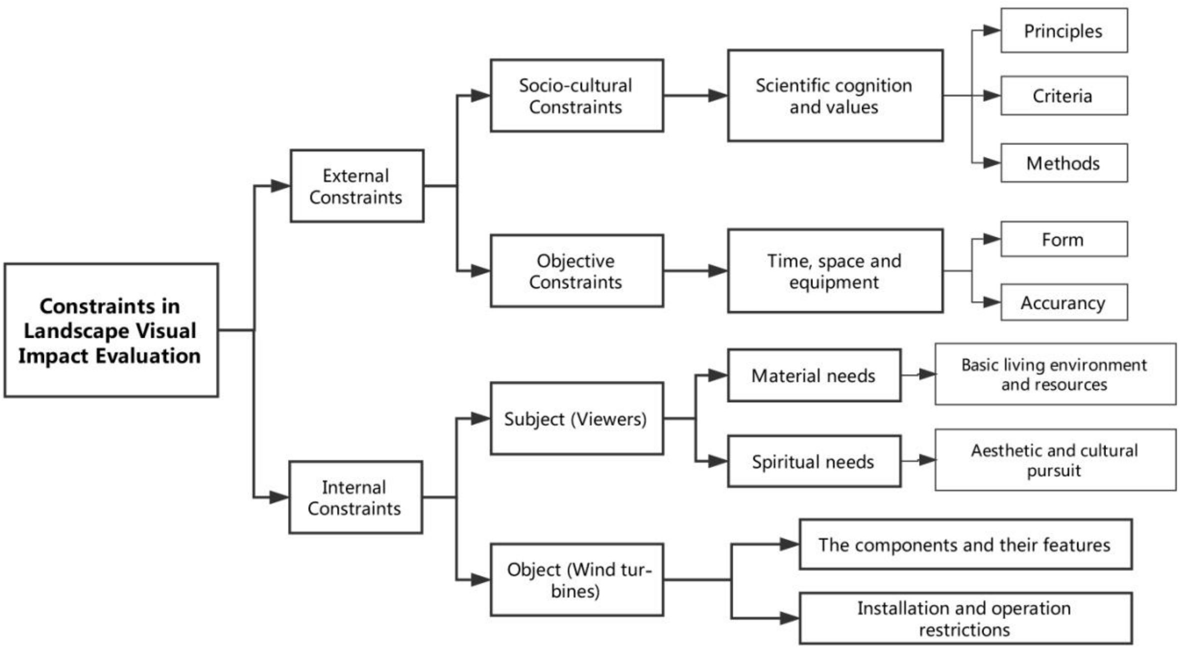


Fig. 32 Constraints in the LVIE model (Source: partly from Tang, 2007)

The external constraints include objective constraints and socio-cultural constraints. First of all, research must be based on a specific time and spatial range, and their attributes and limitations. It is also limited by the accuracy and technical level of the current types of the equipment for detecting and processing data. Though socio-cultural constraints are vaguer and blurred as a cultural background for the research topic, the value systems and cognitive level of the evaluators also decide the evaluation process.

The internal constraints include the subject of evaluation (the viewers) and the object of evaluation. The essence of the evaluation is to examine whether the objective quality of the object meets the evaluation criteria set by the subject. Firstly, the evaluation is constrained by the needs of evaluators. The needs can be divided into many levels. In the Introduction to Karl Marx's Wage Labour and Capital (1891), Friedrich Engels classified the main needs of humans into"means of life, of the enjoyment of life, and of the development and activity of all bodily and mental faculties". The "Hierarchy of Needs" proposed by Maslow (1943) divides the needs of humans into five levels: physical, security, belonging and love, self-esteem, and self-actualization. In this paper, the needs of landscape viewers can be divided into material needs (the essential living environment and resources) and spiritual needs (for aesthetic and cultural pursuit). Secondly, the evaluation is limited by the cognition of the evaluators. The evaluators can only realize the value judgments on the basis of the correct and comprehensive cognition of the elements, structures and functions of the object.

4.4 Selection of evaluation indicator

4.4.1 Selection requirements

LVIE is a complex system integrating landscape sensitivity, the attributes of WTs as well as viewer response to the WTs on regional scales. It is challenging to select appropriate indicators for the evaluation, which depends on specific evaluation paradigms and methods. It is also restricted by the factors mentioned in section 4.3.5. Before the selection of indicators, some key points need to be emphasized:

1) Selected indicators should accurately represent abstract concepts such as landscape naturalness, landscape diversity and landscape aesthetic (Kienast et al., 2015).

2) Selected indicators should be sensitive to the changing of the represented attributes for an early warning, and be easy and cost-effective (Noss, 1990) to be measured or obtained from the open database (Müller & Lenz, 2006).

3) A set of limited number of indicators is designed to achieve the evaluation goals and to save resources. Hersperger et al. (2017) point out that, for meaningful evaluation, the complexity of each set should be balanced, which means each subordinate goal should have a similar number of indicators. If a goal is too complex to be represented by a few indicators, it should be subdivided into several subordinate goals. Kienast et al. (2015) show that 2-5 indicators are suitable for each set of indicators, as a high number of indicators would bear a high risk of redundant information (Hasund, 2011).

4) Selected indicators should be relatively independent of each other to avoid any overlapped influences and conflicts.

5) It is significant to specify international standards for data processing, including data source, processing tools and precision.

6) The indicators should be processed objectively and quantitatively, which means avoiding the subjective factors in the evaluation process.

7) Supplementary information (such as photographs, land use data, or orthophotos) helps the understanding and interpretation of landscape (Ode et al., 2010). The utilization of the indicators of both cartographic view and human perspective view can improve the accuracy and diversity of the evaluation outcome. The evaluation process of these indicators should be applicable and transparent, which is suitable for planning project implementation (Dramstad et al., 2006; Ode et al., 2010).

In summary, in planning-oriented evaluation, the operability of the evaluation, the objectivity, reliability, and validity of the evaluation model (Martín et al., 2016), the diversity of data sources (landscape photos, land cover data, aerial photos, and field observation) should be considered. The evaluation should lead to the same results under the same framework. The evaluation criteria must properly reflect the essential properties of the property (Schmidt et al., 2018). Evaluation indicators should be available from the authoritative database and be updated frequently.

4.4.2 Indicator set

Table 21 lists the target, theoretical foundation, attributes, and indicators in a hierarchical structure, which demonstrate potential indicators influencing visual impact and systematically explains the mechanism of how landscape visual quality is impacted by WTs. For this indicator set, the selected indicators are based on the precise target and theoretical foundation, showing the formation process of the evaluation model.

In terms of content, the influence factors can be categorized into three groups: landscape sensibility, visual impact of WTs and viewer exposure (Fig. 28). They reflect the mechanisms of how the visual impact is generated by WTs upon the landscape and perceived by the viewers. Here the viewer response is replaced by view exposure. Viewer sensitivity in the theoretical framework is removed in the evaluation indicator set because the personal experiences and individual characters are usually neutralized by large samples. The objective outcome of viewer exposure is more representative and practicable for evaluation. The selected indicators should accurately capture slight and subtle changes of attributes that describe how WTs influence the landscape visual quality and how viewers perceive the visual impacts caused by WTs. Moreover, the potential overlapping contents should be explained and distinguished in advance.

Table 21 Indicator set of Landscape Visual Impact Evaluation.

Target	**Theoretical Foundation**		**Indicators**	**Remarks**
Landscape visual impact evaluation	Landscape sensitivity	Landscape Element	Naturalness	See Table 22
		Landscape Structure	Visibility	See Table 23
			Visual threshold	See Table 24

		Patch density	See Table 25
		Patch diversity	See Table 26
	Landscape Function	Ecological function	See Table 27
		Cultural function	See Table 28
		Recreational function	See Table 29
	Visual impact caused by WTs	Total height of WT	See Table 23
		Number of WTs	See Table 23
		Preload	See Table 30
	Viewer Exposure	Influenced proportion of population	See Table 31
		Influenced proportion of the passersby	See Table 32

4.4.2.1 Indicator set of landscape sensitivity

- Naturalness

In landscape sensitivity evaluation, the characteristics of the landscape elements determine whether the landscape blends harmoniously with WTs. The indicator “naturalness” is introduced to represent the sensitivity degree of the landscape element to the impacts of WTs. Naturalness describes the perceived closeness to a preconceived natural state (Ode et al., 2008). The Biophilia hypothesis put forward by Kellert and Wilson (1993) explains the significance of naturalness as the biological need of humans. The indicator "naturalness" is identified as a reflection of "evolution theory" in the landscape and is proven by environmental psychologists as a significant aspect of restorative effectiveness. In landscape sensitivity evaluation, it is an attribute of characterizing the degree of naturalness of each element (or landscape unit). The most natural elements are those free from human influence (Adam et al., 1986). According to the discussion on preload, landscapes without any artificial construction and infrastructural facilities are more sensitive to WTs because the technical-dominated characteristics of WTs conflict with natural features. In contrast, landscapes with various artificial elements (especially vertical elements like a tower, high-rise) are easier to incorporate WTs. Generally, the higher the naturalness is, the lower is the capacity of the visual landscape.

Latinopoulos and Kechagia (2015) develop a multi-criteria evaluation model for wind farm site selection based on the classification of different land covers. The model assesses the land suitability for wind farms according to the characteristics of various land types, categorized by their naturalness. In this thesis, naturalness is represented by several land use types and assigned with scores in GIS spatial analysis (Table 22). It is based on the ecological importance of the area available for the continued existence of natural habitats and hence, for its robustness (Martín et al., 2016). In this evaluation model, the typical land use types are assigned scores from 0 (not sensitive) to 5 (very sensitive) representing different naturalness degrees.

Table 22 Score assignment of land use type according to the “naturalness” indicator.

Land use types	Score
Water Area	5
Forest Land	4
Agricultural Land	3
Village/ Town	2
Industrial Land	1
Infrastructure land	0

- Visibility

The concept of visibility refers to the degree to which it is possible to see within a specific territory through a certain medium (Del Carmen Torres Sibille et al., 2009). According to the published articles of visual impacts from WTs (Möller, 2006; Bishop & Miller, 2007; Arezes et al., 2014; Klouček et al., 2015), visibility is a rather frequent topic of research. The visible area is mainly dependent on the topography, the location and size of WTs. The required data are digital elevation model (DEM) and the coefficients of WTs (height, altitude, and position). The “visibility” indicator can be analyzed and expressed with scores assigned in Table 23.

Table 23 Score assignment of “visibility” indicator.

Visible number of WTs	Score
> 80 % of WTs are visible.	5
61 – 80 % of WTs are visible.	4
41 – 60 % of WTs are visible.	3
21 – 40 % of WTs are visible.	2
1 – 20 % of WTs are visible.	1
All the WTs are invisible.	0

Note: The blade's tip is introduced as the height parameter for the consideration of the worst-case scenario.

- Visual threshold

In the long-range, more coefficients should be considered in visibility analysis, such as the contrast with the background, color, atmospheric scattering, and conventional regional climate. The method of distance classification according to the multiple heights of WTs (shown in Table 20) is used here to replace the complex multi-parameters that cannot be definitely detected yet. Each cell unit should be assigned with scores according to their distance to the closest WTs, as listed in Table 24.

Table 24 Score assignment of “visual threshold” indicator.

Multiple of WTs’ total height	**Score**
＜ 1 H	5
1-3 H	4
3-10 H	3
10-20 H	2
20-30 H	1
＞ 30 H	0

- Patch density

Besides the “elevation variation” of landscape structure, the horizontal structure of the landscape, which is represented by “patch structure”, describes the spatial scale and the size of the natural landscape. The attribute “patch structure” can be classified into “patch density” and “patch diversity”. The conclusion of these two parameters can distinguish the distribution of various patches and their anti-interference capacity.

The patch density indicator has been widely used to present the density of edges between land uses for visual landscape evaluation (Palmer, 2004; Frank et al., 2013). Patch density describes the average number of the patches in the landscape unit area, which is negatively related to visual capacity and can be represented by the number of landscape patches per unit area as the parameter. Generally, patches in small size are not commensurate with the scale of the WT. The landscape with sparse patches has higher acceptance of WTs, i.e., landscape with low sensitivity as shown in Table 25.

Table 25 Score assignment of “patch density” indicator.

Length of the patch edge in the landscape unit (ha)	**Score**
≤ 100 m	0
100-200 m	1
200-400 m	2
400-600 m	3
600-800 m	4
≥ 800 m	5

- Patch diversity

Patch diversity is a measure of how many different land cover types are present per unit area (Palmer & Roos-Klein Lankhorst, 1998; Palmer, 2004). It reveals the richness and complexity of the landscape both with regards to content and spatial configuration (Ode et al., 2008). The attribute of patch diversity is also negatively related to the visual capacity because the increase of patch types reduces the coordination with huge wind facilities. Conversely, comparatively homogeneous land cover types have a high visual capacity for WTs. The score assignment for LVIE evaluation is listed in Table 26.

Table 26 Score assignment of "patch diversity" indicator.

Number of patch types within the landscape unit (ha)	Score
≤ 1	0
1-2	1
2-3	2
3-5	3
5-10	4
≥ 10	5

- Ecological Function

The indicator "ecological function" is represented by the ecological protected areas designated by authorities in charge of nature conservation at the national level, or by state or local government-level authorities. In Germany, all the protected areas, including natural conservation areas, natural parks, national nature monuments, Biosphere reserves, landscape protection areas, nature parks, protected landscape elements, and specially protected habitats are demonstrated in the dataset of the digital landscape model (DLM250). These ecological areas are designated by the Federal Nature Conservation Act can be categorized and assigned the scores according to Table 27. In China, the nature reserves are categorized according to the "Principle for categories and grades of nature reserve" (GB/T 19523-93)(CNEPA, 1994) and the score assignment is listed in Table 27.

Table 27 Score assignment of "ecological function" indicator.

Natural Protection Area Value Rating	Score
National level nature reserve	5
Regional level nature reserve	4
Local level nature reserve	3
Nature area	2
Half-nature area	1
Artificial area	0

- Cultural Function

The indicator "cultural function" in LVIE model is represented by the different categories of cultural heritage, such as the world cultural heritage sites designated by UNESCO, cultural monuments and cultural landscape designated by authorities in charge of the cultural landscape at multiple levels. Cultural landscapes with different significance and protection levels are assigned with scores according to Table 28.

Table 28 Score assignment of “cultural function” indicator.

Cultural Heritage Value Rating	Score
National level cultural heritage	5
Regional level cultural heritage	4
Local level cultural heritage	3
Cultural protection area	2
Normal cultural area	1
Area without specific cultural value	0

- Recreational Function

In terms of the recreational function of landscape, the research area can be categorized into several levels as listed in Table 29. The recreational sites also include national park, nature park, landscape protection area, and other conservation areas that are open to the public for recreation.

Table 29 Score assignment of “recreational function” indicator.

Recreational Sites Value Rating	Score
National level recreational site	5
Regional level recreational site	4
Municipal level recreational site	3
Local level recreational site	2
Areas with recreational function	1
Areas without recreational function	0

4.4.2.2 Indicator set of visual impact of WTs

The indicators related to the characteristics of WTs, such as the total height of WTs, the number of WTs and preload, are expressed in the forms of the cartographic drawing (Fig. 40-2 and Fig. 45-2) as viewshed and preload.

- The total height and number of WTs

The total height and number of WTs can significantly influence the visible area and the degree of visual impact. These two parameters are integrated into the indicator visibility (i.e., viewshed). The indicator "visibility" refers to the cumulative visibility of all WTs in each grid unit. It is also depend on the topography and surface covers on the ground. As listed in Table 23, the degree of visibility is assigned as scores from 0 to 5 to represent a different proportion of the visible number of WTs.

Some parameters are decisive for viewshed analysis, such as the surface of the terrain, the position of WTs, the height of observation points, and the offset of the viewer. Observation height is especially significant for visual impact evaluation in wind farms because the height parameter greatly influences the visible scope. In this evaluation model, the blade's tip (i.e., total height of the WT) is introduced as the height parameter for the consideration of the worst-case scenario even if it tends to overestimate visibility. The offset of the viewer is set at 1.6 m. In flat and open areas, the giant objects like WTs are visible over great distances. The presence of terrain and surface structures such as buildings, trees, and hedgerows significantly affect the actual field of view. The observer's vision, the earth curvature, and atmospheric refraction can also affect the visibility of WTs. Although the surface disappears beyond a distance of about 5 km, the top of WTs can still be seen above the horizontal line. Therefore, the distribution of area with high visibility shows a concentration tendency, while the invisible areas are usually out of 30H distance or hindered by the vertical structure on the terrain surface.

- Preload

As discussed in Section 4.3.3.4.1, preload refers to the dense concentration of infrastructure facilities in a specific area. These potentially polluting and destructive facilities will increase the load and even exceed the capacity threshold in the locality. Here the indicator "preload" represents the facilities constructed formerly near the wind farm that cause either positive or negative effects on the permission of a new project. For instance, the railway, highway, other forms of energy facilities are usually recognized as preload near a wind farm site. These facilities remit the opposition to wind facilities since the existing environmental impact attracts local people's attention. The environmental impact caused by wind turbines may be hardly perceived by inhabitants. Table 30 assigns the scores according to different levels of preload.

Table 30 Score assignment of "preload" indicator

Preload degrees	Score
There is not any preload.	5
There is slight preload.	4
There is medium preload.	3
There is comparatively heavy preload.	2
There is heavy preload.	1
There is severe preload.	0

Note: The quantification of preload depends on the specific types of facilities, the area, height, and fieldwork on social acceptance.

4.4.2.3 Indicator set of viewer exposure

- Influenced proportion of the population

The local residents, who are the strongest protesters to the operation of wind farms, usually suffer most from the severe visual impact and the attached environmental impacts from wind farms nearby. As listed in Table 31, the calculation of the proportion of the influenced population on the basis of the location of their houses is direct and quantitative, enabling the concise conclusion of how many people are suffering from visual impacts. The proportion can be expressed through the spatial analysis in GIS with the data of residential land use, statistics concerning local population, and digital terrain model:

Proportion of the influenced population = Influenced population / Total population

Table 31 Score assignment of “influenced proportion of the population” indicator.

Proportion	Score
⩾ 30 %	5
20-30 %	4
15-20 %	3
5-15 %	2
⩽ 5 %	1
0 %	0

●Influenced proportion of the passersby

The transportation lines are the main visual corridors in a research region. Residents, passersby, and tourists have equal opportunities to suffer from the visual impact during their travel. The exposure of passersby depends on the proportion of the influenced length of the road, that is, how many sections of a road are affected visually by WTs (Table 32). To optimize this method, the transportation flow of each road can be added as a parameter in a regional case study. Therefore, the quantification of visual impacts on the roads can be calculated by the following formula:

Road impact frequency = Influenced length of the roads / Total length of the roads * Road flow level

Table 32 Score assignment of “influenced proportion of passerby” indicator.

Proportion	Score
⩾ 30 %	5
20-30 %	4
15-20 %	3
5-15 %	2
⩽ 5 %	1
0 %	0

4.5 Calculation of the outcomes of the evaluation

The calculation process of the evaluation shows as follows:

LVIE = Mean of landscape sensitivity + Mean of visual impact of WTs + Mean of viewer exposure

Each sub-indicator scores range from 0 to 5 and the final score is the sum of all scores. The higher the score is, the more severe the visual impact imposes upon the landscape. Through the raster calculation in GIS, the score of each grid (20 * 20 m) can be calculated and attain the final score representing the visual impact.

5 Case studies

5.1 Background

5.1.1 Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale, Bavaria, Germany

The project named Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale was approved on 7th May 2012 and built-in May 2017 and officially operated in September 2017 by WT manufacturer Senvion. It is located in the Main-Rhön region, northwest of Bavaria, adjacent to two states: Hessen and Thuringia. Its exact site is in the district Rhön-Grabfeld between the Franconian Saale and communities of Unsleben, Hendungen, Hollstadt, Heustreu, Oberstreu, Bahra, and the municipal Mellrichstadt (Table 33). Its geographical coordinates are between 10°17′11′′ to 10°18′29′′ Eastern longitude and 50°22′16′′ to 50°23′7′′ Northern latitude.

Fig. 33 View of the wind farm on the hub of WT (Foto: Stefan Kritzer)

The wind farm consists of 10 WTs in type of Senvion 3.4M 122 NES, each with a nominal output of 3.4 MW and a total height of 200 m (hub height 137 m and rotor diameter 126 m). They are erected on the farmland with the total capacity of 34 MW (Friedrich-Wilhelm Raiffeisen Windpark Streu & Saale eG and Bad Neustadt a. d. Saale, 2013). The 10 turbines computationally supply the electricity for the inhabitants of the district.

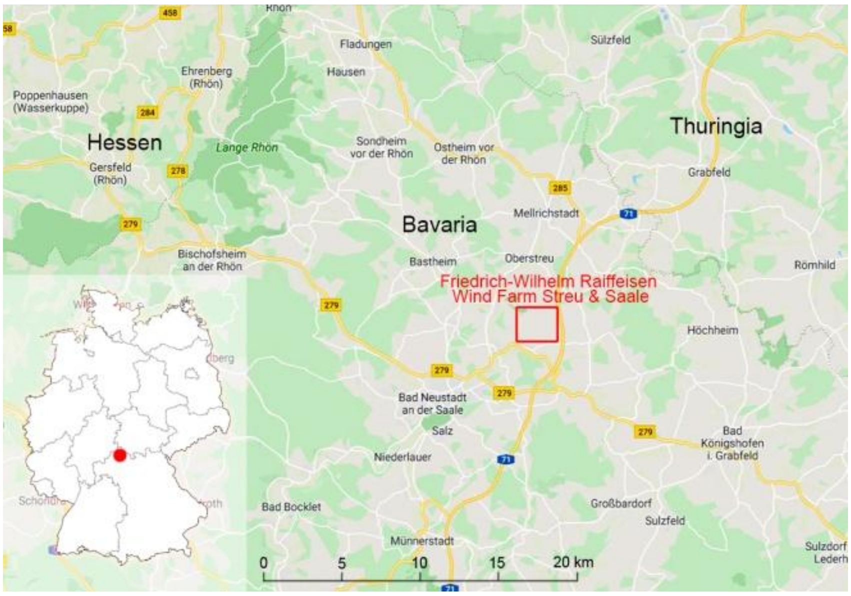


Fig. 34 Location of Friedrich-Wilhelm Raiffeisen Wind Farm (Source: ArcGIS Earth)

The project is located in the natural subdivision "Grabfeld", which is characterized by a flat but slightly undulating landscape. The north of the study area are the foothills of the Thuringian Forest. The wind farm is located on an open plateau with the altitude from 222 to 523 m, which drops relatively steeply to the scattering Saale valley, whereby a far-reaching effect of the project is generated and the project then affects the landscape. The plateau is characterized by intensively used agricultural land, which is interrupted by small forests, fields, and hedges.

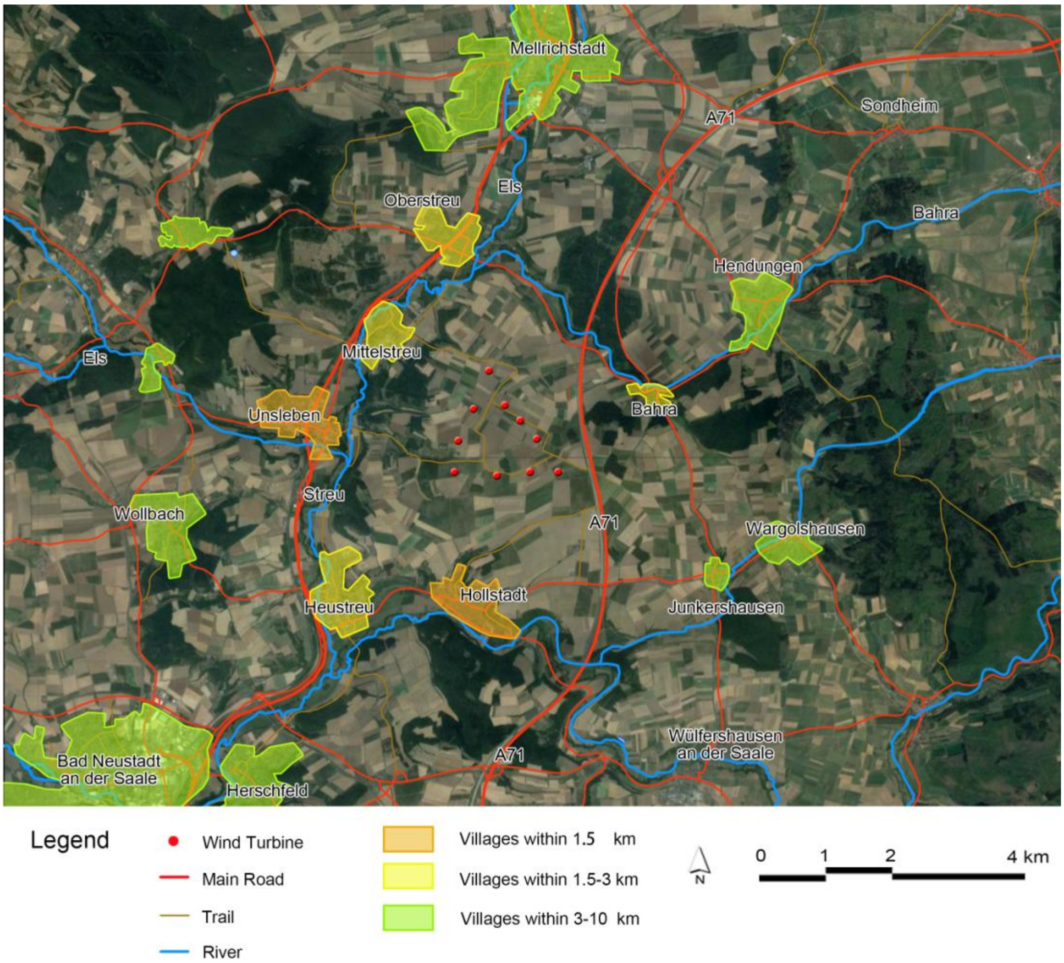


Fig. 35 Master plan of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale (Friedrich-Wilhelm Raiffeisen Windpark Streu & Saale eG & Bad Neustadt a. d. Saale, 2013)

According to the master plan (Fig. 35), the WTs are erected on the farmlands in the west of the A71 motorway. The nearest villages - Hollstadt (1524 inhabitants) and Unsleben (939 inhabitants) - are less than 1500 m away from the WTs. All sites are located on intensively cultivated land. An area of 380 m² will be used per foundation. Additionally, the scrapped crane platforms for construction, maintenance, and repair work comprise approximately 1.44 Hectare. In the west of the site, there are ecological protection areas: Drylands of Mittelstreu with 263.6 Hectare (4 TH level) and Bavarian Rhön with 7601 Hectare (5th level). Nearby the wind farm, there are some recreational sites:

Wechterswinkel Abbey, Schlossmühle, Floriansbrunnen, and Kirchenburg Ostheim. There are also three cultural heritages nearby: Katholische Kirche, Hohntor, and Südwestliche Stadtmauer. The emissions impacts, such as noise, shadow flicker, optical distress, visual impact, and impact on cultural heritages, are included in the Environmental Impact Assessment.

Table 33 Nearby Towns and Villages of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale.

Town or village	Area (Hectare)	Distance (Meter)	Population
Unsleben	72	1500	939
Hendungen	65	3700	908
Hollstadt	69	1000	1524
Heustreu	76	2000	1252
Oberstreu & Mittelstreu	97	1300	1529
Mellrichstadt & Bahra	332	5650	5563
Bad Neustadt an der Saale	480	5300	15154

（Source: https://ugeo.urbistat.com/AdminStat/en/de）

5.1.2 Zhongying Wind Farm in Zhejiang Province, China

Zhongying Wind Farm was built in 2012, located in the Beilun District of Ningbo City in Zhejiang Province, China (Fig. 36). It is a mid-size and low-speed wind farm located on the east coast of China. In total, 18 WD103-2500T WTs have been installed with an annual electricity generation capacity of 125 million kWh, which can provide green energy for 52000 households.

The site is close to Donghai Sea, south of Hangzhou Bay and north of Xiangshan Port. Its geographical coordinates are between 121°38′50′′ to 122°11′00′′ Eastern longitude and 29°41′30′′ to 30°01′00′′ Northern latitude. WTs are located on the peak of Fuquan Mountain at altitudes between 140 and 450 m. The nearby areas are alluvial plains with an average elevation of 2-3 m. The southeast wind is dominant in spring and summer, while the northwest wind is dominant in autumn and winter as the wind rose in Figure 37 shows. The annual average wind speed is 6.6 m/s.

