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Environmental Impacts of Expanding Small-scale Hydropower in Sogn & Fjordane

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I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 10.

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Summary

In this thesis we made use of GIS-software to assess the visible impacts of small-scale hydropower in Sogn & Fjordane and compare it with the area of installation before and after construction. We found that the visible changes in landscape exceeds the land occupation given in the concession applications of five small hydro installations in the county. We study the average land occupation, both temporary and permanent, given in concession applications to NVE. Using NVE's overview of potential hydropower from an analysis conducted in 2003, which mapped the potential for small-scale hydropower in Norway, we estimated the average land occupation necessary to realize all potential hydropower in Sogn & Fjordane. The average value for land occupation, both temporary (42,56 daa[1]) and permanent (7,94 daa), was calculated from 8 concession applications available at NVE's public archive. Further, we explore the potential change in INON if we were to realize all potential hydropower through statistical analysis of the small-scale hydropower sites. We found that the total loss of INON would be 956 149,8 daa, leaving 7 367 510,9 daa of INON area in Sogn & Fjordane. Lastly, we explore the number of conflicts these potential hydropower sites may have with red-listed species within the critically endangered (CR) and endangered (EN) categories. We found that within 100 m of all the potential hydropower sites in Sogn & Fjordane there were 84 observations of red-listed species.

[1] daa is a unit for area used in Norway 1daa= 0,001km². This is the most commonly used unit in the applications to NVE.

Sammendrag

I denne oppgaven brukte vi GIS-software for å vurdere de synlige påvirkningene til små vannkraft I Sogn og Fjordane og sammenlignet området før og etter konstruksjon. Vi så at de synlige påvirkningene overskred tallene oppgitt I konsesjonssøknadene til fem små-vannkraftverk I fylket. Vi undersøkte den gjennomsnittlige arealbruken, både midlertidig og permanent, gitt I konsesjonene som ligger i NVE sine offentlige nettarkiv. Ved å bruke oversikten for potensielle vannkraftverk I Norge regnet vi ut den gjennomsnittlige arealbruken nødvendig for å bygge ut kraftverk på alle de potensielle områdene I Sogn og Fjordane. Den gjennomsnittlige verdien for arealbruk, både midlertidig (42,56 daa) og permanent (7,94 daa), var regnet ut fra tall oppgitt i 8 konsesjoner for forskjellige små- vannkraftverk tilgjengelige på NVE sitt nettarkiv. Vi utforsker den potensielle endringen i inngrepsfritt område hvis det totale utregnede potensiale hadde blitt realisert gjennom statistisk analyse av små vannkraft plasseringene. Vi fant ut at det totale tapet av INON vil være 956 149,8 daa som gir 7 367 510,9 daa av INON stående igjen i Sogn og Fjordane. Til slutt så vi på konfliktene som kunne oppstå mellom potensielle vannkraftverk og rødliste arter i kategoriene kritisk- (CR) og sterkt truet (EN). Vi fant, innenfor en 100 meters sone av de potensielle vannkraftverkene i Sogn og Fjordane, at det ble registrert 84 observasjoner av rødliste arter.

Introduction

Background

Near all electricity production in Norway stems from hydropower. Hydropower comes in several forms, from small run-of-river installations to larger power plants with lake-sized reservoirs. In 2017 the gross energy consumption in Norway was 134,2 TWh, while the energy production was 149,4 TWh. Of the total energy production hydropower contributed 143,1 TWh (Statistisk sentralbyrå (SSB), 2018). This amounts to 106.6% of the energy demand in Norway that year. Of the energy produced from hydropower it was projected that in 2019 small hydropower would account for 10,7 TWh and 134,9 TWh by large scale hydro power plants.

In an increasingly technological and energy demanding society, the need for clean reliable energy is growing. In 2015 CenSES, published a paper on the projected energy and electricity demand for the year 2050 in Norway. The projection evaluates a range of scenarios both for an increase and decrease in industry and the implementation of certain energy efficiency technologies. In most of these scenarios, demand for electricity will increase toward the year 2050, and the projected increase ranges from a 6% increase to 33% with respect to the base year of 2010. The 33% increase scenario, which assumes the highest increase in electricity demand, require an additional production of 37 TWh a year by 2050. If this additional demand should be realised by small-scale hydropower plant alone, assuming an average of 2 MW installed capacity and a capacity factor of 0,7, this would require the installation of further 3016 power plants. This increase in electricity demand therefore calls for the establishment of new power plants (Centre for sustainable energy studies (CenSES), 2015). We chose the 33% increase scenario to simply cover the most energy demanding prediction and to see if there is a possibility to cover the demand with small hydropower alone.

The theoretical hydropower potential of Norway is about 600 TWh, but due to limitations like technical and economic feasibility the potential is limited to ca 213,8 TWh. The total hydro power potential in Norway already exploited, both constructed and under construction, was 136,5 TWh in 2014. The remaining potential hydropower amounts thus to 77,3 TWh. Of this potential, 50,9 TWh would be in protected areas like national parks and is automatically excluded due to legal restrictions, which leaves a potential of 26,4 TWh as of 2014. Of this potential, an analysis of potential sites shows that 13,9 TWh of the powerplants will have a maximum capacity of 10MW or below (Norwegian Water Resources- and Energy Department

(NVE), 2015). Development of all this small hydro potential will provide 38% of the projected energy demand according to the CenSES report.

In the early 1900's, hydropower was a key component in the process of industrialising Norway and providing electricity to all residents. In 1965, there were only 2650 residents that did not have electricity (Rosvold, 2018). As of today, all of Norway has access to electricity. At the start of 2019, Norway's electricity demand was largely met by its 1626 hydropower plants contributing to an average energy production of 134,91 TWh. In a normal year this is 95% of the electricity production. 238 of these power plants are located in the county of Sogn & Fjordane which contributed with a total of 16,43 TWh in 2017(SSB, 2018).

The Norwegian petroleum and energy department assigned the Norwegian Water Resources and Energy Directorate (in short NVE) with the task of implementing a national program for small hydro development in 2002 (Jensen, 2008). The Norwegian government wanted to focus on building small hydro. The government then made, passing regulations making it easier to get approval for smaller hydropower plants through a simplified application process (Ministry of Petroleum and Energy (OED), 2015).

Norway gives specific focus on a sustainable development of its resources. In 2015, Norway ratified the United Nations post 2015 development agenda, containing the Sustainable Development Goals. The resolution includes 17 goals towards 2030 for a sustainable development. 2 of the 17 goals are directly linked to the expansion of hydropower. Goal number 7 demands to "Ensure access to affordable, reliable, sustainable and modern energy for all", and goal number 12 reads: "Ensure sustainable consumption and production patterns" (United Nations General Assembly, 2015). By ratifying the agreement Norway committed to comply with these goals. In consequence, the energy sector in Norway must try to follow the goals when expanding. As a part of the European Economic Area (EEA) agreement with the EU, Norway also has some commitments to environmental issues. One of these commitments agreed upon with the EU is the Renewable Energy directive (2009/28/EC. In short RED). It requires the EU to have 20% of its energy from renewable sources by 2020. The directive sets a goal for the individual countries, these goals vary from Malta's 10% to Sweden's 49% (This is the range for the countries that are a part of the EU) (European parliament (RED), 2009). In 2018, a new and updated version of the RED (2018/2001/EU) entered into force. The revised directive stated that the goal was increased to at least 32% renewable energies by 2030, with a clause for increasing the goal in 2023. Norway has committed to have a renewable energy percent of 67,5 % (Ministry of Petroleum and Energy (OED), 2012). In addition to the RED, Norway is committed to the EU Water Framework Directive (2000/60/EC. In short WFD). The directive ensures that the member states of the EU and the EEA achieve a good status for all bodies of water by 2015 and keep improving towards 2021 and 2027. The damming of rivers and altering of water flow may go against these goals. This puts the achievements of the RED and the WFD in conflict at some point with the expanding small-scale hydropower.

Internally Norway has committed, through the Nature diversity act (Naturmangfoldsloven, 2009), to maintain a healthy diversity in plant and animal life. The act is meant to secure sustainable use and protection of nature's biodiversity, while adding to the human well-being and activities. The act states its purpose to protect biological, geological and landscape diversity and ecological processes through conservation and sustainable use. The act also states that there is to be paid special care to land use, land use change and habitat degradation that is being caused by development projects.

What is small hydropower?

There are several definitions of small hydropower globally, but most use the installed capacity as the defining factor. The upper limit of small hydropower usually lies between 10-30MW and varies by country. In Norway, small hydropower is defined by the Norwegian Water Resources and Energy Directorate (NVE) in three categories based on their installed capacity:

- Micro: 0-100 kW
- Mini: 100-1000 kW
- Small: 1000-10000 kW

For simplicity all three categories covered in this paper are denoted by the term ‘small hydropower’. The water resource legislation (Vannressursloven, 2000, §8) requires plants with 1MW or higher installed capacity to apply for a concession through NVE (NVE, 2015). This requirement does not exclude projects below 1MW should there be any ground to believe that its environmental impacts on nature and societal values outweigh its benefits. The weighing of benefits versus impacts are the base premise of evaluation before a concession is granted. What is considered a negative impact is defined by the municipalities. As a result of this, not all concessions are granted under the same criteria and the impact of an installation on its surroundings may be greater than is administrated in the application.

The application process is steered through NVE as they receive the application from a potential developer. As the first step, NVE invites to an official hearing. After the hearing and consideration of any comments, the case is then decided by NVE. Parties that do not agree with the decision, can file a complaint through NVE who will consider it. Should NVE decide that their previous verdict still stands, the complaint will move up to the Norwegian petroleum and energy department (OED). OED has the final say in this decision, and further complaints will not be evaluated, unless the action violates Norwegian law (OED, 2015).

For every stage in the application process, both the current situation and the potential consequences should be accounted for. Different issues that must be addressed are hydrology, water temperature and local climate, ground water, avalanche and erosion, endangered species, terrestrial environment, aquatic environment, untouched nature (INON), reindeer, and soil, forest and fresh water resources (Disposisjon av konsesjonssøknader for småkraftverk (<10MW), NVE, 2013). Each of the issues should be addressed in an individual section in the application document.

What is a typical hydropower installation?

Hydropower is taking advantage of the energy in moving water used to produce electricity or perform simple mechanical operations. A hydroelectric power plant is made up of three components: the intake, the waterway and the actual power plant, known as the powerhouse which houses the turbine and generator. The intake comes in the form of a barrage or a dam and serves as a regulator, ensuring a constant water flow. The waterway guides the water towards the turbine, and it ensures minimal loss of energy due to swirls and friction (Hveding, 1974, p. 2). The plant is the core part in producing electricity. Blades situated on the turbine shaft rotate as the water push through, rotating the generator's coil to produce electricity which is then sent out through a grid connection.

Knowing only the different components, we can't classify the different installations or tell the specific design of a hydro power plant. Classifying installations is done by assessing:

- The effective head of water H (in meter)
- The flow of water to the turbine Q (in m^3/s)
- The capacity – the rated power output: this maximum available power can be obtained as P=9.81*H*Q (in kW)

A customary way of classifying is in terms of head, the local topography and how much is stored in the reservoir. These characteristics leads to a classification as low, medium or high head. Low heads have at most 10 meters and are operated as run-of-river installations. High head power plants usually have a distance between head and turbine at 100 meters or more and, as a trade-off they often do not have a particularly large water reservoir.

The low head type has a barrage to regulate the flow and maintain a steady flow of water and to house the plant itself. This type of power installation has often little storage capacity and thus makes the installation dependent on a constant flow rate from further upstream to be considered a reliable source of electricity. It is more common in lower elevation seeing that it generally has a gentle slope.

The medium head type is typical for large hydropower installations. Often, it is situated in narrow points of river valleys. This type of placement offers optimal conditions damming up a large body of water and allows the generation of large amounts of electricity from a big reservoir ensuring a reliable operation.

High head relies on a steep elevation gradient to have a high-pressure impact at the turbine. The high pressure is gained by having the reservoir above the actual plant, letting the water run through a penstock using gravity. With 1000 meters in height, the difference in pressure can reach up to 100 atmospheres. This type of power plants often trades large water reservoirs for the high pressure. This makes them reliant on a constant flow of water and are susceptible for seasonal changes like dry and wet periods. Because of the big difference in height, high head power plants are often found in mountainous regions (Kelly-Richards, Silber-Coats, Crootof, Tecklin, Bauer, 2016, p. 2; Boyle, 2012, p. 185-235).

Norway has, per 01.01.2019, 1626 registered hydropower plants, of these 1286 are below 10 MW installed capacity and are defined as small hydro power (NVE, 2019). Datasets published by NVE, tells us that 821 hydropower plants have a head height of 100 m or more 412 has between 99,9m and 10,1m and 76 hydropower plants have between 10 to 0 meters head height. 368 have no registered head height. Together they make up 1682 hydropower plants as of 26.05.2019.

Analyzing the location of registered hydropower plants using the maps provided by NVE, one finds that most of the power plants are in the western parts of Norway. Western Norway has a larger gross precipitation per year and has a larger differentiation in elevation because of the many mountains and fjords. This is optimal for development of high head hydropower, the most common type of hydropower plant in Norway. Due to the high head, small hydro plants in Norway are usually equipped with one Pelton turbine, or two high-head Francis turbines (Lia, Jensen, Stensby, Holm Midttømme, Ruud, 2015) to achieve maximum efficiency.

Environmental impacts of small hydro

The expansion of hydro power makes for a good opportunity to meet the rising energy demand whilst mitigating the effects of climate change. Hydropower is known to be a reliable and clean source of energy where the only real emission of CO_2 is in the construction phase. It is self-sufficient in that the water supply refills due to the natural cycle of water. However, due to environmental impacts, one must be careful not to replace one problem with another. By exploiting the governmental agenda which makes the expansion of small hydro easier to realise as a private user, there may arise new environmental problems. Due to the nature of small-scale hydropower, the expansion will use more previously untouched area than large hydropower plants (Idsø, 2017, p. 1). It is the cumulative effects of all the scattered projects that make the small hydro concept so harmful towards the environment. The difference in the way small- and large-scale hydropower affects the environment makes it important to study and compare the impact per MW of produced electricity.

Both small and large hydro power plants directly impact the water downstream as well as the life residing within the reservoir. Larger hydropower plants have a bigger influence on the area around the powerplant due to a larger reservoir. On the other hand, small hydro, which produces less electricity per installation, require multiple plants to meet the same production of electricity, having a marginally higher environmental impact when compared to large hydropower projects (Bakken, 2012). A paper published by SINTEF Energy Research discusses a scenario where the future energy demand is realised by promoting small hydro power plants (Ruud, Egeland, Jacobsen, Knudsen, Lafferty, 2011). Assuming that the Norwegian government is continuing to promote small hydro power and sufficiently cover the projected amount of electricity used calculated by CenSES, vast areas with no prior or major encroachments would disappear (Bakken, A., Sundt, B., Ruud, A., Harby, B. 2012, p. 191. Kelly-Richards et al. 2017, p. 252). A consequence of the expansion of new small hydropower plants is a reduction or loss of animal activity, of mosses and lichens due to the change in the ecosystem (NVE, 2015). The definition of what is small hydropower often differs from the definition used in Norway. This variation in may cause the perceived impact of small-scale hydropower to differ.

State of art

Current academic literature contains studies that have looked at the environmental impacts of small-scale hydropower, as well as the technologies that help mitigate these. A precise understanding and quantification of small hydropower development on the environment is still missing. However, important contributions to this end are found in several publications (Bakken et al., 2012; Bakken et al., 2014; NVE, 2015; Dorber, May, Verones, 2018; Idsø, 2017; Lia et al., 2015, Kålås et al., 2010).

A study by Bakken et al. in 2012 looked at what kind of environmental impacts small scale hydropower has. The study compiled a list of the frequency of the different issues related to small scale hydropower appearing in the environmental impact assessments required as supplements in the application process. The impact most often mentioned and therefor at the top of the list, is reduced water flow, actually, this impact is mentioned in all reports. The second entry on the list is that fish fauna is affected by the installation of small-scale hydropower.

Table 1: Table adapted from Bakken et al, 2012. The table describes the most frequently reported environmental impacts of small-scale hydropower in Norway.

