

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE
FACULTY OF ENVIRONMENTAL SCIENCES
DEPARTMENT OF LANDSCAPE AND URBAN PLANNING



Efficient Methodologies for Making 3D Simulations to Be Used for
Visual Impact Assessment

Diploma Thesis

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2022

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

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Landscape Engineering
Landscape Planning

Thesis title

Efficient methodologies for making 3D simulations to be used for visual impact assessment

Objectives of thesis

The first objective of this study is to propose an efficient method for making 3D simulations to be used for visual impact assessment in a way that can be generated by not just professionals but by anyone who is interested and eager to spend some time learning the basics of 3D simulation so it can be used not just by companies working on the field of wind farms but also by local decision makers and municipalities to introduce the wind farm projects to the locals and tourists in the best way.

The other objective is to understand the attitude of locals and tourists in terms of visual preferences towards the construction of wind farms in the landscapes in the Czech Republic which have high potentials for the construction of wind farms

Methodology

One of the main methods for visual impact assessment of the wind turbines that have been used widely is the use of photo manipulation software in order to virtually put the wind turbines in the photos taken of the potential places for installation of wind farms and to use them in surveys to examine how people accept a wind farm in different landscapes. The other famous one is called Landscape Visual Impact Assessment (LVIA in short) which uses photo simulation to rate negative impacts for proposed projects according to defined criteria. The novel method which is not widely used yet is the use of 3D software to make animations or to add the wind turbines to the videos captured from the landscapes following the routes that locals and tourists take commonly.

The main method of this study is to test these methods to find out which one has more advantages over the other, if so, detail the benefits and tradeoffs.

The proposed extent of the thesis

70 pages

Keywords

Visual impact assessment, 3D models, wind turbines, tourism

Recommended information sources

Frantal, Bohumil and Josef Kunc. 2010. Wind turbines in tourism landscapes Czech Experience. Annals of Tourism Research, 38, 2, 499-519

Landry, Craig, Tom Allen, Todd Cherry, and John Whitehead. 2012. Wind turbines and coastal recreation demand. Resource and Energy Economics. 34, 93-111.

Expected date of thesis defence

2021/22 SS – FES

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Declaration

I hereby declare that I have independently elaborated the diploma thesis with the topic of: Efficient Methodologies for Making 3D Simulations to Be Used for Visual Impact Assessment and that I have cited all the information sources that I used in the thesis and that are also listed at the end of the thesis in the list of used information sources.

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Prague 20/3/2022

A handwritten signature in blue ink, appearing to read 'A. Jones', is written over the date.

Acknowledgment

I would like to express my highest gratitude to; Doc. Peter Kumble for his guidance, support, inspiration and patience, and to Ing. Vojtech Bartak, Ing. Vítězslav Moudrý and Ing. Shima Yazdanmehr for their help.

Abstrakt

Cílem tohoto výzkumu je navrhnout metodu pro hodnocení vizuálního dopadu větrných turbín pomocí rychlé, bezplatné a dostupné technologie a softwaru pro každého, kdo má základní znalosti GIS. Přesnost metody je prověřena a úspěšně prokázala svoji vysokou preciznost a kvalitu pro použití odborníky nebo v dotaznících určených k vyplnění veřejností. Metoda se skládá ze dvou hlavních částí; jedné prováděné pomocí softwaru a druhé realizované v terénu. Software používaný v této metodě je bezplatný a open-source. Díky tomu je zaručena možnost jeho použití kýmkoli a lze jej použít v široké škále projektů i pro vývoj nových analytických nástrojů. Terénní část nevyžaduje speciální vybavení a lze ji snadno provádět pomocí softwarových a hardwarových nástrojů dostupných každému. Daná metoda se ukázala být užitečnou také pro hodnocení vizuálního vlivu jiných prvků, nicméně tato studie se zaměřila na aplikaci pro simulaci a hodnocení právě vizuálního vlivu větrných turbín.

Klíčová slova

Větrné turbíny, 3D počítačová grafika, Open-source software, GIS, Fotomonáž

Abstract

The aim of this research is to propose a method for visual impact assessment of wind turbines using fast, free and available technology and software for anyone who has the basic knowledge of GIS. The accurateness of the method is examined and successfully proved to have high accuracy and quality for being used by professionals or in questionnaires aimed to be filled by the public. The method consists of two major parts; one done by the use of some pieces of software and the second is performed in the field. The pieces of software used in this method are free of cost and open-source. Therefore, the freedom for anyone to use them is guaranteed and they can be applied in a wide variety of projects and for development of new analytical tools. The in-the-field part does not need special equipment and can be easily performed using software and hardware tools available to everyone. The method was also proved to be useful for the visual impact assessment of different elements other than only wind turbines, however this study focused on its application for simulating and assessing the visual impact of wind turbines.

Keywords

Wind turbines, 3D computer graphics, Open-source software, GIS, Photomontage

Table of Contents

1. Introduction.....	1
2. Objectives.....	3
3. Literature Review.....	4
3.1 Climate Change and the Needed Actions.....	4
3.1.2 Energy Transition and New Energy Carriers.....	5
3.2 The Effects of the Pandemic.....	6
3.3 Wind Energy Development.....	6
3.3.1 Wind Turbines.....	9
3.3.2 Repowering.....	11
3.3.3 Energy Storage Systems.....	11
3.3.4 Onshore Versus Offshore.....	13
3.3.5 Wind Energy Market.....	15
3.3.6 Wind Energy in Urban Areas.....	17
3.3.7 The Disadvantages of Wind Energy Development.....	18
3.3.8 Environmental Impacts.....	18
3.3.9 Health and Noise.....	19
3.3.10 Public Acceptance and Benefits.....	20
3.3.11 Effects on Tourism.....	22
3.3.12 Visual Impact.....	22
3.3.13 Visual Impact Assessment.....	23
3.3.14 Wind Energy development in the Czech Republic.....	24
3.3.15 Energy Resources in the Czech Republic.....	27
3.3.16 Energy Storage Facilities in the Czech Republic.....	28
3.3.17 Open Source Software.....	28
4. Methodology.....	30
4.1. GIS.....	30
4.1.1 The Required Data and Maps:.....	30
4.1.2 The Process.....	32
4.2 3D Modeling and Rendering.....	33
4.3 Photomontage.....	33
5. Case Study and the Detailed Steps.....	34
5.1. GIS.....	34
5.2 3D Modeling and Rendering.....	51
5.3 Photomontage.....	70
6. Results.....	74
7. Discussion.....	78
7.1 Flexibility and the Wide Application of the Method.....	78
7.2 Comparison with the Other Methods and Software.....	79
7.3 The Used Software and the Required Skills.....	80
7.4 Enhancements of the Process.....	81
8. Conclusion and Contribution of the Thesis.....	82
9. Bibliography and the sources used.....	83

1. Introduction

Some of the most severe problems which the world has been faced with are directly related to the use of fossil fuels. Climate change and global warming, energy security and energy access, rising oil prices, along with the effects of air pollution on health all have made the need for energy transition and the use of renewable energies a must.

Geothermal and hydroelectric energy are reliable and efficient but very limited. Solar energy is also a good alternative but not efficient in places with limited sunlight and shorter winter days. The best option for the places such as central and northern Europe with low sunny days is wind energy especially that the wind speed in many regions in Europe is constant and enough for efficient and reliable electricity production and the fact that in most regions wind energy is a cheaper source of new electricity than the least-cost fossil fuel (IRENA, 2019).

Some of the problems associated with reliance on wind energy include the perceived visual impact of the turbines in rural and scenic landscapes, the ambient noise from wind farms, and of course the mortality rate for bird and bat species. Noise reduction can be obtained to a higher degree as the newer and more advanced turbines produce less and less noise. The danger to animals is also being addressed by the help of GIS tools and effort of scientists working on animal habitats so the selection of the sites for the wind farms is becoming less and less harmful for the animal species. The only problem which cannot be solved and becomes even more severe is the visual impact as the turbines are becoming taller and taller.

Installation of taller wind turbines together with the fast growing need for development of wind energy puts more importance on the need for a fast, precise, cheap and easy method for choosing the best sites and more importantly for visual impact assessment. As a result of cutting the prices and the faster process of producing the simulated images of proposed wind farms, the locals can be given the chance to participate in choosing the best site through surveys which in turns leads to higher support of wind farm projects.

In general, there are two categories of visual impact assessment methods; one group are based on defining some criteria and calculating the impacts while the other group are focused on visual results. Within the second category, the older approach is to use photomontage to add wind turbines (from photos of existing wind turbines) to the photos of the site of proposed wind farms. The accuracy in this approach is very low and there is no room for its development. The other approach which is newer is 3D simulation which still has not been developed fully and is being done in different ways. This research is focused on this approach and turning it to a method by defining the steps and the process in details together with using carefully selected pieces of software which are available for everyone. While other options are either not as accurate and organised as this method or require software/tools that are not available widely (due to high costs), this method is proved to be of high accuracy and quality while it comes at no cost.

Some of the existing methods/software: Landscape Theater which is a combination of some pieces of software with large screens. Both the software and screens are expensive and the final result is not realistic. The other option is the use of some pieces of propriety

software such as; WindPRO which is not used only for visual impact assessment but for all the steps of designing wind farms and calculations of energy production and so on.

In this study a site in Ústecký region in the Czech Republic was chosen for testing the aforementioned rapid method. The region has one of the greatest potentials for using the wind energy in the Czech Republic and the chosen site is the site of previously installed wind turbines in 2007. The positioning phase done in this thesis study also shows that the location of the installed wind turbines is one of the best locations possible. A site in vicinity of the existing wind farms was chosen for the proposed turbines. The method was used firstly on the existing wind turbines for confirmation of its precision. The proposed turbines were then added to the 3D model of the landscape and renders were added to the photos taken from different viewpoints.

2. Objectives

The main and primary objective for this thesis research is to introduce an efficient computer aided method for producing simulated images which can be used to test and assess the visual impact of proposed wind turbines either by professionals or to be used in surveys intended to be filled by people. The method is fast, accurate, easy and almost free as all the used software are free and open-source, meaning that they are publicly available at no cost. As a result, this method can be used by planners, engineers, landscape architects, etc., in their work for municipalities or energy utility companies to assess the visual impact of different facilities, especially wind turbines and solar panels. It also helps in gaining higher public acceptance which is one of the biggest problems in development of wind farms.

The secondary objective is to test the method on a site and to prove the above mentioned advantages.

The third objective is to show that the method can be used widely for visual impact assessment of structures.

3. Literature Review

3.1 Climate Change and the Needed Actions

One world wide survey in 2020 determined that 64% of people of 50 countries with more than half of the world's population believe that climate change is the true global emergency, compared to the pandemic (Peoples' Climate Vote" of 2020, The United Nations Development Programme). Local surveys also show that people see climate change as a great threat. In a survey conducted in 2021 in the Czech Republic, climate change was among the first four issues which people were afraid of.

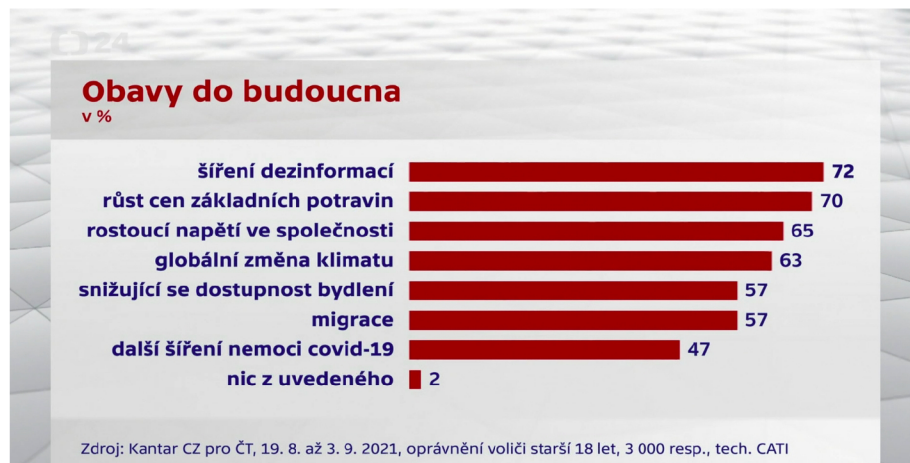


Fig. 1: A Czech TV survey conducted before the parliament elections in 2021 (Czech television, 2021)

It is clear and agreed that oil and gas consumption need to be reduced quickly over the next three decades. It is said that Peak demand for oil has already passed (2019, 2020) and that the fossil fuel industry now faces an inevitable decline although it is slow (IEA World Energy Outlook 2020).

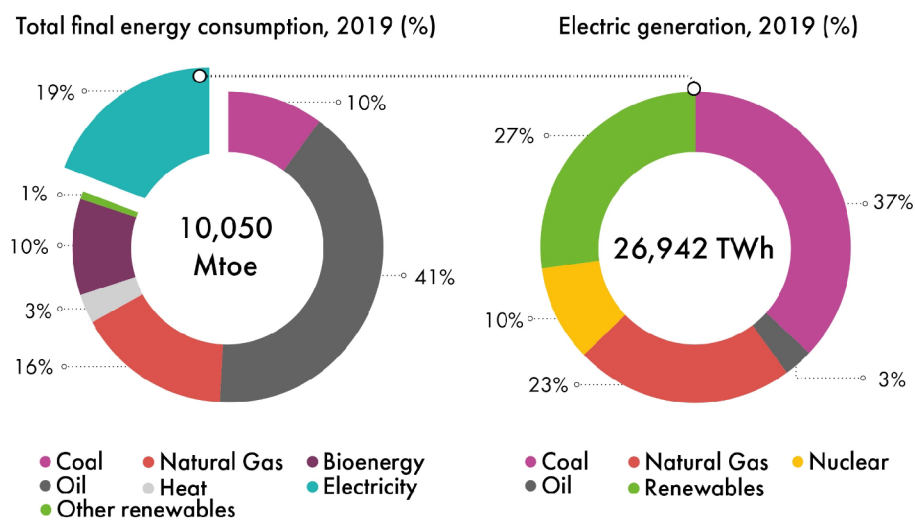


Fig. 2: Global final energy consumption in 2019 (IEA World Energy Outlook, 2020)

Renewable energies are the only alternative for conventional energy resources and have been used more and more. In 2020, renewable energies generated more electricity than fossil fuels in the EU for the first time (WindEurope, 2021).

As the result of understanding the threat, The UN defined a programme for urgent action in order to reach net zero greenhouse gas (GHG) emissions by 2050. Meaning that the amount of greenhouse gases which we add is no more than the amount taken away. Countries including the EU, the US, Japan, South Korea and Canada pledged to reach net zero by 2050. China set 2060 its net zero target. Countries which have adopted or considered net zero target include two-third of the global economy and 63% of global greenhouse gas emissions (World Economic Forum, Net-Zero Challenge: The supply chain opportunity, 2021).

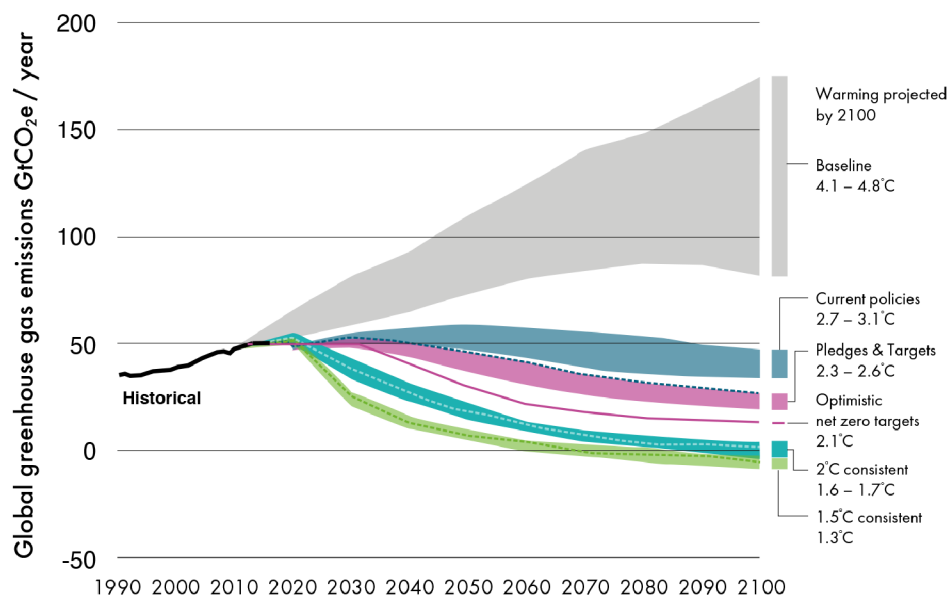


Fig. 3: 2100 Warming projections. Emissions and expected warming based on current policies and situation (Climate Action Tracker, December 2020)

3.1.2 Energy Transition and New Energy Carriers

Energy transition and using electricity for transport and heat is one of the solutions for decreasing CO2 emissions (IRENA, 2019, Future of wind). Decentralisation of power sector which is a key factor in energy transition puts more importance on the use of renewable energies especially wind and solar energy (IRENA, 2020, Rise of renewables in cities). For delivering the target of the EU commitment to climate neutrality by 2050, three quarters of the energy system must be electrified (WindEurope, 2021, Getting fit for 55 and set for 2050: Electrifying Europe with wind energy). The advances in energy storage technology delivered higher capacity batteries with less cost. Since 2010, prices have declined by two-thirds for stationary application (such as grid management) and by 90% for lithium-ion batteries in electric vehicles.

Using other energy carriers is another important factor which will lead to the decrease in greenhouse emissions. For long-duration storage, new technologies are evolving. Green hydrogen (produced via electrolysis, fed by green power) is being considered as a solution especially that the production costs are being reduced. It is very important not only for energy storage but more importantly for “hard-to-electrify” sections such as aviation, shipping, steel production and chemicals manufacturing (GWEC, 2021, Global wind report 2021). In 2020 several countries integrated hydrogen into their pandemic recovery plans and long-term climate strategies. 33 countries published national hydrogen strategy, including European Commission’s Europe-wide hydrogen strategy targeting 40 GW of electrolyser capacity for green hydrogen by 2030 (GWEC 2021, Global wind report 2021).

3.2 The Effects of the Pandemic

Covid-19 pandemic posed a challenge to economies and to the global wind industry and caused many projects to be delayed. On the other side, the pandemic accelerated energy shift and had a great impact on the demand for hydrocarbon-based fuels. The global energy demand declined by around 5% in 2020. The demand for oil, coal and natural gas decreased by 8%, 7% and 3% respectively. At the same time there was a rise in contribution of renewables (GWEC 2021, Global Wind Report). The decline in global oil demand is expected to continue over the next decade and the next peak in oil demand to be not sooner than 2025 (Carbonbrief, 2021).

3.3 Wind Energy Development

Wind turbines emerged firstly more than a century ago in the UK and the US after the invention of the electric generators in 1830s, but modern development of wind power started from Denmark, where horizontal-axis wind turbines were built in 1891 (IRENA, Future of wind, 2019). Since then wind power has become one of the fastest-growing renewable energies world wide. Wind-generated electricity increased from 7.5 GW in 1997 to 564 GW by 2018. It doubled from 2009 to 2013, and in 2016 wind energy accounted for 16% of the generated electricity by renewable energies (IRENA, Renewable capacity statistics, 2019).

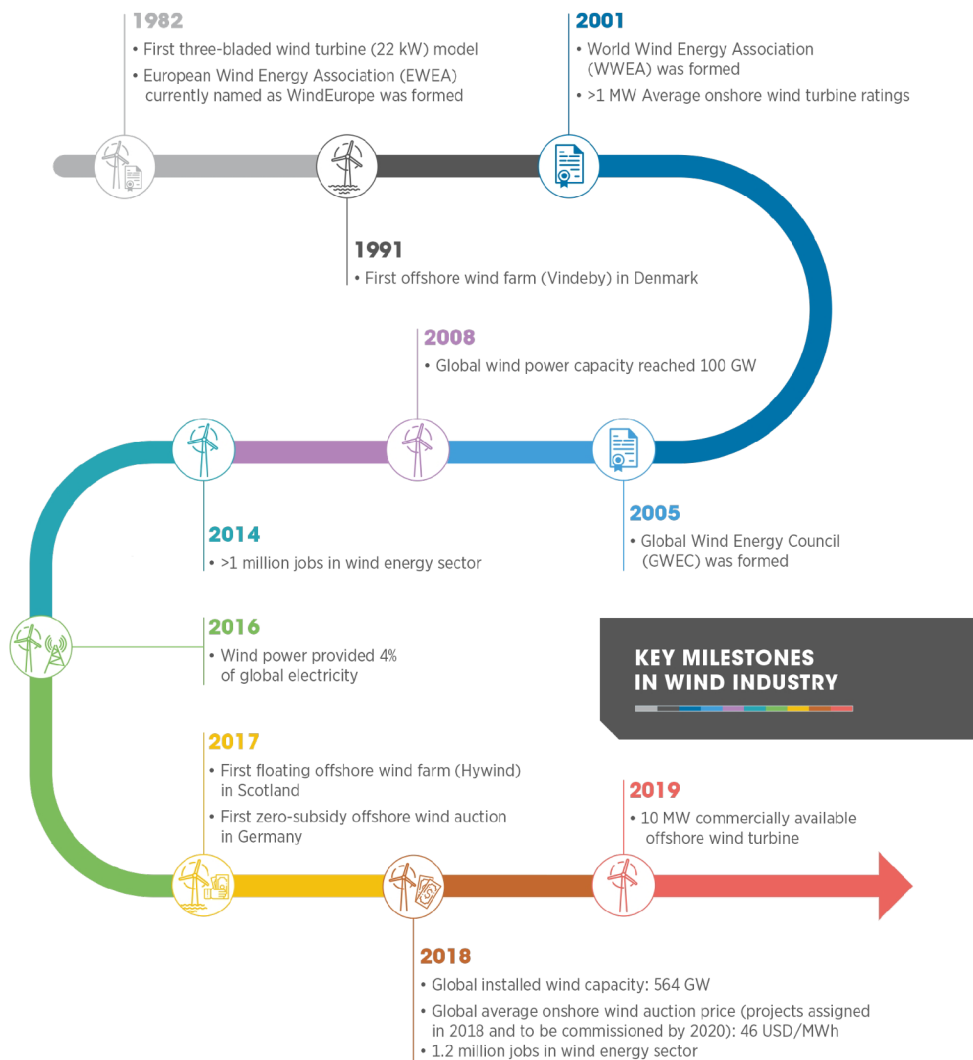


Fig. 4: Overview of key milestones achieved by the wind industry since 1982 (WindEurope, 2019)

Energy transition put more importance on the use of wind and solar energy. The share of electricity in final energy consumption will increase from below 20% in 2019 to around 50% by 2050 and wind power will supply around 35% of total electricity consumption and become the prominent source by 2050 (IRENA, Future of wind, 2019). Some others predict that wind energy becomes the number one source of electricity soon after 2025 as it is already the most cost-effective power generation technology and is highly scalable (WindEurope, 2021, Getting fit for 55 and set for 2050: Electrifying Europe with wind energy).

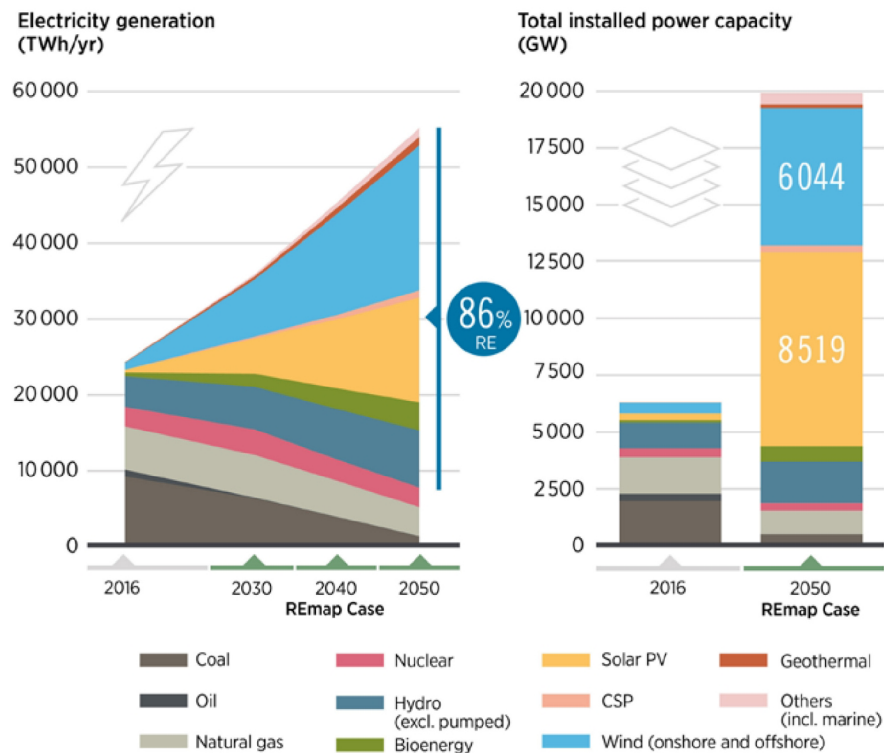


Fig. 5: Electricity generation resources and their future according to International Renewable Energy Agency (IRENA, 2019)

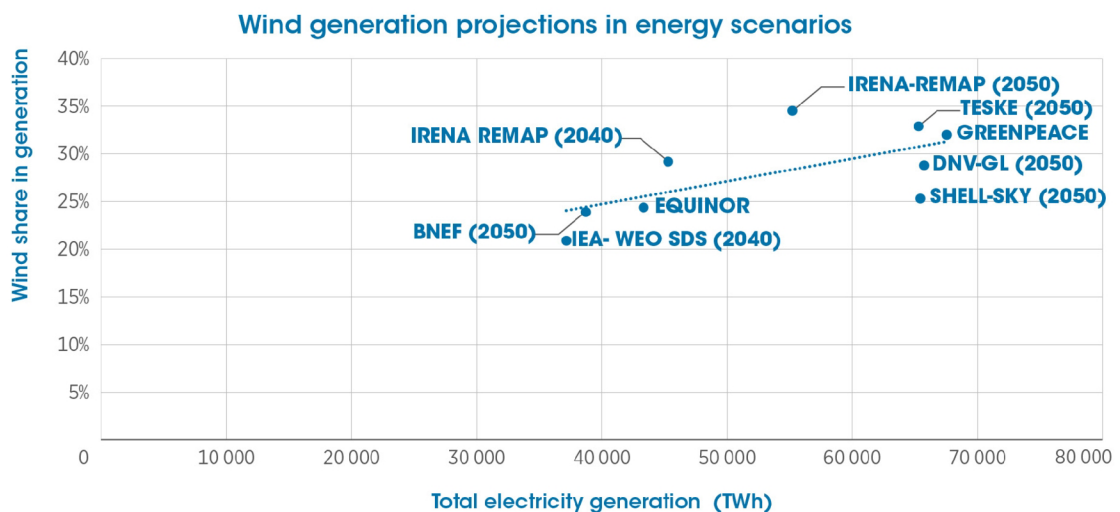


Fig. 6: Future of wind share in total electricity production in different scenarios. In all scenarios, wind energy will witness a steady growth in the next two decades. According to IRENA, the share of wind power in total electricity production will increase to just below 35% by 2050. Although IRENA (2019) estimation of wind power share is higher than other scenarios proposed by other organisations working on this topic, other numbers are not far different considering the difference of the total production they foreseen.

The predictions are not far from reality as 2020 was the best year in history for the global wind industry as the global new wind power installations surpass 90 GW, a 53% growth compared to 2019, bringing total installed capacity to 743 GW, a growth of 14% compared to last year (GWEC, 2021, Global wind report 2021).

