«A new approach towards comparing environmental impacts from small-scale hydropower, large-scale hydropower and wind power.”

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Abstract

In 2012 did Norway, in collaboration with Sweden, agree on a common energy certificate market where both countries set a goal for producing 67, 5 TWh of renewable energy within the year 2020. These certificates are energy neutral, but they are expected to increase the building of small-scale hydropower and wind power plants. This has created much debate surround the environmental impacts and habitat fragmentations which occur from the increased building, and more knowledge is needed to establish better mitigation measures.

This thesis is therefore built on the need for more knowledge of the impacts from Norway's two largest renewable energy resources: hydropower and wind power. I have tried to make a new methodological approach for mapping environmental impacts from three production types: small-scale hydropower, large-scale hydropower, and wind power, based on the same amount of annually produced energy. The mapped impacts are from four parameters: area directly affected by the production site, the visibility of the plant, amount of red listed species present within a radius of 2 and 10 kilometers, and amount of overlap with encroachment-free (INON) areas mapped by the Directorate for nature management in 2008.

This new methodological approach is based in the program geographic information systems (GIS) using data downloaded from the Norwegian Mapping Authority and Artsdatabanken. The four parameters which are analyzed in GIS explores how the impacts from the three different power production types differ, and if the results can be used for a comparison of environmental impacts across different types of energy production.

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Trondheim, May 10. 2013

Anne Guri Aase

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1. Introduction

Climate change is one of the greatest challenges the World has to face in the 21st century. The most severe impacts, listed in reports such as (IPCC, 2007), may still be avoided if the necessary efforts are made for transforming today's energy systems. Renewable energy sources have a large potential in replacing the usage of fossil fuels and thereby mitigate climate change. If the implementation from fossil fuels is done properly, renewable energy can contribute to energy access, to a secure and sustainable energy supply, social and economic development, and to a reduction of negative impacts on the environment (Edenhofer, 2012).

The European Union (EU) has set requirements for all countries in the union to follow the Renewable Energy Source (RES) Directive, which means each country must create a plan on how to reach their own renewable energy targets. The action plan set by Norway states how we plan to reach our renewable energy goal of 67, 5 percent within the year 2020. The most important measure Norway has implemented in order to reach this target is the electrical certificates, also called el-certificates (OED, 2013). As a step towards producing more renewable energy, the Norwegian government has in collaboration with Sweden agreed on a common energy certificate market. The goal is that this joint certificate market will stimulate a renewable production of 26, 4 TWh in both countries within the year 2020, where Norway has committed to build 13, 2 TWh (OED, 2013). These el-certificates are energy neutral, which means they apply to all types of renewable energy, including sun, biomass, wind- and hydropower. This has led to an anticipated building-boom within renewable energy. Even though the el-certificates apply to all renewable energy, the expected building of large-scale hydropower is limited in contrast to small-scale hydropower and wind power.

In the el-certificate system, electricity generation which produces renewable energy receives a certificate for each MWh of electricity produced, while electricity suppliers are required to hold these certificates equivalent to a predetermined percentage of the total amount of electricity they supply. Suppliers must obtain the certificates through production from their own renewable power plants or through purchases from other generating companies using the eligible technologies. The size of this quote obligation changes from year to year, increasing the demand for renewable electricity and certificates. So indirectly, it is the

Government that determines the demand for how much renewable energy that will be produced (Norsk Vindkraftforening, 2013a).

But this expected building-boom within the renewable energy sector does not only produce important energy. The implementation of the el-certificates will most likely increase the pressure on the biodiversity and the environment through increased establishment and use of Norwegian hydro- and wind power resources (Directorate for Nature Management, 2010). During the latter years several researchers have emphasized the lack of knowledge surrounding the environmental impacts from the development of renewable energy. If the implementation of el-certificates creates a demand after licensing new power plants, the need for more thoroughly environmental investigation is needed. The knowledge about environmental impacts from large-scale hydropower is well known, however, there is a lack of documented knowledge about the environmental impacts of small-scale hydropower (L'Abée-Lund, 2005). Studies and reports have been conducted and written in many ways on mapping the different impacts, but there does not exist a common ground, as it differs between the individual reports, sometimes with methodology developed by the researches, some companies have their own practices, or methods that are commonly used in the industry (Størset, 2009). This has led to an increasing demand for a common methodology which can be used by all the different actors in the system, and especially more knowledge about the possible "feedback mechanisms" which occur after the project has been realized.

In his New Year speech in 2001, the Prime Minister Jens Stoltenberg stated that "the time for large-scale hydropower plants in Norway were over" (The Office of the Prime Minister, 2001) and the Norwegian Government and Parliament have by several occasions expressed their objections towards large-scale hydropower (Directorate for Nature Management, 2010). Many believe that small-scale hydropower is the most cost-effective option, but with the implementation of el-certificates it is essential to have a better understanding of the types of renewable energy projects which should be encouraged. In this context it is important to emphasize that the future development of renewable energy does not depend on developing either large-scale hydropower or small-scale hydropower (or the use of other renewable energy source), but to produce the best possible combination of energy production to reduce the overall environmental impacts (Bakken et al., 2012).

With the emphasis on the environment and the need for a better understanding on what impacts the different renewable energy production types have, and the expected increase in production capacity in Norway, I have decided to create a methodology for comparing the environmental impact from three different renewable energy production types. The power production types chosen for this analysis are small-scale hydropower, large-scale hydropower, and wind power. These are the three most established renewable energies in Norway today. There have not been conducted equal studies in Norway before, so this is the first contribution to a new field of study, and I hope this methodology will set the basis for further research.

1.1 Research questions

The aim for this thesis is to map and compare the environmental impacts from three renewable energy production types; small-scale hydropower, large-scale hydropower and wind power. For making this comparison across these three energy production types, four standardized parameters have been chosen: area directly affected by the project, visibility, red listed species, and area overlap with encroachment-free (INON) areas. These parameters will be mapped for each energy production type using geographic information system (GIS).

The research questions for this thesis are as follows:

1. What impacts do the analyzed parameters identify for each of the three renewable energy production types?
2. Does the parameters allow for a comparison across different types of energy production?

2 Background

In the following sections, information about the general energy situation in Norway is presented, followed by a theoretic presentation of small-scale hydropower, large-scale hydropower and wind power and the different licensing requirements for each production type.

2.1 Power plants in Norway

Renewable energy is obtained from the continuing or the repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar energy, geothermal heat, hydropower, tide, waves and ocean thermal energy, and wind energy. Renewable energy is a resource that is replenished by natural processes at a rate that equals or exceeds its rate of use. The implementation of renewable energy fulfills many basic goals of sustainable development because it does not consume any of the World's capital of natural resources (Edenhofer, 2012).

The implementation of renewable energy into the Norwegian energy sector has already been done, since the energy production in Norway is dominated by large-scale hydropower and has been so for many years, but has recently been supplemented by small-scale hydropower. There is also another type of renewable energy which has a theoretic energy potential of the same magnitude as the potential energy in all precipitation within Norway: namely wind power (Holter et al., 2010). Even though most of Norway's energy production has come from hydropower, the definitions of renewable energy in policy documents generally reflect a negative perception of large-scale hydropower projects (Egré et al., 1999) and a positive perception of small-scale hydropower plants.

2.2 Hydropower

Hydropower in Norway dates back over 100 years and has through continuous development given Norwegian entrepreneurs unique expertise covering all aspects of a hydropower project (Tollan, 2002). Norway is today the largest producer of hydropower in Europe and the sixth largest producer in the World, and 99 percent of the energy consumption in Norway is covered by hydropower (OED, 2013).

The production of energy from hydropower is based on a simple process: taking advantage of the kinetic energy freed by falling water. In an hydroelectric generating station, the rushing water drives a turbine, which converts the water's motion into mechanical and electrical energy (Egré and Milewski, 2002). Hydropower is a consequence of the natural cyclic transport of water between the Earth's surface and the atmosphere. The solar energy heats the water up so it evaporates, followed by precipitation and the downward course of water in rivers and streams under the force of gravity. The available energy of water stored at a height above a power generator is the potential energy in the Earth's gravitational field (Aubrecht, 2006). The higher fall the water has from the intake, before reaching the turbine, the more energy the power plant can produce. Figure 2.1 shows the process of hydropower generation.

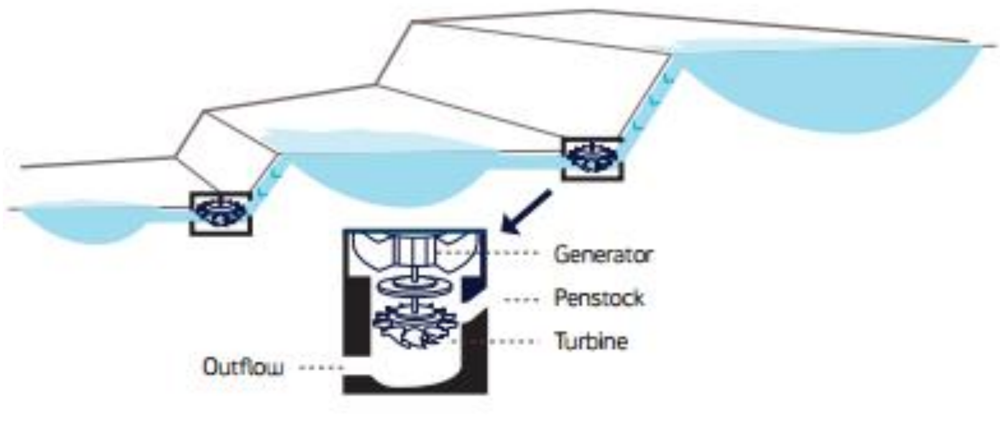

Figure 2.1: Principles behind hydropower generation (Statkraft, 2009)

The installed capacity in Norwegian hydropower plants were at January 1. 2012, 30 172 MW, distributed on 1393 power plant, and the anticipated annual hydropower production for 2012 was set to 130 TWh (OED, 2013). The anticipated annual production is estimated from previous energy production, which means the total amount of hydropower plants and the annual inflow of water to the power plants in one year of normal precipitation (ibid). Hydropower production is divided into two categories according to their amount of installed capacity (MW): small-scale hydropower and large-scale hydropower.

Various countries around the World have different definitions of what constitutes small-scale hydropower and large-scale hydropower. These large differences in definitions of size for hydropower may be motivated in some cases by national rules, such as in Norway, to determine which authority is responsible for the licensing process. Regardless of different classifications, there is no direct link between installed capacity as a classification criterion and general properties common to the hydropower plants above or below the limit. Different examples can here be China, where the definition between small-scale and large-scale hydropower is set at 50 MW, while India has 25 MW, and Sweden 1, 5 MW (Edenhofer, 2012).

The concept of classifying hydropower into small-scale and large-scale has been criticized as this classification does not seem to relate to their environmental impacts (Edenhofer, 2012). This discussion will further be referred to as the small versus large debate.

2.2.1 Small-scale hydropower

Small-scale hydropower has during the last decade become popular in Norway and their value as an energy source has become highly sought after (L'Abée-Lund, 2005). During the latter years the technological development has made it easier and more economical feasible to build and operate these hydropower plants than it has been before (Sægrov and Fimreite, 1999). The locations of small-scale hydropower plants are typically set in smaller rivers and streams and when built, these power plants can run for about 30-50 years (Novakovic, 2000). Therefore, good planning is a key necessity for securing the best possible environmental measurements.

Figure 2.2: Water outlet at Dale small-scale hydropower plant. Source: Tor Haakon Bakken.

Figure 2.2 shows the power house and the water outlet at Dale small-scale hydropower plant in the county Sogn og Fjordane. The picture is taken in May, when the snow melting in the mountains has started and this gives the power plants more water to produce more energy. Small-scale hydropower plants do often not have reservoirs and uses the flow of water within the natural range of the river (Egré and Milewski, 2002). Consequently, this creates annual, seasonal and daily variations in the amount of produced energy, and it varies considerably throughout the year. Power production will therefore increase during the wetter seasons during snow melting and high amounts of precipitations, and decrease during dryer seasons such as midwinter and dry summers.

As previously stated, different countries have different measures of the distinction between small- and large-scale hydropower. Table 2.1 lists the Norwegian definitions of what constitutes small-scale hydropower plants, which is a hydropower plant which has an installed capacity under 10 MW. The small-scale hydropower plants used in this thesis are only those within the range of 1 MW to 10 MW.

Table 2.1: Table showing the three classifications of small-scale hydropower plants (OED, 2007b).

Production type	Production
Micro	> – 0,1 MW
Mini	0,1 MW – 1 MW
Small-scale	1 MW - 10 MW

The classification which has been determined for what constitutes small-scale hydropower has been set by the Norwegian Government. The classifications states also what type of licensing process the different projects must go through and what type of environmental investigations which need to be conducted. The licensing authority for small-scale hydropower plants is the Norwegian Water Resource and Energy Directorate (NVE).

When a landowner with waterfall rights apply for building a new small-scale hydropower plant, it is often difficult to evaluate whether the assessments and investigations made are sufficient to illuminate the environmental impacts (Størset, 2009). Therefore guidelines have been published by the Ministry of Petroleum and Energy (OED) for small-scale hydropower plants (OED, 2007b), where the purpose is to strengthen the basis for comprehensive and thoroughly assessment of impacts for the license applications. It is recommended that the individual municipalities make regional plans that identify and visualize areas with important environmental interests and describe how these interests, based on regional priorities, should be addressed when evaluating individual small-scale hydropower projects. The guidelines should be used as an important basis for the overall assessment for each individual project by the licensing authority. By following the guidelines during the planning process increases the chance for the licensing authority to grant the application.

When a landowner plans to build a new power plant, he sends a request to NVE with a sketch of the project. NVE then decides whether the project should have an environmental impact assessment (EIA) or an environmental assessment (EA). The idea behind an EIA is to gather information of what impacts the power plant might give and to create a decision relevant knowledgebase during the planning of the power plant (OED, 2013). The EA is not as thoroughly as an EIA, but measures the effects of the encroachment and the impacts that are assessed to be the most important for the site. As of today, it is normally given greatest emphasis on landscape effects and red listed species (Korbøl et al., 2009).

When assessing the impacts from a planned small-scale hydropower plant in an EIA, several different thematic aspects is assessed, such as landscape, biological diversity, encroachment-free (INON) areas, fish, and outdoor recreations, amongst some. But also important information which is directly connected to the power plant, such as what sort of encroachment will it be, the area extension, location, and the vulnerability for the area (Erikstad et al., 2011). An another important factor that is done when planning a new small-scale hydropower plant is to assess what type of transmission lines are within the area and evaluate if they need an upgrade to withstand the extra energy which will be connected to the grid. After the EIA is done, the application can be sent to NVE. The time it takes for the licensing process to be completed might be up to several years. If the application is rejected, an appeal can be sent to OED which then evaluates the project.

In addition to produce energy, small-scale hydropower project creates activity surrounding planning and building to the rural districts by giving additional income to landowners with waterfall rights. The building of the power plant gives jobs to local entrepreneurs. Often a company, such as Fjellkraft and Småkraft, rents the right of the waterfall from the landowner over a predefined period of time, often between 40 to 60 years, where the rent is paid after how many meters altitude fall the landowner has. These companies plan, build, and manage the power plant, as the land owner gets a form of compensation for lease of land or loss in cultivated or forest area. This compensation can be a percentage of shares, no more than 49 percent, in owning the power plant, or in a fix percentage of the income from power sales, also called *fallrettsleige* (lease of waterfall right) (Stenersen and Langnes, 2010). From the different choice the landowner has, he will earn most by owning parts of the company when there is a beneficial relation between construction cost and income, but it is a lot of work and a risk by investing so much money.

Even though small-scale hydropower plants are small in size, they are not cheap. The cost for building a small-scale hydropower plant varies between approximately 10 million to over 150 million NOK (Småkraft Foreninga, 2012). There are different reasons why this cost has such high variations. Construction of connecting infrastructure might be costly if the locations is located in a remote area, drilling trough mountain for establishing pipelines are expensive because of the need for advanced equipment and skilled workers.

In 2009 did NVE map the total potential in Norway for new small-scale power plants, and it showed a total potential of 6169 GWh/year (NVE, 2009). The criteria's for locating a small-scale hydropower plant are primarily related to hydrological conditions, power potential such as height differences between a possible intake and power house, and access to available transmission lines. The total hydropower resource potential depends on topography and the volume, variability and seasonal distribution of runoff. Well above half of the total energy potential which was found in this mapping was located in the counties Sogn og Fjordane, Hordaland, and Nordland. Of all the counties in Norway, Sogn og Fjordane is the one with most built small-scale hydropower plants and has many new possible power plants for evaluation at NVE.

The resource mapping for potential small-scale hydropower plants demonstrates that many of the suitable locations with hydropower resources are concentrated in coastal areas and fjords, particularly in the Western part of Norway (OED, 2007b). These areas have therefore during the last years experiences a significant development pressure. Particular attention is therefore given to how the development will affect these landscapes. The removal or limitation of an important single element, such as a waterfall, can have major impact on the overall landscape experience.

Only in 2012 did NVE receive 202 license applications for new small-scale hydropower plants with a combined energy production of 2 TWh. At a total, there were 730 applications under consideration with a combined potential of 6, 7 TWh energy (Flatby, 2013). This is a clear sign that the building of new small-scale hydropower plants will increase during the next few years and the need for more information is important.

2.2.2 Large-scale hydropower

Norway has as stated, a long history within hydropower production. The type of hydropower production which was previously used was large-scale hydropower plants. These plants are defined as hydropower production over 10 MW (OED, 2013). All large-scale hydropower projects have reservoirs, which is a fundamental asset of these projects as the production of the power plant can be adjusted to fluctuations of power demand and not to the fluctuations of water flow (Egré and Milewski, 2002). The reservoirs are dams which are established in lakes or in artificial pools, and the amount of water is dammed up during wet seasons, and used in periods of energy demand. Norway is by nature suitable for damming, with many natural lakes, deep valleys, moderate sediment transport, and with scattered population (Tollan, 2002). This advantage with large-scale hydropower plants by using the reservoir to store energy gives this production type an added value compared to other types of energy productions which must produce when the resource is present, such as small-scale hydropower and wind power.

Large-scale hydropower plants have normally large height differences between intake and power house. The power station is connected with the magazine either directly or through long pipelines or underground tunnels. The power station can be under or above the ground, and may not be built adjacent to the magazine. The power station may receive the waterfall from several magazines to enhance the energy production. This method of using several connecting reservoirs is much used in the already established large-scale hydropower production in Norway.

Figure 2.3: Tunsebergdammen, the reservoir for the large-scale hydropower plant Leirdøla. Source: Tor Haakon Bakken

Figure 2.3 shows how the reservoir looks when the water level is low. This picture has been taken in May, which shows that much water has been used in the energy production during the cold winter. During the summer more water will flow into the reservoir as the snow in the mountains melt. The total regulation capacity with maximum and minimum water level in the reservoir during the year is set by the Norwegian Government (OED, 2013). Large-scale hydropower uses the reservoirs to equalize the effects on the water resources seasonal and daily fluctuations. This creates freedom to allocate and use the resource efficiently. Nevertheless, it can still be great fluctuations in the power production on a year to year basis. An example can be the changes in annual energy production, which in 2000 was 143 TWh, compared to 106 TWh in 2003, while the energy production in a normal year is approximately 120 TWh (Abelsen, 2007).

For building a large-scale hydropower, different guidelines are given than for building a small-scale power plant. Because of a more extensive area usage, both for construction site and reservoir, several law and regulations needs to be followed.

A hydropower project which produces more than 40 GWh/year and with reservoirs which contain over 10 million m^3, must be assessed in an environmental impact assessment (EIA) after regulations given in the plan- and building act. The plan and building act has regulations for planning and assessment of large construction projects (Bakken et al., 2012). New guidelines was published in 2010 by (Jensen et al., 2010) and in this updated guidelines new management elements were added, examples here can be red listed species and encroachment-free (INON) areas.

The guideline points to what elements that needs to be studied in an area for mapping the correct impacts from a new power project, elements such as hydrological relations, landscape, environment, natural resources, and society. Also sum-impacts are mentioned for large-scale hydropower plants, as to create an overview over existing and planned encroachments within a geographical delineated area which extends beyond the influence area of the project. This does especially concern landscape and biodiversity. In addition to the area which is directly used by the power plant, additional area should be taken into account for an eventual expansion of the project, buffer zones, and safety zones. In particular, the planning of larger hydropower development uses guidelines and regulations to ensure that impacts are assessed as objectively as possible and managed in an appropriate manner.

NVE recommend the usage of non-priced impacts, measured from “very large negative” consequence via “insignificant” to “very large positive” consequence. With these consequences it is meant a weighting between the advantages and disadvantages for a defined project (Jensen et al., 2010). The assessment for each aspect is evaluated to what amount of impact the establishment of a new power plant will create. After evaluating all the aspects, they are listed after what type of value they have: great value, medium value, or little value. The valuation states what type of qualities that exist for each of the aspects present in the investigated area.

Before the EIA is conducted for the location where the new large-scale hydropower plant is planned, a notice with a short summary of the proposed project is sent to NVE. The notice should explain the project, also new transmission lines, or eventual reinforcement of the grid. It should have a good presentation of the project and the expected impacts on environment and society. One element that is explained in this notice is the reservoir. For the planned reservoir there should be made maps showing the area which will be flooded, equations showing the differences between lowest water level and maximum level, also by adding possible flooding, extreme precipitation, and avalanches.

If a new large-scale hydropower plant is granted a license, it will at the same time be given terms for mitigating the eventual negative impacts on the environment. One important term here is the regulations to the maximum and minimum water level within the reservoir, and requirements on minimum flow in the river below the reservoir (Jensen et al., 2010). Other mitigation measures which are associated with large-scale hydropower is salmon stairs which makes it possible for the salmon to make its life journey back to the river it was born. NVE is not usually the licensing authority in such large projects, but write a recommendation to OED who prepares the case for the Government which shall decide on the development by Royal Decree. The license is then given for a period of 50 to 60 years (Jensen et al., 2010).

Building a new large-scale hydropower plant is not something one landowner can do as the cost is too high. One company which is leading within large-scale hydropower production in Norway is Statkraft, which has 141 power plants in Norway, and 92 hydropower plants around in Europe (Statkraft, no date-c). In Norway, there are many years since most of our large-scale hydropower plants were granted, so according to the Watercourse law, the power plants requires revision of the conditions after 30 to 50 years, depending on whether the license was granted before or after 1959. In this revising, it is the conditions listed in the license that is evaluated, not the license itself. The main purpose of revision of the conditions is to improve the environmental conditions in previously regulated rivers. The core is to balance the need for power generation and local environmental improvements (Statkraft, no date-a).

2.3 Wind power

Another form of renewable energy which has a large potential in Norway, is wind power. The wind blows continuously, though in different amounts, and are often at its strongest during the winter storms when need of energy for heating is at its highest. Wind energy is today one of the fastest growing renewable energy production types in the world, and is also thought of as one of the most environmental friendly forms (Statkraft, 2010).

The process of producing power from a wind turbine is done by transforming the kinetic energy created by the wind into mechanic energy (Statkraft, 2010). This kinetic energy is transferred sun radiation which creates movements in the air due to temperature differences (Novakovic, 2000). For the transformation of the movements in the air into mechanic energy, the kinetic energy is “absorbed” by three large blades that run a generator. The three blades are fastened to a nacelle, which is a closed capsule that surrounds the generator which converts the movement from the turbines into mechanic energy. The tower is then fastened to a solid fundament fastened into the ground (OED, 2013). Figure 2.4 shows the different parts in the nacelle.

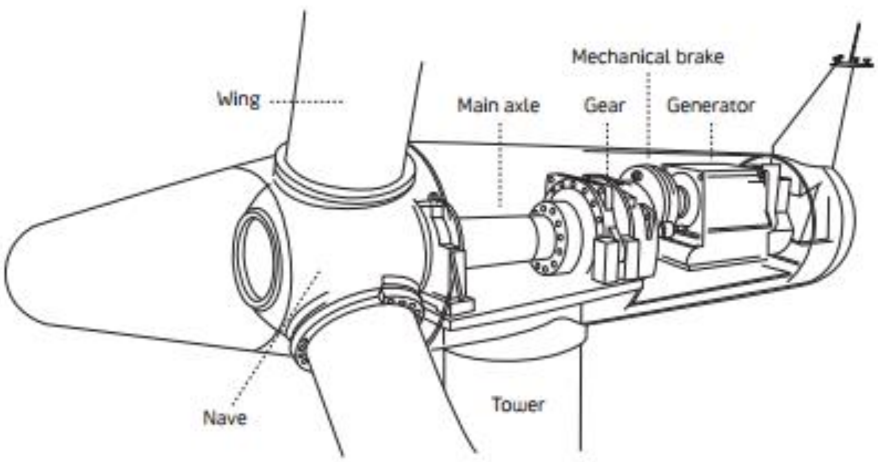

Figure 2.4: The different elements within a nacelle (Statkraft, 2010).

A modern wind turbine produces energy when the speed of wind is between 3-4 m/s and 25 m/s, from light breeze till full storm. When the wind speeds are above 25 m/s the rotor blades are turned straight towards the wind and locked to exclude overload in the rotors. They are set out of production until the wind strengths decreases (Statkraft, 2010). A general principle used is the need for an average wind speed over 6, 5 m/s to be classified as a potential wind farm location. Norway has in comparison to other European countries large wind resources, with an average annual wind speeds between 7 m/s to 9 m/s (ibid).

Wind power has frequently variations in wind strength which are hard to estimate only a couple of hours in advance. This means that the production capacity can change considerably within one hour. But the potential in wind power production in Norway has though a favorable annual profile with the highest production during the winter when the demand for electricity is highest (Abelsen, 2007). Norway is fortunate in having natural conditions both in wind potential and landscape requirements which allows us to expand the building of wind power in years to come. The performance of wind power plants is highly site specific, and is primarily governed by the characteristics of the local wind regime, which varies geographically and temporally. And because the wind varies on a seasonal, daily, and hourly basis, it is therefore an uncontrollable source of energy. Most windy sites are located along the coast and the wind potential increases further away from land. In choosing a location for a wind power plant, detailed wind measures over a number of years are needed to help make a proper site location.