Type of environmental impact	% of cases impacted
Reduction in water flow	100%
Fish fauna affected	78%
INON areas affected	67%
Anadromous fish present in affected part of river (not only bypassed stretches)	56%
Cultural heritage sites affected	44%
Anadromous fish present on bypassed river stretches	15%
Pipelines causing landscape impacts	11%
Changed water quality	11%
Organisms living in or close to water/cryptograms by water falls negatively affected by reduced water flow	7%

Reduced production of invertebrates reducing habitat qualities water ouzel and fish negatively	7%
Area protected due to landscape values	7%
Changed water temperature	7%
Nature with local value negatively affected	4%
Locations with valuable deciduous forest negatively affected	4%
Marsh areas negatively affected	4%
Reduced humidity affecting mosses negatively	4%

The third most frequent reported impact in the study (Table 1) is the loss of untouched nature (Bakken et al., 2012). This is interesting to this study as it supports the idea that small scale hydropower contributes to the loss of wilderness areas in Norway with 67% of the cases reporting a loss of INON. Due to the nature of small hydropower, its environmental disturbance is scattered across many small sites compared to larger and more concentrated intrusions in the case of large hydropower. This scattered encroachment leads to fragmentation of nature and habitats and is rated as the least preferable energy option in terms of the resilience of red-list species (Bakken et al., 2014).

In 2010 Kålås et al. published a paper updating the official red list for Norway made in accordance to the world conservation union (IUCN) guidelines. The paper covered all multicellular species within Norwegian borders in the northern hemisphere. There are approximately 40 000 species in Norway, 21 000 of these was evaluated, 4599 were classified as within the red list, 2389 were classified threatened or above. The largest impacts to the habitat of the red list species in Norway is by far due to changes in land use. The study states that 44,81% of the impact to the habitat for red list species are affected by land use changes, not connected to farming or forestry. (Kålås et al., 2010).

The NVE report from 2015, "etterundersøkelser av flora og naturtyper i elver med planlagt småkraftutbygging", looked at 20 hydropower plants in Norway and studied the state of nature in rivers with small hydropower installations. The objective of the study was to assess if statements on the state of nature at an intended site in the reports by the applicants could be confirmed by NVE. The study by NVE found substantial deviations in the number of identified red list species with 12,8 times as many as reported by the applicants. Also, a large number of important nature types was found. At this point there were almost twice the amount of nature types, among them 14 very important nature types, whereas the applications reported only 1. Due to these deviations, the NVE study assesses the area around the hydropower plants as likely having more important nature types than many application reports stated. This results that the report from NVE rates the loss as a larger negative impact to the environment. Such a site found should not have been approved in the first place, since it is not allowed to encroach upon areas where red-list species have been observed (NVE, 2015).

When it comes to land use and land use changes related to hydro power, there have been studies conducted on the land use of reservoirs for largescale power plants. The study was conducted by Dorber et al. at NTNU (Dorber, May, Verones, 2018). The study used satellite images to track the land use change by 107 hydropower reservoirs in Norway. Using this data, the average land occupation per unit of electricity was estimated to 0,027m2*year/kWh (0,027 daa*year/MWh). A second number for land occupation where an underestimation of water area is accounted for shows an average land occupation of 0,007m2*year/kWh (0,007 daa*year/MWh).

A study by J. Idsø from 2017 looks at the economics of small hydro. The subject of study is what factors determine the building of the small-scale hydropower plants. There is a comprehensive review of the application process for small hydropower plants which is the most interesting part in the context of environmental issues. The study finds that due to the topography and the way agricultural farms are organized in Norway, rivers in Norway often have multiple owners. All of the affected river-owners must be in agreement before the river can be utilized for hydropower. The study also lists different categories that must be considered in the application, and states that it's illegal to build if there are sighted red list species near the site of the power plant (Idsø, 2017).

It is expected that the development of small hydro in Norway will continue toward and beyond 2020, as of 2015 there were 406 licensed small-scale hydropower projects that have yet to be built at the time (L. Lia et al., 2015). This number applies to plants characterized as small hydropower by NVE and does not include plants below 1 MW of installed capacity. However, it is important to assess the consequences of expanding the number of small-scale hydropower as well micro- and mini- power plants.

Research question

The thesis is focusing on the environmental changes when considering future expansion of sustainable small-scale hydropower plants in Sogn & Fjordane. It focuses on the expansion of hydropower through the lenses of preserving wilderness (INON) and ecosystem services and makes an effort to find the environmental changes through three proxies. The main question is:

- *What are the environmental impacts of potential Small- scale hydropower plants in Sogn & Fjordane?*

Due to the scope of this question we try to answer it through three sub questions:

- *How much area is occupied per MW for all potential small hydropower in Sogn & Fjordane?*
- *How much INON area is removed per MW?*
- *How many red list species are affected by the potential small hydropower plants?*

What is INON?

INON is a way to categorize how much nature in Norway is still untouched by human activity. To be characterized as INON area, it must be at a given distance from heavy human impact. Heavy human impact is understood as larger constructions like:

- Roads longer than 50 meters,
- Power lines larger than 33kV,
- Towers and wind turbines,
- Larger waste rock dumps, quarries and mass withdrawals,
- Larger ski lifts, ski jumps and alpine slopes,
- Canals, floodplains and pipelines,
- Water reservoirs (the entire water contour at the highest regulated level), regulated rivers and streams (both increase and decreased water flow).

There are 3 categories of INON, which account for ranges 1-3, 3-5, and 5 km away from human impact. INON has been a governmental planning tool from 1995 to 2014 and the INON area was identified by the Norwegian Environment Agency. In 2013, the Norwegian government decided to no longer use INON as an area planning tool (Regjeringen Erna Solberg, 2013, p.59). This led to the discontinuation of the updating of the INON areas. The last update of the INON area was in 2013 and at that time there was 8,8 million daa still untouched in Sogn & Fjordane county.

Ecosystem services

It is a challenge to operationalize the impact of humans on nature and its consequences within a common framework. The concept of ecosystem services has been put forward with the aim to obtain a common approach

Ecosystem services are defined as "the benefits that people obtain from ecosystems". The idea is that every ecosystem and piece of nature has a value and a role to play for the human existence and well-being. Each patch of land can provide different services and can contain several different types of services. For some of these services an economic value can be given to quantify the importance of certain services, for other services, an economic valuation is rather farfetched or even impossible. By analysis the change in each service provided due to transformation in the land use, a decision support in planning is envisaged. There are four categories of ecosystem services, and within these four are different sub services that happen as nature goes on with its natural cycle. (Millennium ecosystem assessment, 2005). The first category is supporting services. Supporting services contains nutrient recycling, soil formation, primary production, habitat provision, pollination etc. the second category is provisioning services and contains Food, fuel, wood and fibre, fresh water, Energy, etc. The third category is regulating services which includes climate regulation, flood regulation, disease regulation, water purification etc. the fourth and last category is cultural services and contains aesthetic-, spiritual-, educational- and recreational -services etc.

An example of the application of ecosystem services, is the New York water supply. The water supply of the city was provided by a watershed up in the mountains, which cleaned the incoming water. Due to sewage, pesticide and fertilizers in the soil, the level of pollution increased above the Environmental Protection Agency (EPA) standards for drinking water. This situation forced the New York government to choose between either building a new water purification plant at the cost of 6-8 billion dollars, or to invest in something called “natural capital”. Natural capital is a concept that is used in the field of ecosystem services and is the world's stock of natural resources, which contain things like trees, minerals, waterfalls, atmosphere, etc. (Folke, Hammer, Constanza, Jansson, 1994, p. 4). By fixing the watershed that provided the water purification, New York City would invest in their stock of natural capital instead of building a new water treatment facility. The cost of buying the land for restoring the ecosystem services was 1-1,5 billion dollars (Chichilnisky and Heal, 1998, p. 629). This example highlights the importance of viewing nature through the lens of ecosystem services and natural capital. Even if a patch of land doesn't seem to have large value, it could be economically beneficial to protect it for the services it provides.

In the case of hydropower expansion, it is rivers that provide various ecosystem services, among them optionally electricity from hydropower. The rivers are also habitats for plants and animals, create soils and help in nutrient recycling by moving nutrients down from the mountains. Rivers even provide cultural services in being recreational spots or touristic attractions if scenic waterfalls exist. By damming rivers and putting them in pipes, these ecosystem services are changed. There will be less nutrient transportation and the plant and wildlife would be temporary or permanently affected. This would potentially be changing the ecosystem services from the supporting services to an area of provisioning services by creating electricity. The basic approach of assessing the change in ecosystem services by a planned human activity is to identify possible ecosystem services at a construction site. Then, measuring to what extent ecosystem services are changed and finally, come to a metric that allow the changes in ecosystem services to be compared. Most often, this works by economic proxies. However, there are cases where such an approach is not possible.

A visual assessment of environmental changes due to hydropower development

Before going into details on how to quantify environmental changes due to hydropower development, we give a visual assessment in terms of aerial photographs before and after the installation of a hydropower plant at a given construction site. This analysis offers the possibility to identify the infrastructure which is set up to support the hydropower exploitation. In the following paragraphs, we will present such a comparison for a few selected sites. The photographs are compiled from norgeibilder.no, where aerial photos are available from surveys done in Sogn & Fjordane.

Infrastructure installed at a hydropower site

Building roads, waterways and power lines are important infrastructure necessary for a functioning hydropower plant and it can have a large local environmental impact, creating big scars in the landscape. These changes in the landscape can potentially alter areas for many years, impacting the vegetation and the animals using the area. Identifying these impacts at the same time can lead to new technologies which reduce the impacts, e.g. by drilling pipes from the intake to the powerhouse or flying the dam up with a helicopter. Such measures will reduce the amount of vegetation removed and the scars will be less pronounced than before. Figure 1 shows an example of what impact the construction of a small-scale hydropower plant may have. The images show the situation before and after the construction of Holsen power plant in Førde municipality. One can clearly see the grey scars in the vegetation due to the construction of the power plant. The images are collected from norgeibilder.no. The caption Sogn 2010 and Sunnfjord 2018 refers to the layers of aerial images on norgeibilder.no. The layer for the before image is Sogn 2010 which means that it covers all of Sogn and was made in 2010. The same goes for the after image, Sunnfjord 2018. Sunnfjord refers to the area of the image and it was created in 2018.

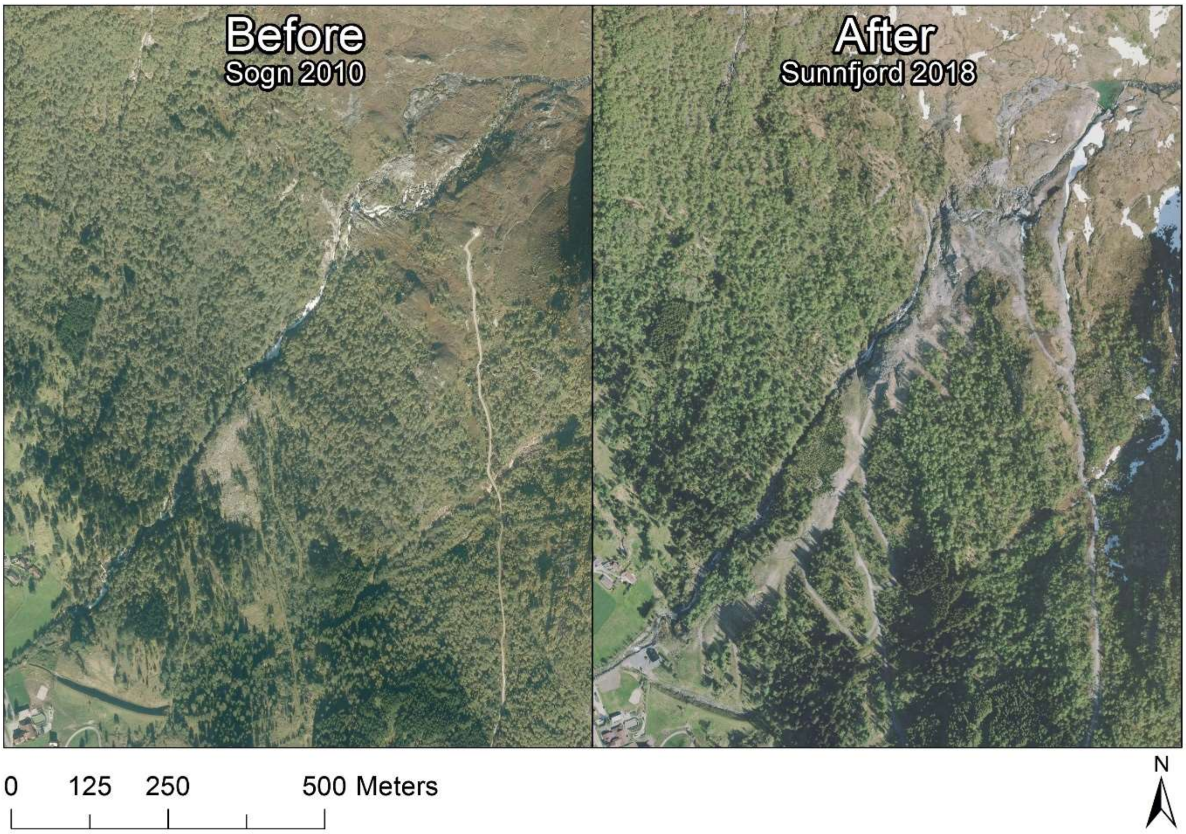


Figure 1: Shows the impact by building roads, waterways and power lines around a hydropower plant in Førde municipality. Clearly visible is a gray scar on the right-hand side of the figure appears after the building of the power plant. This is due to deforestation and the subsequent exposure of the ground. The power plant is Holsen power plant. The photos used are taken from Norgeibilder.no. The caption Sogn 2010 and Sunnfjord 2018 refers to the layers of aerial images on norgeibilder.no. The layer for the before image is Sogn 2010 which means that it covers all of Sogn and was made in 2010. The same goes for the after image, Sunnfjord 2018. Sunnfjord refers to the area of the image and it was created in 2018.

Impacts due to constructing the intake

The intake consists of a dam which alters the area around. The change in ecology by the dam is of local impact, but the altered water flow can also change the habitat for vegetation and animals downstream. The visible impact is small with this type of hydro power, compared to large hydropower using large water reservoirs. An example for the visible changes due to the construction of an intake is shown in figure 2. It shows how a reservoir to a small-scale hydropower plant looks and affect the nearby environment. One can see how an area have quite a bit more water than before and that the water flow downstream is reduced. The reduction downstream may be due to seasonal changes in the water flow. The images were collected from norgeibilder.no. The caption on the images Luster 2007 and Luster 2012 refers to what layers of aerial images from norgeibilder.no were used. Luster refers to the area the specific layer covers and 2007/2012 refers to the years the layers were created.

Figure 2: Example of a dam built in Luster municipality in connection with the Kvåle power plant described later in the thesis. It is clearly visible that the dam alters the water flow downstream and the amount of water above the dam. Pictures collected from norgeibilder.no. The caption on the images Luster 2007 and Luster 2012 refers to what layers of aerial images from norgeibilder.no were used. Luster refers to the area the specific layer covers and 2007/2012 refers to the years the layers were created.

Impacts due to constructing the powerhouse.

The powerhouse itself takes up little space and looks like an ordinary building, although it will have a larger visible impact when built outside already developed areas. An example is presented in figure 3, in this case the powerhouse is constructed in an already developed area. The photograph shows that building housing the turbine and generator. The photograph again indicated, that the water flow has been considerably changed. However, care must be taken in detailed comparisons due to the seasonal changes in water level. The images are collected from norgeibilder.no. The caption on the images Luster 2007 and Luster 2012 refers to what layers of aerial images from norgeibilder.no were used. Luster refers to the area the specific layer covers and 2007/2012 refers to the years the layers were created.

Figure 3: Before and after pictures of the powerhouse for Kvåle power plant in Luster municipality. The red circle highlights the power plant. Pictures collected from Norgeibilder.no. The caption on the images Luster 2007 and Luster 2012 refers to what layers of aerial images from norgeibilder.no were used. Luster refers to the area the specific layer covers and 2007/2012 refers to the years the layers were created.

Examples

In this thesis, we have used 5 case studies from already built small hydro power plants to get an estimate of how big the impact of these projects are. The examples are located in the county of Sogn & Fjordane and have a range from 2,67 to 8,6 MW of installed capacity. The height of head ranges from 112 to 540 meters. Figure 4 shows the location of the 5 different sites used in the examples. The power plants are marked with a yellow overlay and is marked by numbers after when they appear in the text. The first example is Holsen power plant in Førde municipality. Second example is Kvamselva power plant in Gaular municipality. Third comes Kvemma power plant in Lærdal municipality. Fourth is Kvåle power plant in Luster municipality and fifth is Røneid power plant also in Luster municipality. At the left-hand side of the figure there are two maps showing the location of Sogn & Fjordane compared to the rest of Norway. The county border for Sogn & Fjordane is visualized by a red line. The background image is collected from norgeibilder.no. These sites are chosen due to a variety of reasons. They are all built quite recently, which makes them comparable to plants built in the future. They also have a variety of different height of head and maximum capacity. They also have publicly available application documents and aerial photography's both for recently before the construction and recently after construction.