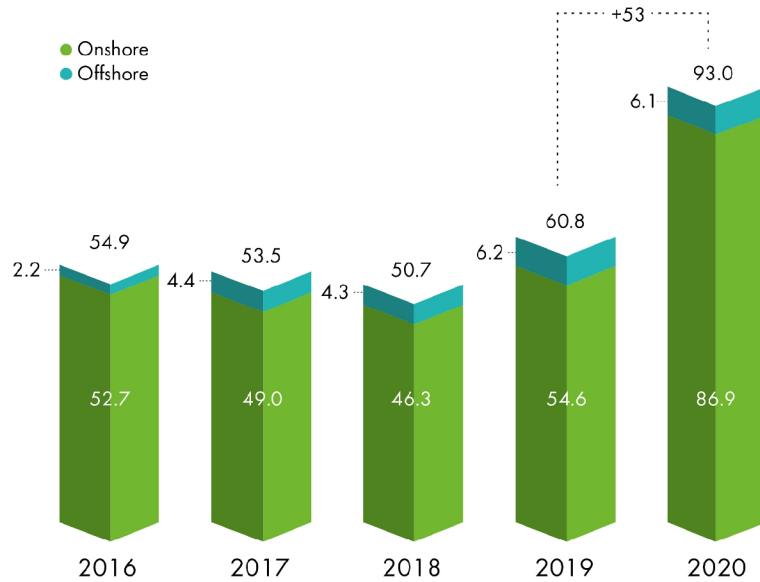


Fig. 7: New installations 2016-2020 (GWEC 2021, Global wind report 2021)

3.3.1 Wind Turbines

Wind turbine technologies have two main characteristics: the axis of the turbine and the location. The axis can be horizontal or vertical and the location is either onshore or offshore. Most of the wind turbines are horizontal-axis with three blades. In these models the key factors in electricity generation are the hub height and rotor diameter (IRENA, 2016. The Power to Change: Solar and Wind Cost Reduction Potential to 2025). In term of the size, the advancements in wind turbines technology and manufacturing leads to more rotor diameter and higher hub height. As a result, the generated electricity increases (Fig. 8) while at the same time the cost (both capital and operation costs) is decreased (IRENA, 2019, Future of wind).

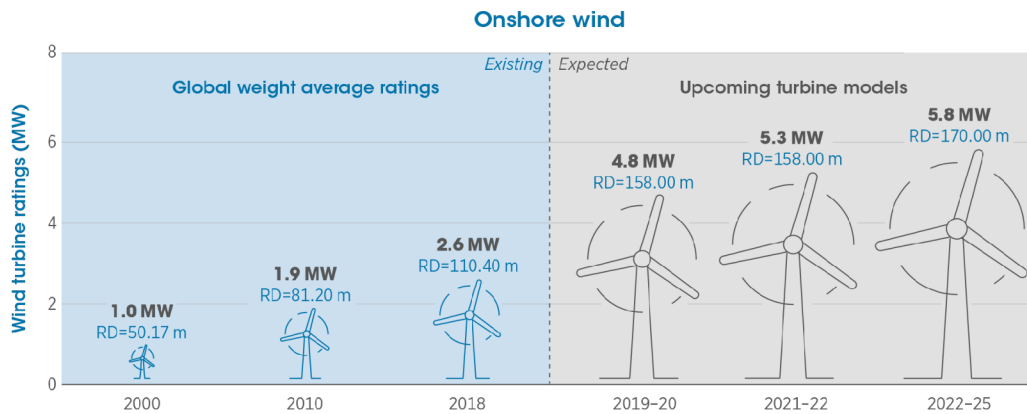


Fig. 8: The evolution of wind turbines. The technological advancements lead to more rotor diameter and higher hub height and – as a result – higher generated electricity (IRENA, 2019)

Although the cost of the new technologies and enhanced parts can be higher at first, the repair costs will be reduced and the energy production will be increased. Therefore, the additional costs will be covered and the whole process will be beneficial (WindTrust, 2016). Another decisive advancement is the emergence of Smart/Intelligent wind turbines. The digital revolution is affecting wind energy with new technologies for turbine monitoring and controls. The aim is to improve the forecasting mechanism and the automatic regulations of turbines to maximise the overall energy output (WindTrust 2016). This is crucial to cut down the unplanned costs due to failures, which currently make up more than half of total maintenance costs (Wood Mackenzie, 2019). Recycling is another issue which becomes more and more important by the increase of wind energy development. 85 to 90% of a wind turbine can be recycled today. The blades are the most challenging component to recycle due to the composite materials they contain. We can recover the material today through cement co-processing and there are alternative recycling technologies under development (WindEurope, 2020).



Fig. 9: Wikado Playground in Netherlands, Rotterdam; using the unrecyclable parts (blades) in a creative way (Photo: Denis Guzzo)

3.3.2 Repowering

Another key issue in increasing the capacity is the replacement of wind turbines that are approaching the end of their technical lifetime, especially that many of the projects which are now 10-15 years old are located in some of the best resource sites (WindEurope, 2017, Repowering and Lifetime Extension). The process is called repowering and can be either replacing the entire turbine system components or upgrading the old turbines or specific components with advanced ones while keeping the components such as the foundation and tower. (US Department of Energy, 2019). Repowering can enhance the benefits from already installed wind farms. In the UK, repowering of Delabole wind farm (initially commissioned in 1991) between 2009 and 2011 doubled the installed capacity (Energy & Climate, 2018).

3.3.3 Energy Storage Systems

Energy storage plays two very important roles in transformation into renewable energies: First, reduction of reserve power plants and second, support for renewable energy by balancing the variability of renewable sources. In general, energy storage systems improve stability and reliability of supply (Faias et al., 2008). The power supplied by renewable energy sources is not as secure and easy to adjust to changes in demand, as the power supplied by traditional power systems (San Martín et al., 2011). Therefore, Energy storage becomes a very important factor for the use of renewable

energies as it can reduce power fluctuation and guarantees reliability (Ould Amrouche et al., 2016) (San Martín et al., 2011).

Energy storage technologies can be classified as: Chemical, electrochemical, mechanical, electrical and thermal (San Martín et al., 2011; Ould Amrouche et al., 2016). Chemical energy storage systems use chemical bonds to store the energy and the energy is released when the bonds in chemical compounds, like petroleum, coal, and natural gas, are broken. Hydrogen storage is the best example of chemical storage systems. Hydrogen is the fuel with the highest energy per mass. However, its low density at ambient temperature requires advanced storage technologies. (Ould Amrouche et al., 2016; PNNL, 2021). Electrochemical storage systems are different kinds of batteries including Nickel-cadmium, Nickel-hydrogen, Nickel-metal hydride, Nickel-zinc, Lead-acid, Sodium-sulfur, Sodium nickel chloride, Lithium-ion and Flow batteries. In general, batteries should have high charge and discharge efficiency, low self-discharge and long lifecycle (Ould Amrouche et al., 2016; San Martín et al., 2011). Mechanical storage systems are including flywheel, pumped hydraulic and compressed air. Flywheel storage converts electric energy to kinetic energy and vice versa. Although it has a very favourable power-to-weight characteristic, its cost is high and it is limited by technical issues. Pumped hydro energy storage consists mainly of a pump, two water reservoirs (upper and lower) and an electricity generator. It can be started-up in few minutes (Ould Amrouche et al., 2016). Pumped hydro storage is considered so far to be the best way to store energy in a huge amount with a high efficiency (70-80 percent) at low cost. It is the most used energy storage in the world (Oberhofer, A., 2016). Compressed air energy storage works by compressing air using the extra electricity and to release the compressed air into a turbine generator system to generate electricity at the time of need (peak times). In this system the energy can be stored for long times. But due to technical issues such as power loss as the result of the generation of very significant amount of heat during the process (Oberhofer, A., 2016) (Ould Amrouche et al., 2016). Electrical Storage is mainly realized by applying super capacitor and magnetic storage. Thermal energy storage stores thermal energy by heating or cooling various mediums in order to use the stored energy for heating, cooling and power generation.

The first and main barrier in the application of energy storage systems is the initial cost. Pumped hydro energy storage and Compressed air energy storage have relatively low costs. Battery technology is less competitive than Pumped hydro energy storage but is more cost efficient (Ould Amrouche et al., 2016).

Most used storage technologies								
Energy storage (ES)	Technologies		Time scale	Application in WECS	Efficiency			
Electrochemical	Batteries (BS)	Nickel-cadmium storage (NCS)	Medium (minutes)	X	60-70			
		Nickel-hydrogen storage (NHS)						
		Nickel metal hydride						
		Nickel-zinc						
		Sodium-sulfur storage (NaS)				86-89		
		Sodium-nickel chloride						
		Lithium-ion storage (LIS)					90-95	
		Zebra						
		Lead-acid storage (LAS)						75-85
		Flooded (FLA)						
Valve-regulated (VRLA).								
Flow batteries storage (FBS)	Vanadium redox storage (VRS)	Medium (hour)	X	70-80				
	Polysulphide bromide storage (PSBS)							
	Zinc bromine storage (ZnBrS)							
Hydrogen (HES)	Hydrogen (HES)	Long	X	65-75				
	Flywheel energy storage (FES)				Short (seconds)	X		
Mechanical (MES)	Pumped hydro energy storage (FHES)	Long (hours)	X	70-85				
	Compressed air energy storage (CAES)							
	Super capacitor energy storage (SES)				Short (seconds)	X	90-98	
	Superconducting magnetic energy storage (SMES)							
Electrical (Eles)	Super capacitor energy storage (SES)	Short (seconds)	X	90-99				
Electromagnetic (ElmES)	Superconducting magnetic energy storage (SMES)							
Thermal (TES)	Thermal (TES)	Medium	X	80-90				

Tab. 1: Storage technologies (Oberhofer, A., 2016 ; San Martín et al., 2011; Ould Amrouche et al., 2016)

System	Capital cost		
	\$ (kW)	\$ (kWh)	\$ (kWh per cycle)
Pumped hydro energy	600-2000	5-100	0.1-1.4
Compressed air energy	400-8000	2-50	2-4
Flywheel Energy Storage	250-350	1000-5000	3-25
Flooded Lead Acid	300-600	200-400	20-100
NickeleCadmium	500-1500	800-1500	20-100
Lithium ion	1200-4000	600-2500	15-100
Sodium-sulfur	1000-3000	300-500	8-20
Vanadium Redox	600-1500	150-1000	5-80
Zinc Bromine	700-2500	150-1000	5-80
Fuel Cell	10,000+	-	6000-20,000
Super capacitor energy	100-300	300-2000	2-20
Electromagnetic Energy	200-300	1000-10,000	-

Tab. 2: The cost of storage systems (Oberhofer, A., 2016 ; San Martín et al., 2011; Ould Amrouche et al., 2016)

3.3.4 Onshore Versus Offshore

Most of the installed capacity goes to onshore wind power and the trend will continue as onshore wind is the cheapest form of new power generation in most of Europe as well as in the rest of the world (WindEurope, 2021).

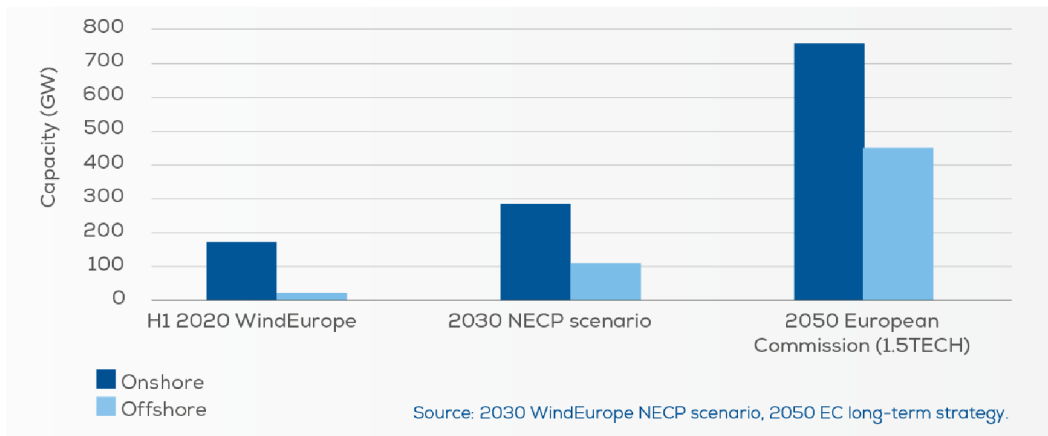


Fig. 10: The future of onshore and offshore wind capacity (WindEurope, 2021)

Although the installed capacity of onshore wind is far more than the offshore, the difference will be decreased as the offshore wind capacity is growing rapidly (IRENA, 2021).

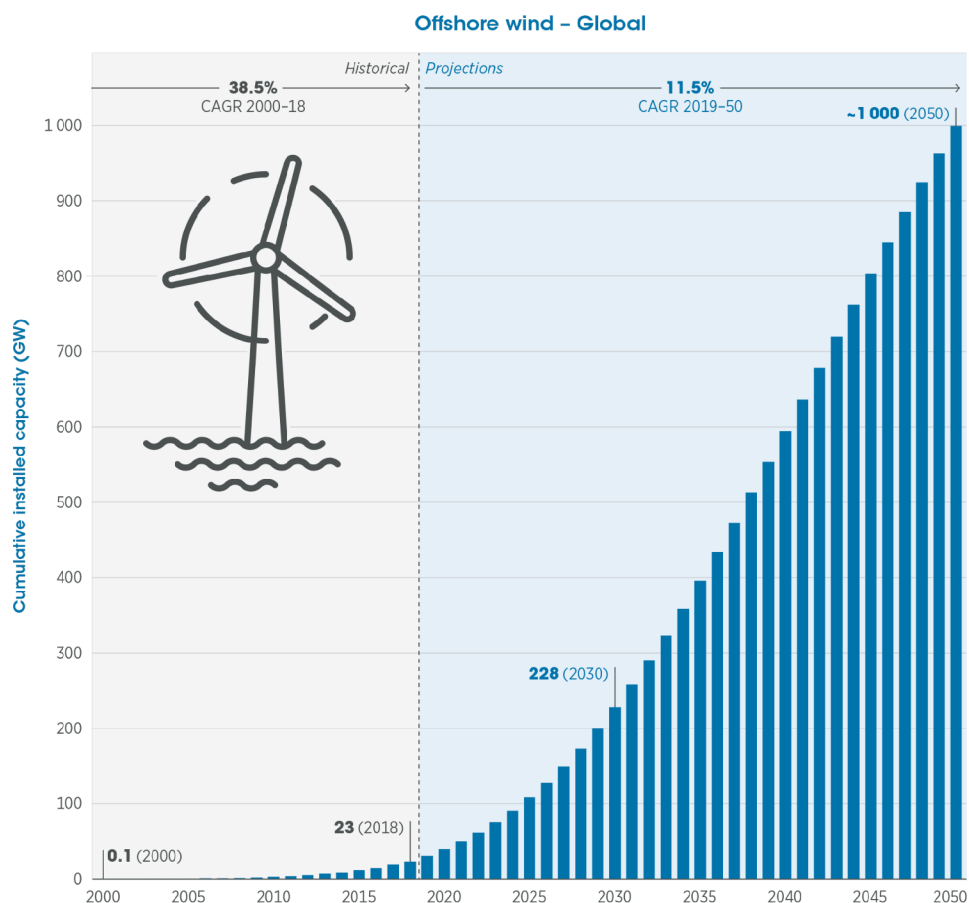


Fig. 11: Offshore wind power deployment by 2050 (IRENA, 2021)

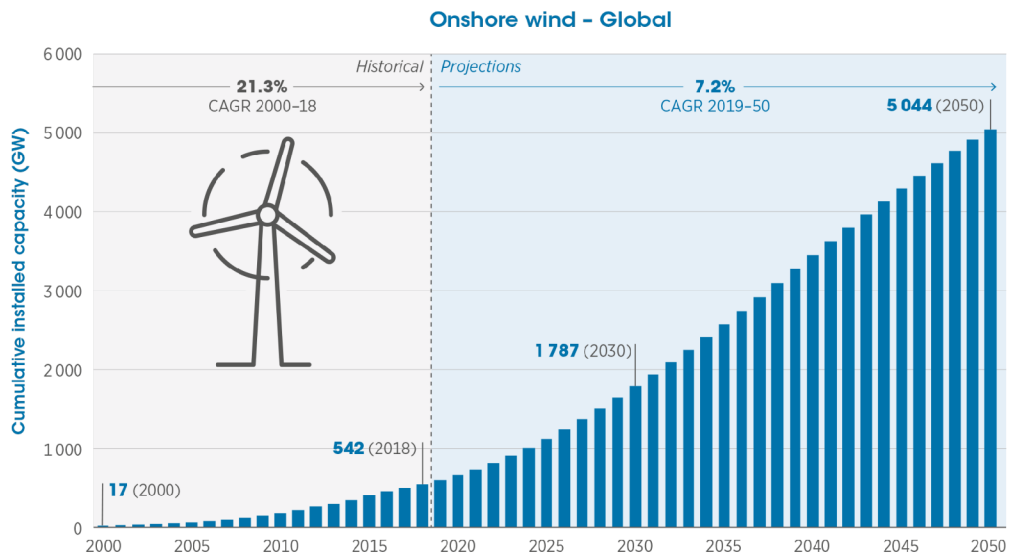


Fig. 12: Onshore wind cumulative installed capacity from beginning to 2050. Offshore wind capacity will increase to ten times more by 2030 and even more to 2025 (IRENA, 2021)

3.3.5 Wind Energy Market

Currently, onshore wind is one of the most competitive sources of new power generation. The global average cost of electricity of onshore wind farms in 2018 was 13% lower than in 2017 and 35% lower than in 2010 (IRENA, 2019, Future of wind).

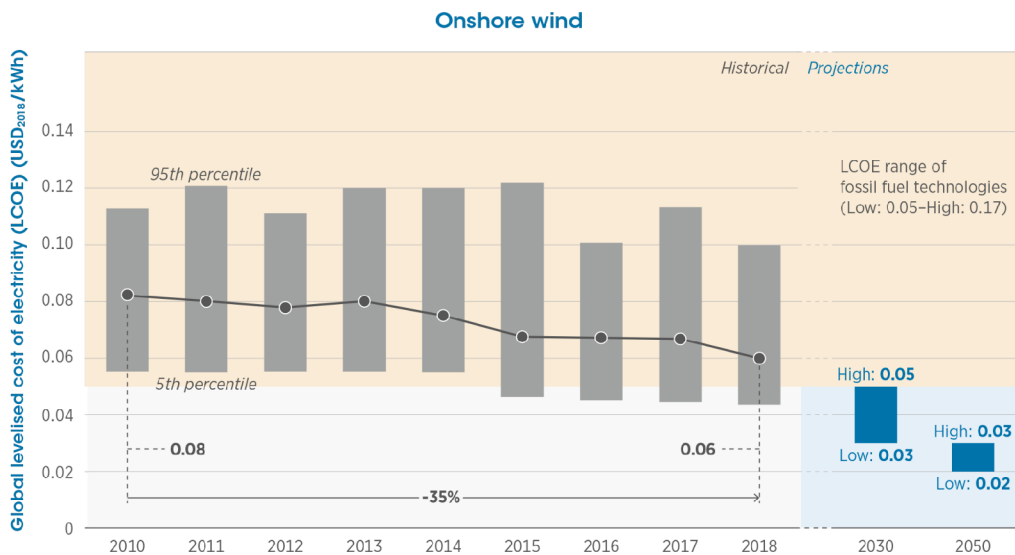


Fig. 13: The levelised cost of electricity for onshore wind (IRENA 2019)

It is believed that for achieving a clean and reliable energy supply at the lowest possible cost in Europe, wind energy plays a key role and European countries had a great share in development of wind energy (Wind Trust, 2017, Designing the wind turbine of the future). In 2010, 47% of global onshore wind installations were in Europe. Since then, wind deployment has accelerated in other regions. By 2018, approximately one-third of global installed capacity was in China. However, European countries continued investing in wind energy. In 2018, the European Union made a record in financing wind energy development with 29.4 billion USD invested in new wind farms projects (IRENA, 2019, Future of wind).

According to the foresights, China and India will continue leading global onshore wind power installations and more than half of the total capacity by 2050 will be in these two countries. North America (mainly the US) will see the second largest onshore wind energy development.

The world's top five markets in 2020 for new installations were China, the US, Brazil, Netherlands and Germany. These five markets combined made up 80.6% of global installations in 2020, collectively more than 10% greater than 2019.

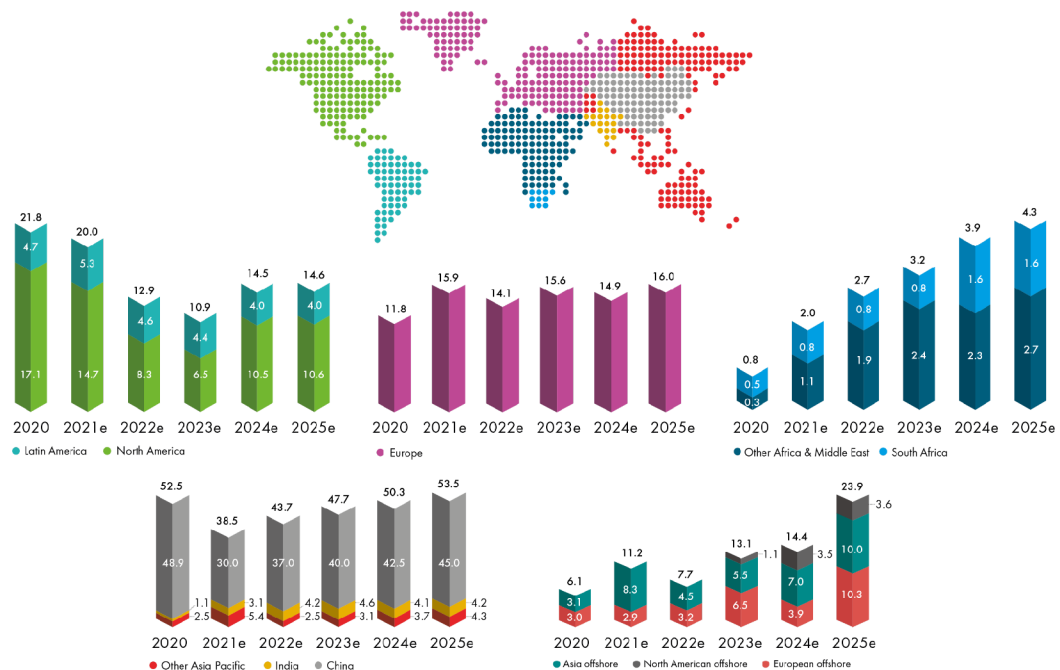


Fig. 14: Market outlook 2021-2025. Regional onshore and offshore wind outlook. New installations (GW) (GWEC 2021, Global wind report 2021)

As a part of the shift to renewable energies, many of major oil and gas companies have already started to invest in renewable energies. Wind energy received \$22 billion investments from oil and gas companies between 2015 to 2020, far more than other low carbon technologies. The example of Ørsted (the largest energy company in Denmark) which used to be an oil and natural gas company (named DONG in that time) which transformed to a green energy company (and the world's highest ranked sustainable

corporation) shows that energy transition plan can be successfully executed by oil and gas companies. Equinor (Norwegian energy company) aims to be the leader of energy transition and becoming a net zero company by 2050 (GWEC 2021, Global wind report 2021).

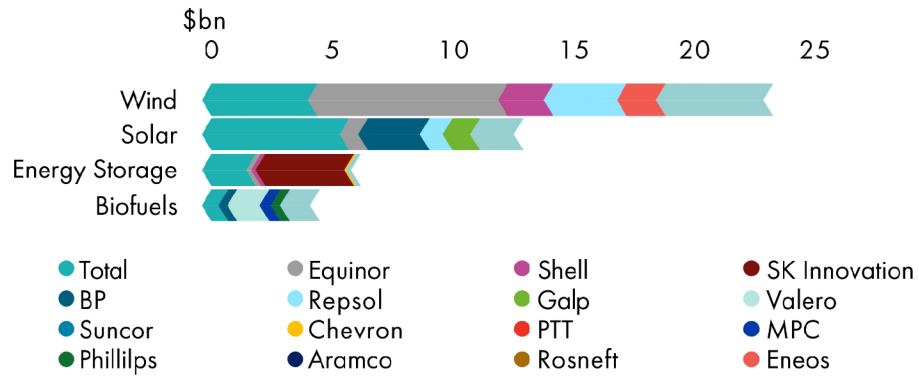


Fig. 15: Oil and gas sector investments in low-carbon technologies, 2015-2020 (BloombergNEF, company reports, 2021)

Oil and gas companies' net zero commitments and renewable targets		
Selected companies	Climate change targets	Renewable investment targets
BP	<ul style="list-style-type: none"> Net zero by 2050 Carbon intensity 50% lower in 2050 compared to 2019 levels 	50 GW renewable installations by 2030
ENI	<ul style="list-style-type: none"> Carbon intensity 50% lower in 2050 compared to 2018 levels 	4 GW renewable installations by 2024, 15GW by 2030 and 60 GW by 2050
Equinor	<ul style="list-style-type: none"> Net zero by 2050 Reduce net carbon intensity to zero by 2050 	4-6 GW renewable installations by 2026 and 12-16 GW renewable installations by 2035
Repsol	<ul style="list-style-type: none"> First oil and gas company to target net zero by 2050 Carbon intensity 20% lower in 2030 and 40% lower in 2040 compared to 2016 levels 	7.5 GW low carbon power capacity by 2025, and 15GW by 2030
Shell	<ul style="list-style-type: none"> Net zero by 2050 Reduce carbon intensity of energy products by 100% by 2050 compared to 2016 levels 	Investing \$2-3bn a year in renewables and energy solutions including hydrogen, and doubling electricity sales by 2030 from current levels
Total	<ul style="list-style-type: none"> Net zero by 2050 Carbon intensity 60% lower in 2050 	35GW renewable installations by 2025 and 100GW of renewables capacity by 2030
Petronas	<ul style="list-style-type: none"> Net zero by 2050 	3GW renewable installations by 2024
CNOOC	<ul style="list-style-type: none"> Emissions peaking and carbon neutrality plan being drafted 	Clean energy accounts for 60% of its energy mix by 2025

Tab. 3: Oil and gas companies' net zero commitments and renewable targets (GWEC Market Intelligence, 2021)

3.3.6 Wind Energy in Urban Areas

Despite the significant development of wind energy over the last decade, it hardly been used in urban areas. The size of normal wind turbines and their inability in capturing low speed wind and turbulent flows is a barrier to the application of regular turbines as well as visual effects and the noise they make. The specifically designed turbines for urban areas are still to be improved to perform better and are to be implemented in large scales (IRENA, 2020, Rise of renewables in cities: Energy solutions for the urban future).

According to IRENA (2020) 40% of the cities which have renewable energy targets are among the top 30% with the high wind potential. Most of these cities which have targets and are in the top 30% with the high wind potential are in Europe. More than half of the cities with good wind potential did not set a renewable target yet.

Vertical-axis turbines are very promising for urban applications, as they can produce power from the turbulent and multidirectional winds of cities (Dilimulati et al., 2018). They can reach very high efficiencies under uni-directional wind and are the most efficient for large-scale wind energy harvesting in open fields (Dilimulati et al., 2018; Óskarsdóttir, 2014). Apart from the fact that vertical-axis turbines are independent of wind direction, their design eliminates the need for a yaw mechanism, and the turbines offer simple design, low maintenance and simple manufacturing. In several types of vertical-axis turbines, straight blades can be used, which greatly reduces the manufacturing costs. In addition, they are easy to be used modularly as separate units or when integrated into electrical networks (Saeidi et al., 2013). Another advantage of vertical-axis wind turbines is that they produce less noise and have more appealing designs. Currently, vertical-axis wind turbines are most common in remote, off-grid applications (Óskarsdóttir, 2014).

3.3.7 The Disadvantages of Wind Energy Development

Noise pollution, shadow or light flickering, impact on aesthetic characteristics of the landscape and other impacts on humans and ecosystems, including the killing of wildlife, especially birds and bats (Dai et al., 2015) are drawbacks of the use of conventional wind turbines.

3.3.8 Environmental Impacts

There are concerns about birds and bats death due to collision with wind turbines. However, some estimations show that wind energy kills approximately 13 times fewer birds than fossil fueled power plants per kilowatt-hour of electricity production due to the pollution only. In general, avian mortality due to wind turbines is small compared to other sources of human-influenced avian mortality (Sovacool, 2013). More importantly, climate change is a far bigger threat to birds than wind turbines. Climate change affects birds in many different ways from harming the ecosystems and habitats to affecting their behaviour and reproduction ability. As a result, climate change is one of the biggest emerging reasons of bird mortality and it will put large number of bird species at the risk of extinction (Bairlein & Hüppop, 2004; Root and Hughes, 2005).