Today, there are 315 wind turbines in Norway with an annual energy production of 1569 GWh (NVE, 2012a). The combined wind power potential in Norway is estimated to be several thousand TWh/year, but the majority of the potential is not feasible because of the environmental and economic aspects. This means that most locations which have a good wind power potential are located in areas with high and important biological diversity which are protected by the Government, but also that the financial aspect of building a wind power plant is so high that only larger companies can afford. Wind power in Norway was before the implementation of the el-certificates not an economical feasible energy production type, and the development was dependent on economic support which meant that the project builder could get refunded some of the eligible investments costs. This support was previously given by Enova, but was replaced by the el-certificates January 1. 2012 (OED, 2013).

Wind power is an expensive renewable energy to build. The highest cost is related to the wind turbine itself. Depending on the size of the project, it is estimated that the turbine account for 70-75 percent of the total investment costs. The total cost of investment is situated around 10-12 million NOK per MW installed capacity. For a large wind power plant the total cost can be summarized to over one billion NOK. The cost per installed MW varies somewhat according to what type of turbine one chooses, the complexity of the terrain, how far from the main road the park will be established, and how far from the grid the site is located. The costs associated with connecting the power plant till the existing power grid is the type of cost which varies the most between different projects (Norsk Vindkraftforening, 2013b).

Figure 2.5: Smøla wind power plant. Source: author.

Figure 2.5 shows an image from the wind power plant Smøla, which is located at the island of Smøla in the county of Møre and Romsdal. Smøla archipelago consists of a large main island surrounded by more than 5500 smaller islands and islets. The landscape on the main island is characterized by heather moors with some extensive blanket bogs and a few rocky outcrops (Dahl et al., 2012).

The wind power plant is located in a flat and open landscape, 10 to 40 meters above sea level and with distances between each windmill in one row is between 240 to 350 meters, while the distance between the rows varies between 700 to 1000 meters (Holter et al., 2010). There have been built connecting roads between all the windmills, and buried electricity cables to a transformation station located in the center of the wind power plant. Figure 2.6 shows the locations of the 68 turbines within the Smøla wind power plant which combined have an installed capacity of 150 MW and an annual production of 356 GWh (Statkraft, 2010).

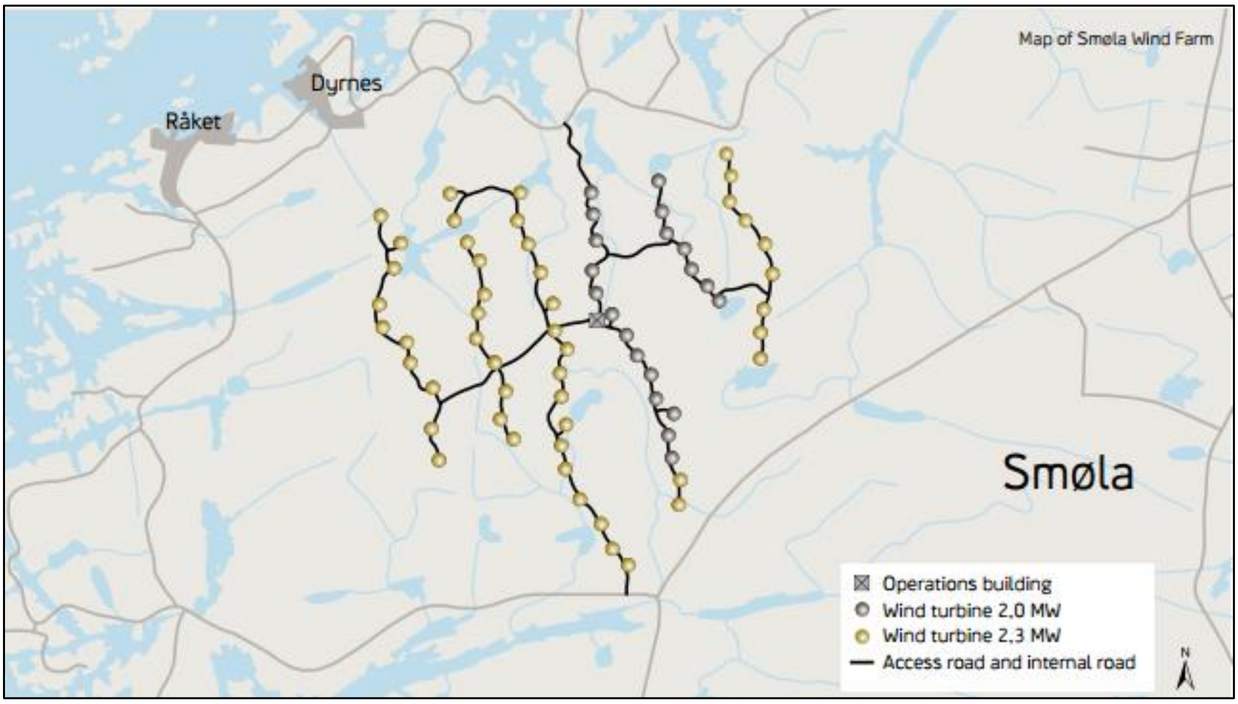

Figure 2.6: The locations of the windmills at Smøla wind power plant (Statkraft, no date-b).

The wind power plants were built in two phases, with the first phase finished in 2002 and the second finished in 2005. The different wind mills in Figure 2.6 show the two different building phases. The wind mills with 2.0 MW capacity were finished in 2002 and the turbines with 2.3 MW were finished in 2005 (Statkraft, 2010).

According to the Plan- and Building act, all wind power plants with an installed capacity above 10 MW must have an EIA (Directorate for Nature Management, 2012a). The purpose behind an EIA for wind power is to emphasis the impacts it has on the environment, natural resources and society, and to take them into consideration during planning and during the licensing process done by NVE (OED, 2007a). If the license is granted, it is valid for 25 years. This means that when the 25 years are over, the project owner needs to apply for a new license if they want to continue the wind power plant. During this licensing process, there will be done an evaluation over whether the power plant should continue its production or not based on experiences from the time the power plant was operational (OED, 2007a).

In addition to conduct an EIA for all location when planning a new wind power plant, has it in since 2005 been conducted a thematic conflict evaluation of the project in relation to nature- and environmental consideration. The thematic conflict evaluations are used as a supplementary basis for NVE during the licensing process for better assess the impacts. The licensing process has been further more strengthen by the inclusion of evaluating sum impacts, which means facilitating the licensing process for wind farms in selected regions so they are coordinated in time and viewed in conjunction with any needs and plans for strengthening the transmission network (OED, 2007a).

3 Theory

There has been done some research within comparing environmental impacts between small-scale hydropower and large-scale hydropower, and some research for measuring amount of sum-impacts. I will give an outline of these different papers below.
Then the environmental impacts from the three renewable energy production types: small-scale hydropower, large-scale hydropower, and wind power are presented followed by the four chosen parameters.

3.1 Related research

As far as I know, no previous studies have been conducted with the purpose of comparing the environmental impacts across different types of renewable energy productions, such as between hydropower and wind power. Attempts have been done in comparing the cumulative impacts from small-scale hydropower plants against the average impacts from large-scale hydropower, in what is called the small versus large debate. This research was published in 2012 by researches from SINTEF Energy in Norway (Bakken et al., 2012). The comparison of environmental impacts was made based on a similar amount of annual produced energy. The cumulative energy from small-scale hydropower was 390 GWh from 27 power plants, and the average energy from large-scale hydropower at 350 GWh from 3 power plants. The selected small-scale hydropower plants were chosen from Sogn og Fjordane, while for large-scale hydropower was two plants from Sogn og Fjordane and one from Møre and Romsdal.

The chosen plants were relatively new project within the large-scale hydropower development, because this would imply that the environmental impacts were thoroughly assessed. To summarize the environmental impacts of all the selected small-scale hydropower plants, the environmental impacts were simply summed together or counted where they were quantified and identical. For large-scale the impacts were averaged. The different values have not been valued or weighted, but listed in a matrix and systematically compared. The data used to assess the environmental impacts were based on the EIAs done for the chosen power plants, this because these assessments would give a more complete picture of the total impacts. Information taken from the assessments were then set into the matrixes and compared based on yes/no or from “largely negative” till “largely positive” statements. The results they found in this report, with the same weighting on all the impacts, showed a tendency towards large-scale hydropower having a slightly lesser degree of impact than the summarized small-scale hydropower plants.

Others have also done work in the small versus large debate. An example can be Egré and Milewski (2002), who have discussed the comparison between the environmental impacts from small-scale and large-scale hydropower. In their report they do not quantify values or compare found evidence, but that environmental impacts from different power plants depend on geometry. They argue that it is not the size that defines whether a project is renewable or not, but the specific characteristics of the project and its location (Egré and Milewski, 2002) . As a rule of thumb they state that the environmental impacts are roughly proportional to the area inundated.

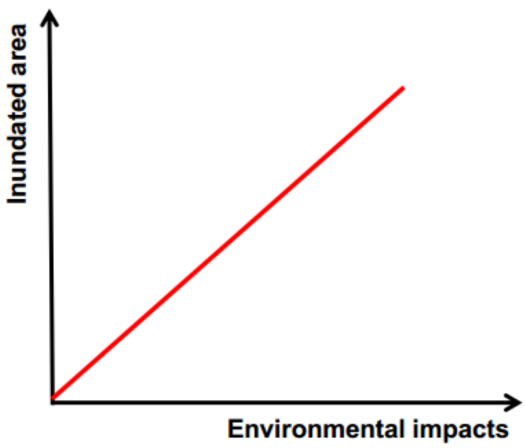

Figure 3.1: Relation between environmental impacts and inundated areas (Schmutz et al., 2010).

The concept of mapping the area inundated by a hydropower plant as a general outline of how much environmental impact the type of power production can be seen Figure 3.1 where the relationship is presented. This figure indicates that large-scale hydropower with large reservoirs have to a degree larger environmental impacts that small-scale hydropower plants without any inundated area (Schmutz et al., 2010).

Although it is obvious that small intervention on a specific habitat has fewer impacts than a very large intervention on the same habitat, they state that one should compare hydropower projects based on the energy and power produced. Egré and Milweski (2002) states in their results they do state that the impacts of a single large project might be significantly less than the cumulative impacts of many small projects, given the diversity in projects affected and in the much greater total area inundate (Egré and Milewski, 2002).

In the IPCC report SRREN published in 2012, the debate of small versus large hydropower was mentioned (Edenhofer, 2012). In this report they discuss the assumptions made from Egré and Milewski (2002), surrounding the concept that cumulative impacts from many small project might have a large impact on the environment than one large hydropower project. But they state that the environmental impacts of large versus small hydropower development remain unclear because of the low amount of research, and that all examples are highly context dependent (Edenhofer, 2012).

Another article which discusses the large versus small debate is published by Egré et al. (1999). According to popular beliefs, large-scale hydropower has greater environmental impacts than small-scale hydropower. In their article, they present a way to fallacy this perception. By comparing the units of energy produced by a single large-scale hydropower plant demonstrates that the impacts may be much less than the cumulative effects of several small projects yielding the same power and generation capacity. They do also use geometry to show that a small object has a greater surface area in proportion to its volume than a large area, and states that the true comparison lies in the energy and power requirements which must be met. Because of this, the sum impacts of a set of small-scale hydropower plants will therefore have a greater amount of environmental impacts because of the diversity of ecosystems that will be affected (Egré et al., 1999).

An article which mostly discusses the facts and fallacies surrounding water resources, who also mentions the small versus large debate, is Koutsoyiannis (2011). He states that through legislation and scientific documents, the debate of which energy production type to focus on has evidently been won by small-scale hydropower. In measuring what is most environmental damaging between large-scale and small-scale hydropower he, also, uses geometry and states that large-scale has "spectacularly increased efficiency". From calculating the geometric differences between small-scale and large-scale, he states in the conclusion that large-scale hydropower plants are superior, because only these are energy-efficient and multi-purpose, and can therefore be seen as less damaging to the environment than small-scale hydropower (Koutsoyiannis, 2011) .

In 2009 an article from the Norwegian institute for nature research (NINA) was published mapping the sum-impacts from small-scale hydropower plants in the county of Nordland in the Northern part of Norway (Erikstad et al., 2009). As map data they used the NVE resource map for potential small-scale hydropower plants. They found that many of the built small-scale hydropower plants which are built in Nordland actually was not listed in the potential resource map, which indicates that the resource map only is a sketch and illustration for the total potential. As a general evaluation they state that the authorities has established that the thoroughly environmental investigations for small-scale hydropower is not necessary, which means that the investigations conducted should be as relevant as possible.

They also found that if all the potential power plants were built, it would have an impact on the amount of encroachment-free (INON) areas in the county, and this would impact national targets related to land use. As a solution they recommend that the measure of impacts on encroachment-free (INON) areas should be seen as an actual sum-impact and should be mapped for all new small-scale hydropower projects. They also emphasis that the usage of mapping sum-impacts should be used as a systematic tool and that is helps to identify the good options to be developed and plan in a way that provides the overall best possible environmental solution (Erikstad et al., 2009).

A report that emphases the importance of environmental assessments for building new small-scale hydropower plants is L'Abée-Lund (2005). In the report he evaluated the environmental impacts from 12 micro-, mini-, and small-scale hydropower plants with digital map analysis and field surveys of the vegetation, benthic communities, and birds. This to investigate how each thematic group reacted to the establishment of the power plant. Results from the analysis indicate that the degree of conflict is largest for vegetation and birds with the establishment of new small-scale hydropower plants (L'Abée-Lund, 2005). Other research has also emphasized the importance of investigating environmental impacts, and especially on species in the river, by the building of new small-scale hydropower plants. In his report Rørslett (1989), investigated 17 Norwegian lakes before and after the establishment of a new small-scale hydropower plant. He found that large response feature in the hydrological vegetation for the lakes in question. Different responses which found were a decline in species richness, and a gradual disappearance of the shallow water and mid-depth communities (Rørslett, 1989).

There exist many different guidelines on how to conduct an environmental impact assessment, and Størset (2009) has tried to summarize parts of the methodology and practices which are suitable for evaluating the environmental impacts from small-scale hydropower plants. He lists the different elements that are investigated in an environmental impact assessment and states how thoroughly each part should be explained (Størset, 2009).

These two report are important as they show both parts of the environmental report process: what elements to assess, and how the actual impacts are after the construction of the power plant (Størset, 2009). Also, another report which emphasized the importance of proper documentation of biodiversity used in the licensing process of small-scale hydropower plants in Norway is Gaarder and Melby (2008). In this report they try to find if the total amount of red listed species in a location where there has been established a small-scale hydropower plant, and if the findings of red listed species have been reported to the licensing authority, and what/if is the reason to why this has failed to be done. Some of the answers they list are that the people conducting the search for red listed species often concentrate their search on the direct water stream, while excluding the nearby locations, while they found that almost half of all the red listed species where located in the nearby area. Also, that the researches conducting the search often lack the proper knowledge to spot the red listed species in the surrounding vegetation. Different proposed solution which they present for enhancing the mapping and collection of red listed species is to use mappers with better knowledge of these species, an increased knowledge at the licensing authority and further develop their control procedures (Gaarder and Melby, 2008).

3.2 Environmental impact

For analyzing and discussing environmental impacts, one needs to know what is meant by the terms environment and impacts. Environment is a complex term that refers to all living and non-living components that makes up what surrounds an organism, and can be described through a set of different natural qualities (IUCN, no year). The term impact is meant by shocks and disturbances that occur to the natural environment and creates changes in its surroundings. When combining these two terms into environmental impact, the word means the shocks and disturbances that occur to all living and non-living things that makes up the surroundings of an organism.

The environment within an area can be defined as either terrestrial or aquatic. The terrestrial environment is defined as the environment which is not related to the water string, but can be affected by the building project. Aquatic environments are defined as the environment related to the water string and will be affected by hydrological changes (Størset, 2009). Even though it might sound as there are a distinct separation between terrestrial and aquatic environments, this is not the case. They have fleeting transitions and both environments can be affected by the same impact, but have different responses.

There is also a distinction between direct and indirect impacts. Direct impacts are meant by an actual negative change in the conditions in the river such as building a wall which turns a part of a river into a reservoir. While indirect impacts are changes in the physical or chemical environment that causes a change in the habitats for plants and fishes in the river, which can be caused by an eventual acidification from stagnant water (Bakken et al., 2012). Changes in the physical or chemical environments is not necessary harmful on its own, but might lead to a degradation in the longer term because it changes the living conditions for species (Erikstad et al., 2011).

An associated element with the development of small-scale hydropower, large-scale hydropower and wind power is the term sum-impacts. This means that the cumulative impacts of many small encroachments within one defined area can be higher than impacts from one single large encroachment (Erikstad et al., 2009). There are two objectives for analyzing the sum-impacts from power plants. First, the direct consequences which might occur of a number of planned projects within an area, and second: it is an important tool for analyzing what the impacts translates into on a larger extent (Erikstad et al., 2009). These two objectives are important because different impacts have significance on different levels. Local impacts might only have local effects, but the sum of a series of impacts on a local level might create effects that affect regional or even national level. An example here can be red listed species where the impacts might occur on a local level, the effects will be on a national level, since the red list classification is an official representation of threatened and vulnerable specie (Erikstad et al., 2009, OED, 2007a). An example on how the sum-impacts can be addressed as a concept in the licensing process can be taken from Sørfjorden, a fjord in the county of Hordaland in the Western part of Norway, where NVE had a total of 10 licensing applications during the same time period. Here it was conducted a combined evaluation with a special emphasis on landscape, tourism and outdoor recreation. As a result, 6 small-scale hydropower plants were granted a license, while 4 power plants were rejected (Flatby, 2013).

When mapping and assessing what impacts renewable energy sources might have on the environment, it is difficult to know which impact is more important than the others. In order to conduct a more consistent assessment, a list with the most common environmental impacts has been compiled. This is intended to be a checklist for both power project planners and authorities for assuring that an application and an EIA and EA have considered the relevant consequences (Størset, 2009).

3.2.1 Environmental impacts from small-scale hydropower

Small-scale hydropower is regarded as green and environmental friendly energy because it does not have emissions of greenhouse gases during energy production, but there is no doubt that the production type involves infrastructure development that causes impacts on the natural environment (Erikstad et al., 2009). The establishment of a new small-scale hydropower plant causes direct influence on the river or stream by changes in water flow, fragmentation of habitats in and by the river, and area usage changes.

Figure 3.2: River section between intake and outlet at Dale small-scale hydropower plant. Source: Tor Haakon Bakken.

Figure 3.2 shows the built waterway at Dale small-scale hydropower in Sogn og Fjordane. The part of the river which is shown on the picture is the set between the intake and outlet of water. As one can see, this part of the river has a very low amount of natural flowing water.

The influences on water from small-scale hydropower development relates to changes in natural flow and amount of water, the distribution of water in the river throughout the year, and the release of water below the power station. Many species that live by or in the river might be dependent on continuously moisture supply from the flowing river, and a reduction in water flow might destroy their habitat. The building of small-scale hydropower plants does to a lesser degree have an impact on fish species, compared to large-scale hydropower, as these power plants are mostly located in rivers and streams which are not suitable for fish populations (L'Abée-Lund, 2005). The impacts on the water ways can either be short-termed and only related to the construction period during the building of the power plant or they can be long-termed and last for a long time after the power plant has been completed.

The establishment of a new small-scale hydropower plant might impact the watercourses importance in the environmental scenery. The water is a central element in the landscape in many areas and an encroachment might have a large impact on the overall impression. Important esthetical values are the contrast between deep, slow-flowing water and the fast flowing rapids and change between low side vegetation and trees along the river bend. Landscape experiences related to watercourses is key point in the construction of small-scale hydropower plants. This applies to both long waterfalls and slow flowing stretches.

There are published several guidelines and reports concerning environmental impacts on biodiversity from small-scale hydropower development. Examples can be (Erikstad et al., 2009, Erikstad et al., 2011, Kålås et al., 2010, L'Abée-Lund, 2005, Størset, 2009, Sægrov and Fimreite, 1999). They do all highlight different aspects, but they all emphasis the lack of information for project planners in collecting the best possible environmental information, but also the lack of information of what the actual impacts are after the power plant has been established. Most consulting firms which conducts EIAs or EAs for small-scale hydropower plants uses a guideline published by NVE (Korbøl et al., 2009). In this guideline not much is stated about the subject methodology for the collection and valuation of biodiversity (Størset, 2009).

There are several known species who are affected by the building of a new small-scale hydropower plant, but one example can be *Fossekall (Cesiun censiun*), a bird which is site specific in its location and the need for a continuous spray of water. Other red listed species which might be affected by the establishment of a new small-scale hydropower plant is fungi and lichens which grow on rocks in or close by the river. Changes might also cause damage in possible nesting grounds for birds such as Hubro (*Bubo bubo*). Other changes which occur in the chemical and physical conditions in the river might change the water temperature to reach a level which is above what the specie can endure. An example here can be the removal of side vegetation which is a key element in regulating the amount of solar radiation in the river during warm periods. By removing this vegetation, the result is higher maximum temperature in the river during warm periods of low water flow and greater fluctuations in temperature throughout the day (Directorate for Nature Management, 1994)

Figure 3.3: Area directly affected at Sværen small-scale hydropower plant. Soure: Tor Haakon Bakken.

Figure 3.3 shows the area encroachment from the establishment of Sværen small-scale hydropower plant in Sogn og Fjordane. The area usage associated with the building of new power plants is primarily related to the development of road infrastructure, building of pipelines, and the need to strengthen the existing power grid (Sægrov and Fimreite, 1999). The different extent of these procedures varies widely between the individual projects, but can be extensive. The amount of area usages depends on factor such as distance to existing roads, route selection, site conditions, and the size of the plant. In addition, the availability of loads and handling of mass surplus/deficit affect the scope of intervention. Not only roads and transmission lines needs to be build, but also technical installations and buildings are a natural part of the project. Technical installations include water intake with an associated dam, power production house, outlet area of water, and additional area for handling and storing equipment and construction materials (Erikstad et al., 2011).

Building new small-scale hydropower plants does also affect the areas which are categorizes as encroachment-free areas (INON) areas, and creates a "piece by piece" fragmentation of the untouched areas that Norway has left. This has received extra attention after the last official mapping of INON areas was published in 2008 by the Directorate for nature management. This "piece by piece" fragmentation of the encroachment-free (INON) areas is one of the most used arguments towards the continuous building of new small-scale hydropower plants and has set the usage of sum impacts in small-scale hydropower planning on the agenda.

3.2.2 Environmental impacts from large-scale hydropower

Environmental impacts from large-scale hydropower are well documented based on the size and amount of encroachment which originates from the project. Mapped impacts are changes in flow patterns, generation of ecological changes from terrestrial to lake-environment in the reservoir areas, land use changes, and construction activities from building the project. By having such a large variety of impacts, large-scale hydropower plants has been perceived as having the largest amount of impacts and the most controversy (Egré and Milewski, 2002).

The reservoir for a large-scale hydropower plant has large environmental impacts on the area it covers. One important impact from storing the water in reservoirs is the sudden releases of water when there is energy production. The water which is released is cold water from the bottom of the reservoir, which then flows down the river below the power plant. This water is much colder than the original temperature in the river and is damaging for the aquatic species. There are also strict rules and regulations to maximum and minimum water levels within the reservoir. Many people have stated that the visible difference between maximum water level and the actual water level is an aesthetic scare in the environment. This level which is covered by cold, melt water some parts of the year is often laid bare as the reservoir is drained for the energy production during the colder seasons.

Large-scale hydropower plants affect the river's ecology by creating a change in the rivers hydrological characteristic and by disrupting the continuity of sediment transport through the building of the dam. But to what extent the rivers physical, chemical and biological characteristics are modified depends on the size of the project. The creation of a reservoir for hydropower storage is a large environmental change as it transforms a running fluvial ecosystem into a still lacustrine one. The extent to which a large-scale hydropower plants has severe environmental impacts are highly site specific and to a certain degree dependent on what resources can be used for mitigation measures.

Figure 3.4: Water level in Tunsebergdammen, reservoir to Leirdøla large-scale hydropower plant. Source: Tor Haakon Bakken.

Figure 3.4 shows the Tunsebergsdalsdammen, which is the reservoir to Leirdøla large-scale hydropower plant located in Sogn og Fjordane. The picture is taken in May when the water level in the reservoir is low due to the power production during the previous winter and one can clearly see the area between maximum and actual water level.

Large-scale hydropower generation changes the water flow in the direct affected and nearby rivers. Quantities of freely flowing water are removed from the rivers and dammed up into a reservoir. This causes deprivation of water, changes in water courses, and changes in the living environment for species dependent of flowing water (OED, 2013). One that the changed water flow has a large effect on, is the well-known salmon, which life cycle has been severely interrupted by the building of large-scale hydropower plants in many large rivers (Aubrecht, 2006). Although there are regulations regarding the minimum measure of water flow in the rivers below the intake, the sudden releases of cold water when the energy is being produced, damages the living environment. It has been shown that this type of sudden discharge into rivers have a considerable higher potential to cause negative impacts on physical and biological conditions compared to hydropower plants that discharges into either a reservoir or lakes (Harby, 2012). Even though the impacts on fishes and other aquatic living organisms are important, they are not one of the factors evaluated in this thesis.

When building a new large-scale hydropower plant with a reservoir, the damming of water will convert some amount of terrestrial environment into an aquatic environment (Frey and Linke, 2002). This can create loss of habitat and species biotopes through inundation, and changes in the chemical composition and water temperature (Edenhofer, 2012). In Norway the reservoirs are usually located in mountainous areas, narrow valleys and areas where very few people live. Storage reservoirs are often situated upstream from major population centers and this might presents a considerable risk in event of dam failure, such as might be expected from an earthquake (Koutsoyiannis, 2011). Norway has thus no history of large earthquakes which have cause such catastrophes and the building requirements are strict to avoid catastrophes of any type related to dam disruption.