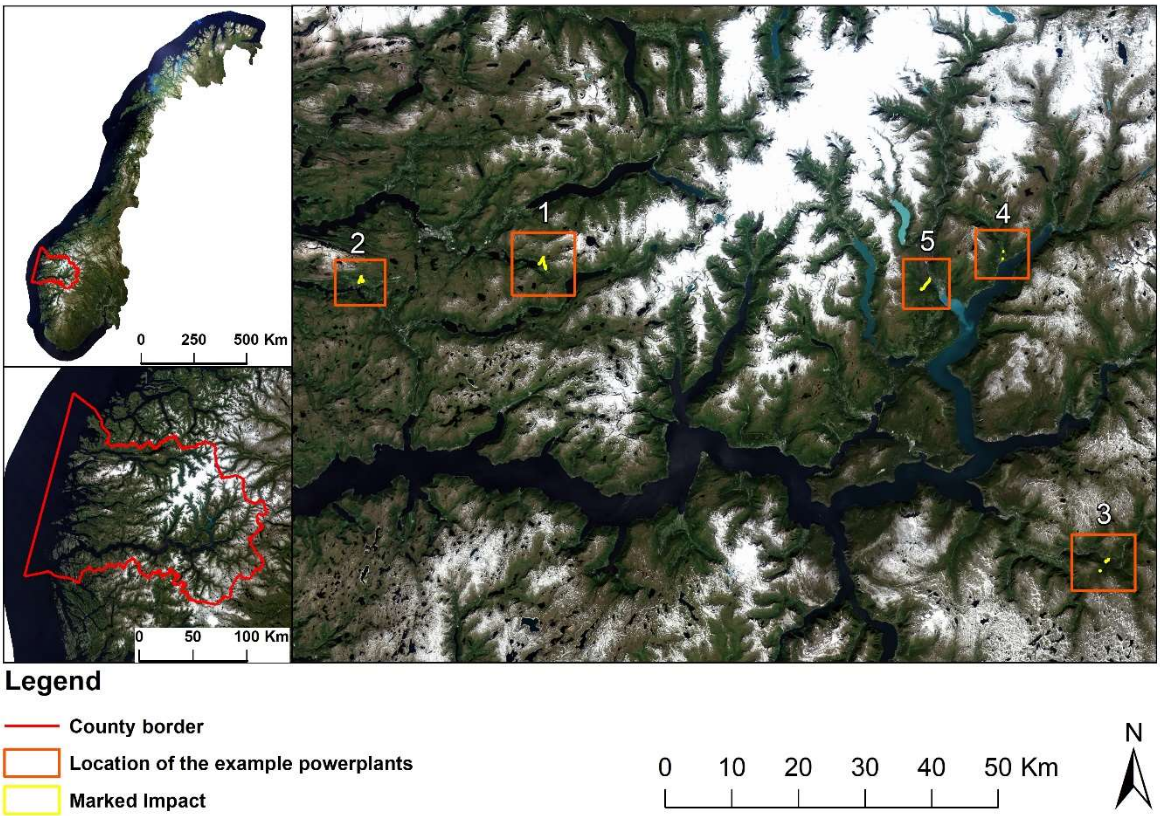


Figure 4: The orange boxes with yellow overlay inside shows the location of the power plant used in the example section of this paper. 1. Holsen power plant in Førde municipality. 2. Kvamselva power plant in Gaular municipality. 3. Kvemma power plant in Lærdal municipality. On the left hand side there is two images highlighting where the county of Sogn & Fjordane is located in Norway. This is visualized by a red line. The background image is an aerial photograph from norgeibilder.no. The white areas are snow and indicates high altitude, when these areas are close to the fjords it indicates high difference in altitude.

Case study 1: Holsen power plant – Førde

Holsen power plant is located in Førde municipality and started its energy production in 2017. It has a head of 451,34 meters and a maximum capacity of 8,6 MW and uses a Pelton turbine. The yearly production is estimated to be 26,3 GWh accounting for the typical efficiency under the specific conditions. In the application it is estimated that the building will permanently use 13,2 daa of land, while 36 daa are used temporary in the building process. In the permanently used area, the intake takes up most of the area with its 10 daa. The rest of the permanent area is used by the waterway (2 daa) and the powerhouse (1,2 daa). The temporary use is mainly due to clearing land in the construction of the waterway with 17 daa and the intake with 14 daa. In addition, there is 2 daa used for stone landfill, and 2 daa for the powerhouse. Most of the affected area is heather and forest. At Holsen power plant it is estimated in the application document that there will be some loss of INON area. The lost area is due to the position of the intake, and there will be 220 daa of Category 2 INON lost.

Figure 5 shows aerial photographs for the area around Holsen power plant taken in the years 2010 and 2018 the comparison of these photographs shows that there is a significant change in the environment around the power plant. The most notable is the scar in the landscape due to the construction of the waterways. The caption in the images Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and Sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images were taken.

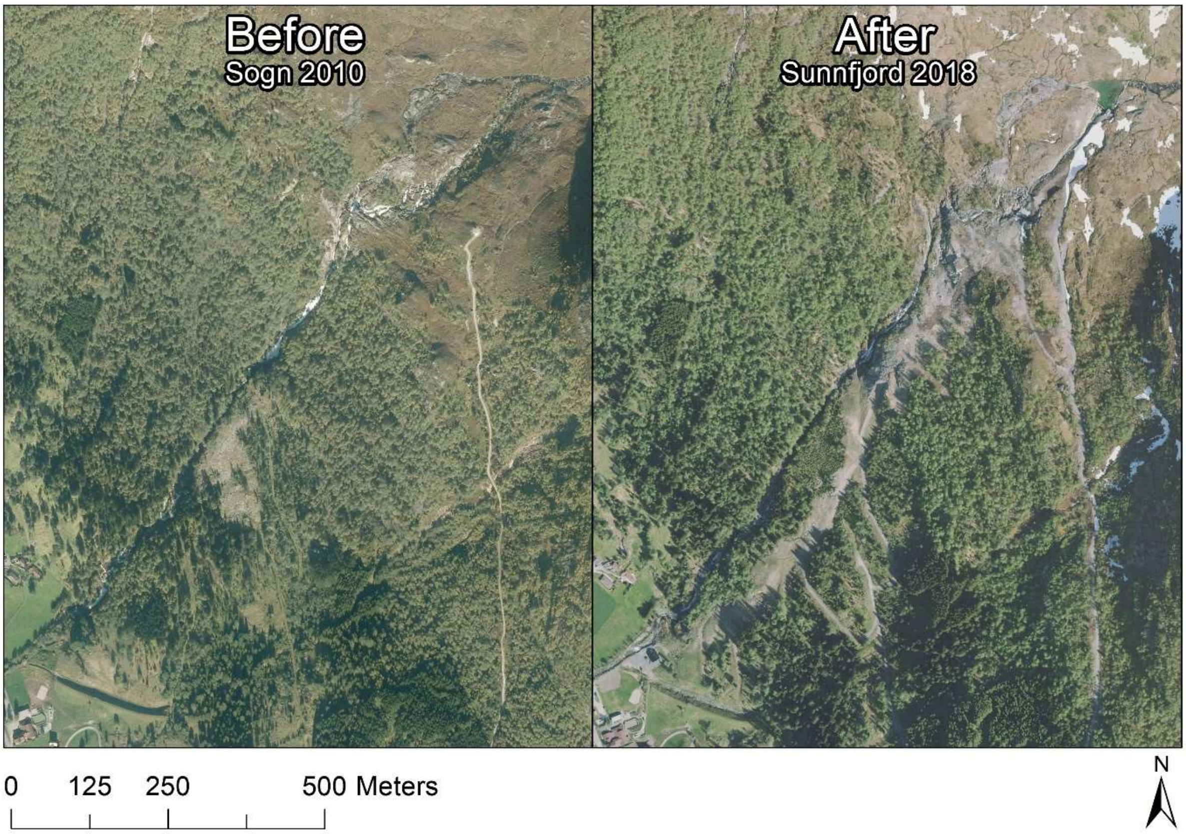


Figure 5: The road and waterways connected to Holsen power plant in Førde municipality makes a large scar in the local forest. Building the waterways will use 17daa in temporary area. Images collected from Norgeibilder.no. The caption in the image Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images was taken.

Figure 6 shows aerial photographs for the area around Holsen power plant taken in the years 2010 and 2018 the comparison of these photographs shows that there is a significant change in the environment around the reservoir created by the dam. The reservoir has a land use of 10 daa estimated by the application documents. The caption in the images Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and Sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images were taken.

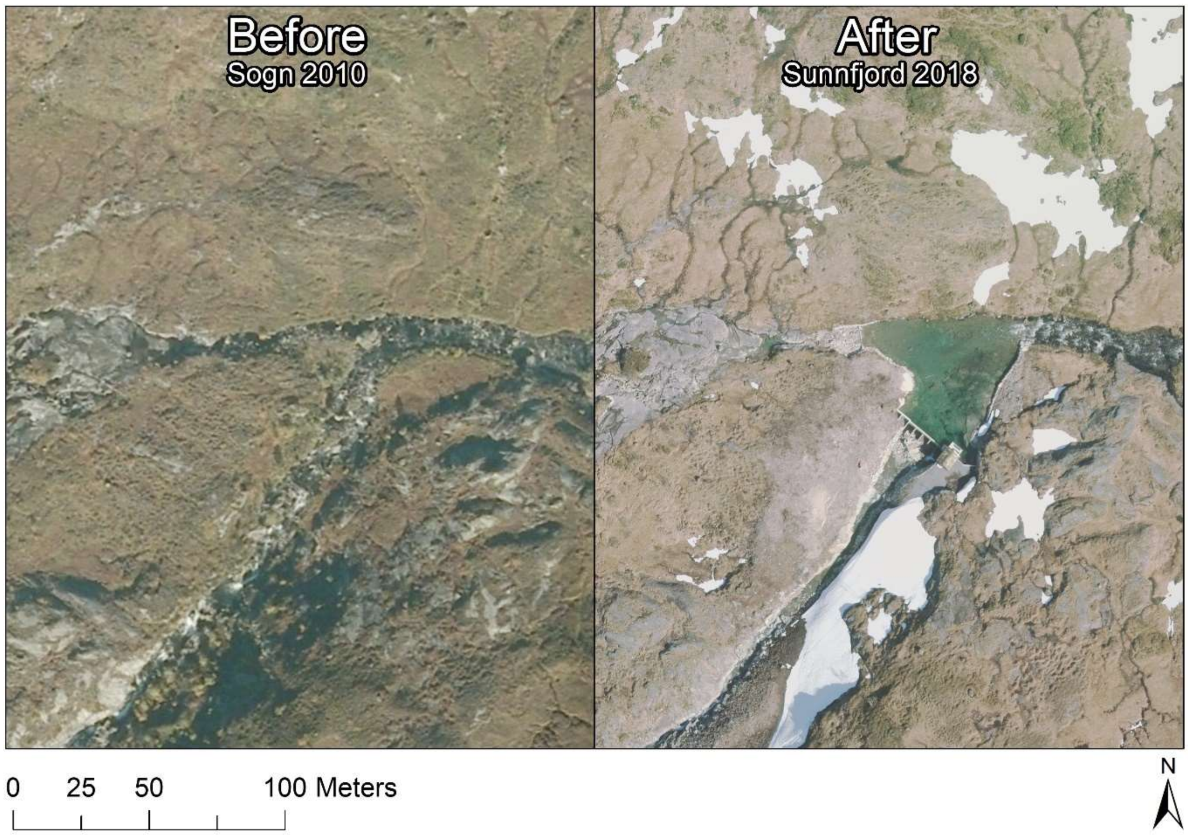


Figure 6: the dam at Holsen power plant changes the river downstream and makes a new small pond. The new lake is estimated to be 10daa in permanent area. Images collected from Norgeibilder.no. The caption in the image Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and Sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images were taken.

Figure 7 shows aerial photographs for the area around Holsen power plant taken in the years 2010 and 2018 the comparison of these photographs shows that there is some changes in the environment around the power house. The powerhouse will use 1,2 daa estimated by the application documents. The caption in the images Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and Sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images were taken.

Figure 7: The powerhouse for Holsen power plant is located 451meters below the intake. The powerhouse contains one 8,6 Pelton turbine. The application estimates that the powerhouse uses 1,2 daa in permanent area and 2 daa in temporary area. Images collected from norgeibilder.no. The caption in the image Sogn 2010 and Sunnfjord 2018 refers to the layers from norgeibilder.no used in the relevant image. Sogn and Sunnfjord refers to the area which is available in the relevant layer while 2010 and 2018 refers to the year the aerial images were taken.

Table 2 in addition compiles some of the information available for the hydropower plant as offered in the application document and on the website of NVE. Data starts from an object_id used to identify the power plant to basic parameters of the plan. The table also contain a concession status. This number says something about where in the concession process the application is. Holsen power plant has a concession status of 5 which means that the application is approved. Further information in the table is basic parameters for the plant.

Table 2: Specifications for Holsen power plant in Førde municipality. The table compiles some of the information available for the hydropower plant as offered in the application document and on the website of NVE. Data starts from an object_id used to identify the power plant to basic parameters of the plan. The table also contain a concession status. This number says something about where in the concession process the application is. Holsen power plant has a concession status of 5 which means that the application is approved. Further information in the table is basic parameters for the plant.

Powerplant name	Holsen
OBJECTID	104
Object type	Hydropower plant
Powerplant number	1893
Status	In use
In use year	2017
Concession number	5032
Concession status	5
Concession status date	09.09.2009
Maximumpower MW	8,6
Turbine	Pelton
Yearly production	25 GWh
Height m	451,34
Energy equvalents kWh m^3	1,039
Owner	HOLSEN KRAFT NORDDØLA AS
Municipality number	1432
Municipality	Førde
River	Holsaelva/Jølstra
Permanent area	13,2 daa
Temporary area	36 daa
Loss of INON	220 daa

Case study 2: Kvamselva – Gaular

Kvamselva in Gaular municipality started its production in 2016 and has a maximum capacity of 2,67 MW, provided by a Pelton turbine. The head is 247 meters. The application estimates a yearly production of 8,8 GWh. The area use described in the application is 29 daa temporary and 2 daa permanent. The largest temporary use is due to the waterways with 25 daa, followed by 2 daa for the intake, 1 daa for roads and 1 daa taken up by the powerhouse. In the permanent category, the intake takes the largest part with 1 daa while roads and powerhouse use 0,5 daa each.

Figure 8 shows aerial photographs of the area around Kvamselva power plant. The photographs are taken in the years 2007 and 2018. One can clearly see the deforestation by the construction of the waterways and the new reservoir created by the dam. There is also an area cleared for the construction of the powerhouse, but this is quite small compared to the impact of the waterway and the dam. The caption on the figures refers to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

Figure 8: Before and after the building of Kvamselva powerplant in Gaular municipality. The construction of the waterways leaves a scar in the vegetation that is estimated to be 25daa. Images collected from norgeibilder.no. The caption on the figure refer to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

Figure 9 shows aerial photographs of the area around Kvamselva power plant. The photographs sho the environmental changes by building the dam and a reservoir. The reservoir is predicted to use 1 daa permanent area and 2daa temporary area by the application documents. The caption on the figures refers to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

Figure 9: The intake at Kvamselva power plant uses 2daa temporary area and 1 daa permanent area according to the concession application. The dam has noticeable effect on the amount of water downstream. Images collected from norgeibilder.no. The caption on the figure refer to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

Figure 10 shows aerial photographs of the area around Kvamselva power plant. The photograps show the area use by the powerhouse. One can clearly see that some trees have been cut down to clear area for the powerhouse. The area used for the powerhouse is estimated to be 0,5 daa permanent and 1 daa temporary area by the application documents. The caption on the figures refers to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

Figure 10: At Kvamselva power plant the powerhouse uses 1daa in temporary area while 0,5 daa in permanent area according to the application. The powerhouse contains a 2,67MW pelton turbine. Images collected from norgeibilder.no. The caption on the figure refer to the layers used from norgeibilder.no, Ytre Sogn 2007 and Sunnfjord 2018. Ytre Sogn and Sunnfjord refers to the area covered of the layer and 2007 and 2018 refers to the year the aerial photographs were collected.