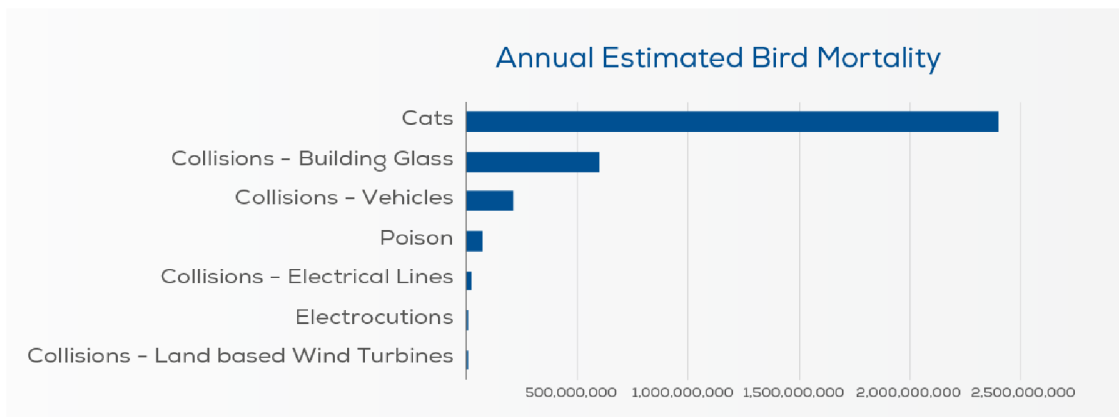


Fig. 16: Collision with the wind turbine has a very little impact on birds mortality rate in comparison to other factors (U.S. Fish and Wildlife Services, 2017)

3.3.9 Health and Noise

There is a debate on the association between wind turbines and health issues. Many believe that when the wind farm is sited correctly, the effects that are reported to be connected to light shadow flicker and noise are more subjective and result in annoyance or stress (Knopper et al., 2014). Mroczek et al. (2012) found no effect on people's quality of life due to proximity to wind farms in Norway. Freiberg et al. (2019) conducted an extensive study on the all studies conducted on the subject of the health impacts of wind turbines. They chose 84 publications from 2000 to 2017 (most of them were published after 2011) and from 22 countries. Firstly, they examined the characteristics and methodological aspects of the studies and then they worked on the findings of the studies. They put the studies in groups according to the criteria such as information bias. Wind turbine noise was the most frequently investigated issue. In high quality studies, wind turbine noise was not associated with sleep disturbance and anxiety. Some other studies of lower quality observations found an existing association between noise from wind turbines and annoyance, but they also found no association with stress and sleep problems. low-frequency noise, and infrasound are also reported as not likely to have health effects (Taylor et al. ,2012). Turnbull et al. (2012) measured infrasound at two Australian wind farms as well as in the vicinities of a beach, a coastal cliff, the city of Adelaide, and a power station. Reported that the measured levels at wind farms below the audibility threshold and similar to that of urban and coastal environments and near other engineered noise sources. Level of infrasound from wind farms at 360 and 85 m [61 and 72 dB, respectively] was comparable to that observed at a distance of 25 m from ocean waves (75 dB). Another issue which should be considered is that the visual impact of wind turbines affect the perception of associated noise from the turbines themselves. Increased distance leads to less perceived sound, noise annoyance and stress caused by that sound (Maffei et al., 2013).

Israel et al. (2011) conducted EMF (electromagnetic field), sound and vibration measurements at wind energy parks in Bulgaria. From this study, it was concluded that EMF levels were not of concern from wind farms. In another study conducted in Canada, magnetic field measurements were collected in the proximity of 15 wind

turbines, two substations, buried and overhead collector and transmission lines that were nearby residential homes sites. Results suggest that there is nothing unique to wind farms with respect to EMF exposure; in fact, magnetic field levels in the vicinity of wind turbines were lower than those produced by many common household electrical devices and were well below any existing regulatory guidelines with respect to human health (McCallum et al., 2014).

3.3.10 Public Acceptance and Benefits

As community opposition is one of the key obstacles to the development of wind energy production, it is important to investigate the reasons behind it (Landeta-Manzano et al., 2018). Public attitudes may differ sharply. As many find wind turbines aesthetically pleasant, while many other do not. Some may face the risk of the fall in their property's prices, while others see the new job opportunities or financial benefits. There are also many examples of high acceptance among those who live in close proximity to wind farms, solar parks and nuclear power plants. It is reported as "inverse NIMBY" (Not In My Back Yard) syndrome where those with wind farms in their "backyard" support wind energy (Warren et al., 2005). In a study conducted in Ontario, Canada, two communities were assessed: one located in proximity to two operating wind farms and a control community without turbines. Authors found that residents from the community with operational wind energy projects were more supportive of wind turbines than residents in the area without turbines (Baxter et al., 2013).

The negative attitude towards wind turbines is mainly due to visual impacts as when the wind farms are sited properly, wind turbines are not related to health effects (Knopper et al., 2014). Others found out that visual aspects can influence the perception of noise from wind turbines and as a result, on public acceptance (Maffei et al., 2013). As a result, planning can be very important. Some researchers found that in order to achieve public acceptance, placement of wind turbines must respect the qualities of the landscape (Molnarova et al., 2012).

In a study conducted in the US, residents of Lewes, DE, two locations were studied; one location of a 2 MW wind turbine, and nearby Millsboro, DE, location of a coal fired power plant were surveyed. A mail survey was sent to the 1000 closest residents to each facility. The study found that – despite the normal belief – the visual and auditory effects of the coal power plant were more negative than for the wind turbines. The other finding was that for the wind turbines, the positive perception effects were stronger than the negative ones, while for the coal power plant, the negative perceptual effects were stronger than the positive ones. While there was a small tendency to accept the form of power generation which was already used in one's local community, both communities perceived greater visual and noise impacts from coal power plant than the wind farms. It is especially important as the community near the coal power plant was provided with employment in the facility. Even in this community the majority recognised the disadvantages of coal power plant over the use of wind and understood the need to switch from fossil fuels to renewable ones. Despite the common expectation, neither the distance from the facilities, nor the demographic characteristics had a significant effect. Interestingly, residents near the wind farm said they would pay \$2.56 (on average) a

month to keep it, whereas the residents near the coal power plant were willing to pay \$1.82 (on average) a month to remove the facility (Thomson and Kempton, 2018).

In some research studies, the change in real estate prices is investigated to examine the local preferences for views of wind farms. It can be especially meaningful in places like England and Wales where the wind farms are often close to residential areas (Gibbons, 2015). A study done by Gibbons (2015) found out that wind farm developments reduce prices in locations where the turbines are visible. The reduction was around 5-6% for houses within 2 km of the visible turbines and it went down to under 2% for the distances between 2 and 4 km, and finally close to zero for distances between 8 to 14 km. Though the impact is not only due to the presence and visibility of wind turbines as the results of a study conducted in Scotland showed that physical proximity and visibility of pylons for overhead electricity lines have a significant and negative impact on the value (Sims and Dent, 2005).

Some researchers chose a different approach to this subject. Maehr et al., (2015) focused on emotional responses to the visual impact of wind turbines on the landscape. They used images of wind turbines, churches, pylons and power plants against the rural scenes. The psychophysiological responses to turbines were stronger than the responses to churches but did not differ from that of other industrial constructions. Interestingly, wind turbines were rated as less aversive and more calming compared to other industrial constructions and equivalent to churches. It is important to consider that churches are – like wind turbines – prominent, man-made environmental stimuli but unlike wind turbines, they are familiar (Pheasant, Watts, & Horoshenkov, 2009).

The processes around wind project planning and development can significantly affect public acceptance (Firestone et al., 2012) and a lack of opportunity for local residents to engage meaningfully in the planning process may reduce support or increase local conflict (Phadke et al., 2011). A study surveyed Dutch and Romanian citizens and found that financial benefits has an important role in increasing public acceptance of wind farms, as well as several subjective factors such as the visual impacts and the placement of the turbines (Nichifor, 2016). Direct financial benefits is another factor in gaining public acceptance. Onshore wind farms bring significant benefits to communities in the local taxes they pay and other financial contributions they make. Polls across Europe show that 75-80% of those who live near wind farms support them (WindEurope, 2021).

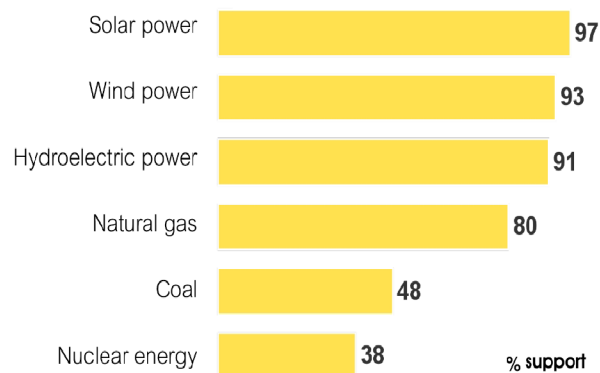


Fig. 17: Public support for various energy sources according to a survey from 18,787 global adults aged 16+; April 2011. Renewable energies gained the highest public acceptance worldwide (Wallard et al., 2012)

Nuclear power is proposed as a good alternative to fossil fuels, however, it is clear from public polling that there is a huge difference in public attitudes towards renewable energy sources and to nuclear power (Wallard et al., 2012). Nuclear disasters had a significant effect. The Fukushima nuclear disaster of 2011 had an impact on public acceptance especially that – unlike Chernobyl – it was of the same design as western nuclear plants. Rapid political decisions on stopping the development plans for nuclear power were made in Germany and Switzerland even before assessment of the impact on public attitude (Warren et al., 2005).

3.3.11 Effects on Tourism

A survey study conducted in the Czech Republic showed that installation of wind turbines in suitably selected locations may have only a very small negative impact on tourists' perception and experience of landscape and their destination choice. Wind turbines can even be used to support development of new forms of tourism by the use of proper marketing. In general, wind turbines are not perceived as disturbing as other industrial and infrastructures such as factories, mines or telecommunication (Frantál and Kunc, 2011).

3.3.12 Visual Impact

All indicators show an enormous change in the land use in the next decades as the rising demand to reduce greenhouse gas emissions require the exploitation of the renewable energies. As a result, the landscapes in many of the world natural areas will be affected (Sæþórsdóttir and Ólafsdóttir, 2020). The use of renewable energy systems has an aesthetic effect on landscape and influences the public acceptance of large projects. In a survey conducted in Switzerland, some photos of typical landscape types were taken and were edited in two ways with lower and higher number of wind turbines and photovoltaic cells. In general, people preferred the landscapes with lower amount of wind turbines and photovoltaic cells, but they also preferred the more natural landscapes

to the more urban ones and there was a significant difference in preferences among landscape types (Spielhofer et al., 2021). Visual impact is one of the main factors which influence the public acceptance towards wind turbines. However, the assessment of visual impacts is subjective (Sklenicka and Zouhar, 2018). In a study conducted in South Africa – West Coast Region of the Western Cape Province – on areas around thirteen onshore wind farm projects and to examine the social perception, 70% of all respondents supported the development of wind farms even though the landscape is considered to be very special (Lombard, 2017). In another survey done in the Czech Republic, wind turbines in landscapes with high aesthetic quality received some of the most negative reactions from the respondents while the turbines installed in the least attractive landscapes did not change the respondents' attitude toward those landscapes and some of the respondents considered the installation of the wind turbines in such landscapes as improvement. The results also showed that the higher acceptance is achieved when the number of turbines is limited and if they are far from observation points such as settlements and transportation network (Molnarova et al., 2012).

3.3.13 Visual Impact Assessment

Wind turbines become bigger to generate more power and reduce the cost of energy. However, the visual impact is also increased (Landeta-Manzano et al., 2018). Therefore, visual impact assessment becomes even more important. There is no fixed and agreed range to assess the visibility. Bishop (2002) believed that new tall turbines can be visible even from more than 30 km, however, for above 20 km the visibility is very limited; its impact is very low. Others suggest distances of 35km (Miller et al., 2010) or even 40km (Vissering et al., 2011). The visibility and the degree of impact depend on a mixture of different factors such as the nature of the background and the landscape between the viewer and the turbines, lighting, atmospheric conditions and moving or stationary blades (Bishop and Miller, 2007).

The visual impact assessment is done by some different methods which can be classified into four groups; 1- Methods which include subjective evaluations made and assessed by experts (Tsoutsos et al., 2009). 2- Methods based on landscape classifications, which generalise the impact of wind turbines for individual landscape types (Betakova et al., 2015). 3- Methods such as the Spanish method which use specific multi-criterion indicators of visual impact (Manchado et al., 2015). 4- Methods which use exactly measurable map-based indicators (Frank et al., 2013) (Sklenicka and Zouhar, 2018).

In terms of tools, geographic information system (GIS) has become a major tool for three-dimensional analysis recently (Hernández et al., 2004). Viewshed analysis in GIS environment has become widely accepted for visual impact assessment of wind turbines (Möller, 2010).

3.3.14 Wind Energy development in the Czech Republic

The Czech Republic has one of the lowest rates of the deployment of wind energy in Europe although it is among the EU leaders in exploitation of solar energy and biogas (Roth et al., 2018). The realisable wind potential in the Czech Republic (estimated between 2,500-3,500 MW according to Chalupa and Hanslian, 2015) is far from being effectively utilised (Fig. 18, 19 and 20). In 2020 the capacity was 339 MW (IRENA Statistics for EU countries, 2021). A study conducted by Hanslian et al. (2008) at the Institute of Atmospheric Physics, Czech Academy of Sciences, assessed the technical potential of wind energy (considering the environmental, infrastructural and other limitations and constraints) and calculated a realisable potential of wind energy for Czech districts (Fig. 18).

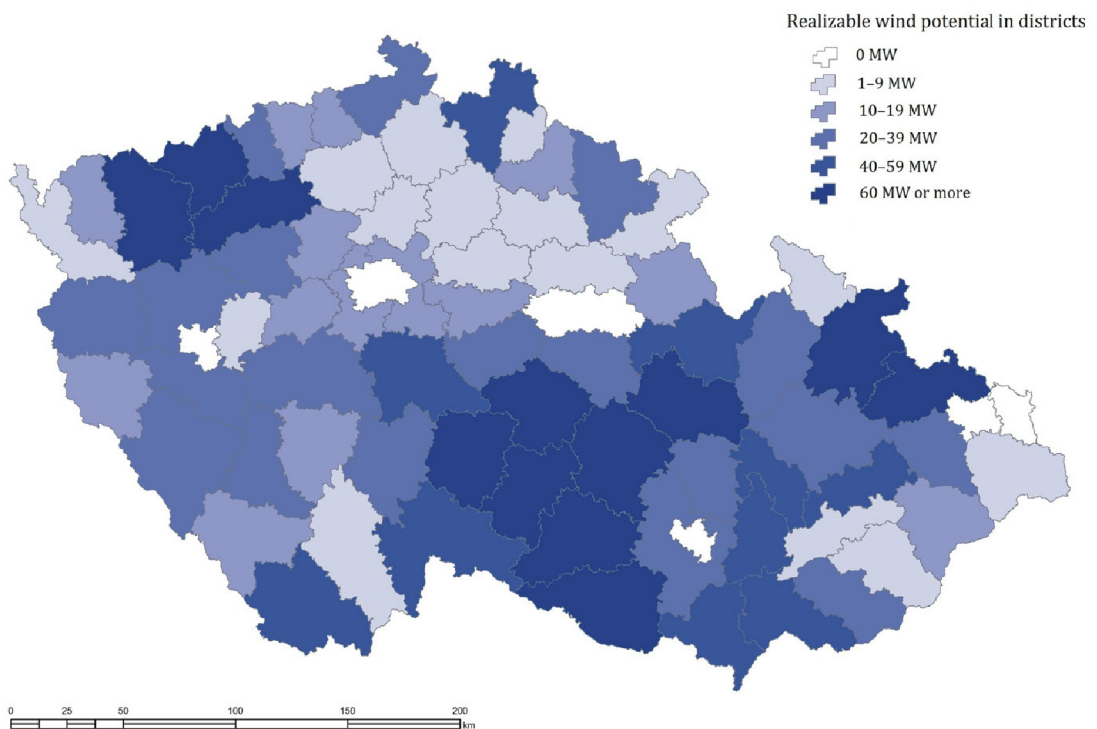


Fig. 18: Regional realizable wind potential (Hanslian et al., 2008)

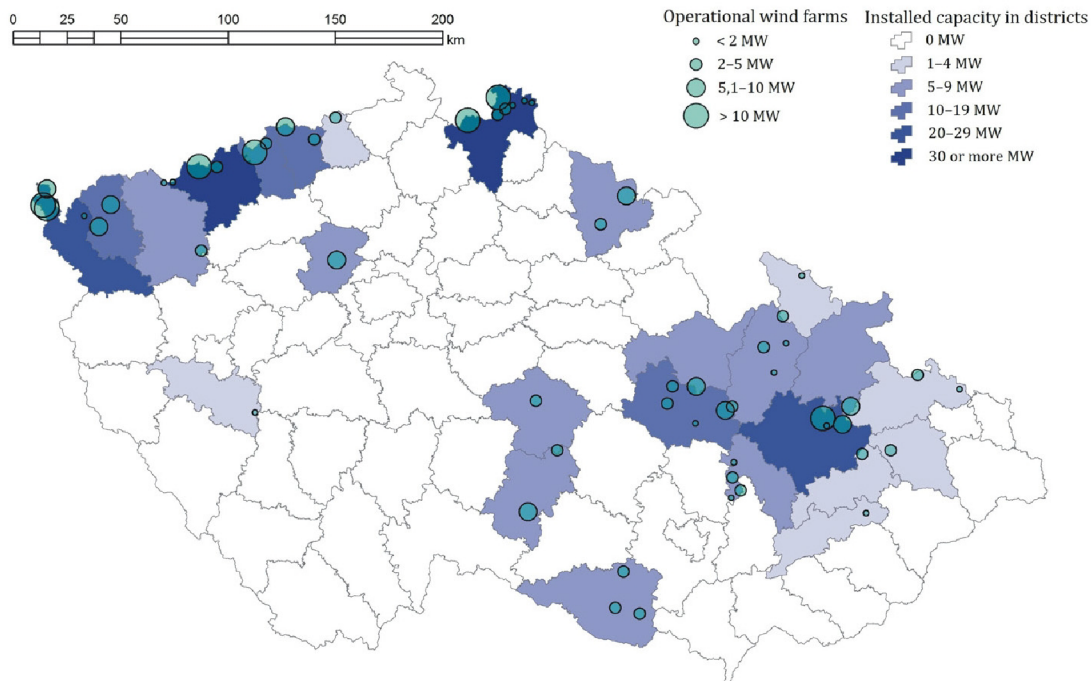


Fig. 19: The location of implemented wind energy projects (circles) and total installed capacity (MW) in districts of the Czech Republic (Czech Wind Energy Association, 2018). Comparing the two maps shows the unutilised wind potential in most regions.

There is a significant spatial difference in the implementation of wind farms (Fig. 20).

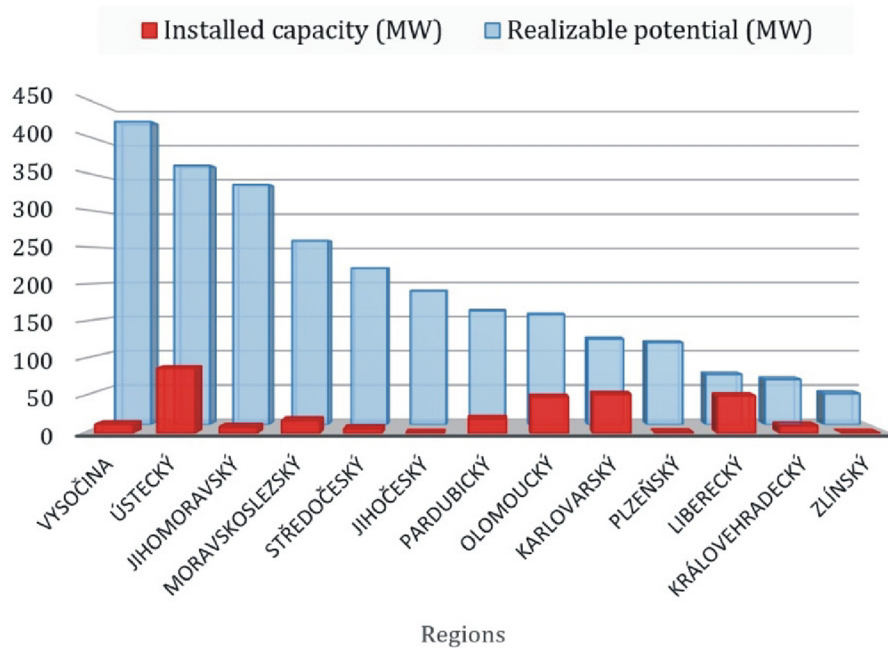


Fig. 20: Regional differences in the deployment of wind energy in the Czech Republic as of 2018 (Czech Wind Energy Association, 2018). There is a huge unutilised potential in many regions.

Frantál and Nováková (2019) did a wholistic study on the correlation between different characteristics of the Czech districts and implementation of wind energy. The strongest correlations were found between the installed capacity of wind energy and the presence of coal mining and the installed capacity of coal-fired power plants within the district (which in turn leads to some other factors with high correlation such as air pollution, structural depression, unemployment, health problems, lower life expectancy and higher infant mortality). The proportion of uneducated people and ethnic minorities in such districts can be simply because the coal energy is environmentally unjust. The other reason for supporting the wind farms can be that the people living in coal mining landscapes are aware that the electricity has to be produced somehow and somewhere. The most influential variables were: wind energy potential of the district, urbanisation rate, installed capacity of coal-fired power plants and the votes for the Green Party (The Green Party is the only political party in the Czech Republic which supports the development of renewable energy resources in the long term). The other reason why wind energy is more accepted in environmentally deprived areas can be considering it as an alternative to coal and its economical motivation (financial benefits for municipalities) that affect local acceptance positively, however, it is not a phenomenon in the Czech Republic as Balta-Ozkan et al. (2015) found that smaller households in highly polluted areas in the UK are early adopters of PV installations. The other factor that should be considered is that the Czech coal power plants do not provide (in comparison with nuclear power plants and wind farms) local communities with direct financial benefits and investments. In general, in the Czech Republic, wind farms are mostly in small municipalities with low populations and in more polluted areas, and the municipalities which already have wind farms are more likely to install new wind farms.

In the Czech Republic, the potential landscape impacts are the most important limiting factor for further development of renewable energies (Frantál and Nováková, 2019), however, the lack of organised opposition to wind farms does not directly mean that people are actually in favour of them. The [passive] acceptance can be just an indicator of low political efficacy (due to lower education and lack of social capital) and resignation, which is often a characteristic phenomenon in environmentally deprived areas (Van der Horst, 2007).

3.3.15 Energy Resources in the Czech Republic

The current energy policy is still highly dependent on traditional resources. Electricity generation is based primarily on coal (ERO, 2020). While the goal of EU funds is to support a sustainable low-carbon-emission economy and ensure energy security by utilizing alternative energies, the Czech approach is different. As described in the State Energy Policy, the future Czech energy mix will be primarily based on nuclear power with a goal of reaching 50% of the energy supply with nuclear (International Trade Administration, 2021).

The Czech government provides subsidies to household projects consisting of photovoltaic panels with electricity storage systems. Batteries and thermal energy storage are the two most commonly used methods of electricity storage for households in the Czech Republic (CMS, 2021).

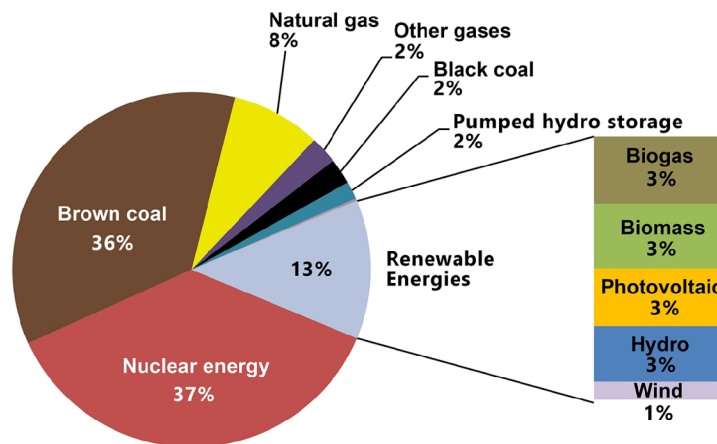


Fig. 21: The share of fuels and technologies in gross electricity generation in the Czech Republic in 2020 (ERO, 2020). Electricity production is still highly dependent on traditional resources.

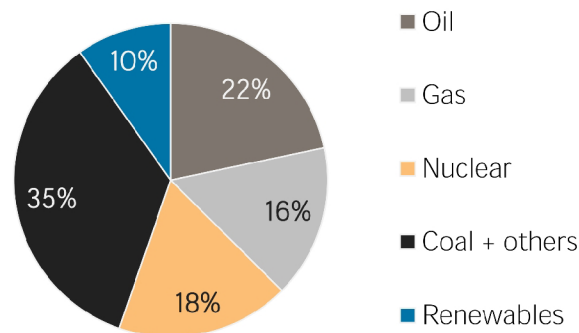


Fig. 22: Total primary energy supply in the Czech Republic 2018 (IRENA, 2021). Energy sector in the Czech Republic is highly dependent on coal, oil and natural gas.

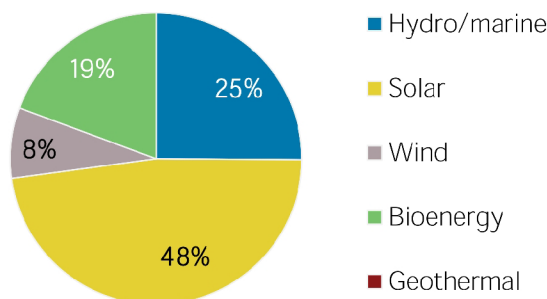


Fig. 23: Renewable energy capacity in the Czech Republic in 2020 (IRENA, 2021)

3.3.16 Energy Storage Facilities in the Czech Republic

Czech Republic has three pumped-hydroelectric storage facilities which makes it easier to use wind energy at high degrees (as explained in; 3.3.3 Energy Storage Systems). These three facilities are; Stechovice with a capacity of 45 MW, Dalesice with a capacity of 480 MW and the newest Dlouhé Stráně with a capacity of 650 MW. All of them are owned by CEZ Group, which is the largest energy group in the Czech Republic and is controlled by the Czech government. Dlouhé stráně pumped storage power plant can supply 3,500 MWh of electricity to the Czech energy network within one pumped cycle. This amount would cover the consumption of one thousand Czech households for one year. The facility is situated in Moravia region and has the largest reversing water turbine in Europe (325 MW) and the biggest installed capacity in the Czech Republic (2x 325 MW) (CEZ Group, 2021).

3.3.17 Open Source Software

The open source movement is based on a radical retake on copyright law to create high quality software which can be used, developed/modified and shared by the public. The first open-source projects were revolutions against the unfair profits that closed-source

software companies like Microsoft were gaining through the monopoly that they obtained and forcing the users to use and pay for whatever they make. A substantial amount of open source software in all fields currently exist and many are added every day by the huge and powerful community which is the heart and the most powerful feature of open source movement. In addition, and as a result of sharing the codes, peer review minimizes the bugs and security risks (Raymond, 1999; Gacek and Arief, 2004) (Carillo and Okoli, 2008).