Norway do not have a history of establishing large-scale hydropower with reservoirs in areas where many people live, such as the case of the Three Gorges in the Yangtze river in China where 1, 2 million people where displaced (Heming et al., 2001). Since Norway has located its large-scale hydropower reservoirs in mountainous areas, the chance that these areas were encroachment-free before the project started, is high. The area which is most likely to affect and reduce the encroachment-free areas is the extension of the reservoir.

3.2.3 Environmental impacts from wind power.

Wind power is environmental friendly energy and in comparison with other energy production types, the environmental impacts are relatively minor in terms of pollution. But this type of renewable energy has a high cost, namely the loss of natural quality (Kålås et al., 2010). Environmental impacts listed in literature originating from wind power are visual impacts, noise pollution, conflicts with conserved areas, and impacts on biodiversity (Abelsen, 2007).

Area usage by wind power plants are not among the most discussed impacts, even though windmills require a safety zone of approximately 500 meters in all directions because of risk for the windmill or the wings to wholly or partly falling down, of lumps of ice are thrown into the air (Holter et al., 2010). Many windmill farms are located in areas without human settlement, which often implies that these are areas located away from heavier technical encroachment and might therefore be classified as encroachment-free (INON) areas (Directorate for Nature Management, 2012b). If the area has been classified as encroachment-free (INON) area, the establishment of the wind power plant might have cause a reduction of the total area in Norway.

Impacts such as visual and noise pollution can be a challenge, both for humans and birds (OED, 2013). The building of wind power plants occupies large areas and represents major infrastructure development. Because of large area usage and the noise pollution, wind power development are generally concentrated on larger sites where there are good wind conditions (OED, 2007a, Follestad et al., 2007). Visual impacts, and especially how wind turbines and related infrastructure fit into the surrounding landscape, are often among the top concerns for municipalities considering establishing wind power plants. Moreover, wind turbines and power plants have grown in size, making the turbines and related transmission infrastructure more visible. Also, as wind power plants increase in number and geographic spread, plants are being located in a wider diversity of landscapes.

When planning a new wind power plant, a major concern by the public is the visual appearance of several kilometers of windmills with associated transmission lines. Visual impact is of great importance for communities, second home residents, and might cause decreased interest in important local tourist attractions. Wind turbines are often placed in an open terrain to have the best access to the wind resource. This changes the character of the landscape from an open, almost untouched area, into an area visually dominated by technical installations for power production. Wind power plants are often thought of as large area consumers, but by summarizing the area within a power plant which is directly used by connecting roads and the area the turbines are bolted to the ground, only one till three percent of the total area is used (Abelsen, 2007). If the total area of the wind power plant is taken into consideration, a utilization of approximately 5 - 10 MW/km^2 is expected (Edenhofer, 2012). This applies to all wind power plants in Norway, but of course this estimation might vary between each wind power plant according to different area designs and capacity of the wind turbines.

One of the environmental concerns which have had the highest media reach surrounding wind power production is the bird and bat fatalities through collision with wind turbines. Wind power plants can also cause impacts on habitats and ecosystems through avoidance or displacement from an area, habitat destruction and reduced reproduction from affected species (Edenhofer, 2012).

Figure 3.5: Remaining feathers from a bird fatality at Smøla wind power plant. Source: author.

Figure 3.5 shows the remaining feathers after a bird-turbine collision at Smøla wind power plant in May, 2012. There were found no bird, so either had the bird only been hurt and was able to move away from the site, or the dead bird had been taken away and eaten by predators. The differential pressure gradients around the wind turbines can be a problem for birds. The island Smøla has a particularly high breeding density of the white-tailed sea eagle *Haliaeetus albicilla*, which is estimated to contain more than 50 breeding pairs (Bevanger et al., 2009). The European population is estimated at 5000-6600 pairs and comprise more than 50 % of the global population (Dahl et al., 2012). As a result of the population increase the species has been down-listed to “least Concern” on the IUCN Red List, which is the international red list (IUCN, 2009). Norway is a stronghold of the white-tailed eagle and has approximately 40 % of the European population (BirdLife International, 2002). Therefore Norway have a species responsibility for management because population development in Norway is essential to the species existence in the European perspective (Ministry of the Environment, 2004).

Records from the investigation done by NINA researchers at Smøla between 2005 – 2010 shows, based on weekly searches throughout the year, an average of 7, 8 sea eagles in the searched area. There has been a large variety of annual death of sea eagles, ranging from 2 till 11 (Bevanger et al., 2010). From the pathological investigations of the dead eagles, result shows that the birds have been exposed to massive mechanical forces (Follestad et al., 2007). From the findings done in 2012 by Reitan, shows that there were found 6 sea eagles, all deceased from collision with the wind turbine. The six sea eagles were also found at six different wind turbine, which indicates randomness to which wind turbine the collision occurs at (Reitan, 2013). Findings from the investigations done by NINA for the sea eagle shows that the reproduction both inside and outside the windmill farm has declined after the windmills were built. But it is not only the white-tipped sea eagles that have fatal encounters with the wind turbines, also birds such as: seagulls, northern bat, and grey goose (Follestad et al., 2007).

Other research done on the sea eagle at Smøla has been done by Dahl et al, in (2012). In their article they assessed the impacts from wind power plants on the breeding success of birds, and showed that there was a negative effect of the wind power plants on the proportion of successful breeding attempts of the white-tailed eagle in territories close to and within the wind farm. And another factor that birds killed by the turbines are not replaced by immigrants. In their findings, they found that the population had moved from the power plant to a location to the northwest on the island (Dahl et al., 2012).

3.3 Standardized parameters

The comparison of environmental impacts from different renewable energy sources are a new research field, here particularly between hydropower and wind power, which is methodological very challenging. For making a comparison of environmental impacts, four different parameters have been chosen. The four parameters chosen are area directly affected, visibility, red listed species and encroachment-free areas, and are presented below.

3.3.1 Area Directly Affected

One of the most important factors when building a new power plant, no matter what type of energy production, is the area directly affected. This is meant by the area that surrounds the project, where the dams and wind power plant are located, construction roads are build, and the rivers loses its natural water flow. All types of energy productions use some degree of land, even though the total amount of area has a large degree of variation. The phase in a new renewable energy power project which decides the amount of area usage is the planning, and the best location should be chosen for the project without being bound to existing ownership (Backer, 2002). Different guidelines have been published to show the approximately amount of area power plants use (OED, 2007b, OED, 2007a, Statkraft, 2009), but there are no clear methodology how to assess the extent of the impact from the area usage.

As stated, most energy production technologies have different ranges of land requirement. A variety of metric has been used in the literature to describe and compare land requirements by different technologies. Examples here are area occupies (m^2/kW) and percent effective land use (Edenhofer, 2012). For most renewable energy source, land use requirements are largest during the operational stage, as the power plant after some years are adapted into the environment, and construction sites are turned back to its original state. One element that is important with area sage is the quality of the area used for the power production, and the duration and reversibility of the land transformation. In particular, the assessment of environmental impacts of land transformation is very complex, but this element will not be assessed in this thesis.

Figure 3.6 shows a predefined description of the expected area usage for building a small-scale hydropower plant. This figure shows that there is more than just the river which has area alterations. The construction roads have in some cases already been established if there are any tractor roads, or alike, beside the location.

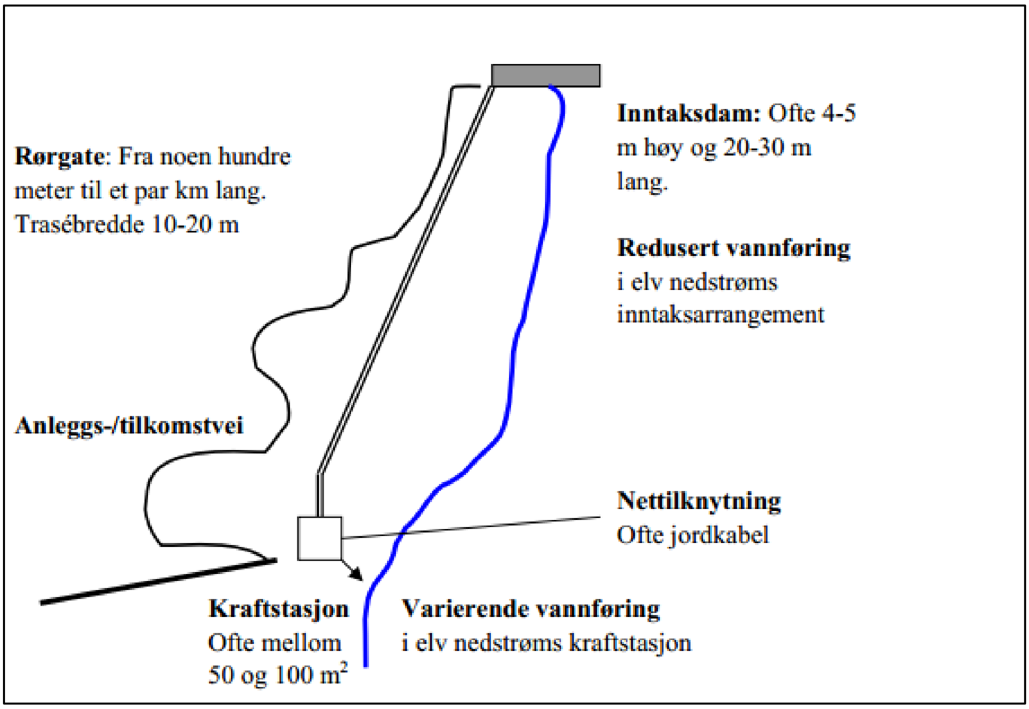

Figure 3.6: Estimated area usages for small-scale hydropower plants by OED (OED, 2007b).

Figure 3.6 shows the guidelines which are only given as an indication and the approximately measures cannot apply to all small-scale hydropower plants. It is therefore important to provide better knowledge on area directly affected before one can state how different impacts affect the environment.

One of the elements that represent a significant environmental impact in building new power plants is road construction, if a road is not already established. The construction of permanent roads to power plants can be combined with other business interests and user needs, such as forestry, recreation and access to recreational buildings. The roads are generally maintained by the commissioning of the plant for maintenance and monitoring, while the vegetation around the buried pipelines will hide the construction sides as it grows. Burying the pipeline is often justified in environmental considerations, but the burying represents a major intervention in the area for the pipeline route, length of pipeline and deposits of any excess masses affects land use and possible mitigation measures (Erikstad et al., 2011).

In particular, the assessment of environmental impacts of land transformation is very complex, with many methodological challenges yet to be solved. It should be noted that land requirements for the establishment of future energy systems may be substantial with the growth of renewable energy (Edenhofer, 2012).

3.3.2 Visibility

Norway is a country blessed with beautiful scenery from coast till mountain plateaus, and many tourists migrate to Norway to get a glimpse of our nature. The landscape is an essential part of our natural resource base, as it is a valuable recreational resource, and evokes cultural and spiritual responses to our quality of life (Teigland, 1994). We live in a contemporary reality that makes it possible to visualize most of what we plan to do in our environment, and it has emerged a conscious opinion that requires and expects us to do so. The Norwegian coastal water has generally good visibility as it may cover an area more than 25 kilometers on half of all days in a year (Simensen, 2007). Because of this reason, it is important for new energy projects in the planning process to show what the different close- and remote effects are, visibility from different viewpoints, and how visible the establishment of the plant will be in the surrounding areas.

The location of a new power plant might have caused a burden or stress to the environment and might thereby change how people view it. Location of renewable energy plants can be unfortunate for the appearance of an area (Sægrov and Fimreite, 1999). Even though visibility in itself is not an environmental impact, it is a parameter that holds great importance. However, being visible is not necessarily the same as being intrusive. Aesthetic issues are highly subjective and proper siting decisions can help to avoid any aesthetic impacts to the landscape (Ramos and Panagopoulos, 2010). Visualization is an important factor and should be implemented in all phases for planning, to ensure local knowledge and involvement. The earlier the impacts can be envisioned for the public and decision-makers, the better grounds are established for making the project more adapted into the environment.

The fjord landscapes in Norway have qualities of regional, national and international value. Some of them, as Geiranger and Nærøy is on the UNESCO list over the world natural- and cultural heritage list and is thought of to be one of the most spectacular and beautiful fjord landscapes in the World (OED, 2007b).

In Norway many people use nature for recreational purposes and have a special attachment to the feeling of being outdoors. Different emotional characteristic are related and associated with a landscape, and this is independent of the use of the area. Any change in a landscape will cause conflict to a greater or lesser degree. An example of the emotional attachment people have to nature can be the development of the “monster lines” in Hardanger in the Western part of Norway. Here, people positive attitudes and emotional connection to nature caused large conflicts and demonstrations towards the development of a new transmission line between Sima and Samnanger, across Hardangerfjorden.

In earlier years, agriculture and forestry were the biggest contributors to landscape changes, as today the driving forces are more complex. Today, the development of power plants in Norway together with road constructions is one of the factors that have contributed to major changes in natural landscapes. These elements does also relate to the subjective experience of the landscape. There is no doubt that changes in landscape appearance can affect how people perceive it, where for many people the introduction of a foreign element such as a power plant will decrease the experience of a natural area (Tangeland and Aas, 2010).

More generally, a rethinking of traditional concept of “landscape” to include wind turbines has sometimes been recommended, for example, setting aside areas in advance where development can occur and others were it is precluded (Edenhofer, 2012).

3.3.3 Red Listed Species

In today's society, many species are on the brick of extinction. A high number of these threatened species have become so because of human activity and environmental alterations of their habitats, such as fragmentation and destruction (Kålås et al., 2010). In Norway it is a national strategy for decreasing the loss of biodiversity and the red list has given this problem great attention.

The Norwegian red list for species was last published in 2010 by Artsdatabanken and is a ranking of species to what degree they might go extinct from Norwegian nature. Vulnerability is here used as the degree to which a system is susceptible to cope with change. In Norway, a total of 2398 species have been classified as threatened and 1284 as almost threatened (Erikstad et al., 2011).

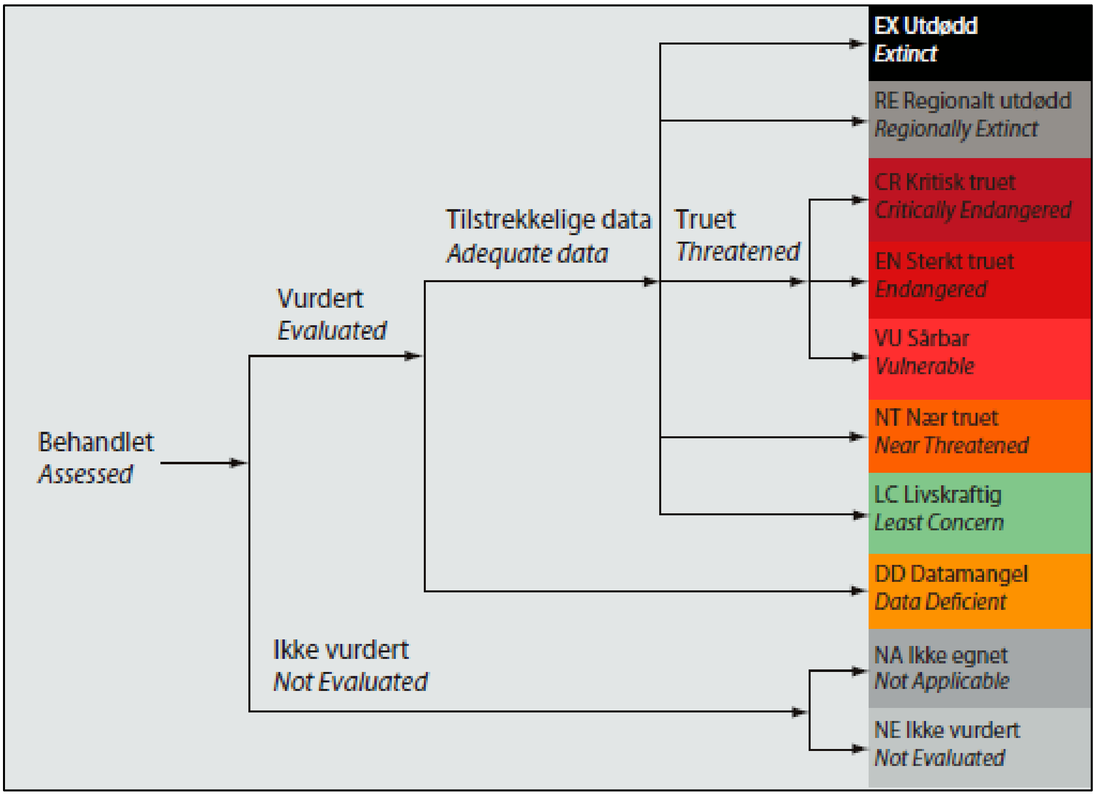

Figure 3.7: The different categories within the red list classification (Kålås et al., 2010).

Figure 3.7 shows the different categories within the Red List classification system. The threatened and vulnerable species are categorized as: CR, EN, VU and NT. The class DD is also important as it may contain species which have not been properly mapped. No less than 87 percent of the threatened and near threatened species on the 2010 Red List have been or are negatively affected by human-induced land-use changes (Kålås et al., 2010).

The most obvious effect of land-use changes it that an area has changed so much it no longer remains a suitable habitat for the species. Reduced habitat quality can result from changes in insolation, altered moisture, poorer access to food, increased competition with other species, poorer opportunities to find concealment, amongst some. In cases where habitats have been altered or reduced, it may take time for the effects on the population to become visible (Kålås et al., 2010, Berntsen and Hågvar, 2010).

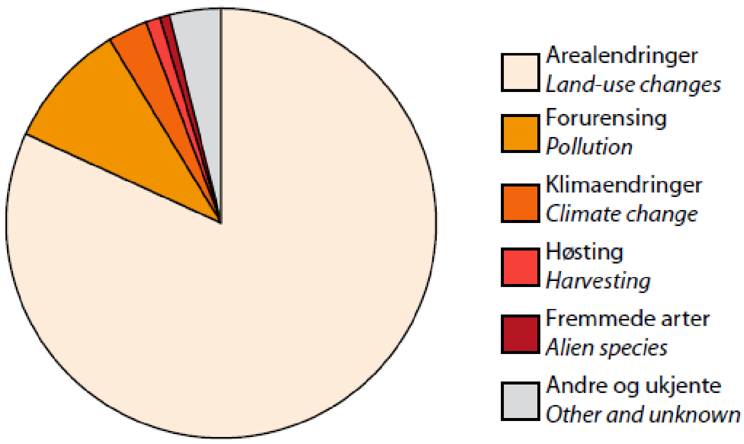

Figure 3.8: Changes that causes loss of biodiversity (Kålås et al., 2010).

Figure 3.8 shows a diagram over the five major global threats to biodiversity. As one can see, land-use changes are by far the biggest reason. One important effect from land-use change is habitat fragmentation. Fragmented landscapes influence movement and dispersal of organisms, rates of gene flow, and invasion by competitors among many other factors (Heywood and Iriondo, 2003).

New renewable energy production projects that are in conflict with biodiversity of a medium or larger value are expected to implement orders on mitigation measures to reduce the conflict (OED, 2007b). The findings and identification of red listed species can delay or even stop a power project and may lead to changed measurements for creating the least possible impact. For the licensing authority, the presence of red listed species is a difficult challenge because of lack of knowledge surrounding the occurrence and vulnerability of the species (ibid.).

3.3.4 Encroachment-free areas (INON)

As previously stated, Norway is a beautiful country which has large mountain areas which is known and thought of as areas untouched by humans. Norway has special responsibility to preserve a representative sample of our fjords, coastal-, and mountain areas, which are areas not found equivalent elsewhere. Seen from a natural scientific perspective it is a well-known fact that our nature needs a continuous management of encroachment-free (INON) areas, or our last remains of wilderness might disappear very quickly (Skjeggedal et al., 2005). It has therefore become a political and administrative objective to mitigate the loss of these untouched areas (Berntsen and Hågvar, 2010).

With the technological development and the steadily increased use of natural resources has led to a gradually loss of encroachment-free (INON) areas in Norway, especially during the last 20-30 years (The Directorate for Nature Management, 1995). The changed use of remote areas for different purposes has led to a "piece by piece" fragmentation. The impacts from road development, the building of renewable energy such as wind and hydropower, pipelines, and commercial and residential purposes stands as the biggest threats against encroachment-free areas (ibid.). The tool encroachment-free areas (*Inngrepsfrie NaturOmråder i Norge – INON*) was established as an indicator of the changing area uses over time, and for giving status on nature without heavier technical encroachment in Norway. The last official mapping of the encroachment-free areas in Norway was done in 2008. In the official mapping, areas which are located more than 1 kilometer away from heavier technical encroachment are classified as encroachment-free areas. These encroachment-free areas are then divided into zones after the distance they have to the nearest technical encroachment. Table 3.1 lists the different classifications.

Table 3.1: The four classifications of encroachment-free areas (Skjeggedal et al., 2005).

Encroachment-near areas:	*<1 kilometer away from heavier technical encroachment*
Encroachment-free zone 2:	*1-3 kilometers away from heavier technical encroachment*
Encroachment-free zone 1:	*3-5 kilometers away from heavier technical encroachment*
Wilderness like areas:	*>5 kilometers away from heavier technical encroachment*

Encroachment-free areas are considered to have species value for the society since these are areas where most of our animal- and plant species live, also including threatened and vulnerable species (Kålås et al., 2010). Extra focus is given to the areas which are located more than 5 kilometers away from heavier technical encroachment, also called wilderness like areas. These areas are called wilderness like areas, as they are the furthest to wilderness the Norwegian areas has (Skjeggedal et al., 2005).

Today, approximately 45 percent of Norway's nature is defined as encroachment-free areas, where fewer than 12 percent can be classified as wilderness like areas (Skjeggedal et al., 2005). Table 3.2 lists the different construction measures that are classified as heavier technical encroachment.

Table 3.2: Different infrastructure elements included in the INON methodology (Skjeggedal et al., 2005).

Elements included in the INON methodology
- Public roads and railroads longer than 50 meters. Tunnels are not included.
- Forest roads longer than 50 meters.
- Tractor-, agricultural-, construction- and mountain pasture roads in addition to other private roads longer than 50 meters.
- Old roads renovated for tractor use, equivalent to tractor road class 7/8 (which is roads used for transportation of lumber and agricultural products) or roads with better standard.
- Approved bare ground courses (in the county of Finnmark).
- Massive towers and wind turbines.
- Larger stone quarries and soil extraction sites.
- Larger ski tow, ski hills and ski slopes.
- Power lines built for voltage of 33 kV or more.
- Reservoirs (all water at highest regulated water level), regulated rivers and streams ➢ Applies to regulated rivers and streams where the water flow is increased or decreased. ➢ Mainly applies to reservoirs where periodic regulation involves an increase or decrease of water levels of one meter or more. ➢ The water flow all the way to the sea is considered as infrastructure.
- Power stations, utility lines above ground, canals, retaining walls and flood protection.

The classification measures listed in Table 3.2 are all impacts that will change the original state of the environment in an area that makes it difficult or impossible to restore (The Directorate for Nature Management, 1995). As seen from the table above, not all kinds of infrastructure are included, examples such as cabins and dirt roads. This will make the classification not consistent to what is affected by encroachment and what is not.

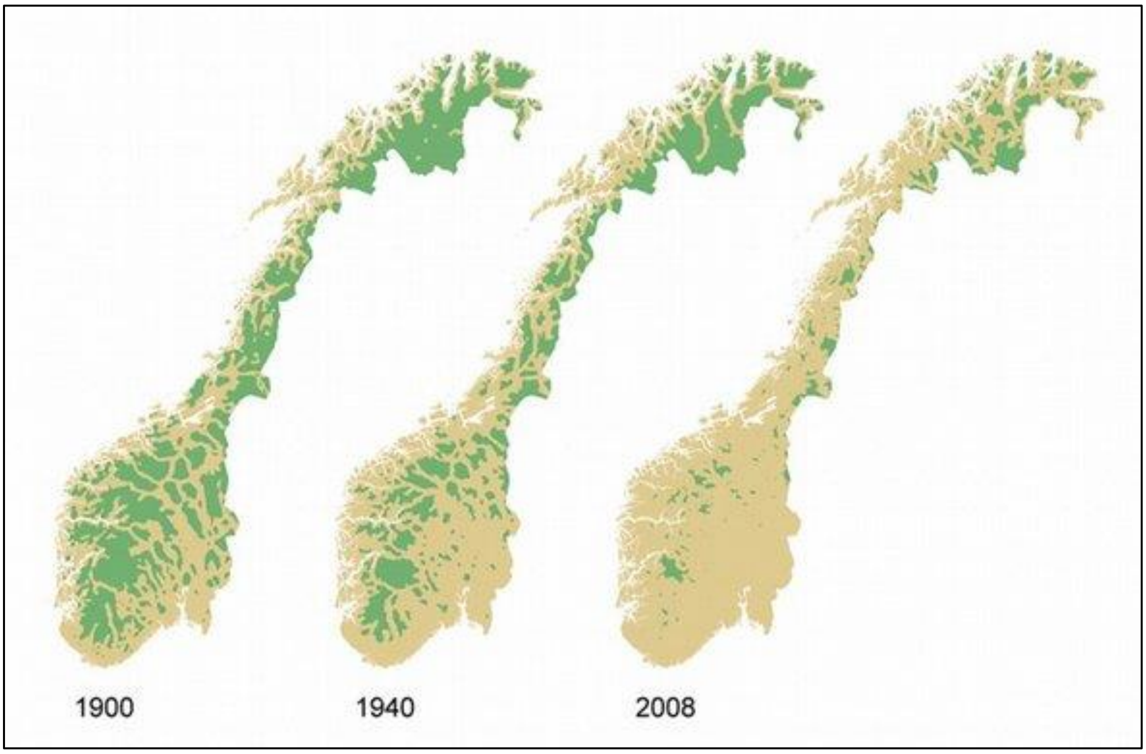

Figure 3.9: The gradual disappearance of INON areas from 1990 till 2008 (Directorate for Nature Management, 2012c).