In addition, table 3 contains some relevant information from the application documents for the hydropower plant from the website of NVE. The table starts with an Object_id which refer to the id the power plant has in the dataset provided from NVE. There is also a concession status in the table which says something about where in the concession process the power plant is. Kvamselva power plant has a concession status of 5 which means that the concession is approved. Further information in the table is basic parameters for the plant.

Table 3: Specifications for Kvamselva power plant in Gaular municipality. The table contains some relevant information from the application documents for the hydropower plant from the website of NVE. The table starts with an Object_id which refer to the id the power plant has in the dataset provided from NVE. There is also a concession status in the table which says something about where in the concession process the power plant is. Kvamselva power plant has a concession status of 5 which means that the concession is approved. Further information in the table is basic parameters for the plant.

Powerplant name	Kvamselva
OBJECTID	253
Object type	Hydropower plant
Powerplant number	1877
Status	In use
In use year	2016
Concession number	4882
Concession status	5
Concession status date	2010-12-23
Maximumpower MW	2,67
Turbine	Pelton
Yearly production	8,8 GWh
Height m	247
Energy equivalents kWh m^3	0,571
Owner	KVAMSELVA KRAFTVERK AS
Municipality number	1430
Municipality	Gaular
River	Kvamselva/Fauskeelva
Permanent area	29 daa
Temporary area	2 daa
Loss of INON	0 daa

Case study 3: Kvemma – Borgund

Kvemma power plant in Borgund is placed in Lærdal municipality, the building was erected by 2015. The power plant has a maximum capacity of 5 MW, and a height of 540 meters. The powerhouse is containing a Pelton turbine, which has a yearly production of 14, 4 GWh as estimated in the application. The application documents for Kvemma do not contain separate information on the temporary and permanent area use. This is because it is built in a different way to the other 4. The waterways were built by drilling tunnels into the mountain connecting intake and powerhouse. This construction method minimizes the temporary impact because forest has not been cleared for the above ground pipelines. This makes the area used small and the temporary areanot larger than the permanent. The permanent area used is 8,1 daa. The area used is 0,9 daa on the dam, 4 daa on the waterways, 0,2 daa to the powerhouse and 3 daa to the roads.

The impact to the INON in Kvemma will be large. The application documents estimate that there will be 2950 daa of category 2 INON lost. Additionally, there will be 1150daa re-categorized from category 1 to category 2.

Figure 11 shows aerial photographs of Kvemma power plant in Lærdal municipality. The before image is taken in 2010 and the after one is a composite of 2 aerial photos from 2015 and 2017. This is because neither of them covers the whole area, but they show it sufficiently when shown together. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 11 the layers used is Sogn 2010 and Lærdal 2017, Sogn 2015, the first part of the name Sogn and Lærdal refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images was taken. The right-side image is a composite of two aerial photographs because neither of them contained the whole area.

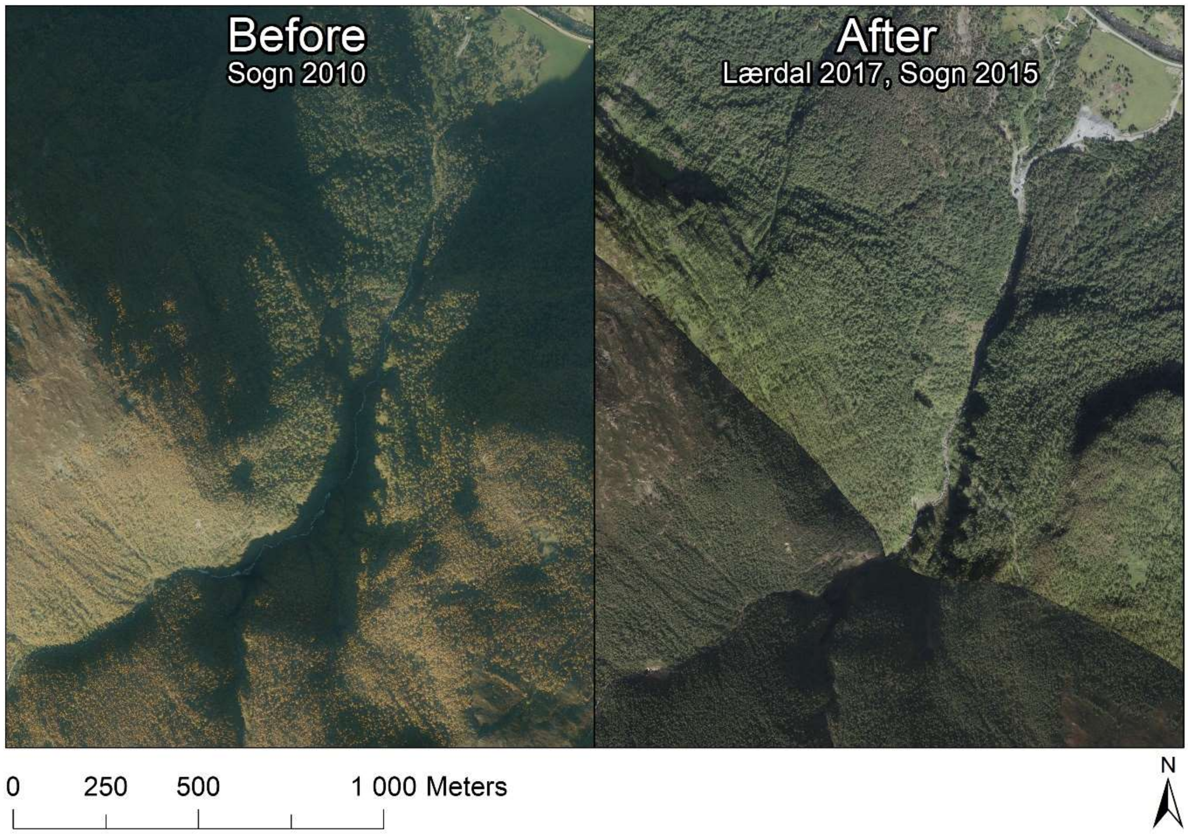


Figure 11: The temporary area usage of Kvemma power plant in Borgund municipality is quite small due to the construction method. The waterways are constructed by drilling the main part of the waterways fitting it with metal pipes. As seen at the images above the impact on the waterways are barely visible. Images collected from norgeibilder.no. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 11 the layers used is Sogn 2010 and Lærdal 2017, Sogn 2015, the first part of the name Sogn and Lærdal refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images was taken. The right-side image is a composite of two aerial photographs because neither of them contained the whole area.

Figure 12 show an aerial photograph of the intake connected to Kvemma power plant. The images are from 2010 and 2015 and show that there is a reduced water flow downstream and a minimal impact to the environment due to the construction method. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 12 the layers used is Sogn 2010 and Sogn 2015, the first part of the name Sogn refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images was taken.

Figure 12: Due to the construction method of the waterways the intake is also quite well hidden. It has a permanent area usage of 0,9daa. Because there is no deforestation from building waterways the intake is hidden in a forested valley and not visible from the valley. Images collected from norgeibilder.no. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 12 the layers used is Sogn 2010 and Sogn 2015, the first part of the name Sogn refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images was taken.

Figure 13 shows the powerhouse connected to the power plant. The photos are taken in 2010 and 2017. One can clearly see the impact on the local environment by the powerhouse, roads and quarry in connection to the power plant. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 13 the layers used is Sogn 2010 and Lærdal 2017, the first part of the name Sogn and Lærdal refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images was taken.

Figure 13: At Kvemma power plant the application estimates that the powerhouse and the roads connected to it have a total area usage of 3,2daa. The powerhouse contains a 5MW Pelton turbine. One can clearly see the impact on the local environment by the powerhouse, roads and quarry in connection to the power plant. Images collected from norgeibilder.no. The captions on the image refers to the layer on norgeibilder.no used in the image. In figure 13 the layers used is Sogn 2010 and Lærdal 2017, the first part of the name Sogn and Lærdal refers to the area mapped in the relevant layer. The second part of the caption refers to the year the aerial images were taken.

Table 4 compiles the specifications of Kvemma power plant in Borgund. The information in the table is collected from the concession documents from NVEs website. The object_id is the number identifying the power plant in the dataset from NVE showing all existing power plants in Sogn & Fjordane. It also contains the concession status, this is a number which says something about where in the concession process the application is. Kvemma power plant have a concession status of 5 which mean that the concession application is approved. Further information in the table is basic parameters for the plant.

Table 4: Specifications for Kvemma power plant in Lærdal municipality. The table compiles the specifications of Kvemma power plant in Borgund. The information in the table is collected from the concession documents from NVEs website. The object_id is the number identifying the power plant in the dataset from NVE showing all existing power plants in Sogn & Fjordane. It also contains the concession status, this is a number which says something about where in the concession process the application is. Kvemma power plant have a concession status of 5 which mean that the concession application is approved. Further information in the table is basic parameters for the plant.

Powerplant name	Kvemma
OBJECTID	77
Object type	Hydropower plant
Powerplant number	1776
Status	In use
In use year	2015
Concession number	6106
Concession status	5
Concession status date	2012-03-27
Maximumpower MW	5
Turbine	Pelton
Yearly production	14,4 GWh
Height m	540
Energy equvalents kWh m^3	1,263
Owner	KVEMMA KRAFT AS
Municipality number	1422
Municipality	Lærdal
River	Kvemma/Lærdalsvassdraget
Permanent area	8,1 daa
Temporary area	~0 daa
Loss of INON	2950 daa

Case study 4: Kvåle – Luster

Kvåle powerplant in luster municipality was approved in 2006 and started its production in 2009. It has a height of 112 meters and a maximum output of 4,6MW. This capacity is provided by two 2,3 MW Francis turbines. The application estimates that the power plant will have a yearly production of 17,6 GWh. In the application, there is no reliable estimate for how much permanent area will be used, but due to the type of construction it will probably be comparable to the power plant in Kvemma. The powerhouse is estimated to use 0,1daa. There is an estimate of how much temporary area that will be used. The temporary usage is 12,5 daa and is due to the building of the waterways after the tunnel from the intake. The temporary area use is an agricultural field. The application documents states that it will be set back to the original state after the construction period. The construction period is estimated to last 12-15 months.

Figure 14 shows aerial photos of the Kvåle power plant in Luster municipality. The pictures are made in 2007 and 2012, which provides a good view of the impact of the construction of the power plant. On the overview in figure 14 one can see that due to the drilling of the pipes and fast reconstruction of the agricultural field, the impact of the power plant is small. The most notable change is the reservoir at the dam and a reduced water flow in the river. The reduction in water flow may be because of seasonal changes. The captions on the images refers to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were created.

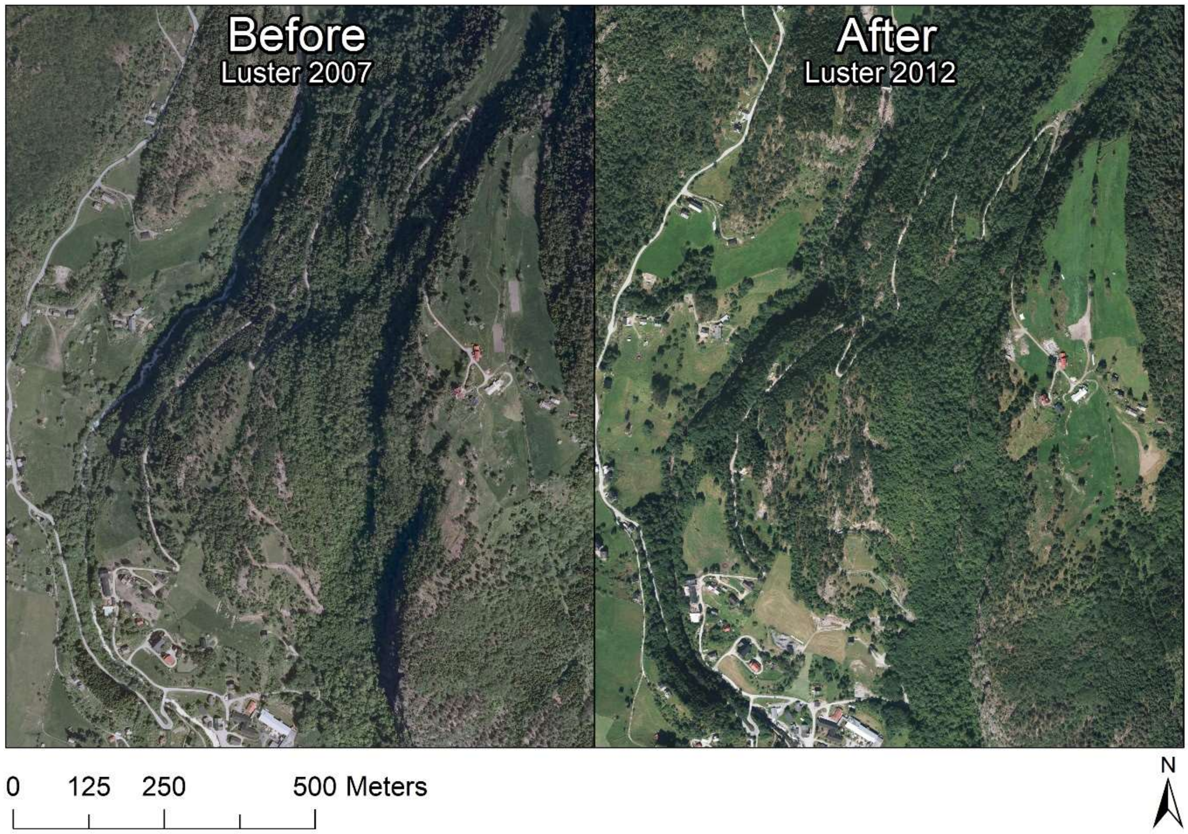


Figure 14: The waterways at Kvåle are constructed by drilling holes in the mountain and fitting them with metal pipes. The result is that only a small part of the waterways requires temporary area. This area is located between the pipes and the powerhouse and are 12,5 daa. The temporary area is stated by the application documents to be restored to its original state after the construction. The construction period is estimated to be 12-15 months. Images collected from norgeibilder.no. The captions on the image refer to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were taken.

Figure 15 shows how the dam makes a new reservoir on the upside of the dam and heavily reduces the water flow downstream. The application does not give a number for how much area is used for the intake. The captions on the images refers to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were created.

Figure 15: The dam makes a new reservoir on the upside of the dam and heavily reduces the water flow downstream. The application does not give a number for how much area is used for the intake. Images collected from norgeibilder.no. The caption on the images refers to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were taken.

Figure 16 shows that the powerhouse at Kvåle power plant is located in the middle of the small village of Luster and blends in well with the surrounding buildings. The powerhouse contains 2 Francis turbines and have a maximum capacity of 4,6 MW. The powerhouse is estimated to use 0,1 daa The captions on the images refers to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were created.

Figure 16: The powerhouse at Kvåle power plant is located in the middle of the small village of Luster and blends in well with the surrounding buildings. The powerhouse contains 2 Francis turbines and have a maximum capacity of 4,6 MW. The powerhouse is estimated to use 0,1 daa. Images collected from norgeibilder.no. The caption on the images refers to the layers from norgeibilder.no. Luster 2007 and Luster 2012 is the layers used. The first part of the caption is the area the layers contain, here it contains aerial photos from Luster, Sogn & Fjordane. The second part is the year the aerial photographs were taken.

Table 5 contains some basic parameters for Kvåle power plant collected from the application documents at NVEs website. The table starts with an object_id which is the number identifying the power plant in the dataset from NVE showing all existing power plants in Sogn & Fjordane. It also contains the concession status, this is a number which says something about where in the concession process the application is. Kvemma power plant have a concession status of 5 which mean that the concession application is approved.

Table 5: Specifications for Kvåle power plant in Luster Municipality. The table contains some basic parameters for the power plant collected from the application documents at NVEs website. The table starts with an object_id which is the number identifying the power plant in the dataset from NVE showing all existing power plants in Sogn & Fjordane. It also contains the concession status, this is a number which says something about where in the concession process the application is. Kvemma power plant have a concession status of 5 which mean that the concession application is approved.

Powerplant name	Kvåle
OBJECTID	422
Object type	Hydropower plant
Powerplant number	1465
Status	In use
In use year	2009
Concession number	4093
Concession status	5
Concession status date	2006-05-24
Maximumpower MW	4,6
Turbine	2 Francis
Yearly production	17,6 GWh
Height m	112
Energy equvalents kWh m^3	
Owner	LUSTER SMÅKRAFT AS
Municipality number	1426
Municipality	Luster
River	Dalsdalselvi
Permanent area	
Temporary area	12,5 daa
Loss of INON	0 daa

Case study 5: Røneid – Gaupne

Røneid powerplant is located in the small village Gaupne in luster municipality, it has a maximum output of 4,3 MW and a head of 487 meters. The powerhouse is containing a Pelton turbine, and have an estimated yearly output at 13,1 GWh. The power plant started its power production in 2016. The application sent to NVE estimates 1,6 daa of permanent use, and 34,8 daa of temporary use. The temporary use is split in two categories, i.e. waterways with 33 daa and construction roads with 1,8 daa. The permanent area has 3 categories namely roads, intake and powerhouse and is 03 daa for the intake and reservoir, 1,1 daa for road to the power plant and 0,2 for the power house itself.