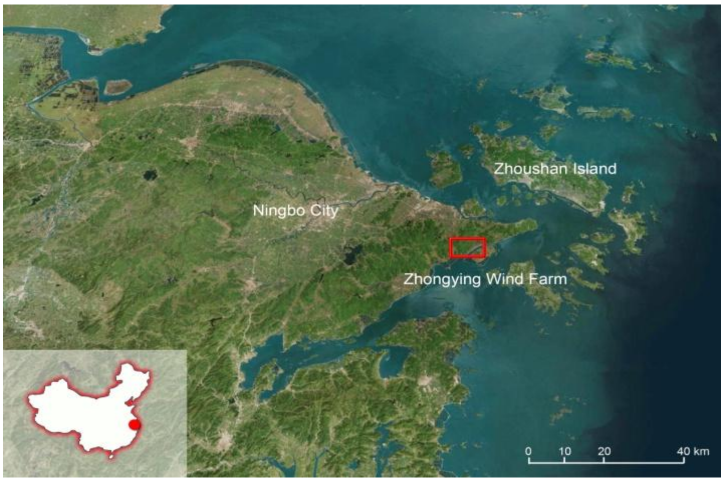


Fig. 36 Location of Zhongying Wind Farm (Source: ArcGIS Earth)

The research area mainly consists of agricultural land, forest, settlements, and historical cultural land. There are 17 villages around the wind farm, with about 5800 residents in total. 68 % of the residents are natives who have lived there since they were born. 32 % are immigrants who migrated from other provinces, rent houses, and work nearby. Since downtown Ningbo is only about 40 km away, the vast majority of young people have immigrated there or to other big cities for better job opportunities.

Around the wind farm, there are a great number of cultural resources, such as Buddhist temples (Changshou Temple, Qinglong Temple, Daci Nunnery), landscape parks, harbors, and scenic areas with high-value landscape and long histories (Fig. 37). The wind turbines are located approximately 600 meters from the nearest boundary of the village and 1.1 km from the nearest road. There are about 1.4 km as the crow flies from the closest edge of the cultural heritage (Changshou Temple) and 2.1 km from the closest edge of the recreational district (Shangliu Park).

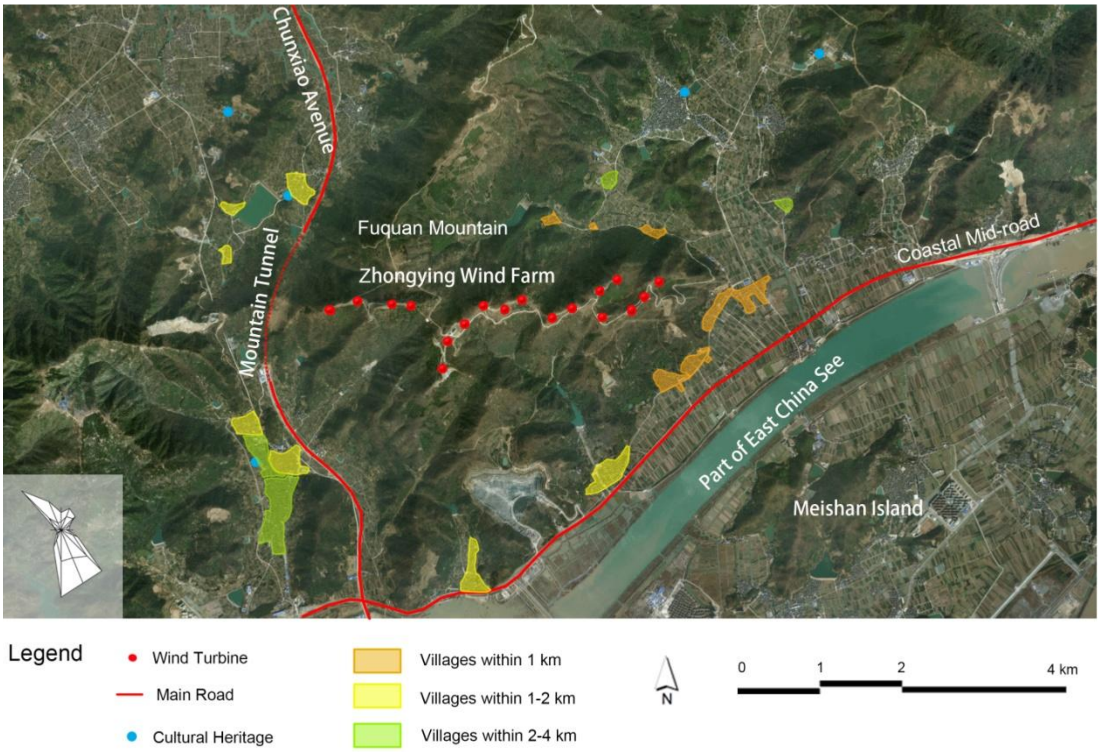


Fig. 37 The plan of Zhongying Wind Farm and wind rose

5.2 Establishment of the Digital Landscape Model

The three-dimensional digital landscape model can replace the very elaborate manual workload and optimize the precision of visibility analysis. With such a model, it is also easy to adjust the parameters to compare different proposals of decision making. CAD, GIS, 3D-MAX, and Lumion are the most commonly used modeling software.

The case studies are conducted on ArcGIS 10.6 from the Environmental Systems Research Institute (ESRI) with the functions of Spatial Analysis and 3D Analysis. The digital landscape model is generated through the combination of the Digital Elevation Model (DEM), Digital Surface Model (DSM), and the cartography of land use in GIS. DEM is the data of the height of the earth's surface.

DSM is the data of the artificial constructions and plantation added to the earth's surface. The cartography of land use is the officially planning data that decide the height constraint of the DSM and spatial capacity. These are open data available on the official websites of local governments. Before the discussion on the evaluation, the basic parameters, cartographic specifications, and data sources need to be determined and unified.

1) Determine the actual effective area of visual impacts, which is influenced by the scale and accuracy of the cartography. According to the discussion in section 4.3.3.3, the fixed distances cannot accurately capture the range of influence, which should be replaced by the multiple of the height of WTs (or visual angle), as shown in Table 20. In the digital landscape models, 30H is selected as the range of research area, corresponding to 6 km in the German case and 2.4 km in the Chinese case.

2) Collect the following data: the types, sources, and coordinate systems of data need to be determined first. The required data are listed in Table 34.

Table 34 Data sources of two cases.

Data of Zhongying Wind Farm:	**Data of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale:**
Satellite Images from ArcGIS Earth 10.6 Land Use Plan from Ningbo Urban Master Plan (2004-2020) Traffic network map from Ningbo Urban Master Plan (2004-2020) Elevation point distribution map of Zhongying Wind Farm	Satellite Images from ArcGIS Earth 10.6 ATKIS-DLM250-DATA The Digital Landscape Model 1: 250 000 (DLM250) is a part of the Official Topographic-Cartographic Information System (ATKIS), Which includes the layers of elevation, land use, natural protection areas, administrative regions, and transportation. (Source: www.bkg.bund.de)
Field Work and interviews (experts, residents, and planning authorities) for collecting the land cover, ecology, vegetation, and social acceptance, as well as for detecting Noise (decibel), the rotation speed of WTs, road flows, etc (2018-2019).	Field Work and interviews (experts, residents, and companies) for collecting first-hand information like ecology, vegetation, social acceptance of WTs, and project implementation (2017).

3) Ensure the accuracy and timeliness of the data: the reliability and timeliness of the data sources determine the quality of the evaluation. Therefore, a reasonable precision for the researched area should be set beforehand. The effectiveness of the evaluation and the data processing capacity in the analytical model should be considered. The resolution of the resulting image is assigned with a 20 m grid-resolution that can distinguish large obstacles on the ground such as forests and building groups. These results are then displayed cartographically on a scale of 1: 80,000 (German case) and 1: 50,000 (Chinese case). Given that China is still in a period of rapid urbanization, it is particularly

important to pay attention to data changes and replacement. The satellite data and planning documents collecting for the evaluation are the latest versions of 2018.

4) Conduct the evaluation: digital landscape models are constructed in GIS for case studies, which aim to assess the potential visual impact on the landscape. The indicators discussed in the theoretical framework of LVIE are transferred into practicable parameters in GIS for further application.

5) With the development of the 3D simulation software, the model can be constructed as realistic as possible for the visualization of the decision process. Improved on the basis of the traditional landscape model of topography, the new 3D model can even imitate the vegetation and climate of the real world. It is also possible to analyze any sight point with the viewers' perspective. The vertical surface construction is particularly a significant factor influencing the visibility area. These are the reasons for the continuous refinement of the analysis model of the landscape visual impact.

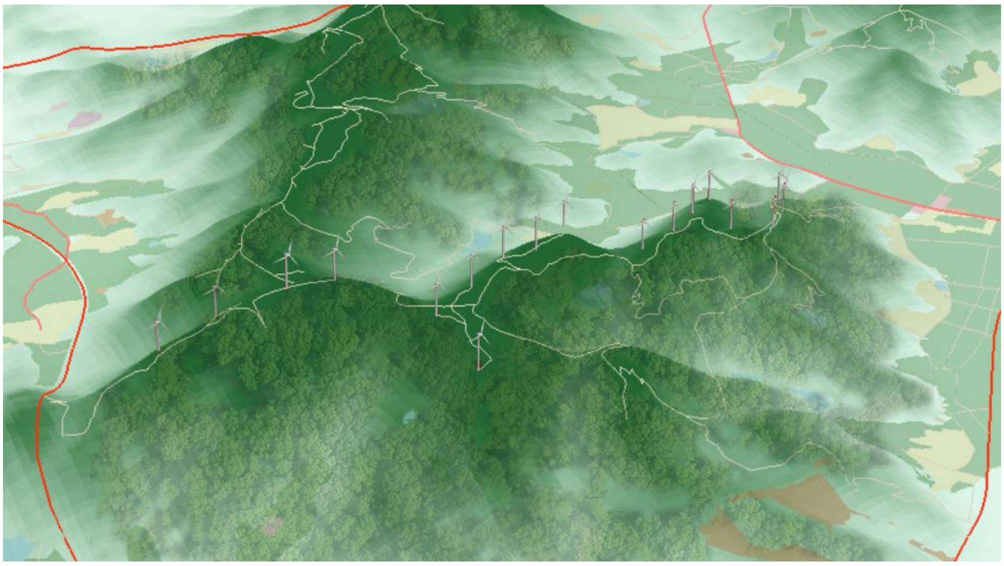


Fig. 38 Visualization and optimization of 3D landscape model of Zhongying Wind Farm

However, it has to be considered that the visualization results produced by computer just provide the experts and decision-makers with the reference parametric analysis. The computer-aided evaluation cannot replace manual analysis and review. The critical part of the establishment of the evaluation model always relies on human intelligence. The optimization of the landscape model can provide more dimensions and more accurate information to ensure the quality of the evaluation.

5.3 Results

5.3.1 Results of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale

5.3.1.1 Result of landscape sensitivity

Landscape sensitivity is an indicator for determining the visual capacity of WTs within a specific research space. It refers to a level above which visual impact on the landscape is no longer tolerated.

In the evaluation model, landscape sensitivity consists of three indicators: landscape element (Fig. 39-1), landscape structure (Fig. 39-2), and landscape function (Fig. 39-3).

The comprehensive result (Fig. 39-4) represents the landscape sensitivity degree with a research scope based on the buffer distance of 30 H (30 * 200 m). Each raster is assigned a score from 0 to 5. Score 0 means low sensitivity, and score 5 refers to high sensitivity. According to the geographical information statistics based on the layer of "landscape sensitivity" in GIS, the average score of landscape sensitivity in the research area is 2.61 (a scale between 0 and 5). The sensitivity degree is closely connected to the naturalness of the landscape. For instance, the ecological protection areas (e.g., Drylands of Mittelstreu and Bavarian Rhön) located west of Streu River, and areas near the water areas (e.g., Eis, Streu, Bahra, and Fränkische Saale) are highly sensitive. While the agricultural land near the wind farm site has a medium-degree of sensitivity. Other resources, such as cultural heritage, recreational sites, and forest are also affected by WTs as illustrated in Fig.39-4.

5.3.1.2 Result of visual impact of WTs

The visual impact of WTs is a combination of indicators of multiple-viewpoint viewshed and preload. The viewshed is the visibility of the research area that indicates whether or not the viewpoints can be seen from particular observer grids. The viewshed algorithm used in ArcGIS determines the visibility for each grid-cell center by comparing the vertical angle to the center of the cell with the vertical angle to the local horizon. The local horizon is the terrain that intervenes with the line-of-sight. A point is considered to be visible if it lies above the local horizon (Möller, 2006).

Viewshed analysis is binary in the sense that an object is either visible or invisible. However, when the viewpoints are not single (such as 10 WTs in this case), the viewsheds have to be accumulated. The result of the multiple-viewpoint viewshed analysis is thus a continuous raster map in which each cell presents the proportion of visible WTs (Fig. 40-1). According to the spatial analysis in GIS, 33.57 % of areas have a score of 0 (i.e., invisible), while the areas suffer from the highest level of visual impact with score 5(i.e., ＞ 80 % are visible) accounts 49.03 %. Other visible proportions account for 4.23 % (score 1), 4.58 % (score 2), 4.59 % (score 3), and 4.01 % (score 4) respectively. The cluster-layout of WTs contributes to the phenomenon of polarization of the visibility ratio. Areas have either extremely high visibility or extremely low visibility depending on their relative locations to the WTs.

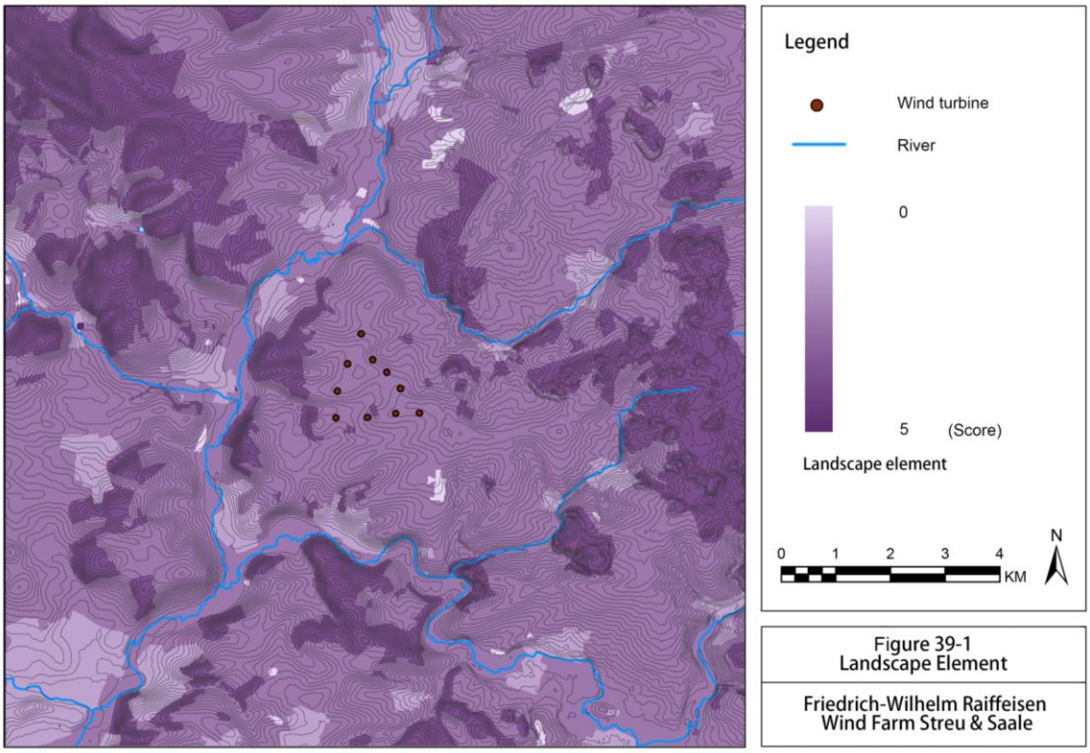


Figure 39-1
Landscape Element

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale

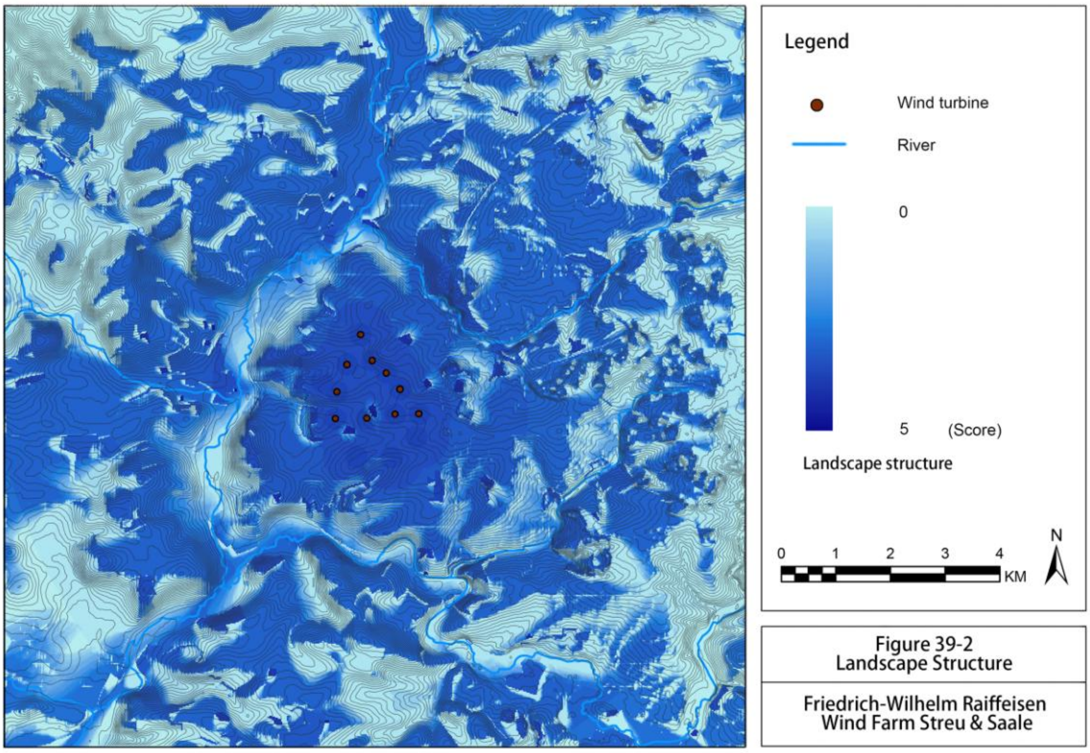
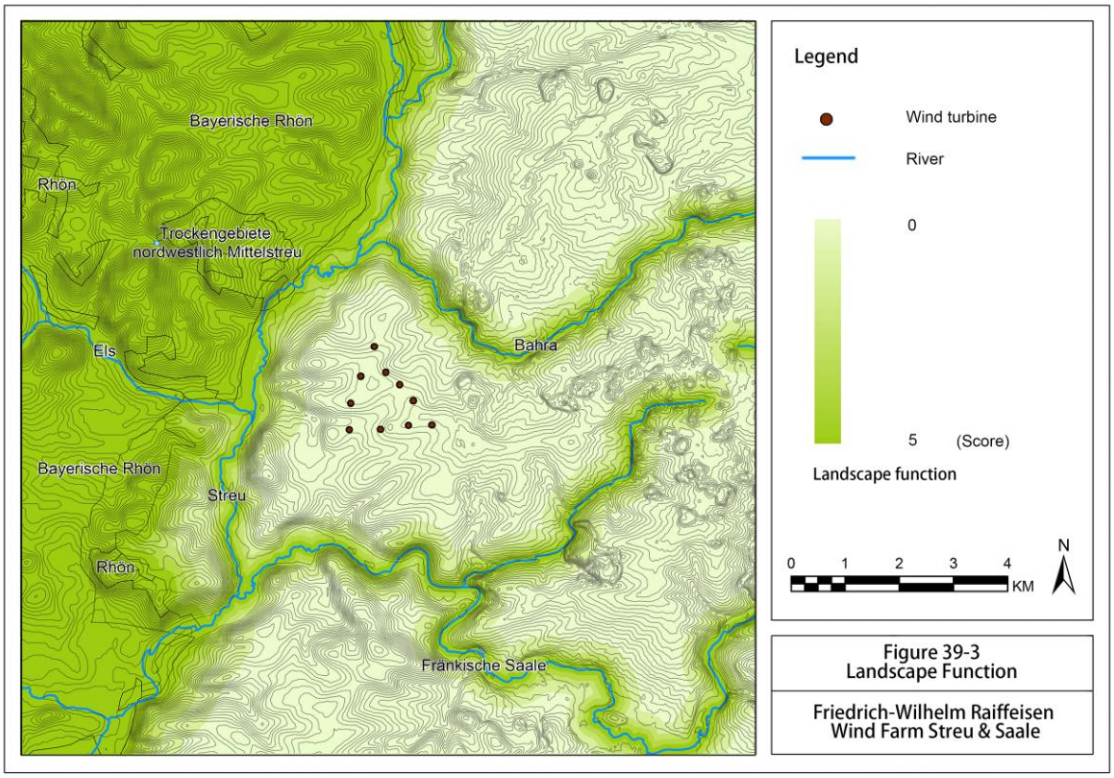


Figure 39-2
Landscape Structure

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale



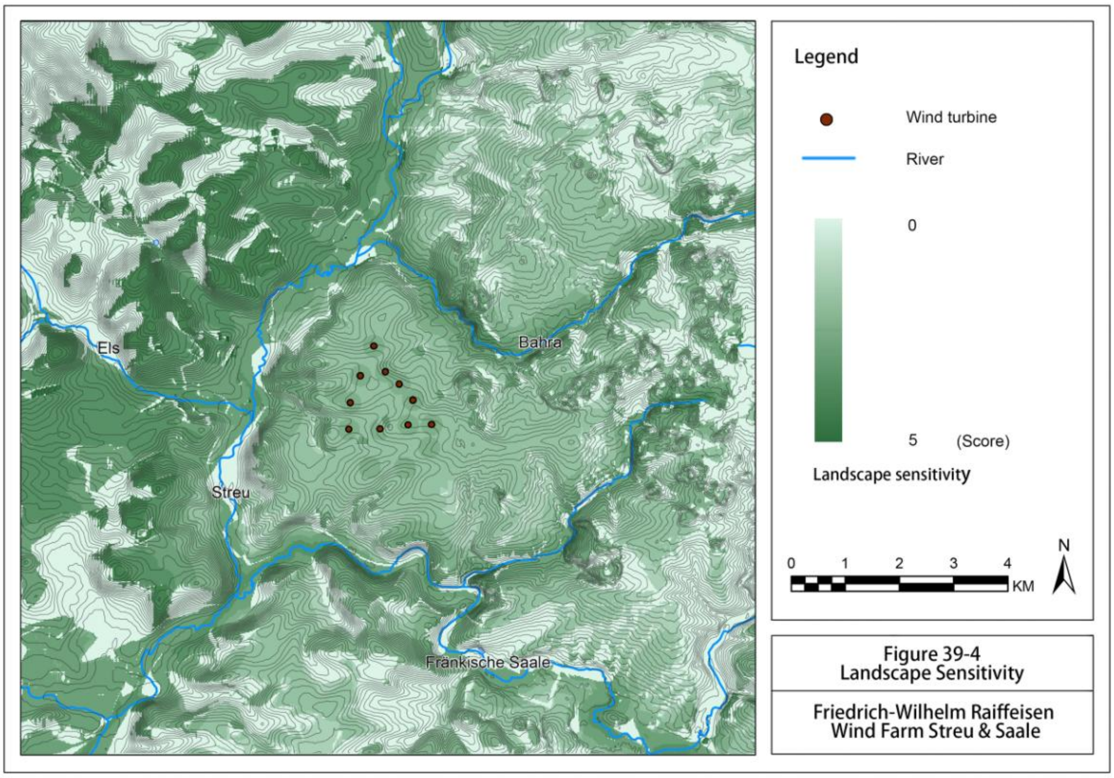


Fig. 39 Result of Landscape Sensitivity

Additionally, the preload also affects the visual impact to some extent (Fig. 40-2). Here the preload refers to the phenomenon that other infrastructure facilities in a close distance can offset the environmental impact of WTs. In the German case, highway A71, transportation lines, and settlements are significant preloads that can release local people's negative attitudes toward the WTs to some extent. The perception distance is as significant as the above mentioned elements in preload that the WTs perceived by human eyes can be simulated through the distance classification until the visual threshold (30 H).

The visual impact of WTs has been processed and presented in Fig. 40-3, which presents the average score of 3.10 (ranging from 0 to 5) and shows the scattered characteristics of visual impact distribution. The high visual impact (red color) mainly concentrates within an extremely close distance to the WTs and reduces with the distance grows. The scattered distribution is due to the flat terrain and prominent vertical structures. Whether the WTs are visible or not in the raster unit is dependent on the terrain and vertical structures (e.g., forests, shrubs, houses, and farms).

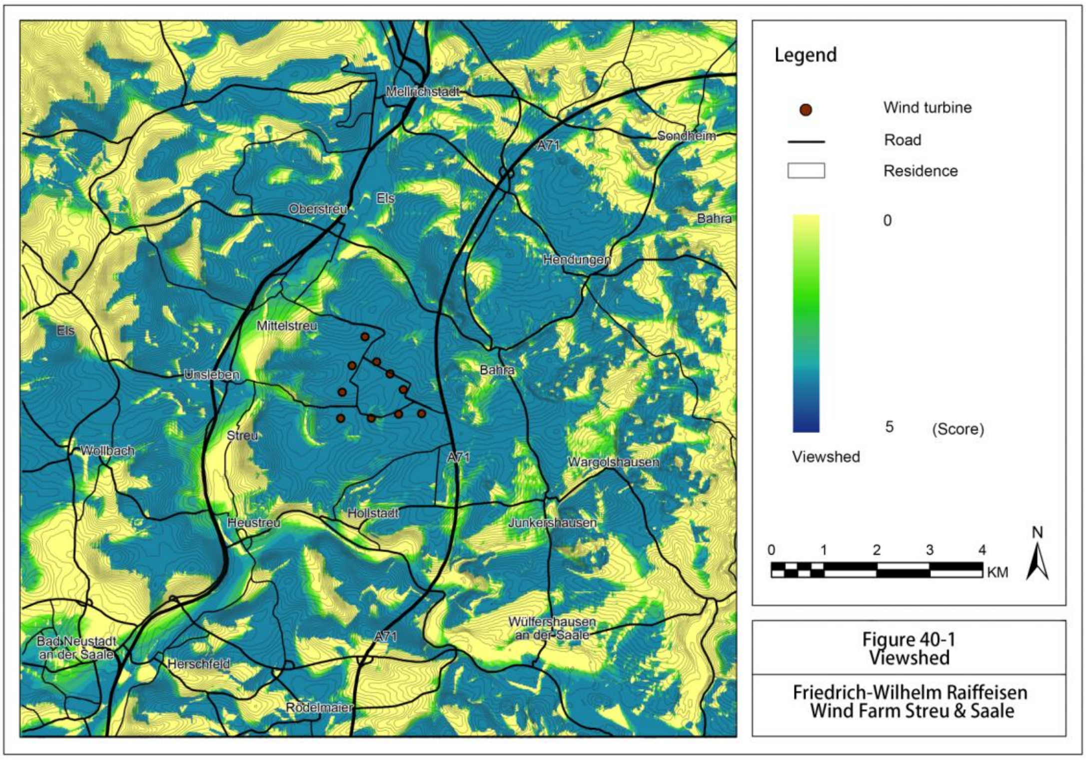
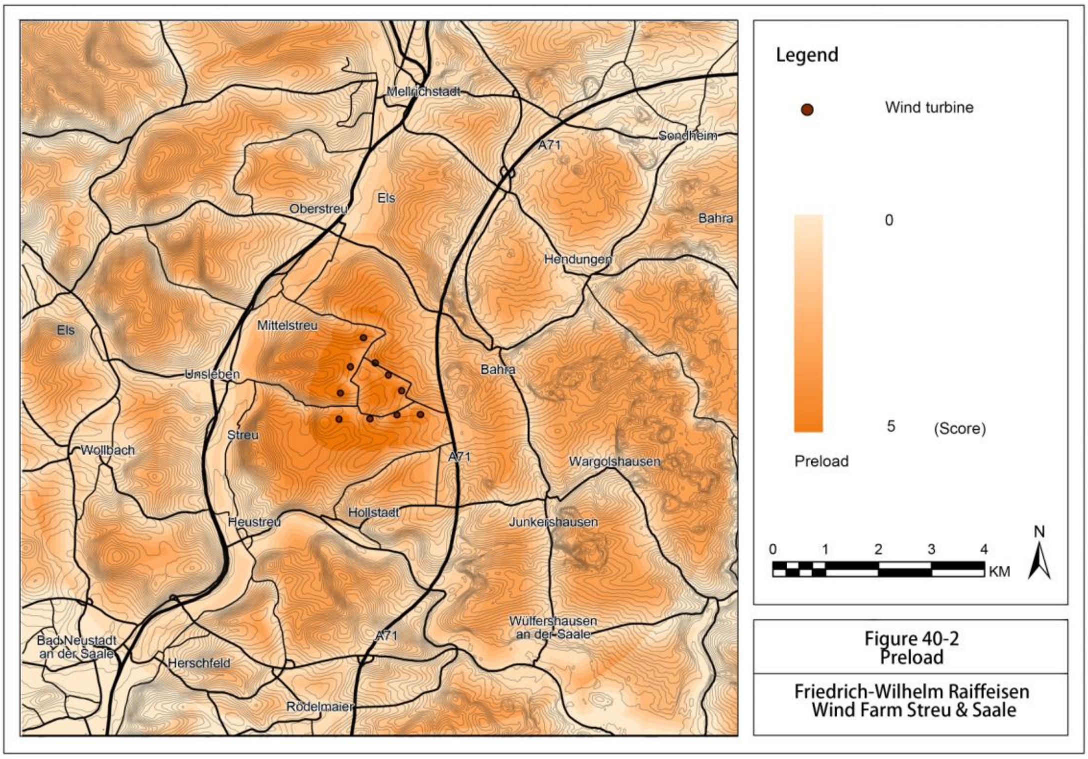


Figure 40-1
Viewshed

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale



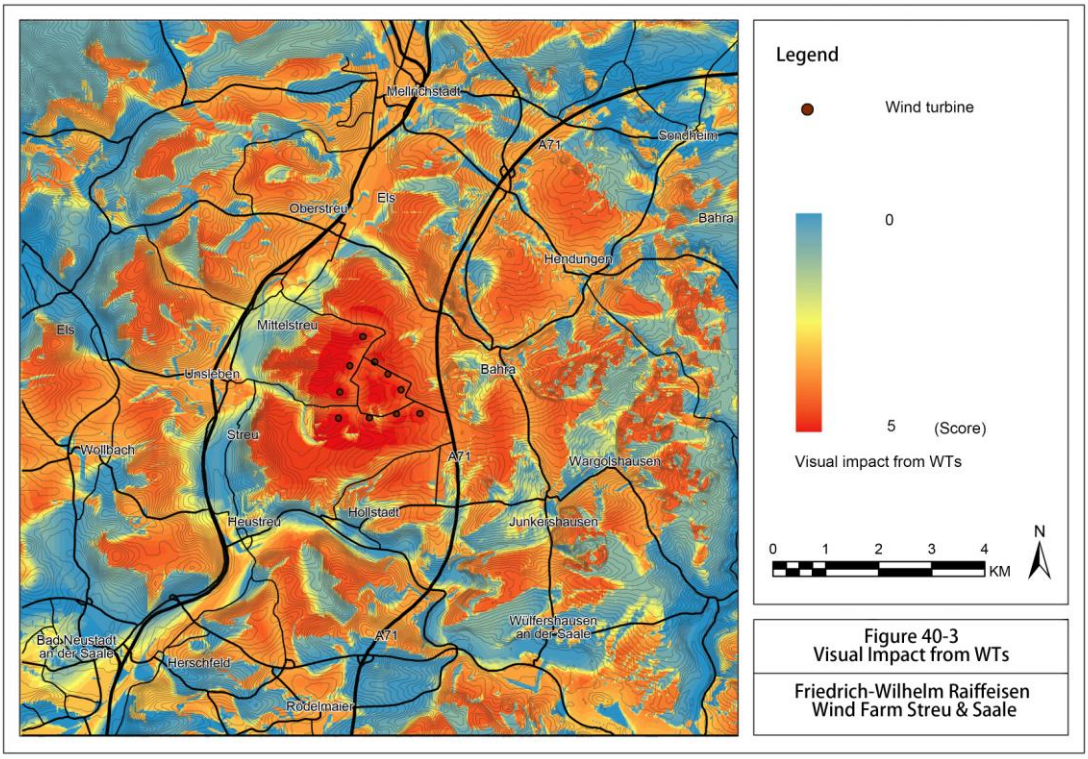


Fig. 40 Result of Visual Impact from Wind Turbine Evaluation

5.3.1.3 Result of viewer exposure

The viewer exposure evaluation, based on the influenced proportion of the population (Fig.41-1) and passersby (Fig.41-2), helps to quantify the visual impact upon viewers. Normally, the relative position and motion status of viewers affect their perception of visual impact. For instance, how often and how long people are faced with turbines, and how many proportions of the population is impacted by WTs at the locality, make quantitative visual impact evaluation extremely complicated. By including such high subjective indicators, it is still practicable to conduct the viewer response through comparative analysis. Figure 41-3 illustrates the different degrees of viewer exposure in each raster unit. The average is 2.39, represents a comparatively low exposure degree. The highly exposed areas concentrate on transportation lines across the wind farm, especially the highway A71 and railway, as well as the dwelling close to the wind farm, such as Unsleben, Mittelstreu, Oberstreu, and Bahra.