Figure 3.9 shows the gradual disappearance of INON areas from 1900-2008. The loss of encroachment-free areas in Norway is negative, and that over 1000 km ^{2} of encroachment-free areas were lost in the period from 2003 – 2008, and 40 percent of this were lost due to energy development (Directorate for Nature Management, 2011). An example here can be the county of Sogn og Fjordane where the loss on encroachment-free areas between 2003-2008 was 96 km^2 (Directorate for Nature Management, 2011). A new official mapping is in project this year (2013) with an expected publishing in the end of 2013 and will contain a status from January 2013.

4 Methodology

In the following chapter, I will present how the mappings of the four standardized parameters for calculate the environmental impacts from the three renewable energy production types have been done.

4.1 Datasets and metadata

All the data which have been used in this thesis have been downloaded from the Norwegian Mapping Authority (www.norgedigital.no) and Artsdatabanken (www.artsdatabanken.no), and made available to me by my supervisor. All the downloaded datasets are secondary data collected by highly qualified workers at governmental departments, such as the Norwegian Water Resources and Energy Directorate (NVE), the Directorate for Nature Management (DN).

The downloaded maps used as source layer are N50 maps at a scale of 1:50 000 and covers the mainland of Norway and the territorial sea, and has an accuracy of +/- 2 to 50 meters (Berge, 2008). The N50 dataset contains information of terrain, settlement, roads, and more. It was decided to use N50 data for the analysis because N50 is the most detailed nationwide dataset in Norway (Kartverket, 2012). The different datasets which have been downloaded from the National Mapping Agency are N50 data, datasets on pipelines, water intake, location on power plants, and information on encroachment-free areas from the last official mapping in 2008 by DN. The information on red listed species was downloaded from Artsdatanbaken.

The downloaded data was used as they are after being converted to a common spatial reference (UTM coordinates). Data downloaded from Artsdatabanken are from a database that is continuously updated when new information is available, while the data on hydropower plants downloaded from Norwegian Mapping Authority are only updated once a year. This can make the downloaded data outdated compared to what information which is available today. All the information was downloaded in November 2012. For more information about the downloaded data, see Appendix A.

4.2 Selecting power plants

For comparing the environmental impacts from three different renewable energy sources by the usage of four parameters, a common basis which allows for a comparison is needed. The decision was made to use the same amount of annual energy production, which was done by Bakken et al. (2012) in their report and mentioned by Edenhofer (2012), in the IPCC report as a good foundation for comparing environmental impacts (Bakken et al., 2012, Edenhofer, 2012). Due to time constraints, the decision was set on using only one wind power plant, Smøla, which has an annual energy production of 356 GWh/year. Though Norway has many wind power plants located around the country, the choice of using Smøla in this analysis was based on the fact that it is the largest wind power plant in Norway, but it has also the most thoroughly research on the environmental impacts. Since only one wind power plant was to be used in the analysis, the annual energy production from Smøla was set as the energy base.

The different hydropower plants (both small-scale and large-scale) were chosen from the same region, the county of Sogn and Fjordane, to ensure that the identified impacts would not differ due to differences in topography, climate and biological characteristics. For selecting hydropower plants, the same procedure from Bakken et al (2012), was used: choose randomly small-scale hydropower plants which combined produced an set amount of energy (Bakken et al., 2012), as in this thesis, the energy base set by Smøla. Three large-scale hydropower plants were chosen to create a more robust result by using the average impacts from the plants in the analysis, and comparing them against the cumulative impacts from a set of small-scale hydropower plants and the annual energy production from one wind power plant. The amount of annual energy production was gathered from NVE's web pages and corresponds to the information available in October 2012. Different numbers are listed to what Smøla's annual energy production is, but the information used in this thesis have been collected from Statkraft (Statkraft, no date-b). Table 4.1 shows the amount of annual energy production from the different renewable energy productions and the amount of power plants used in this thesis.

Table 4.1: The annual energy production and amount of power plants chosen. Source: author.

Power production	Annual production	Number of power plants
Small-scale hydropower	350 GWh	27
Large-scale hydropower	347 GWh	3
Wind power	356 GWh	1

For the random selection of small-scale and large-scale hydropower plants within the county of Sogn og Fjordane, the downloaded datasets on power plants from the National Mapping Authority were used. Here, the power plants were rated into either small-scale or large-scale after the national classification of 10 MW, and then randomly chosen till I had an annual energy production which came as close as possible to Smølas production. Table 4.2 lists the power plants with name, power plant number, and annual energy production.

Table 4.2: The 27 small-scale hydropower plants and their annual energy production. Source: author.

Name	Power plant nr.	Annual production
Skolten	1341	6,30 GWh
Frammarsvik	1491	9,48 GWh
Kråkenes	1361	8,96 GWh
Sagevikelv	823	16,50 GWh
Dale	836	9,00 GWh
Kaupanger 3	1493	11,70 GWh
Steindøla	1456	9,08 GWh
Kandal	1521	20,45 GWh
Skjerdal	1434	24,43 GWh
Øvre Årdal	1441	11,00 GWh
Nedre Årdal	1497	7,30 GWh
Jardøla	1425	20,21 GWh
Vanndøla	1410	12,80 GWh
Sanddal	1569	11,40 GWh
Hjelle	1357	12,84 GWh

Kvåle	1465	19,50 GWh
Egge	1378	18,90 GWh
Bjørndalselva	1242	17,40 GWh
Rognkleiv	1243	11,28 GWh
Trollelva	1237	4,83 GWh
Nydal	839	7,30 GWh
Vindedal	1231	15,00 GWh
Rivedal	825	15,60 GWh
Brekkefossen	1247	18,01 GWh
Neselva	803	12,50 GWh
Hugla	834	5,50 GWh
Sandal	807	12,50 GWh
27 power plants		Total = 350 GWh

The cumulative annual energy production from the 27 small-scale hydropower plats was 350 GWh/year. For the comparison of environmental impacts, the average value of three large-scale hydropower plants was used. Table 4.3 shows which power plants were selected for the analysis, their individual annual energy production and power plant number. Here the average annual energy production is set to 347 GWh/year. The large-scale hydropower plants were also randomly chosen, such as the small-scale hydropower plants.

Table 4.3: The three large-scale hydropower plants and their annual energy production. Source: author.

Name	Power plant nr.	Annual production
Øksenelvane	511	135 GWh
Leirdøla	242	462 GWh
Årøy	530	446 GWh
		Average = 347 GWh

For wind power, Smøla wind power plant was used. Table 4.4 lists the annual energy production for Smøla, which is 356 GWh/year. Wind power has therefore the highest produced energy of three different production types. This is random and a result of using random selection of the two other types of energy production.

Table 4.4: The annual energy production for Smøla wind power plant. Source: author

Name	Annual production
Smøla	356 GWh

4.3 Geographic Information Systems

As a method for solving the research question for this thesis, the program Geographic Information Systems (GIS) version 10.1 by ESRI is used. The GIS method has roots from cartography and is a modern display of maps by making them digital. GIS makes it possible to represent our living world in a digital form and it helps us to assemble increasingly more information about the Earth because of the possibility of storing large quantities of digital information in databases (Longley et al., 2011).

The main advantages by using GIS technology in this thesis is its flexibility in handling available data on different levels of spatial analysis and to highlight the spatial relationships between the different datasets (Voivontas et al., 1998). Also, GIS contains different techniques which makes it possible to compare the spatial information available regardless of how the information was collected (Tollan, 2002).

GIS has become an increasingly valuable and important tool in environmental impact modeling and have been used in the evaluation of development proposals in many ways, often relating to visual and aesthetic values (Bishop and Karadaglis, 1996). The steadily increasing availability of high graphic databases offers new possibilities for combining environmental modeling with visualization for better supporting environmental decisions done by, for example, OED and NVE. Digital representation of data in GIS is done by discrete objects or by continuous fields. These are often connected to different methods of representations, such as vector data for discrete objects and raster data for continuous fields, but both methods may initially present both discrete objects and continuous fields. Discrete objects are phenomena with a restricted distribution where there are no data surrounding or between the phenomena. This can be for example buildings, roads or rivers.

Continuous fields has no defines boundaries, but can be calculated (through interpolation) values for all positions on the map. Continuous fields present information which can be precipitation amounts or temperature (Longley et al., 2011).

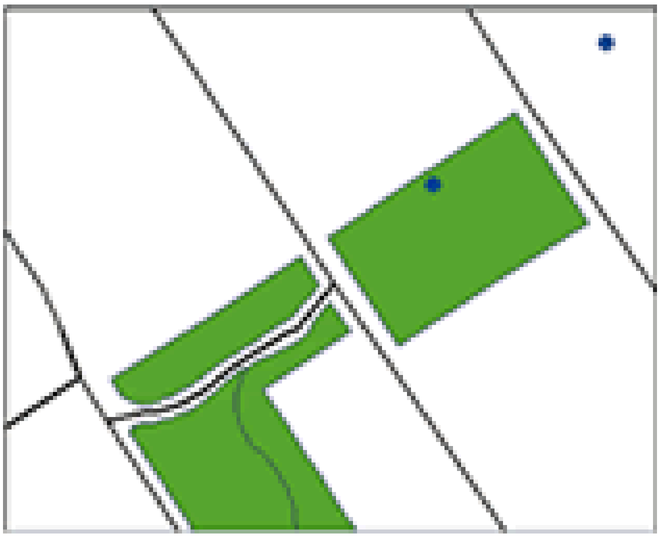

Figure 4.1: The different elements in vector data presentation, point, line and polygon (ArcGIS Resource Center, 2005).

Continuous fields and discrete objects define two conceptual views of geographic information, but the methods which are used are raster and vector because they are reduced forms of geographic information which can be coded in computer databases. These two ways of representing data in GIS are both important and are both used in this thesis.

Vector data is identifiable objects that can be presented either by point, line or polygon. While raster data on the other hand, is a generalization of reality consisting of regular cells which is represented by systematic and union surfaces (Longley et al., 2011).

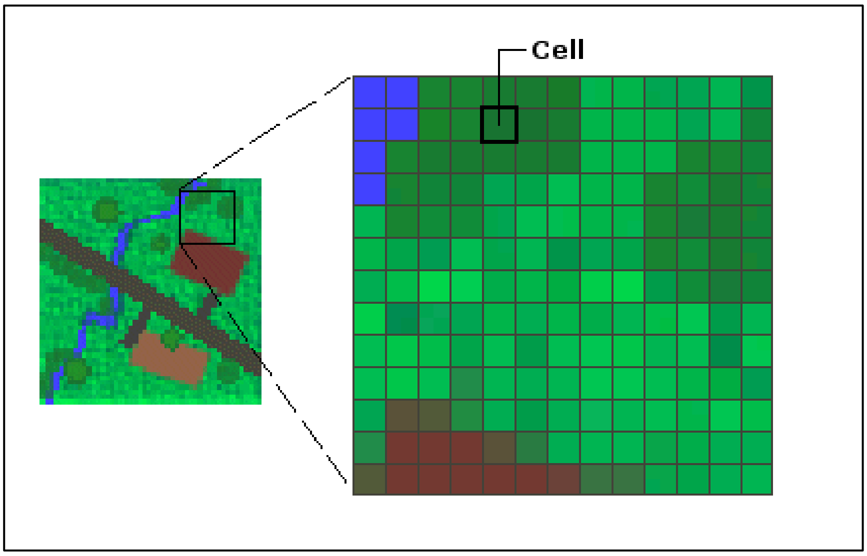

Figure 4.2: The representation of data in raster format (ArcGIS Resource Center, 2009).

Figure 4.1 shows the representation of vector data as this data is identified by their dimension from point (0 dimension), line (1 dimension), or polygon (2 dimension).

The information on vector data is stored in tables, where each row corresponds to a different object, and each column to an attribute of the defined object (Longley et al., 2011).

Figure 4.2, the data is represented in a raster format. As one can see from the figure, a raster is composed of an array of cells where all the cells have the same size (Hengl and Evans, 2009). The raster cells are organized into rows and columns where each cell contains one value. Figure 4.2 one can see that the different cells have different colors.

By using raster representation, it means that one cell only has one value. By assigning one value to each cell also means the detailed information within each cell is lost. For determining the cells value, two different methods can be used: largest share rule and central point. Largest share rule is when the attribute with the largest share of the cells area is set to the whole cell, but with central point the attributes that covers the center of the cell is assigned (Longley et al., 2011).

For displaying geographical data such as terrain models, which is three-dimensional data, triangulated irregular networks (TINs) can be used to create and represent surfaces. The TIN structure represents the surface as contiguous non-overlapping triangular elements. A TIN is created from a set of points with x, y, and z-coordinate values.

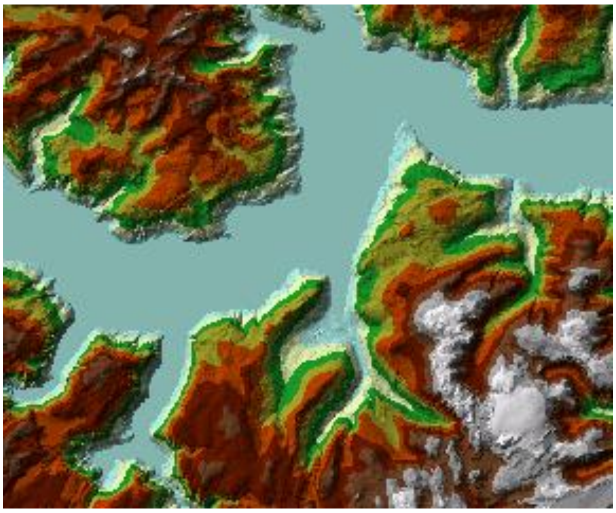

Figure 4.3: Data represented by a TIN. Source: author.

A key advantage of using TIN structure is that the density of sampled points can be adjusted to reflect the relief of the surface being modeled, with more densely sampled points in areas with variable relief. Figure 4.3 shows an example of how a TIN displays the elevation values, where the blue areas are the lowest values which represent the ocean and the grey and white are the highest elevations which represent the bare mountains and snow. When creating a TIN, the output can only be as good as the input sample data.

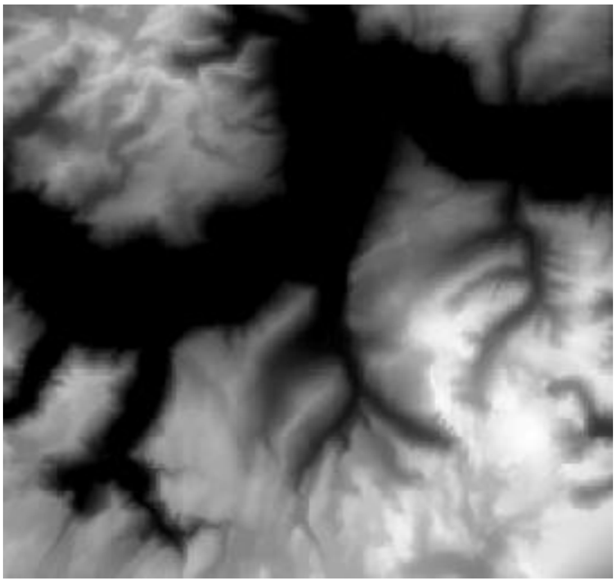

Figure 4.4: The representation of relief by a DEM. Source: author.

To represent the terrain with a raster, one can use a digital elevation model (DEM). A DEM is a complete representation of the continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points) (Hengl and Evans, 2009). The usage of a digital terrain model is suitable for different types of terrain visualizations since it displays the differences in height variations in a visual and three-dimensional way (Kartverket, 2012). Figure 4.4 shows an example of a DEM can be seen in where the differences in elevation values are marked from black to white, where white are the highest elevation values. To present the data in a DEM, one must convert the data from TIN to DEM, from vector to raster.

When converting a TIN into a DEM, the cell size, which is the distance between two grid nodes expressed in ground meters, defines the technical characteristics of the DEM. Having a smaller cell size makes the output map more accurate and displays a better view of the complexity of the landscape, while a larger cell size makes the conversion process faster, but gives coarser maps and a lesser degree of accuracy. As the map becomes coarser, the overall information content in the map will progressively decrease. In most cases the value recorded will be the elevation at the center of each raster cell (Hengl and Evans, 2009).

4.4 Area directly affected

The areas usage when building a new renewable energy production types vary greatly in size, to what type of landscape values they are located in and how the boundaries around the power plant are defined. In this thesis there will not be investigated on what type of landscape type the projects are located in and not to what type of value the areas have. The goal is to measure the areas directly affected by the three different energy production types. The areas defined for this parameter will function as a base for the next parameters. The reason for choosing the parameter area directly affected was done because it is a parameter that gives numeric results which can be compared across different energy production types and one can visually see the impact by using satellite photos from the different sites.

For mapping the areas directly affected by energy production projects, the area needs to be delineated and calculated. The tracing around the area is done by heads-on digitizing, which means tracing the shape of a defined area on a source layer and store it as a new feature (Longley et al., 2011). The new feature will be a polygon because it is a closed line around a defined area. In order to digitize and properly trace the areas used by the power project, satellite photos for each of the specific sites are downloaded from "Norway in photos" (www.norgeibilder.no) and georeferenced against the base map. Georeferencing refers to the process of assigning coordinated to a specific location on the target layer to a feature in the source layer (Longley et al., 2011). Control points are added to locations that are easily recognizable both in the satellite photos and the base map. The control points were set at roads from the two layers, especially elements that are clearly recognizable such as bus stops and cross roads. After adding enough control points, the satellite photo coincides with the base map and the heads-on digitizing can start.

Since the areas which are mapped as directly affected by the three energy production types are used further in the other analysis as a basis, it is important that they are measured accurately. For hydropower the area usage differ between the different locations, but the same principles are used when mapping the areas.
For small-scale hydropower the principles for area delineation are based on the guidelines from OED (2007), shown in Figure 3.6 (OED, 2007b). The area is being traced from where the water in front of the hydropower intake is directly affected, or if there is no dam above the intake the boundary is set where the water is being directed into the intake. This because

the water would flow naturally until it either is dammed up or is directed into the intake. Then, built roads, potential forest clearance, river lengths with changed water flow, and eventual dam, is being evaluated. This evaluation decides if the road has been constructed for the hydropower plant, if the clearance of forest has been done for either road construction or water intake, or if these encroachments were done because of other interests and activities. The downloaded satellite photos are used as a basis in identifying what purpose the encroachment has been done for. If the road in question continues further to either a parking area or to houses or second homes, the road is classified as to not have been built because of the hydropower power plant. The road is then not taken into the mapping.

The area directly affected stops where the water, which has been used in the power generation, is being released into another river, lake, or fjord. An example can be from Figure 4.6 where the river is flowing into another river.

A flowchart for the different steps in the mapping the area directly affected can be seen in Figure 4.5. More information on the datasets used in mapping the area directly affected can be found in Appendix B.

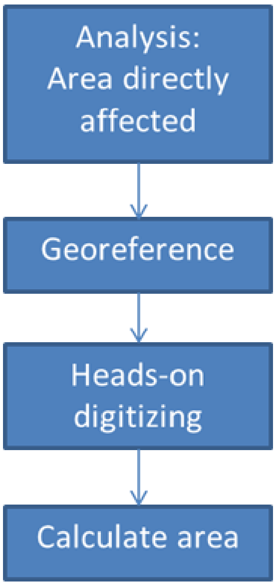

Figure 4.5: Flowchart for the analysis area directly affected. Source: author.

For large-scale hydropower, some of the same principles were used as for small-scale hydropower. Since large-scale hydropower has a reservoir, the line was drawn around the maximum water level in reservoir which is distinctly shown on the satellite photos. An example can be Øksenelvane which has three reservoir and all mapped together. Any additional natural water storage creating possible large amounts of run off, such as glaciers, was not included.

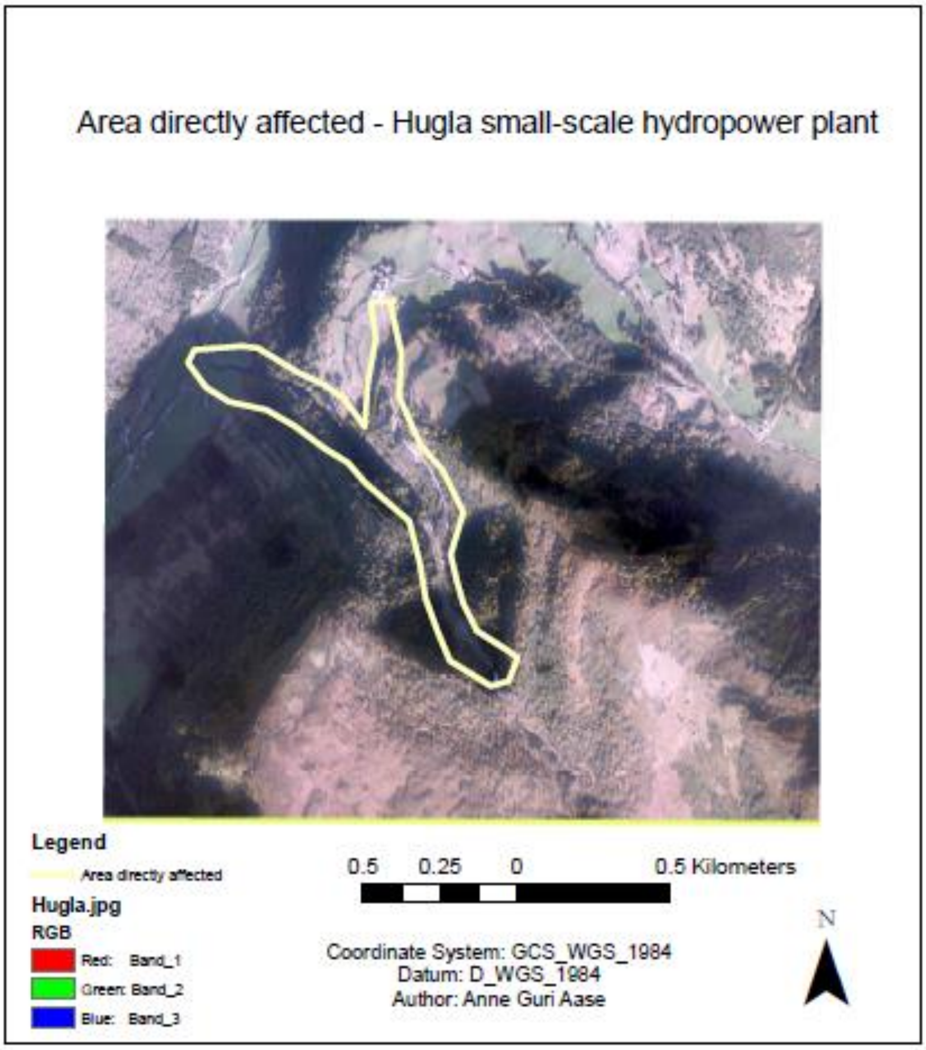

Figure 4.6: The mapped area directly affected by Hugla small-scale hydropower plant. Source: author.

The line directly affected does also include an extra buffer around the affected area which is approximately 50 meters. These additional meters are subjectively chosen and are meant to include any possible side interventions which are not clearly shown on the satellite photo. When the digitizing is complete, the mapped area directly affected can be found listed in the attribute table listed in square meters.

Figure 4.6 shows how the georeferenced satellite photo and the polygon which indicated what the area directly affected looks like. This example is taken from the small-scale hydropower plant Hugla in the municipality of Vik. In this example one can see that the additional buffer of approximately 50 meters is somewhat lesser in distance, but does include a good margin for additional environmental impacts.

For wind power the mapping of area directly affected was different. The official boarders surrounding Smøla wind power plant set by Statkraft was used. An image from the licensing application was downloaded from NVE's homepage (www.nve.no) containing the official boarder and georeferenced towards the base map. No extra buffer was added to the mapping as was done for hydropower, as a safety area surrounding the wind power plant has already been set by Statkraft.

4.5 Visibility

Visualization is a powerful tool for displaying changes in the environment and is increasingly becoming more powerful as people valuate the natural environment more. From a simple data driven model in GIS, the result becomes a great tool for understanding actual and perceived visibility and even the visual impact from a renewable energy production type becomes presentable (Möller, 2006). This is also the reason why I have chosen to use visibility as one of my parameters. Visibility is a tool that gives a numeric result which can be used for comparison across different types of energy productions.

There are different ways in mapping the visibility, but in this thesis I have chosen to use viewshed analysis. The viewshed analysis is widely accepted for mapping the visual-impact for wind turbines (Möller, 2006), and will in this thesis also be used on hydropower plants.

Viewshed analysis is binary in the sense that an object is measured as being either visible or not. In this type of analysis, the results do not respond to vegetation cover, buildings, or other natural obstacles which might disturb the visibility in real life. When the analysis has run, the output receives a value identifying whether the cell can observe the object in question or not.

Each cell that can see the observer point is given a value of 1 and all cells that cannot see the observer point are given a value of 0 (ArcGIS Resource Center, 2011, Longley et al., 2011, Möller, 2006). As an input for a viewshed analysis several different elements can be used, such as points, lines or polygons, but in this thesis the polygon from area directly affected is used.

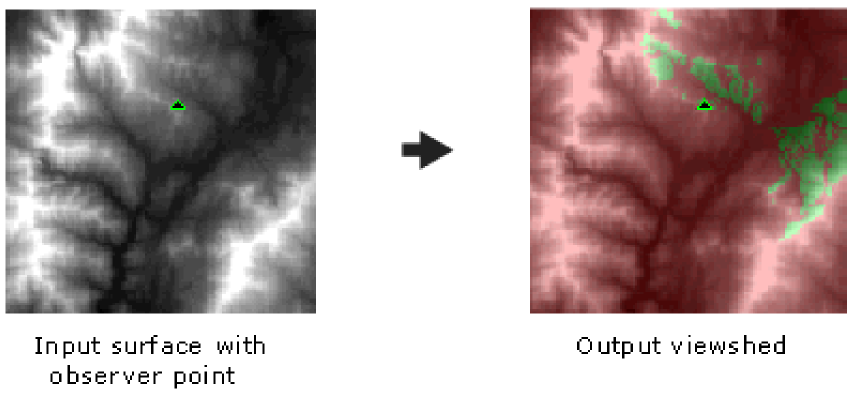

Figure 4.7: The input and output from a viewshed analysis (ArcGIS Resource Center, 2011).