4. Methodology

The methodology used in this thesis consists of three main Parts: 1- GIS part 2- 3D part 3- Photomontage part

In terms of the principal software that will be used, GIS part is done by QGIS, 3D part by Blender and an add-on named BlenderGIS. The last part by GIMP. Other additional software are: LibreCAD (other free and open-source CAD software like QCAD are also available), LibreOffice (other office software can be used)

All of these pieces of software are free and open-source and can be downloaded from these websites:

QGIS: <https://www.qgis.org/>

Blender: <https://www.blender.org/>

BlenderGIS: <https://github.com/domlysz/BlenderGIS>

GIMP: <https://www.gimp.org/>

LibreCAD: <https://github.com/LibreCAD/LibreCAD> , Main website: <https://librecad.org/>

LibreOffice: <https://www.libreoffice.org/>

The versions used for this study are as follow; QGIS 3.16, Blender 3, GIMP 2.10.13, LibreCAD 2.1.3, LibreOffice 7.2.5

4.1. GIS

At this part the author will use maps and data to 1- determine the best points where the wind turbines should, or could be installed; 2- Conduct a visibility analysis; 3- Define the viewpoints to the wind farm; and 4- make the project ready for 3D part.

4.1.1 The Required Data and Maps:

DSM/DEM and Vegetation maps

A digital elevation model (DEM) is a raster which has the height data of the ground, while a digital surface model (DSM) has the height data of the highest surface of features on the ground where the ground surface is covered. It is the same as DEM in places where the ground surface is not covered. A digital terrain model (DTM) is generally the same as DEM. DSM is preferred as it has the built and natural features and therefore there is no need to add more data to it. In case of using DEM, adding the average height of the trees in forested areas is an important step.

There is no need to say that the most precise available data should be used, however, using high resolution data requires more powerful computers to process the data and handle working with the files. Therefore, one should consider using the best data that suits the project and needs and not necessarily the highest resolution (or the most detailed) data. Some sources for DEM and DSM are available for the whole world or for specific regions. For some countries, high resolution DSMs are available for free.

Roads and Settlements Maps

In general, finding the precise maps (Shape files) of roads and settlements is easier. Such maps are available from local sources in different countries as well as from some sources which provide world wide open data (such as: <https://mapcruzin.com/> which makes maps from <https://www.openstreetmap.org> available to download). These maps can be helpful for positioning the wind turbines (to choose the places as far as settlements as needed) and for defining the viewpoints from the places that people are more likely to pass.

Wind maps

In general, there are two kinds of wind maps. The first one is the mean wind speed and the second one is the mean wind power density which is a better indicator of wind resource as it is the mean annual power available per square meter of swept area of a turbine (The swept area refers to the area of the circle created by the blades as they sweep). Power density includes the effect of wind velocity and air density and its unit is watts per square meter (w/m²).

One of the best sources of both maps at different heights which is available for free is Global Wind Atlas (<https://globalwindatlas.info/>). The maps are available at different heights (10, 50, 100, 150 and 200 m).

Protected areas maps

Protected areas such as Natura 2000 sites of European importance and national parks should be considered. Other important sites might also include UNESCO world heritage sites. Specific protected areas in each country must be also considered. For example; Protected Landscape Areas (PLA) in the Czech Republic.

Orthophoto

Using an orthophoto does not add more accuracy to the projects but can be helpful in understanding the setting and editing some layers like vegetation.

Countries Borders, Regions

These maps can be used for site selection and orientation as well as for being used as mask layer to clip the other maps which is necessary for map creation purposes and also for technical issues (keeping the project file as light as possible and not to waste time for calculation on areas which are not supposed to be included).

Map Services

Some maps are available as map services (online) to be added to the GIS software from servers so that the resolution is very high.

Coordinate Reference System

One important issue in this part is CRS (coordinate reference system). It is better to choose a widely used CRS, therefore, there would not be any problem with changing the CRS of some layers, especially that it is better to do it for importing maps and data into 3D software and for having coordinates that can be entered in any GPS tool. For example, in this research, ETRS89-extended / LAEA Europe (EPSG:3035) was used. S-JTSK / Krovak East North (EPSG:5514) – which is for the Czech Republic – could also be used but as the research is intended to propose a methodology, a widely used CRS was preferred over a local one.

4.1.2 The Process

Site selection

Add all the maps of the protected areas and put the wind speed (or power density) below them to investigate the available areas with high potential for wind exploitation. As mentioned, the maps of roads and settlements are used to choose the best sites where are close enough to the roads and far enough from settlements.

Positioning the Wind Turbines

After choosing a site, a CAD software can be used for designing the plan of the wind farm for the best and most efficient positioning of the wind turbines. The site border shapefile can be saved as a DXF file and opened in the CAD software. The plan then can be imported to QGIS and points of the proposed wind turbines are added according to the plan.

Visibility Analysis

The aim of doing a visibility analysis is to find the places from where the wind turbines are visible. A DEM/DSM raster is used at this step. After using visibility analysis and examining it in reality, two main issues were detected which cause higher rates of negative error (when the analysis shows degrees of visibility but in reality there is no visibility or lower degrees). Number one is caused by vegetation (forests, more precisely) especially while working with a DEM. It is crucial to add the average canopy height of the typical type of the forest trees into the DEM. There is no need for this step if high resolution and accurate DSM is available as it already has the forests in it (the effect of vegetation will be obvious in the raster). Using the new raster file with forest canopy height added to it, a new visibility analysis must be made. Number two error is due to less visibility of blades especially from higher distances and from over the trees. For reducing the error caused by this factor, a new visibility analysis is made but with the hub height instead of general height of the turbines. An average of three rasters will show the visibility more accurately.

The next step is defining the viewpoints to the wind farms. The points must not be put within the forested areas. Next, the coordinates of the points should be exported and made ready for being used for finding the exact locations for taking the photos.

The last step is to make the project ready for importing into the 3D software and making the 3D model. A contour map of the DSM (or a modified DEM) is needed. The points of wind turbines and viewpoints must contain elevation data added to them.

4.2 3D Modeling and Rendering

A 3D model of the terrain is made at first by importing the contour line shapefile and making a surface based on it. Next, the points are imported and put on the right coordinates and heights. A 3D model of wind turbine is then copied to the points for proposed turbines and virtual cameras are put on the points of viewpoints. The dimensions of the 3D turbine model must be modified to match the turbine model which is going to be installed. The lens properties of the virtual cameras must be changed to match the properties of the physical camera lens which is going to be used for photography. The direction of each camera must be set according to the view to the turbines and followed while taking the photos so that the photos direction match the direction of the renders. The last step is to adjust the settings and render the camera views.

4.3 Photomontage

If all previous steps are followed, this part is very straight forward. There is no need for scaling the renders as the scale of the 3D model matches the real scales exactly. The renders are to be put on the photos only. The parts of the turbines which are covered by trees, buildings or hills are to be erased. The colour, contrast, etc. of the renders can be modified to match the real photos better.

It is to say that although 50mm lens is mostly said to be the closest to what human eye sees, anything between 35-50mm is very close to human eye and the author realized during this study that especially for landscape photography, 35mm lens is more close to how one sees a landscape as human eye covers higher range than what a 50mm lens covers and when one is not focused on a feature but generally watching a wide view (landscapes) 35mm works better and gives us a closer photo to how we perceive a landscape. In this study a Nikon Z6 camera was used for taking photos. Different lenses (24, 35, 50 and 70 mm) were used for taking photos from each viewpoint to test the difference of the lenses in the result. Two middle range phones were also used to test the method in case of using phone cameras (24 and 26 mm lenses).

5. Case Study and the Detailed Steps

After using the method and the mentioned maps, a site in Ústecký region in northwest of the Czech Republic was identified as one of the best locations for new wind farms. There is one wind farm in vicinity of the chosen site which is a good opportunity to test the accuracy of the method.

5.1. GIS

Used Data

The DEM used in this study is Europe DEM version 1.1 from Copernicus Programme. The resolution of this DEM is 25m. The data is free and available at <https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1/view>

Two tiles of the data contain the Czech Republic territory. E40N30 tile contains the northern and E40N20 tile contains the southern part. The site that we chose is in the northern tile.

The author used the layers of roads, settlements and forests from this source:

<https://www.openstreetmap.org>

The data used here is the mean wind speed at 100m from <https://globalwindatlas.info/>

The maps of protected areas used in this study are: nature reserves, nature monuments, national parks, protected landscapes, habitat of protected large mammals, Natura 2000, UNESCO world heritage sites and wetlands. All of the maps are from Nature Conservation Agency of the Czech Republic (<https://www.ochranaprirody.cz/> , <https://data.nature.cz/>).

The general maps of the country and regions boundaries are available at [https://geoportal.cuzk.cz/\(S\(04qukty4i0dpidxdijkeidpp\)\)/Default.aspx?lng=EN&mode=TextMeta&side=dsady_RUIAN&metadataID=CZ-CUZK-SH-V&mapid=5&menu=252](https://geoportal.cuzk.cz/(S(04qukty4i0dpidxdijkeidpp))/Default.aspx?lng=EN&mode=TextMeta&side=dsady_RUIAN&metadataID=CZ-CUZK-SH-V&mapid=5&menu=252)

The Process

QGIS can be downloaded from <https://www.qgis.org> . After installation and opening the software for the first time, the user will see the default layout (Fig. 24)

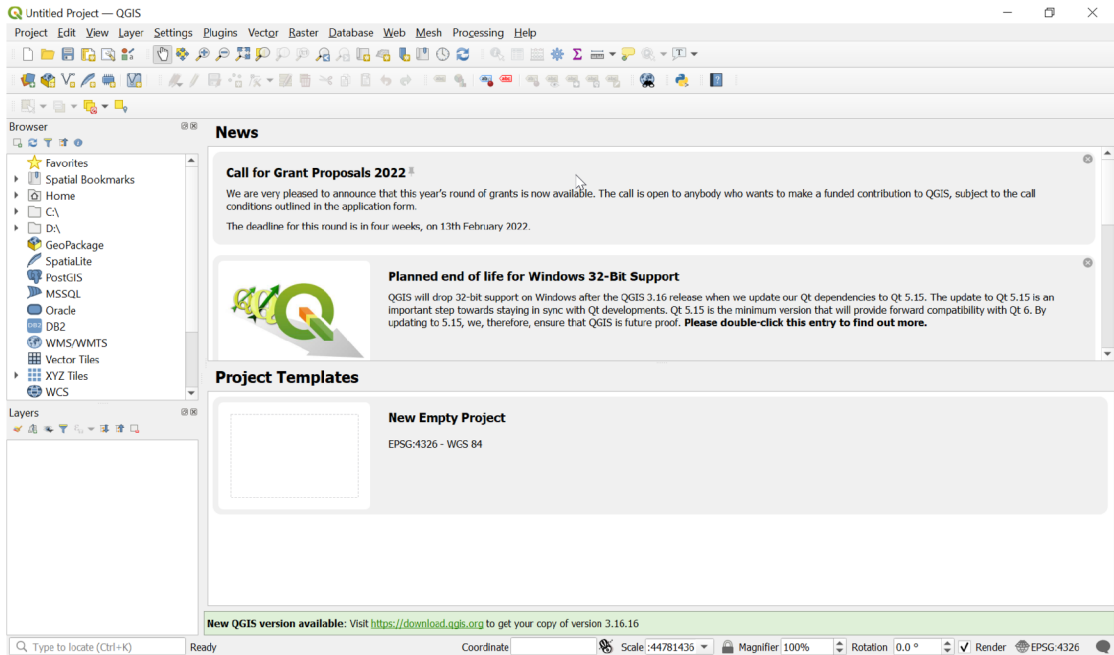


Fig. 24: The default layout of QGIS

Toolbox can be added from Processing menu. A new project can be made from Project menu.

The layout will look like:

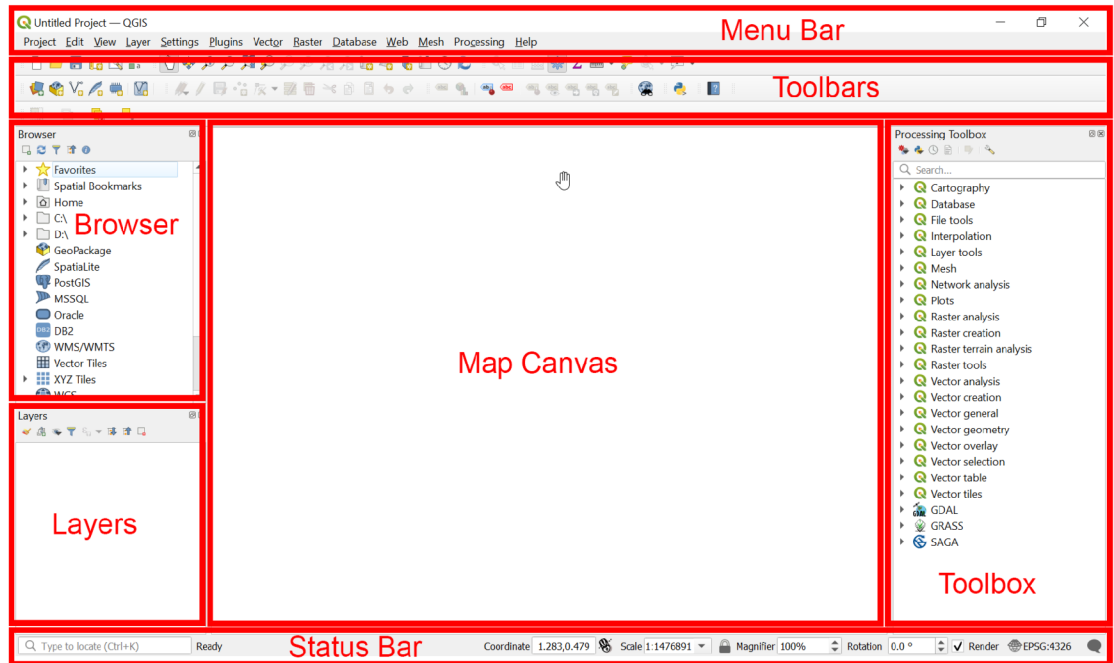


Fig. 25: The basic layout for working with QGIS

The next step is to set the CRS of the project. It can be found at the lower right corner of the software window. As it is already explained why, ETRS89-extended / LAEA Europe (EPSG:3035) is used for this research.

After adding each layer, it is critical to make sure that each layer is projected correctly in the CRS of the project. Most of the times it is done automatically as the information about the CRS of a map file comes with it and QGIS projects it to the project CRS. If a question mark appears in front of a layer after adding it to the project, it means that it does not have the information of its CRS and the user must add it manually. By clicking on the question mark *Coordinate Reference System Selector* window pops up. Be careful that the CRS of the layer (map) must be entered here, not the CRS of the project.

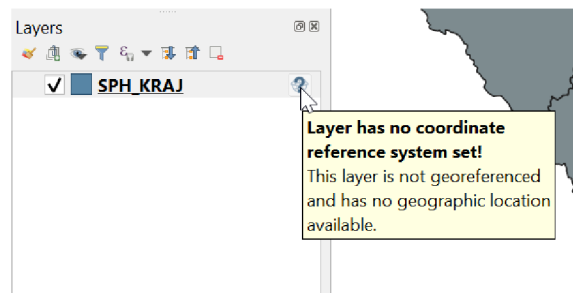


Fig. 26: Adding the CRS of a layer in case the layer does not have CRS information

It is better to cut the parts of the DSM (DEM) which are not needed as the file will be difficult to handle and process. This can be done using *Clip* tools for rasters (Fig. 27).

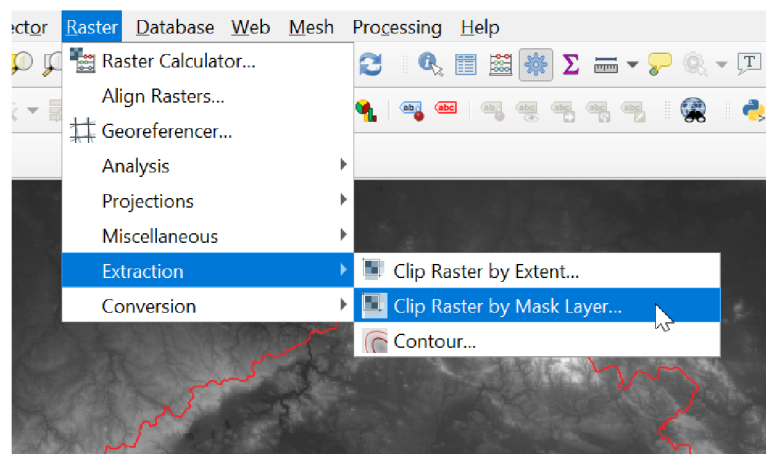


Fig. 27: Clipping the rasters

One can use country border, regions, etc., shapefiles to clip the DSM (DEM) and other required rasters. Be careful that the shapefile should consist one shape. If it has multiple shapes (like regions of a country) first use *Dissolve* tool to break them into one single shape (Fig. 28).

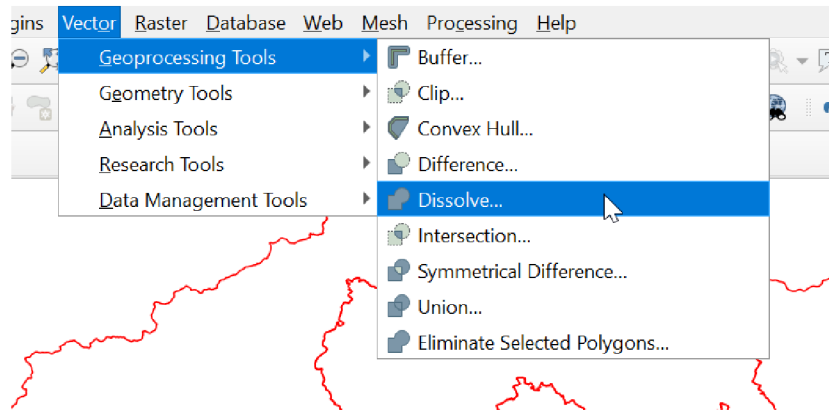


Fig. 28: Dissolving the shapefiles

Next step is to add all layers of the areas that wind farms cannot be installed there (Fig. 29).

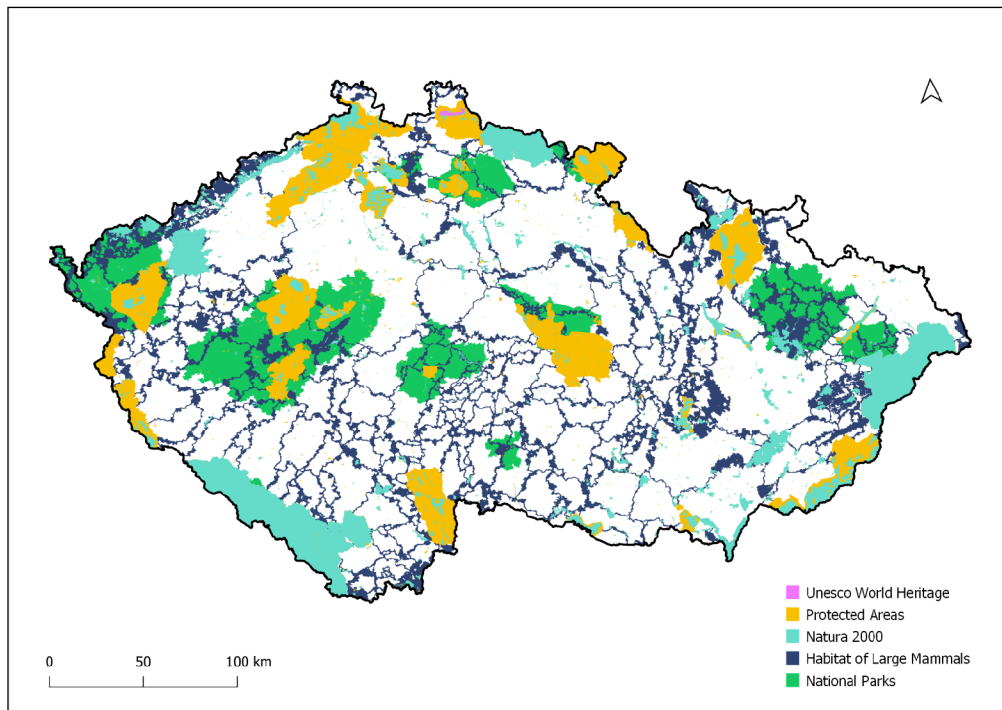


Fig. 29: A map of all areas where wind farms cannot be constructed there

Merging all the layers can help to know what areas are left available (Fig. 30).

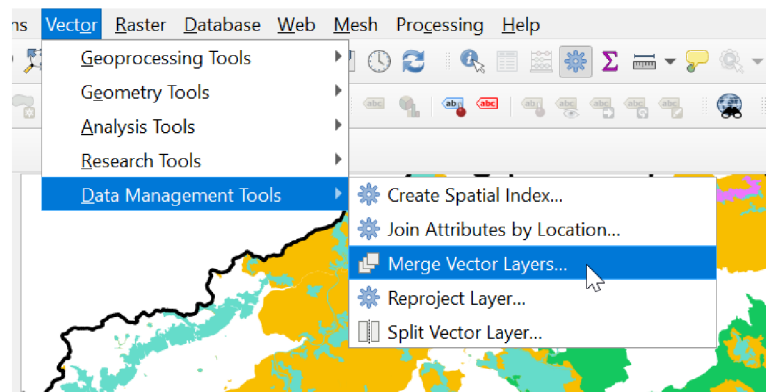


Fig. 30: Merging vector layers

Then the layer of wind speed or wind potential is being added to find the areas that are left and have potential for wind energy exploitation (Fig. 31)

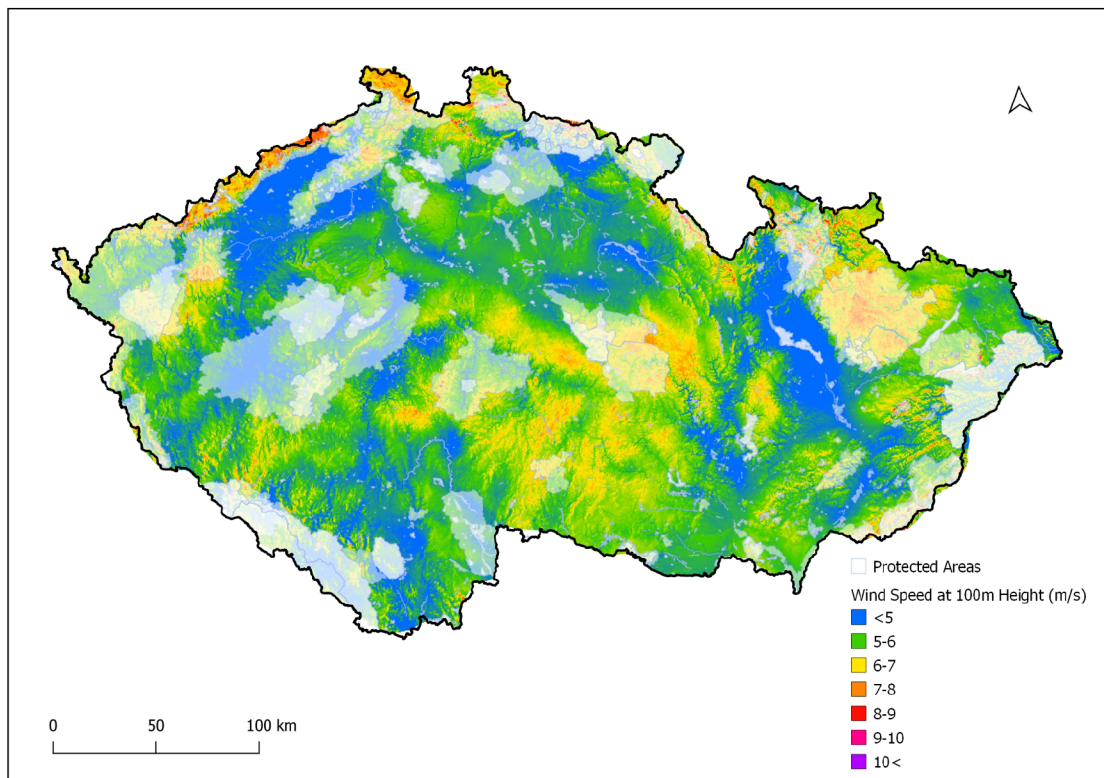


Fig. 31: Potential suitability for wind energy exploitation

This map shows the potential for installation of wind farms. A linear part by the border with Germany in the northwest of the Czech Republic has the highest potential for wind power exploitation in the country and most of the wind farms are constructed there. The site that is chosen for examination of the proposed method in this research is in that area and in vicinity of one existing wind farm and near another one.

One can use server services and add maps from different sources to their project. Different maps are available from Google and ESRI as well as many other sources. Sources for national maps are available for different countries such as <http://geoportal.cuzk.cz> for the Czech Republic. The author used open street map (which is available by default in QGIS) and Google satellite imagery. One can add maps using *XYZ Tiles* from *Browser Window* (Fig. 32).

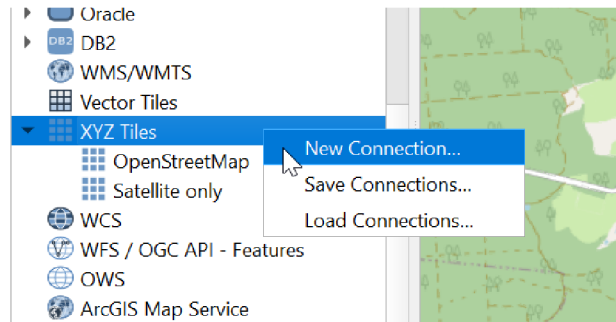


Fig. 32: Adding maps from Server Services

One also can use a plugin named *QuickMapServices*. It can be enabled from plugins menu and then it will be added and available in *Web* menu. For having access to a wider range of maps one should open the settings of the plugin and then on *More services* tab, click on *Get contributed pack*. Then any map can be simply added by clicking on it in the list of the maps.

In case the user wishes to have all the layers on their computer, the user can extract the extent needed from these maps. It can be done by using *Export* option of the map layer and by clicking on *Save as*. In *Save Raster Layer* window, *Create VRT* must be disabled, one should then choose a file name and directory, select the extent (it is possible to select a layer extent using *Calculate from layer* option). Finally, the desired resolution should be specified. One should note that high resolutions require high amount of computer power (especially RAM) to handle downloading and creating the map (lower values make higher qualities).

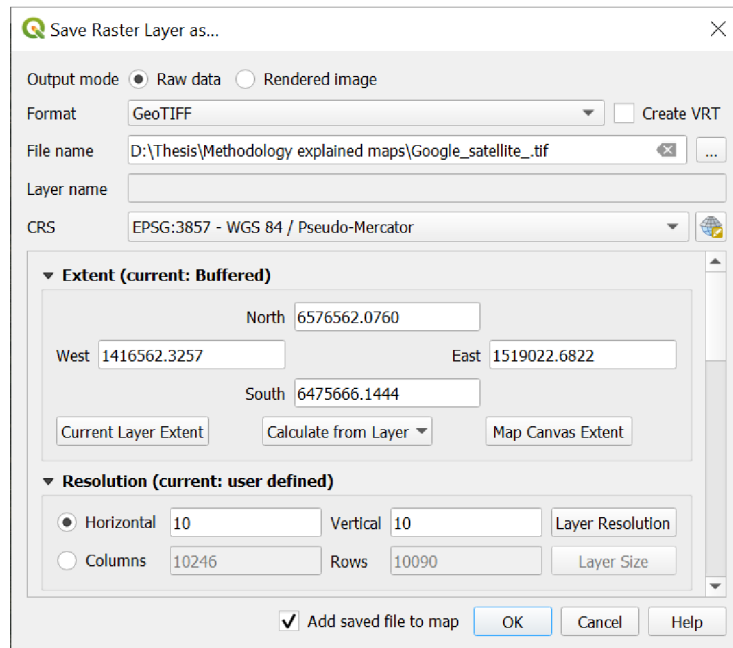


Fig. 33: Extracting maps from Server Services maps

Using such maps makes it very easy to find the best places especially in terms of choosing a site that is far enough from settlements and close enough to roads. There are some other factors such as slope which can be investigated using the DEM. In case of using DSM data the slope will have errors around vegetated areas. Slope analysis is very straight forward in QGIS using *Slope* tool from *Raster terrain analysis*.

The next step is to design the plan of the wind farm and positioning of the turbines. The distance between turbines in two directions should be considered carefully. It can be done in QGIS by making a new shapefile layer and choosing points for *Geometry Type*.