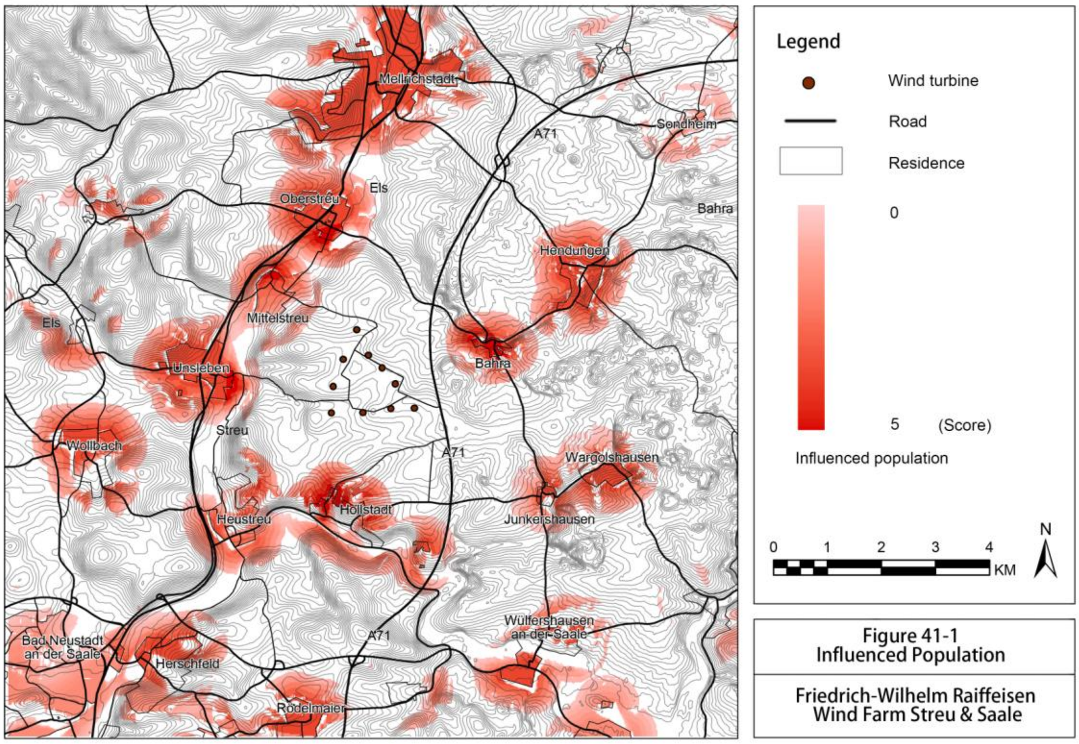


Figure 41-1
Influenced Population

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale

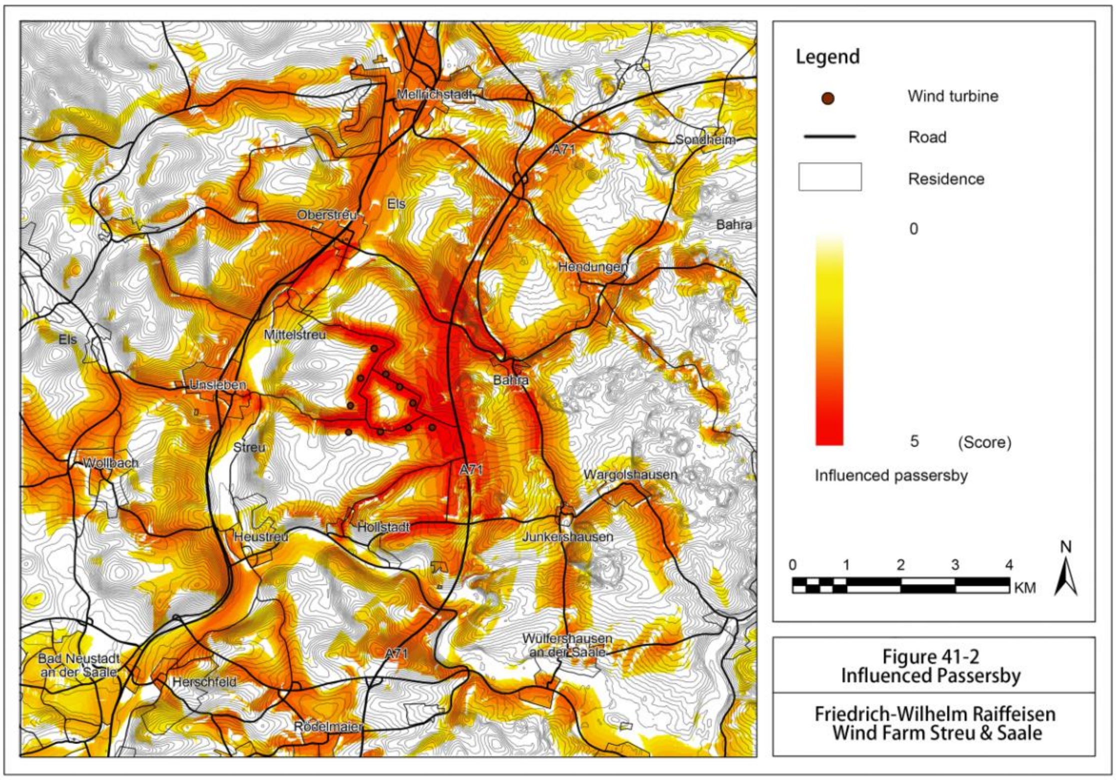


Figure 41-2
Influenced Passersby

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale

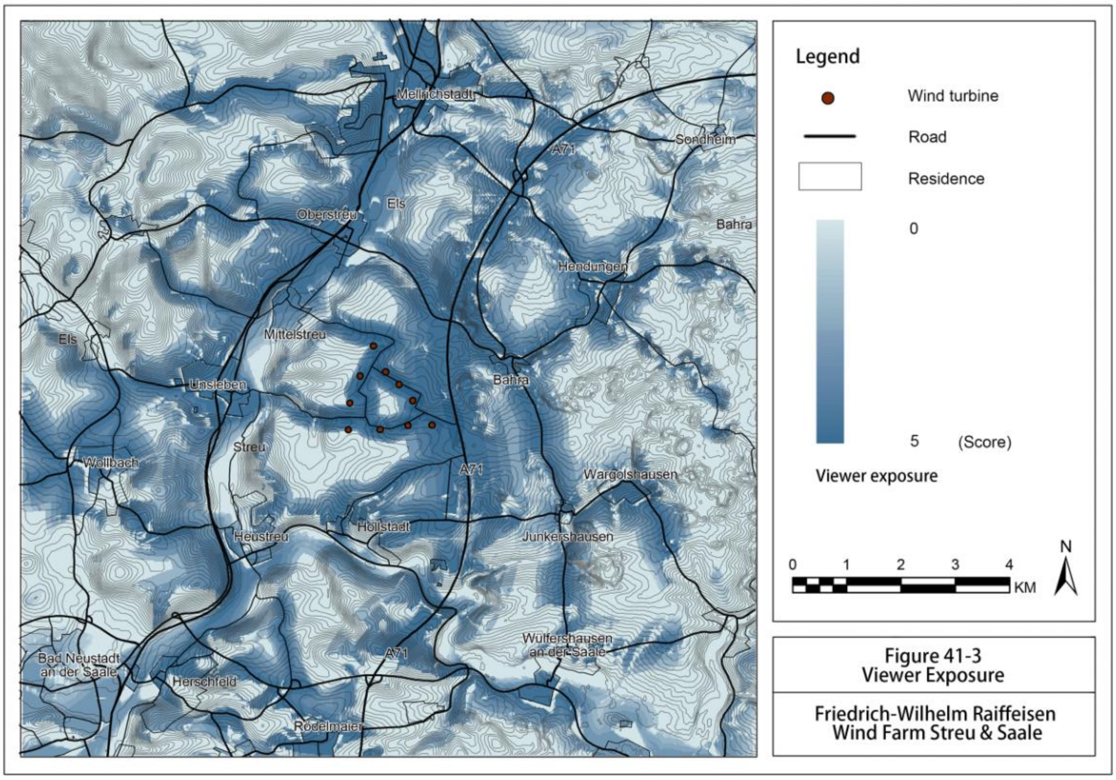


Figure 41-3
Viewer Exposure

Friedrich-Wilhelm Raiffeisen
Wind Farm Streu & Saale

Fig. 41 Result of viewer Exposure Evaluation

5.3.1.4 Comprehensive result

The comprehensive result integrates the scores of landscape sensitivity, visual impacts of WTs, and viewer exposure. The result (Figure 42) shows a non-homogeneous pattern of visual impact. The heavily suffered areas concentrate on the western side of the railway, areas along the highway A71, and other roads near the site. The areas with low visual impact are mainly hindered by vertical structures, such as forests, settlements, and ridges. The statistical data can be looked up in GIS, such as the affected proportion of each land use type, the specific location of visual influence, and the proportion of visible WTs (Table 35). Therefore, these impacts can be mitigated by specific measures in the planning (see section 6.2).

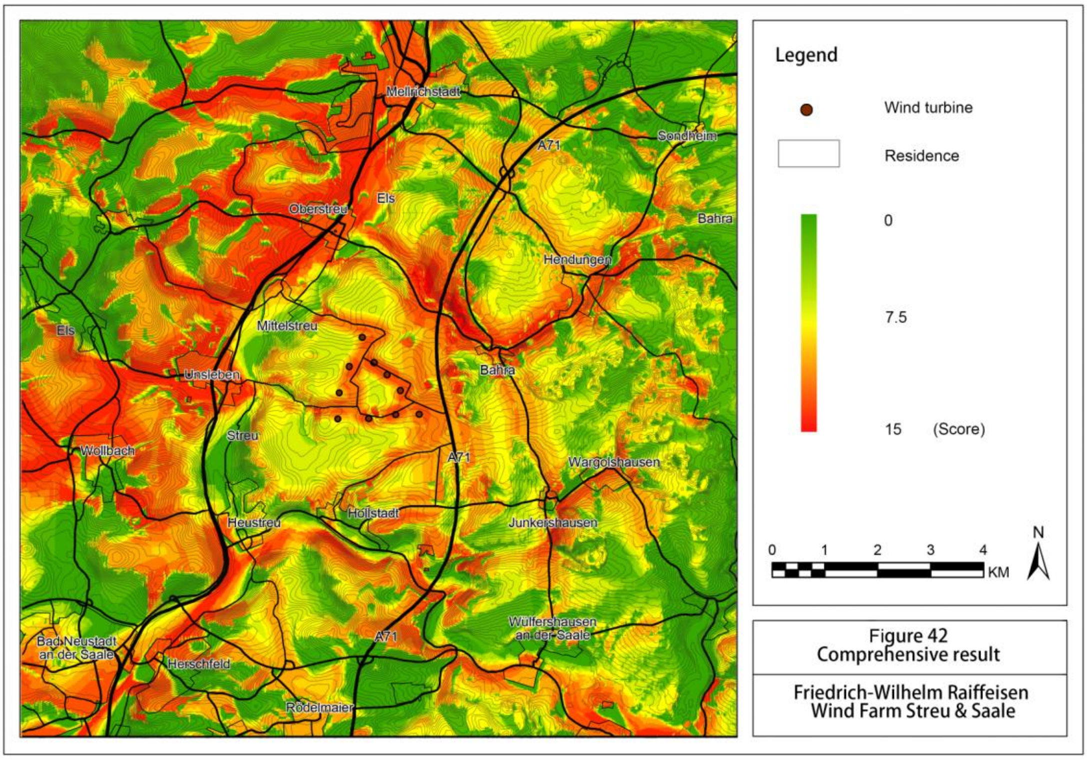


Fig. 42 Comprehensive result of the German case

The visually affected spaces increase with the growing height of turbines. However, these visual impacts are not homogeneously distributed. Although the visible area of the total 10 complete turbines is limited, most WTs are partly visible, which undoubtedly causes impairment in the landscape. The visibility is greatly dependent on the terrain and height of surface structures. Despite the height of turbines about 200 m, many localities concentrated in the valley areas are free from optical interference. Such as Heustreu, Hendungen, and Bad Neustadt an der Saale with low altitude and hidden in shrubs and woods have almost no exposure to the WTs and experience only weak or no visual impact.

Most villages and towns are partly affected, and the visual impacts are unequally distributed according to the terrain and vertical structures. The villages of Unsleben, Oberstreu, and Bahra, the north part of Mittelstreu and Wollbach, the southeast part of Heustreu, the west part of Hollstade suffer from the severe visual impact. Except for these parts, other areas can only see the blade tip of the WTs, which poses no threat to the inhabitants' daily life. Although the WTs are surrounded by farmland (Fig.43) that accounts for two-thirds of the research area, the mean score of visual impact in farmland (2.86) is lower than that in towns (3.46), forests (2.94), industrial land and infrastructure facilities (3.37). The cultural heritage (1.40), water (0), recreational facilities (0.77) and villages (2.78) suffer a comparatively low visual impact.

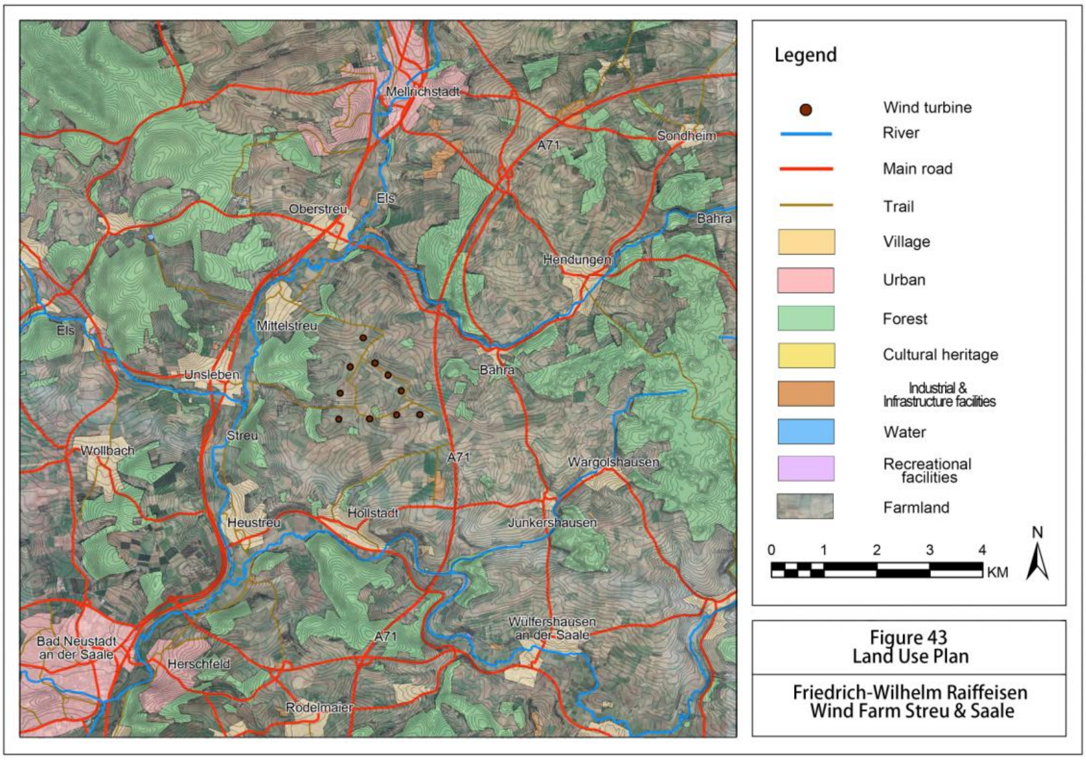


Fig. 43 Land Use Plan of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale

Table 35 Statistical data of the visual impact in different types of land use in the German case.

Land use	**Area (ha)**	**Area proportion**	**Mean score (0-5)**	**Medium visual impact (Score ≥ 3)**	**Heavy visual impact (Score ≥ 5)**
Village	894.76	4.82 %	2.78	55.46 %	44.70 %
Town	828.64	4.47 %	3.46	70.04 %	54.72 %
Forest	4406.68	23.76 %	2.94	58.79 %	52.59 %
Water	0	0.00 %	0	0.00 %	0.00 %
Industrial & infrastructure facilities	93.12	0.50 %	3.37	65.16 %	61.43 %
Farmland	12325.32	66.44 %	2.86	57.13 %	48.26 %
Cultural heritage	0.20	0.001 %	1.40	20.00 %	20.00 %
Recreational facilities	1.72	0.01 %	0.77	16.28 %	13.95 %
Total	18550.44	100.00 %	2.88	57.63 %	49.03 %

5.3.2 Results of Zhongying Wind Farm

5.3.2.1 Result of landscape sensitivity

The evaluation of the landscape elements (Fig. 44-1) illustrates a clear distribution of different land use and their naturalness. The land use surrounding the WTs is forest, which accounts for over half of the total research area. The landscape structure (Fig. 44-2), which consists of sub-indicators (e.g., visibility, visual threshold, patch density, and patch diversity indicators) show significant differences between the east and west sides of the research area. The east side of Fuquan Mountain is a narrow valley. Due to the elevation difference between the mountain top and the valley, the villages in the valley are totally exposed to the WTs. In contrast, although having a similar distance buffer, the areas in the west suffer less visual impact because of different topography. The WTs are buffered by the mountains and most of them are invisible from settlements in the west part. Only a small portion of high-altitude woodlands is affected. The landscape function (Fig. 44-3) illustrates the sensitivity degree associated with the high-valued landscape property. The water areas (part of East China Sea, reservoirs on the mountain, and rivers), cultural heritage sites (Changshou Temple, Qinglong Temple, Daci Nunnery), and recreational sites (harbor, landscape parks, scenic platforms on the mountain) are identified as local landscape resources and are highly sensitive areas to the WTs.

The landscape sensitivity (Fig. 44-4) represents the sensitivity degree to newly erected WTs, with a research scope based on the buffer distance of 30H (80 m *30). The grids with light color represent low sensitivity, and the grids with dark color refer to high sensitivity. According to the geographical data calculation based on the layer of the landscape element, landscape structure, and landscape function in GIS, the average score of the research area is 2.82 for landscape sensitivity (in a rating between 0 and 5). The highly-sensitive areas are the reservoirs on the mountains, broad water areas, the northeast plain at the foot of Fuquan Mountain, and the Meishan Island in the southeast corner.

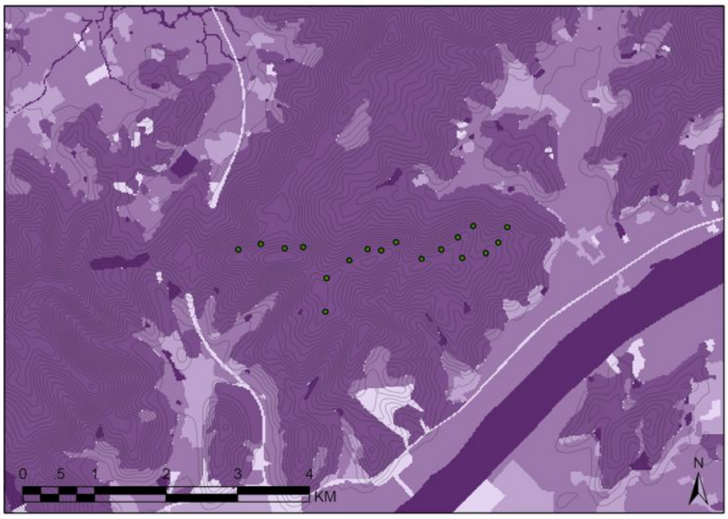


Figure 44-1
Landscape Element

Zhongying Wind Farm

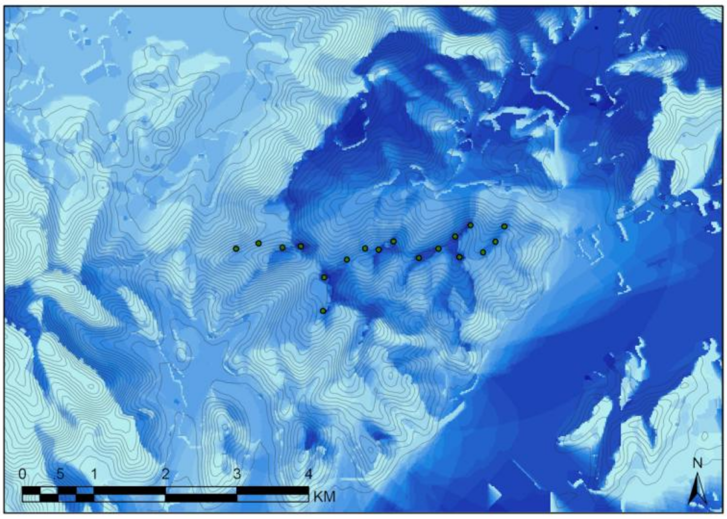


Figure 44-2
Landscape Structure

Zhongying Wind Farm

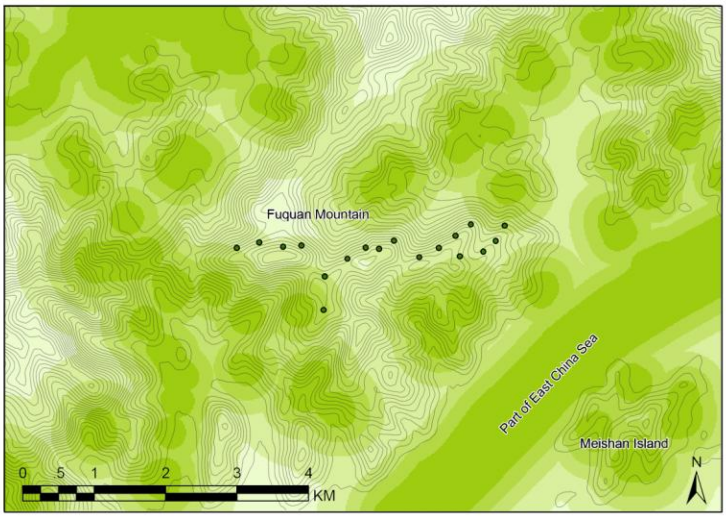


Figure 44-3
Landscape Function

Zhongying Wind Farm

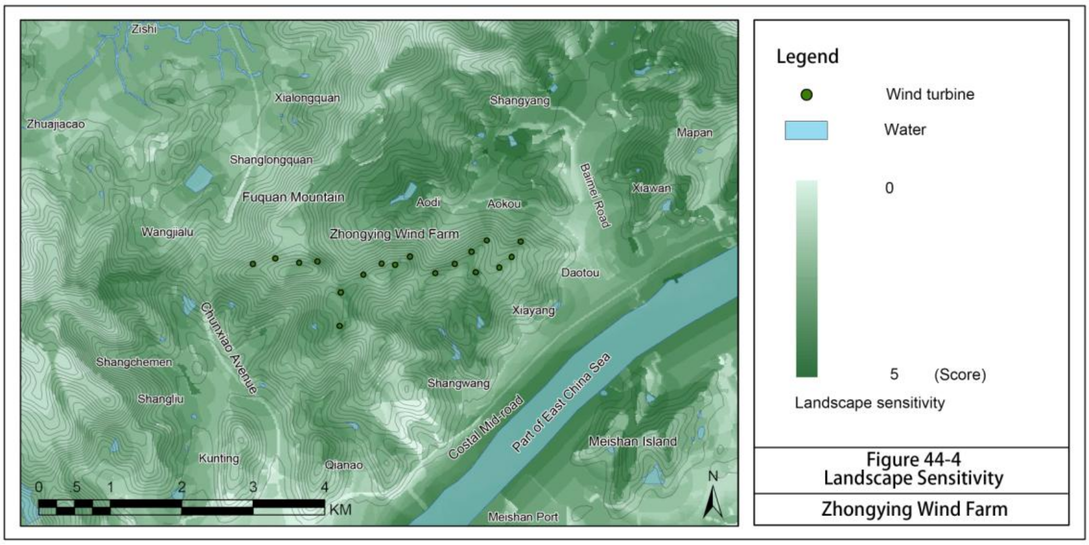
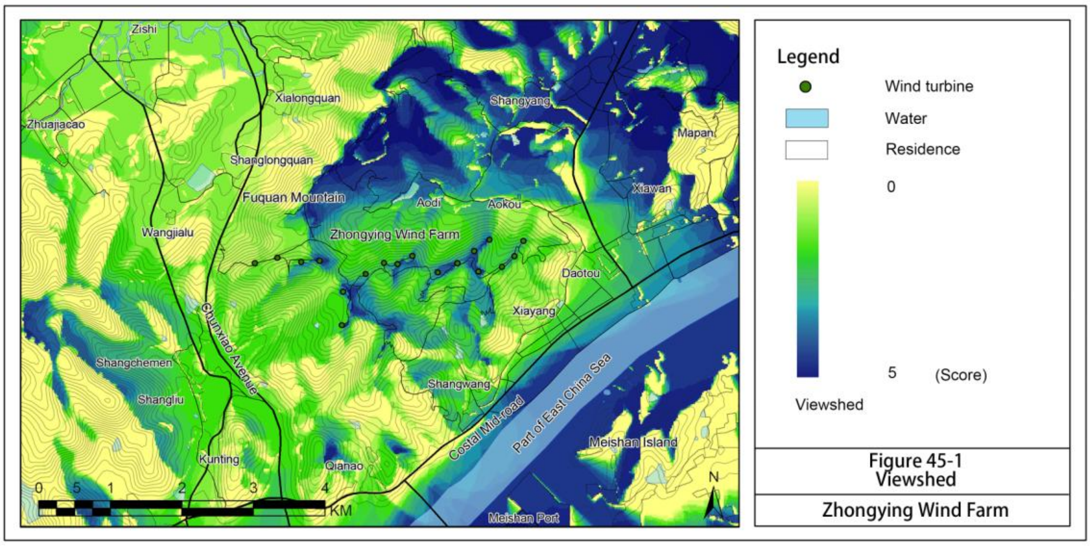


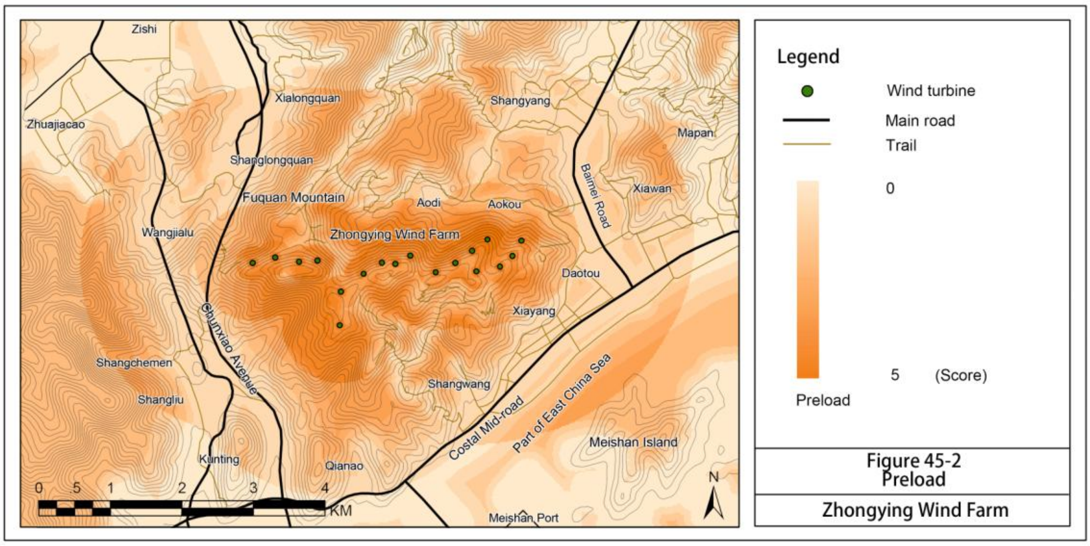
Fig. 44 Result of Landscape Sensitivity Evaluation

5.3.2.2 Result of visual impact of WTs

As shown in Figure 45, the visual impact of WTs is an integration of multiple-viewpoint viewshed and the preload. The viewshed map illustrates a continuous raster map counting the visibility of a total of 18 WTs (Fig. 45-1). Each cell presents the proportion of visible WTs as listed in Table 23, represented as scores ranging from 0 (All the WTs are invisible.) to 5 (＞ 80 % of WTs are visible.). According to the spatial analysis in GIS, 21.40 % of areas have a score of 0 (i.e., invisible), while the areas suffer from the highest level of visual impact with score 5 (i.e., ＞ 80 % are visible) accounts 20.04 %. Other visible proportions account 11.41 % (score 1), 28.01 % (score 2), 8.83 % (score 3), and 10.31 % (score 4) respectively. The average distribution of scores is mainly due to the scattered layout of WTs. These 18 WTs are separately distributed on the east (14) and west side (4) of Fuquan Mountain. The visible number of the east side is apparently higher than that of the west. Areas with low altitudes or the basin between hills have comparatively low visibility, while the WTs are highly visible on broad plains and water areas. The layout of the wind farm avoided most visual impact on villages, except for Aodi, Xiawan, and Shangyang villages.