The result is thus a raster layer with cells with two different values, either visible or not. Figure 4.7 shows first a DEM with an observer point marked as the green triangle. The second image is an output from the analysis which displays the resulting raster layer with the green areas as visible and the red areas as not visible areas. The raster layer has been set to a high degree of transparency to visualize the underlying DEM.

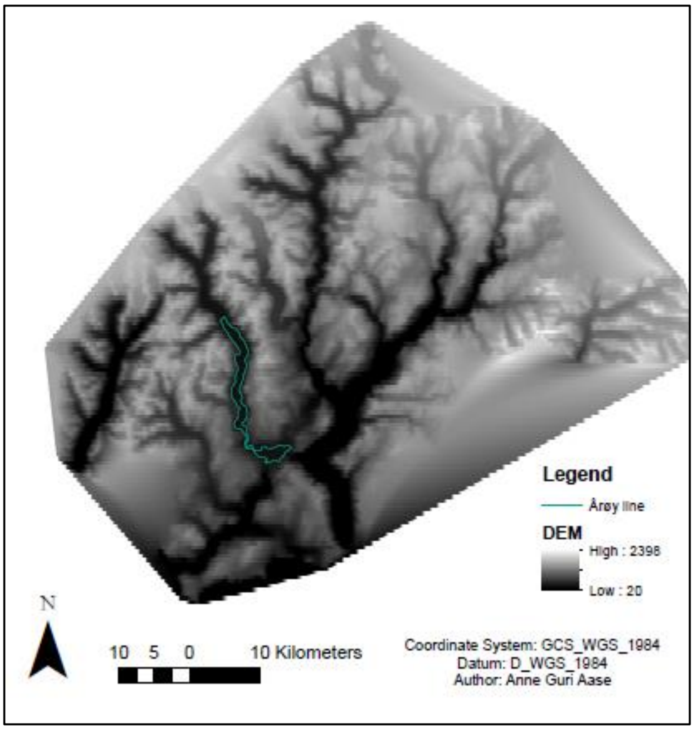

Figure 4.8: DEM for the viewshed analysis for Årøy large-scale hydropower plant. Source: author.

For calculating the visibility of a power plant to its surrounding area in GIS, a digital elevation model (DEM) of the landscape is needed. A TIN is created from the available contour lines from each downloaded municipality dataset and municipality boarders. The contour lines are used to generate a representation of the elevation values and the municipality boarders are used for delineating the area. The TIN is then converted to a DEM. Figure 4.8 shows an example of how a DEM from using the contour lines and municipality boarders from the municipalities Sogndal and Luster looks like. The darker areas have the lowest elevation value, while the lighter areas have high elevation values. The green line is the polygon from the mapping of area directly affected for the large-scale hydropower plant Årøy. This line is used as the input for the viewshed analysis.

For getting the best possible visibility for each site, several municipalities' contour lines were merged together for creating a better output. The decision on how many municipalities which were merged together depended on the location of each individual power plant. Because of this some of the small-scale hydropower plants in the municipality Gloppen needed two additional municipalities to merge for creating the best possible visibility results, while other only needed one.

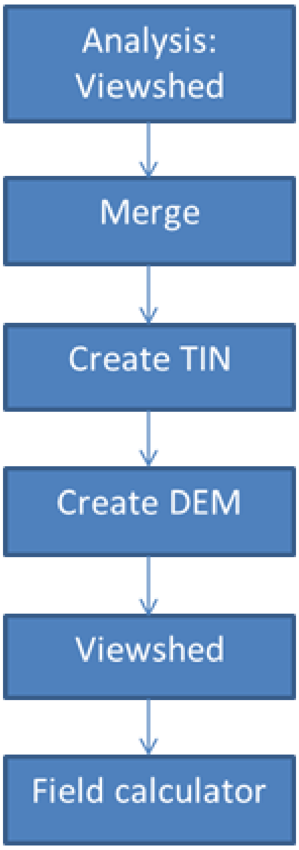

Figure 4.9: Flow chart for the visibility analysis. Source: author.

As input for the visibility analysis, the polygon created in areas directly affected is converted into a line surrounding the affected area. Figure 4.8 one can see the polygon marked with a green line. The idea behind using the polygon boarders and not only use the point for the power station is to make an emphasis on the entire area. This is done to create a more solid result since it is not only the power house that can be seen, but also pipelines, water intake, roads and clearance of forest. These encroachments in the environmental are not often mentioned and therefore they are an important part to incorporate in this study.

For mapping the visibility for the three different renewable energy production type I have not set any influence zone for the possible visibility. The range which ArcGIS operates with is that the result is accurate up to 30 kilometers away from the input point. In this analysis I have allowed GIS to map as far as the input data are available. Some delineation towards the total area in the visibility mapping is the boarders set by the municipalities used as basis for the DEM.

When conducting a visibility analysis one can define the elevation (z) value for the input. For windmills, the z value in the analysis is set to 110 meters, since the tower heights is 70 meters and the radius of the rotating blades are approximately 40 meters (Statkraft, 2010). For both small-scale and large-scale hydropower, no extra z value is added, this due to height changes within the area from power house to water intake. So for excluding eventual large errors in the results, the elevation value was set to 0 for all hydropower plants. Figure 4.9 shows a flow chart with a representation of the different stages in the visibility analysis. More information about the different datasets used in the analysis can be found in Appendix C.

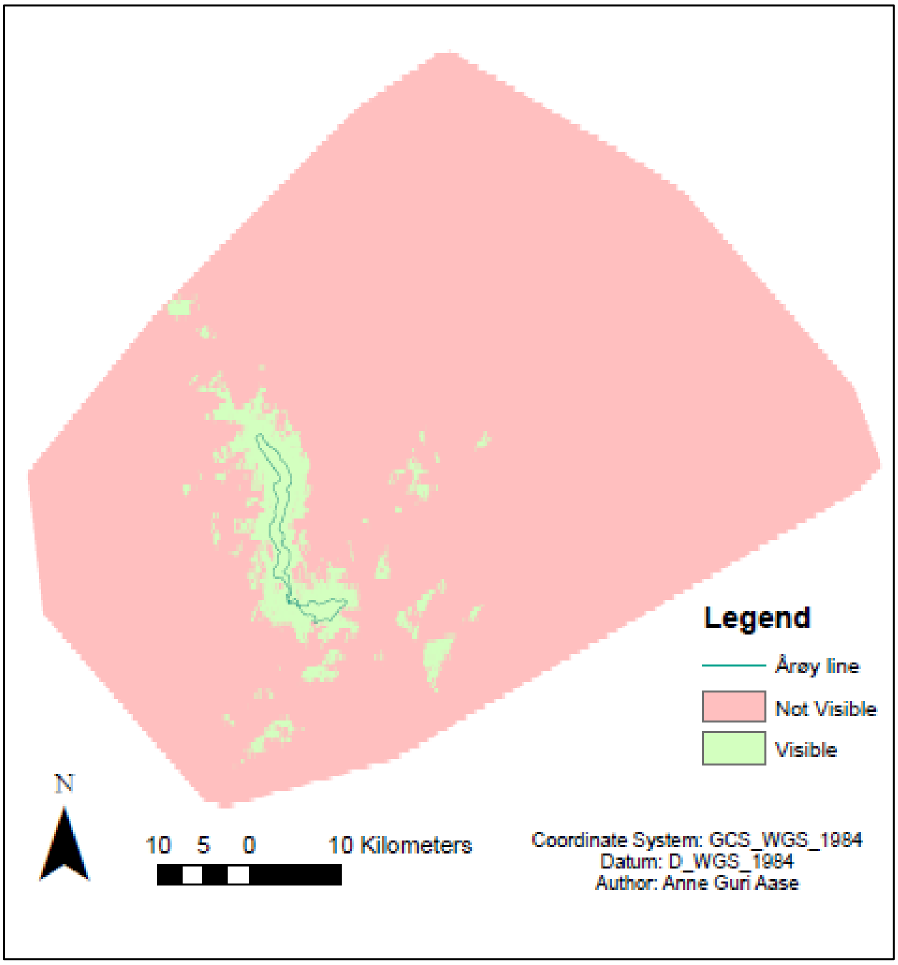

Figure 4.10: Output from the visibility analysis of Årøy large-scale hydropower plant. Source: author.

Figure 4.10 shows how the output for a viewshed analysis looks. The light green areas are the visible areas, while the pink are not visible. As input one can see the line from the area directly affected which was used as input for the visibility analysis. The municipality lines which have delineated the total area used as a basis for the visibility analysis of Årøy shows that the two merged municipality lines for Sogndal and Luster might have potentially not include all the theoretical visible area.

4.6 Encroachment-free areas INON

It is a well-known fact that the establishment of renewable energy such as wind power and hydropower creates a decrease in the amounts of encroachment-free (INON) areas in Norway. Therefore, it is interesting to see how much impact the chosen power plants actually have on INON areas. For mapping the amount of overlap between the power plants and INON areas, there is a need for geoprocessing of the data.

Geoprocessing is one of the most powerful components in GIS. The fundamental purpose behind geoprocessing is that it allows you to define, manage, and analyze the information which is used to form decisions (ArcGIS Resource Center, 2010b). Geoprocessing is based on several tools for data transformation and a typical analysis performs an operation on a dataset and produces a second dataset as the result of the operation. There are over 200 different geoprocessing tools available in GIS, but in this thesis only intersect and buffer operations will be used.

The creation of buffers means to set a defined area surrounding the object under investigation (ArcGIS Resource Center, 2010a). Figure 4.11 shows the principle behind a buffer operation, where a predefined amount of area is drawn around the feature. This operation can be done for either both sides of the object or on one side.

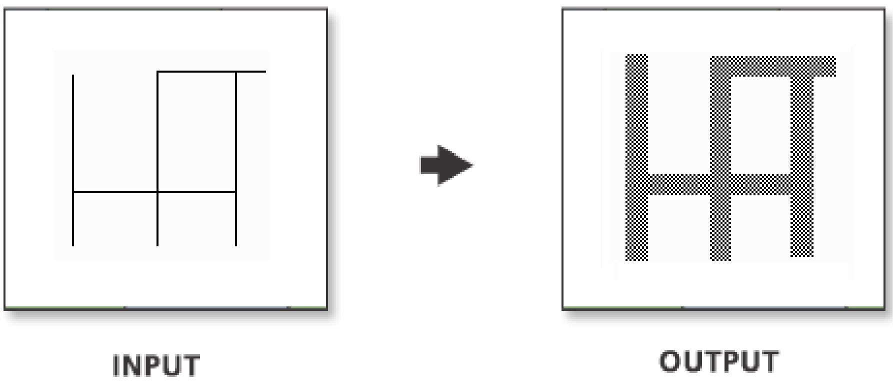

Figure 4.11: The principle behind buffer analysis (ArcGIS Resource Center, 2010a).

Intersect is a tool that computes the intersection of the input features. Figure 4.12 shows the principle behind the tool intersects. In the figure to the left, the two features are shown to overlap. In the figure to the right, after using the intersect tool, only the overlapping area is saved in the output. Polygons can intersect in three different ways: overlap, common boundary/touch at a line, and touch at a point. The example of intersect showed in the figure is overlap.

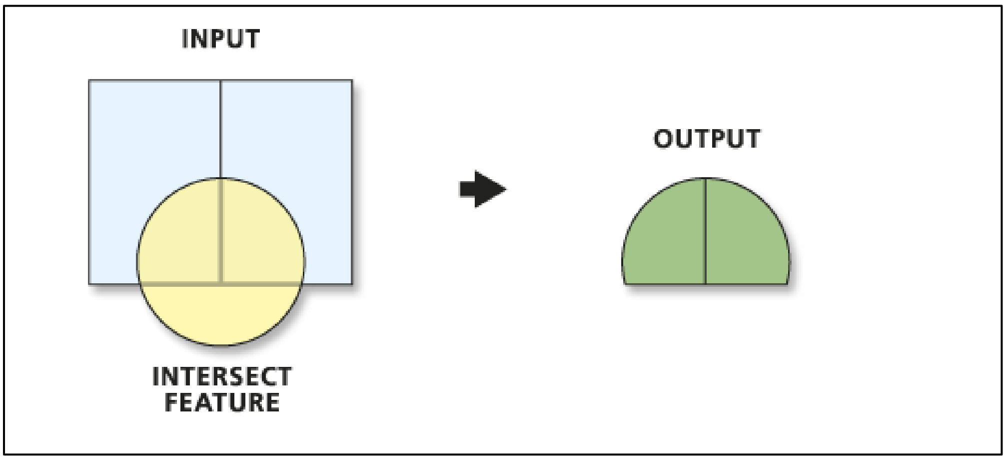

Figure 4.12: The principle behind the analysis intersect (ArcGIS Resource Center, 2012a).

The data containing information from the last official mapping is downloaded from Norway Digital (www.norgedigital.no) as a SOSI-file and converted into shape files and to same geographic reference as the base map. SOSI (Systematic Organisation of Spatial Information) is a national standard for the hierarchy exchange of geographic information between different systems (Geodata, 2013).

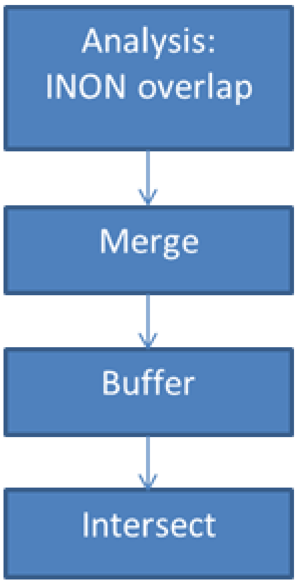

Figure 4.13: Flowchart for the INON overlap. Source: author.

The mapped boarders from the analysis area directly affected are used as base for the buffers. All the area directly affected polygons from small-scale hydropower are merged together into one file before creating the buffers. The same is done for the three large-scale hydropower plants, while the polygon from wind power is used as it is without any alterations. Three buffers are drawn with lengths of: 1 km, 3 km, and 5 km from the boarder lines of area directly affected. The boarder of the buffers is set to dissolve, so no lines overlap each other. The intersect tool were then run for the different buffers and the last official INON mapping from 2008. Figure 4.13 show the flowchart for the analysis of mapping the overlap between the power plants and the last official INON mapping from 2008.

The category which is most interesting for mapping the amount of overlap is the areas more than 5 kilometers away from major infrastructure development, also called wilderness-like areas. There areas are important because of the genetic diversity and because they contain important ecological functions. But mostly because INON is used as an important indicator for measuring if the political and national goals for land use are met.

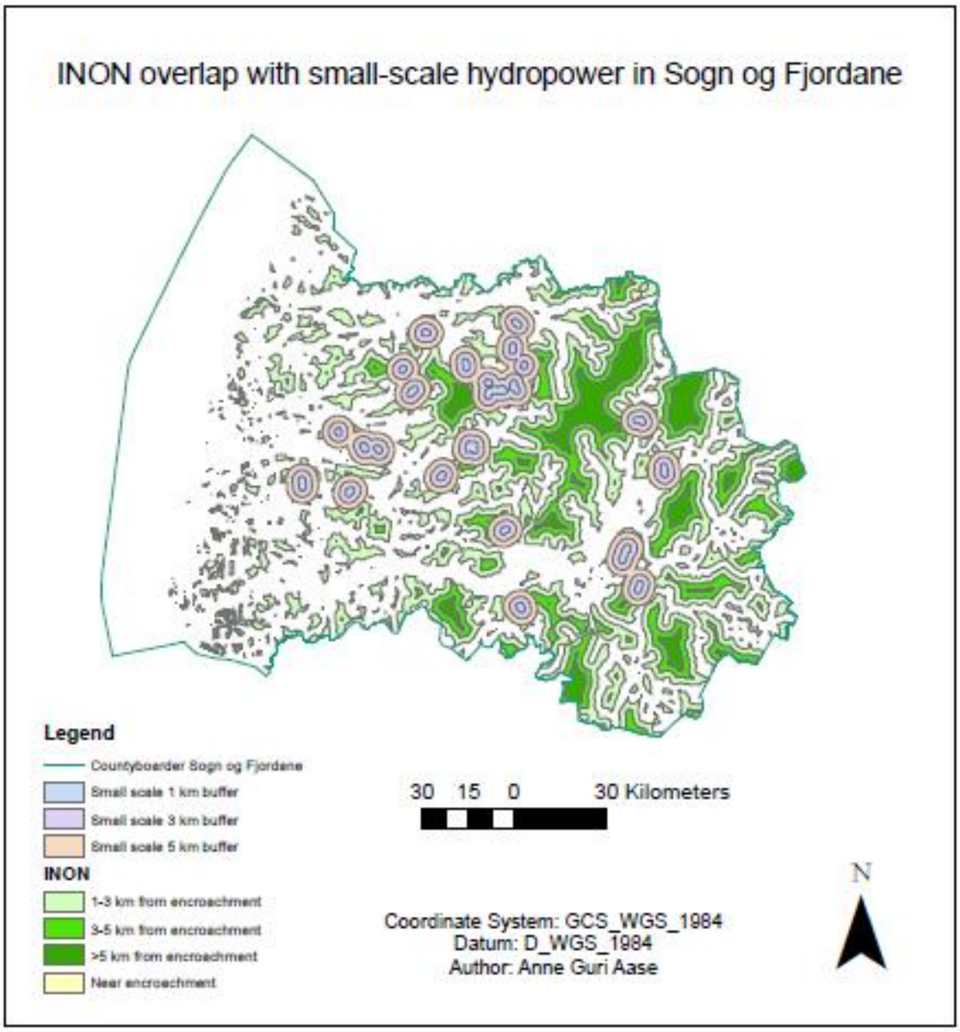

Figure 4.14: The two layers used in mapping the INON overlap. Source: author.

Figure 4.14 shows how the intersect analysis works. Here, the base layer which is data from the last official mapping in 2008 is shown with different shades of green. The darkest green is areas called wilderness-like areas. The buffers with three different lengths of 1, 3 and 5 kilometre are shown with light blue, light purple and light pink. The output from the analysis would be a new feature which only showed the amount of area overlap between these two layers.

4.7 Red listed species

Red listed species is such an important factor when building a new power plant, no matter whether it is a fungi or a bird. The choice of using red listed species as one of my parameters was easy, as the presence of one can pause or even stop a new project. It is therefore interesting to see how many species are within a certain range of the chosen power plants. In this thesis there will not be separated between fungi or bird, even though they have different needs of area usage and physical needs for survival. I have decided on given all red listed species equal weighing.

The information of red listed species is downloaded from Artsdatabanken (www.artsdatabanken.no) as an (*.csv) file, which is an Excel sheet with each field of text separated with a comma character. The table is also called a geocoded table since each record listed represents a single location with coordinates and allows each record in the table to create a new point feature in the base layer (ArcGIS Resource Center, 2012c).

After preparing the *.csv file into an Excel table, it is added to Arc Map and given the same UTM coordinates as used for the base map, UTM 32. The excel file do now show the information on all the mapped red listed species within the counties of Sogn og Fjordane and Møre og Romsdal. Then the polygons created in the analysis area directly affected for all the different power plants are used as base for the buffer analysis. For the buffer, two for each power production site are created, respectively on 2 kilometers and 10 kilometers. During the EIAs, there are conducted searches for eventual red listed species present in the specific location. But this search is only conducted in the affected river or defined construction area. Many species have different home ranges and needs different conditions for survival. Since there are made no distinction between what type of red listed species is present at the different locations in this thesis, the choice were set on using two buffers of 2 and 10 kilometers to see how the distribution of mapped red listed species changes between these two distances.

The data management tool *select by locations* selects features in a layer based on spatial relationship to features in another layer. (ArcGIS Resource Center, 2012b). This means that one feature is used as a delimitation of the other feature. Figure 4.15 shows the amount of species from the red listed species layer that is located within the geographic specifications of the area directly affected around the Smøla windmill farm. Those species that are found within the defined area are highlighted. To use the tool select by location for mapping the distribution of red listed species is thus very site sensitive, as the species will have a very diverse distribution after what type of energy production types one is investigating. As there are many small-scale hydropower plants the results might be stochastic. But within this frame, a simplification of the species diversity is needed.

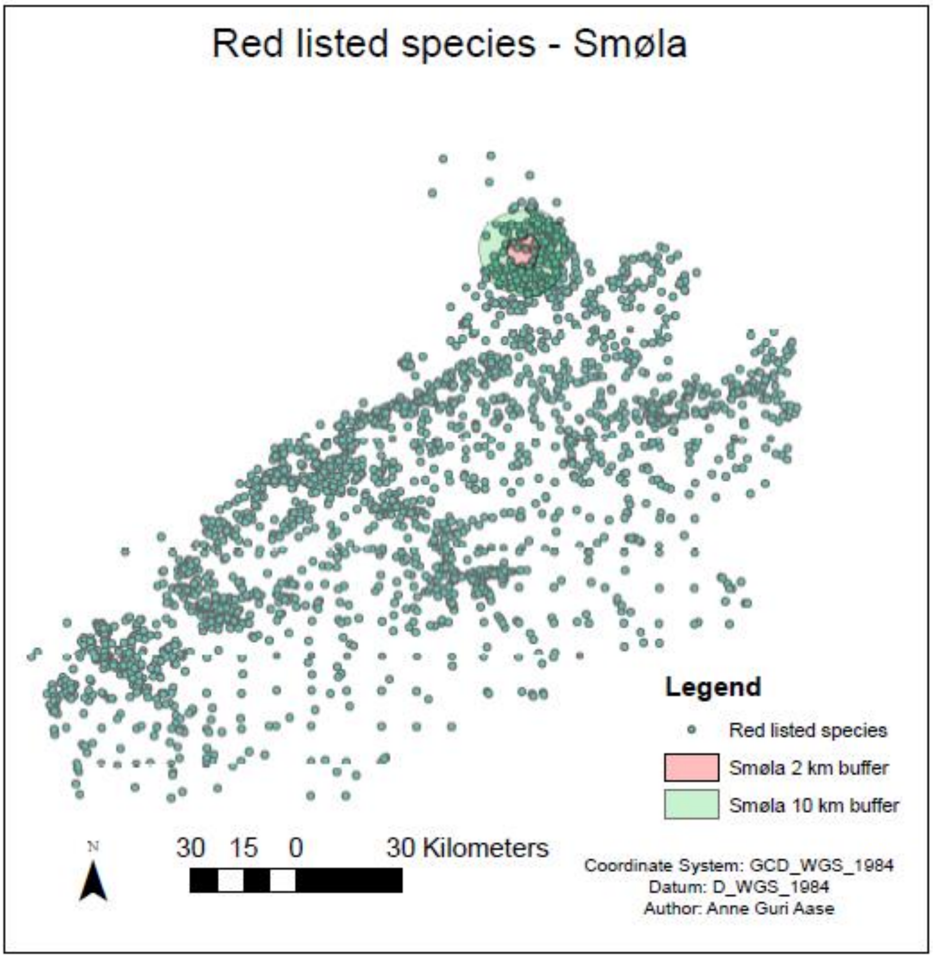

Figure 4.15: The distribution of red listed species in Møre og Romsdal, and the two buffers around Smøla wind power plant. Source: author.

The two buffers are used for mapping the amount of species. The information about the amount of species within the buffers is then highlighted in the attribute table for the mapped red listed species and saved as new table.

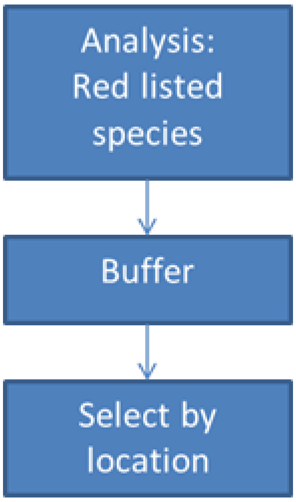

Figure 4.16: Flowchart mapping the amount of red listed species. Source: author.

Figure 4.16 shows a flowchart over the different operations which has used in the mapping of the red listed species for the two buffer lengths.

More information on the different datasets used in mapping the amount of red listed species can be found in Appendix D.

5 Results

In this chapter I will present the results from the four parameters in the analysis for the three renewable energy production types. I will review each of the parameter, starting with area directly affected, visibility, red listed species, and overlap with INON areas.

5.1 Area directly affected

Area directly affected was measured based on standardized measures from (OED, 2007b) and addition buffer of approximately 50 meters. The results were read out from the attribute table for each power project. Figure 5.1 shows the different amounts of area directly affected for each of the three energy production types. For small-scale hydropower the amount of area for each power production site is summarized, while for the three large-scale hydropower plants the average measured area is used. The measure form the wind power site is used without any alterations.