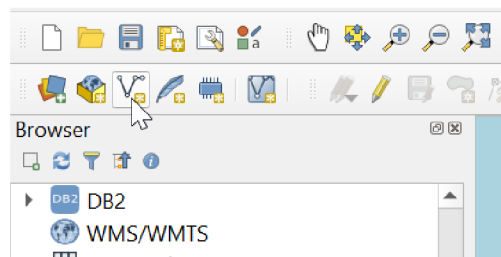


Fig. 34: Creating new shapefiles

For better use of space the user can do the planning in a CAD software such as QCAD, LibreCAD or Archimedes (all are free and open source). User can draw a line around the selected area for the wind farm and export it as a DXF file which can be opened in CAD software.

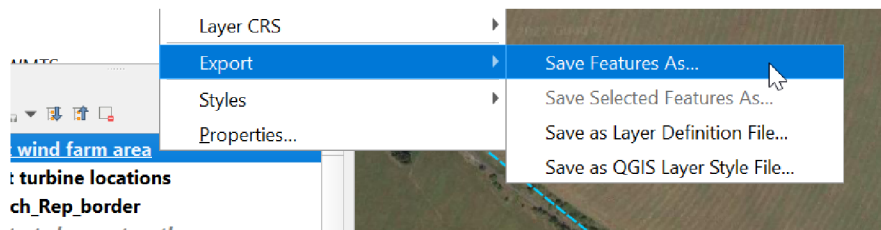


Fig. 35: Exporting a shapefile to other file formats

A pattern of best distance between turbines can be drawn in the CAD software and used in positioning the turbines to have the best spatial distribution. Here is an example made in LibreCAD (Fig. 36).

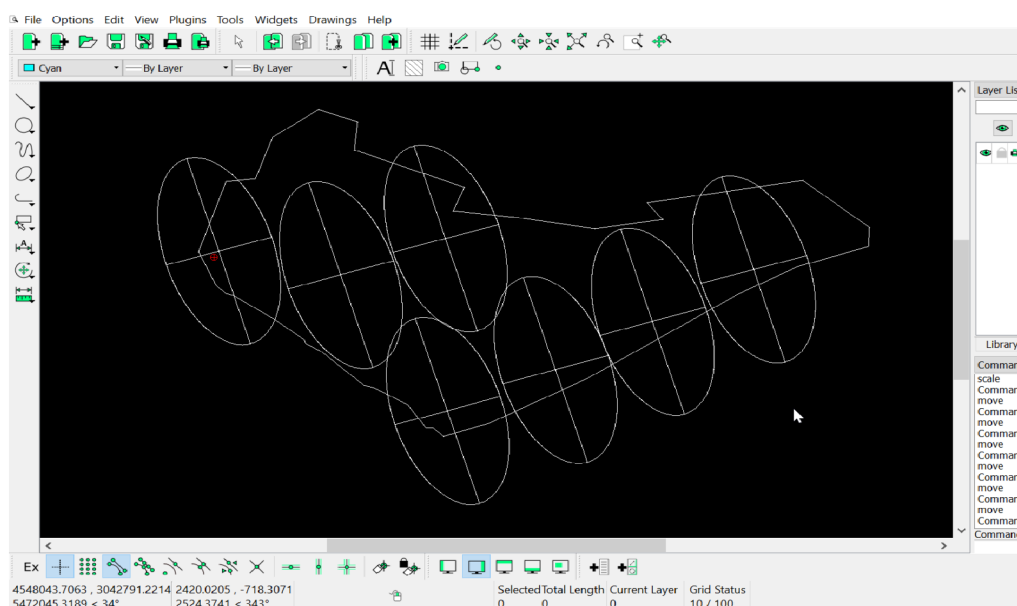


Fig. 36: Designing the wind farm in LibreCAD

The DXF file can be opened in QGIS as a layer. It needs to be saved (exported) as a shapefile and then it can be edited and moved to the exact place. A new shapefile layer should be made for the points where the turbines are proposed to be installed.

Visibility Analysis

After positioning the proposed turbines it is the time to do visibility analysis. In QGIS the tools for visibility analysis are not active by default and the user needs to install a plugin named *Visibility Analysis*. It can be simply done through Plugins menu and *Manage and Install Plugins* which opens Plugins window. In the search bar, user can search *visibility* to find the plugin and install it. Visibility Analysis tools will be added in the toolbox (Fig. 37).

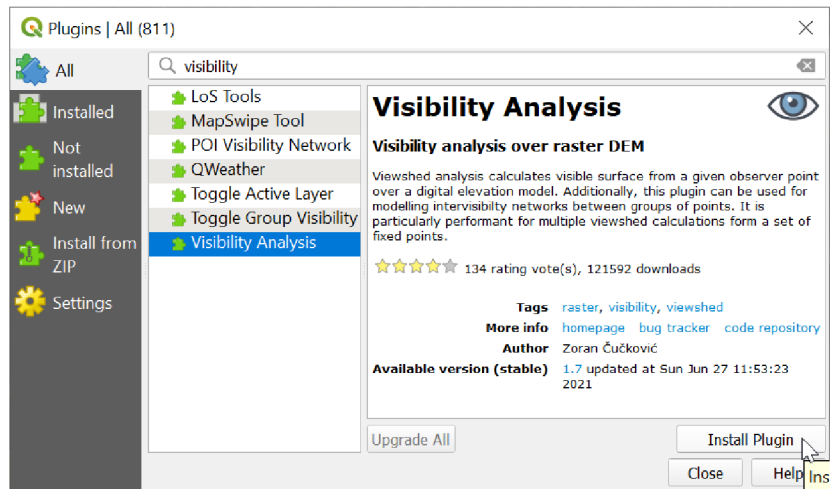


Fig. 37: Installing Visibility Analysis plugin

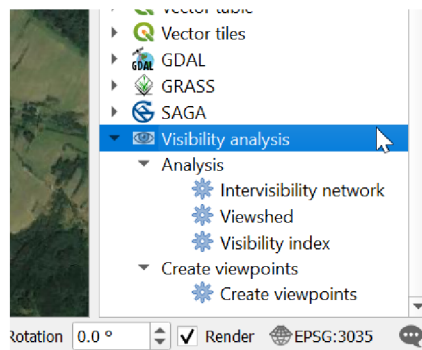


Fig. 38: Visibility analysis in the toolbar

First, *Create viewpoints* tool should be used to add required information to turbines points map and to make it ready for the process.

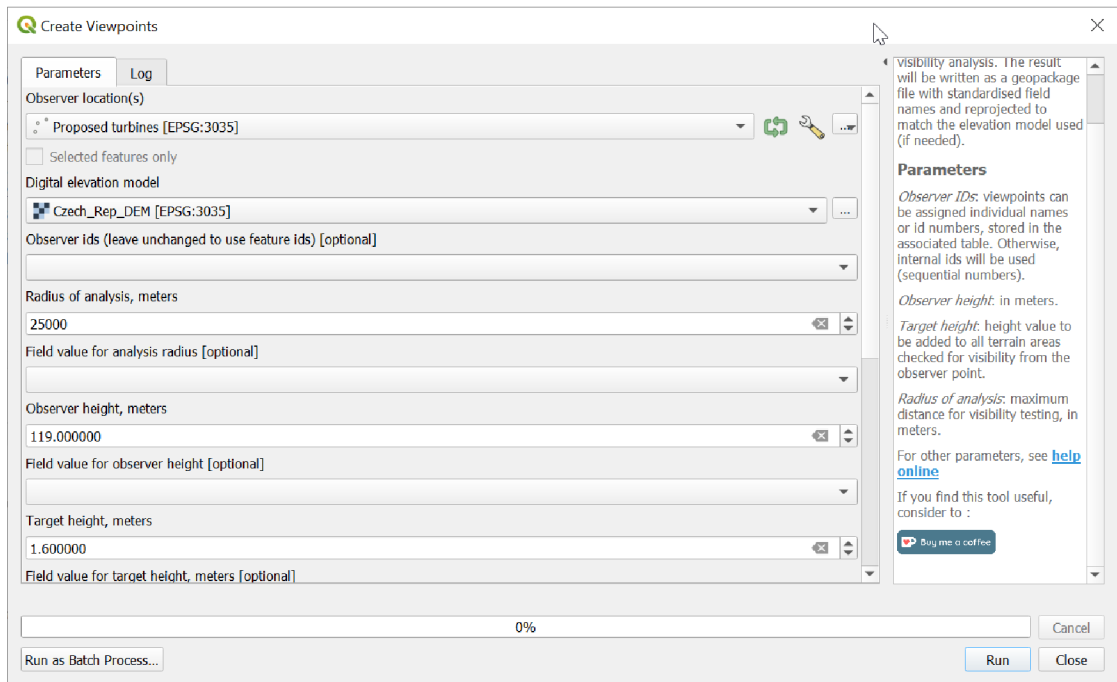


Fig. 39: Creating viewpoints

For *Observer location(s)* the user must select the points shapefile of the turbines locations. In *Radius of analysis* the distance to which the visibility is examined must be entered. In this research, analysis is done within 25km radius. *Observer height* is the height of the wind turbines and *Target height* is the average height of a person's eye level. Next, the user should run *Viewshed* from *Visibility analysis* tools.

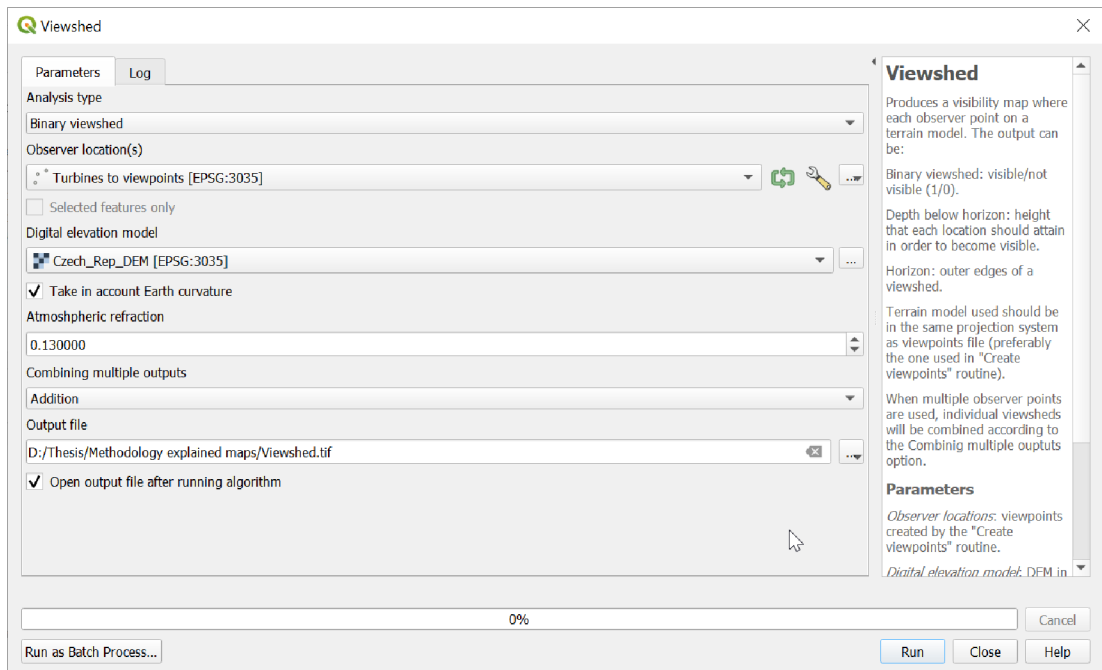


Fig. 40: Running viewshed

It is better to clip the raster (DEM or DSM) into a smaller area especially for the two additional steps that are found helpful in this research in order to reduce the error of viewshed which is high generally. After using visibility analysis and examining it in reality, two main issues were detected which cause higher rates of negative error (when the analysis shows degrees of visibility but in reality there is no visibility or lower degrees). Number one is caused by vegetation (forests, more precisely) especially while working with a DEM. The average canopy height should be added to a DEM as it shows ground surface elevation.

It is a good practice to use the analysis radius to clip the forest layer and edit it to have the best result.

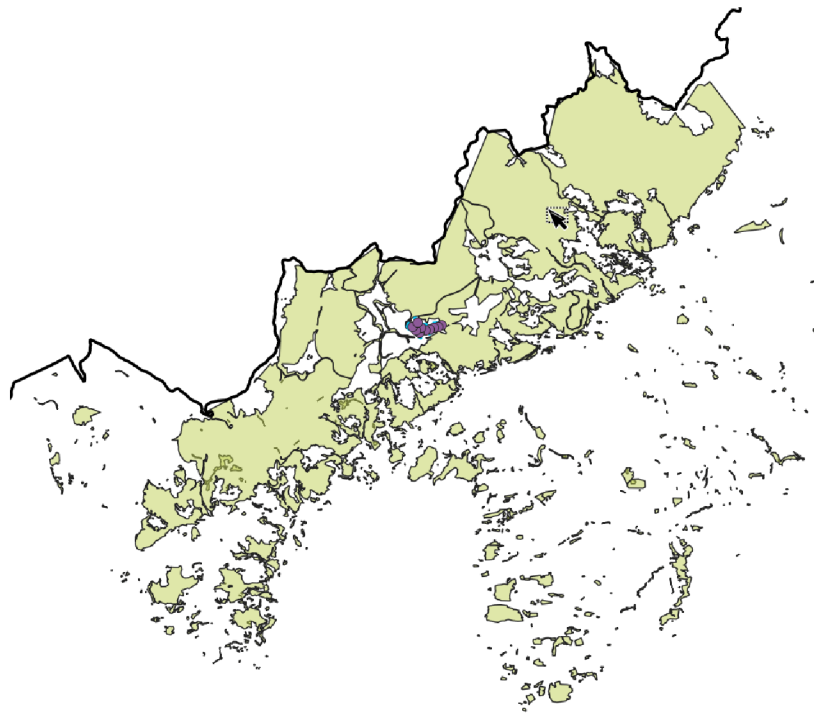


Fig. 41: Making the forest map ready for being added to the raster

Two small villages which were in the forest layer were cut out to make the analysis more precise.

As there is no way to add a shapefile to a raster there is the need to convert the shapefile to a raster first. The raster tile size is important when defining the tile size of the converted raster of the shapefile. Before creating the raster, the average height value is to be added to the shapefile. Different values according to the type of the trees can be added through the attribute table or one value can be given to all simply by adding a new field and using field calculator to enter the value in the new field for all geometries.

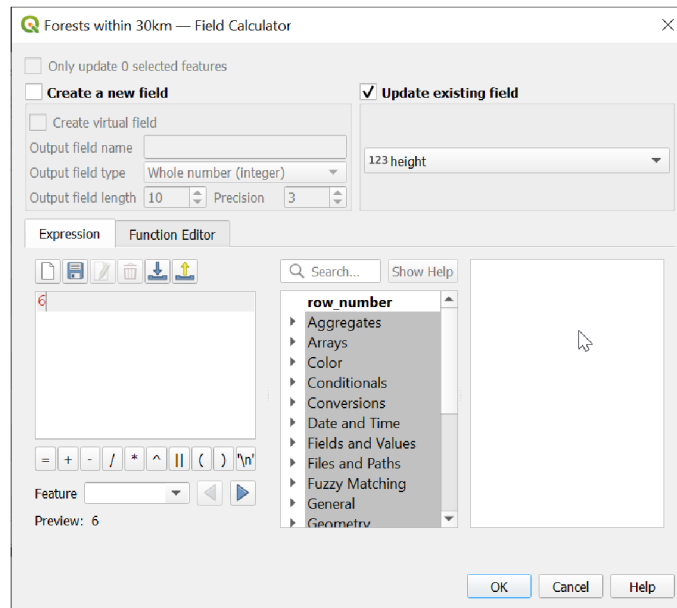


Fig. 42: Giving the average canopy height to the forest layer by using *Field Calculator*

For creating the raster, *Rasterize (vector to raster)* tool from *GDAL/ Vector conversion* can be used (Fig. 43).

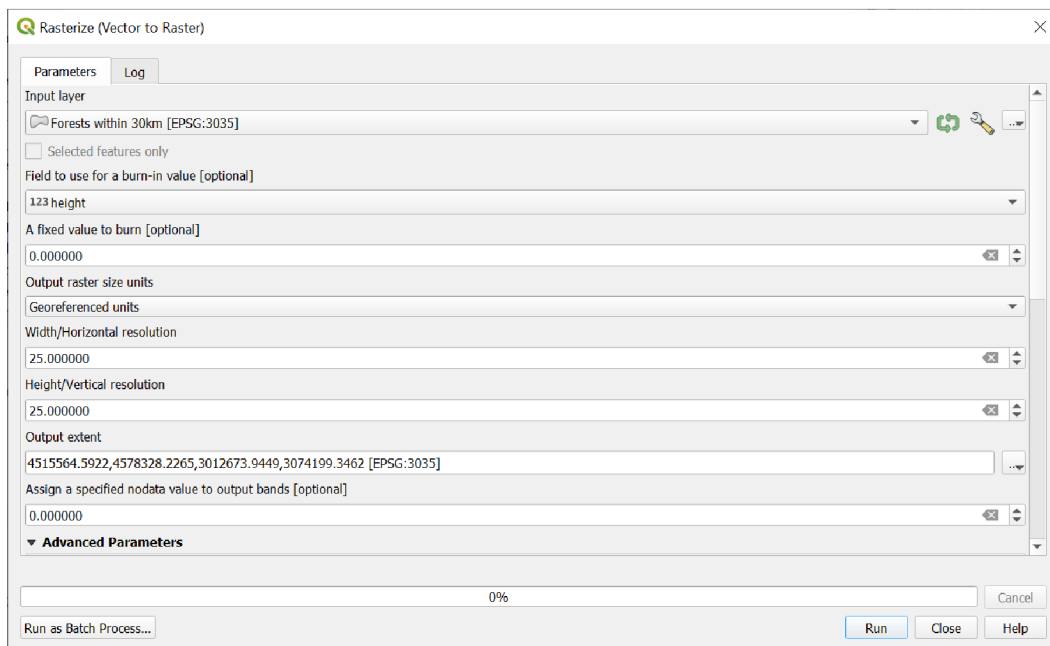


Fig. 43: Creating a raster out of the forest layer shapefile (vector)

The height value can be added by selecting the height field for *Field to use for a burn-in value*. In case there are not different height values, the preferred value for height can be also entered here in *A fixed value to burn*. The tile size can be defined by choosing the right unit (Georeferenced Unit) and entering the width and height values of the preferred tile size.

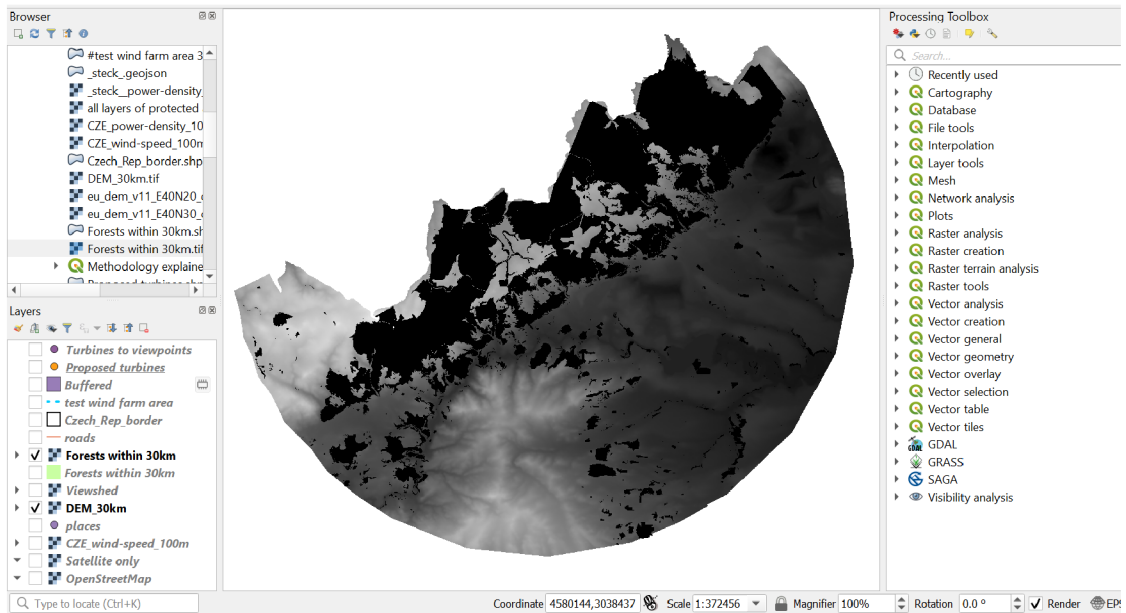


Fig. 44: The raster of the forest layer

Next, the sum of the pixel values of the two rasters should be calculated. It can be done by using *Raster Calculator* from Raster menu. Before doing so, there is a small but important change that should be done to the forest raster as its no-data parts will cause a problem while summing up. User should open the *Properties* of the forest raster and in *Transparency* tab, uncheck *No data value*.

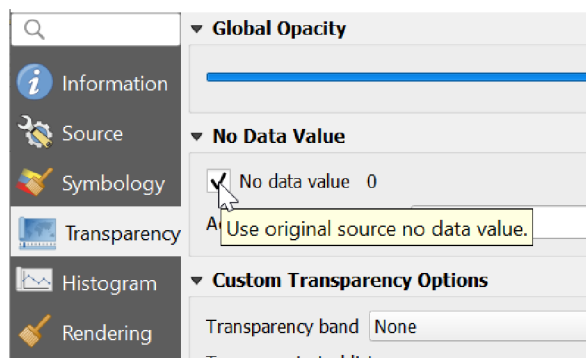


Fig. 45: Disabling *No data value 0*

The next step is to open *Raster calculator* from Raster menu and sum up the two rasters. It can be easily done by double clicking on the DEM (or DSM) raster in the list, adding + sign and then double clicking on the forest raster (Fig. 46).

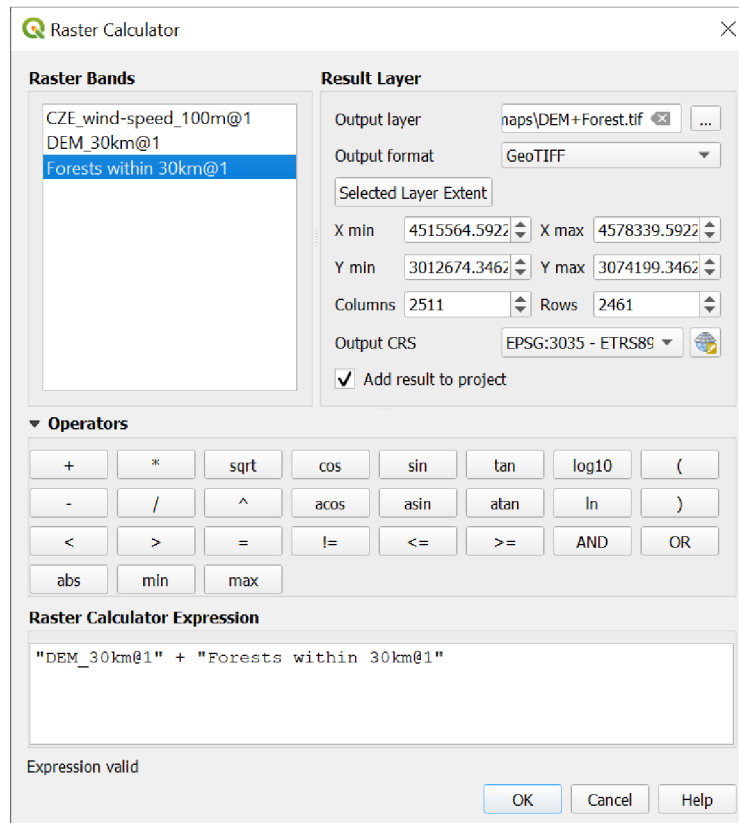


Fig. 46: Summing up the rasters

Next, another viewshed using the new raster should be made. The two viewsheds may look the same but one can see the difference in the edges of the forests.

Another viewshed is needed for the extra step for reducing the error. This time the only thing needed is to change *observer height* value to the hub height of the turbines. The reason is that the blades are less visible when the hub is not visible especially in higher distances. It is based on the results of the real experience of real visibility from the viewpoints in this case study.

An average of all viewsheds is to be made next. *Raster calculator* can be used again to make an average of all three rasters.

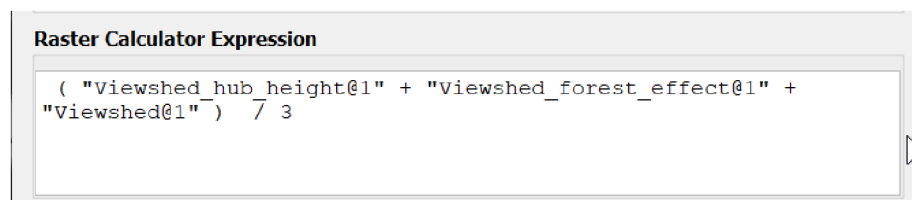


Fig. 47: Using *Raster Calculator* to make an average of the rasters

According to the result, the places for viewpoints can be chosen and the points shapefile can be made. User should note that putting forest layer can help in choosing the best places as the turbines cannot be seen from within forest areas, obviously.

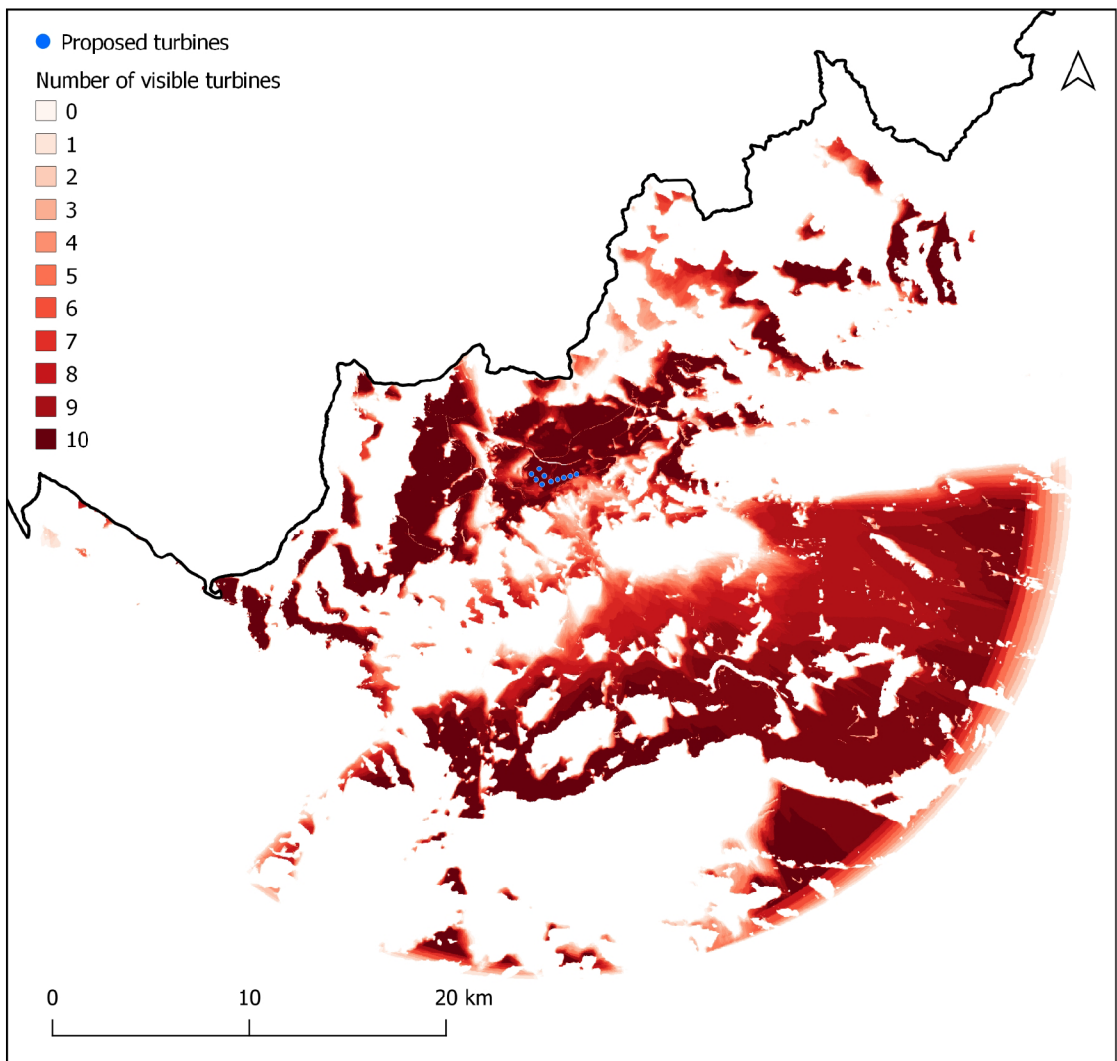


Fig. 48: The average of all visibility analyses

After adding the points, having their coordinates in a format that can be read by GPS devices is needed. In this study – to show how easy and low cost this method is – Google maps on a phone is used as a GPS device. The coordinates of the points are extracted and saved in Google maps. While being logged in to Google account, the user should open Menu/ Your places, and then make a new list. Now every time that the coordinates of a viewpoint are entered into Google maps, the point can be saved in the list and be given a label and a note. In this way, the points can be simply reached using a phone. As Google maps uses degrees in the format of latitude, longitude (north, east), viewpoints coordinates must be extracted in decimal degrees and put in the order of y,x (as y represents latitude and x represent longitude). For the extraction, the user must first reproject the viewpoints layer to WGS 84 (EPSG:4326) as it uses degrees. Next, reproject tool can be used, it is can be reached from the toolbox under *Vector general* tool set or from Vector menu. The user should open the attribute table of the reprojected layer. Then, fields for latitude (y) and longitude (x) should be added. *Decimal Number* for *Type* should be selected.