Figure 17 shows aerial photos of Røneid power plant in Luster municipality. The before image is from 2007 and the after image is a composite from 2018 and 2017. This is because neither of the images cover the whole power plant. The images clearly show where the forest have been cut to make room for the waterway. The captions on the figures refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2018 contains aerial photos from the area of Sogn from 2018.

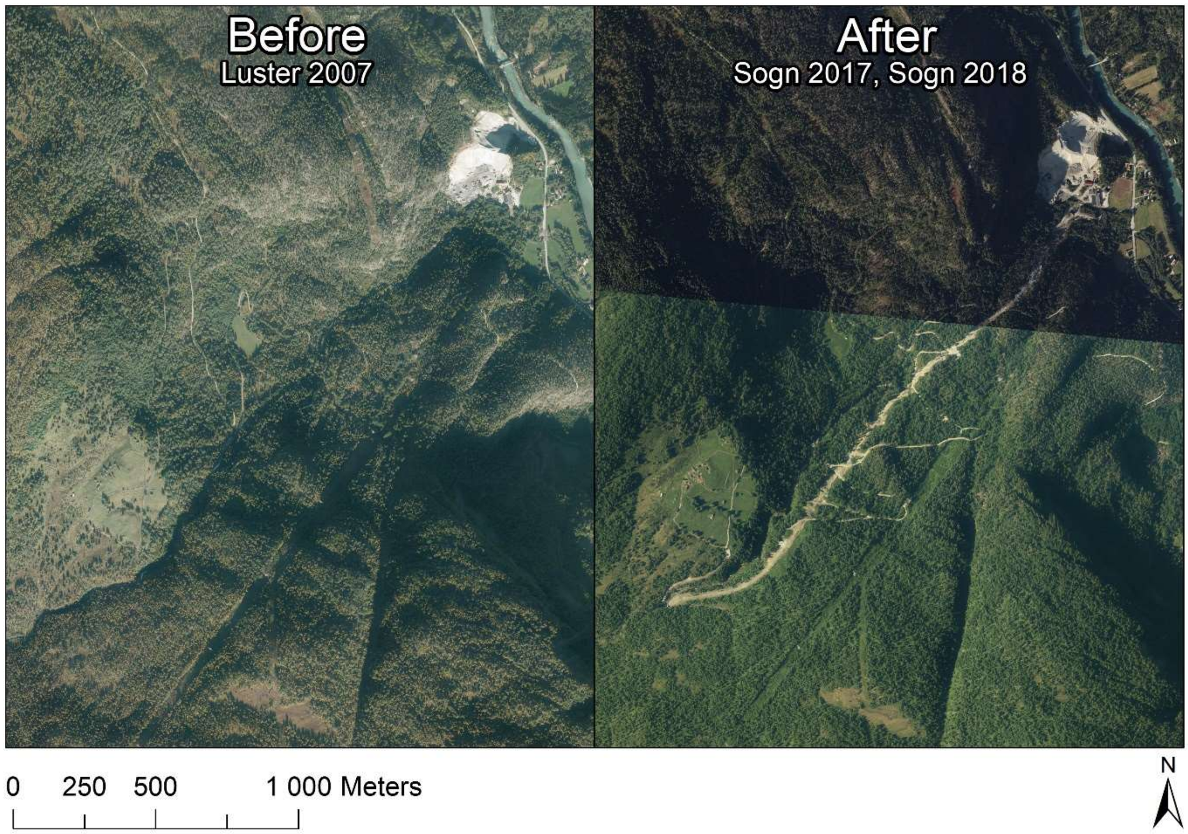


Figure 17: Røneid power plant in Luster municipality shows a clear scar after the power plant is built. The main part of this scar in the forest is the deforestation of the waterway path and the roads. The area usage of the waterways and roads is estimated by the application documents to be 34,8 daa. Images collected from norgeibilder.no. The caption on the figure refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2018 contains aerial photos from the area of Sogn from 2018.

Figure 18 has aerial photos from 2007 and 2017 and shows the intake for the power plant. One can clearly see the impact the dam, waterway and roads have near the intake. The captions on the figures refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2018 contains aerial photos from the area of Sogn from 2018.

Figure 18: The intake at Røneid power plant is estimated to use 0,3 daa in the application. Images collected from norgeibilder.no. The caption on the figure refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2018 contains aerial photos from the area of Sogn from 2018.

Figure 19 shows the powerhouse at Røneid power plant. The aerial photos are from 2007 and 2018. The photographs show that there is some impact to the forest by constructing the power plant. There is already a quarry in the area so the impact is of limited importance due to already disturbed surroundings. The captions on the figures refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2017 contains aerial photos from the area of Sogn from 2017.

Figure 19: The powerhouse at Røneid power plant is situated in the near proximity of a quarry. The effect of this is that the powerhouse itself doesn't add much to the negative impact of the area. The application estimates that the powerhouse will use 0,2 daa. Images collected from norgeibilder.no. The caption on the figure refers to the layers form norgeibilder.no and is the name of the layers containing the aerial photos. The first part of the caption refers to the area contained in the layer and the last part refers to the year the aerial photos was created i.e. Sogn 2018 contains aerial photos from the area of Sogn from 2018.

Table 6 in addition compiles some of the information available for the hydropower plant as offered in the application document and on the website of NVE. Data starts from an object_id used to identify the power plant to basic parameters of the plant. The table also contain a concession status. This number says something about where in the concession process the application is. Røneid power plant has a concession status of 5 which means that the application is approved. Further information in the table is basic parameters for the plant.

Table 6: Specifications for Røneid power plant in Luster municipality. The information is available for the hydropower plant as offered in the application document and on the website of NVE. Data starts from an object_id used to identify the power plant to basic parameters of the plan. The table also contain a concession status. This number says something about where in the concession process the application is. Røneid power plant has a concession status of 5 which means that the application is approved. Further information in the table is basic parameters for the plant.

Powerplant name	Røneid
OBJECTID	301
Object type	Hydropower plant
Powerplant number	1864
Status	In use
In use year	2016
Concession number	5179
Concession status	5
Concession status date	2010-06-01
Maximumpower MW	4,3
Turbine	Pelton
Yearly production	13,1 GWh
Height m	487
Energy equvalents kWh m^3	1,149
Owner	RØNEID KRAFT AS
Municipality number	1426
Municipality	Luster
River	Kvernelvi/Jostedøla
Permanent area	1,6 daa
Temporary area	34,8 daa
Loss of INON	0 daa

Potential small hydropower in Norway

The Norwegian Water Resources and Energy Directorate (NVE) has carried out an analysis of potential small hydropower sites. The analysis was first published in 2004 and was updated in 2015. The result of this analysis was a mapped overview of potential small hydropower sites in all of Norway. This analysis contains detailed information of the sites such as location, head, maximum capacity, estimated construction costs in NOK/kWh, production factor, power line cost, road cost and production. There are 1145 power plants located in Sogn & Fjordane in the dataset, which have a combined capacity of 835,2 MW. In Sogn & Fjordane there is 2,7 TWh/year in production with an investment limit of 3kr/kWh in the 2015 update. (Jensen. T., 2004)

Overview of methods applied in this thesis

Method 1: Assessing visible changes

We studied land occupation by comparing aerial photographs of the construction area before and after construction. The data on these land changes for this research were obtained with the use of WMS services from "Norgeibilder.no", Norwegian satellite photos. To estimate the size of the transformed area, the photos were digitalized manually with the help of Geographical information systems (GIS). In this research, the software ArcGIS 10.6, provided by ESRI was used. Area considered as visibly affected by Hydropower is the associated mechanical structures needed such as water intake/dam, waterway/pipes and powerhouse. Roads that are clearly connected, built or modified for the sake of constructing the hydropower is also considered as a visible change. The software offers the possibility to obtain a quantitative estimate of the size of affected area. The software offers the possibility to obtain a quantitative estimate of the size of affected area.

Historical aerial photos of hydropower sites before installation and aerial photos of the current situation were obtained from norgeibilder.no by commission.

Method 2: Statistical analysis of hydropower sites

Data processed and assessed in this study is sourced from the database of potential hydropower in Sogn & Fjordane, developed by NVE in 2004 (Jensen, 2004). The data consist of vector, point and line information for 1145 potential hydropower sites in Sogn & Fjordane, with information about intake position, waterway and powerhouse placement. The data was downloaded from nve.no by commissioning the dataset from NVE. We imported this dataset into ArcGIS 10.6 together with the dataset 'vBase', which contains vector data on roads longer than 50 meters as well as walking- and bike paths. This information was obtained from the public map catalogue at geonorge.no. With this we found the distances for all potential hydropower to the nearest road using ArcGIS's 'Near' tool. We repeated this process with datasets for power lines in Norway, obtained from nve.atlas.no. Lastly, the dataset of INON areas in Norway was obtained from kartkatalogen.no as a WMS service. This map layer shows the state of remaining 15 501 INON areas in Norway per January 2013. In this study we limit ourselves to Sogn & Fjordane which according to the official INON overview has 1032 areas remaining per January 2013. The areas consist mostly of smaller fragmented parts distributed from the coast and inward along the fjords. There are a few larger uninterrupted areas north of Sognefjorden, one of these being Jostedalsbreen glacier, but the remaining

INON are mainly smaller wilderness areas on mountains and other hard to access or inaccessible locations. For Sogn & Fjordane this is expected as the shorelines along the fjords and the lowlands of valleys have a flatter topography that allow for settlement of towns and small cities. The fragmentation of INON may also be explained by the scattered farming communities and villages that are iconic to western Norway. We repeated the 'near' tool process for the INON overview to find the distance of powerhouses and intakes to the closest INON border. Prior to this we decided to update the INON overview, as it had not been updated since January 2013, to prevent overlap and over-estimation of change in INON. Since then, several new hydropower projects have been developed, and an overview of this was obtained from NVE at nve.atlas.no. This dataset contains information for 898 water intakes, 861 waterways and 497 powerhouses that are under construction, planned and already operational in Sogn & Fjordane.

Using the dataset for existing hydropower in Sogn & Fjordane in ArcGIS, we created buffer zones of 1km around the intakes, waterways and powerhouses. We identified the buffer zones intersecting with INON polygons and cut the intersecting area from the INON overview. The result produced is an updated INON overview of Sogn & Fjordane per May 2019.

The open source software Rstudio was used to plot the results for how many intakes, power plants, roads and power lines were within a kilometre's distance of the nearest INON registered area. We produced logarithmic histograms using functions found in the package 'ggplot2'. A logarithmic scale on the x-axis was chosen to better represent the left side of the results as numbers vary from the tens to the thousands across the x-axis.

Method 3: Estimating the land occupation

Data on land occupation is collected by analyzing applications submitted to NVE. 8 different applications were used where each application distinguishes between permanent and temporary area usage. Even though some of the studied projects are not realized, the applications help to estimate how much area a typical small-scale hydropower plant uses.

Method 4: Estimating changes in INON

The environmental impact measured in this study is based on the INON lost due to future hydropower expansion if all the remaining available hydropower potential is realized. We will be measuring the number of intakes and power plants within range of INON, but also the area claimed per MW of installed capacity. In addition, the distance to roads and power lines will be considered to get a broader idea of what expanding hydropower means for area use.

Intakes or power plants within 1km of the closest INON border will be considered a loss of wilderness area. The total area lost will be calculated using a 1km buffer around the intruding intake, waterway and power plant. Buffers overlapping with INON will give us an area and a number representing the loss of INON in decares (daa).

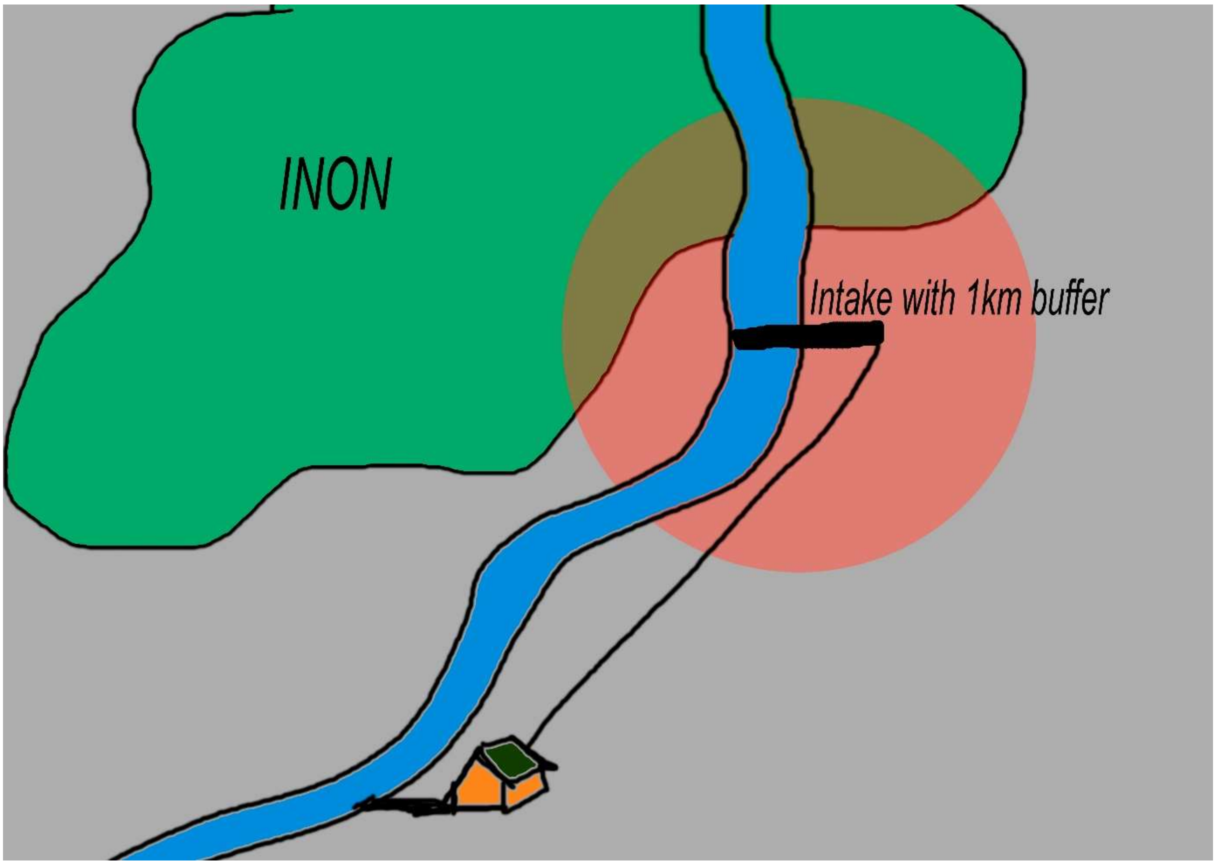


Figure 20: This figure illustrates the process of identifying changes in INON. A 1 km buffer is placed around the power plant, in this example on the intake, and any area of the buffer zone intersecting with the INON is considered a change in INON area.

The calculation for changes in INON area was done in ArcGIS 10.6, provided by ESRI. In the software we combined the two-point datasets and made sure there was no overlapping in the data. To measure if an intake or power plant were close enough to violate an INON categorized area we created a buffer of 1 km around intake and power plant as well as the waterway between them. To reduce potential error created by the many overlapping buffers we used the tools Dissolve and Merge. We first merged the buffers from the water way and the points (intake and powerhouse) making them into one layer, we then used dissolve to remove all borders between the buffers and have one clean layer containing the collective covered area by the buffers without overlapping. Next, we removed the area where the buffer layer intersected with the INON layer. The intersecting areas show how much INON is lost if all potential hydropower is realized. Figure 20 illustrates the process of identifying changes in INON.

Method 5: Impact on red list species

Information on red-list species in Norway were available and free to download at the website "artsdatabanken.no". The database contains observations of species in Norway detailing on species identity, location and date. For this examination we used only the data for critically endangered and endangered species.