The preload (Fig. 45-2) presents the ability of the surrounding environment that the environmental impact of WTs can be offset by other infrastructure facilities at a close distance. The light color presents the higher carrying capacity for the newly installed WTs because of the previous artificial constructs at the location. For instance, Chunxiao Avenue, Costal Mid-road, Baimei Road, large settlements, infrastructure facilities, and industrial land have a higher capacity for new energy facilities. However, the grids with high scores indicate that the impairment from the WTs is not so easily accepted due to the high level of naturalness.





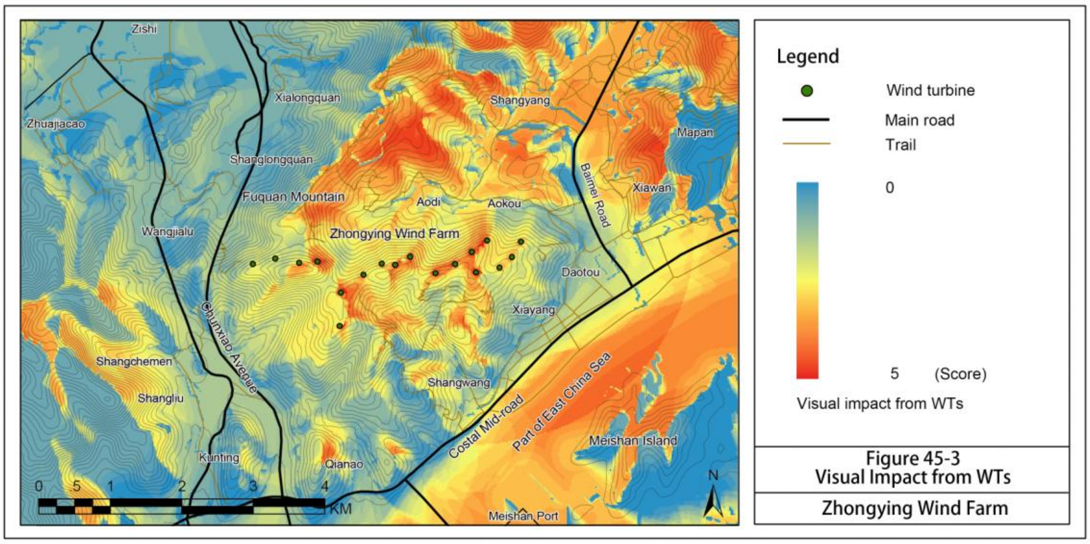


Fig. 45 Result of Visual Impact from Wind Turbine Evaluation

The illustration of the visual impact of WTs is expressed in Figure 45-3, which shows the partly concentration of the visual impact. The average score is 2.37 among the range of 0 to 5. The highly influenced areas (red color) are mountain areas in the north of the WTs, the plain in the northeast direction, and water areas in the southeast of the wind farm. The mountain slope in the southwest is also severely influenced since it is directly faced with the wind farm. Other areas are free from visual impairment due to the undulating topography.

5.3.2.3 Result of viewer exposure

The evaluation of viewer exposure is based on the calculation of the influenced proportion of the population and passersby. The indicator "viewer exposure" helps to quantify the visual impact upon viewers. The influenced proportion of the population (Fig. 46-1) is calculated based on the proportion of settlements that are exposed to the WTs and the average population in each household near the wind farm, which is not only dependent on the distance but also the population density. According to the analysis in GIS, the settlements on Meishan Island and along Baimei Road suffer the most severe influence.

The influenced proportion of passersby is calculated based on the transportation lines with their traffic flows as weights (Fig.46-2). The Costal Mid-road and Baimei Road are heavily affected due to their close distances to WTs. Additionally, the huge amount of traffic increases the opportunities for pedestrians to be exposed here. The trails on Fuquan Mountain also suffer from significant visual impact due to high accessibility to WTs.

The viewer exposure (Fig. 46-3) shows the frequency of visual impact that local inhabitants and passersby may suffer. The average score 2.12 represents a comparative low exposure degree due to the undulating topography. The trails around Zhongying Wind Farm are highly exposed to the visual impairments. The main roads (e.g., Costal Mid-road and Baimei Road) are secondly influenced because of their high traffic flows. The villages in the northeast and southeast directions (e.g., Aodi, Aokou, Shangyang, Shangwang villages) are severely influenced. Due to the undulating terrain, the villages in the east of Fuquan Mountain are not affected much.

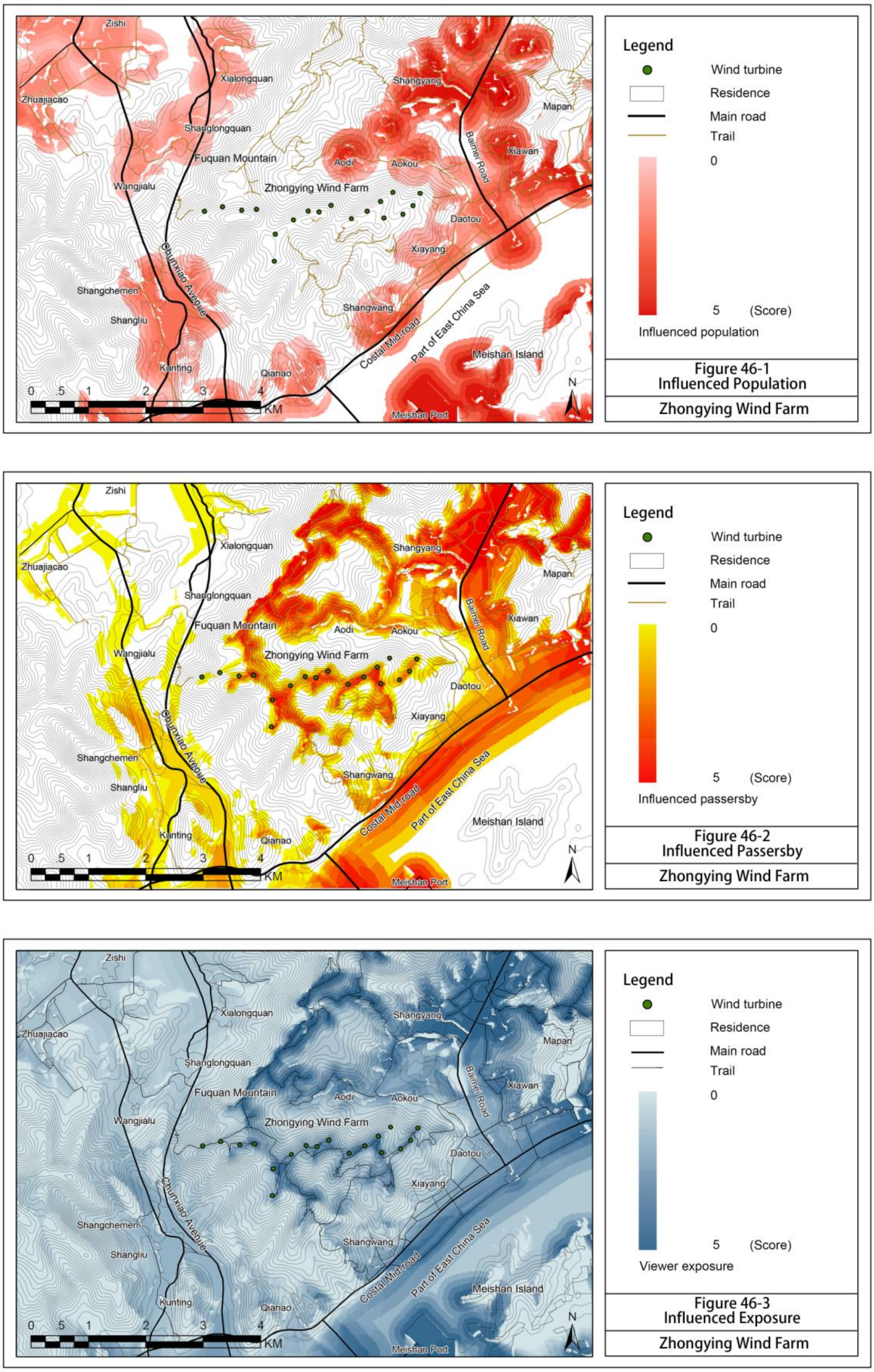


Fig. 46 Result of viewer Exposure Evaluation

5.3.2.4 Comprehensive result of LVIE in Zhongying Wind Farm

The wind farm is located on the top of Fuquan Mountain, at the highest altitude (around 450 m) in the research area. The higher altitude brings higher electricity production and meanwhile intensifies the visual impact of the WTs. Moreover, due to the undulation of the terrain and the diversification of land use, the situation of visual impact is very complicated. The visual impact is not only related to the distance between WTs and the viewer but also includes the factors of ecological sensitivity, the undulation of the terrain, and the spatial scale of the landscape.

Figure 47 demonstrates the final result of landscape visual impact in Zhongying Wind Farm in a continuous raster map. The degree of visual impact can be looked up in the attribute table in GIS, such as the affected proportion of each type of land use (Table 36), the specific location suffered the severe visual impact, and the visible proportion of WTs in each raster.

The areas suffering from severe visual impact are concentrated in the valleys on the northeast side of Fuquan Mountain, as well as along the vast waters and on the island plains on the southeast side. However, villages in the west of the wind farm are free from visual impact due to the undulating terrain and dense woods. For example, closest to the WTs, Wangjialu, Xialongquan, and Kunting villages are not significantly affected by the visual impact because they are located in the valleys on the back of the ridge. The visual impact is also mitigated by the preload of Chunxiao Avenue (the main road with high traffic flow) and sheltered by woods.

Villages located in the south of Zhongying Wind Farm, such as Shangwang and Xiayang villages, have suffered severe interference, not only because of the short distance (less than 1 km) to the WTs but also because of the cumulative height of both the mountain (around 300 m) and the WT (80 m). Moreover, the soil erosion caused by the construction of WTs on the mountain-top damages the

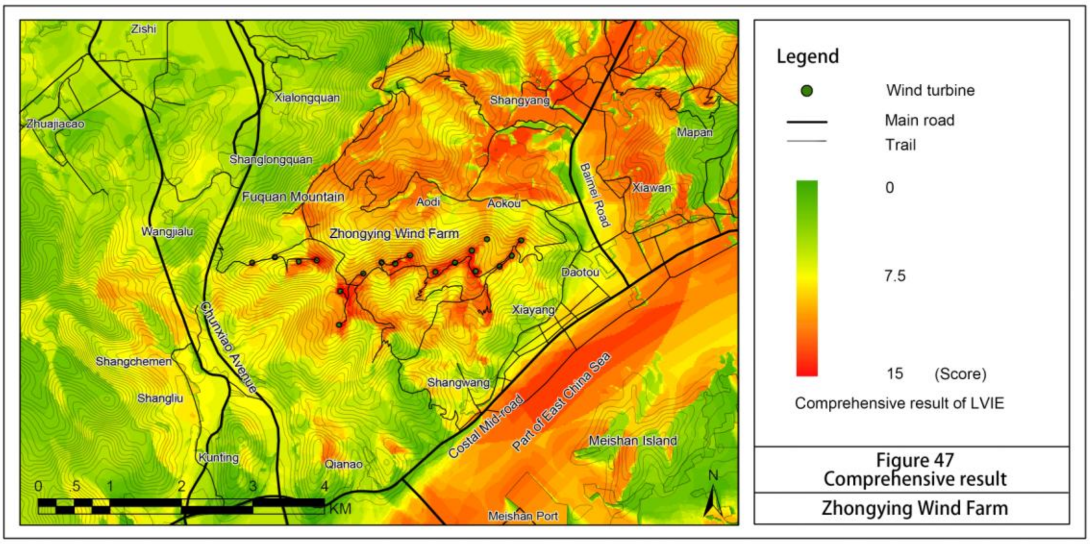


Fig. 47 Comprehensive result of the Chinese case

water quality of the reservoirs, the water source for local inhabitants. The side effect on the ecological environment provoked strong opposition from the inhabitants. The small villages Aodi and Aokou in the northeast direction are closest to the wind farm, at a direct distance of less than 800 m. They locate in the narrow valley with a low altitude. Therefore, the visual impact is particularly severe.

According to the land use plan (Fig. 48), the WTs are surrounded by the forest, the area of which accounts for over a half in the research area. However, forest land suffers comparatively low visual impact with a mean score of 1.95. Only 16.41 % of forest land is suffering the heavy visual impact, i.e., the proportion of visible WTs account for over 80 % (see Table 36). The most affected land types are water areas and urban construction land, respectively, with the heavily influenced proportion of 62.70 % and 40.80 %. This is mainly because the flat water surface and high-rise buildings are easily exposed to the WTs. The farmland (19.28 %) is also vulnerable due to the open outdoor space. The villages, cultural heritage, and recreational facilities are not highly affected by the WTs, with the heavily influenced proportion of 15.97 %, 1.88 %, and 5.61 %, respectively.

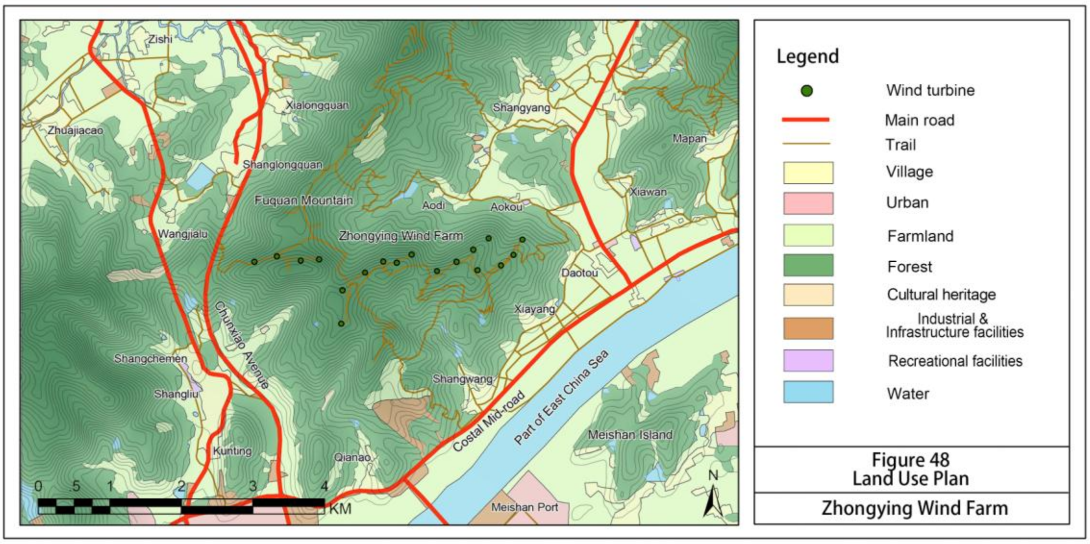


Fig. 48 Land Use Plan of Zhongying Wind Farm

Table 36 Statistical data of the visual impact in different type of land use area in the Chinese case.

Land use type	Area (ha)	Area proportion	Mean score (0-5)	Medium visual impact (Score ≥ 3)	Heavy visual impact (Score ≥ 5)
Village	349.56	4.92 %	1.75	25.74 %	15.97 %
Urban constructed land	105	1.48 %	3.00	64.61 %	40.80 %
Forest	4001.8	56.37 %	1.95	36.41 %	16.41 %
Water	402.52	5.67 %	3.80	82.43 %	62.70 %
Industrial & infrastructure facilities	197.56	2.78 %	1.47	25.41 %	13.42 %
Farmland	2017.68	28.42 %	2.07	38.79 %	19.28 %

Land use type	Area (ha)	Area proportion	Mean score (0-5)	Medium visual impact (Score ≥ 3)	Heavy visual impact (Score ≥ 5)
Cultural heritage	17.04	0.24 %	1.48	3.52 %	1.88 %
Recreational facilities	7.84	0.11 %	2.59	50.51 %	5.61 %
Total	7099	100.00 %	2.08	39.22 %	20.06 %

5.3.3 Comparison between two cases

Both the case of Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale in Germany and the case of Zhongying Wind Farm in China have been analyzed by the same LVIE model. As listed in Table 37, the mean scores of final results, as well as indicators, have been processed through grid algebraic operations in GIS. The mean scores of each indicator and final results can be horizontally compared to explore various reasons for visual impact.

First of all, the biggest difference between the two cases is the number and height of the WTs, which directly causes different research areas: 18550.44 hectares in the German case and 7,099 hectares in the Chinese case. The visual threshold areas are preset based on the 30-times the height of the installed WTs as analyzed in Table 20.

In the overall evaluation of "landscape visual impact", the mean score of the German case (8.21) is higher than that of the Chinese case (7.15), which means the comprehensive visual impact of WTs is more severe in the German case than in the Chinese case. The indicators need to be compared one by one to analyze the detailed differentiation.

For the "landscape sensitivity" indicator, the site in the Chinese case is more sensitive to the WTs than that in the German case. From the ecological perspective, the majority of land use is forest, which contains diverse flora and fauna, and complex ecosystems. In terms of landscape structure, Zhongying Wind Farm is established on more undulating terrain that includes various spatial structures (e.g., mountains, valleys, rivers, sea, and island). In the German case, the land is characterized by intensively used agricultural land, which is interrupted by small forests, fields, and hedges. The landscape sensitivity is not as high as that in the Chinese case due to comparative flat terrain. As a result, the landscape with a higher degree of sensitivity has a lower carrying capacity for wind facilities.

For the "visual impact of WTs" indicator, the German case gets a higher score (3.10) than that in Chinese case (2.37) due to higher turbines and more flat terrain. In contrast, the small turbines in the Chinese case are hindered by the undulating terrain, and visual impact has been reduced.

Due to the higher transportation accessibility and the higher visibility in the residential area in the German case, as well as the high visibility in the residence area, the "viewer exposure" indicator score (2.30) is higher than that in the Chinese case (2.12). Conversely, the transportation lines in the surrounding of WTs in the Chinese case are mainly small trails without much traffic flow, which reduces the exposure of passersby.

Table 37 Comparison of two case studies in Germany and China.

Score	**Friedrich-Wilhelm Raiffeisen Wind Farm Streu & Saale (Germany)**	**Zhongying Wind Farm (China)**
Number of WTs	10	18
Height of WTs	200 m	80 m
Research area	18550.44 HA	7099 HA
Landscape sensitivity (0-5)	2.61	2.82
Visual impact of WTs (0-5)	3.10	2.37
Viewer Exposure (0-5)	2.30	2.12
Landscape Visual Impact (0-15)	8.21	7.15

However, the detailed comparison between the two cases cannot be conducted on the specific spatial grid in GIS. The mean scores provide only an overview of each indicator, which cannot present the definite score of each spatial grid. A definite spatial analysis can only be conducted between two proposals based on the same site or the visual impact before and after the construction of a wind farm.

5.3.4 Validation of LVIE in the Chinese case

Since the LVIE model is established and implemented on a theoretical basis, its validation should be examined in empirical studies. Therefore, fieldwork and questionnaires on community acceptance have been conducted in the Zhongying Wind Farm of China to validate the veracity and reliability of the evaluation result. This section aims to verify whether the results of the evaluation fit the real situations or not, and adjust the recommendations for wind farm planning.

In this section, a questionnaire is designed to identify, classify, and analyze the relationship between community acceptance of wind energy and potential affecting factors. These factors include socio-demographic features (e.g., distance to the living house, gender, age, education level, and length of residence) and various environmental impacts (e.g., visual impact, noise, ecological impact, water pollution, soil erosion, impact on the quality of life and health) as listed in Table 39. Since the local residents are the direct victims of wind facilities and local opposition is usually the most fierce resistance to wind project (Swofford & Slattery, 2010; Petrova, 2016; Simcock, 2016). Due to their opposition, proposed wind facilities may end up being either postponed or even canceled (Roddis et al., 2018; Hammami et al., 2016). Studying the factors that affect community acceptance and cause opposite opinions is an effective solution for optimizing the planning procedures in wind farm planning.

Table 38 Factors affecting community acceptance of Zhongying Wind Farm.

Categories	Factors	Sources
Socio-demographic features	Distance to the living house	(Swofford & Slattery, 2010; Hübner & Pohl, 2015; Bishop, 2002; Bishop & Miller, 2007; Hurtado et al., 2004)
	Gender	(Molnarova et al., 2012)
	Age	(Caporale & Lucia, 2015)
	Educational level	(Molnarova et al., 2012; Bidwell, 2013)
	Length of residence	(Devine-Wright, 2005; Petrova, 2013)
Environmental impacts and accompanied annoyances	Noise	(Manyoky et al., 2016; Tabassum et al., 2014; Wang & Wang, 2015)
	Ecological impact	(Devlin, 2002)
	Soil erosion	Investigation
	Water pollution	Investigation
	Landscape visual impact	(Nohl, 2010b; Bishop, 2002; Möller, 2006; 2010; Kokologos et al., 2014; Cornwall Council, 2013; Beauchamp et al., 2006; Maehr et al., 2015; Petrova, 2013)
	Quality of life	(Hübner & Pohl, 2015; Herbrandson & Messing, 2009; Harry, 2007)
	Health	(Petrova, 2013; McKenna et al., 2016; Herbrandson, 2009)

The questionnaire was designed to have an appropriate length and to be understandable, free of bias. It consisted of four parts: the first part collected socio-demographic data of the interviewees. The second part concerned the individual perception of environmental impacts. In the third part, the attitude towards the local wind farm was investigated with an 11-point Likert-type scale (i.e., 0: strong opposition, 10: strong support) (Musall & Kuik, 2011; Jones & Eiser, 2010; Ntanos et al., 2018). The interviewees were asked to provide a score regarding their acceptance of wind energy. An open-ended question to obtain additional, intuitive feedbacks about factors was added at the end of the questionnaire.

Questionnaires were undertaken in 17 villages and along the roads of rural areas around Zhongying Wind Farm. The evaluation of factors for community acceptance was performed by a total of 180 questionnaires, with 169 valid questionnaires returned. These surveys were distributed through a method of random sampling by interviewing people living locally in the research area. The sample accounts for around 3 % of the local inhabitants. The detailed data collected from the investigation is given in Table 40. All the samples were classified into four groups by the distance factor: Group 1 (very near) within 0.5-1 km; Group 2 (near) within 1-2 km; Group 3 (mid-distance) within 2-4 km; and Group 4 (remote distance) above 4 km (Table 2). In Group 4, the interviewees were nearby residents, passersby, and tourists, who came here regularly.

Table 39 Statistics of villages near Zhongying Wind Farm.

Groups	Distance to the nearest WT	Source of respondents	Distance (m)	Population
1 Very near	0.5-1 KM	Shangwang Village	710	379
		Xiayang Village	790	293
		Daotou Village	570	776
		Aokou Village	670	60
		Taipingao Village	600	12
		Aodi Village	900	55
2 Near	1-2 KM	Shanglongquan Village	1300	339
		Wangjialu Village	1500	118
		Dongshan Village	1200	92
		Shangchemen Village	1500	421
		Kunting Village	1700	850
		Ganao Village	1650	327
		Caojiatang Village	1680	466
		Dongyuan Village	1600	254
3 Mid-distance	2-4 KM	Shangliu Village	2200-2800	590
		Guichi Village	2300-3200	595
		Xiawan Village	2800-3800	162
4 Remote distance	＞ 4 KM	Nearby residents	-	-
		Passers	-	-
		Tourists	-	-

Note: The distance factor refers to the direct distance between the center points of villages where interviews were conducted and the nearest wind turbine.

As shown in table 40, the average score of community acceptance was 4.8, with an 11-point Likert-type scale from 0 to 10, which was much lower than it was expected according to the results of Yuan et al., (2015). Further analysis of community acceptance was conducted at a disaggregated level by creating sub-groups. Firstly, the data collected by questionnaires were processed by dividing into groups under various factors: distance factor and socio-demographic factors (e.g., age, gender, educational level, and length of residence). One-way ANOVA between each factor (independent variable) and community acceptance (dependent variable) was executed to distinguish the differences between the mean values of two or more groups and the mean values within groups (Caporale & Lucia, 2015). The analysis revealed the statistically significant factors (Distance: F= 40.74, p = 0.000; Age: F= 13.82, p = 0.000; Educational level: F= 10.93, p = 0.000; Length of residence: F= 10.88, p = 0.000), while gender was not significantly relevant (F=0.28, P=0.76 ＞ 0.05).

Table 40 Descriptive statistics and ANOVA for results collected by questionnaires.

Factor	Subgroup	Number	Proportion (%)	Community acceptance (Mean)	Community acceptance (Standard Deviation)	F (ANOVA)	P (Significance)
Sum		169	100	4.8	2.4	/	/
Distance	0.5-1 km	49	29.0	2.4	2.4	40.74	0.000
	1-2 km	46	27.2	5.4	2.0		
	2-4 km	37	21.9	5.8	1.0		
	>4 km	37	21.9	6.2	1.4		
Gender	Male	93	55.0	4.9	2.5	0.28	0.76
	Female	76	45.0	4.7	2.3		
Age	< 18	8	4.7	7.3	0.7	13.82	0.000
	18-40	34	20.1	6.2	1.4		
	40-60	89	52.7	4.6	2.4		
	> 60	38	22.5	3.4	2.4		
Educational level	Primary school	21	12.4	3.1	2.9	10.93	0.000
	Secondary school	115	68.0	4.6	2.2		
	High School	21	12.4	5.7	2.0		
	College &University	12	7.1	7.4	1.5		
Length of residence	< 5 years	15	8.9	6.5	0.9	10.88	0.000
	5-10 years	19	11.2	6.5	1.0		
	10-20years	20	11.8	5.7	2.6		
	> 20 years	115	68.0	4.1	2.4		

Note: In the result of ANOVA, if the probability 'p' is less than 0.05, the relationship is deemed statistically significant.

- Distance factor

Among all the factors, distance was the most significant factor with the highest F value of 40.74 (P=0.000), which confirmed that distance was the most influential factor deciding community acceptance, especially within distance from 1 to 4 km. Compared with other groups, Group 0.5-1 km showed extremely low acceptance with a score of 2.4, far below the average score of 4.8. This phenomenon was attributed to 17 respondents (34.7 % in Group 0.5-1 km) giving a score of 0 and expressing extremely negative attitudes towards the wind farm. Additionally, the number of interviewees holding a negative attitude with a score below 4 accounted for 69.4 % in 0.5-1 km, constituting the bulk of the opposition to the wind farm. With an increase of distance above 1 km, the scores tended to be normally distributed with a median score of 6 (Fig. 49-a).