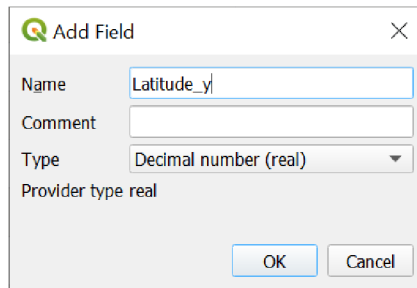


Fig. 49: Adding the new fields for extracting the coordinates of points

Field calculator should be used at this step. The user must enable *Update existing field* and select the field that they made. The following must be entered in expression field; \$y for latitude and \$x for longitude. After adding the values to the field, the user should open *Field calculator* again and does the same for the other field.

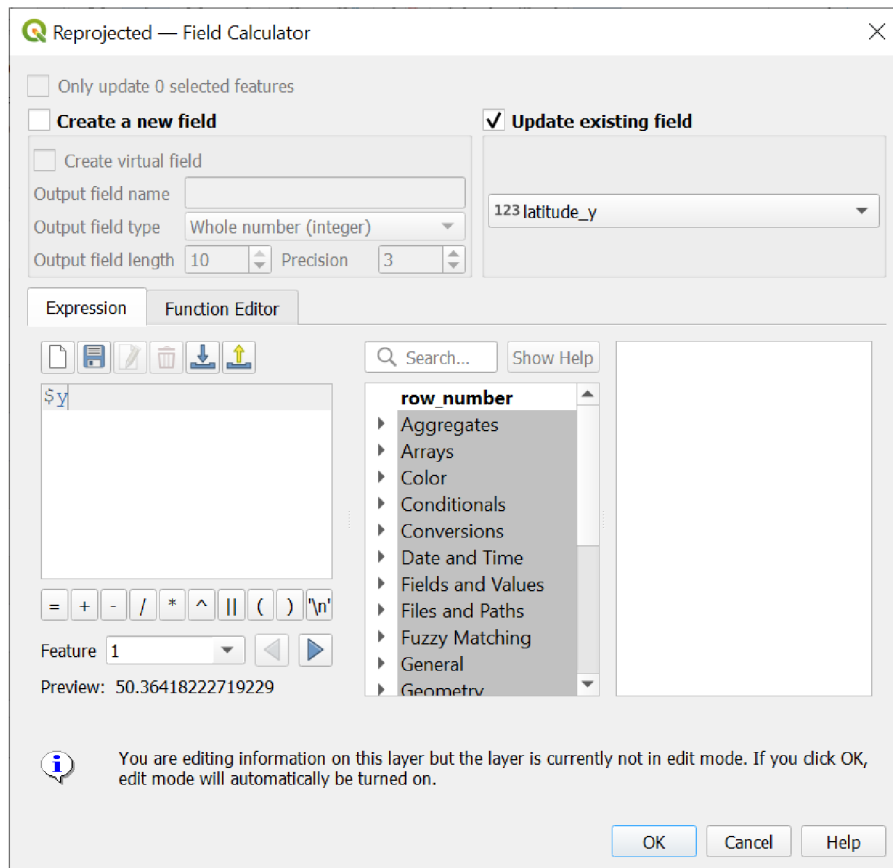


Fig. 50: Extracting the coordinates of points

The layer should be exported to a CSV file and opened in a spreadsheet software. The one used in this research is LibreOffice which is a free and open source office suit and can be downloaded from <https://www.libreoffice.org/>

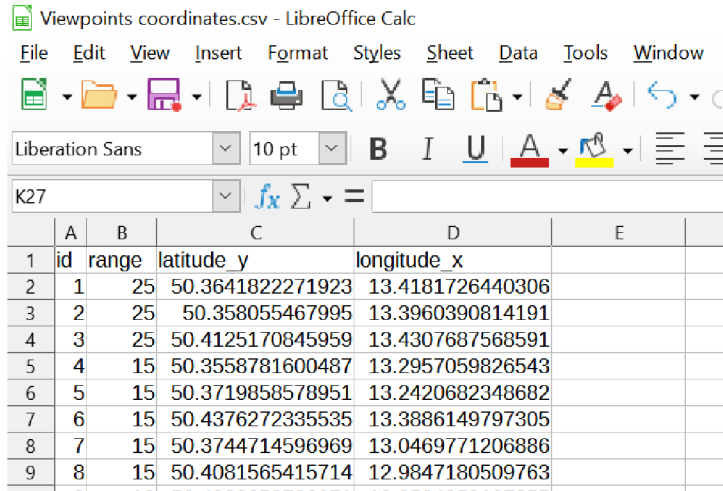


Fig. 51: Opening the coordinates in *LibreOffice Calc*

The last step is to make the project ready for importing into the 3D software, Blender. A contour map of the DSM (or a modified DEM) raster is needed, together with the shapefiles of the points of the locations of the wind turbines and the points of the defined viewpoints. Shapefiles must have the height of the points in their attributes.

Contour tool can be found from either *Raster menu/ Extraction*, or *Toolbox/ GDAL/ Raster extraction*.

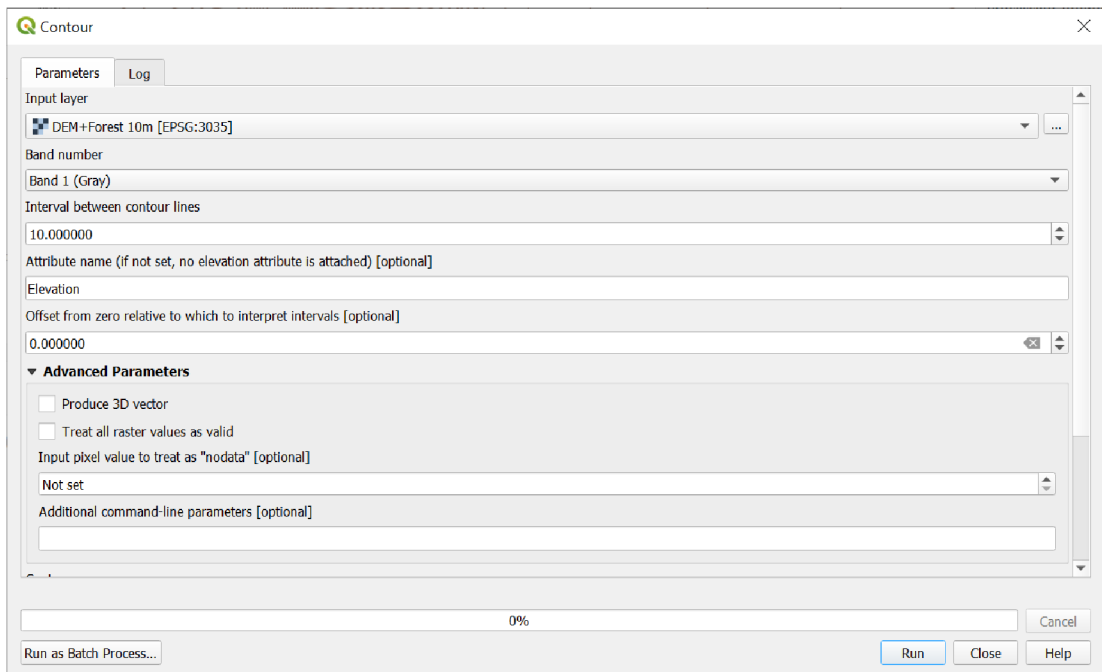


Fig. 52: Contour tool window

Interval between contour lines must be given a value which suits the project the best. The lower values result in more precise and more smooth 3D models, however, the precision of the 3D model depends firstly on the precision of the raster. Therefore, there

is no fix number. Trying some numbers and examining can help to find out what value is the best for the data. Lower values are better not to be used as the contour lines will have too much information and it will require a powerful computer to handle working with it. Elevation of the contour lines will be put in a field which can be given the desired name while using this tool.

For adding the height to the points, *Sample raster* tool is used. It can be found in Toolbox under Raster analysis toolset. The user should select the DSM (or the modified DEM) for raster layer and a name for the field where the value from the raster will be entered for each point. It is named Elevation in this research.

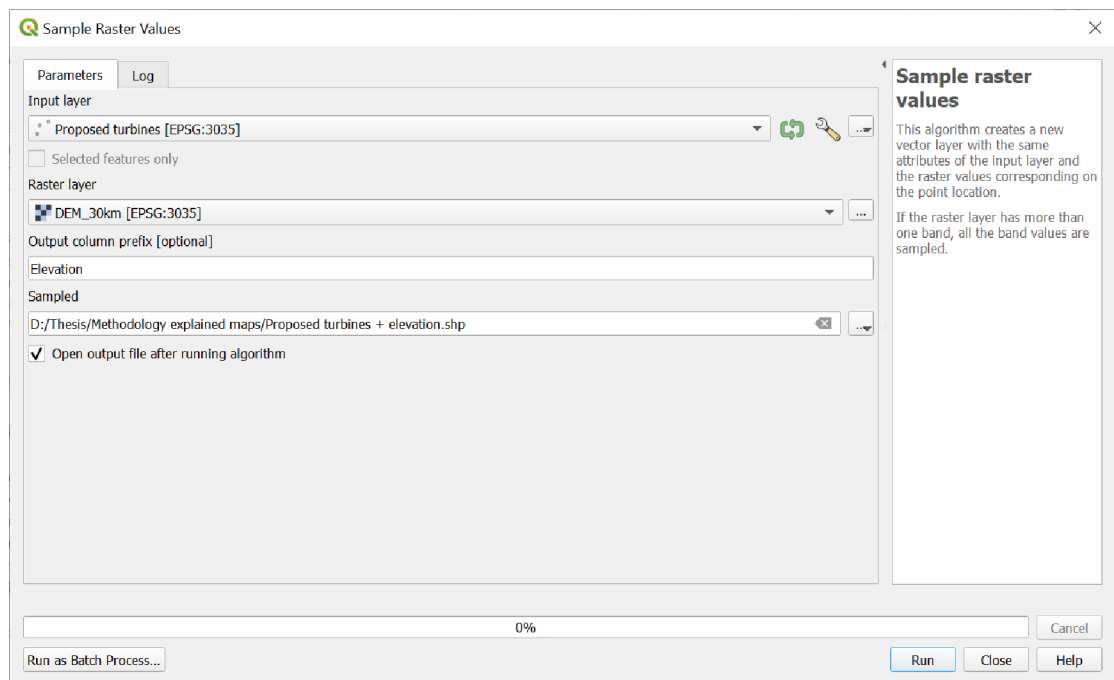


Fig. 53: Adding the height data to the points shapefile

It must be done for the other point layer too. These three files are imported into Blender. It is better to do an extra step which does not cause any error or problem if skipped, but it makes it easier to find the right direction for taking photos and match them with renders. As the north direction is not towards up direction in many CRSs, it is better to reproject the layers to a CRS in which north direction is upward, therefore, in Blender it is easier to distinguish the right direction where the camera should face. For such purpose *WGS84 Web Mercator Spherique* is suitable.

5.2 3D Modeling and Rendering

In this part – despite the GIS part – it is tried to explain not only the process but also working with the software (not a complete guide, but the tools and functions which are used), as most people never work with any 3D software.

Blender interface theme in the screenshots in this study is different from what the user sees when they open Blender for first time. The default is dark grey theme but a print friendly theme is used here so that the screenshots are more legible.

There are two ways of doing this step, one is by the help of an external Blender add-on which makes the process easier and the other one is only by Blender itself and though the default process of making a 3D model. As the add-on is also free and open source and it makes the process easier, this way is explained.

Blender can be downloaded from: <https://www.blender.org/>. After opening Blender, the starting window (splash screen) will be showed and from it the user can open new files for different uses (General, 2D Animation, Sculpting, etc.) and recently opened files. Clicking anywhere outside the splash screen makes it disappear. By default there are three objects in the scene, they may be deleted.

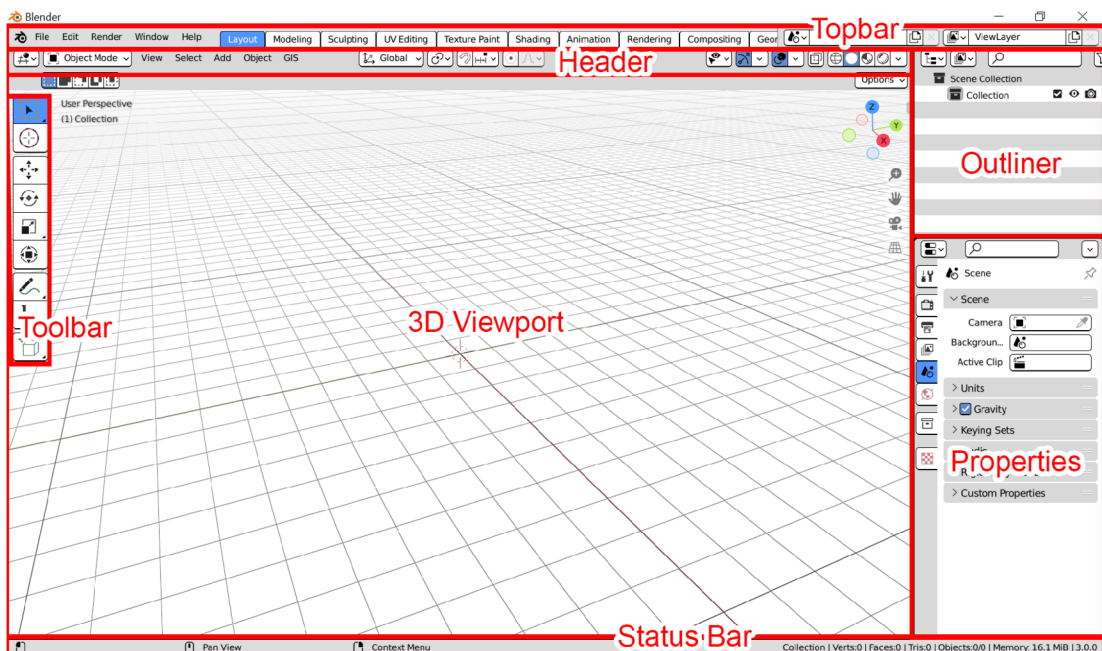


Fig. 54: Blender default layout explained

It is the general user interface. Although Blender is well designed in many aspects including user interface, it is still complected – like all 3D software – and some practice is needed at first.

Navigation

Rotation is by holding mouse middle button or by holding mouse left key on Gismo. Moving is by holding shift and middle mouse button or by holding mouse left key on the hand icon on the right side of 3D viewport. Zooming is by rotating middle mouse button or by holding mouse left key on the magnifying glass icon.

BlenderGIS

For importing the project files, a free and open source add-on named BlenderGIS can be used. It is not included in Blender yet (it may be added in the future). It can be downloaded from: <https://github.com/domlysz/BlenderGIS>
One should click on *Code* and then *Download ZIP*.

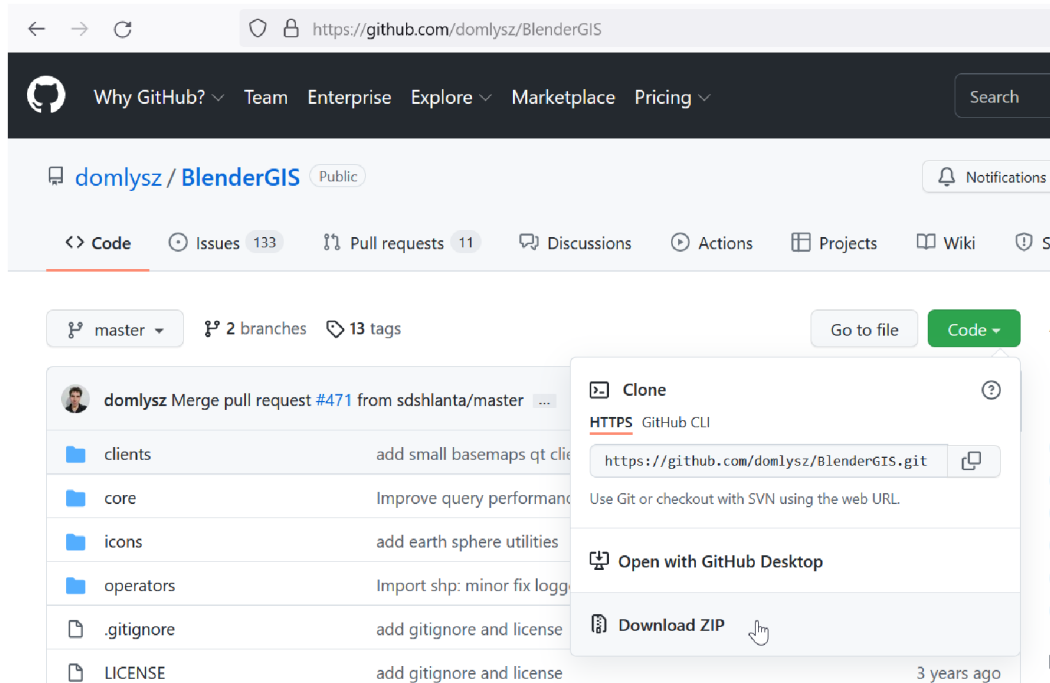


Fig. 55: Downloading BlenderGIS

In Blender, user must open *Edit* menu, *Preferences* and then in the preferences window go to *Add-ons* tab and click on *Install* button on the top of the window. User should find and select the *ZIP* file that was downloaded. *3D Views: BlenderGIS* will be added and showed in the list of add-ons. It must be enabled and then, from its properties, a directory for *Cache* folder should be selected.

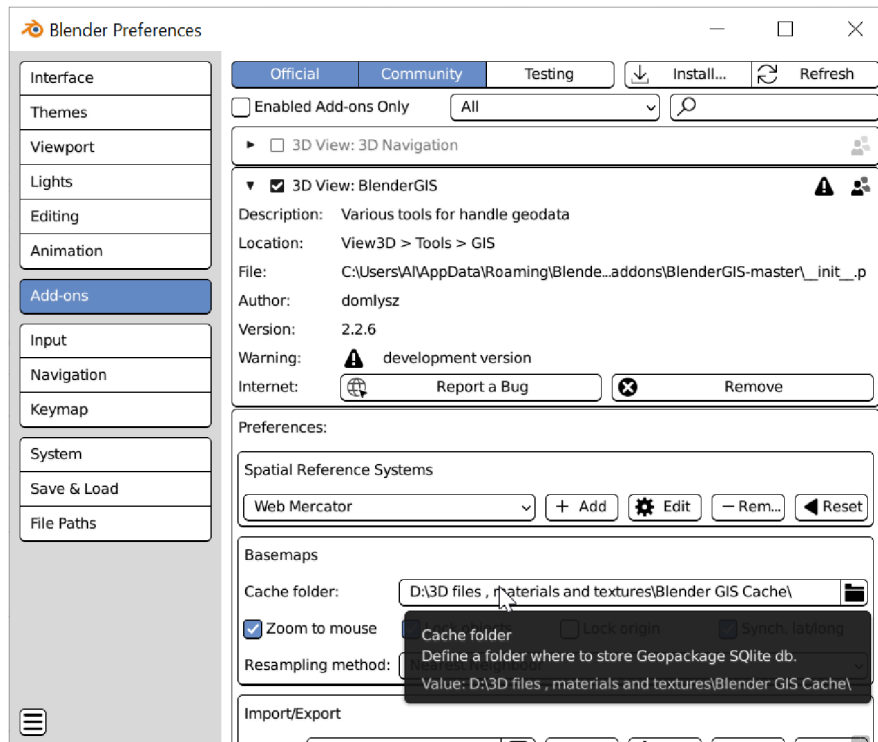


Fig. 56: Installing BlenderGIS

GIS menu will be added to the top of 3D viewport. User should go to *Import* and select *Shapefile (.shp)*.

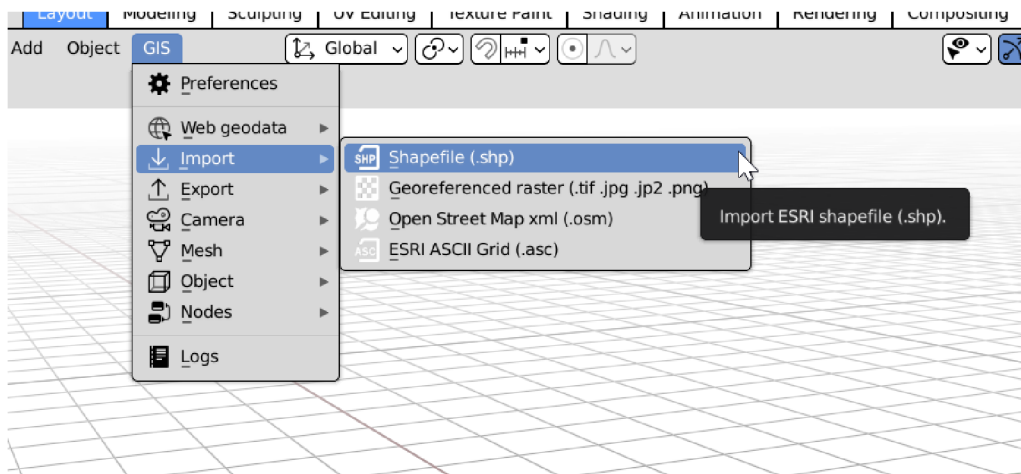


Fig. 57: Importing the shapefiles into Blender

User should select the contour line file of the project. *Import SHP* properties window will open. User must select *field* for *Elevation source* and for *Elev.field* select the field where elevation values are stored. For CRS, the CRS of the shapefile is selected. In this research – as already explained why – it is Web Mercator. The list contains only Web Mercator and WGS84. It is possible to add other CRSs to the list by pressing + icon and searching for a CRS.

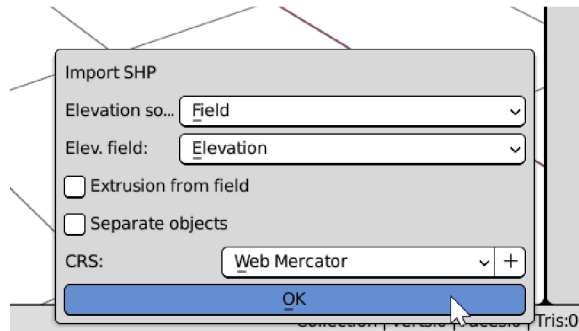


Fig. 58: Import Shapefile properties window

The 3D dimensional contour lines will be shown in 3D viewport (Fig. 59).

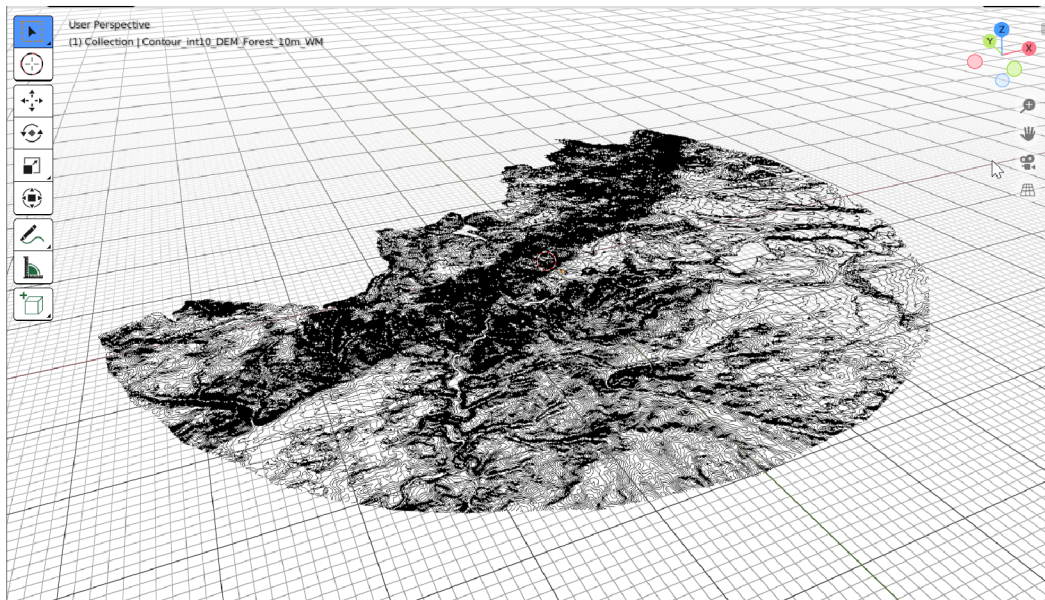


Fig. 59: Imported contour line shapefile in Blender

User should select the contour, open GIS menu and from *Mesh*, select *Delaunay*. It takes some time (depending on the computer. As this process uses RAM, it is better to close other software on the computer while doing this step) and the result will be a terrain model.

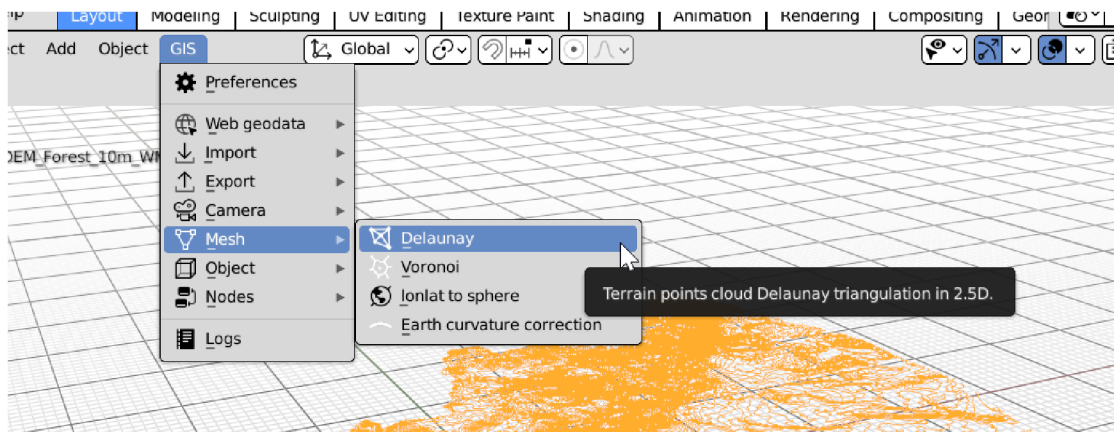


Fig. 60: Making a 3d terrain model out of a contour line map

The two points shapefiles (Proposed turbines and viewpoints) must be imported the same way and given the height. If all steps are followed correctly, the points will be placed in the right coordinates and on the surface of the terrain model (maybe not exactly, as the 3D terrain is not as accurate as the source DSM (or modified DEM) raster). *Import SHP* window will be a bit different but there is no need to change anything except selecting the elevation field (like what was done for the contour) if the CRS of the new file is the same as the first one (which is the CRS of the project now).