We produced the result by making a buffer zone of 100m around the potential hydropower sites in Sogn & Fjordane from the NVE dataset. Next, we made use of the 'near' tool in ArcGIS 10.6 to see if any of the registered critically endangered or endangered species overlapped with these defined distances. The results were exported to Rstudio and categorized by their respective biological kingdom to better represent the significance of each finding. Due to the low distance used in this analysis, observations from the animal kingdom may not be as significant to the impact of hydropower as stationary species such as plants and fungi. We produced the result by making a buffer zone of 100m, then made use of the 'near' tool in ArcGIS to calculate which planned hydropower plant were inside of said species habitat.

Results

In this section we describe the results obtained by the various quantitative methods introduced in the previous section to assess the impact of small hydropower expansion on the environment. We follow the same order of analysis as in the overview of methods applied in this thesis.

Results 1: Quantifying visible changes due to small hydropower

Visible changes were quantified by measuring the area of visible changes from orthophotos provided by norgeibilder.no. The results show that there are in some cases large disparity between the estimates stated in the applications sent to NVE and what actually is affected. We discuss the findings for the 5 sites also studied in the qualitative analysis and highlight the identified areas in the photographs.

Site 1: Holsen – Førde

In the applications sent to NVE for the Holsen power plant the land use is estimated to a total of 49,2 daa. In the manually review of land usage we found a larger area use. The area used as obtained from orthophotos is 95,4 daa. This is about twice the amount of total area affected compared to the amount from the application. Figure 21 shows the identified area as an orange overlay to the photograph. The caption on the image refer to the layer used from norgeibilder.no. The layer used in figure 21 is Sunnfjord 2018 which covers the area of Sunnfjord created in 2018.

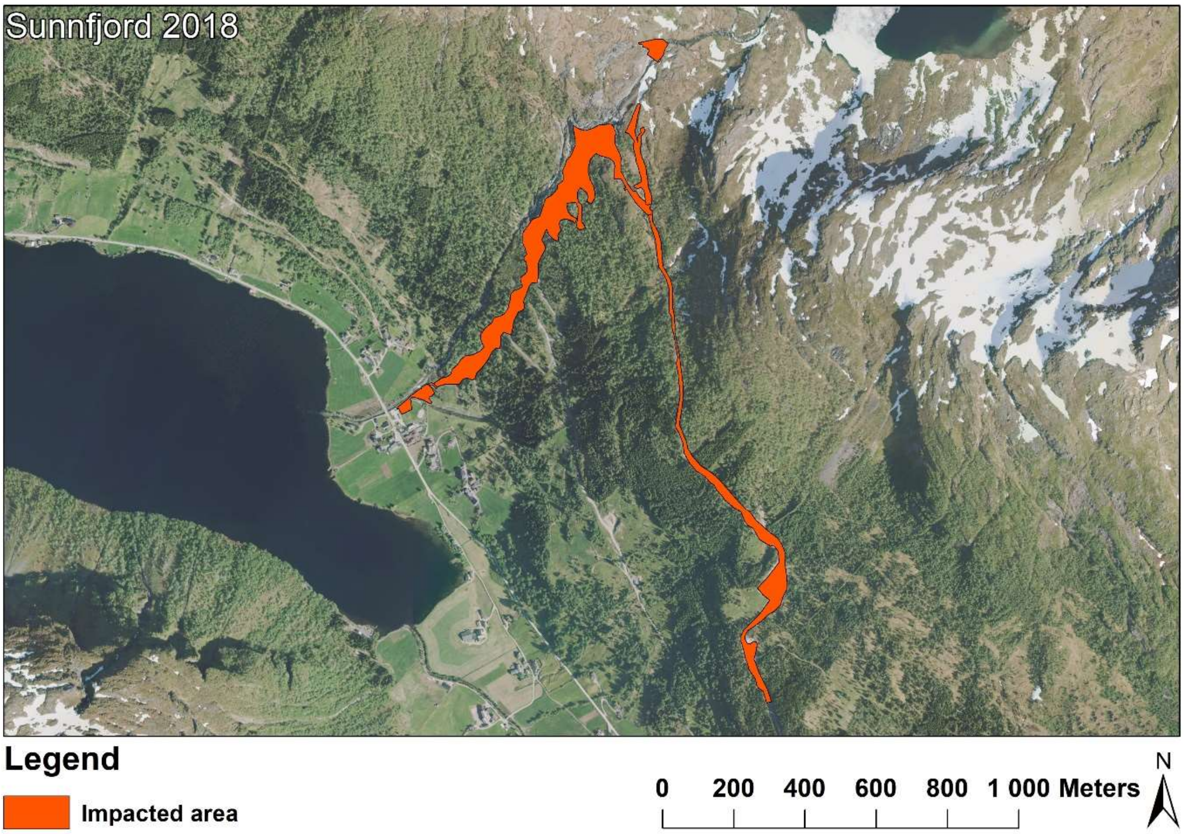
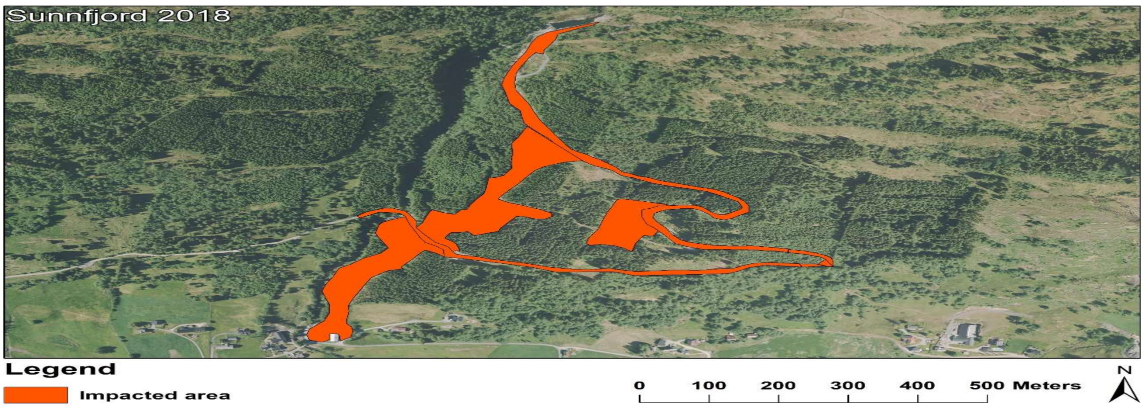


Figure 21: The image shows the area that have visible impacts due to the construction of the Holsen power plant in Førde municipality. The orange field marks the impact and is 95,4 daa. Image collected from norgeibilder.no. The caption on the image refer to the layer used from norgeibilder.no. The layer used in figure 21 is Sunnfjord 2018 which covers the area of sunnfjord created in 2018.

Site 2: Kvamselva – Gaular

The area usage collected from the orthophotos for Kvamselva power plant is 74,8 daa. This area usage is more than twice the area estimated in the applications documents, on which the decision to approve the power plant was based. The estimation in the application was 31daa. Figure 22 shows the impact by the construction of Kvamselva power plant as an overlay on the photograph. The caption shown on the figure refer to the layer used from norgeibilder.no. The name of the caption tells where which area is covered by the map and which year it was created. This layer was made in 2018 and covers the area of Sunnfjord.



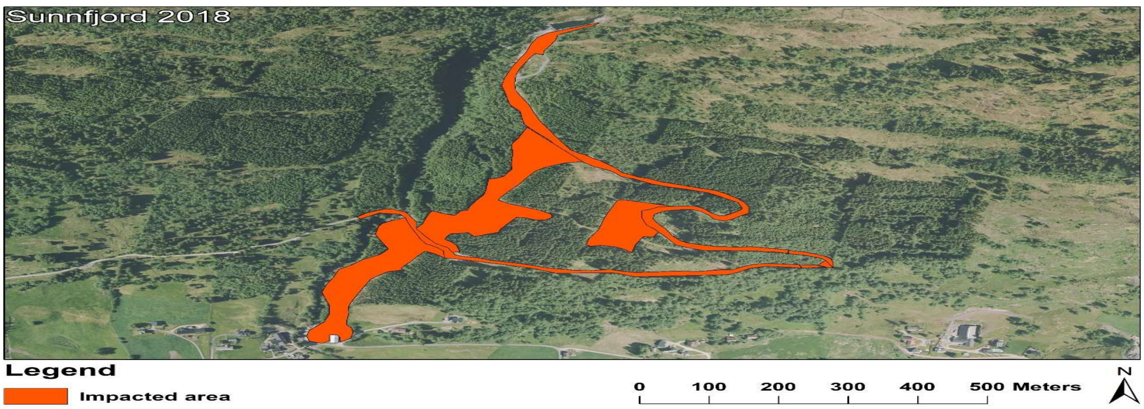


Figure 22:The orange fields show the visible impact of the construction of Kvamselva power plant in Gaular municipality. The impacted fields are 74,8 daa. Images collected from norgeibilder.no. The caption shown on the figure refer to the layer used from norgeibilder.no. The name of the caption tells where which area is covered by the map and which year it was created. This layer was made in 2018 and covers the area of Sunnfjord.

Site 3 Kvemma-Borgund

The area usage for Kvemma power plant in Lærdal municipality have a visible area usage of 10,7 daa. This is 2,6 daa more than the area estimated in the application which is 8,1 daa. Therefore, the results in this thesis is in good agreement with the value stated in the application documents. Figure 23 shows the area impacted by the construction of Kvemma power plant in Lærdal municipality. The impact is represented by an orange overlay to the image. The caption on the figure shows which layers from norgeibilder.no is used. The name of the layers are referring to the area covered by the image and the year the photos was taken. Figure 23 uses 2 layers to get the full area of the power plant. The layers are Sogn 2015 and Lærdal 2017.

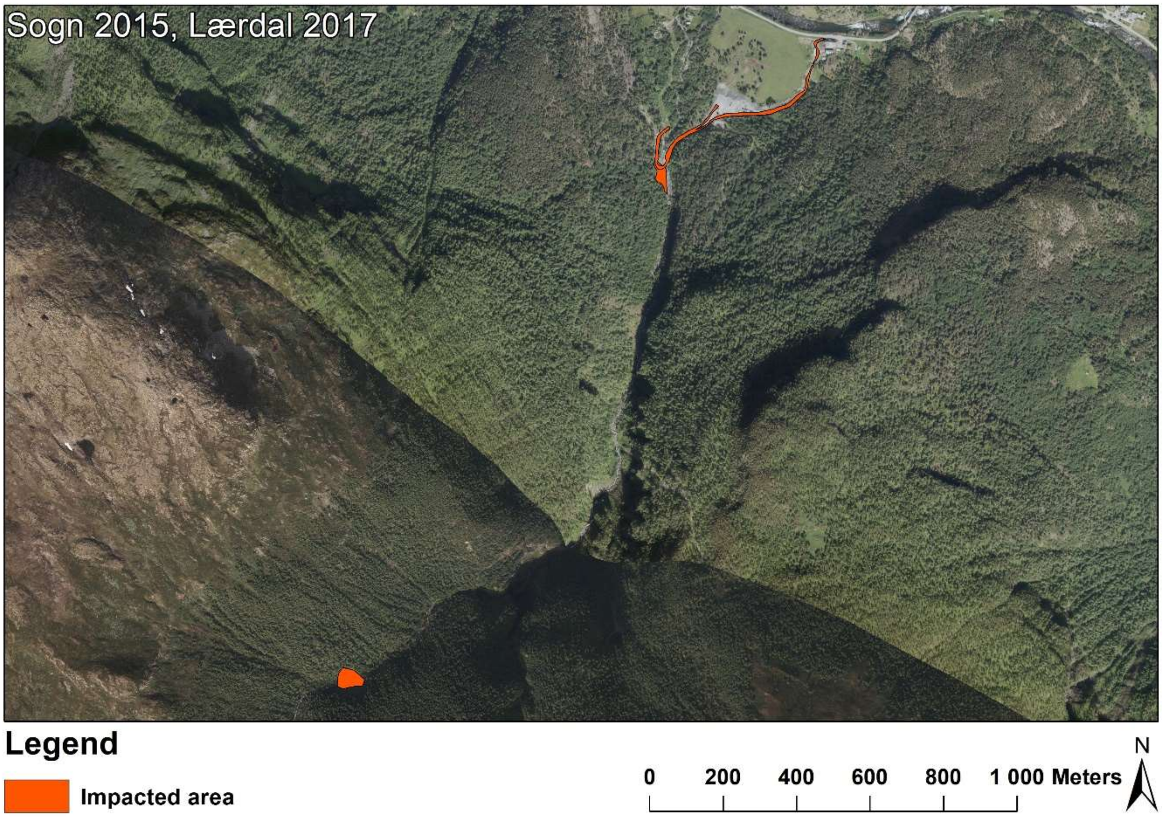


Figure 23: The image shows the visible impacts of building the Kvemma powerplant in Luster municipality. The orange fields mark the area impacted. The impact is 10,7 daa. Images collected from norgeibilder.no. The caption on the figure shows which layers from norgeibilder.no is used. The name of the layers are referring to the area covered by the image and the year the photos was taken. Figure 23 uses 2 layers to get the full area of the power plant. The layers are Sogn 2015 and Lærdal 2017.

Site 4: Kvåle – Luster

The estimated area usage for Kvåle power plant is a total of 12,5 daa. The area usage found in the study is 1,3 daa. This is a significant reduction. The reason for this is that the main temporary area used was an agricultural field, which has been restored after the building was complete. Figure 24 shows the area with a visible impact in Luster by Kvåle power plant. The orange overlay represents the visibly impacted area. The caption Sogn 2017 refers to the layer from norgeibilder.no used in the figure. The name of the layer refers to the area in the layer and the year the photography's was taken.

Figure 24: The image shows the impact due to the construction of the Kvåle power plant in Luster municipality. The impacted area is 1,3daa and is marked by the orange fields. Images collected from norgeibilder.no. The caption Sogn 2017 refers to the layer from norgeibilder.no used in the figure. The name of the layer refers to the area in the layer and the year the photography's was taken.

Site 5: Røneid – Luster

The Røneid power plant in Luster municipality have a total estimated area usage of 36,4 daa in the application documents sent to NVE. The area usage found in the study in the orthophotos is 54,3 daa. Thus, the identified area is about 50% larger than the value given in the application documents. Figure 25 shows an image of Røneid power plant in Luster municipality. The orange overlay represents the visible impacted area by the construction of the power plant. The caption shows what layers the image from norgeibilder.no is used in the figure. The caption is the name of the layers and refers to the area in the layer and the year the photographs was taken. The image uses two layers because neither of the layers cover the whole power plant.

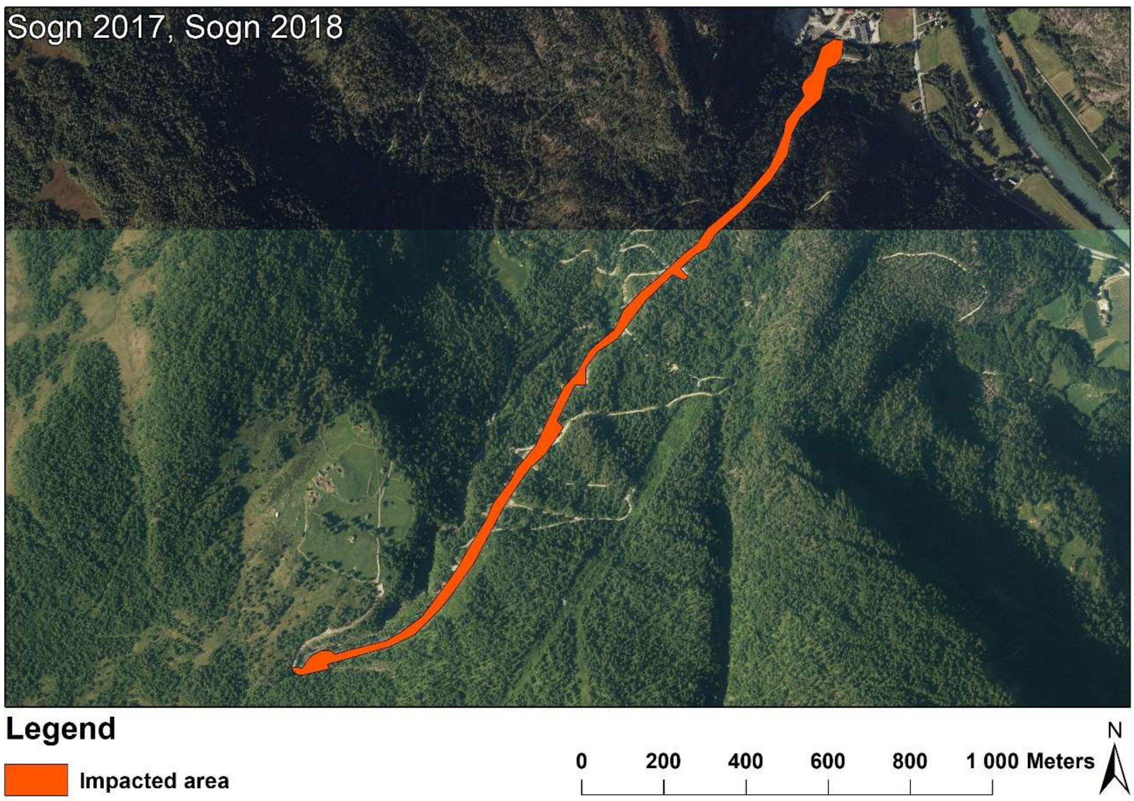


Figure 25: Røneid power plant in Luster municipality have a visible impact of 54,4 daa. The orange fields illustrate the impacted area. Images collected from norgeibilder.no. The caption shows what layers the image from norgeibilder.no is used in the figure. The caption is the name of the layers and refers to the area in the layer and the year the photographs was taken. The image uses two layers because neither of the layers cover the whole power plant.