- Gender factor

The One-way ANOVA analysis revealed that the gender factor did not correlate to the community acceptance from a statistical perspective ($F=0.28$, $P=0.76 > 0.05$). Among the respondents, 93 were males (55 % of the sample) and 76 were females (45 % of the sample). There were more male than female respondents interviewed because men were inclined to be more actively involved in the questionnaire. The explanation for this is found in the traditional role of males in the research area, where the men show more participation in decisions. The average score given by males (4.9) was slightly higher than that by females (4.7). Males tended to give more extreme scores, while females gave flatter score distributions. For instance, 0 scores were given by 13 males (14 %) and 7 females (9 %), reflecting that men were more direct when expressing dissatisfaction. Meanwhile, exceptionally high scores of 10 were given by two males.

- Age factor

The age factor ranked as the second significant factor affecting community acceptance with the F value of 13.82 ($P=0.00$). There was a definite correlation between age and community acceptance in a way that the younger respondents generally held a higher community acceptance than elderly people. According to the randomly selected respondents, the majority were middle-aged (53 %) or elderly (22 %), only 25 % of respondents were young people under 40, which reflected the aging population in the locality. The results indicated that children and young people had more opportunities to acquire knowledge and information about renewable energy in school or through social media; correspondingly, most of them held a comparatively positive attitude toward wind energy.

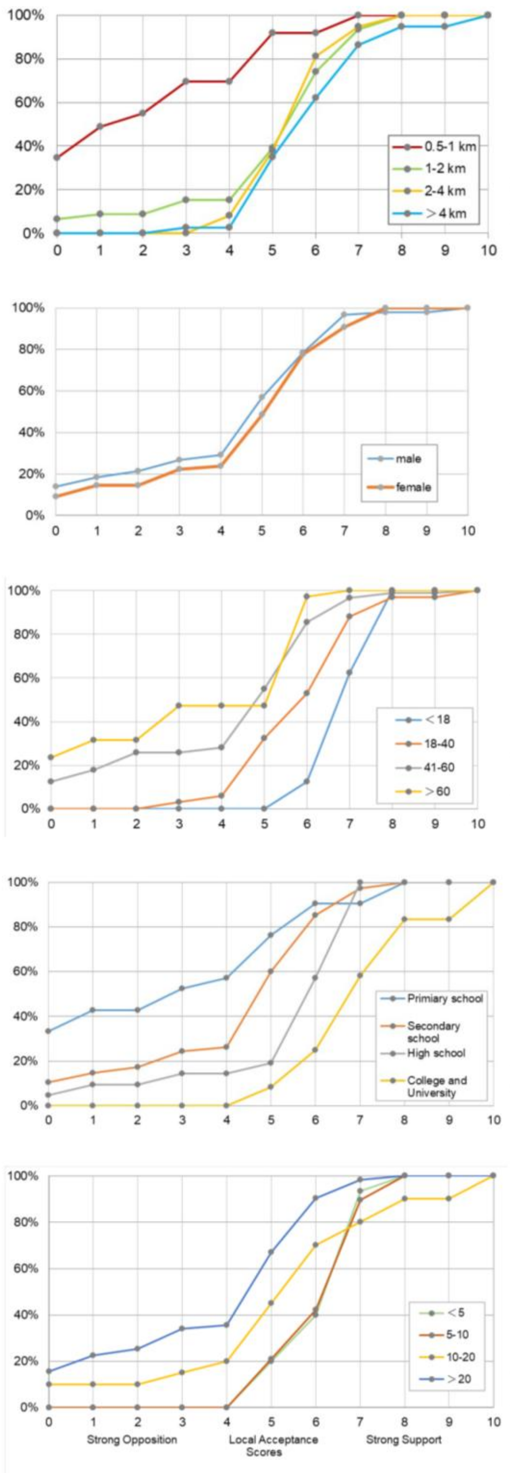
- Educational level factor

Educational level showed a positive correlation with community acceptance with the F value of 10.93, $P=0.000$. The samples were divided into four groups: primary school (12.4 %), secondary school (68 %), high school (12.4 %), and college and university (7.1 %). The low educational level in the locality was mainly because it was a rural area with pillar industries being the agricultural industry (cotton, tea tree, rice, wheat), light industry (food processing), and service industry; therefore, there are hardly any positions were requiring higher education.

The results indicated that the higher the educational level of the respondents, the more open their attitudes to the wind farm were. Highly educated people had the ability to analyze problems and had a stronger sense of social responsibility, which might make them more cautious and rational in the treatment of wind energy participation. Additionally, during long-term outdoor work, farmers were more severely impacted by wind turbines, while highly educated people usually work indoors.

- Length of residence factor

Community acceptance is also significantly correlated with length of residence with the F value of 10.88 and $P=0.000$. The analysis showed that long-term residents (living in a locality for more than 10 years) held a more negative attitude towards wind energy, while short-term residents (living in a locality for less than 10 years) tend to higher scores of accepting. There was no significant difference between groups of the length of residence below 5 years and 5 to 10 years.



a) Community acceptance as a function of the distance of participants'

b) Community acceptance as a function of gender

c) Community acceptance as a function of respondents' age (in years)

d) Community acceptance as a function of respondents' educational level

e) Community acceptance as a function of the length of residence (in years)

Fig. 49 Cumulative relative frequency distributions of local acceptance (scores on a Likert scale 0-10) of the Zhongying wind farm as a function of various influencing factors

Around 68 % of respondents are native residents who have lived here for more than 20 years. The primary type of dwelling is the self-built detached house in the countryside. Though the land belongs to the village collective, the individuals own their self-built house (Long, 2014). The policy of rural collective land ownership results in fewer immigrants in the rural area. However, East China is economically developed with higher GDP and more job opportunities than West China. The immigrants from poorer provinces usually rent a room and live here for work.

The second part of the questionnaire aimed to acquire the individual perception of environmental impact suffered from the wind farm. The critical point here is to analyze comparative impacts among different distances, rather than absolute values. Therefore, the number of respondents who perceived the environmental impact and annoyance was counted and categorized by distance (Fig. 50).

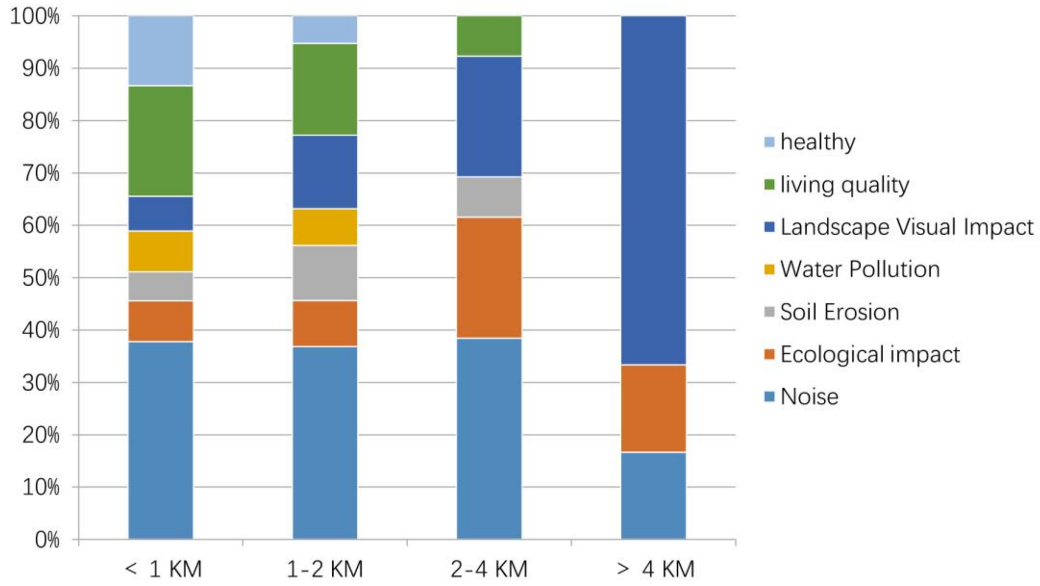


Fig. 50 Proportion of perceived environmental impact and annoyances in four distance groups

Comparisons between the four distance groups indicated that the noise factor ranked first within 4 km of the wind farm, presenting a stable percentage of between 37 % and 38 %. As the distance increased, the significance of the environmental impacts, which perceived mainly through auditory, tactile and olfactory senses, decreased more dramatically than perceived by visual sense. The intensity of the noise was gradually ineffective beyond 4 km and was overwhelmed by other co-existing influential factors. Conversely, the landscape visual impact showed a dramatic increase from 7 % to 67 %, followed by the ecological impact from 8 % to 17 %. The landscape impact was highly concerned in open spaces that directly face to the rotating surface of the wind turbines. Furthermore, as the distance increased, the number of influential factors in the environmental impact category showed a gradual decrease from seven to three factors, which illustrated the severe and multiple environmental impacts within a close distance. In this case study, the threshold was about 4 km, equivalent to 50H (H refers to the height of the wind turbine).

Interviewees in Group 1 indicated that residents not only suffered from acoustic pollutions but also perceived serious irritations on their quality of life (18 %) and individual health (11 %) caused by the continuous and loud “Huhu”-noise, which was related to both decibel level and frequency of noise emission (Hübner & Pohl, 2015). The noise generated by wind turbine blades can reach 50 to 60 dB within 1 km and cause severe physical and psychological annoyance to residents. Other associated influences such as loss of serenity in the countryside, property shrinkage, family disharmony, and low social consensus to local wind facilities have brought about broader social influence and public attention. Group 2 within 1 to 2 km was still dominated by the impact of noise. Other environmental impacts like soil erosion (10 %) and landscape visual impact (14 %) obtained more local attention with an increase in distance. From Group 3, the factors threatening health and water quality disappeared, replaced by other impacts like landscape visual impact (23 %), ecological impact (23 %), and soil erosion (8 %). Noise remained a significant reason for local rejection but not the most severe factor. In regions above 4 km, the dominant factor was replaced notably by landscape visual impact with 67 %, followed by ecological impact (17 %) and noise (16 %).

6 Discussion

6.1 Advantages of the LVIE method

In line with the target of optimizing the onshore wind farm planning procedures, the LVIE model has decomposed the visual impact into three dimensions: landscape sensitivity, the visual impact of WTs, and viewer exposure. This innovation can help to integrate the evaluation results deeply with the planning recommendations.

Among the existing methods discussed in section 3.3, the forms of evaluation results are not user-friendly enough for planners and other stakeholders to obtain useful information and participate effectively in the decision-making. The objective assessment provides a decisive conclusion to demonstrate the degree of visual impact or decide how much the wind company should pay for the compensation (Nohl, 1993; Paul et al., 2004; Roth, 2012). The result is single-dimensional and succinct, which can not mitigate the complex effects that visual impact causes in the locality and can not even provide feedback useful for further improving the evaluation method. The single result can only be used in conclusion-oriented planning implementation and is useless in improving the planning procedures. In contrast, the guidelines for visual impact assessment provide detailed descriptions and evaluation of the landscape quality before and after the installation of WTs (Oligmüller et al., 2017). The results of the evaluation are diversified and provide sufficient information to support planning implementation, such as landscape restoration, concentration zone assignment, and public participation. However, the qualitative assessment is time-consuming, not concise enough, and lacks unified standards for comparison among different cases.

The LVIE model in this thesis is a new method that combines the theoretical framework and practical solutions. It is both scientific and feasible for the cooperation between different planning departments. Moreover, the evaluation results are comparable between different cases. The method can be used for comparison between different regions with the independent variables of the number and height of WTs, the visibility of WTs, topography, surface smoothness, and demographic characteristics of the population.

For instance, the evaluation result of landscape sensitivity illustrates the sensitive areas and types of landscape resources that need extra protection. Definite protection targets and restoration measures can be implemented according to the visualized conclusion. The universal targets for landscape protection are: the restoration of the destroyed plantation, the maintenance of the ecological service of the landscape, the avoidance of soil erosion, the protection of the water sources, significant sightlines and wild animal habitats, and the strengthening of the buffer zones surrounding the ecologically sensitive areas. The natural conservation areas, national parks, biosphere reserves, landscape protection areas, and nature parks should be first excluded from wind farm site selection according to the landscape sensitivity evaluation. Other natural and cultural landscape resources should also be protected according to their values. Additionally, continuous environmental monitoring should be conducted to ensure that the long-term impact of wind turbines on landscape ecology is maintained within a controllable range.

The evaluation of the visual impact of WTs is closely related to the site selection of wind farms, the spatial layout of WTs, associated facility planning, and wind farm operation. The spatial analysis in GIS can calculate the visibility of WTs quantitatively and compare the visual impacts of WTs under different layout designs. Other parameters, such as topography, vegetation, and vertical constructions, are also taken into consideration to refine the visibility analysis. The result of the evaluation can put forward constraints for the number and height of WTs in specific regions and recommendations to improve the layout of WTs, reaching a compromise with other resource protection. This indicator evaluates the visual impact and aims to provide feedback to adjust the layout and design of WTs, compare different scenarios, and finally choose a plan with minimum impact.

The evaluation of viewer exposure illustrates certain influenced areas and influence frequency. In the process of public participation, the result of viewer exposure can be provided to the public as pre-information, which helps to improve the transparency of information, promote communication efficiency and increase the mutual trust between wind companies and the local population. The wind operators can negotiate with the communities to mitigate the visual impact or pay for compensation according to the evaluation result. For severely influenced areas, such as dense settlements and main roads with high traffic flows, some measures are suggested to mitigate the impairment of local people. For example, installing protective walls and planting dense vegetation are practical solutions to minimize the visual impact. Besides, it is also effective to reduce the accessibility of the wind farm by discarding unnecessary trails for the mitigation of the visual impact.

In summary, the LVIE has considered the theoretical framework and planning implementations comprehensively. It is open for the participation of multi-stakeholders (e.g., communities, planning authorities, landscape protection departments, wind operators, and local governments). The planning recommendations are put forward according to different evaluation sections, which are specific for different implementation departments. Compared with existing visual impact evaluation methods, the LVIE model is planning-oriented and more targeted, which can provide visualized evaluation results for decision-making.

6.2 Recommendations for wind farm planning procedures

6.2.1 Planning procedures

In Germany, setting the minimum buffer distance for different land use is the universal measure in wind farm planning (Fachagentur Windenergie an Land, 2019). However, these decrees reduce available areas for wind farms because the buffer zones occupy too much priority area. (Nkomo, 2018). Strict local decrees for height constraints and animal protection further reduce the available priority areas (Richarz et al., 2013; Guan, 2020). The one-size-fits-all method assigning a fixed buffer distance can no longer meet the needs of site selection. The LVIE model can be used to calculate how much distance should be assigned as a buffer under different scenarios. This method helps to achieve a more sustainable and compact land use plan and a fixed buffer distance is no longer the only standard for site selection. The comprehensive results of LVIE are of high significance in decision-making, instead of depending on the distance only. If the result of visual impact evaluation is of a "low" level, shorter distance is accepted as a buffer.

For instance, before the promulgation of the "10 H" regulation in Bavaria in November 2014, the permit of Friedrich-Wilhelm Raiffeisen Wind Farm had been approved. This "10 H" regulation requires that the distance of a wind turbine to its neighboring inhabited building needs to be away multiplying with 10 of the wind turbine height (Bayerische Staatsregierung, 2014). However, the distance between the WTs and the village Hollstadt, as well as the village Unsleben, is less than 10 H. During the investigation, inhabitants suffering from the visually distressing effect complained that the project has not been up to the new regulations. With the continuous negotiation between wind operators and local communities, the proposed project kept cutting down the number of WTs for several times according to the visual impact analysis, from the original 18 WTs to 14, and finally, only 10 were approved and installed. With the reduction of the installation number, the visual impact on Hendungen, Bahra, Hollstadt, and Unsleben has been mitigated to some extent. Finally, even part of the WTs has not met the “10 H” regulation, the project has been approved by the planning authorities and reached a compromise with local communities with a reasonable layout.

While in the Chinese case, the situation is different. Even the buffer distance from most settlements to WTs is over "10 H", inhabitants still suffer from severe visual impact due to the high visibility in undulating topography. The LVIE model is used to assess the visual impact in a broader scope of over "30H", instead of the original "10 H" assumption, to put forward reasonable suggestions for mitigation and compensation for severely affected settlements and landscape resources.

WTs should not be randomly scattered on the landscape. Otherwise, the irreversible impact would be exerted on the landscape, the environment, the cultural and recreational value of the region. The potential conflicts between wind energy and other resources, such as landscape protection, nature reserve, and the tourism industry should be analyzed during the planning process. Before the application for the permission, sufficient communication and assessment are necessary for landscape protection authorities, cultural assets, and tourism management departments at an upper level.

For the German case, the Regional Planning Association of the Main-Rhön region and the authorities for the regional development plan and the landscape plan should jointly assign the priority, reserved, and exclusion areas in a spatially compatible way by keeping updating their plans. It is intended that the erection of spatially significant WTs are based on anticipatory site planning. The

Friedrich-Wilhelm Raiffeisen wind farm is outside of tourist centers and has a distance of around 30 km from the Bavarian Rhön Nature Park. Therefore it has a relatively low impact on tourism and local recreation. However, the operation of WTs still has slight impacts on the biosphere and wild animals, such as skylark, partridge, meadowsweet, quail, golden plover, Black kite, and eagle owl.

In the Chinese case, new regulations for landscape protection under wind energy expansion have been promulgated in recent years. However, there is a lack of detailed implementation guidelines. More delicate solutions are necessary at the local level. For Zhongying Wind Farm, the forest surrounding the WTs are partly affected but not been detected and mitigated in advance. LVIE model provides scientific assessment results of landscape sensitivity areas, which helps to reach a compromise between landscape protection and wind farm construction.

6.2.2 Mitigation measures

Besides the common mitigation measures, such as the adjustment of the wind farm layout and the reduction of the height and number of WTs, the LVIE method puts forward specific and targeted solutions for mitigation.

According to the visibility analysis in GIS, vertical surface structures (e.g., vegetation) are competent to "hide" WTs. Vegetation with a certain height and density, preferably evergreen plant, can effectively block sight disturbance and optical disturbance as shown in Figure 51. For instance, even with a close distance to WTs, the southeast of Mittelstreu and north of Heustreu is free from visual impact because the villages are partly blocked by the forests between the wind farm and settlements. Therefore, vegetation can shelter the WTs if it located on the sightline. Based on the visualized conclusion in the LVIE model, it is easily to find out heavily influenced areas. The analysis from human perspective view can further draw definite visual impact and find out mitigation solutions.

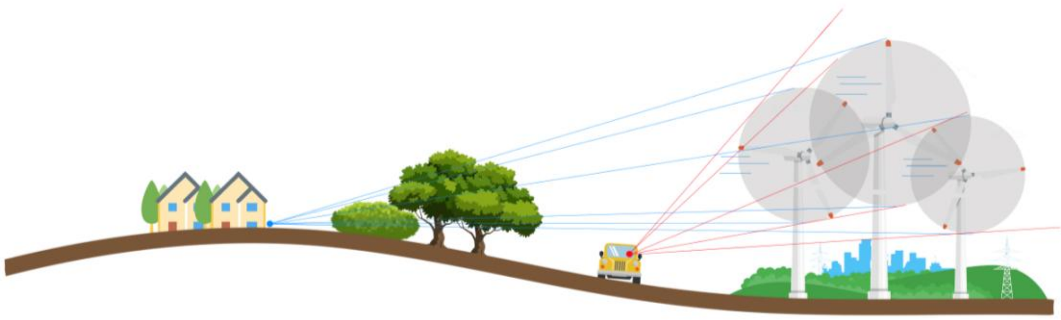


Fig. 51 Analysis from human perspective view

In the site with undulating topography, the relationship between the location of WTs and micro-terrain is of great significance for the reduction of the visual impact. For the topography of different areas, different layouts styles are recommended. On the flat plain, a cluster of WTs can effectively control the visual impact in a certain spatial scope. For instance, the proposed plan of 18 WTs in the German case scattering on both sides of the highway A71 had been initially rejected, and the number of WTs was finally cut down to 10 with a cluster layout. While in the Chinese case, the ridge of the mountain blocks the WTs and reduces visual impact. Therefore, when the site locates on the mountains, the ridge can be a natural barrier against visual impact. Avoidance of the construction of WTs near settlements at the foot of the mountains can also mitigate visual impact.

6.2.3 Compensation measures

Due to the impairment of the landscape value, compensation and replacement measures must be considered. In the existing methods for calculating the compensation fees, the payment is averagely handed out to landowners according to the areas of influenced land (Unland & Wittmann, 2016). However, according to the result of this thesis, the magnitude of visual impact is more important than the area. Although all of the areas are visible to WTs, the visual impact each area suffers is of a different extent. In the LVIE model, the compensation fee can be classified into several degrees according to the evaluation results of different influence degrees, which makes the distribution of compensation fee more equal and transparent.

In addition to the measures for avoidance, compensation, and replacement listed in the project documents, additional requirements put forward by the state nature conservation and cultural assets authorities should be fulfilled. For the visual impact on the landscape with specific natural and cultural value, extra compensation should be paid to recover their value and function. For instance, specific subsidies to the tourism and recreational industry, agriculture and forestry are necessary as a type of compensation for the economic loss in these industries. The Bavarian State Office for the Preservation of Historic Monuments points out that the villages surrounding the planned area almost always have high quality and a valuable historic building substance (Friedrich-Wilhelm Raiffeisen Windpark Streu & Saale eG and Bad Neustadt a. d. Saale, 2013). Landmarks particularly sensitive to optical impairments are, from the perspective of conservation, the church of St. Michael in Heustreu, the church of St. James in Hollstadt and Unsleben Castle. Part of the compensation is suggested to be retained for subsequent distribution when necessary.

From a perspective of sustainability, a communal fund for managing and using the compensation fee is much better than paying each individual landowner. Compensation fees can be divided into two types: short-term and long-term, and they are paid at different stages instead of one-off compensation. It can be managed and distributed as a communal fund to improve the local environment, which is an effective way to offset the environmental impact caused by wind turbines Local objections due to unequal payment of compensation and benefit share have raised social attention, which causes a standstill of the wind farm planning and the application for the permisison (Cowell et al., 2012). This solution can reduce the opposite voices from landowners due to uneven distribution.

6.3 Method limitations

It should be noted that there may be other effective variables that have not been included in the LVIE model. Moreover, some variables are not possible to detect and measure through current technologies. Consequently, the methods, data, and evaluation model in this study have inaccuracies and simplifications due to the simplifications. Uncertainties arise due to the discrepancies between the line-of-sight model and the real-world visual process, as well as the input parameters and geographical data. A few methodological problems should be mentioned:

1) The simulation of visual perception in reality concerns multi-disciplines such as geography, psychology, sociology, and physiology. It is impossible to establish an ideal model to cover all aspects in each subject. This research focuses on the planning procedures of wind energy planning.

2) In indicator selection, some subjective attributes, such as individual landscape preference, personal experiences on renewable energy, coordination between WT, and the background of landscape, should be approached by empirical research, which is time-consuming. These factors have been discussed but not involved in the evaluation model due to their low operability.

3) In GIS analysis, some indicators are processed in a simplified manner due to the limited research time, for instance, the visual impact decays with distance (van Leusen, 2002). The distance-decay function improves the evaluation accuracy by simulating the relationship between the visual perception and the distance. This, however, is not possible with the viewshed analysis in GIS.

Another indicator difficult to simulate is atmospheric scattering (Bishop, 2002). Atmospheric haze has not been included because the viewshed should be employed for the case with the worst-case visibility. A satisfactory way has not been found to simulate the contrast between wind-turbines and their background through GIS. Changes in weather conditions have been excluded from the model. Atmospheric effects such as haze and scattering of rain have not been included in the calculation of the cut-off distance.

The choice of the size of the raster is significant in the spatial analysis of GIS. It was set to 20 * 20 m. Landscape elements smaller than 20 m are excluded, such as trees, bushes, and small houses. Population data for this cell size means that the precise location of a person is not known.

The rotational speed of turbines has not been included as a model parameter, notwithstanding that smaller and faster-rotating turbines are more likely to draw attention than those larger and slower-rotating ones.

6.4 Public participation and investment in wind farm planning

6.4.1 Public participation and its procedures

Although landscape perception is a subjective issue that is hard to quantify, the attitudes of stakeholders, especially local inhabitants, can be changed by affirmative planning instruments and public participation. Then, the opposition to wind farms caused by landscape visual impact can be reduced. There is a tremendous number of studies advocating that public participation is closely related to social acceptance for wind energy (e.g., Lane, 2005; Devine-wright, 2010; Swofford & Slattery, 2010; Hammami et al., 2016; Jami & Walsh, 2014; Petrova, 2016; Enevoldsen & Sovacool, 2016). Given these researches, a significant factor influencing social acceptance is the public participation and involvement in the wind energy planning process, which even ranks before the well-known influential factors such as WT size, buffer distance, and visibility. Wolsink (2007a) holds that the public's attitude towards local projects is highly related to their involvement: the higher their involvement is, the greater the tolerance they show to wind farms. It is suggested by Pedersen et al. (2009) that the respondents economically benefiting from a wind energy project generally feel less annoyance. Conversely, the lack of community ownership is identified as the main reason for social rejection (Hammami et al., 2016).

Public participation is a process that provides private individuals with an opportunity to participate public decisions, which represents the democratization of decision-making (Quick & Bryson, 2016). Although public participation is believed to be too expensive and time-consuming, tangible benefits can be brought by the energy program with effective public participation procedures: local support, extra information about the project, avoidance for protracted conflicts with local inhabitants and potential risks of legal disputes, as well as the cooperation and trust between the agency and the public.

In Germany, public participation has been refined and well-conducted in multi-phases process of wind farm planning (pre-participation, information collection, involvement in comments on the draft plan and permits, and compensation). Legally, wind energy planning also has a complete set of provisions about public participation, which can be divided into formal and informal participation. The former goes through a set of legal provisions, and the latter goes beyond the legislative framework and is voluntary for local authorities (Schmidt et al., 2018). At the municipal level, pre-participation can be arranged to provide necessary information about the designation of the priority areas to the public, which is a voluntary and informal process. When it comes to the land use plan regarding the "hard taboo" and "soft taboo", the citizens are allowed to discuss the soft taboo criteria in an informal form, while criteria for hard taboo are strictly controlled by law. At the zoning level, before the council decides to amend the zoning plan to assign the concentration zones, a formal participation process is mandatory. In the draft plan phase, the formal participation program is mandatory, which means that the public must be informed about the potential effects of the proposed project and given opportunities to express their opinions on the project. Once the draft plan has been prepared with justification, the second stage of public participation is mandatory for allowing the public and planning authorities to comment on the draft plan and its justification. The draft plan will be open to the public for one month. With the approval of the higher administrative authority and its announcement, the new land use plan enters into force. The approved land use plan is available for the public at the town council.

However, areas where there is no renewable energy program may still hold opposite attitudes due to the lack of information, knowledge, and transparency for the public. Misinformation would be easily spread, which leads to the NIMBY phenomenon. Therefore, the information should be shared with all stakeholders as early as possible to avoid major objection in the deployment and development of wind farms. A high level of popularity of participation procedures can prevent project delays and objections caused by misinformation from the source.

In China, the land use policy and collective ownership for communities in rural areas are different from those in western countries, which poses challenges in developing regulations and procedures for public participation (Long, 2014). The current procedures for public participation are directly introduced from other countries and cannot properly merge into the local political environment. The challenge for China lies in the fact that public participation does not have a theoretical framework and implementation guidelines complied with the Chinese social context. There is a gap between regulation and practice in terms of participation. Proper guidelines and measures should be formulated with regard to multi-cultural respect and with the help of political skills based on abundant empirical studies.

Through the investigation in the villages near Zhongying Wind Farm, over 80 % of the interviewees said that they had not received any information about Zhongying Wind Farm before it was installed, not to mention taking any form of participation. Thus, they were so irritated that their impression on wind energy was negative. Even though the residents complained about the site selection, the final outcome clearly shows that their opinions were not taken seriously. There was no notification for or negotiation with the public before the approval of the project. However, according to the local government, the approval document of Zhongying Wind Farm had been released online before its construction. The whole procedures complied with the law.

There is no flexible instrument for local planning authorities to promote public participation. Reasons are listed as follows: 1) There is no adequate government funding and education in public participation; 2) Inhabitants lack the awareness of public involvement; 3) There is no platform that provides public participation; 4) There is a lack of related regulations and decrees. Transparent and standardized procedures of public participation are widely identified solutions to improve local acceptance since they increase the familiarity and improve the impression of local people to wind farms. Another crucial factor is the perceived fairness, which means that when respondents receive equal treatment, they feel a sense of fairness and trust (Friedl & Reichl, 2016), which encourages their active participation. The procedures of public participation should be improved step by step from pre-information, consultation, cooperation, and finally, self-operation (Friedl & Reichl, 2016). Public participation should be integrated into the Chinese social context with proper measures implemented such as expert consultation, public meetings, open days, school visits, a website updated with project information and videos, etc.