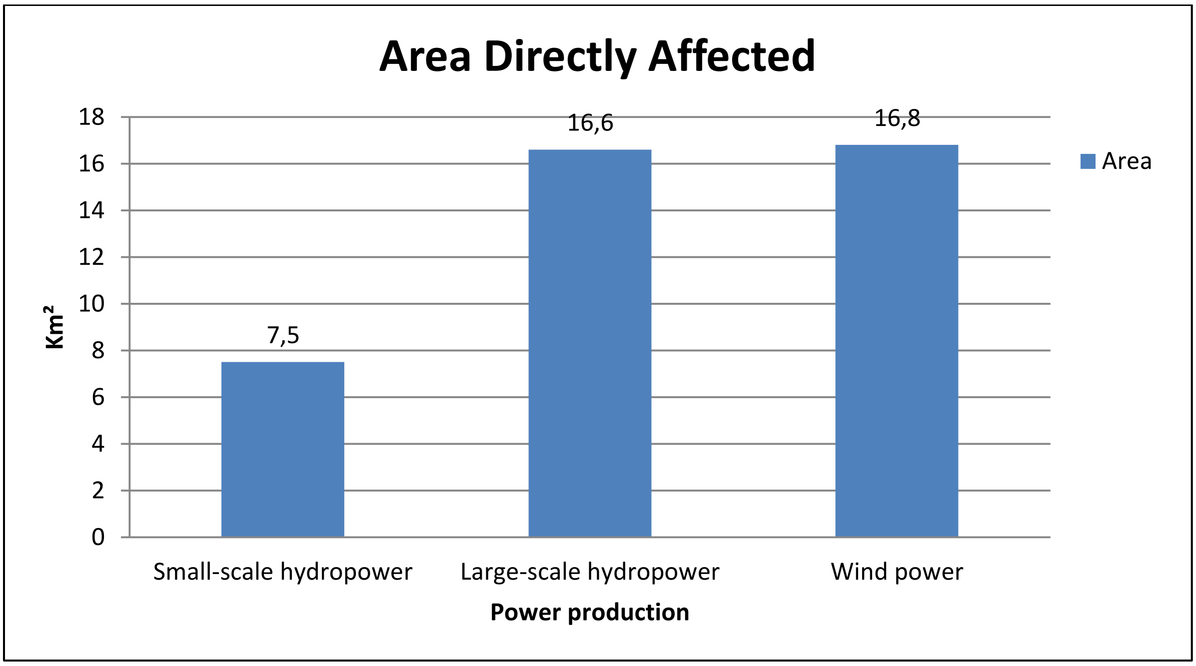

Figure 5.1:The mapped area directly affected by the different power production types. Source: author.

Figure 5.1 shows that small-scale hydropower has the lowest mapped area with a combined area of 7, 5 km², while large-scale hydropower has the least with an average area use of 16, 6 km². Wind power has 16, 8 km² area directly affected. Large-scale hydropower, which is listed in the figure with the average value between three different projects, shows that the variations between the three different power plants are large. Øksenelvane has an area of 4,964 km², Leirdøla has 16, 8 km², and Årøy has 27, 8 km².

Listed in Table 5.1 is the measure of annual energy production for the different energy types with the amount of area directly affected by the different projects. This shows that there are small differences in the annual energy production used as basis for the analysis in this thesis. For more accurate measures for each specific production site, see Appendix X.

Table 5.1: The annual production and the mapped areas directly affected by the three production types. Source: author.

Power type	GWh	Area (km²)
Small-scale hydropower	350	7,5
Large-scale hydropower	347	16,6
Wind power	356	16,8

The values of area directly affected and the annual energy production for each power production type does not show if and what relationship there is between these values. The information which is listed in Table 5.2 shows the amount of annual energy production for the three different power production types per square kilometre.

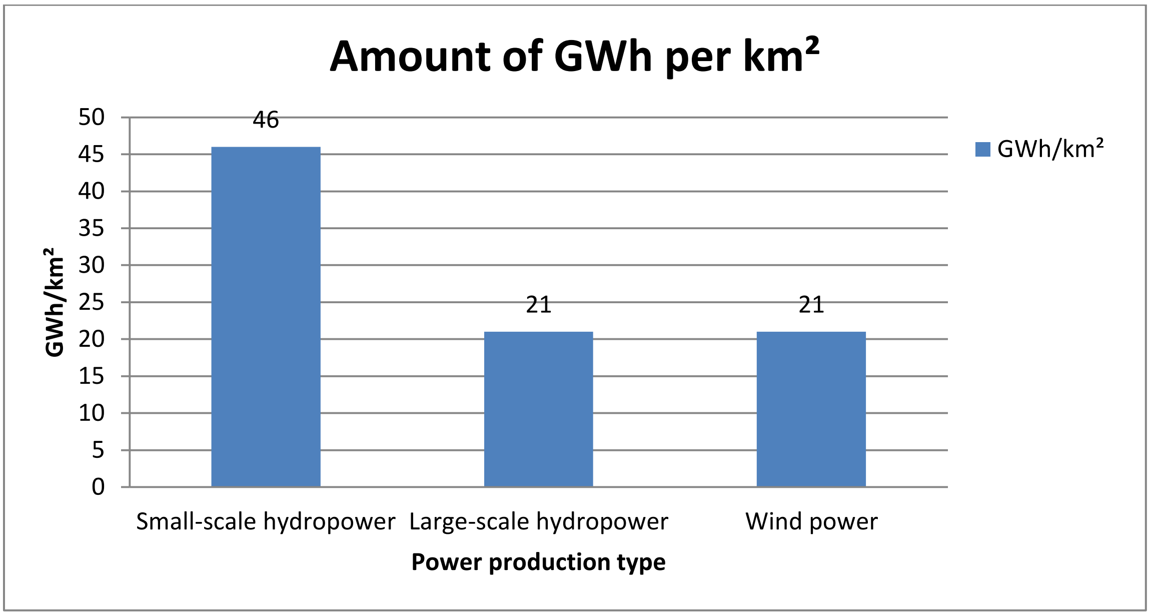

Figure 5.2: The amount of annual energy production each power production type has per km². Source: author.

The results show that small-scale hydropower has the most effective energy production per square kilometre with 46 GWh/km², while large-scale hydropower and wind power has the same energy production, 21 GWh/km². The results also show that the small-scale hydropower plants have over double energy production per square kilometres compared to large-scale hydropower and wind power.

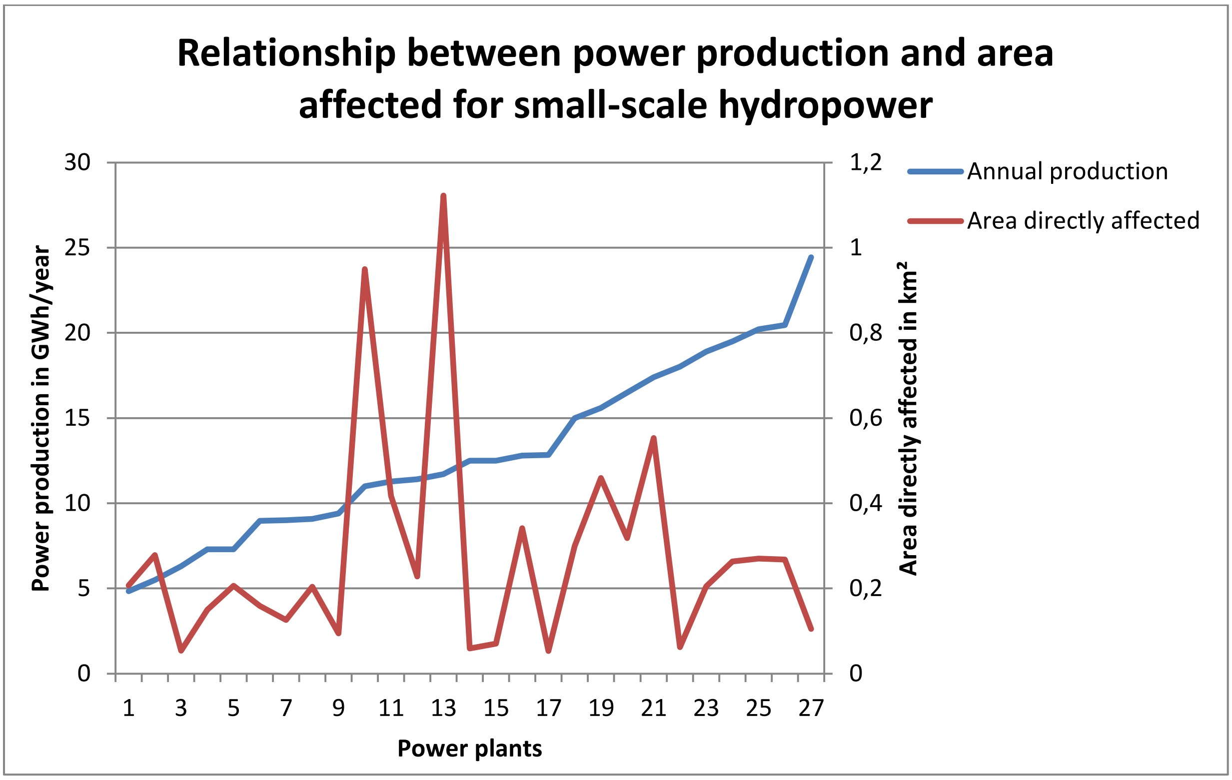

Figure 5.3: The relationship between power production and area directly affected for small-scale hydropower plants. Source: author.

When choosing 27 random small-scale hydropower plants within an area, it is interesting to see how the relation between annual energy production and their area usage are. Figure 5.3 shows the relationships between the 27 chosen small-scale hydropower plants and the areas they directly affect. The power plants are arranged after their annual energy production shown by the blue line, from lowest on the left to highest on the right, more information to which number are associated to what power plant can be found in Appendix F. One can see that two power plants (number 10 and 13) have a higher degree of area usage without being the projects with the highest energy production. This presentation therefore shows the variation in amount of areas directly affected according to amount of annual energy production. For the plants with the highest production, the area usage is smaller in comparison to the others. The two small-scale hydropower plants which are number 10 and 13 are Øvre Årdal and Kaupanger 3. These two power plants do not only have the highest areas directly affected, but also the highest ratio between power production and area usage.

This means that the area usage is much more than what should be “expected” from the graph in comparison to the other power plants.

Table 5.2: The annual energy production for the three large-scale hydropower plants per km². Source: author.

Power plant name	GWh/km²
Øksenelvane	27,2
Leirdøla	27,3
Årøy	16

In this thesis the average value of three large-scale hydropower plants is used, which makes it interesting to see who the results look like for each individual plant. Table 5.2 shows the production efficiency for each square kilometre the power plants have been measured to directly affect. The results show that Leirdøla is the most efficient, with Øksenelvane as a close second, and Årøy with the least production efficiency. Øksenelvane is the power plant with the lowest annual energy production and mapped area directly affected. Leirdøla and Årøy have both one large reservoir used for power production, while Øksenelvane has three smaller reservoirs which are connected and combine provides the water for energy production.

5.2 Visibility

The visibility analysis has been done with the area measure mapped in area directly affected. Figure 5.4 shows the amount of visibility for the three different energy production types. Small-scale hydropower is with its 27 power plants the production type with the highest amount of visibility with a total area of 339 km², this is the cumulative visibility for all small-scale hydropower plants. Wind power is visible to a total area of 163 km².

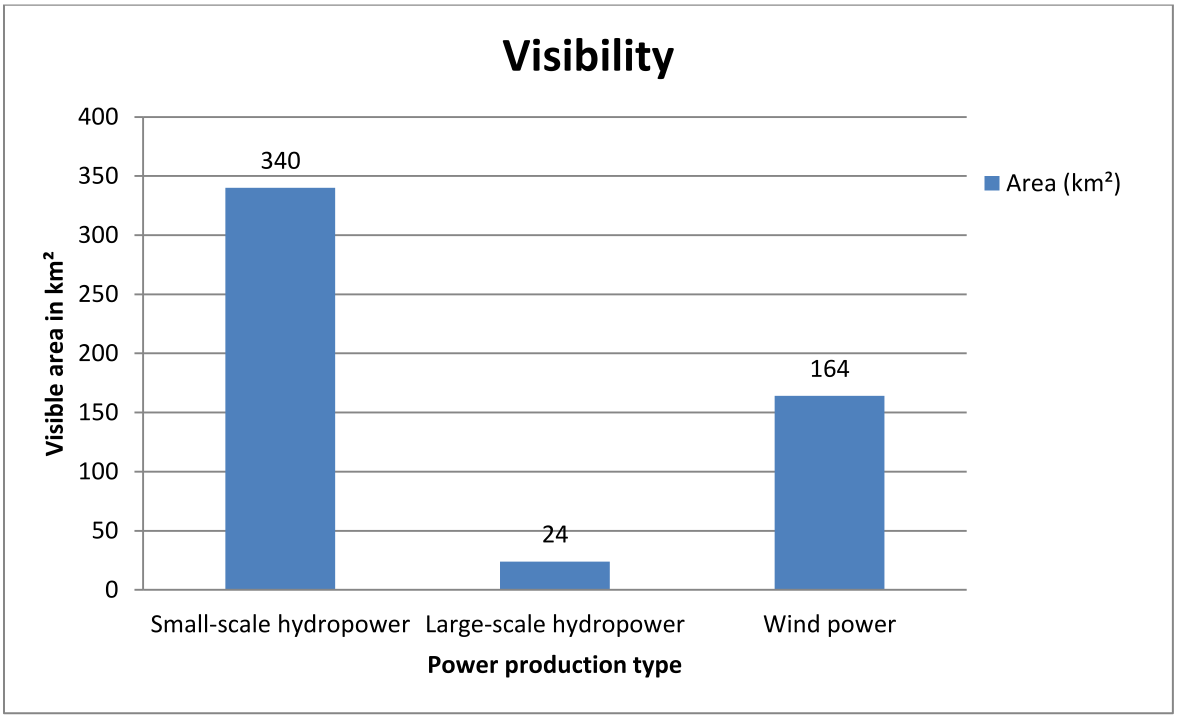

Figure 5.4: The differences in visibility for the three power production types. Source: author.

Large-scale hydropower is the power production type with the least measured visible area of 24 km². This value is the average for the three chosen large locations. If one looks further into the three different power plants, one can see that Leirdøla has a visible area of 15 km², Øksenelvane of 42 km², and Årøy of 15 km². This shows large differences within the average value for large-scale hydropower.

Small-scale hydropower has over double the visibility than what wind power has, and over 14 times more than large-scale hydropower has. For the visibility for each of the individual small-scale and large-scale hydropower plant, see Appendix X.

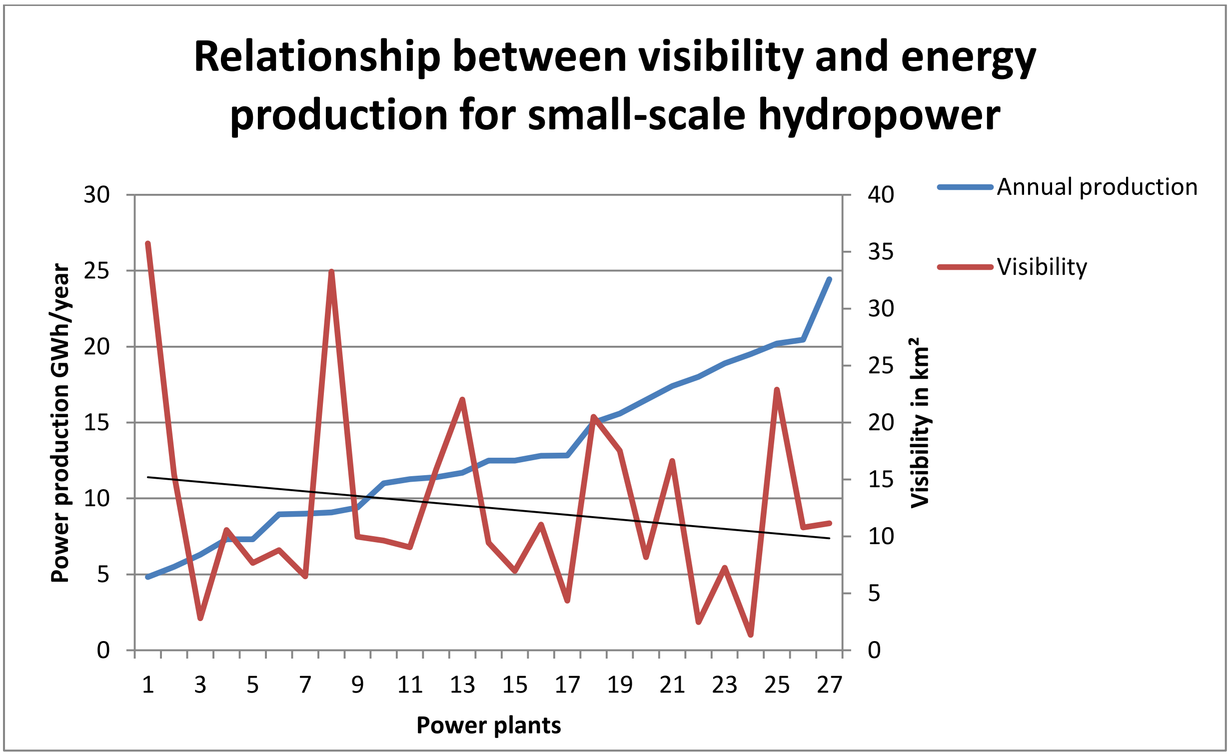

Figure 5.5: The relationship between visibility and energy production for small-scale hydropower plants. Source: author.

Since small-scale hydropower has so much more visibility than the two other energy production types, it is interesting to see why. Figure 5.5 shows the relationship between the 27 small-scale hydropower plants and their visibility. The 27 small-scale hydropower plants are sorted after their amount of annual energy production, where number 1 has the lowest amount produced energy and number 27 ha the highest amount of produced energy. A linear trend line is added for the visibility analysis which indicates that the visibility declines as the annual energy production increases. The small-scale hydropower plant with the highest visibility is the one with the lowest annual energy production. See Appendix X for more information on the small-scale hydropower plants.

It is not only interesting to investigate the relationship between the chosen small-scale hydropower plants, but also for large-scale hydropower.

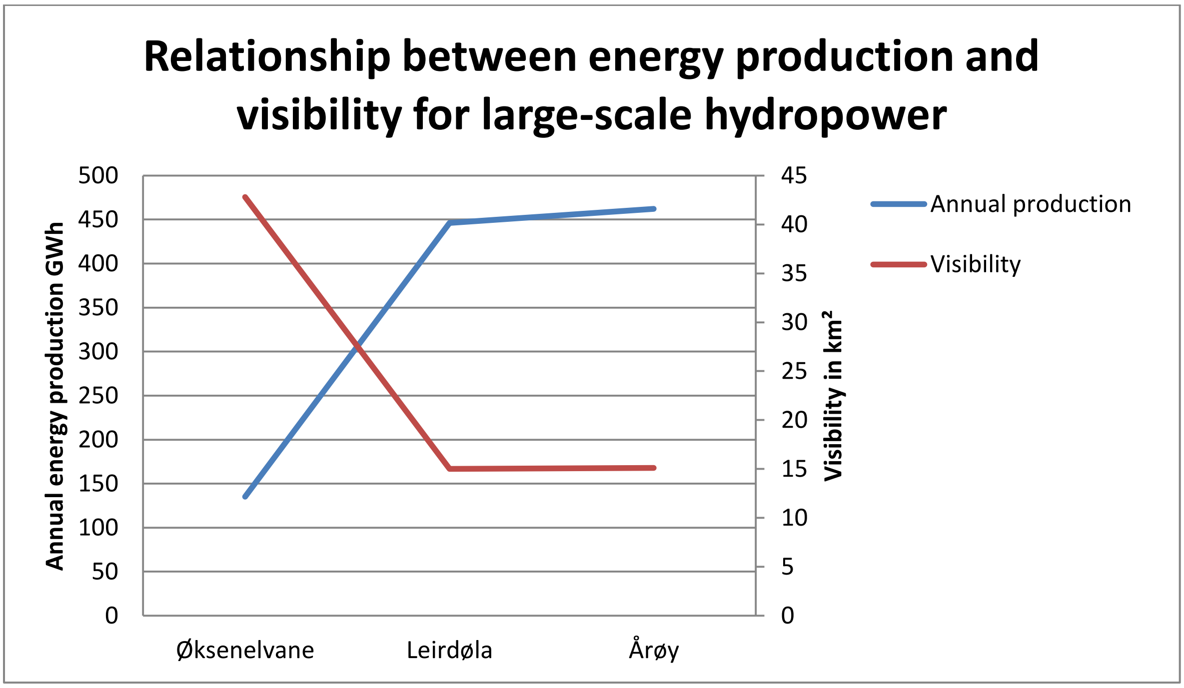

Figure 5.6: The relationship between energy production and visibility for the three large-scale hydropower plants. Source: author.

In Figure 5.6 , one can see the relationship between annual energy production and the visibility for the three large-scale hydropower plants, which have been ranged after increasing annual production, starting with Øksenelvane, Leirdøla, and Årøy. In this figure, one can clearly see the decrease in visibility as the annual energy production increases. Both Leirdøla and Årøy have reservoirs which are located in a valley in a mountainous area, while Øksenelvane with its three reservoirs are situated more spread.

5.3 Red listed species

Table 5.3 shows the amount of red listed species that is identified within two buffers of different sizes, 10 kilometres and 2 kilometres for the three different energy production types. The numbers of identified red listed species do decline when reducing the area of investigation around the power plant. For the species listed in Table 5.3 , they are not sorted into the different categories, so classes range from DD (data deficient) to CR (critically endangered).

For wind power, most of the observations within this nearest buffer are birds, such as Hen Harrier (*Circus cyaneus*), Northern Lapwing (*Vanellus vanellus*), but also fish such as Eel (*Anguilla Anguilla*). Within the buffer of 2 kilometre for large-scale hydropower plants species such as Goshawk (*Accipiter gentilis*), Eurasian Eagle-Owl (*Bubo bubo*) were found, but also different kinds of fungi such as *Cortinarius spendens* and *Porpoloma metapodium.*

Table 5.3: The amount of mapped red listed species within the two different buffers for the three energy production types. Source: author.

Power type	Red listed in 10 km buffer	Red listed in 2 km buffer
Small-scale hydropower	4125	349
Large-scale hydropower	1263	346
Wind power	1316	49

The numbers of identified red listed species for large-scale hydropower are listed in the table as summarized values. Within the buffer of 2 kilometre for large-scale hydropower plants, species such as Goshawk (*Accipiter gentilis*), Eurasian Eagle-Owl (*Bubo bubo*) live, but also different kinds of fungi such as *Cortinarius spendens* and *Porpoloma metapodium.* For more information of amount of red listed species for each of the three large-scale hydropower plants, see Appendix G.

Small-scale hydropower is the power production with the highest number of identified red listed species, with a total of 4125. This amount is a summarized value from all the 27 locations. Even though there is a decline in number of species in the 2 kilometre buffer, small-scale is still the power production with the highest number. Some locations do not have red listed species within the 2 kilometre buffer, such examples can be Øvre Årdal, Neselva, and Kandal, but on the other hand some locations have up to 12 identified red listed species, such as Skjerdal. Species which have been identified here are all vascular plants such as *Ulmus glabra* and *Pseudorchis albida,*, except one which is a lichen species called *Bryoria bocolor.* For more information about the number of red listed species found for each individual small-scale hydropower plant, see Appendix F.

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5.4 INON

The following figures show the overlaps between the different energy production types and the last official INON mapping done by the Directorate for nature management (DN) in 2008. The values for each of the production types in Figure 5.7 shows the values found at the 5 kilometre buffer for all the three renewable energy production types. Here, small-scale hydropower has an overlap of 4216 km², while the average value for the three large-scale hydropower plants is 1595 km². Wind power has the lowest measure of overlap with only 33 km². Small-scale hydropower has the highest amount of overlap, almost three times as for the large-scale hydropower plants.

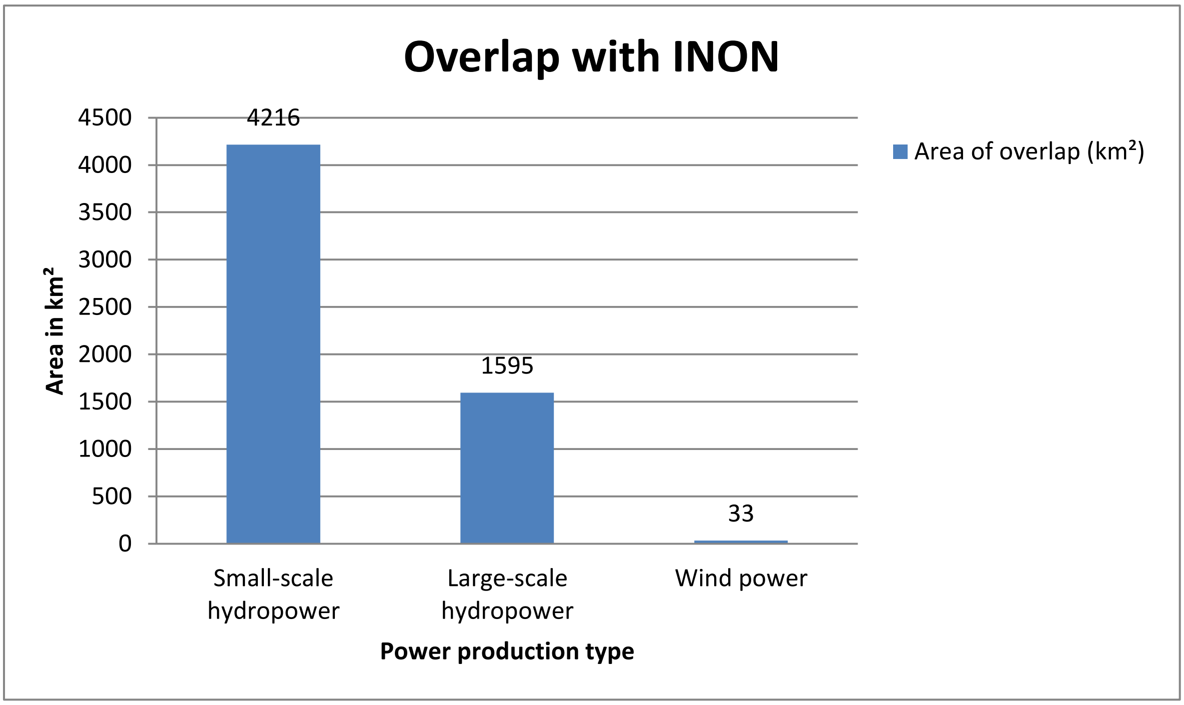

Figure 5.7: The different mapped measures of area overlap with INON areas. Source: author.