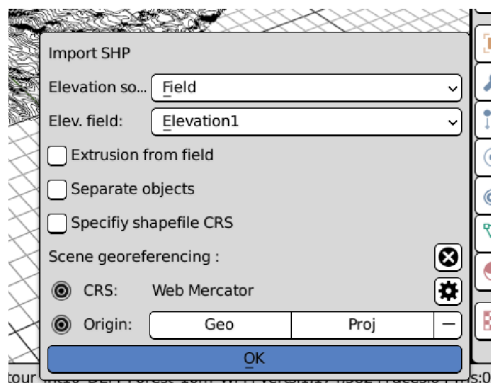


Fig. 61: *Import SHP* window for the new shapefiles

All objects are shown in Outliner panel by their names. User can select them by clicking on their names in the list and turn on/off the visibility for any of them by clicking on the eye icon in front of them.

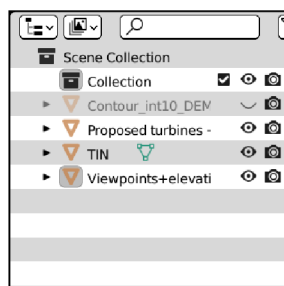


Fig. 62: Outliner

It is important to note that hiding objects in viewport does not mean that they will not be rendered. If the user does not want an object to be rendered (like the contour line) they must turn off the camera icon in front of the object name in *Outliner*.

The next step is to import a 3D wind turbine model into Blender and copy it on the proposed locations points. Different free 3D models are available in different websites. Mostly, the 3D models of some widely installed models of turbines. One also can make a model according to the turbine model specifications and parameters (the manufacturers provide detailed information about their turbines).

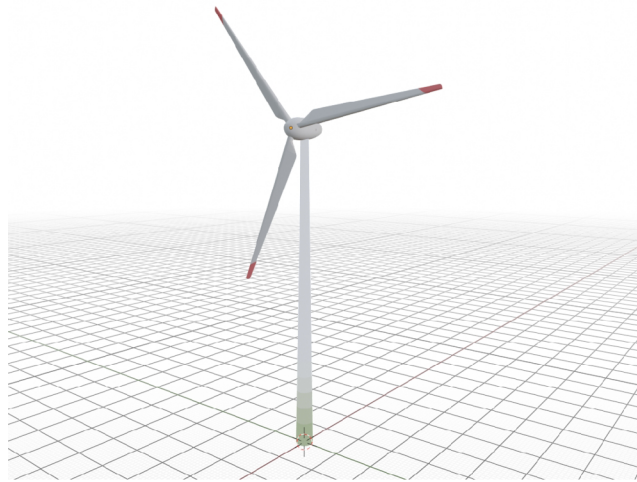


Fig. 63: The 3D wind turbine model used in this study

The 3D model that is used in this study lacks detail as it looks a bit flat, but it is adequate for the purpose. For easier copying and placement of the models on the points, one must set the object origin (a point which is defined for each 3D object and represents the location of the object in 3D space, so while rotating the object, it rotates around that point) on its lowest part of the structure. User must press tab to go to *Edit Mode*, select all parts of the turbine by pressing A. Next, the model must be moved in the way that the origin point (shown in orange, in the default theme) is placed at the lowest part of the structure. By pressing tab again, user can go out of *Edit Mode*. It is a good idea to have the turbine model in two parts, structure and hub in one part, blades in another. Thus, it is possible to rotate the blades of some turbines later to make the renders more realistic. For making sure that blades move with the structure, user must select the blades and then the structure while holding shift. User must then use mouse right click and select *Object* from *Parent* menu. In this way the blades move together with the structure and there is no need to select both for moving them, however, user still needs to select both for copying.

If desired, one may hide the terrain (TIN) and viewpoints layers to make it easier to copy the turbine model on the points for proposed turbines. For importing the 3D model, the user can drag and drop it into the Blender and from the menu which appears, select *Append*. The file viewer will open and shows the contents of the 3D model file. User must open *Collection* and select the collection which contains the model parts in case the

user put them in one specific collection, if not, the user can find the model (or model parts) in *Object* category. *Append* can be also found in *File* menu. For easy and precise positioning, one can enable snap and change *Snap To* to *Vertex*, and *Snap With* to *Center*.

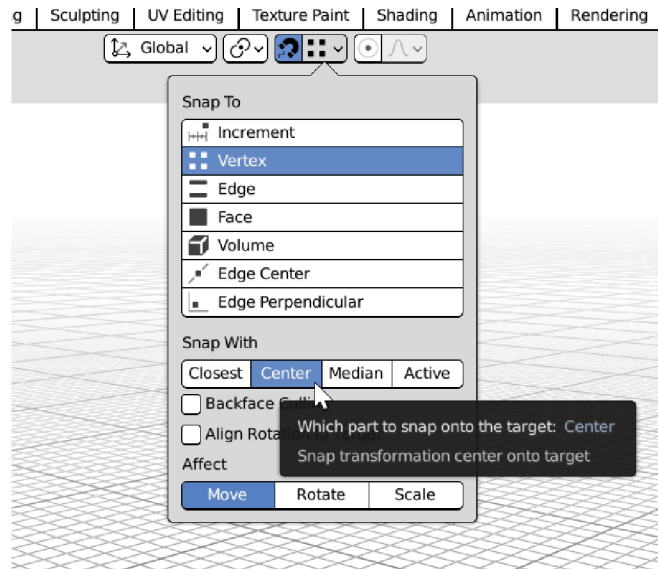


Fig. 64: Snapping

One should select the model and press G (stands for grab) to move it to the first point. Then is pressing alt+D to copy and place the copy on another point. The shortcut for copying is shift+D but alt+D is used to make copies which are linked together and it helps later on if the user wants to change anything so they can apply the change on one model and all models will be changed the same way.

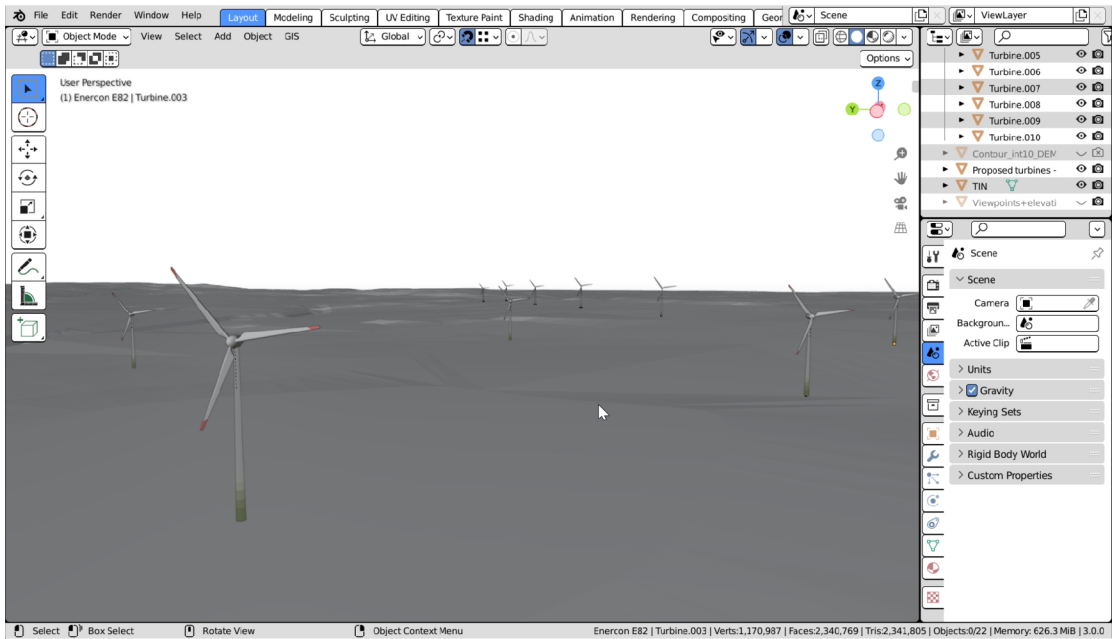


Fig. 65: Turbine models placed on their points on the terrain model

Next, the cameras are added. User must click on *Add* menu to add the first camera. The default camera – if not deleted – can be used as the first one too.

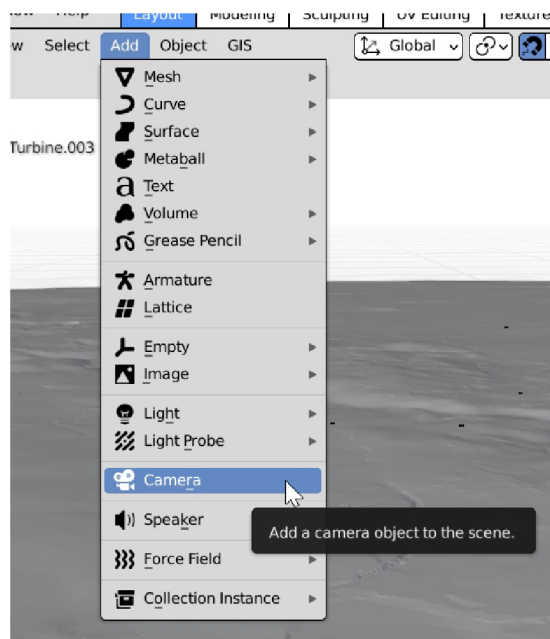


Fig. 66: Adding a camera

The first camera must be placed on one of the points. If user cannot see the camera after zooming, it is because of the viewport settings and how they change after adding a large-scale map using BlenderGIS. By pressing N, a panel opens on the right side of the 3D

viewport area. From *View* tab and by reducing *Clip Start* to a low value, the problem is solved.

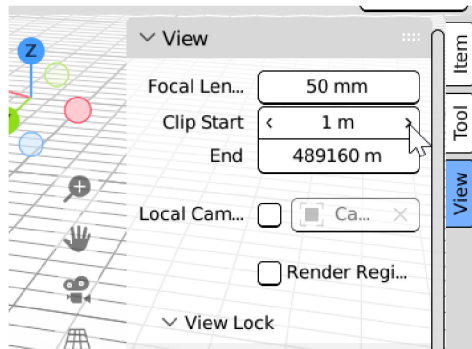


Fig. 67: View setting

The camera will look like this;

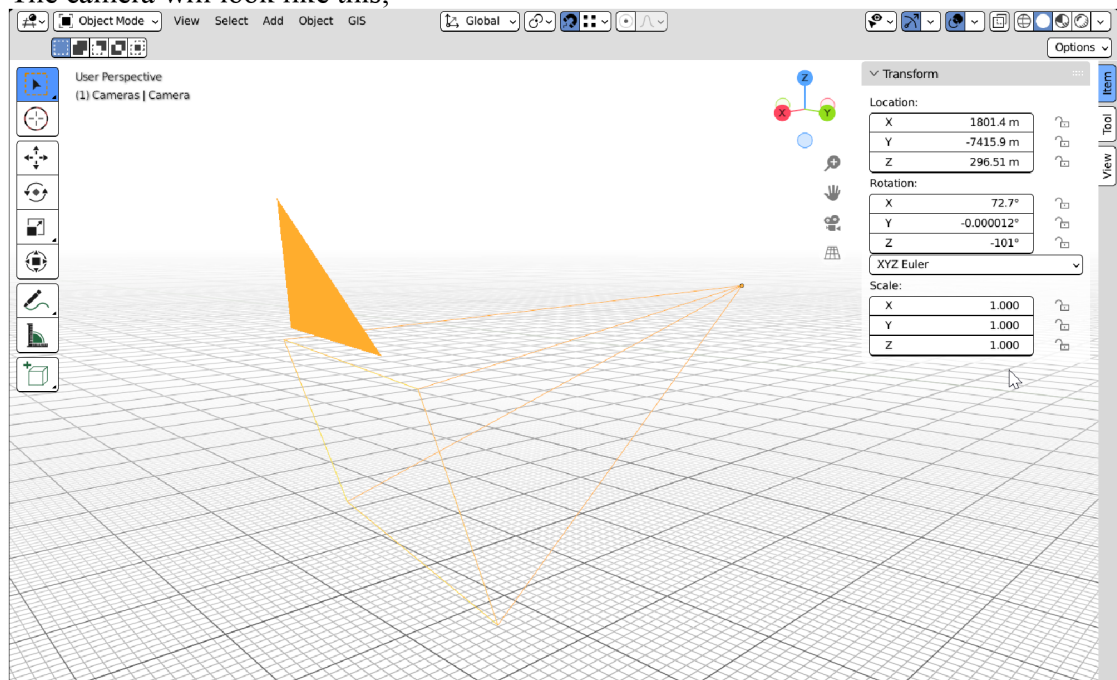


Fig. 68: a camera in Blender

From the same panel which can be accessed by pressing N, user can see location, rotation and scale of the objects. It is better to set the rotation in the way that the camera is facing north (Fig. 69).

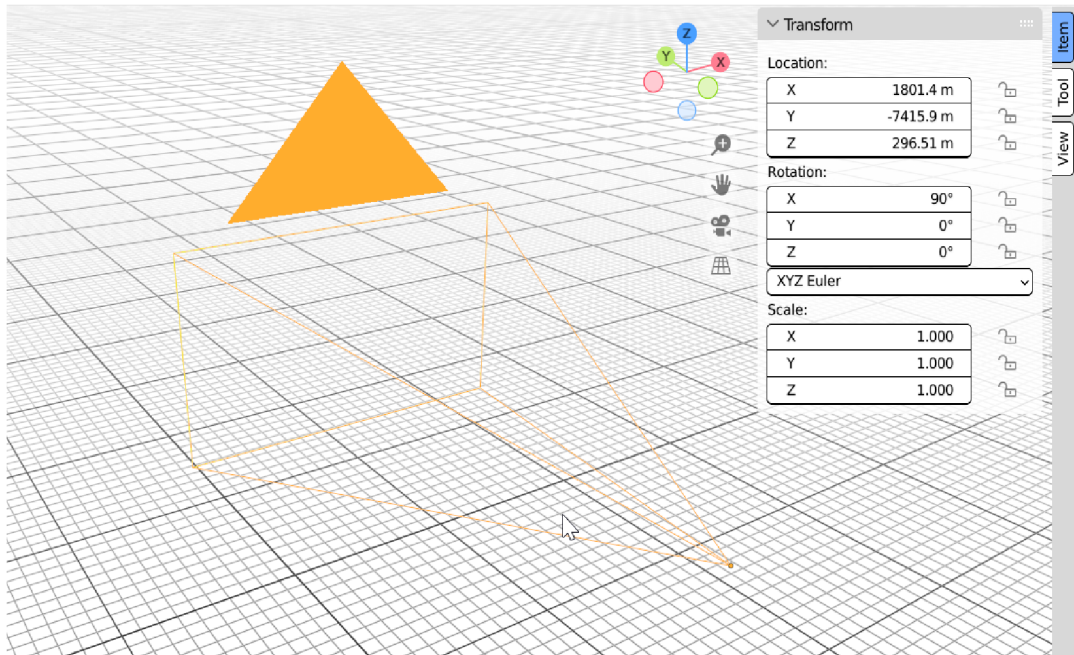


Fig. 69: Setting a camera to face north

User must copy the cameras on the viewpoints the same as what was done for turbines. Then select all cameras and move them up to put them on the average eye height (1.6m in this study) by selecting all the cameras and pressing G and then Z to restrict the move to Z axis, then the desired value should be typed and then *enter* key should be pressed to complete the move function.

User can press the camera icon on the right side of 3D viewport to go to active camera (the camera which the render will be from it) view. One can change the active camera by clicking on the camera icon in front of each camera in *Outliner* list.

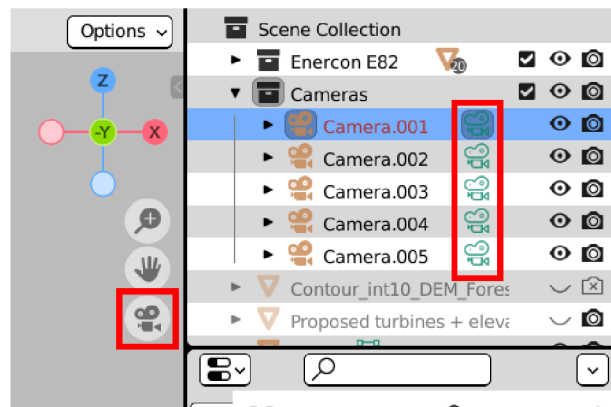


Fig. 70: Changing the active camera

In this example (Fig. 70) the camera number 001 is the active one and user can know it from the camera icon being turned on.

Now user should set the cameras settings to make them work as the camera which is going to be used for taking photos. User can access the setting by selecting a camera and reaching the camera tab in Properties. User only needs to change *Focal length* and *Clip Start/End*. For the lens, it is generally accepted – and suggested in the methods which include taking photos – that 50mm lens is the closest to what human eye see, however, anything between 35-50mm is very close to human eye and the author realized during this study that especially for landscape photography, 35mm lens is more close to how one sees a landscape as human eye covers higher range than what a 50mm lens covers and when one is not focused on a feature but generally watching a wide view (landscapes) 35mm works better and gives us a closer photo to how we perceive a landscape.

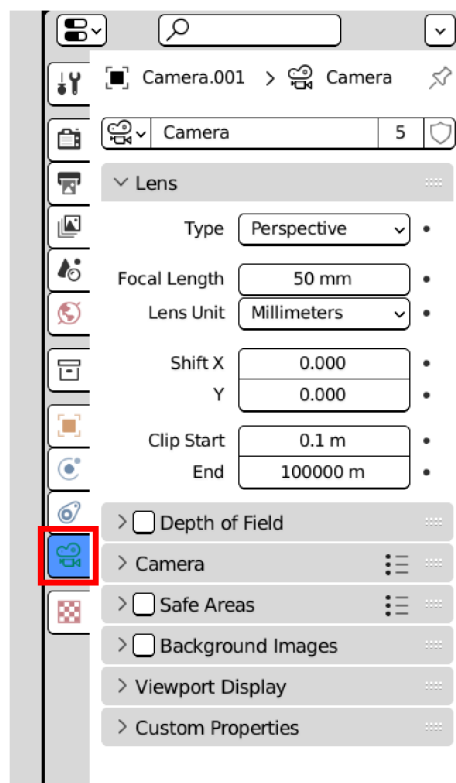


Fig. 71: Camera settings

In case the user is going to use their phone camera, its focal length has to be entered for focal length of virtual camera. For the *Clip Start* a low value must be entered and for *End* vice versa so the camera captures a wide range in terms of distance. The height and width of the camera view (and so the render) is defined from *Output Properties* tab in Properties panel. The resolution of the physical camera must be entered in this part (Fig. 72).

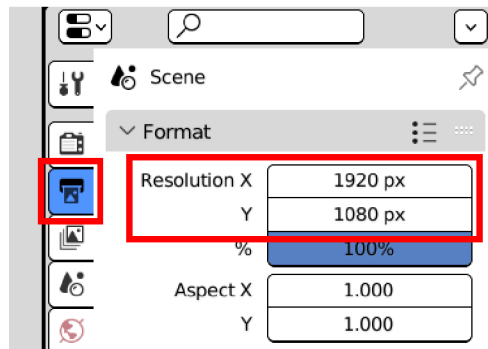


Fig. 72: Setting the resolution of the renders

User can have the side panel always on, so they always know to which direction the camera is facing (Fig. 73).

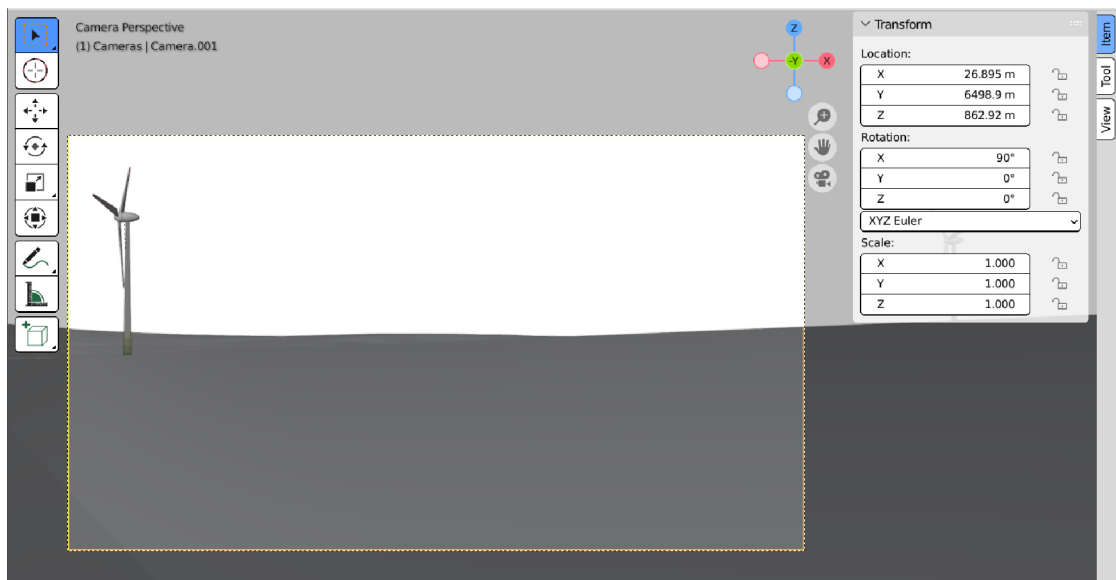


Fig. 73: Setting the virtual cameras to the best directions

If the camera is set correctly, Z parameter is the one which defines the direction. 0° is north direction, 90° is west, 180° south and 270° (or -90°) is east. For rotating the camera freely, user can press R and then Z so the camera will rotate around Z axis.

User also can make a graphical compass and put it in front of the virtual cameras for more ease while taking photos. It is simply a linear image put on a cylinder around the camera.

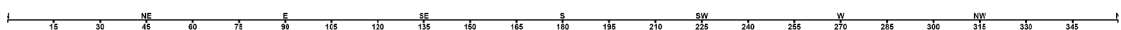


Fig. 74: Graphical compass

After setting the cameras and fixing the directions, it is the time for the last step of 3D part; rendering. For having good renders of the turbines which look relatively real when added to the real photos, user needs to set lighting and to do a bit of making materials.

Lighting

User should add a sun from *Add/ Light* menu. The default spot light can also be used but a sun light matches the real settings far better. The sun object in the scene is mostly for demonstrating the direction of light and it does not matter where the sun is.

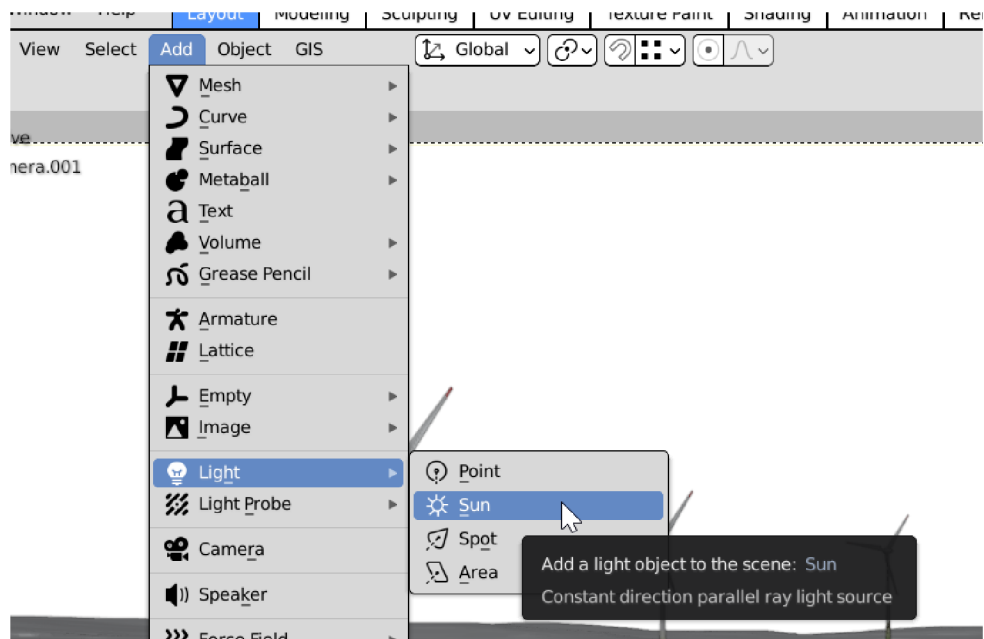


Fig. 75: Adding a sun

User can change the rotation to match the direction of sunlight to geographic setting of the site (Fig. 75).

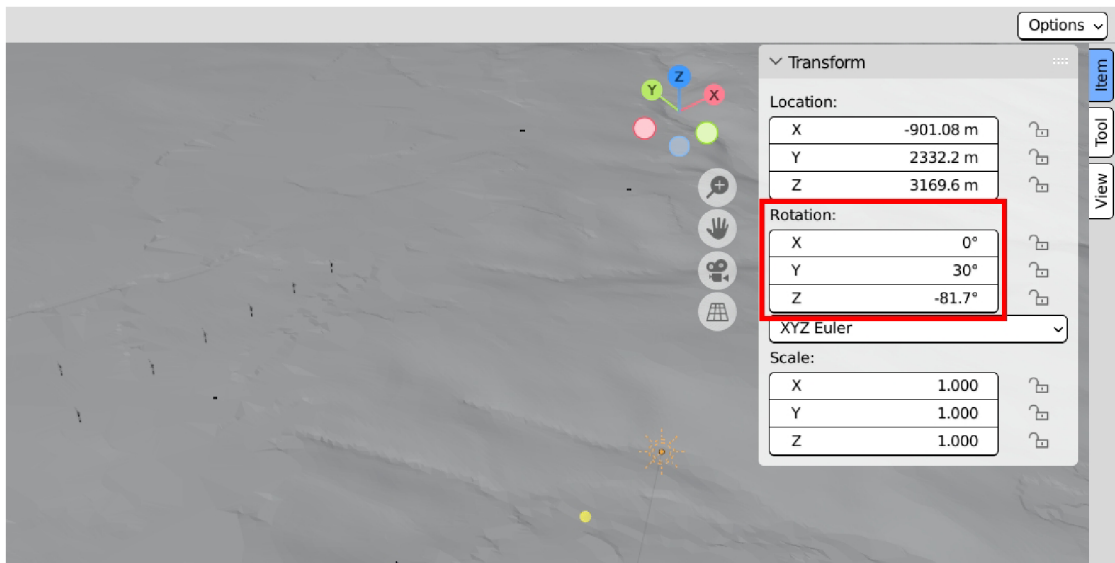


Fig. 76: Setting the direction of sunlight

Now it is possible to see how the turbines will look in renders by going to *Rendered* from *Viewport Shading* options from top right of the 3D viewport (Fig. 77).