Summarizing our results, we see that there is some underestimation of the land usage in the application documents. The documents for the 5 sites estimated a total of 137,2 daa of total area usage for the sites. This total area use contains both the permanent and temporary area which means that they estimate that it will be reduced over time. The land use we have estimated is 236,5 daa for the 5 sites, which is quite a lot more than the application documents estimate. Most of the difference is due to the temporary area. This temporary area may be restored over time, but it takes a long time to regrow a full forest. The difference in area use is an average of 19,86 daa for the 5 sites.

Results 2: Statistical analysis of small hydropower sites

In this section we explore the dataset for potential small-scale hydropower in Sogn & Fjordane, assessing the distances from powerhouse and intake to INON, as well as the distances to nearest infrastructure.

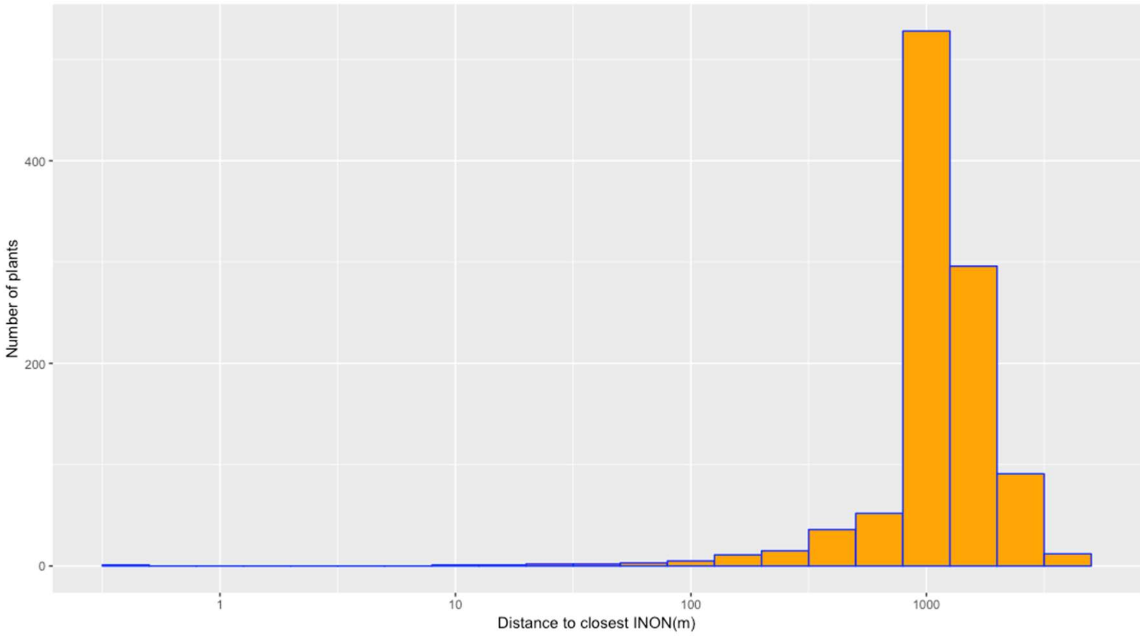


Figure 26: This histogram shows the number of plants as a function of the distance to the closest INON polygon. The distance is measured in Euclidean distance or "as the bird flies". Plants within a distance of 1000m in this histogram contribute to a reduction in INON area in Sogn & Fjordane.

The histogram in figure 26 shows the distances between potential hydropower sites to the closest INON polygon in Sogn & Fjordane for all sites in the dataset. The distance is shown for a point, the powerhouse, to the edge of the nearest polygon measured in Euclidean distance or “as the bird flies”. The number of plants is shown as a function of the distance to the closest INON given in meters. The data is presented on a logarithmic scale to better represent the results as there are only a few plants within 100 m down to as close as 1m and inside INON. Observing the peak bin, we see that a significant amount of potential hydropower sites is at the border of, or within, an INON categorized area. Of the 1145 powerhouses in the dataset, 795 with a collective effect of 580,4 MW, are not in conflict with INON.

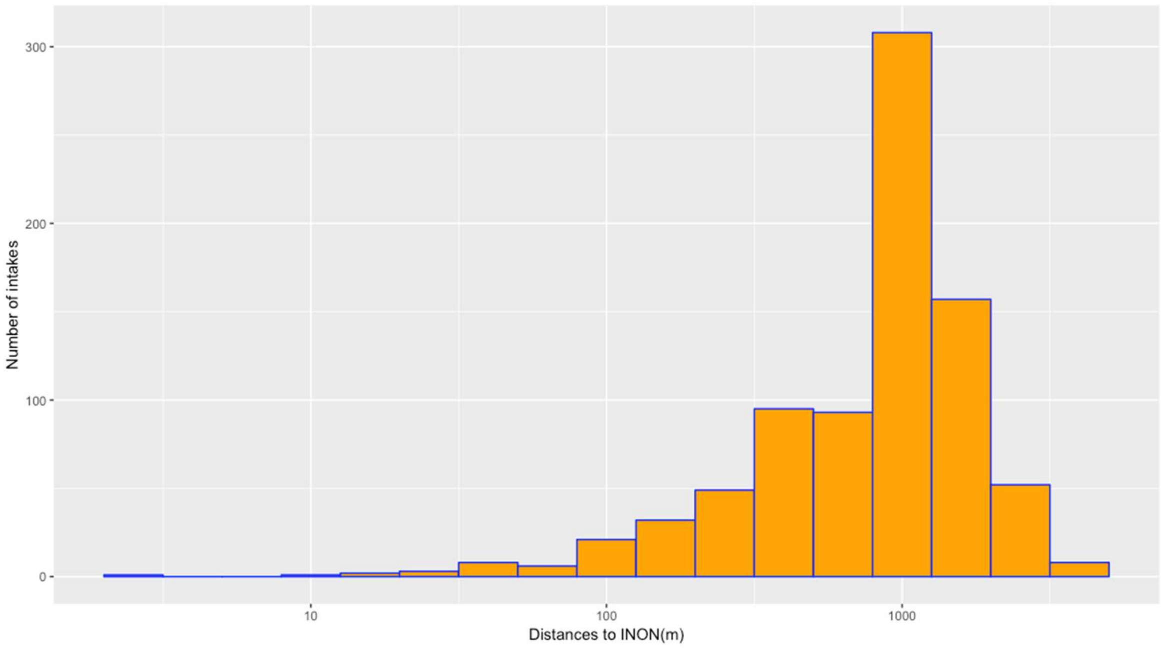


Figure 27: This histogram shows the number of intakes as a function of the distance to the closest INON in meters. The distance is measured in Euclidean distance or "as the bird flies". There is a significant number of intakes within 1000m of the closest INON.

We now repeat this investigation to the position of the intake.

The number of water intakes as a function of the distance to closest INON are shown in the histogram in Figure 27. The distance is measured in Euclidean distance or “as the bird flies”. The distance on the x-axis is presented on a logarithmic scale since distances vary from as little as a few meters to several kilometers. Intakes closer than 1km from INON in this histogram will remove the INON-classification of the surrounding area and push the current INON border 1km back from the intake construction point. Also, here as in the histogram of plants within distance of INON, there are many intakes that would violate INON should all potential small hydropower in Sogn & Fjordane be realized. Out of the 1146 intakes in the dataset, 429 are not in conflict with INON.

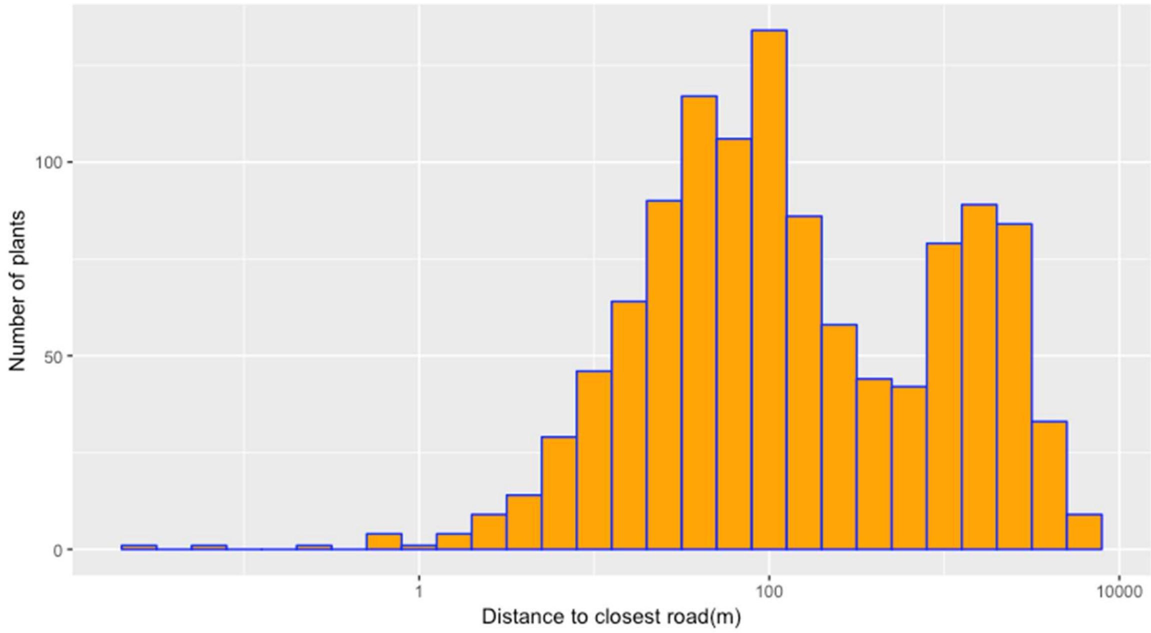


Figure 28: The histogram shows the number of plants as a function of the distance to the closest road, given in meters. The distance is measured in Euclidean distance or "as the bird flies". As roads are necessary infrastructure to construct and maintain small hydropower it is important to consider the amount required to realize potential hydropower.

Figure 28 shows the number of plants as a function of the distance to the closest road. The distance is measured in Euclidean distance or “as the bird flies”, which is not a realistic depiction of the necessary area required to construct roads to reach the power plants as local topography poses unique challenges to the construction of infrastructure. These numbers may however be used as an estimate for required land occupation for infrastructure.

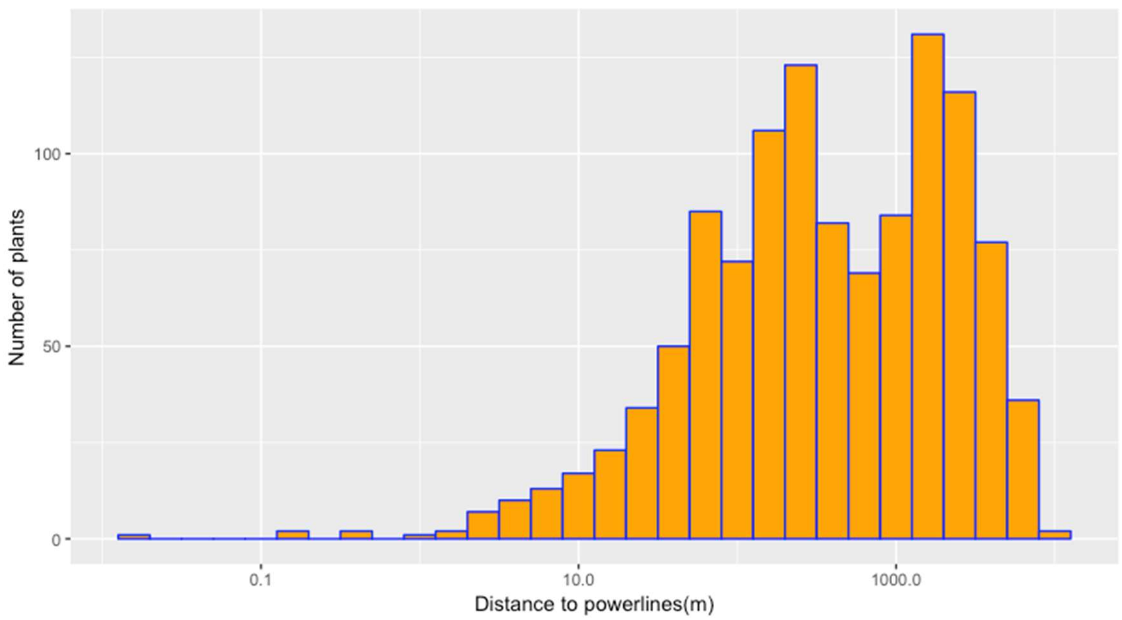


Figure 29: The histogram shows the number of plants as a function of the distance to existing power lines, given in meters. The distance is measured in Euclidean distance or "as the bird flies". Constructing longer stretches of power lines may have consequences for local nature and contribute to the patching of animal habitats.

In addition to the roads, an infrastructure of power lines is necessary to deliver the produced energy to the grid. Figure 29 shows the number of plants as a function of the distance to existing power lines. The distance is measured in Euclidean distance or “as the bird flies”. The challenges of topography also apply to the construction of power lines as a straight line may not be the best practical solution. In the histogram we see that a majority with 64% of power plants are within a 1km distance of the closest power line. It is important to remember that power lines as well as roads encroach on INON should they be closer than 1km of the nearest INON area. While the results for infrastructure in this study are limited in terms of generalization due to the methods applied, we consider these results significant in terms of what it means for loss of INON if we were to realize all small hydropower potential in Sogn & Fjordane.

In conclusion, the statistical analysis of small hydropower sites shows that it is possible to realize 580,4 MW of potential hydropower, with respect to the powerhouse, without encroaching on INON area. Further analysis of the connected intake(s) and necessary infrastructure may reduce this number.

Results 3: Loss of INON due to small hydropower expansion

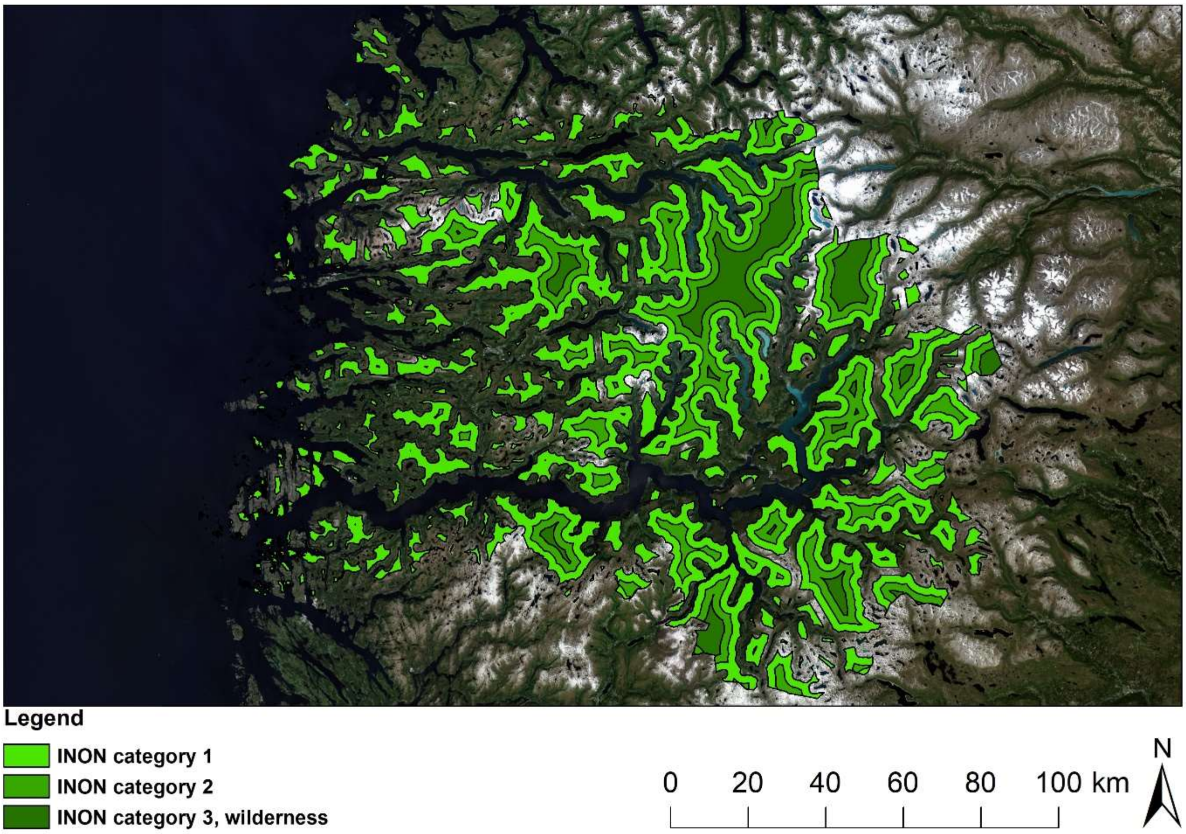


Figure 30: This is an updated map of remaining INON area per May 2019, developed based on the current hydropower overview of Sogn & Fjordane provided by NVE, and the official overview of INON per January 2013. The updated INON area is calculated by removing the area that is violated by hydropower plants built after 2013. The base layer is an ortophoto from norgibilder.no.