6.4.2 Investment and involvement in wind farm

The economic incentive is another favorable factor for promoting wind farm acceptance, which includes the concession of local electricity prices, job creation, and regional economic revitalization. If subsidies and tax relief are offered for wind farm operators, and for local residents who suffer from the environmental impact, the public support for wind energy will be easily obtained.

From the financial perspective, there are both gains and losses for the residents, village collectives, and the government. On a personal level, the financial loss is more intuitive, reflecting on the deterioration of the residential environment and property values, the functional impairment of agricultural land occupied by WTs, and the impacts on health. Macroscopically, the benefits to society are apparent in terms of the reduction in carbon emissions, creation of jobs, and revitalization of the local economy, as well as the establishment of the local industry of green energy.

In the Chinese case, it was found through the questionnaires that the benefits had not been equally shared among the residents, which resulted in severe opposition from those who had not received enough compensation to offset their loss. Broadly, the hazards and benefits of wind energy are unequally distributed among the regional stakeholders causing fierce resentments. However, it is impossible to achieve absolute equality and meet the demands of everyone. The balance of financial gains and losses is not only related to equal benefits being shared but also community involvement and economic incentives.

In Germany, the Public-Private Partnership (PPP) model encourages individuals and communities to invest in renewable energy projects, which can develop distributed and small-sized power plants and reduce the burden on the grid. This paradigm of widespread local ownership of smaller turbines erected all over the country has contributed to the generally positive image of wind power and increased the investment enthusiasm of residents and their acceptance of wind farms. It also provides a high degree of local support for planning approval, construction, and operation of wind farms. Furthermore, the Feed-in Tariff, as a financial incentive, has facilitated the private investment in power plants in the past decade. However, with the continuous reduction of remuneration rates for onshore wind Feed-in Tariff that regulated in the newly amended Renewable Energy Sources Act (Bundesministerium für Umwelt, 2011), private investors' willingness to invest in small and medium-sized wind farms is fading. This is because small-scale wind farms cannot profit with insufficient Feed-in Tariff under market conditions. It is foreseeable that when large wind companies monopolize the wind energy industry, opposition caused by inhabitants' missed investment opportunities will be fiercer.

In China, although most wind companies are private companies, there are few opportunities for individuals and communities to invest in wind farm projects. There is currently no regulation and experience to guide the PPP model. It also reflects the fact that citizens in China, especially in remote areas, have a weak awareness of citizenship and no willingness to participate in public projects.

Different from the private ownership emphasized by the Western institution, in the rural area of China, the assets of rural communities are collectively owned by the mass (Long, 2014). Therefore, community investment and operation for wind farms can be conducted to benefit the nearby inhabitants.

Equal sharing of benefits among stakeholders significantly increases local support, especially in less developed regions (Guo et al., 2015). The investigation in Zhongying Wind Farm shows that although compensation had not been distributed to individual villagers, the money went to the village committee and was used as a fund for village infrastructure facilities. The impression of wind energy can be improved through a series of measures, such as announcing a collective compensation financial plan or naming the wind farm by local landmarks.

6.5 Social acceptance and energy ethics

6.5.1 Social acceptance

Another decisive factor for wind farm planning is the social acceptance for renewable energy, which is closely related to social construction (Firestone et al., 2015). Social consensus on renewable energy development can be established through the strengthening of the public's perception and the formation of positive social values on renewable energies (Walker et al., 2010). The local attitude toward wind energy is culturally and politically infiltrated by the social media and institutional system. When a society positively promotes renewable energy with national development targets, comprehensive legislation, regulation, and market system, it lays a solid institutional foundation for wind energy development and promotes a gradual growth in the social acceptance of renewable energy (Jobert et al., 2007).

In Germany, the social acceptance of wind energy is generally higher than that in China, which is related to Germany's vigorous popularization of wind energy and the goal of renewable energy achieving the proportion of 80 % in national electricity consumption by 2050. Although the electricity price is higher than conventional energy, wind energy is more popular than coal and nuclear power due to the social consensus that developing renewable energy is the best solution to reduce carbon dioxide emissions and mitigate climate change. With the government’s promotion of renewable energy from 1998 and the enactment of the Renewable Energy Sources Act, a legal binding amount of electricity production was assigned to each nuclear power plant and a maximum of 2.62 Million GWh to be produced together. After the Fukushima accident, the government decided to terminate the use of nuclear power for energy production in Germany by 2022. The brown coal and hard coal are expected to be replaced by renewable energies soon. According to the annual increase and decrease of energy capacity (Fig.52), renewable energies gradually achieve the dominant position in the energy industry in Germany and form the social identification and acceptance.

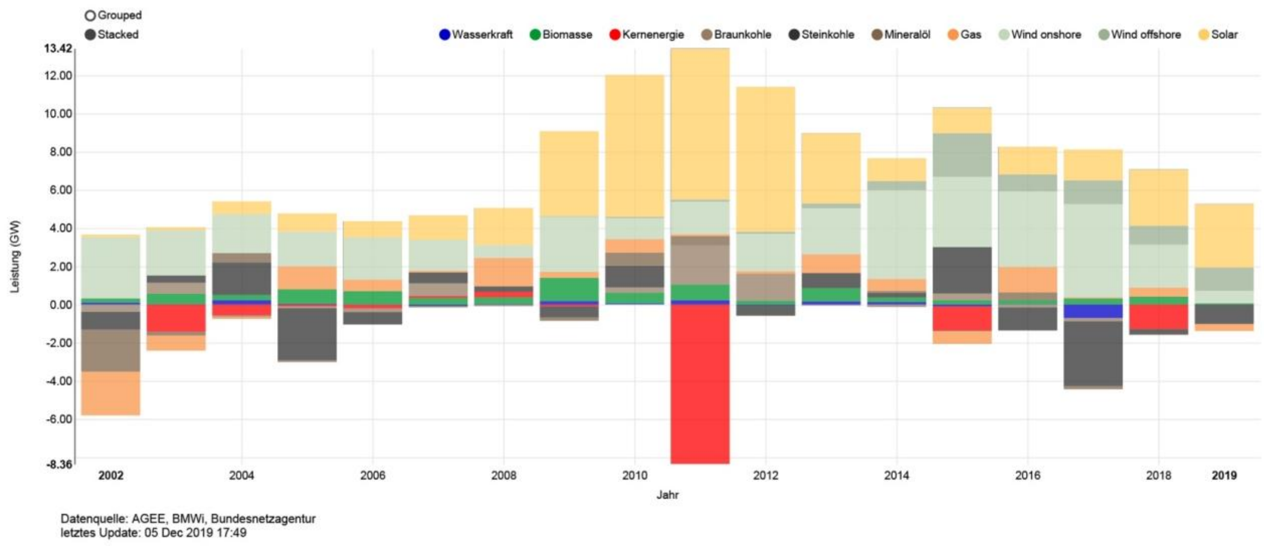


Fig. 52 German annual energy increase and decrease capacity
(Source: Fraunhofer, www.energy-charts.de)

In China, the institutional framework is being continuously improved to provide a basis for wind energy development. The Renewable Energy Law launched in 2006 has dramatically accelerated the pace of the development of the domestic wind industry. Additionally, the Environmental Impact Assessment Law, as well as the Urban and Rural Planning Law, guarantee the expansion of wind energy in China. The green energy trading mechanism is currently being drafted to establish an open market. Though the gap between social acceptance and local opposition cannot be filled soon, it can be narrowed with the help of social media. Adequate knowledge and accurate information that explains both the advantages and disadvantages of wind energy can reduce local opposition to some extent. Additionally, the media can build a positive image of wind energy by promoting ideas such as "progressive-community" or "green community" and highlighting the significant role played by the projects (Musall & Kuik, 2011). Some residents even think of WTs as the green landmarks and the symbol of progress (Firestone et al., 2015).

6.5.2 Energy ethics

For the development of wind energy, an unavoidable issue is the justice of resource utilization and land designation. Since wind energy brings environmental impact, the expansion of wind energy exacerbates the spatial range of environmental impact. Especially for visual impact, the impacted area can be enlarged with the growing height of turbines, even to reach dozens of km^2.

The concentration zones at specific locations are carved out by the planning authorities in Germany to reduce extra environmental impact. Therefore, as many WTs as possible should be permitted at concentration zones so that the impact on the landscape is counteracted by the largest possible amount of feed-in electricity, and other landscapes can be free from any impact. From a spatial planning perspective, on the one hand, the concentration of large-scale wind farms in a relatively small area entails a high level of pollution; on the other hand, it ensures that other sensitive landscape spaces have no problem with the impact, thus preventing the sprawl of WTs.

More emphasis has been paid on procedure justice, information balance, and trust in the government in the context of wind farm planning. Transparent planning procedures help to reduce residents' opposition and win the local support (NABU, 2019). However, the concentrated impact causes inequality to the locality of wind farms. Wind farm projects are more easily approved in areas with similar artificial facilities because of preload. Excessive concentration of infrastructure like wind farms can damage the environment in the area. The research of NABU (2019) reveals that fierce protest against wind facilities mainly comes from the minority of residents who suffer from severe impacts, while this cannot represent the opinions of the majority of citizens. The polarization of environmental quality between areas with and without wind farms reveals the social problem that land designation brings about (NABU, 2019).

7 Conclusions, contributions and implications

This section summarizes the significant findings during the research and answers the questions put forward in the Introduction.

7.1 Concluding the thesis

In the context of the global energy transition, developing wind energy is a practical way to deal with climate change and reduce carbon dioxide emissions. However, the expansion of onshore wind energy encounters obstacles from spatial planning. There is not enough space for wind farms in compact land use areas due to the growing distance of clearance. The giant turbines also bring severe environmental impact and landscape visual impairment against human health and wildlife. The demand for balancing wind energy development and environmental protection can be met through the advanced planning instruments that can scientifically evaluate the visual impact caused by WTs and provide proper mitigation measures. The existing evaluation methods have been researched and classified into three categories: the guidelines, quantitative evaluation methods, and 3D visualization analysis.

The knowledge framework of landscape visual impact caused by WTs has been clarified, researched, and reorganized for the result of this thesis: the Landscape Visual Impact Evaluation (LVIE) for wind farms. The thesis contributes a clear illustration of the evolution of the meaning of landscape, including the exploration of the lexical and cultural origin of the term "Landscape", its precise definition, and the difference of landscape as a notion between China and Europe. Then, more aspects related to visual impact evaluation are discussed, such as landscape perception, landscape aesthetics, and landscape function, as well as existing evaluation methods for landscape quality. A complete literature review about the history of wind energy, the development of the wind energy industry, turbine technologies, and the planning regimes of wind energy is given for an establishment of the theoretical framework. Finally, the LVIE model has been established based on relevant theories and verified through case studies.

The influential factors affecting landscape visual impact have been systematically divided into three indicator sets: landscape sensitivity, the visual impact of WTs, and viewer response. An evaluation model has been established based on the theoretical framework with a hierarchy indicator set. A standardized process of indicator selection ensures the reliability and applicability of this model. The case studies of the German and Chinese wind farms have verified the LVIE method and the results are illustrated cartographically to demonstrate detailed locations and the degree of visual impact. The results provide the detailed framework to support decision-making for planning.

7.2 Contributions to knowledge

The contributions of this thesis can be outlined as follows:

1. It fills the research gap between onshore wind energy expansion and visual landscape quality protection through the establishment of a theoretical framework of landscape visual impact evaluation for wind farm planning.
2. It enriches the connotation of the landscape in terms of the dynamic evolution of landscape under the background of the global energy transition.
3. It establishes an implementable, visualized, quantitative, and standardized GIS-based Landscape Visual Impact Evaluation model for planning procedures.
4. It compares the wind energy industry between Germany and China from the perspectives of industry development, future scenarios, and planning procedures. The comparison provides specific recommendations based on detailed problems which the country for wind energy planning.

7.3 Implications

Based on the conclusion of this thesis, this research suggests the following implications for protecting landscape quality in the visual threshold of WTs:

First, the landscape visual impact evaluation should be required as a mandatory process for wind energy planning. Not only for the developed countries that advocate environmentalism but also for developing countries that seek economic development, landscape protection is the embodiment of environmental justice and is always a challenge for different political goals. Decision-making for spatial planning and wind farm site selection needs not only professional knowledge of planning and the respect for local culture but also political attention. Economic development indeed comes at the expense of the consumption of environmental resources. However, when a uniform baseline for environmental protection is set, the situation will be under control.

Second, given the subjectivity of the perception of visual impact among individuals, the quantification of the evaluation process is necessary. It helps to standardize the evaluation results by quantifying the evaluation steps, the approaches of indicator selection, and sources of data. It also provides the possibility to compare the changes of landscape quality before and after the project, as well as horizontal comparisons between different projects. Establishing the evaluation model requires the consideration of the meaning and purpose of evaluation from a methodological perspective.

Third, the significance of public participation needs to be emphasized during the wind energy planning. The different attitudes held by German and Chinese inhabitants towards wind farm result partly from their different understanding of nature, and partly from their various land management and economic policies. These attributes have greatly influenced the individual acceptance of wind energy facilities in both countries. Therefore, when establishing the evaluation model, it is necessary to take the different levels of landscape carrying capacity in different regions into consideration.

Forth, the concept of landscape is constantly evolving, the same as the standards of landscape evaluation. With the development of human society, from the original primitive landscape to a semi-artificial and semi-natural environment, and then to the development of urban agglomerations, the appearance of landscape is always changing. Therefore, the visual impact for people may become an indispensable part in daily life after several decades, and the social acceptance for WTs may therefore increase. However, we still need to be conservative and cautious, and have awe for the nature.

References

Ackermann, T., Söder, L., 2002. An overview of wind energy-status 2002. Renew. Sustain. Energy Rev. 6, 67–128. https://doi.org/10.1016/S1364-0321(02)00008-4

Adam, K., Nohl, W., Valentin, W., 1986. Bewertungsgrundlagen für Kompensationsmaßnahmen bei Eingriffen in die Landschaft, XII, 399 S. Düsseldorf.

AILA (Australian Institute of Landscape Architects), 2018. Guidance Note for Landscape and Visual Assessment. Queensland State, Australia.

Albert, G., 2005. Hermeneutischer Positivismus und dialektischer Essentialismus Vilfredo Paretos, Hermeneutischer Positivismus und dialektischer Essentialismus Vilfredo Paretos. https://doi.org/10.1007/978-3-322-80669-7

Allmendinger, P., Haughton, G., Knieling, J., Othengrafen, F. (Eds.), 2015. Soft spaces in Europe. Re-negotiating governance, boundaries and borders. Routledge.

Amin, A., 2004. Regions unbound: Towards a new politics of place. Geogr. Ann. Ser. B Hum. Geogr. 86, 33–44. https://doi.org/10.1111/j.0435-3684.2004.00152.x

Ancona, D., Mcveigh, J., 2001. Wind Turbine-Materials and Manufacturing.

Antrop, M., 2013. A brief history of landscape research, in: Howard, P., Thompson, I., Waterton, E. (Eds.), The Routledge Companion to Landscape Studies. Routledge Taylor & Francis Group, New York.

Antrop, M., 2005. Why landscapes of the past are important for the future. Landsc. Urban Plan. 70, 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002

Antrop, M., 2004. Landscape change and the urbanization process in Europe. Landsc. Urban Plan. 67, 9–26. https://doi.org/10.1016/S0169-2046(03)00026-4

Antrop, M., 2000. Changing patterns in the urbanized countryside of Western Europe. Landsc. Ecol. 15, 257–270. https://doi.org/10.1023/A:1008151109252

Appleton, J., 1988. Prospects and refuges revisited, in: Nasar, J.L. (Ed.), Environmental Aesthetics: Theory, Research, and Applications. Cambridge University Press, Cambridge, UK, pp. 27–44. https://doi.org/10.2307/1575726

Appleton, J., 1975. The Experience of Landscape. Wiley, London, UK.

Araújo, K., 2014. The emerging field of energy transitions: Progress, challenges, and opportunities. Energy Res. Soc. Sci. 1, 112–121. https://doi.org/10.1016/j.erss.2014.03.002

Archie, L., Archie, J.G., 2006. Readings in the History of Esthetics. Open Source DocBook.

Arezes, P.M., Bernardo, C.A., Ribeiro, E., Dias, H., 2014. Implications of Wind Power Generation: Exposure to Wind Turbine Noise. Procedia - Soc. Behav. Sci. 109, 390–395. https://doi.org/10.1016/j.sbspro.2013.12.478

Argyropoulos, D., Godron, P., Graichen, P., Litz, P., Pescia, D., Podewils, C., Redl, C., Ropenus, S., Rosenkranz, G., 2016. Energiewende: What do the new laws mean? Agora Energiewende.

AWEA (American Wind Energy Association), 2019. Wind’s Environmental Record [WWW Document]. Am. Wind Energy Assoc. URL https://www.awea.org/wind-101/benefits-of-wind/environmental-benefits (accessed 11.26.19).

Bacon, W.R., 1979. The Visual Management System of the Forest Service, USDA, in: Proceedings of Our National Landscape: A Conference on Applied Techniques for Analysis and Management of the Visual Resource. General Technical Report (GTR), pp. 660–665.

BayBO, 2007. Art. 82 Windenergie und Nutzungsänderung ehemaliger landwirtschaftlicher Gebäude (1) § 35 [WWW Document]. URL https://www.gesetze-bayern.de/Content/Document/BayBO-82?AspxAutoDetectCookieSupport=1 (accessed 9.2.19).

Bayerische Staatsregierung, 2014. Bayerisches Gesetz- und Verordnungsblatt. Germany.

Beauchamp, G., Armstrong, W., Buchan, N., 2006. Visual Representation of Windfarms Good Practice Guidance (No. FO3 AA 308/2), SNH COMMISSIONED REPORT. UK.

Bell, S., 2012. Landscape: Pattern, Perception and Process, 2nd ed. Routledge Taylor & Francis Group, USA and Canada.

Bidwell, D., 2013. The role of values in public beliefs and attitudes towards commercial wind energy. Energy Policy 58, 189–199. https://doi.org/10.1016/j.enpol.2013.03.010

Bishop, I.D., 2011. What Do We Really Know? A Meta-Analysis of Studies Into Public Responses to Wind Energy. World Renew. Energy Congr. – Sweden, 8–13 May, 2011, Linköping, Sweden 4161–4168. https://doi.org/10.3384/ecp110574161

Bishop, I.D., 2002. Determination of thresholds of visual impact: The case of wind turbines. Environ. Plan. B Plan. Des. 29, 707–718. https://doi.org/10.1068/b12854

Bishop, I.D., Miller, D.R., 2007. Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. Renew. Energy 32, 814–831. https://doi.org/10.1016/j.renene.2006.03.009

Blessing, M., 2017. Planung und Genehmigung von Windenergieanlagen. Kohlhammer, Stuttgart.

Blotevogel, H.H., Döring, T., Grotefels, S., Helbrecht, I., Jessen, J., Schmidt, C. (Hrsg. ., 2018. Handwörterbuch der Stadt- und Raumentwicklung. Band 2. ARL, Hannover, Germany.

Bluestone, D.M., 1988. Detroit ’ s City Beautiful and the Problem of Commerce. J. Soc. Archit. Hist. 47, 245–262.

BMJV (Bundesministerium der Justiz und für Verbraucherschutz), BFJ (Bundesamt für Justiz), 2019a. Umweltinformationsgesetz [WWW Document]. URL https://www.gesetze-im-internet.de/uig_2005/ (accessed 9.29.19).

BMJV (Bundesministerium der Justiz und für Verbraucherschutz), BFJ (Bundesamt für Justiz), 2019b. Gesetz über Naturschutz und Landschaftspflege (Bundesnaturschutzgesetz - BNatSchG) [WWW Document]. URL https://www.gesetze-im-internet.de/bnatschg_2009/BNatSchG.pdf (accessed 8.26.19).

BMJV (Bundesministerium der Justiz und für Verbraucherschutz), BFJ (Bundesamt für Justiz), 2005. Verordnung zum Schutz wild lebender Tier- und Pflanzenarten (Bundesartenschutzverordnung - BArtSchV). Germany.

Bogner, A., Littig, B., Menz, W., 2002. Das Experteninterview. Theorie, Methode, Anwendung, Springer Fachmedien Wiesbaden GmbH. https://doi.org/10.1007/978-3-8349-9441-7_28

Bolin, K., Bluhm, G., Eriksson, G., Nilsson, M.E., 2011. Infrasound and low frequency noise from wind turbines: Exposure and health effects. Environ. Res. Lett. 6, 1–6. https://doi.org/10.1088/1748-9326/6/3/035103

BP, 2019. BP Statistical Review of World Energy.68th edition.

BP, 2018. Statistical Review of World Energy 2018. 67th edition.

Breukers, S., Wolsink, M., 2007. Wind power implementation in changing institutional landscapes: An international comparison. Energy Policy 35, 2737–2750. https://doi.org/10.1016/j.enpol.2006.12.004

Brown, M.A., Sovacool, B.K., 2011. China’s National Improved Stove Program, 1983–1998, in: Climate Change and Global Energy Security: Technology and Policy Options. MIT Press, Cambridge, Massachusetts; London, England. 292-300.

Brown, T.C., Daniel, T.C., 1990. Scaling of ratings: Concepts and methods. USDA Forest Service Research Paper RM-293. Fort Collins, CO. https://doi.org/10.2737/RM-RP-293

Bruhns, A., Schultz, S., Stotz, P., Tack, A., 2019. Geplante Abstandsregel für Rotoren.Windjammera: Die von Wirtschaftsminister Altmaier geplanten Mindestabstände von Windrädern zu Wohnhäusern sorgen für Streit in der Koalition. Das Vorhaben gefährdet die Energiewende. Spiegel Online.

Buhyoff, G.J., Leuschner, W.A., Wellman, J.D., 1979. Aesthetic impacts of Southern Pine Beetle damage. J. Environ. Manage. 8, 261–267.

Buhyoff, G.J., Wellman, J.D., Harvey, H., Fraser, R.A., 1978. Landscape architects’ interpretations of people’s landscape preferences. J. Environ. Manage. 6, 255–262.

Bundesministerium für Umwelt, 2011. Vergütungssätze , Degression und Berechnungsbeispiele nach dem neuen Erneuerbare-Energien-Gesetz (EEG). Germany.

Bundesministerium für Wirtschaft und Energie, 2017. Erneuerbare-Energien-Gesetz 2014 (EEG 2014)，Die Reform des EEG im Jahr 2014: Wichtiger Schritt für den Neustart der Energiewende [WWW Document]. Bundesministerium für Wirtschaft und Energ. URL https://www.erneuerbare-energien.de/EE/Redaktion/DE/Dossier/eeg.html?cms_docId=73930 (accessed 11.22.19).

Bundesverband Windenergie, VDMA Power Systems, 2016. Status of Land-based Wind Energy Development in Germany. Year 2016. Varel,Germany.

Burckhardt, L., 2006. Landschaftsentwicklung und Gesellschaftsstruktur, in: Warum Ist Landschaft Schön? Die Spaziergangswissenschaft. Kassel, pp. 19–33.

Caporale, D., De Lucia, C., 2015. Social acceptance of on-shore wind energy in Apulia Region (Southern Italy). Renew. Sustain. Energy Rev. 52, 1378–1390. https://doi.org/10.1016/j.rser.2015.07.183

Castiglioni, B., Nardi, A. De, Dalla-Zuanna, G., 2015. Landscape Perception as a Marker of Immigrant Children's Integration. An Explorative Study in the Veneto Region (Northeast Italy), in: Bruns, D., Kühne, O., Schönwald, A., Theile, S. (Eds.), Landscape Culture – Culturing Landscapes: The Differentiated Construction of Landscapes. Springer VS., Wiesbaden. https://doi.org/10.1007/978-3-658-04284-4

Chang, Y.C., Wang, N., 2017. Legal system for the development of marine renewable energy in China. Renew. Sustain. Energy Rev. 75, 192–196. https://doi.org/10.1016/j.rser.2016.10.063

Chilla, T., Kühne, O., Neufeld, M., 2016a. Regionalentwicklung. UTB GmbH.

Chilla, T., Kühne, O., Weber, Florian, Weber, Friedericke, 2016b. „Neopragmatische" Argumente zur Verein- barkeit von konzeptioneller Diskussion und Praxis der Regionalentwicklung. In O. Kühne & F. Weber (Hrsg.), Bausteine der Regionalentwicklung, Bausteine der Regionalentwicklung. Springer VS., Wiesbaden.13-24. https://doi.org/10.1007/978-3-658-02881-7_16

CMA (China Meteorological Administration), 2009. China wind energy resource reserves and distribution [WWW Document]. China Meteorol. News. URL http://www.cma.gov.cn/kppd/kppdkpdt/201211/t20121127_192640.html (accessed 8.26.20).[In Chinese].

CNDRC (Chinese National Development and Reform Commission), 2007. Mid- and Long-term Renewable Energy Plan. Beijing, China.

CNDRC (Chinese National Development and Reform Commission), 2003. Wind Farm Site Selection Technical Regulation. Beijing, China.

CNEA (Chinese National Energy Administration), 2019a. Wind power grid connection operation in 2018 [WWW Document]. URL http://www.nea.gov.cn/2019-01/28/c_137780779.htm

CNEA (Chinese National Energy Administration), 2019b. Notice on promoting wind power and photovoltaic power generation without subsidies. Beijing, China.

CNEA (Chinese National Energy Administration), 2016. The 13th Wind Energy Five-Year Plan (2016-2020). China.

CNEPA (Chinese National Environmental Protection Agency), 1994. Principle for categories and grades of nature reserve. China.

CNERC (National Electricity Regulatory Commission), 2007. Measures on Supervision and Administration of Grid Enterprises in the Purchase of Renewable Energy Power (SERC [2007] No. 25). China.

Coeterier, J.F., 1996. Dominant attributes in the perception and evaluation of the Dutch landscape. Landsc. Urban Plan. 34, 27–44. https://doi.org/10.1016/0169-2046(95)00204-9

Cornwall Council, 2013a. An Assessment of the Landscape Sensitivity to On- shore Wind Energy and Large- scale Photovoltaic Development in Cornwall. Cornwall.

Cornwall Council, 2013b. An Assessment of the Landscape Sensitivity to On- shore Wind Energy and Large- scale Photovoltaic Development in Cornwall.

Cosgrove, D.E., 1986. Social Formation and Symbolic Landscape. Geogr. Rev. 76, 119–121.

Council of Europe, 2000. European Landscape Convention. Florence. https://doi.org/http://conventions.coe.int/Treaty/en/Treaties/Html/176.htm

Cowell, R., Bristow, G., Munday, M., 2012. Wind energy and justice for disadvantaged communities. Joseph … 1–44.

Dai, J., Yang, X., Wen, L., 2018. Development of wind power industry in China: A comprehensive assessment. Renew. Sustain. Energy Rev. 97, 156–164. https://doi.org/10.1016/j.rser.2018.08.044

Dai, K., Bergot, A., Liang, C., Xiang, W.N., Huang, Z., 2015. Environmental issues associated with wind energy - A review. Renew. Energy 75, 911–921. https://doi.org/10.1016/j.renene.2014.10.074

Daniel, T.C., 2001. Whither scenic beauty? Visual landscape quality assessment in the 21st century. Landsc. Urban Plan. 54, 267–281. https://doi.org/10.1016/S0169-2046(01)00141-4

Daniel, T.C., 1976. Criteria for Development and Application of Perceived Environmental Quality Indices, in: Craik, K.H. (Ed.), Perceiving Environmental Quality. Plenum Press, New York, pp. 27–45. https://doi.org/10.1007/978-1-4684-2865-0

Daniel, T.C., Boster, R.S., 1976. Measuring Landscape Aesthetics: The Scenic Beauty Estimation Method. USDA Forest Service Research Paper RM-167,Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Daniel, T.C., Schroeder, H.W., 1979. Scenic beauty estimation model: Predicting perceived beauty of forest landscapes. Our landscape. A Conf. Appl. Tech. Anal. Manag. Vis. Resour.

Daniel, T.C., Vining, J., 1983. Methodological Issues in the Assessment of Landscape Quality, Human Behavior & Environment: Advances in Theory & Research.

Del Carmen Torres Sibille, A., Cloquell-Ballester, V.-A., Cloquell-Ballester, V.A., Darton, R., 2009. Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms. Renew. Sustain. Energy Rev. 13, 40–66. https://doi.org/10.1016/j.rser.2007.05.002

Devine-Wright, P., 2005. Local Aspects of UK Renewable Energy Development:Exploring public beliefs and policy implications. Local Environ. 10, 57–69. https://doi.org/https://doi.org/10.1080/1354983042000309315

Devlin, E., 2002. Factors Affecting Public Acceptance of Wind Turbines in Sweden. Lunds Univ. Lunds University. https://doi.org/10.1260/030952405776234580

Dorda, D., 2018. Windkraft und Naturschutz, in: O.Kühne, F.Weber (Eds.), Bausteine Der Energiewende. pp. 749–771. https://doi.org/doi.org/10.1007/978-3-658-19509-0_37

Dramstad, W.E., Tveit, M.S., Fjellstad, W.J., Fry, G.L.A., 2006. Relationships between visual landscape preferences and map-based indicators of landscape structure. Landsc. Urban Plan. 78, 465–474. https://doi.org/10.1016/j.landurbplan.2005.12.006

Drexler, D., 2010. Landschaft und Landschaftswahrnehmung.Untersuchung des kulturhisto- rischen Bedeutungswandels von Landschaft anhand eines Vergleichs von England, Frankreich, Deutschland und Ungarn. Tech. Univ. MÜNCHEN. TECHNISCHE UNIVERSITÄT MÜNCHEN.