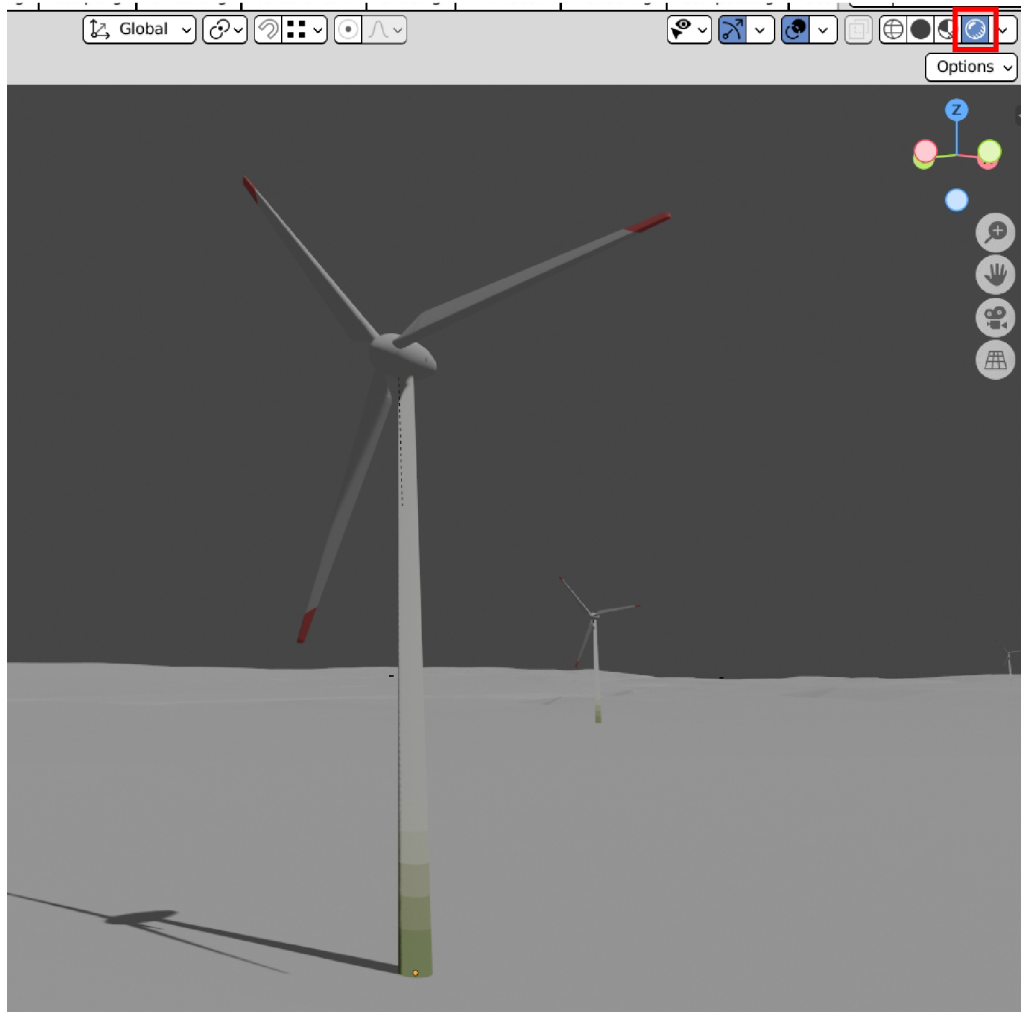


Fig. 77: Rendered view

It does not look good at first but by the help of Eevee (Blender real time render engine) relatively good renders can be achieved in very short times and without the need for a powerful computer.

For giving desired colours to the different parts, user should select them first and then go to *Material Properties* in *Properties panel*. User can add a material and choose the desired colour for *Base Color*. User must press *Assign* if the colour of the object does not change after choosing a colour for *Base Color*.

User should go to *Render Properties* tab in *Properties panel*, put *Viewport value* on 8 to see the changes in viewport faster (or if the computer is not powerful enough). Enabling *Ambient Occlusion* can add to realism. In *Shadows* section user can select 1024 px for *Cube Size*. In *Film* section, enabling *Transparent*, removes the background and makes it easy to add rendered turbines to the photos (Fig. 78).

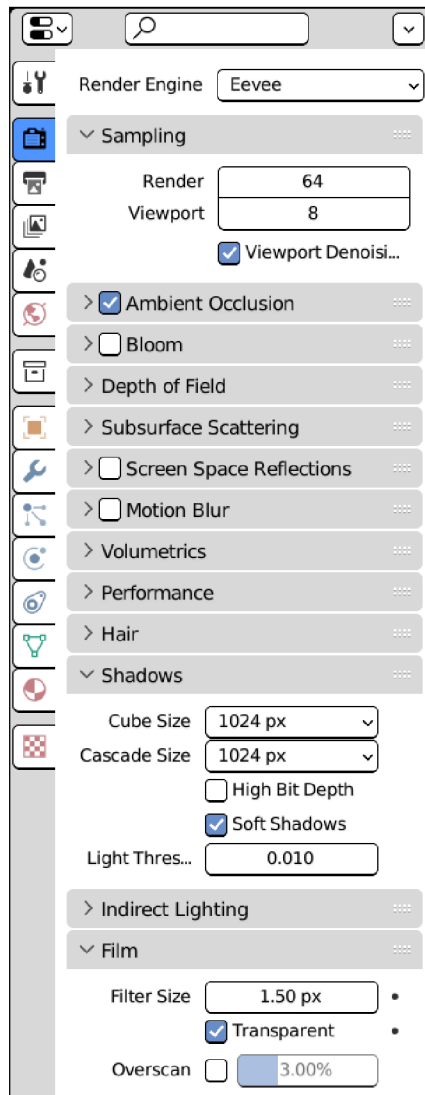


Fig. 78: Render settings

It is to say that all settings introduced in this study are for an efficient workflow, but one can go further on making more realistic renders. User should then go to World Properties from Properties panel and change Color to a brighter color (Fig. 79).

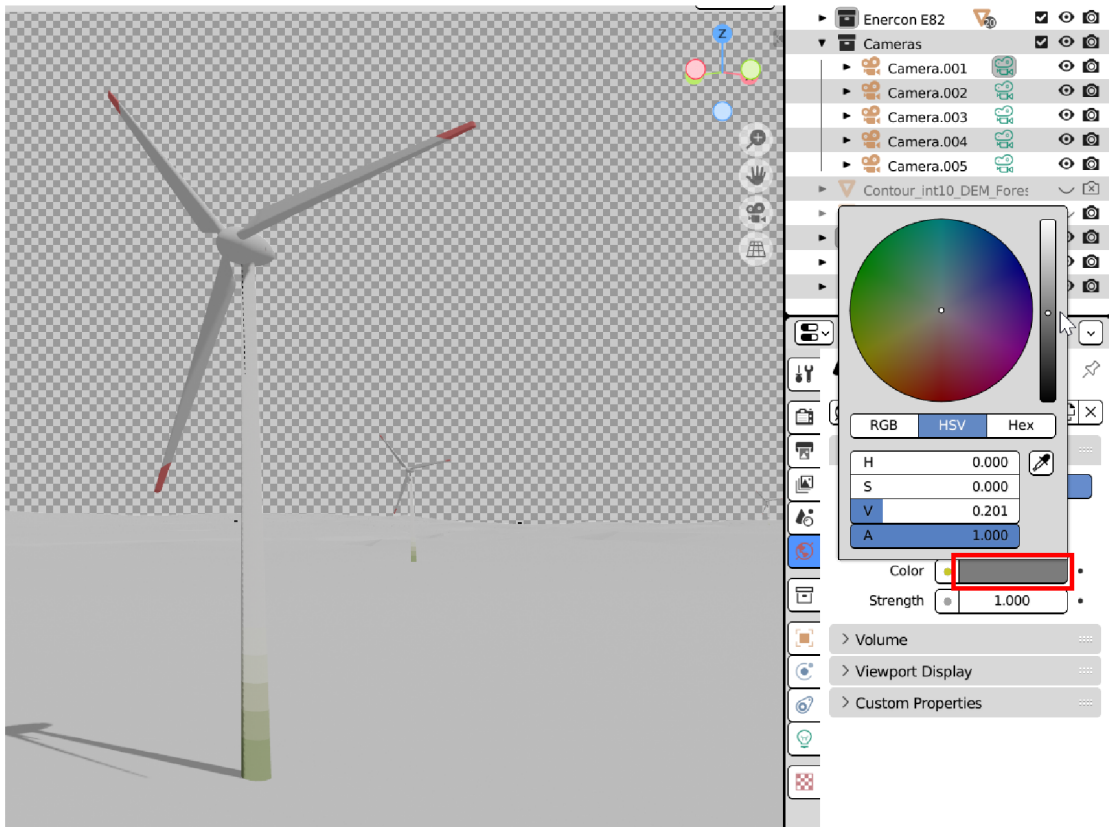


Fig. 79: World color and light strength

User should then select the sun and go to *Object Data properties* from Properties Panel. A warmer color can be given to sunlight and *Strength* of light can be increased. Angle should be changed to higher values if user wants to make shadows less sharp and to be like cloudy days. Enabling *Contact Shadow* can add realism to the renders. Distance and Thickness must be changed to lower values if some inaccurate shadows appear on the objects (Fig. 80).

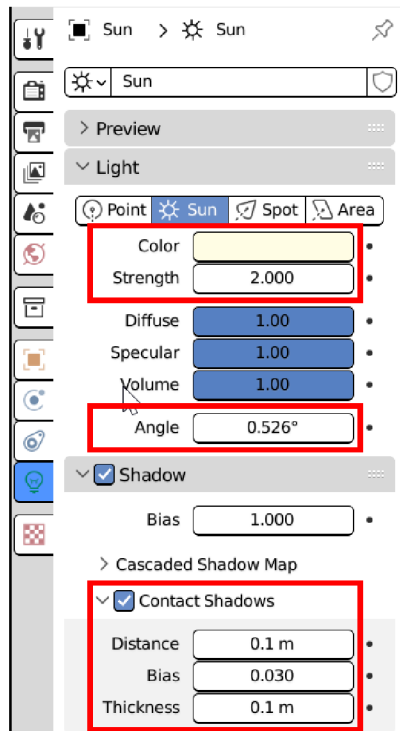


Fig. 80: Light settings

For running a render, user should press *Render Image* from *Render* menu or F12 key.

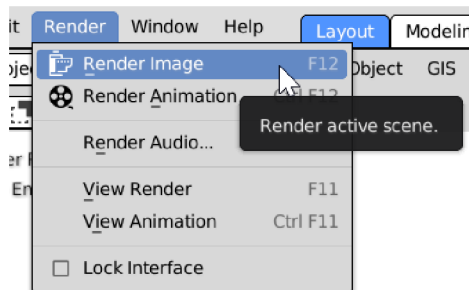


Fig. 81: Running a render

Render window will pop up and it takes couple of seconds (depending on your computer) to render an image. A render is saved by selecting *Save As...* from *Image* menu (Fig. 82).

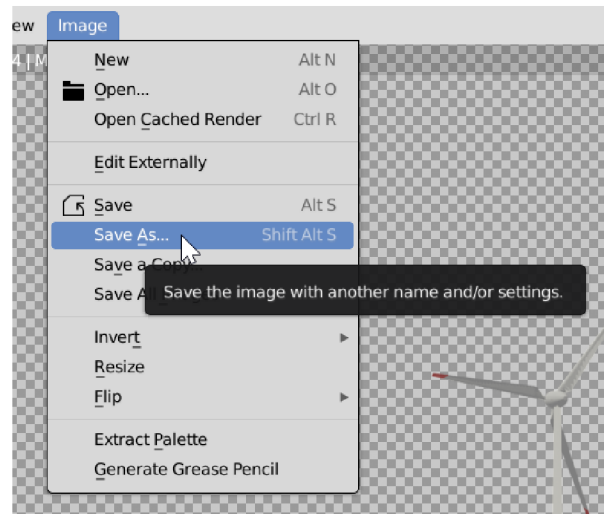


Fig. 82: Saving a render

It is a good idea to render two sets of images, one set with the terrain and the other one without the terrain so it will be easier when user wants to add rendered images to photos (Fig. 83).

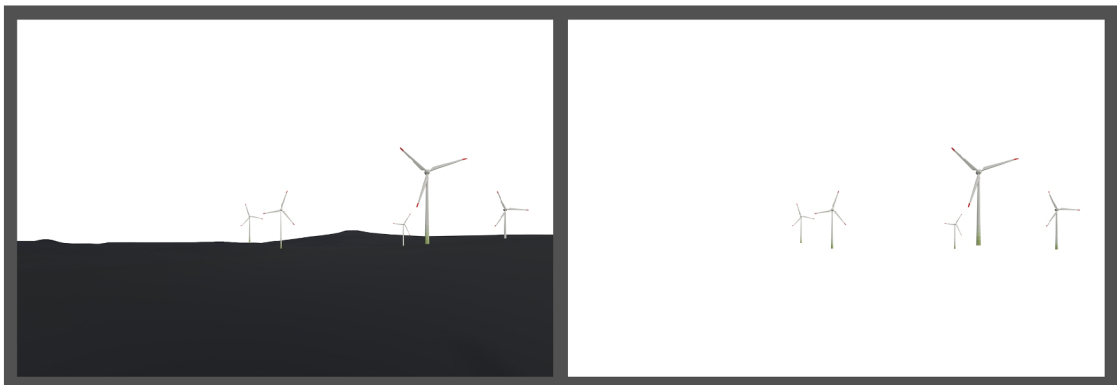


Fig. 83: One set of renders with the ground and the other set without it

5.3 Photomontage

This part is very straight forward (if all steps are followed). The piece of software used in this research is GIMP which is available at: <https://www.gimp.org/>

As the focal length and resolution (width and length) of the renders are the same of that for the physical camera, the dimensions on the renders and photos match and there is no need for any change in the size of renders (scaling) when added to the photos.

A photo and the render from the same point are opened in the software. The render should be added as a layer to the photo and user should delete the parts of the turbines which would be behind the trees, hills or other natural or man-made features. User can change parameter such as brightness, hue, contrast, etc. to make the renders match the photos better. If user made two sets of renders with and without the ground, they can add

two renders as layers to the photo and move them together according to ground elevation to match the real ground elevation in the photo and then turn off the layer with the ground and continue with turbines render only.

After opening GIMP for the first time, it loads its default window layout and theme which is dark. In this study the author changed the theme to make screenshots more legible and better for printing.

Some changes in windows positioning can be helpful for the edit work. User can make all changes from *Preferences* in *Edit* menu. User may change the theme from *Interface/theme*. From *Toolbox* user can change how the tools are displayed (e.g. by disabling *Use tool groups* all the tools in the toolbox are shown at once and not in groups). The windows can be added from *Windows* menu and *Dockable dialogs*. In general, for photo editing it can be helpful to add *Navigation*, *Undo history* and *Layers*. One can put any window on the sides by clicking and holding on its header (the part with its name) to see some blue lines which appear to guide the user where the window can be put and user can put it on the part of their choice by dragging it to that blue line and drop it.

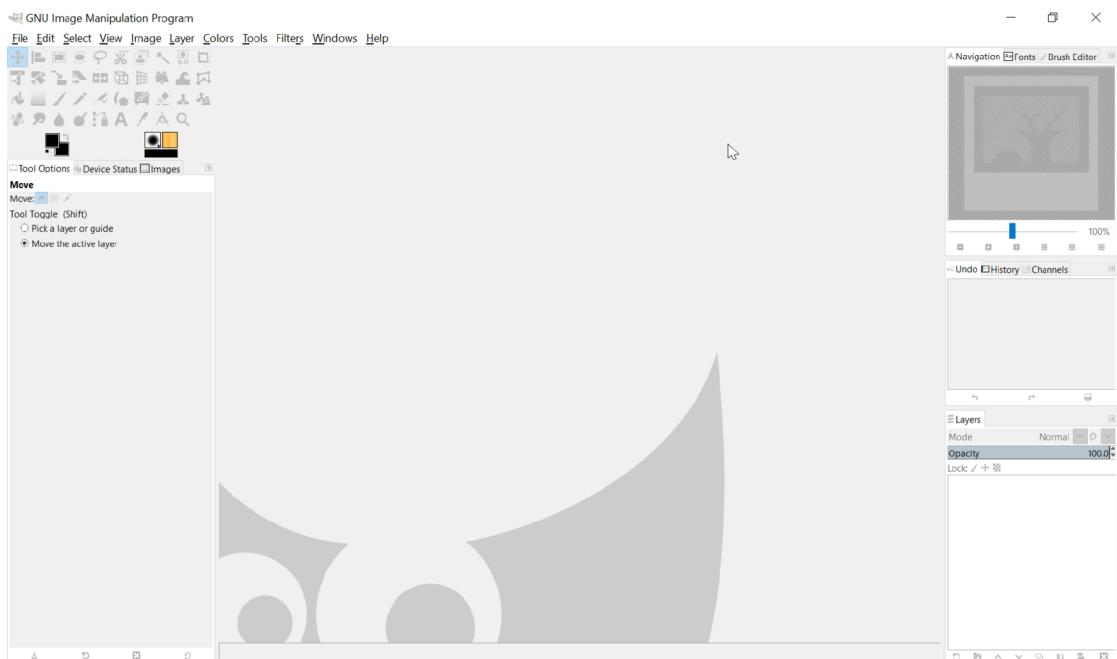


Fig. 84: The layout which can be helpful for photo editing

Photos are opened and renders are added as layers to the corresponding photos. It can be done by dragging and dropping them into GIMP window. Ground elevation can be considered in matching the renders with photos more precisely. In case there is no distinguishable elevation, making sure that the directions match is enough. Here is an example of how to work with the renders and how even a hill can confirm that a render matches the real world (Fig. 85).

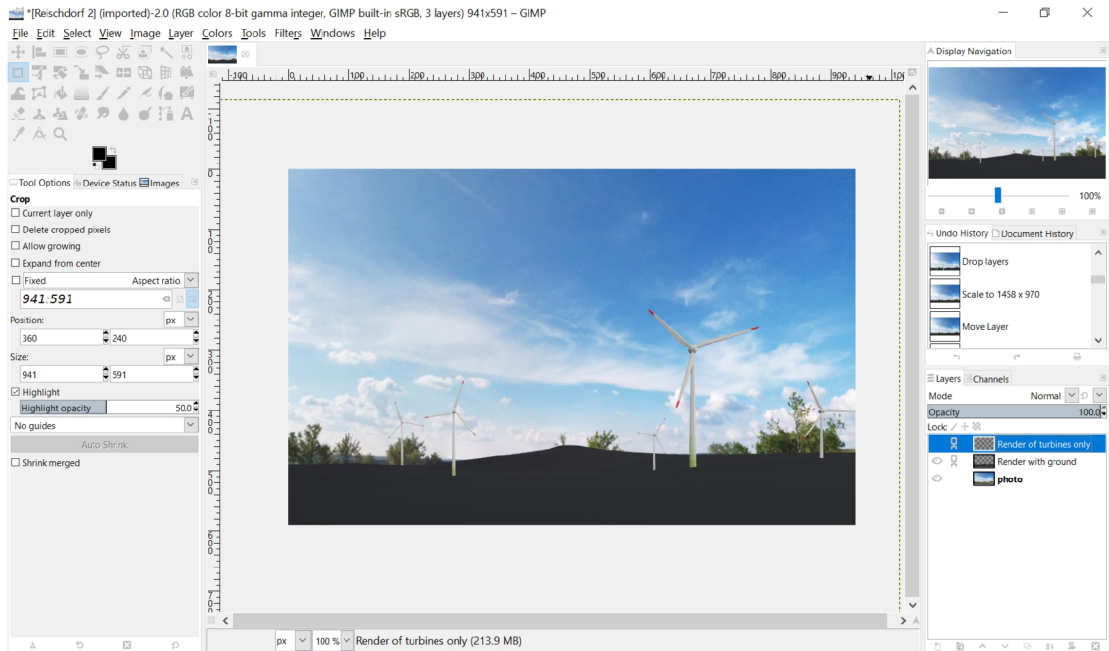


Fig. 85: Adding the renders to the photo and putting them in the right place

Here are some images to demonstrate how a hill can help to place the renders at the right place on photos. It also shows the accuracy of the method (Fig. 86).



Fig. 86: Demonstrating how to use natural features to place a render on a photo and how accurate this method is in making 3D model of the real terrain

To illustrate the point, the author turned the render to plain red and then made it transparent, so it is obvious that the ground-plane elevation in the render matches the topography of the real hill. The reason why some features do not match, like the higher elevation on the left in this example is that they are not within the area (radius) of assessment. They can be too far or outside the area for other reasons such as being in the neighboring country (like this example).

The next step is to erase the parts of the turbines that would not be visible. In this example some parts would be covered by trees and the hills. User should use *Select tools* to select the parts and erase them by pressing delete or by *Eraser tool* especially in case of being covered by trees so that the edges are more realistic. *Free Select Tool* is the most-handy one for this purpose. It allows the user to draw straight lines by clicking on different points or free hand lines by holding the left mouse button and drawing the line, then the line must be closed to make an area for selection.

Finally, it is possible to adjust brightness, contrast, colors, etc. by using tools from *Colors* menu. *Brightness-Contrast* and *Color Balance* are the most useful and simple ones in this case. One can save the image by selecting *Export As* from File menu so that user can choose the name and file format for the image.

6. Results

In this chapter the results of the case study are presented to show the quality and accuracy of the method. For testing the accuracy of the method, some renders of the wind turbines and terrain were turned to plain red colour and put on the corresponding photos. As it can be seen in Fig. 86 (Case study chapter) the 3D terrain is very accurate; the render matches the ground elevation. For testing the accuracy, the existing turbines were also added to the 3D model and specific viewpoints were defined and the process was done for them. The locations of the existing turbines were imported into Blender and 3D models of the wind turbines were put on their locations in the 3D model of the site. The virtual cameras were put in places where the existing turbines were visible from and photos were taken from those points. Figures 87 and 88 confirm that first: the 3D terrain matches the real ground, and secondly: the 3D turbine models match the real ones as depicted. It is important to note that the photo in figure 88 was made by using a phone camera and some visual distortion and error are present due to some imperfections in the lens. In addition, some GPS error is expected, especially for farther distances. Although, as the height of the 3D turbines are the same as the real ones, the difference in their location is mostly because of the inaccuracy of GPS (which can be up to tens of meters).

Another important issue is the effect of adding the forest layer which can be seen in figure 88 (at the left of the photo where the 3D model elevates where the forest begins)



Fig. 87, 88: Testing the method in terms of both the 3D terrain and wind turbines

Followings are the photos for testing the visual impact of the proposed turbines from the places where the existing turbines are visible too. First, there are the photos of the site. The created images with the proposed turbines come after each photo.



Fig. 89: A panoramic photo (of the site and existing turbines) made from three individual photos taken by a 35mm lens



Fig. 90: The proposed turbines are added (from the middle of the photo to the left)



Fig. 91: A panoramic photo (of the site and existing turbines) made of four individual photos taken by a 35mm lens



Fig. 92: The proposed turbines are added to the last photo (Fig. 91)



Fig. 93: Proposed turbines added to a photo of the site taken by a phone camera (24 mm lens)



Fig. 94: Proposed turbines are added to a photo of the site taken by a 55mm lens

7. Discussion

7.1 Flexibility and the Wide Application of the Method

What that makes this method unique is the combination of its main features together with its flexibility to be used for different projects. The main features of this method are its accuracy and ability to bring high quality results at almost no cost. As different pieces of software are used and the user can change the process to suit their needs, it is also very flexible especially when compared with some existing pieces of software. The method can be used for simulating urban wind turbines and other intrusions. In case that the structure is not within urban areas, the process is the same as what is explained in this study. In case the structures are within urban areas or on the top of buildings, it can be done in different ways. If the user has access to high quality DSM of the urban area, a 3D model can be made in the same way as explained in the method. The only difference is that the interval between contour lines should be lower to make a better 3D model of the elevation of buildings. In case of using a DEM, the map of buildings boundaries with their height data (the number of stories) is needed to be added to the 3D model and being used for making a model of buildings elevation. In this way, the shapefile should be divided into different files for different story numbers. Then, the base elevation of the buildings is added to them the same way that was done for points in the case study. Then the shapefile is imported into Blender and the elevation of the shapefile elements is given to them. In case the number of buildings is limited, there is no need for knowing the buildings heights (stories). The user can add the photo into 3D view of the virtual camera, give a random height to each building boundary line. The buildings heights can be then matched with the real building in the photo. After having the 3D model of the buildings, the turbines are added to the scene and rendered twice, once with the buildings and the other time without them, as it was done for the turbines in the case study (with the ground and without it). Then the rendered turbines are put on top of the photos and the covered parts are erased.



Fig. 95: Examples of produced images for visual impact assessment of wind turbines simulated in an urban context by the use of the presented method

7.2 Comparison with the Other Methods and Software

The base of the method presented in this study is the British method for visual impact assessment and it has been used by many professionals including professor Simon Bell (Estonian University of Life Sciences) who uses a set of software and hardware which together are called Landscape Theatre. Landscape Theatre uses expensive pieces of software and equipment and the quality is still not satisfactory, according to professor Simon Bell and Peeter Vassiljev (lecturer at Estonian University of Life Sciences).



Fig. 96: Landscape Theatre (Simon Bell)

The advantages of using the method proposed in this study over Landscape Theatre is its availability, higher quality and that it is free. It does not need any especial equipment and the pieces of software which are used are free. The results of Landscape Theatre are not realistic and very weak especially in simulating the vegetation.

There are other pieces of software that does the same job, more or less. WindPRO is a piece of software which can be used in different parts of designing wind farms such as selecting the site, calculating the generated electricity and visual impact assessment. The results of WindPRO visual impact assessment are basically the same as the ones obtained from the method presented in this thesis study in terms of its general approach (rendering 3D wind turbine models and photomontage) and therefore, the quality of outcomes are very close. However, Blender is a professional software for visualization and if the user puts enough time and effort, there is no doubt that the quality of renders made by Blender will be far higher than the ones generated by WindPRO. It is also very important to consider that WindPRO is a very expensive piece of software. Other options such as LandSim3D which is aimed at making visualizations for different purposes of presenting projects are all proprietary and expensive while there is no documentation on how to work with them and how to achieve satisfactory results.

7.3 The Used Software and the Required Skills

Using free and open-source software guarantees that the method will be always free in terms of software price. The main three pieces of software used for this method are developed well. Blender and QGIS are already very popular and used by many companies and studios. The other one (GIMP) is not as popular as the other two yet, but it has been developed more rapidly in recent years and therefore it is becoming more and more popular. It is said by many that the strongest advantage of open-source software over the proprietary ones is their community of user support and communal program development; strong community provides help and guarantees future development. Another great advantage of open-source software is – obviously – that their codes are available for anyone to see and to use (the only rule is that if someone uses the codes of an open-source piece of software to write a new piece of software, it must be open-source too).

In terms of the skill level needed for using the proposed method, basic knowledge of GIS is needed for understanding the general idea and the difference between different pieces of data. By following the instructions given in the case study chapter and some effort in understanding the 3D part, the user can achieve the same results as provided in this thesis study. Experience in working with other GIS software can help to complete the GIS part faster, as many of the commands such as visibility analysis work quite the same in different pieces of GIS software. A detailed guide is provided for the use of the 3D section however, it is strongly recommended to learn and practice the basics of working with Blender. There are a lot of beginner tutorials freely available on not only the websites dedicated to 3D works but also on YouTube. As already mentioned, open-source software communities are very strong and supportive. There are some forums where anyone can post questions and many users are ready to help. The photomontage part is easy even for those who never used any image manipulation (photo-editing)

software before. The guide in the case study part is enough for photomontage needed in this method.

7.4 Enhancements of the Process

One modification done to visibility analysis suggested in this study – as already explained – is to add the forest effect and to consider the difference between seeing the structure and hub of turbines with the situation when only the blades can be visible. The suggestions are concluded from conducting the visibility analysis on existing wind farms and checking it in reality. For this aim, the process was done firstly on the existing turbines. After comparing the photos with renders, it was concluded that some simple steps can increase the accuracy of visibility analysis for the places where the turbines are visible according to the analysis but not in reality. It was mostly due to the trees blocking the view. After adding the average height of trees to forested areas in DEM, the results were closer to reality.

It was also found that using a smart phone for taking the photos not only helps to reduce the cost of image capture (if the user does not have a camera), it also makes it easier to check the visibility from any point even if someone else takes the photos. A user only needs to turn on the GPS on the phone and the coordinates of the places are saved into the photo files. The direction must be checked by the one who takes the photo, however they also can use some applications which save the coordination and direction into the photos. The user must enter the focal length of the camera used into the virtual camera settings and the rest of the process is the same.

8. Conclusion and Contribution of the Thesis

The goals of this thesis which were to propose an accurate and free method for visual impact assessment and testing the methodology were successfully achieved. The focus in this study is on the visual impact assessment of wind turbines, however, the method can be used for simulating a variety of other structures as well, such as changes in the landscape features, modifications to the architectural features of a building, placement of outdoor advertising signage, etc. A detailed description of the process is presented in the Methodology/Case study chapter to guide anyone who has a basic GIS knowledge. Both the results of the case study and the description of the steps and how to use the software were reviewed by different academic professionals (who teach GIS or have experience in visual impact assessment) to ensure that the results are of high quality for being used in surveys, and that the description of the steps (see Methodology and Case Study chapters) is clearly explained and contains adequate detail, such as menus for the rendering and simulation of images.

There are of course many more opportunities to advance the use and application of this methodology and to use it as the basis for development of a system which uses available technologies for augmenting visual reality to further the quality and engagement of the results as well as making the process easier and faster. The great opportunity which the use of open-source software brings is that the future development can be based on the codes extracted from the used pieces of software and improved by the help from the online user communities.

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