Figure 5.8 shows the different levels of overlap between the three buffers created around the three large-scale hydropower plants and the official mapping. The 1 kilometre buffer has an overlap of 664 km², while the 3 kilometres buffer has an overlap of 1240 km². The overlap between the 5 kilometres buffer and the official mapping is 1594 km². Figure 5.10

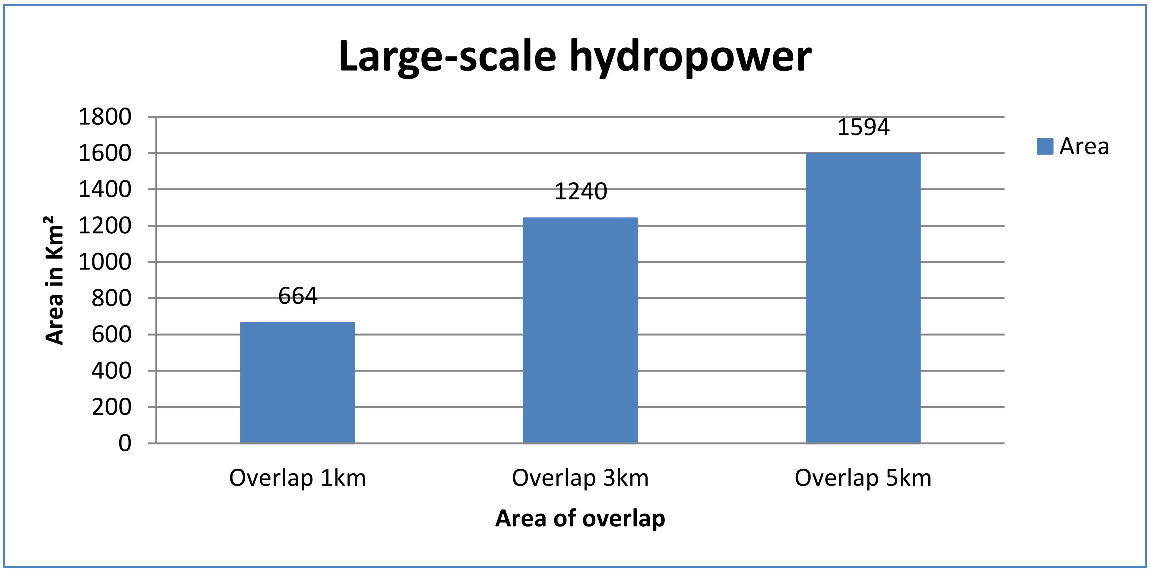

Figure 5.8: The measured area overlap between INON areas and large-scale hydropower plants. Source: author.

For small-scale hydropower the area of overlap with the last official mapping shows that within the 1 kilometre buffer, a total of 1816 km² overlap shown in Figure 5.9. For the 3 kilometre buffer, the overlap is 2965 km², while at the 5 kilometres buffer the area measure is 4126 km². This shows a steadily increase in the amount of overlap, and also the highest overlap for all the three different buffer of all the three energy production types.

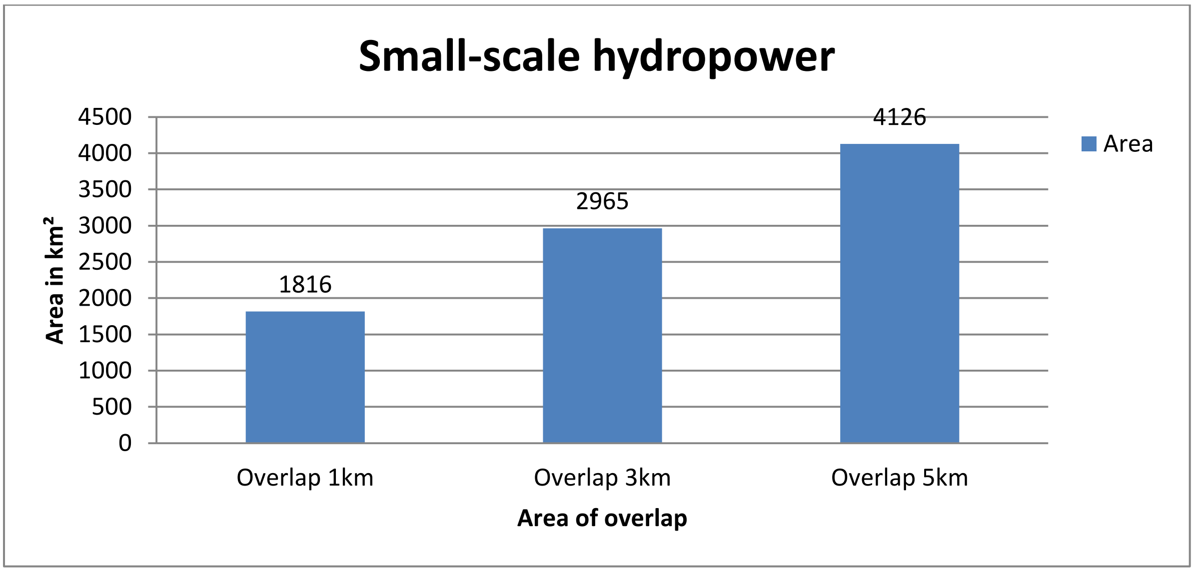

Figure 5.9: Graph shows the amount of area overlap between INON areas and small-scale hydropower plants. Source: author.

In comparison to the two previous energy production types, wind power has only a 0, 6 km² area overlap for the 1 kilometre buffer in Figure 5.10. For the 3 kilometres buffer the area overlap is 26 km², and 5 kilometres buffer has an overlap of only 33 km². This is by far the lowest overlap of all the three energy production types.

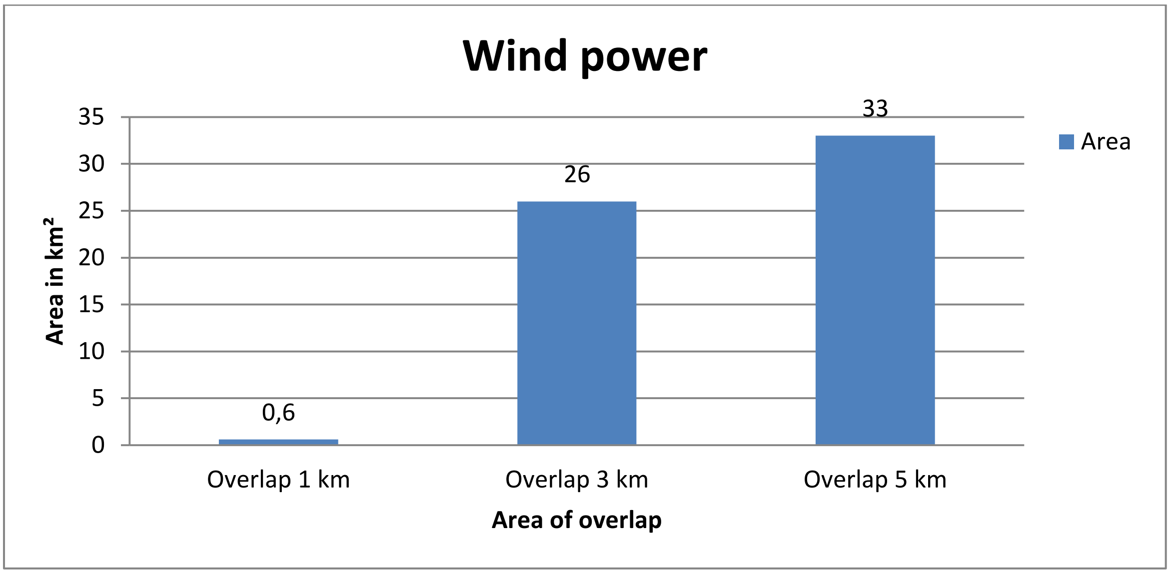

Figure 5.10: The amounts of area overlap between INON areas and wind power. Source: author.

For more information about the results for the four different parameters, see Appendix F, G, and H.

6 Discussion

In this chapter I will discuss the results from my analysis and relate them to previous studies. At the same time I will answer my research questions, discuss weaknesses and strengths in the methods used and implications for the results.

6.1 Parameters

6.1.1 Area directly affected

Several studies have emphasized the importance in measuring area usage and the need for better planned design of the power plants. In this thesis I have mapped the areas directly affected by three renewable energy production types, with varying degree of resulting area usage. Large-scale hydropower and wind power were the production type with the highest area usage, while small-scale hydropower had the lowest mapped area directly affected. Measuring the area usage for a power plant is not just about the areas directly affected, but also on the utilization of the area used by the power production type. From the results in this thesis, one can see that small-scale hydropower has the highest energy production per square kilometre of 46 GWh/km², in comparison to large-scale hydropower with 21 GWh/km² and wind power with 21 GWh/km². This is interesting results as it shows that the power production Norway has its highest focus on today, is actually the most efficient area user. On the other hand, the production type with the lowest area utilization is large-scale hydropower and wind power.

The results showed that large-scale hydropower and wind power had the largest area usage, because these production types are commonly associated as and sort of expected to be extensive and obtrusive compared to the small-scale hydropower plants. There are several reasons for this. Large-scale hydropower plants do often cover a large area because of the reservoir. Regarding of the hydropower plant size, the reservoirs can vary in area by several orders of magnitude depending on the height of the dam, local topography, and the desired energy production (Egré and Milewski, 2002). Not all large-scale hydropower plants have one large reservoir, whereas some plants have several dams with different elevation heights. An example here can be Øksenelvane, a large-scale hydropower plant with three reservoirs. By having several dams operating as reservoirs compared to one large, the first thought is that this gives the power plant a higher amount of area usage and less production capacity because of the spread locations. This is not the case as Øksenelvane has energy production efficiency of 27 GWh/km², while Leirdøla with the highest annual production has 28 GWh/km². Leirdøla is the large-scale hydropower plant with the highest annual energy production of the three, but not the highest amount of area directly affected, while Øksenelvane has the lowest annual energy production and the least amount of mapped area directly affected. This shows that there is no given relation between highest amount of energy production and area usage to cause the most efficient area utilization per GWh.

From the mapping of area directly affected, wind power had the highest measured area. The reason to why wind power plants occupy such a large area is because of the safety areas which needs to around each wind turbine. As stated in the theory, the area which the wind turbines and connecting roads occupy is only one till three percent of the total area in the park (Abelsen, 2007), where the rest is defined as safety areas. By including the total area within the wind power plant, a utilization of 5 – 10 MW/km² is expected (Edenhofer, 2012). For Smøla wind power plant this estimation is optimized as they produce 8, 92 MW/km². Wind power has an area utilization of 21 GWh/km² which is the same as the average value for the three large-scale hydropower plants. It is interesting that wind power and large-scale hydropower has similar results. Large-scale hydropower has for many years been sworn off by the Norwegian Government as an undesirable energy source. Wind power, on the other hand, is one of the most sought after renewable energy production types today, although it has approximately the same annual energy production, area measures, and GWh/km² as large-scale hydropower.

As I have done in this thesis by randomly choosing 27 small-scale hydropower plants, it is very likely that not all power plants exhibit the same characteristics according to area usage and annual energy production. The results in Figure 5.3, shows that the results might be driven by two power plants which have a higher area directly affected than the others. But what the results indicate is that when the annual energy production increases, there is a decrease in area directly affected. These results show that the higher energy production a new project has, the more effort and planning is done for securing low area impacts. These two small-scale power plants which have a higher area directly affected than the others are located in a typical fjord landscape with tall and steep mountain sides. Often this location of the project means that a previously road is not present, pipelines that need to be buried down or drilled through the mountain, and the construction gives large scares which needs several years to heal before they blend back into the surrounding nature.

6.1.2 Visibility

Analysing the visibility for the three energy production types shows interesting results. Small-scale hydropower is the power production that has by far the highest amount of visibility with a total of 340 km^2 which is the combined visibility of the 27 small-scale hydropower plants. Second is wind power with 164 km^2, and large-scale hydropower has the least visible area with an average value of 24 km^2 between three power plants.

From my findings in the visibility analysis, small-scale hydropower has the highest amount of visibility. Since there were 27 different power plants, it is interesting to see what and if there are any relationship between visibility and the annual energy production. From Figure 5.5 one can see very interesting results. The power plants are ranged after their annual energy production and as a result one can see that the visibility decreases as the energy production increases. This result is confirmed by the added trend line. The small-scale hydropower plant with the least amount of annual energy production is the one with the highest amount of visibility. This can be explained as the larger the energy production planned in a new power plant, the more systematic and comprehensive planning is done. One reason why the combined visibility for all the small-scale hydropower plants is this high can be because of their locations. Many of them are located in the fjord landscape with steep mountains where the power plant is visible from mountain tops and from the other side of the fjord over larger areas. It might also be a factor that the entire area directly affected by the power plant is used as a basis for the analysis, which includes the possible built road, pipelines and river lengths with reduced amount of water.

As a second in the amount of measured visibility is wind power. This type of renewable energy has very specific site requirements for producing as much energy as possible, something which often corresponds to large visibility. These locations are coastal areas where the visibility is high and the landscape consists of low hills and rocks. To some degree it is interesting why not wind power is the power production type with the highest amount of visibility as it ranges so high above ground compared to hydropower.

Large-scale hydropower has the least amount of visibility to its surrounding areas. Even though this is an average value between three different power plants, the values are still low compared to small-scale hydropower and wind power. There might be different reasons to why the results are like this: location, planning and area directly affected. It is a well-known fact that large-scale hydropower and wind power has large controversies and therefore creates a demand for good planning. Locations might be sensitive for local people and many will therefore be involved and interested in the planning process. Large reservoirs need large areas and therefore most of Norway's large-scale hydropower is located in mountainous areas to avoid large conflicts with people's daily life. There is reason to believe that planners of large-scale hydropower tend to be more professional in their planning and mitigation measures of their projects compared to local entrepreneurs developing small-scale hydropower, due to access to competence and years of experience. The larger the project in hydropower development, the more attention the specific project gains from local community, NGOs, governments and authorities, and might lead to better environmental performance within the actual project.

My findings on the relationship between small-scale hydropower plant and its visibility, do to some degree correspond with the findings in the article by Bakken et al. (2012), where they states that large-scale hydropower plants have to a higher degree more professional planning than small-scale hydropower plants does (Bakken et al., 2012). From Figure 5.6, one can see that the visibility for large-scale hydropower plants decreases as the annual production increases and therefor there is no reason to doubt that this relationship also exists for large-scale hydropower. Planning and mitigation measures become a more important factor in the planning process when the annual energy production increases no matter what type of energy production type.

6.1.3 Red listed species

Mapping the amount of red listed species within two different distances from the power production sites shows large differences. Small-scale hydropower has the highest amount of red listed species within a buffer of 2 kilometres from the site defined by the area directly affected, with an amount 349 species. Large-scale hydropower comes as a close second with 346 species within the 2 kilometres buffer, and wind power has the lowest amount of identified species with a total of 49 species.

From the results one can see that the amount of mapped red listed species is high, especially for small-scale hydropower and large-scale hydropower. This might be because these two types of energy production are located in the fjord and mountainous landscape which to some degree contain different biodiversity as coastal areas where Smøla wind power plant is located.

There is not only put much emphasis in the importance for identification and mapping red listed species when building a new power plant, but also the lack of knowledge surrounding these species which might cause them to be lost from the actual sites. In his report Rørslett (1989), found that the response feature in hydrological vegetation in 17 Norwegian lakes after the establishment of a hydropower plant to be a decline in species richness, a gradual disappearance of the shallow water and mid-depth communities (Rørslett, 1989). This indicates that the environmental changes cause disturbances which are irreversible to many marine species in locations with hydropower development. In most of the published guidelines, the emphasis has been set towards locations which are continuously moisturized by the flowing water in the river. These locations represents habitats for important species such as for the Fossekall (*Cinclus cinclus*) (Størset, 2009). But also in the guideline published by Gaarder and Melby (2008), there are suggestions to specific locations one should investigate for identifying red listed species (Gaarder and Melby, 2008). It is positive that many different guidelines have been published for the mapping of these species; there is thus no common method for sampling and documenting the existing data. In addition, there are limited numbers of people in Norway who can classify these groups of species which might cause some species to be overlooked.

In this thesis I have not made any distinction between different red listed species, and all the species have been weighted the same. This does have some implications. By evaluating all the red listed species the same, the differences in species habitats and requirements are not addressed. Hydropower and wind power have very different contexts, whereas different energy production types affect different types of species, and these species are thus affected in different ways. The impacts from a newly established reservoir will affect species in a different way than the risk of colliding with a wind turbine. The reason behind weighting all species the same is because when discussing impacts on species from the establishment of renewable energy, it is sometimes given enhanced focus on particular species which often are not red listed. Examples here can be the sea eagles and salmon, which both have generated much attention in the media. Both these species have functioned as sort of flagship species affected by hydropower and wind power, which in some cases leverage more support for taking other species that also live in the same habitats into consideration. When discussing the conflicts between red listed species and the implementation of new power plants, the example of the sea eagle is important because of the well-known conflict. The sea eagle is not a red listed species in Norway, but has previous been a Norwegian protection species. Though there have been done several studies mapping how the eagles respond to the presence of wind turbines, the results show no positive trend for the establishment within the wind power plant (Dahl et al., 2012, Reitan, 2013).

Measuring a possible decline in species richness invoked by either hydropower or wind power cannot be performed unless before impacts data exist. Unfortunately, such data tend to be missing in Norway (Erikstad et al., 2009). But for Smøla wind power plant the collection of data started in 2003, while the wind power plant became operational in 2005. This has given the researchers good information on territory, productivity, and the birds' activity related to the wind turbines. Since good information is so crucial in evaluating mitigation measures and how to make projects more environmental friendly for the future, more research needs to be done.

The mapping of red listed species which is reported to Artsdatabanken, is from people who has identified the species when out in nature. This means that the species is only mapped if it is located. But many species, and especially birds, have nests which have previously been used but are at the moment empty. An example here can be the owl Hubro (Bubo bubo) who stopped the building of a new small-scale hydropower plant in the municipality Førde in Sogn og Fjordane in 2011 (Norsk Ornitologisk Forening, 2011). In this case, the Norsk

Ornitologisk Forening did fieldwork in two day trying to spot the owl, but without luck, but because of the request from the Directorate for nature management, the building was stopped. In the case for the management of Hubro, the goal is to re-establish the species in locations where it has been nesting before and is a goal set in the published action plan for the owl (Directorate for Nature Management, 2009).

A report done by Gaarder and Melby (2008), focuses on the documentation of biodiversity on the sites which are planned for building small-scale hydropower plants. This report identifies several points which emphasize the need for new and clear requirements for conducting documentation of biodiversity. However, they state that the individual municipality maps do often not contain correct information, and that only 10-20 percent of the sites planned for power production has previously been investigated. There have also been identified that encounters with red listed moss and lichens are rarely reported and documented in databases (Gaarder and Melby, 2008). There have been conducted several studies to investigate why this is the case, but one reason is that there does not exist any guidelines to how red listed species should be properly mapped and sampled in the best possible way for people who are not biologists (Størset, 2009).

6.1.4 Encroachment-free areas (INON)

Mapping the amount of areas overlapping from renewable energy with encroachment-free areas shows that small-scale hydropower has the highest amount of overlap with the last official mapping done by the Directorate for Nature Management in 2008 with a measure of 4216 km². Second is large-scale hydropower with 1595 km², and wind power with the least amount of overlap of 33 km².

My results show that small-scale hydropower has by far the highest amount of area overlap, with more than twice as much area overlap found for large-scale hydropower. As stated by the OED in their guidelines from 2007 are that encroachment-free areas in conflict with the building of small-scale hydropower plants should be treated with extra value (OED, 2007b). The mapped results clearly show that this request is not taken enough into consideration from the project planner and licensing authority concerning the building of new small-scale hydropower plants. The results from small-scale hydropower is many times higher than for large-scale hydropower and wind power, which are both known to be area extensive and located in remote areas. As one would expect from this statement, these two production types should have had the highest overlap. The increasingly amount of new small-scale hydropower plants creates a “piece by piece” destruction of the encroachment-free areas which will eventually reduce the amount of wilderness-like areas to a minimum within years. Many areas has gone through reallocation from their originally usage as farm land, especially coastal areas and the most productive inland areas in Norway, into more industrial areas (The Directorate for Nature Management, 1995). This change might increase further as the renewable energy goals for year 2020 are being implemented.

Large-scale hydropower has the second highest amount of overlap with INON areas, but only half the mapped value of what small-scale hydropower has. This is interesting results as the reservoirs for large-scale hydropower plants in Norway are often located in remote areas which one would assume would be classified as INON areas.

Wind power areas which overlap with the last official INON mapping shows the smallest value of overlap between the three power production types. The case from Smøla wind power plant is unique as the plant is located on an island which had settlement and existing technical encroachment prior to the wind power production and might be a reason for the low measured overlap. This might though not be the case for other newly established wind power plants. As stated before, wind power had certain site requirements such as high annual wind resources which is often located in remote areas. This means that many of the areas in Norway that have the highest potential for wind power production are located in areas without previous technical encroachment, and might cause a large loss in INON areas.

IINON methodology has been a topic of much discussion in Norway where it has been used for nature management purposes. According to, a major problem is that newer INON maps have broader inclusion criteria for which type of infrastructure to include. It is important to note that the datasets from the INON analysis are just for reference on national scale, not on a detailed local scale. Because of the simplicity in its data presentation and a tendency among decision makers to only accept the values without being critical to the accuracy. In order to be an efficient tool in land use planning and management, the datasets need to be verified and updated more often than every four years. One example on how impractical the

INON methodology works in relation to encroachment-free areas is how different types of interventions are included while others are omitted. Transmission lines over 33 kV are for example defined as an encroachment, while transmission lines with 11-22 kW are omitted (Skjeggedal et al., 2005). This means that the local transmission lines can go straight through areas which on map are indicated to be a part of the last remaining wilderness-like areas in Norway.

The official INON mapping does not include information on what quality or type of environment the actual areas has, which is an important factor since this tool is used for nature management. By being aware of these weaknesses with the INON tool, the Ministry of Environment uses it in collaboration with other environmental factors and interests. The areas which are classified as wilderness-like areas do not necessary mean that they contain special and important biodiversity as the INON methodology is not set as a definition of biodiversity richness. These other interests might then overshadow the importance of the wilderness-like areas, because there has not been stated what type of value the wilderness-like areas have. As mentioned in the theory, INON is made to give an outline of the development over time and visualizing how much of the wilderness is lost as the infrastructure expands. Norway had at the last official mapping only 12 % wilderness-like areas left. (Directorate for Nature Management, 2012c). The wilderness-like areas are important to preserve as they are thought of as the last "untouched" areas in Norway.

From the analyses of the four parameters, small-scale hydropower has the least favourable results in three out of four parameters, compared to the results for large-scale hydropower and wind power. These findings relate to what Bakken et al. (2012) found in their article, that small-scale hydropower has a slightly higher degree of environmental impacts that large-scale hydropower (Bakken et al., 2012). The power production which had the most favourable results from the analyses, where wind power, closely followed by large-scale hydropower.

6.2 Environmental impact

Norway does already produce large amount of renewable energy, but has still a large potential within both hydropower and wind power which has not been utilized. Even though Norway is such a large producer within renewable energy, the knowledge of the environmental impacts from these power production types is limited. With the implementation of el-certificates, the need for more thoroughly knowledge is crucial for the management authorities to assess the licensing process in the best possible manner. Problems in assessing environmental impacts are often based on the lack of knowledge on the cause/effect relationship which occurs after the power plant has been built (Størset, 2009) and relates to the lack in follow-up studies.

The different relationships within nature hangs together in the most complex ways and a change in one end can cause impacts on the other end. One would have thought that after so many years of building hydropower in Norway and the solid wind industry in Denmark and Holland would give good indications on what impacts the buildings would cause. But the case is that all new power projects are site specific, and especially Norway which has a different topography and thereby different biodiversity than for example Denmark and Holland. For large-scale hydropower which has deep roots in the Norwegian society, is that the biggest systems were built either in the first years of 1900's or in the 1970-80's in the time before environmental mapping became an element in the concept of energy production. With the increased planning for building more power plants, the energy needs to be transported from the power plant till the consumer. To do so a strong power grid is needed. A bottleneck is therefore the transmission lines which are not strong enough to handle this increasing amount of produced energy. Therefore, Statnett which is Norway's transmission service operator is planning for several new lines which will strengthen the grid around in Norway. This does of course create much conflict with environmental interests, but this will not be discussed in this thesis.

When the EIA and EA have been completed for the new power plant, the license is sent to the licensing authority for evaluation. This process is long as it can take up to several years, and translates into a competitive disadvantage for renewable energy producers compared to other forms of power generation. The long licensing process generates significant cost for all participants in the project as it takes many years before they receive income from the power production. There is a lot of money at stake in establishing a new power production plant, both in investment cost, but also in income from energy sales. The cost for a landowner to be a co-owner in a company that invests 100 million NOK on a small-scale hydropower is a large risk. One reason to why the licensing process takes so long is because of the different elements which need to be evaluated, such as sum-impacts.

The concept of sum-impacts states that the amount of planned new energy production projects within the same area should be evaluated up against each other to assess the overall combined environmental impacts. But at the same time, sum-impact is a confusing concept which is difficult to analyse and there are few agreed upon methods for their assessments. It should be stated that when NVE receives many license applications for power projects within an area, they try to coordinate the licensing process as far as possible. The question then is what is too much for an environment where several small-scale hydropower plants are planned, or an area with more than one wind power plant. An example can be from Sørfjorden in Hordaland, where a total of 10 applications for small-scale hydropower plants, where 6 projects were granted and 4 declined. The arguments given by NVE for declining the power plants, were their locations in the valuable nature and building of the power plant would ruin this scenic beauty which is associated with the fjord landscape (NVE, 2012b). In this example, NVE emphasised the importance of conserving the rivers that they believe makes the most quality and character to Sørfjorden, and at the same time looked at the environmental adaptations of each individual project to reduce possible conflict.

In this thesis I have used the boundary between small-scale hydropower and large-scale hydropower which has been set by the licensing authorities in Norway. The impacts from small-scale hydropower and large-scale hydropower are to some degree the same, though they vary in magnitude according to power plant size, which is expected. The boarder set for separating small-scale from large-scale at 10 MW represents an artificial distinction on how to classify and assess environmental impacts (Edenhofer, 2012). For the environment, there are no different responses to whether a large-scale hydropower plant on 12 MW or a small-scale hydropower plant on 9 MW has been established, even though they undergo different environmental investigations and licensing processes. Using a size-dependant threshold has in Norway acted as a barrier for further development of large-scale hydropower plants.