Duntley, S.Q., 1948. The Visibility of Distant Objects. J. Opt. Soc. Am. 38, 237–249. https://doi.org/10.1364/josa.38.000237

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

Eichhorn, M., Masurowski, F., Becker, R., Thrän, D., 2019. Wind energy expansion scenarios – A spatial sustainability assessment. Energy 180, 367–375. https://doi.org/10.1016/j.energy.2019.05.054

Enevoldsen, P., Sovacool, B.K., 2016. 283. Examining the social acceptance of wind energy: Practical guidelines for onshore wind project development in France. Renew. Sustain. Energy Rev. 53, 178–184. https://doi.org/10.1016/j.rser.2015.08.041

European Commission, 2018. Renewable Energy Prospects for the European Union.

EverPower, 2017. Shadow Flicker Report.Baron Winds Project. Towns of Cohocton, Dansville, Fremont, and Wayland - Steuben County, New York. New York.

Fachagentur Windenergie an Land, 2019. Überblick zu den Abstandsempfehlungen zur Ausweisung von Windenergiegebieten in den Bundesländern.

Fachagentur Windenergie an Land e.V, 2017. Energiepolitische Programmatik Nordrhein-Westfalen [WWW Document]. URL https://www.fachagentur-windenergie.de/veroeffentlichungen/laenderinformationen/laenderinformationen-zur-windenergie/nordrhein-westfalen.html (accessed 8.2.19).

Fines, K.D., 1968. Landscape Evaluaton: A Research Project in East Sussex. Reg. Stud. 2, 41–55. https://doi.org/10.1080/09595236800185041

Firestone, J., Bates, A., Knapp, L.A., 2015. See me, Feel me, Touch me, Heal me: Wind turbines, culture, landscapes, and sound impressions. Land use policy 46, 241–249. https://doi.org/10.1016/j.landusepol.2015.02.015

Fischer, L., 2013. Kulturlandschaft und Arbeit: Nachdenken über das Selbstverständliche, in: Leibenath, M., Heiland, S., Kilper, H., Tzschaschel, S. (Eds.), Wie Werden Landschaften Gemacht? Sozialwissenschaftliche Perspektiven Auf Die Konstituierung von Kulturlandschaften. Bielefeld, Germany, pp. 39–60.

Flick, U., 2016. Qualitative Sozialforschung. Eine Einführung, 7th ed, Rowohlt Verlag GmbH. Rowohlts Enzyklopädie, Berlin, Germany. https://doi.org/10.1515/9783111410609-007

Forman, R.T.T., 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK. https://doi.org/10.2307/2261341

Forman, R.T.T., Godron, M., 1986. Landscape Ecology. John Wiley and Sons, New York. https://doi.org/10.1007/978-1-4419-0851-3_575

Forschungs Verbund Erneuerbare Energien, 2010. Energy Concept 2050 for Germany with a European and Global Perspective. Berlin, Germany.

Fouquet, R., Pearson, P.J.G., 2012. Past and prospective energy transitions: Insights from history. Energy Policy 50, 1–7. https://doi.org/10.1016/j.enpol.2012.08.014

Frank, S., Fürst, C., Koschke, L., Witt, A., Makeschin, F., 2013. Assessment of landscape aesthetics-Validation of a landscape metrics- based assessment by visual estimation of the scenic beauty. Ecol. Indic. 32, 222–231. https://doi.org/10.1016/j.ecolind.2013.03.026

Fraunhofer Institute, 2017. Das Barometer der Energiewende [WWW Document]. URL https://www.herkulesprojekt.de/de/Barometer/barometer_2017/windenergie.html (accessed 12.15.19).

Friedl, C., Reichl, J., 2016. Realizing energy infrastructure projects - A qualitative empirical analysis of local practices to address social acceptance. Energy Policy 89, 184–193. https://doi.org/10.1016/j.enpol.2015.11.027

Friedrich-Wilhelm Raiffeisen Windpark Streu & Saale eG, Bad Neustadt a. d. Saale, 2013. Landesplanerische Beurteilung für die Errichtung und den Betrieb des Friedrich-Wilhelm Raiffeisen Windparks Streu & Saale. Würzburg.

Gasch, R., Twele, J., 2011. Windkraftanlagen - Grundlagen, Entwurf, Planung und Betrieb, 7th ed, Vieweg + Teubner. Vieweg + Teubner Verlag. https://doi.org/10.1017/CBO9781107415324.004

Geraint, E., Gianluca, F., 2016. The social acceptance of wind energy: JRC Science for Policy Report. https://doi.org/10.2789/696070

Gerhards, I., 2003. Die Bedeutung der landschaftlichen Eigenart für die Landschaftsbildbewertung. Freiburg University.

Gibbons, S., 2015. Gone with the wind: Valuing the visual impacts of wind turbines through house prices. J. Environ. Econ. Manage. 72, 177–196. https://doi.org/10.1016/j.jeem.2015.04.006

Gobster, P.H., 1999. An Ecological Aesthetic for Forest Landscape Management. Landsc. J. 18, 54–64.

Gobster, P.H., Nassauer, J.I., Daniel, T.C., Fry, G., 2007. The shared landscape: What does aesthetics have to do with ecology? Landsc. Ecol. 22, 959–972. https://doi.org/10.1007/s10980-007-9110-x

Golding, E.W., 1976. Generation of electricity by wind power, Polar Record. United Kingdom. https://doi.org/10.1017/S0032247400047483

Granö, J.G., 1929. Reine Geographie: Eine methodologische Studie beleuchtet mit Beispielen aus Finnland und Estland. Helsinki-Helsingfors.

Grotz, C., Jensen, B., Schroth, G., 2012. Repowering von Windenergieanlagen.Effizienz, Klimaschutz, regionale Wertschöpfung, Bundesverband WindEnergie e.V. (BWE). (Eds.), MüllerDitzen, Bremerhaven.

Guan, J., 2020. Westerly breezes and easterly gales: A comparison of legal, policy and planning regimes governing onshore wind in Germany and China. Energy Res. Soc. Sci. 67, 1–12. https://doi.org/10.1016/j.erss.2020.101506

Guan, J., 2018. Lessons from German On-shore wind farm planning. J. Phys. Conf. Ser. 1102 012029 1–7. https://doi.org/10.1088/1742-6596/1102/1/012029

Gulinck, H., Múgica, M., De Lucio, J.V., Atauri, J.A., 2001. A framework for comparative landscape analysis and evaluation based on land cover data, with an application in the Madrid region (Spain). Landsc. Urban Plan. 55, 257–270. https://doi.org/10.1016/S0169-2046(01)00159-1

Guo, Y., Ru, P., Su, J., Anadon, L.D., 2015. Not in my backyard, but not far away from me: Local acceptance of wind power in China. Energy 82, 722–733. https://doi.org/10.1016/j.energy.2015.01.082

GWEC (Global Wind Energy Council), 2019. Global Wind Report 2018.

GWEC (Global Wind Energy Council), 2017. Global Wind Report 2016, Wind energy technology. Ulaanbaatar, Mongolia.

GWEC (Global Wind Energy Council), 2016. Global Wind Report 2015.

Haber, W., 2008. Biological Diversity – a Concept Going Astray? GAIA 17, 91–96. https://doi.org/10.1017/CBO9781107415324.004

Hammami, S.M., Chtourou, S., Triki, A., 2016. Identifying the determinants of community acceptance of renewable energy technologies: The case study of a wind energy project from Tunisia. Renew. Sustain. Energy Rev. 54, 151–160. https://doi.org/10.1016/j.rser.2015.09.037

Han, F., 2006. The Chinese view of nature: tourism in China's scenic and historic interest areas. Queensland University of Technology, Australia. 56-60.

Harries, K., 2012. History of Aesthetic, Yale University. https://doi.org/10.1007/s00384-004-0654-9

Harris, D., Ruggles, D.F., 2007. Sites unseen: Landscape and Vision, European Pharmaceutical Contractor. University of Pittsburgh Press, Pittsburgh. https://doi.org/10.2307/j.ctt7zw9w9

Harry, A., 2007. Wind Turbines , Noise and Health [WWW Document]. URL https://docs.wind-watch.org/wtnoise_health_2007_a_harry.pdf (accessed 2.28.20).

Hasund, K.P., 2011. Developing environmental policy indicators by criteria - indicators on the public goods of the Swedish agricultural landscape. J. Environ. Plan. Manag. 54, 7–29. https://doi.org/10.1080/09640568.2010.502750

Hau, E., 2016. Aerodynamik des Rotors, in: Windkraftanlagen.Grundlagen, Technik, Einsatz, Wirtschaftlichkeit. Springer Vieweg, Krailling, Germany, pp. 91–170.

Heier, S., 2018. Windkraftanlagen.Systemauslegung, Netzintegration und Regelung, 6th ed. Springer Vieweg, Kassel,Germany.

Heier, S., 2016. Nutzung der Windenergie, 7th ed. BINE-Fachbuch, Bonn, Germany.

Henry Hoare II, Flitcroft, H., n.d. Stourhead Garden [WWW Document]. URL http://www.greatbuildings.com/buildings/Stourhead_Garden.html (accessed 7.21.20).

Herbrandson, C., Messing, R., 2009. Public Health Impacts of Wind Turbines. Minnesota.

Hersperger, A.M., Mueller, G., Knöpfel, M., Kienast, F., 2017. Evaluating outcomes in planning: Indicators and reference values for Swiss landscapes. Ecol. Indic. 77, 96–104. https://doi.org/10.1016/j.ecolind.2017.02.004

Herzog, T., Smith, G.A., 1988. Danger, Mystery, and Environmental Preference. Environ. Behav. 20, 320–344.

Herzog, T.R., 1987. A Cognitive Analysis of Preference for Natural Environments: Mountains, Canyons, and Deserts. Landsc. J. 6, 140–152.

Hewitt, S., Margetts, L., Revell, A., 2018. Building a Digital Wind Farm. Arch. Comput. Methods Eng. 25, 879–899. https://doi.org/10.1007/s11831-017-9222-7

Hirsh, R.F., Jones, C.F., 2014. History’s contributions to energy research and policy. Energy Res. Soc. Sci. 1, 106–111. https://doi.org/10.1016/j.erss.2014.02.010

Hötker, H., 2006. The impact of repowering of wind farms. Bergenhusen.

Howett, C., 1987. Systems, Signs, Sensibilities: Sources for a New Landscape Aesthetic. Landsc. J. 6, 1–12. https://doi.org/10.5822/978-1-61091-491-8_17

HPDI (Hydropower Planning and Design Institute), 2012. Land use indicators for power engineering projects-Wind farm. Beijing, China.

Hua, Y., Oliphant, M., Hu, E.J., 2016. Development of renewable energy in Australia and China: A comparison of policies and status. Renew. Energy 85, 1044–1051. https://doi.org/10.1016/j.renene.2015.07.060

Hübner, G., Pohl, J., 2015. Mehr Abstand – mehr Akzeptanz? Ein umweltpsychologischer Studienvergleich, Windindustrie in Deutschland. Berlin.

Hunziker, M., 2010. Die Bedeutungen der Landschaft für den Menschen: objektive Eigenschaft der Landschaft oder individuelle Wahrnehmung des Menschen?, in: Landschaftsqualität.Konzepte, Indikatoren Und Datengrundlagen. Eidgenössische Forschungsanstalt WSL, Birmensdorf, Germany, pp. 33–43.

Hurtado, J.P., Fernández, J., Parrondo, J.L., Blanco, E., 2004. Spanish method of visual impact evaluation in wind farms. Renew. Sustain. Energy Rev. 8, 483–491. https://doi.org/10.1016/j.rser.2003.12.009

IEA (International Energy Agency), 2019. Global Energy & CO2 Status Report, Global Energy & CO2 Status Report.

IEA (International Energy Agency), ERI (Energy Research Institute), 2011. China Wind Energy Development Roadmap 2050. Beijing, China. https://doi.org/10.1007/SpringerReference_7300

IPCC, 2011. Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow . Cambridge, United Kingdom and New York, NY, USA.

IRENA(International Renewable Energy Agency), 2019. FUTURE OF WIND - Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper). International Renewable Energy Agency, Abu Dhabi.

IRENA(International Renewable Energy Agency), GWEC(Global Wind Energy Council), 2013. Germany. In: 30 Years of Policies for Wind Energy. Lessons from 12 Wind Energy Market. Abu Dhabi, United Arab Emirates. 68-75.

IRENA (International Renewable Energy Agency), 2018. Global Energy Transformation: A Roadmap to 2050, International Renewable Energy Agency, Abu Dhabi. This report is available for download from www.irena.org/publications. Abu Dhab.

Jacobs, M.H., 2006. The Production of Mindscapes.A Comprehensive Theory of Landscape Experience. Wageningen Univ. Wageningen University.

Jami, A.A.N., Walsh, P.R., 2014. The role of public participation in identifying stakeholder synergies in wind power project development: The case study of Ontario, Canada. Renew. Energy 68, 194–202. https://doi.org/10.1016/j.renene.2014.02.004

Ji, C., 1634. Yuan Ye. Ming Dynasty. [In Chinese].

Jobert, A., Laborgne, P., Mimler, S., 2007. Local acceptance of wind energy: Factors of success identified in French and German case studies. Energy Policy 35, 2751–2760. https://doi.org/10.1016/j.enpol.2006.12.005

Joly, D., Brossard, T., Cavailhès, J., Hilal, M., Tourneux, F.-P., Tritz, C., Wavresky, P., 2009. A Quantitative approach to the visual evaluation of landscape. Ann. Assoc. Am. Geogr. 99, 292–308. https://doi.org/10.1080/00045600802708473

Jones, C.R., Eiser, J.R., 2010. Understanding “local” opposition to wind development in the UK: How big is a backyard? Energy Policy 38, 3106–3117. https://doi.org/10.1016/j.enpol.2010.01.051

Jorgensen, A., 2011. Beyond the view: Future directions in landscape aesthetics research. Landsc. Urban Plan. 100, 353–355. https://doi.org/10.1016/j.landurbplan.2011.02.023

Journalism for the energy transition, 2018. Germany set to retire 20 GW of wind power by 2023 - Renewable Energy Federation head. Journal. energy Transit. 1.

Kaplan, R., Herbert, E.J., 1987. Cultural and sub-cultural comparisons in preferences for natural settings. Landsc. Urban Plan. 14, 281–293. https://doi.org/10.1016/0169-2046(87)90040-5

Kaplan, R., Kaplan, S., Brown, T., 1989. Environmental preferences: A comparsion of four domains of predictors. Environ. Behav. 21, 509–530.

Kaplan, S., 1975. An imformal model for the prediction of preference, in: Zube, E.H., Brush, R.O., Fabos, J.G. (Eds.), Landscape Assessment: Values, Perceptions and Resources. Dowden, Hutchinson and Ross, Stroudsburg, PA, pp. 92–101.

Kaplan, S., Kaplan, R., 1982. Cognition and Environment : Functioning in an Uncertain World. Praeger, New York.

Katsaprakakis, D. Al, 2012. A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete. Renew. Sustain. Energy Rev. 16, 2850–2863. https://doi.org/10.1016/j.rser.2012.02.041

Kellert, S.R., Wilson, E.O., 1993. The Biophilia Hypothesis. Island Press/Shearwater Books, Washington, DC. https://doi.org/10.5840/enviroethics199618323

Kienast, F., Frick, J., Steiger, U., 2013. Neue Ansätze zur Erfassung der Landschaftsqualität:Zwischenbericht Landschaftsbeobachtung Schweiz (LABES). Bundesamt für Umwelt, Bern.

Kienast, F., Frick, J., van Strien, M.J., Hunziker, M., 2015. The Swiss Landscape Monitoring Program - A comprehensive indicator set to measure landscape change. Ecol. Modell. 295, 136–150. https://doi.org/10.1016/j.ecolmodel.2014.08.008

Kirchhoff, T., 2014. Energiewende und Landschaftsästhetik.Versachlichung ästhetischer Bewertungen von Energieanlagen durch Bezugnahme auf drei intersubjektive Landschaftsideale. Naturschutz und Landschaftsplan. 46, 10–16.

Kirchhoff, T., Trepl, L., 2009. Landschaft, Wildnis, Ökosystem: zur kulturbedingten Vieldeutigkeit ästhetischer, moralischer und theoretischer Naturauffassungen. Einleitender Überblick, in: Kirchhoff, T., Trepl, L. (Eds.), Vieldeutige Natur: Landschaft, Wildnis Und Ökosystem Als Kulturgeschichtliche Phänomene. Bielefeld, Germany, pp. 13–68.

Klaus, T., Vollmer, C., Werner, K., Lehmann, H., Müschen, K., 2010. Energieziel 2050: 100% Erneuerbaren Strom. Umwelt Bundesamt, Dessau-Roßlau,Germany.

Kletzsch, K., 2018. Deutsche Windtechnik launches independent service for Enercon wind turbines [WWW Document]. Dtsch. Wind. URL https://www.deutsche-windtechnik.com/press-information/item/190-Deutsche-Windtechnik-launches-independent-service-for-Enercon-wind-turbines (accessed 12.16.19).

Klouček, T., Lagner, O., Šímová, P., 2015. How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. Appl. Geogr. 64, 46–54. https://doi.org/10.1016/j.apgeog.2015.09.005

Kokologos, D., Tsitoura, I., Kouloumpis, V., Tsoutsos, T., 2014. Visual impact assessment method for wind parks: A case study in Crete. Land use policy 39, 110–120. https://doi.org/10.1016/j.landusepol.2014.03.014

Köppel, J., Feickert, U., Spandau, L., 1998. Praxis der Eingriffsregelung. Schadenersatz an Natur und Landschaft? Ulmer.

Křováková, K., Semerádová, S., Mudrochová, M., Skaloš, J., 2015. Landscape functions and their change - a review on methodological approaches. Ecol. Eng. 75, 378–383. https://doi.org/10.1016/j.ecoleng.2014.12.011

Kühne, O., 2008. Distinktion - Macht - Landschaft. Zur sozialen Definition von Landschaft. Springer VS., Wiesbaden. https://doi.org/10.1017/CBO9781107415324.004

Kühne, O., Bruns, D., 2015. Gesellschaftliche Transformation und die Entwicklung von Landschaft. Eine Betrachtung aus der Perspektive der sozialkonstruktivistischen Landschaftstheorie. In: Transformation und Landschaft. Freising, Deutschland. 17-34.

Kühne, O., Megerle, H., Weber, F. (Eds.), 2017. Landschaftsästhetik und Landschaftswandel. Springer, Wiesbaden. https://doi.org/10.1007/978-3-658-15848-4

Kühne, O., Weber, F., 2017. Bausteine der Energiewende.

LANA (LÄNDERARBEITSGEMEINSCHAFT NATURSCHUTZ LANDSCHAFTSPFLEGE UND ERHOLUNG) (eds.), 1996. Methodik der Eingriffsregelung.Gutachten zur Methodik der Ermittlung, Beschreibung und Bewertung von Eingriffen in Natur und Landschaft, zur Bemessung von Ausgleichs- und Ersatzmaßnahmen sowie von Ausgleichszahlungen. Teil III: Vorschläge zur bundeseinhei. Stuttgart.

Lane, M.B., 2005. Public participation in planning: An intellectual history. Aust. Geogr. 36, 283–299. https://doi.org/10.1080/00049180500325694

LANUV (Landesamt für Natur Umwelt und Verbraucherschutz Nordrhein-Westfalen), 2016. Verfahren zur Landschaftsbildbewertung im Zuge der Ersatzgeld-Ermittlung für Eingriffe in das Landschaftsbild durch den Bau von Windenergieanlagen [WWW Document]. URL Verfahren zur Landschaftsbildbewertung im Zuge der Ersatzgeld-Ermittlung für Eingriffe in das Landschaftsbild durch den Bau von Windenergieanlagen (accessed 4.5.20).

LANUV (Landesamt für Natur Umwelt und Verbraucherschutz Nordrhein-Westfalen), n.d. Windkraft und Landschaftsbild——Landschaftsbildbewertung im Zuge der Ersatzgeld-Ermittlung für Eingriffe in das Landschaftsbild durch den Bau von Windenergieanlagen [WWW Document]. URL https://www.lanuv.nrw.de/natur/eingriffsregelung/windkraft-und-landschaftsbild (accessed 4.5.20).

Latinopoulos, D., Kechagia, K., 2015. A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece. Renew. Energy 78, 550–560. https://doi.org/10.1016/j.renene.2015.01.041

Lee, S.W., Ellis, C.D., Kweon, B.S., Hong, S.K., 2008. Relationship between landscape structure and neighborhood satisfaction in urbanized areas. Landsc. Urban Plan. 85, 60–70. https://doi.org/10.1016/j.landurbplan.2007.09.013

Lenzen-Schulte, M., Schenk, M., 2019. Windenergieanlagen und Infraschall. Der Schall, den man nicht hört. Dtsch. Arztebl. Int. 116, 264–268.

Leung, D.Y.C., Yang, Y., 2012. Wind energy development and its environmental impact: A review. Renew. Sustain. Energy Rev. 16, 1031–1039. https://doi.org/10.1016/j.rser.2011.09.024

Lewis, J.R., 1964. British Rocky Shores Hormone Action. English Universities Press, London, UK.

Li, F., 2006. Landscape and Power in Early China.The Crisis and Fall of theWestern Zhou, 1045–771 bc. Cambridge University Press, Cambridge, UK.

Li, L., Ren, X., Yang, Y., Zhang, P., Chen, X., 2018. Analysis and recommendations for onshore wind power policies in China. Renew. Sustain. Energy Rev. 82, 156–167. https://doi.org/10.1016/j.rser.2017.06.114

Linke, S., 2017. Ästhetik, Werte und Landschaft, in: Kühne, O., Megerle, H., Weber, F. (Eds.), Landschaftsästhetik Und Landschaftswandel. Springer VS., Wiesbaden, pp. 23–40.

Litton, R.B., 1974. Visual Vulnerability of Forest Landscapes. J. For. 72, 392–397. https://doi.org/https://doi.org/10.1093/jof/72.7.392

Litton, R.B., 1972. Aesthetic demensions of the landscape, in: Krutilla, J. V. (Ed.), Natural Environments. Studies in Theoretical and Applied Analysis. Resources for the Future. John Hopkins University Press, Baltimore, pp. 262–291.

Litton, R.B., 1968. Forest landscape decription and inventories: A basis for land planning and design.U.S.D.A. Forest Service Research Paper PSW-49. Pacific Southwest Forest and Range Experiment Station Forest Service, U. S. Department of Agriculture, Berkeley, California.

Liu, B., Fan, R., 2013. Research on Visual Attraction Elements and Mechanism of Landscape Space 5, 5–10.

Liu, J., 2019. China's renewable energy law and policy: A critical review. Renew. Sustain. Energy Rev. 99, 212–219. https://doi.org/10.1016/j.rser.2018.10.007

Long, H., 2014. Land use policy in China: Introduction. Land use policy 40, 1–5. https://doi.org/10.1016/j.landusepol.2014.03.006

Lothian, A., 1999. Landscape and the philosophy of aesthetics: Is landscape quality inherent in the landscape or in the eye of the beholder? Landsc. Urban Plan. 44, 177–198. https://doi.org/10.1016/S0169-2046(99)00019-5

Luderer, G., Pehl, M., Arvesen, A., Gibon, T., Bodirsky, B.L., de Boer, H.S., Fricko, O., Hejazi, M., Humpenöder, F., Iyer, G., Mima, S., Mouratiadou, I., Pietzcker, R.C., Popp, A., van den Berg, M., van Vuuren, D., Hertwich, E.G., 2019. Environmental co-benefits and adverse side-effects of alternative power sector decarbonization strategies. Nat. Commun. 10, 1–13. https://doi.org/10.1038/s41467-019-13067-8

Luo, G.L., Li, Y.L., Tang, W.J., Wei, X., 2016. Wind curtailment of China's wind power operation: Evolution, causes and solutions. Renew. Sustain. Energy Rev. 53, 1190–1201. https://doi.org/10.1016/j.rser.2015.09.075

Lupp, G., Steinhäußer, R., Starick, A., Gies, M., Bastian, O., Albrecht, J., 2014. Forcing Germany's renewable energy targets by increased energy crop production: A challenge for regulation to secure sustainable land use practices. Land use policy 36, 296–306. https://doi.org/10.1016/j.landusepol.2013.08.012

Lütkehus, I., Salecker, H., Umweltbundesamt, 2013. Onshore Wind Energy Potential in Germany:Current study by the Federal Environment Agency on the nationwide area and output potential. DEWI Mag. 23–28.

Maehr, A.M., Watts, G.R., Hanratty, J., Talmi, D., 2015. Emotional response to images of wind turbines: A psychophysiological study of their visual impact on the landscape. Landsc. Urban Plan. 142, 71–79. https://doi.org/10.1016/j.landurbplan.2015.05.011

Magill, A.W., Litton, R.B., 1986. A Color Measuring System for Landscape Assessment. Landsc. J. 5, 45–54. https://doi.org/10.3368/lj.5.1.45

Manyoky, M., Wissen Hayek, U., Pieren, R., Heutschi, K., Grêt-Regamey, A., 2016a. Evaluating a visual-acoustic simulation for wind park assessment. Landsc. Urban Plan. 153, 180–197. https://doi.org/10.1016/j.landurbplan.2016.03.013

Manyoky, M., Wissen Hayek, U., Pieren, R., Heutschi, K., Grêt-Regamey, A., 2016b. Evaluating a visual-acoustic simulation for wind park assessment. Landsc. Urban Plan. 153, 180–197. https://doi.org/10.1016/j.landurbplan.2016.03.013

Martín, B., Ortega, E., Otero, I., Arce, R.M., 2016. Landscape character assessment with GIS using map-based indicators and photographs in the relationship between landscape and roads. J. Environ. Manage. 180, 324–334. https://doi.org/10.1016/j.jenvman.2016.05.044

Marx, K., 1891. Wage labour and capital [WWW Document]. URL https://www.marxists.org/archive/marx/works/1847/wage-labour/ (accessed 8.26.20).

Maslow, A.H., 1943. A theory of human motivation. Psychol. Rev. 50, 370–396.

McKenna, R., Ostman, P., Fichtner, W., 2016. Key challenges and prospects for large wind turbines. Renew. Sustain. Energy Rev. 53, 1212–1221. https://doi.org/10.1016/j.rser.2015.09.080

Meeus, J.H.A., Wijermans, M.P., Vroom, M.J., 1990. Agricultural landscapes in Europe and their transformation. Landsc. Urban Plan. 18, 289–352. https://doi.org/10.1016/0169-2046(90)90016-U

Metcalf, G., Stock, J., 2015. The Role of Integrated Assessment Models in Climate Policy: A User's Guide and Assessment. Discussion Papers Series, Department of Economics, Tufts University 0811, Department of Economics, Tufts University.

Meuser, M., Nagel, U., 1991. ExpertInneninterviews - vielfach erprobt, wenig bedacht: ein Beitrag zur qualitativen Methodendiskussion, in: In D. Garz, & K. Kraimer (Hrsg.), Qualitativ-Empirische Sozialforschung: Konzepte, Methoden, Analysen. pp. 441–471. https://doi.org/10.1177/004057368303900411

Miller, C.A., Richter, J., O'Leary, J., 2015. Socio-energy systems design: A policy framework for energy transitions. Energy Res. Soc. Sci. 6, 29–40. https://doi.org/10.1016/j.erss.2014.11.004

Minelli, A., Marchesini, I., Taylor, F.E., De Rosa, P., Casagrande, L., Cenci, M., 2014. An open source GIS tool to quantify the visual impact of wind turbines and photovoltaic panels. Environ. Impact Assess. Rev. 49, 70–78. https://doi.org/10.1016/j.eiar.2014.07.002

MOHURD (Ministry of Housing and Urban-Rural Development), 2015. Code for wind farm design (GB 51096-2015). China.

Molina-Ruiz, J., Martínez-Sánchez, M.J., Pérez-Sirvent, C., Tudela-Serrano, M.L., García Lorenzo, M.L., 2011. Developing and applying a GIS-assisted approach to evaluate visual impact in wind farms. Renew. Energy 36, 1125–1132. https://doi.org/10.1016/j.renene.2010.08.041

Möller, B., 2010. Spatial analyses of emerging and fading wind energy landscapes in Denmark. Land use policy 27, 233–241. https://doi.org/10.1016/j.landusepol.2009.06.001

Möller, B., 2006. Changing wind-power landscapes: Regional assessment of visual impact on land use and population in Northern Jutland, Denmark. Appl. Energy 83, 477–494. https://doi.org/10.1016/j.apenergy.2005.04.004

Molnarova, K., Sklenicka, P., Stiborek, J., Svobodova, K., Salek, M., Brabec, E., 2012. Visual preferences for wind turbines: Location, numbers and respondent characteristics. Appl. Energy 92, 269–278. https://doi.org/10.1016/j.apenergy.2011.11.001

MUGV (Ministerium für Umwelt Gesundheit und Verbraucherschutz des Landes Brandenburg), 2011. Beachtung naturschutzfachlicher Belange bei der Ausweisung von Windeignungsgebieten und bei der Genehmigung von Windenergieanlagen. Brandenburger, Germany.