Regardless of this threshold between small-scale hydropower and large-scale hydropower, there is no immediate link between installed capacity and the general properties to all hydropower plants above or below the MW limit. Hydropower plants come in many project types and is a highly site-specific technology, where each individual project is a tailor made outcome for each location to meet specific needs for energy production. To classify hydropower into either small-scale or large-scale is common and administrative simple, while also to some degree arbitrary as the classification of small or large are not technical or scientific indicators of environmental impact, economics or characteristics. It would be better to classify the different hydropower project based on their sustainability or economic performance, which would act more as realistic indicators. This barrier in the development of large-scale hydropower plant in Norway has therefore fuelled the public perception that small is beautiful and large is environmental damaging. Wind power is often thought of as equally environmental damaging as large-scale hydropower and has a tendency to scare people because of its large installation. After what results have shown in this thesis, it should be more emphasis on building more large-scale hydropower plant and wind power plants, and to limit the broad extension of small-scale hydropower plants. The issue and concern of fragmentation of the environment is more important than ever with the public perception and the licensing authority's goal to grant more small-scale hydropower plants in the future.

In thesis I have tried to compare mapped environmental impacts from three different energy production types based on numeric values generated from GIS, whereas numeric values are comparative across different types of production. It is however difficult to measure environmental impacts up against each other when by using non-comparable entities. In an EIA, the measures "positive" and "negative" are used for comparison what degree the impact has and the project gets granted a license if the overall positive impacts are greater than the negative impacts (OED, 2013). When using these measures in an EIA does not mean that one medium negative measured impact has the same amount of impact as another medium negative measured impact. This type of measuring environmental impacts where the degree of consequence is created as a combination of value and scope, but is relative for each project it is set for. There is reason to believe that the scale of impact is created based on an anticipated amount of environmental impacts from the given power plant, and is therefore a more relative measure without being descriptive. In their article Bakken et al.

(2012), have turned the values from one of their large-scale hydropower plants, Trollheimen, from detailed numeric measures of the direct environmental impacts into the diffuse measures as example “middle positive” and “middle negative”. This is a form for aggregation where large quantities of valuable information are lost and the results are distorted and the comparison of quantities is based on general values which makes the results weak. But one element they introduce for strengthening the methodology would be to compare the environmental impacts towards the energy production (Bakken et al., 2012). This form of mapping has also been done by Egré et al. (1999), who means that by using the amount of energy production as a base for comparing impacts will demonstrate the fallacy of the popular belief that large-scale hydropower have greater environmental impact that small-scale hydropower(Egré et al., 1999). This corresponds to the findings in this thesis, where small-scale hydropower has the highest amount of less favourable results compared to large-scale hydropower and wind power. On the other hand does Erikstad et al. (2011) state in their report that the degree of environmental impact does not relate to the amount of energy produced, but to the changes in the actual area (Erikstad et al., 2011). By measuring the amount of change in each area, one must conduct fieldwork at each location, measuring all the different elements to get the best possible results.

One of the findings in this thesis was that the area usage for small-scale hydropower plant generally decreases as the annual energy production increases. The same was found in the visibility analysis, that the visibility for the small-scale hydropower plants decrease as the annual energy production of the power plant increases. These findings suggest that the planning which has been done for the small-scale hydropower plants with the least amount of annual energy production is not as thoroughly as for those with higher energy production and implies the need for more thoroughly planning also for the small-scale hydropower plants with low annual energy production.

In the results found in this thesis, it shows that small-scale hydropower has a slightly larger degree of environmental impact compared to large-scale hydropower and wind power from the four mapped parameters. This corresponds to some degree to what Koutsoyiannis (2011), states in his article, even though his comparison between small-scale versus large-scale hydropower is based on another parameter: geometry. He states that because of differences in geometric measure between small-scale and large-scale gives large-scale “spectacular increase in efficiency”, and because of differences in geometric measures states that small-scale hydropower has more environmental impacts than large-scale hydropower. He bases this statement on how efficient it is to store large quantities of water for meeting peak demand when the energy is needed, in comparison to account for possible environmental impacts (Koutsoyiannis, 2011). This article has included a more social comparison rather than including the different environmental elements to make a comparison, but he has a point. The extra value that is set by using a large-scale hydropower plant with a reservoir creates more secure energy production and production when the energy is needed. This positive element is not included in the comparison done in this thesis.

During the mappings in this thesis I have not taken into consideration the valuation of areas used by hydropower or wind power, even though this is an important factor in nature management, this because the valuation has already been done by the licensing authority. Landscape and nature values are thus taken into consideration during the planning process of a new power plant. In the guidelines for small-scale hydropower plants published by OED in 2007, they recommend that during the planning process for a new plant, one should identify a larger area where possible building would create conflict with important landscape values. And as a result, this would create a better picture over what landscape values to conserve for obtaining the natural quality in a best possible way. Of course, one needs to keep in mind that these are only guidelines stated by the government, not regulations or laws which the authorities and planners need to follow. This does raise questions concerning to what degree these mapped landscape values actually will be taken into consideration. An example can be the national goal for conserving INON classified areas, and especially wilderness-like areas. These areas are being fragmented by a continuously expansion of new small-scale power plants. From my results for mapping the INON overlap shows that only these 27 small-scale plants combined have decreased the encroachment-free areas by approximately 4100 km^2. As previously stated, in the planning process the value of INON areas are considered in combination with other interests and here often economic interest, which means that INON areas often ends up as the losing party.

When comparing the environmental impacts from three different renewable energy production types, one dilemma arises. How can the reduction on one type of species be valued towards the reduction in another species type? By using the measurement of red listed species, threatened and vulnerable species from the areas around the three different power production types are compared based on the amount of species present within two different buffer lengths. But other species which are not listed in the red list are excluded. Most of the known species which are affected by hydropower and wind power, examples as the sea eagle and salmon, is not mentioned in this comparison. It is very complex to measure the amount of impact on the different species and to compare the values. Is the amount of impact from one deathly collision between a sea eagle and a wind turbine the same as a salmon which is stranded and suffocates because of too low water level in a regulated river? Also, to state that one energy production type is more environment friendly than another raises another dilemma. To answer these two dilemmas, there are no clear objective answers: it will include an application of political, management and subjective valuations. By comparing environmental impacts, one must be aware that it is seldom compare “like with like”, but that there are used normative simplification. From what has been done in this thesis based on the methodology might thus give an indication of what can have a lesser degree of environmental impact than the others, but there are no clear answers. What can be discussed is that the evaluations done in this thesis has a subjective tone, and all boundaries and measures have eventually been chosen by me. Even though, I do not think that measuring environmental impacts between different energy production types can be done without some degree of subjectivity.

In this thesis I have chosen four different parameters to map the environmental impacts from three different energy production types, where the four parameters have been weighted the same. Though the measure of area directly affected have been used as a basis for further investigations in the other three parameters, it is not weighted as more important than the others. This is a simplification of the complexity of the different elements in the environment affected by a new power production plant.

6.3 Methodological discussion and limitation

In this thesis the basis for comparison of environmental impacts is the annual energy production for the three different energy types. The amount of annual production that has been chosen differ to a small degree between the three types, but to have the exact same energy production requires the selection of power plants to be non-random. There has not been any selection to what type of landscapes the power plants have been located in, even though it has been done indirectly by choosing power production types which has specific requirements to topography. This might also have affected the results in different ways, as to the number of red listed species found, overlap with INON, visibility and amount of area directly affected. Small-scale and large-scale hydropower productions are both selected from typical fjord landscape, while wind power plant is from the characteristic coastal landscape. The element of landscape will thus always differ, because of the requirements for optimum energy production it is hard to find a wind power plant and a hydropower plant within an area which exhibit the same nature elements for all the parameter investigated.

In the analyses I have used four different parameters for mapping the environmental impact, where the choice has been set on giving all parameters equal weight as an additional choice. Many might argue with this. Depending on who you ask, some impacts might be considered less important than others, as impacts on salmon fish is often considered more important than other aquatic species, due to their known level of conflict and as a source of income though tourism and fishing. At the same time, one impact, for example area usage, can be more acceptable in one location than the other, depending on the status of the area and the local interest. In order to weigh the different impacts mapped in this thesis, individual and subjective judgements are introduced, together with political and management priorities. It is impossible to say that one environmental impact is more important or severe than others. Based on this, the results in this thesis are only presented as indications.

Large-scale hydropower is area extensive because of the reservoir, which gives this type of energy production a large advantage because of the possibility to store and produce energy when there is a demand. This advantage has not been given an extra weighting in this thesis, even though it is one of the most positive thing elements with this production type.

What is interesting to investigate, is to what degree the chosen power plants are representative for the rest of Norway and to what degree a generalisation of the results found in this thesis is possible. As stated in the methodology chapter, the decision behind choosing hydropower plants from the same county was based on the access to good data from a county with a high density of built hydropower, as was the same argument for using Smøla for wind power. It has not been evaluated if the results can be transferred to other counties, but it is clear that Sogn og Fjordane is unique in its nature and topography compared to other counties in Norway. But the same parameters which have been used in this thesis are universal and can be used for other areas in Norway. It is thus important to emphasise that the case studies chosen will be site specific no matter where in the country they would be selected from.

The use of GIS as the methodological tool in this thesis has given a valid representation of the analysis done as where the base map can be overlaid with other layers of information in order to view spatial information and relationships. GIS allows for better viewing and understanding of the physical features and relationships which influence the different element in the environment or impact one seeks to understand. These elements are also what make the use of GIS as a good tool for mapping environmental impacts as have already been showed by Erikstad et al. (2009) who mapped sum-impacts for the county Nordland (Erikstad et al., 2009) using GIS.

The purpose of the methodology in this thesis was to do a map analysis to study factors related to specific renewable energy production project with the usage of N50 maps. These maps are the most precise maps that cover the entire Norway. A possibility would be to use N5 data, but they do only cover economic regions, which mountainous are not. When there are new maps with larger resolution, a possibility would be to study the locations in more detail, supplied by aerial photograph analysis with associated field inspections. Another factor that would be interesting to investigate further is what type of landscape types and values of the areas used, and if the establishment of the energy production projects have caused any changes in the usage. It would also be interesting to evaluate to what degree these renewable power plants interfere with protected areas.

6.3.1 Limitations

The basis for analysing all the parameters have been the measures of area directly affected. The decision on what borders to map has set the basis for the rest of the analysis. This might have had effect on the results in either positive or negative direction, as the mapping of the area either has been too small and therefore underrepresents the results, or that the mapping has included too much of the area and has enlarged the results.

One large limitation to this study is that the transmission lines are not included. These are an important factor in the establishment of a new power plant and might be the reason for many arguments. If they were implemented in this thesis, this would be a factor that might have had a great impact on how the results would have turned out. Many of the power plants are located in areas where might have been an additional building of the transmission lines to manage the new power production.

There has not been used any area delineation in the visibility analysis, which means that the analysis for wind power might have calculated areas with further distance than 30 kilometres, as in this case as far as the input data allows. The viewshed analysis does not take vegetation or buildings into conisation, so the amount of area mapped as visible is a theoretical measure, together with distances over 30 kilometres away. Very few humans can see that far, even on a clear day. In the visibility analysis no additional height measure for mapping the hydropower plants were added. This decision was based on the fact that most hydropower plants have large differences from reservoir/water intake till the power house and water outlet, sometimes as much as several hundred meters. For eliminating any possible errors by setting the power plant at for example 342 meters above sea level, they were all set at 0.

The mapping of red listed species present within the buffer does not measure what type of species it is or where within the 2 and 10 kilometre buffer they are located. Which means that fungi located at the boarder of the mapped buffer is mapped as being close to the power plant. Also, by using the same energy production as basis has in this thesis given 27 small-scale hydropower plants with 27 different locations where there have been mapped for red listed species, compared to wind power which had only one area. The different in amount of location, and different environmental locations, gives therefore the results large variations.

The three large-scale hydropower plants which have been used in this thesis are all built before 2008, which means that they can be a part of the last official mapping from 2008. This might explain the low amount of area overlap found in the analysis compared to small-scale hydropower, especially when large-scale hydropower had such a higher amount of area directly affected.

7 Conclusion

With this thesis I have tried to map and compare the environmental impacts from three different renewable energy production types: small-scale hydropower, large-scale hydropower, and wind power.

My first research question was to identify what type of environmental impacts the four analysed parameters for the tree renewable energy production types had. All results are listed in chapter 5 for more accurate numeric values. For all the four parameters, small-scale hydropower was the production type with the least favourable total result, with the highest amount of red listed species within 2 kilometre buffer, most overlap with INON areas, and the highest amount of visibility. However, small-scale hydropower plants had the highest area utilization with the highest amount of energy production per square kilometres it occupied. The production type with the most favourable results is wind power, which had the least overlap with INON area, least amount of red listed species, but the highest amount of area usage. As a close second comes large-scale hydropower comes in between with low visibility, high amount of red listed species, INON overlap and area usage.

My research question 2 was to evaluate if the four parameters allowed for a comparison across different types of energy production. Yes, the parameters used in this thesis do allow for a comparison across different energy production types because by analysing them they give results which are numeric and uses the same units, and thereby comparable. A large factor to why these parameters have been comparable is because GIS, which allows for comparisons of geographic data and meets the methodological challenges which are raised by this research question.

8 Recommendations

Further research to enhance our knowledge on environmental impacts from the building of renewable energy needs to be strengthened as an increasing number of new power plants are being licensed. Research on sites to create a before-after comparison will enhance the knowledge on what effect the different elements in the building process which creates the largest change in the environment. These elements can then be taken into the planning process to create the best possible mitigation measures.

An element that can be strengthened is the guidelines set by the licensing authority. The guidelines need to be clear and concise so the assessment, collection, and reports of findings are followed up for all new projects.
The overall licensing process needs to be stricter in their requirements for what environmental investigations that needs to be conducted, and to ensure proper follow-up studies for each site.

The classification scheme which today is being used by EIA and EA is not sufficient enough to enlighten the real and site specific impacts by using a classification scheme which generalize impacts into categories. Therefore, a transition towards an environmental mapping which emphasizes each individual impact should be used. The methodology used in this thesis is a good foundation to build a strong method of assessments, closely follow up by field measurements.

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10 Appendix

10.1 Appendix A – Downloaded thematic data

Table 10.1: This table displays the downloaded thematic data. Source: author.

Name of shapefile	Description and feature type	Original coordinate system/Datum	Source	Comments
Evi221400	Intake stations for hydropower plants (point)	UTM Zone 33 WGS 1984	From www.norgedigitalt.no	Only for Sogn and Fjordane.
Evk221400	Hydropower plants above 1 MW (point)	UTM Zone 33 WGS 1984	From www.norgedigitalt.no	Only for Sogn and Fjordane.
Evv221400	Pipelines and tunnels to power house (line)	UTM Zone 33 WGS 1984	From www.norgedigitalt.no	Only for Sogn og Fjordane.
Fri221400	Encroachment-free area in Norway (polygon)	UTM Zone 33 WGS_1984	From www.norgedigitalt.no	Covering all of Norway.
INON_SandF	Encroachment-free areas in Sogn and Fjordane (polygon)	UTM Zone 32 WGS 1984	Extracted from Fri221400	INON dataset for Sogn og Fjordane.
INON_MogR	Encroachment-free areas in Møre og Romsdal (polygon)	UTM Zone 32 WGS 1984	Extracted from Fri22140	INON dataset for Møre og Romsdal.

10.2 Appendix B – Data used in mapping area directly affected

Table 10: Data used for mapping area directly affected. Source: author.

Name of shapefile	Description and feature type	Original coordinate system/Datum	Source	Comments
Contour_lines	Elevation values (line)	UTM Zone 32 WGS 1984	From the N50 dataset.	Used for basis in the TIN.
Municipality_boarders	Municipality boarders (line)	UTM Zone 32 WGS 1984	From the N50 datasets	For delineating the area in question.
Plant_satellite.jpg	Satellite photo of the surrounding area	UTM Zone 32 WGS 1984	Satellte photo from Geonorge.no for each site.	Satellite photo for delineating the area affected.
_Samferdsel	Roads in the municipality (line)	UTM Zone 32 WGS 1984	From the N50 dataset for each municipality.	Used for point for georeferencing.
_ByggogAnlegg	Buildings and constructions (point)	UTM Zone 32 WGS 1984	From the N50 dataset	Used as reference point in the georeferencing.
Plant_areadirr	Area marked as directly affected (polygon)	UTM Zone 32 WGS 1984	From the N50 dataset.	Digitized area based on satellite photo.

10.3 Appendix C – Data used in visibility analysis

Table 10.2: Data used in the visibility analysis. Source: author.

Data	Description and feature type	Original coordinate system/Datum	Source	Comments
_AdminOmrader	Adminstrativ border (polygon)	UTM Zone 32 WGS 1984	From N50 dataset.	Used as delineation the area.
_Hoyde	Elevation (lines)	UTM Zone 32 WGS 1984	From N50 dataset.	Height input for the TIN.
Plant_line	Line around area directly affectd	UTM Zone 32 WGS 1984	From plant_areadirr.	Line from the polygon area directly affected.
Plant_TIN	Elevation displayed as TIN (polygons)	UTM Zone 32 WGS 1984	Created from _AdminOmrader and _Hoyde.	TIN made for each power plant.
Plant_DEM	Elevation as DEM (raster)	UTM Zone 32 WGS 1984	Created from plant_TIN.	DEM made for each power plant.
Plant_vis	Visibility measure (raster)	UTM Zone 32 WGS 1984	Viewshed map from plant_DEM and plant_line.	Visibility for each power plant.

10.4 Appendix D – Data used in mapping red listed species

Table 10.3: The data used in mapping the red listed species. Source: author.

Name of shapefile	Description and feature type	Original coordinate system/Datum	Source	Comments
Plant_areadirr	Area directly affected of the power plant(polygon)	UTM Zone 32 WGS 1984	Made in the area directly affected analysis.	All the power plants.
Merge-small	All small-scale hydropower plants into one file (polygon)	UTM Zone 32 WGS 1984	From plant_areadirr	Merged all small-scale power hydropower plants.
Merge-large	All large-scale hydropower plants into one file (polygon)	UTM Zone 32 WGS 1984	From plant_areadirr	Merged all lareg-scale hydropower plants.
Smøla_areadirr	Area directly affected Smøla (polygon)	UTM Zone 32 WGS 1984	From the area directly affected analysis.	Area directly affected by Smøla wind power plant.
Redlist_SogF	List of red listed species in Sogn og Fjordane	UTM Zone 33 WGS 1984	From Artsdatabanken.	Downloaded table of red listed species.
Redlist_MogR	List of red listed species in Møre og Romsdal	UTM Zone 33 WGS 1984	From Artsdatabanken	Downloaded table of red listed species.
Buffer_2km_plant	Buffer around the power plant (line)	UTM Zone 32 WGS 1984	Made by author.	Delineates the red listed species within 2 km.
Buffer_10km_plant	Buffer around the power plant (line)	UTM Zone 32 WGS 184	Made by author.	Delineates the red listed species within 10 km.

10.5 Appendix E – Data used in mapping INON overlay

Table 10.4: Data used in mapping the INON overlap. Source: author.

Name of shapefile	Description and feature type	Original coordinate system/Datum	Source	Comments
Plant_areadirr	Area directly affected by the power plant (polygon)	UTM Zone 32 WGS 1984	From the analysis area directly affected	Area directly affected for all the power plants.
Plant_1kmbuff	Buffer of 1 kilometer (polygon)	UTM Zone 32 WGS 1984	Made by author.	Buffer around the plant_areadirr.
Plant_3kmbuff	Buffer of 3 kilometers (polygon)	UTM Zone 32 WGS 1984	Made by author.	Buffer around the plant_areadirr
Plant_5kmbuff	Buffer of 5 kilometers (polygon)	UTM Zone 32 WGS 1984	Made by author.	Buffer around the plant_areadirr
INON_SogF	List of red listed species (table)	UTM Zone 33	Downloaded from Artsdatabanken	Table of all the mapped red listed species in Sogn og Fjordane
INON_MogR	List of red listed species (table)	UTM Zone 33	Downloaded from Artsdatabanken	Table of all the mapped red listed species in Møre og Romsdal.
Intersect	Measure of overlap	UTM Zone 32	Made by author.	Overlap between the different buffers and INON layers

10.6 Appendix F – Result small-scale hydropower

Table 10.5: Results for small-scale hydropower for area directly affected. Source: author.

Number	Power plant name	Annual production	Area directly affected
1	Trollelva	4,83	0,207
2	Hugla	5,5	0,278
3	Skolten	6,3	0,0537
4	Nedre Årdal	7,3	0,15
5	Nydal	7,3	0,206
6	Kråkenes	8,96	0,159
7	Dale	9	0,126
8	Steindøla	9,08	0,204
9	Frammarsvik	9,4	0,094
10	Øvre Årdal	11	0,95
11	Rognkleiv	11,28	0,417
12	Sanddal	11,4	0,228
13	Kaupanger 3	11,7	1,122
14	Neselva	12,5	0,0699
15	Sandal	12,5	0,0592
16	Vanndøla	12,8	0,341
17	Hjelle	12,84	0,0529
18	Vindedal	15	0,299
19	Rivedal	15,6	0,459
20	Sagevikelv	16,5	0,318
21	Bjørndalselva	17,4	0,553
22	Brekkefossen	18,01	0,062
23	Egge	18,9	0,205
24	Kvåle	19,5	0,263
25	Jardøla	20,21	0,27
26	Kandal	20,45	0,268
27	Skjerdal	24,43	0,1047

Table 10.6: Results for the visibility analysis for small-scale hydropower. Source: author.

Number	Power plant name	Annual production in GWh/year	Visibility in km²
1	Trollelva	4,83	35,738
2	Hugla	5,5	15,459
3	Skolten	6,3	2,801
4	Nedre Årdal	7,3	10,557
5	Nydal	7,3	7,655
6	Kråkenes	8,96	8,798
7	Dale	9	6,502
8	Steindøla	9,08	33,272
9	Frammarsvik	9,4	9,967
10	Øvre Årdal	11	9,642
11	Rognkleiv	11,28	9,05
12	Sanddal	11,4	15,868
13	Kaupanger 3	11,7	22,01
14	Neselva	12,5	9,433
15	Sandal	12,5	6,957
16	Vanndøla	12,8	11,036
17	Hjelle	12,84	4,351
18	Vindedal	15	20,511
19	Rivedal	15,6	17,526
20	Sagevikelv	16,5	8,16
21	Bjørndalselva	17,4	16,629
22	Brekkefossen	18,01	2,476
23	Egge	18,9	7,237
24	Kvåle	19,5	1,359
25	Jardøla	20,21	22,893
26	Kandal	20,45	10,796
27	Skjerdal	24,43	11,14

Table 10.7: Results for the mapping of red listed species within two buffers. Source: author.

Power plant namne	Municipality	Red lister in 10 km buffer	Red listed in 2 km buffer
Brekkefossen	Gloppen	47	0
Egge	Gloppen	100	2
Hjelle	Gloppen	90	3
Jardøla	Gloppen	372	75
Nedre Aardal	Gloppen	75	0
Neselva	Gloppen	78	0
Ovre Aardal	Gloppen	73	0
Rognkleiv	Gloppen	51	0
Sandal	Gloppen	64	1
Skjerdal	Gloppen	332	12
Kandal	Gloppen	66	0
Skolten	Flora	153	3
Frammarsvik	Naustdal	132	1
Nydal	Førde	64	0
Kråkenes	Førde	183	6
Sagevikelv	Fjaler	122	11
Dale	Balestrand	144	7
Kaupanger 3	Sogndal	402	69
Steindøla	Stryn	144	6
Trolldalen	Stryn	112	7
Daleee	Luster	16	0
Kvåle	Luster	219	44
Bjørndalselva	Jølster	66	2
Sanddal	Jølster	59	2
Vindedal	Lærdal	369	0
Rivedal	Askvoll	236	11
Hugla	Vik	356	87

Table 10.8: Data used in mapping the INON overlap. Source: author.

Small hydropower	Mapped area in km²
Overlap 1km	1815,88
Overlap 3km	2965,02
Overlap 5km	4126

10.7 Appendix G – Results large-scale hydropower

Table 10.9: Results for area directly affected for large-scale hydropower. Source: author.

Power plant name	Annual production (GWh)	Area directly affected (km²)
Øksenelvane	135	4,964
Leirdøla	462	16,898
Årøy	446	27,88

Table 10.10: Results for visibility analysis for large-scale hydropower. Source: author.

Power plant name	Annual production (GWh)	Visibility (km²)
Øksenelvane	135	42,8
Leirdøla	446	15
Årøy	462	15,1

Table 10.11: Results for mapping red listed species for large-scale hydropower. Source: author.

Power plant	Municipality	Red listed species in 10 km buffer	Red listed species in 2 km buffer
Årøy	Sogndal	753	285
Leirdøla	Luster	299	45
Øksenelvane	Bremanger	208	16

Table 10.12: Results for mapping the overlay with INON areas. Source: author.

Large hydropower	Mapped area in km²
Overlap 1km	664
Overlap 3km	1241
Overlap 5km	1594

10.8 Appendix H - Results wind power

Table 10.13: Results for area directly affected by wind power. Source: author.

Power plant name	Installed capacity	Annual production	Area directly affected (km²)
Smøla	150	356	16,85

Table 10.14: Results for visibility analysis. Source: author.

Power plant	Annual energy production (GWh)	Visibility (km²)
Smøla	356	164

Table 10.15: Resuls for mapping red listed species within two buffers. Source: author.

	Municipality	Red listed species within 2 km buffer	Red listed species within 10 km buffer
Smøla	Smøla	1316	49

Table 10.16: Results for mapping INON overlap. Source: author.

Wind power	Area (km²)
Overlap 1 km	0,574
Overlap 3 km	25,6
Overlap 5 km	32,63