Müller, F., Lenz, R., 2006. Ecological indicators: Theoretical fundamentals of consistent applications in environmental management. Ecol. Indic. 6, 1–5. https://doi.org/10.1016/j.ecolind.2005.08.001

Musall, F.D., Kuik, O., 2011. Local acceptance of renewable energy-A case study from southeast Germany. Energy Policy 39, 3252–3260. https://doi.org/10.1016/j.enpol.2011.03.017

NABU - Naturschutzbund Deutschland, 2019. Naturverträgliche Energiewende. Akzeptanz und Erfahrungen vor Ort.

Naveh, Z., Lieberman, A.S., 1990. Landscape Ecology: Theory and Application. Springer Series on Environmental Management, New York. https://doi.org/10.1007/978-1-4757-4082-0

Nijhuis, S., Lammeren, R. van, Antrop, M., 2011a. Exploring visual landscapes– Introduction in:Exploring the visual landscape, in: Hoeven, F. van der, Nijhuis, S. (Eds.), . IOS PRESS.

Nijhuis, S., van Lammeren, R., Antrop, M., 2011b. Exploring the Visual World, 2nd ed. IOS PRESS. https://doi.org/10.2307/j.ctt1xp3nmm.13

Nkomo, F., 2018. WWEA Policy Paper Series (PP-02-18-b). Bonn, Germany.

Nohl, W., 2010a. Landschaftsästhetisches Erleben: Grundformen und ihre nachhaltige Wirkung. Stadt+Grün 59, 29–36.

Nohl, W., 2010b. Ist das Landschaftsbild messbar und bewertbar? – Bestandsaufnahme und Ausblick. Presentation at the University of Natural Resources and Life Sciences Vienna, Wien, pp. 1–18.

Nohl, W., 2001a. Ästhetische und rekreative Belange in der Landschaftsplanung.

Nohl, W., 2001b. Landschaftsplanung-Ästhetische und rekreative Aspekte. Berlin, Hannover.

Nohl, W., 1993. Beeinträchtigung des Landschaftsbildes durch mastenartige Eingriffe: Materialien für die naturschutzfachliche Bewertung und Kompensationsermittlung. Ministeriums für Umwelt, Raumordnung und Landwirtschaft des Landes NordrheinßWestfahlen, München, Germany.

Norton, B., Costanza, R., Bishop, R.C., 1998. The evolution of preferences: why 'sovereign'preferences may not lead to sustainable policies and what to do about it. Ecol. Econ. 24, 193–211. https://doi.org/10.1016/s0921-8009(97)00143-2

Noss, R.F., 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conserv. Biol. 4, 355–364.

Ntanos, S., Kyriakopoulos, G., Chalikias, M., Arabatzis, G., Skordoulis, M., Galatsidas, S., Drosos, D., 2018. A social assessment of the usage of Renewable Energy Sources and its contribution to life quality: The case of an Attica Urban area in Greece. Sustainability 10. https://doi.org/10.3390/su10051414

NZILA (New Zealand Institute of Landscape Architecture), 2010. Best Practice Guide: Landscape assessment and sustainable management.

Ode, Å., Tveit, M., Fry, G., 2008. Capturing landscape visual character using indicators: Touching base with landscape aesthetic theory. Landsc. Res. 33, 89–117. https://doi.org/10.1080/01426390701773854

Ode, Å., Tveit, M.S., Fry, G., 2010. Advantages of using different data sources in assessment of landscape change and its effect on visual scale. Ecol. Indic. 10, 24–31. https://doi.org/10.1016/j.ecolind.2009.02.013

Office of the Deputy Prime Minister of UK (ODPM), 2004. Planning for renewable energy: a companion guide to planning policy statement 22. London, UK.

Oligmüller, R., Ökol, L., Schäfers, A., Gers, A., 2017. Landschaftsbildbewertung.B-Plan Nr. 74n "Fernholte" (No. O 15118), 02. Recklinghausen.

Orians, G.H., 1980. Habitat selection: general theory and applications to human behavior, in: J. S. Lockard (Ed.), The Evolution of Human Social Behavior. Elsevier, pp. 49–77.

Oxford English Dictionary, 2019a. Perception [WWW Document]. URL https://www.oed.com/view/Entry/140560?redirectedFrom=perception#eid

Oxford English Dictionary, 2019b. NIMBYism [WWW Document]. URL https://www.oed.com/view/Entry/245895?redirectedFrom=NIMBY#eid

Pahl-Weber, E., Henckel, D., 2008. The Planning System and Planning Terms in Germany, Studies in Spatial Development. Academy for Spatial Research and Planning, Braunschweig, Germany.

Palmer, J.F., 2004. Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts. Landsc. Urban Plan. 69, 201–218. https://doi.org/10.1016/j.landurbplan.2003.08.010

Palmer, J.F., Roos-Klein Lankhorst, J., 1998. Evaluating visible spatial diversity in the landscape. Landsc. Urban Plan. 43, 65–78. https://doi.org/10.1016/S0169-2046(98)00077-2

Pang, J., 2012. Ideas and Tradition behind Chinese and Western Landscape Design - similarities and differences. Swedish University of Agricultural Sciences.

Pasqualetti, M.J., Brown, M.A., 2014. Ancient discipline, modern concern: Geographers in the field of energy and society. Energy Res. Soc. Sci. 1, 122–133. https://doi.org/10.1016/j.erss.2014.03.016

Paul, V.H., Uther, D., Neuhoff, M., Winkler-hartenstein, K., Schmidtkunz, H., 2004. GIS-gestütztes Verfahren zur Bewertung visueller Eingriffe durch Hochspannungs- freileitungen.Herleitung von Kompensationsmaßnahmen für das Landschaftsbild. Naturschutz und Landschaftsplan. 35, 139–144.

Pauleit, S., 2017. Wende, Wolfgang; Walz, Ulrich (Eds), Die Räumliche Wirkung der Landschaftsplanung. Springer, Wiesbaden.

Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2009. Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am. 126, 634–643. https://doi.org/10.1121/1.3160293

Pedersen, E., Waye, K.P., 2007. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 64, 480–486. https://doi.org/10.1136/oem.2006.031039

Petrova, M.A., 2016. From NIMBY to acceptance: Towards a novel frmawork for organizing and interpreting community concerns. Renew. Energy 86, 1280–1294. https://doi.org/https://doi.org/10.1016/j.renene.2015.09.047

Petrova, M.A., 2013. NIMBYism revisited: Public acceptance of wind energy in the United States. Wiley Interdiscip. Rev. Clim. Chang. 4, 575–601. https://doi.org/10.1002/wcc.250

Pickett, S.T.A., White, P.S., 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, Orlando, FL. https://doi.org/10.2307/5048

Potter, W.J., 1996. Chapter 1 Whether to enter? In: An Analysis of Thinking and Research About Qualitative Methods. New York. 3-12. https://doi.org/https://doi.org/10.4324/9780203811863

Pregger, T., Nitsch, J., Naegler, T., 2013. Long-term scenarios and strategies for the deployment of renewable energies in Germany. Energy Policy 59, 350–360. https://doi.org/10.1016/j.enpol.2013.03.049

Price, T.J., 2005. James Blyth — Britain's First Modern Wind Power Pioneer. Wind Eng. 29, 191–200. https://doi.org/doi.org/10.1260/030952405774354921

Price, T.J., Blyth, J.C., 2005. Britain's First Modern Wind Power Pioneer. Wind Eng. 29, 191–200.

Quick, K.S., Bryson, J.M., 2016. Public Participation, in: Torbing, J., Ansell, C. (Eds.), Handbook in Theories of Governance. Edward Elgar Press, pp. 1–12. https://doi.org/10.1093/oxfordhb/9780199552153.013.0029

Real, E., Arce, C., Sabucedo, J.M., 2000. Classification of landscapes using quantitative and categorical data, and prediction of their scenic beauty in north-western Spain. J. Environ. Psychol. 20, 355–373. https://doi.org/10.1006/jevp.2000.0184

REN21 (Renewable Energy Policy Network for the 21st Century), 2018. Renewables 2018 Global Status Report. A comprehensive annual overview of the state of renewable energy.

REN21 (Renewable Energy Policy Network for the 21st Century), 2017. Renewables 2017. Global Status Report, REN21. Paris. https://doi.org/10.1016/j.rser.2016.09.082

Renterghem, T. Van, Bockstael, A., Weirt, V. De, Botteldooren, D., 2013. Annoyance, detection and recognition of wind turbine noise. Sci. Total Environ. 456, 333–345. https://doi.org/https://doi.org/10.1016/j.scitotenv.2013.03.095

Richarz, K., Hormann, M., Braunberger, C., Harbusch, C., Süßmilch, G., Caspari, S., Schneider, C., Monzel, M., Reith, C., Weyrath, U., 2013. Leitfaden zur Beachtung artenschutzrechtlicher Belange beim Ausbau der Windenergienutzung im Saarland betreffend die besonders relevanten Artengruppen der Vögel und Fledermäuse. Saarbrücken.

Ridenour, J., Ruth, R., 2014. Dialectical Materialism, in: Teo T. (Ed.), Encyclopedia of Critical Psychology. Springer, New York, pp. 416–421. https://doi.org/10.1007/978-1-4614-5583-7

Risser, P.G., Karr, J.R., Forman, R.T.T., 1984. Landscape Ecology.Directions and Approaches. Illinois Natural History Survey, Special Publication Number 2.

Ritter, J., Grunder, K., Brožek;, J., 1997. Historisches Wörterbuch der Philosophie, 9th ed. https://doi.org/10.1037/000403

Roca, Z., Claval, P., Agnew, J. (Eds.), 2011. Landscapes, Identities and Development. Ashgate Farnham.

Roddis, P., Carver, S., Dallimer, M., Norman, P., Ziv, G., 2018. The role of community acceptance in planning outcomes for onshore wind and solar farms: An energy justice analysis. Appl. Energy 226, 353–364. https://doi.org/10.1016/j.apenergy.2018.05.087

Rodrigues, M., Montañés, C., Fueyo, N., 2010. A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. Environ. Impact Assess. Rev. 30, 240–246. https://doi.org/10.1016/j.eiar.2009.10.004

Rosenkranz, K., 1996. Ästhetik des Hässlichen. Leipzig: Reclam.

Roth, M., 2012. Landschaftsbildbewertung in der Landschaftsplanung, IÖR Schriften Band. Leibniz-Institut für ökologische Raumentwicklung, Berlin.

Roth, M., Bruns, E., 2016. Landschaftsbildbewertung in Deutschland.Stand von Wissenschaft und Praxis.Landschaftsbildbewertung im Spannungsfeld von Wissenschaft und Praxis. Literaturdatenbank "DNL-online," Bonn, Germany.

Roth, M., Gruehn, D., 2012. Visual Landscape Assessment for Large Areas - Using GIS, Internet Surveys and Statistical Methodologies. Proc. Latv. Acad. Sci. 129–142.

Schafer, E.L., Hamilton, J.F., Schmidt, E.A., 1969. Natural Landscape Preferences: A Predictive Model. J. Leis. Res. 1, 1–19. https://doi.org/10.1080/00222216.1969.11969728

Schaub, M., 2012. Spatial distribution of wind turbines is crucial for the survival of red kite populations. Biol. Conserv. 155, 111–118. https://doi.org/10.1016/j.biocon.2012.06.021

Schmidt, C., von Gagern, M., Lachor, M., Hage, G., Hoppenstedt, A., Schuster, L., Kühne, O., Weber, F., Rossmeier, A., Bruns, D., Münderlein, D., Bernstein, F., 2018. Landschaftsbild und Energiewende. Bonn, Germany.

Schneider, N., 2017. Geschichte der Ästhetik von der Aufklärung bis zur Postmoderne, 6th ed. Stuttgart: Reclam.

Schöbel, S., 2012. Windenergie und Landschaftsästhetik. Jovis, Berlin, Germany.

Schönfelder, G., 2010. Die Kulturlandschaft und ihre Bestandsaufnahme. Bonn, Germany.

Schuman, S., Lin, A., 2012. China's Renewable Energy Law and its impact on renewable power in China: Progress, challenges and recommendations for improving implementation. Energy Policy 51, 89–109. https://doi.org/10.1016/j.enpol.2012.06.066

Scottish Natural Heritage, 2012. Assessing the cumulative impact of onshore wind energy developments. Scotland, UK.

Seel, M., 1996. Eine Ästhetik der Natur (Suhrkamp Taschenbuch Wissenschaft, Bd. 1231, 1. Aufl). Suhrkamp, Frankfurt am Main.

Sevenant, M., 2010. Variation in landscape perception and preference: Experience from case studies in rural and urban landscapes observed by different groups of respondents. Ghent Dep. Geogr. Ghent Univ. Gent University.

Sevenant, M., Antrop, M., 2010. The use of latent classes to identify individual differences in the importance of landscape dimensions for aesthetic preference. Land use policy 27, 827–842. https://doi.org/10.1016/j.landusepol.2009.11.002

Shafer, E.L., Brush, R.O., 1977. How to measure preferences for photographs of natural landscapes. Landsc. Plan. 4, 237–256. https://doi.org/10.1016/0304-3924(77)90027-2

Shafer, E.L., Tooby, M., 1973. Landscape Preferences: An International Replication. J. Leis. Res. 5, 60–65. https://doi.org/10.1080/00222216.1973.11970142

Shang, H., Bishop, I.D., 2000. Visual Thresholds for Detection, Rrcognition and Visual Impact in Landscape Settings. J. Environ. Psychol. 20, 125–140. https://doi.org/10.1006/jevp.1999.0153

Simcock, N., 2016. Procedural justice and the implementation of community wind energy projects: A case study from South Yorkshire, UK. Land use policy 59, 467–477. https://doi.org/10.1016/j.landusepol.2016.08.034

Sklenicka, P., Zouhar, J., 2018. Predicting the visual impact of onshore wind farms via landscape indices: A method for objectivizing planning and decision processes. Appl. Energy 209, 445–454. https://doi.org/10.1016/j.apenergy.2017.11.027

Soini, K., Pouta, E., Salmiovirta, M., Uusitalo, M., Kivinen, T., 2011. Local residents' perceptions of energy landscape: The case of transmission lines. Land use policy 28, 294–305. https://doi.org/10.1016/j.landusepol.2010.06.009

Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. Energy Res. Soc. Sci. 13, 202–215. https://doi.org/10.1016/j.erss.2015.12.020

Sowińska-Świerkosz, B.N., Chmielewski, T.J., 2016. A new approach to the identification of Landscape Quality Objectives (LQOs) as a set of indicators. J. Environ. Manage. 184, 596–608. https://doi.org/10.1016/j.jenvman.2016.10.016

Steiner, F., 2011. Landscape ecological urbanism: Origins and trajectories. Landsc. Urban Plan. 100, 333–337. https://doi.org/10.1016/j.landurbplan.2011.01.020

Strumse, E., 1996. Demographic Differences in the visual preferences for agrarian landscapes in western norway. J. Environ. Psychol. 16, 17–31. https://doi.org/10.1016/S0272-4944(05)80219-1

Swanwick, C., 2002. Landscape Character Assessment： Guidance for England and Scotland. UK. https://doi.org/10.1016/j.jenvman.2008.11.031

Swofford, J., Slattery, M., 2010. Public attitudes of wind energy in Texas: Local communities in close proximity to wind farms and their effect on decision-making. Energy Policy 38, 2508–2519. https://doi.org/10.1016/j.enpol.2009.12.046

Syrbe, R.U., Walz, U., 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. Ecol. Indic. 21, 80–88. https://doi.org/10.1016/j.ecolind.2012.02.013

Tabassum, A., Premalatha, M., Abbasi, T., Abbasi, S.A., 2014. Wind energy: Increasing deployment, rising environmental concerns. Renew. Sustain. Energy Rev. 31, 270–288. https://doi.org/10.1016/j.rser.2013.11.019

Tacke, F., 2004. Windmühlen - Die Herausforderung. Gestern, Heute, Morgen. Frankfurt am Main.

Tang, X., 2007. The theories, Methodology of Landscape Visual Environment Assessment and their Application: The case of the three Gorges of the Yantze River (Chongqing). Fudan University. [In Chinese].

Taylor, J.G., Zube, E.H., Sell, J.L., 1982. Landscape perception: Research, application and theory. Landsc. Plan. 9, 1–33.

The Landscape Institute with the Institute of Environmental Management & Assessment of UK, 2005. Guidelines for Landscape and Visual Impact Assessment, 2nd ed. Spon Press, London & New York.

Trepl, L., 2012. Die Idee der Landschaft.Eine Kulturgeschichte von der Aufklärung bis zur Ökologiebewegung, Edition Kulturwissenschaft. Bielefeld, Germany. https://doi.org/10.14361/transcript.9783839419434

Tsoutsos, T., Tsouchlaraki, A., Tsiropoulos, M., Serpetsidakis, M., 2009. Visual impact evaluation of a wind park in a Greek island. Appl. Energy 86, 546–553. https://doi.org/10.1016/j.apenergy.2008.08.013

Turner, M.G., 1989. Landscape Ecology: The Effect Pattern on Process. Annu. Rev. Ecol. Syst. 20, 171–197.

Turowski, G., 2002. Spatial Planning in Germany: Structures and Concepts. Bundesministerium für Verkehr, Bau- und Wohnungswesen, Hannover, Germany.

Tveit, M., Ode, Å., Fry, G., 2006. Key concepts in a framework for analysing visual landscape character. Landsc. Res. 31, 229–255. https://doi.org/10.1080/01426390600783269

Tveit, M.S., 2009. Indicators of visual scale as predictors of landscape preference; a comparison between groups. J. Environ. Manage. 90, 2882–2888. https://doi.org/10.1016/j.jenvman.2007.12.021

Ulrich, R.S., 1986. Human Responses to Vegetation and Landscapes. Landsc. Urban Plan. 13, 29–44. https://doi.org/10.1080/01426397908705892

Ulrich, R.S., 1983. Aesthetic and affective response to natural environment, in: Altman, I., Wohlwill, J.F. (Eds.), Behavior and the Natural Environment. Plenum Press, New York and London, pp. 170–172. https://doi.org/10.1037/10519-077

UN Environment, Center, F.S.-U., 2019. Global Trends in Renewable Energy Investment 2019.

UNESCO (United Nations Educational Scientific and Cultural Organizayion), 1996. World Heritage Convention concerning the protection of the World Cultural and Natural Heritage. Berlin, Germany.

Unland, A., Wittmann, A., 2016. Kompensation von Eingriffen in das Landschaftsbild durch Windenergieanlagen im Genehmigungsverfahren und in der Bauleitplanung. Fachagentur Windenergie an Land, Berlin, Germany.

USDA (U.S. Department of Agriculture Forest Service), 1974. National forest landscape management. Volume 2.The Visual Management System, Agricultural Handbook 462. US Government Printing Office, Washington, D.C.

van Leusen, P.M., 2002. Pattern to process: methodological investigations into the formation and interpretation of spatial patterns in archaeological landscapes. Groningen University.

Vortex Bladeless, 2019. Reinventing wind turbines [WWW Document]. URL https://vortexbladeless.com/

Wagner, A., 2012a. German legislation and planning process for solar and wind energy [WWW Document]. URL http://lehre.umweltpruefung.tu-berlin.de/wiki_mw/doku.php?id=german_legislation_and_planning_process_for_solar_and_wind_energy

Wagner, A., 2012b. Planning and permission process for energy onshore [WWW Document]. URL http://lehre.umweltpruefung.tu-berlin.de/wiki_mw/doku.php?id=planning_and_permission_process_for_wind_energy_onshore

Walker, G., Devine-Wright, P., Hunter, S., High, H., Evans, B., 2010. Trust and community: Exploring the meanings, contexts and dynamics of community renewable energy. Energy Policy 38, 2655–2663. https://doi.org/10.1016/j.enpol.2009.05.055

Walz, U., 2015. Indicators to monitor the structural diversity of landscapes. Ecol. Modell. 295, 88–106. https://doi.org/10.1016/j.ecolmodel.2014.07.011

Wang, F., Yin, H., Li, S., 2010. China's renewable energy policy: Commitments and challenges. Energy Policy 38, 1872–1878. https://doi.org/10.1016/j.enpol.2009.11.065

Wang, Shifeng, Wang, Sicong, 2015. Impacts of wind energy on environment: A review. Renew. Sustain. Energy Rev. 49, 437–443. https://doi.org/10.1016/j.rser.2015.04.137

Wang, X. (1096-1119), n.d. Qianlijiangshantu.

Ware, C., 2012. Information Visualization: Perception for design, 3rd ed. Morgan Kaufmann.

Weber, F., Kühne, O., 2016. Räume unter Strom. Raumforsch. Raumordn. 74, 323–338. https://doi.org/10.1007/s13147-016-0417-4

Wellman, J.D., Buhyoff, G.J., 1980. Effects of regional familiarity on landscape preferences. Environ. Behav. 11, 105–110. https://doi.org/10.1192/bjp.112.483.211-a

Whyte, I.D., 2002. Landscape and History since 1500. Reaktion Books Ltd, London, UK. https://doi.org/10.1016/S0169-2046(11)00176-9

Wind Europe, 2019. Wind energy in Europe in 2018 - Trends and statistics. Brussels, Belgium.

Wolsink, M., 2007. Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. Energy Policy 35, 2692–2704. https://doi.org/10.1016/j.enpol.2006.12.002

Wrózyński, R., Sojka, M., Pyszny, K., 2016. The application of GIS and 3D graphic software to visual impact assessment of wind turbines. Renew. Energy 96, 625–635. https://doi.org/10.1016/j.renene.2016.05.016

WWA (World Wind Assoociation), 2015. Wind energy 2050 on the shape of near 100% RE grid. J. Hossain (Eds.), World Wind Assoociation. https://doi.org/10.16373/j.cnki.ahr.150049

Xu, J., He, D., Zhao, X., 2010. Status and prospects of Chinese wind energy. Energy 35, 4439–4444. https://doi.org/10.1016/j.energy.2009.06.058

Ye, Q., Wenjuan, D., Changgui, D., Caiwei, H., 2019. Understanding institutional barriers for wind curtailment in China. Renew. Sustain. Energy Rev. 105, 476–486. https://doi.org/10.1016/j.rser.2019.01.061

Yuan, X., Zuo, J., Huisingh, D., 2015. Social acceptance of wind power: A case study of Shandong Province, China. J. Clean. Prod. 92, 168–178. https://doi.org/10.1016/j.jclepro.2014.12.097

Zhang, L., 2017. Legal framework and practice for environmental protection and application of green energy in China. Int. J. Ambient Energy 38, 489–496. https://doi.org/10.1080/01430750.2017.1337358

Zhou, X., 1995. Aesthetic Research in Landscape Planning. Urban Plan. J. 2, 54-61. [In Chinese].

Zube, E.H., 1974. Cross-Disciplinary and Intermode Agreement on the Description and Evaluation of Landscape Resources. Environ. Behav. 6, 69–89.

Appendices: Questionnaires

Questionnaire for inhabitants around Zhongying Wind Farm in Ningbo, China

This questionnaire is used for the PhD program "optimizing the visual impact of onshore wind farms upon the landscapes – Comparing recent planning approaches in China and Germany" in the Faculty of Geosciences, Ruhr-University Bochum, Germany. Please answer based on your true thoughts. This questionnaire promises that it will only be used for academic research, not for commercial purposes and external publicity.

1.**Your age:** 1) ＜ 18 2) 18-30 3) 30-40 4) 40-50 5) 50-60 6) ＞ 60

2.**Your gender:** 1) Male b2) Female

3.**What is your marital status?** 1) Single 2) Married 3) Divorced 4) Widowed 5) Other

4.**Your educational background** 1) Primary school or lower 2) Middle school 3) High school 4) Professional academy 5) University or higher 6) Other

5.**Your job**____

6.**How long do you live here?** 1) ＜ 1 year 2) 1-5 years 3) 5-10 years 4) 10-20 years 5) ＞ 20 years

7.**Do you know about Zhongying Wind Farm Project?** 1) I know clearly 2) I know about it 3) Not very familiar 4) I don't know it at all

8.**The distance from your residence to the nearest wind turbine** 1) ＜ 500 m 2) 500-1000 m 3) 1000-3000 m 4) ＞ 3000 m

9.**Visibility of the wind turbines from your residence** 1) Invisible 2) Small part visible 3) Most visible 4) Fully exposed

10.**Does the environmental impact (noise, flicker) of the wind farm affect your life?** 1) Not at all 2) It has a certain impact 3) Medium impact 4) Unbearable impact 5) Other thoughts _______________

11.**How long you are affected by the wind farm each day?** 1) None at all 2) ＜ 1 hour 3) 1-3 hours 4) 3-5 hours 5) 5-8 hours 6) ＞ 8 hours

12.**What is your opinion on the visual impact of the wind farm?** 1) No impact 2) Positive impact 3) Have negative effects 4) Not clear

13.**Does the wind farm project have compensation measures for surrounding residents?** 1) No compensation 2) Yes ______________ 3) Unknown

14.Your opinions and suggestions on wind farm planning

____

____

Thank you for your participation!

10. March 2019

Appendices: Expert Interviews

Interview for Landscape visual impact in onshore wind farm planning

Dear Sir/Madam,

this is an interview about “Landscape visual impact in onshore wind farm planning”, which will be included in Jinjin Guan’s Ph.D. project research. It would be ensured that confidential content will only be used for academic research and not be open to the public. Your answer will be very important and helpful for the research. Please answer the following questions with your working experience and educational background. If there are some questions, please feel free to contact me. Thank you for your warm support and help.

Contact information:

Jinjin Guan

Institute of Geography

Building NA 4/174, Universitätsstraße 150, 44801 Bochum, Germany

Cell phone +49 157 7426 3944

Email: Jinjin. Guan@rub.de

Educational background:

Tongji University-TJU, Shanghai, China, 09.2009-04.2016

Master of Landscape Architecture

Bachelor of Science

Department of Landscape Architecture, College of Architecture and Urban Planning

Ruhr University Bochum, Germany, 10.2016-

Ph.D. student, Chinese Scholarship Council Project, Geoscience Institute

Research topic: Optimizing the visual impact of onshore wind farms upon the landscapes – Comparing recent planning approaches in China and Germany

Supervisor:

Dr. Thomas Held

Institute of Geography, Building NA 5/158, Universitätsstraße 150, 44801 Bochum, Germany

Fon +49(0) 234 32-2 47 90

Fax +49(0) 234 32-14 180

Email: thomas.held@rub.de

Interview Background:

The growing attention on global de-carbonization, energy security and sustainable development has made wind energy one of the most popular renewable energy sources in the 21st century. With the trend to ever growing wind turbines and more GW-level wind farms constructed globally, the side effects of wind energy on landscape can't be ignored with its huge demand of land use. Compared with other environmental impacts (e.g., acoustic impact, shadow flicker, light at night, impacts on flora and fauna), the issue of landscape visual impact is more controversial and subjective. To date, landscape visual impact has not been integrated into the national legal framework of wind farm planning.

As a crucial and formally required part in EIA, Landscape Visual Impact Assessment refers to a systematic analysis of potential impacts to scenery and views (positive and negative impacts) resulting from a proposed development, develop reference indicators (e.g., individuality, diversity and beauty) and evaluation systems for landscape impacts in wind farm, but the practicality in various regions is yet to be verified.

In this interview, professional opinions and practical experiences from planners and engineers are sought to give meaningful information to researchers. It would be appreciated if first-hand information and project experience can be provided.

Interviewee

Personal information

Name: __________________________ Occupation: _________________________

Tel: ____________________________ Age: _______________________________

Email: __________________________

Educational background

University： _____________________________

Degree: __________________________________

Subject: _________________________________

Work experiences

1. Company: ________________________ 2. Company: _________________________

Position: ___________________________ Position: ___________________________

Years of work: ______________________ Years of work: ______________________

Technical title: ______________________ Technical title: ______________________

Description of work:

____

____

____

Open-ended questions

1.Please describe the part of your company/institute in the planning process of wind farms, e. g. general contractor, general engineering services etc.

2.What role do you actually have within the planning and/or building of wind farms?

3.In planning, building and operating wind farms, what steps are you aware of (e. g. project development, site assessment, final investment decision, decommissioning?

4.Could you please give an ideal process example for wind farm planning?

5.Which authorities, organizations etc. are actors in the planning process?

6.Which role does the public and its participation in the planning process play?

7.Are there significant differences in the planning process and it´s regulations, e. g. between the German states/ Chinese provinces?

8.Will you take the issue of “landscape visual impact” into consideration in practical wind farm projects? In which planning stage will you assess the visual impacts and integrate it into the decision-making framework?

9.During the planning process, which laws, regulations, superior planning texts or guidelines should be mainly referenced for avoiding landscape visual impact? (eg: Bundes-Immissionsschutzgesetz, Naturschutzgesetz, Flächennutzungsplan, Landschaftsplan, Windenergieerlass, Bewertungsverfahren Landschaftsbild etc.)

10.As an index included in wind farm planning, how much does “landscape visual impact” weigh in the whole decision-making framework? When conflicts emerge, how to balance the benefits between landscape protection and production efficiency?

11.Are there any basic criteria in your own state or in your company, which regulate the detailed statistics like minimum distance for avoiding landscape visual impact?

12.Will you take protective measures against landscape visual impact? For instance, compensation measures to avoid or minimize the visual impact? How about the detailed measures?

13.What are the commonly used analytical methods or computer software aids? What are their advantages and limitations respectively?

14.Will non-government organizations or vicinity communities take part in decision-making process for landscape protection? How about the detailed approach?

15.Could you please recommend some other experts in wind farm planning to receive this interview?

Thanks again for your professional answers and enthusiastic help!

23. April 2017