In Sogn & Fjordane there was an estimated area of 8 808 429,6 daa of INON in January 2013 when the last update was published. The number of fragmented INON at that time amounted to 1032 individual areas excluding the different categories. In May 2019 we updated the INON map by removing the area had been impacted by the existing hydropower. The area lost due to already existing installations was 484 124,6 daa. The number of individual areas had now increased to 1056 amounting to 8 319 305,6 daa remaining. The area of Sogn og Fjordane is 18 619 210 daa where 44,68% of the area consist of INON. Figure 30 shows the updated map of INON in Sogn & Fjordane. We can see that the coastline contains much more fragmented INON area than further in-land. The largest INON area on this map is attributed to Jostedalsbreen. After getting an up-to-date map we conducted the same procedure as when updating and studied how much INON would be lost if expanding the total small hydropower potential in Sogn & Fjordane. We found that the total amount of INON area lost would be 956 149,8 daa. The remaining INON area left would be 7 367 510,9 daa distributed over 1109 areas, showing further fragmentation of wilderness. Figure 31 shows the location of INON areas lost due to the expansion of hydropower. Note that the location of many areas close to the fjords is expected, since these locations have usually a high elevation gradient and are therefore suitable for hydropower installations.

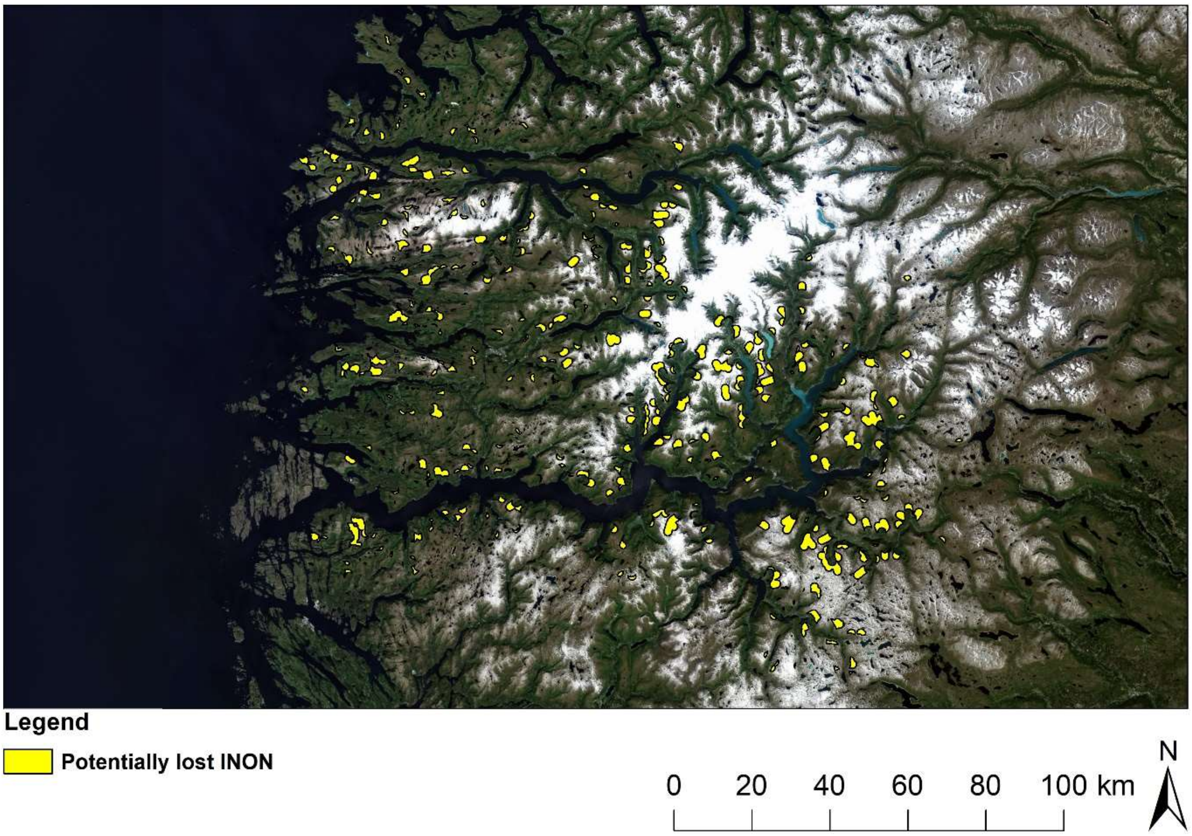


Figure 31: An overview of where INON area is lost should all potential hydropower in Sogn & Fjordane be realized. The yellow areas show the total loss of INON. The majority of INON area is lost along the fjords of Sogn & Fjordane. This is due to waterways marked for potential hydropower end at the fjords, and the steep gradient of the mountainsides that contribute to hydropower potential.

Results 4: Land occupation by small hydropower expansion

Table 7 lists the temporary and permanent land occupation for the 8 approved hydropower sites in our sample. As discussed before, the values are taken from the application documents as stated by the applicants.

In the applications there are numbers for both permanent and temporary land occupation. Our comparison of the land occupation of the 8 concession applications show that the average permanent land occupation lies at 7,94 daa for small scale hydropower. The temporary land occupation refers to the land occupied during construction and establishment of the hydropower and necessary infrastructure. The average temporary land occupation based on these applications are calculated to 42,56 daa. It is important to note that these numbers derive from the applicants and not from fieldwork or measurement of the actual land occupation and may deviate from actual land occupation. Using the number for installed capacity for potential small-scale hydropower in Sogn & Fjordane we find that the average land occupation for permanent and temporary land occupation is 0,0095 daa per MW and 0,0510 daa per MW respectively, in total amounting to 0,06 daa per MW. The average land occupied per MW in these results are similar to that of (Bakken, 2014) for small hydropower with 0,01752 daa per MW. A reason for the deviation in results is that we consider micro and mini in this study, while the Bakken study limits itself to the strict definition of small hydro of 1 – 10 MW capacity. For hydropower with water reservoirs the land occupation is 61 daa per MW (Dorber et al, 2018), showing a ratio of land occupation to installed capacity in favour of small hydro, as water reservoirs are more common for larger installations. Land occupation in our sample of 8 hydropower sites vary from 1,86 daa to 13,2 daa for permanent occupation, and from 3,36 daa to 62,4 daa for temporary land occupation. These variations in land occupation are reflected in (Bakken, 2014) showing a great variation in land occupation for the 27 small hydropower sites in that study.

Table 7: Shows the specific sites used in the comparison and calculation of average values. The values vary very much from the highest to the lowest value. This variation is due to the site-specific challenges of hydropower such as local topology and method of construction.

Kviafossen	NVE Application ID		daa	
Permanent	201300124		1,86	
Temporary			3,36	
Botnaelva				
Permanent	200904768		12	
Temporary			74	
Brekka				
Permanent	200904056		8,9	
Temporary			69	
Tverrdøla				
Permanent	201000031		4,05	
Temporary			14,75	
Skeidsflåten				
Permanent	201207912		4,5	
Temporary			62,4	
Fardalselvi				
Permanent	201300089		17	
Temporary			52	
Holsen-Førde				
Permanent	200703280		13,2	
Temporary			36	
Kvamselva				
Permanent	200703514		2	
Temporary			29	
	Average Area Use			
	Avg Permanent		7,94	daa
	Avg Temporary		42,56	daa

Results 5: Red-list species affected by expansion of small hydropower

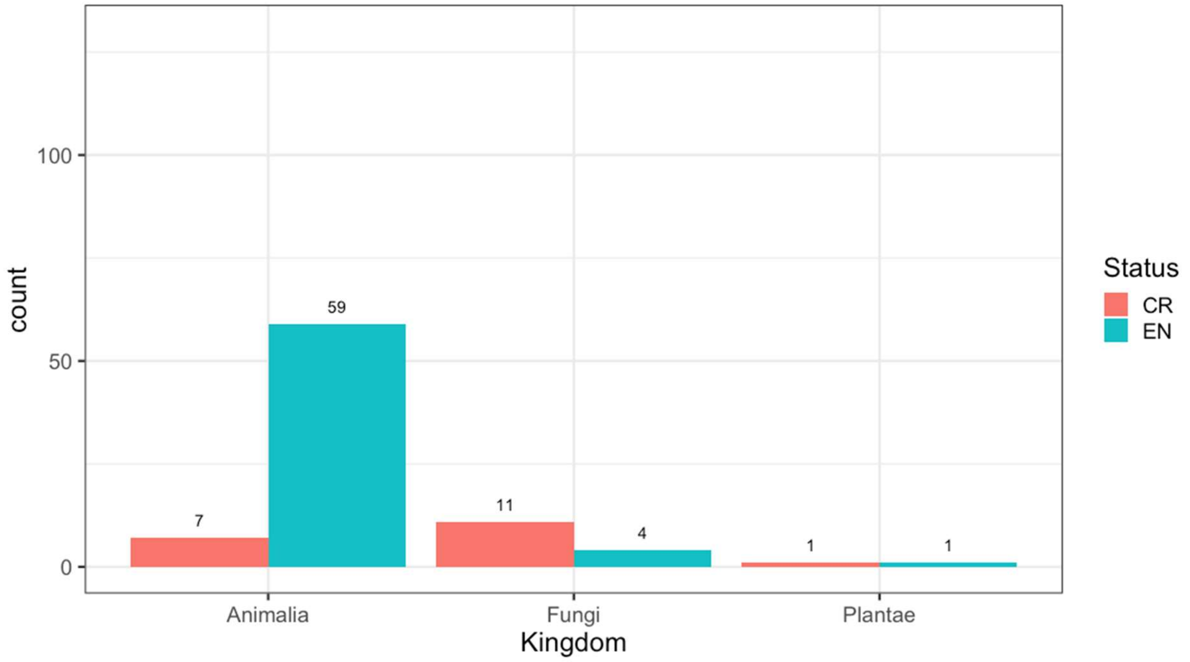


Figure 32: This graph shows the count for each animal kingdom separated by their status in artsdatabanken. The majority of endangered (EN in blue) or critically endangered (CR in red) species within 100m of a potential hydropower site are those within the animal kingdom. Only two plants have been observed within 100m of potential hydropower sites, one in each status category.

We found that there are a number of red-listed species affected by potential hydropower expansion in Sogn & Fjordane, mainly in the endangered category (EN). Figure 32 shows the distribution of 83 observations identified within a 100m buffer zone around the potential sites. In the endangered category, 59 were from the Animalia kingdom, 4 fungi and 1 plantae. For critically endangered species (CR), these numbers are 7 Animalia, 11 fungi, and 1 plantae. It is difficult to assess the actual impact on Animalia as an extensive knowledge of the specific animal's behaviour and territorial needs are required. For the stationary species found, the fungi and plantae, it is safer to assume that a reduction in water flow will affect it. According to table 1, adapted from Bakken et al., 2012, reduced water flow was reported as a consequence of small-scale hydropower 100% of the time. A later study assessing the impacts on red-listed species by different power production technologies, among them small hydropower, found that small hydropower had a higher number of conflicts per unit of electricity than large hydropower and wind power (Bakken et al., 2014). The study used significantly larger buffer zones in their methods, 2 and 10 km respectively, but in both cases small hydro averaged above wind power and large hydro.

Discussion

Discussion 1: Quantifying visible changes due to small hydropower

The land usage of small-scale hydropower varies greatly. In the different sites studied here, the land usage ranges from 1,3 daa to 95,4 daa. The reason for this large range of total land usage is the way hydropower plants are constructed. The largest visible change when building small-scale hydropower plants is the construction of the waterways. The sites with the lowest area used have the waterways drilled in the bedrock of the mountain, instead of on the surface or in the soil. This reduces the visible impact greatly and leaves the power plant with low permanent and temporary area usage.

The calculation of the visible changes has its limitations. It is subject to interpretation of what an impact is and what is not. Is the receding tree line due to the expansion of the road, due to the power plant, or due to the general maintenance and expansion of the road networks? The identification and classification from the photographs are subjective. Having a clear idea of what is counted is key to mitigate the error. Here, consulting municipal development plans would be helpful in identifying the objectives for e.g. road construction.

Discussion 2: Statistical analysis of hydropower sites

The statistics presented in this paper are limited by the context they are in. We present distances as straight lines from point A to point B, but this may not reflect reality with regard to topography and site-specific challenges. The distances measured from the power plants to INON and the intakes to INON are done based on a point-to-polygon border, but in reality, a power plant or intake will have an area. In the case of small hydropower this does not present a particularly great error to our final result, due to the scale of small hydropower. Giving these sites an area would not change the results in any significant way, but should these methods be applied to projects of a larger area such as wind power or large-scale hydropower, the difference between an area and a point would be much more significant. Such an extension of our method is straightforward with the help of GIS software. It has not been implemented in the current study due to time constraints.

Another limitation in terms of interpreting these results with respect to the expansion of hydropower in Sogn & Fjordane is the remaining intakes and power plants that are not in conflict with INON. We found that 429 intakes and 795 power plants are not in conflict with INON in Sogn & Fjordane through statistical analysis of the potential hydropower sites. To realistically assess how many of these potential sites are not in conflict with INON, each powerhouse and connected intake(s) should be analyzed together, but in this study they are analyzed separately. This means that even if a powerhouse is found not to be in conflict with INON, the connected intake may still be within range of encroaching on INON area. In such a situation the entire hydropower plant would be considered as encroaching on INON area. This method of analysis is possible with the available data, but was omitted from this study due to time constraints.

Discussion 3: Loss of INON due to small hydropower expansion

According to Norway's environmental directorate, in the period 2008-2012, expansion of energy supply is responsible for approximately 26% of the total loss of INON area in the given period (Norwegian Environment Agency, 2018). The result of this potential expansion is an accumulating loss of INON, which should be an important discussion point when evaluating the benefits and disadvantages of small-scale hydropower friendly policies. If we were to realize all potential hydropower in Sogn & Fjordane, it would mean that for every MW of installed capacity, INON will be reduced by 1 144,8 daa. In total this equals a loss of 956 149,79 daa INON area in Sogn & Fjordane alone. As Sogn & Fjordane has the highest capacity for hydropower in Norway, furthering policies promoting small hydro as the environmental-friendly option may have degrading effects on the country's overall INON area. Small hydropower is often promoted as an option to mitigate climate change, but its effect on local environments as well as the cumulative impact of small hydro are not well-enough understood or acknowledged yet (Kelly-Richards et al., 2017). Applying the methods in this study to calculate potential loss of INON may prove a useful tool on the municipal level to assess and evaluate the cost of expanding hydropower for local communities. The loss of INON parameter is not enough to evaluate total impacts of environmental changes. It may still prove valuable as an indicator for loss of previously untouched nature and the potential loss of animal and flora habitats and other ecosystem services provided by wilderness today.

Discussion 4: Land Occupation by small hydropower expansion

All power generation claims some amount of area and, small hydropower may require area that is not already influenced by human encroachment. A comparison of eight different applications for small hydropower projects in Sogn & Fjordane estimates an average permanent area use of approximately 7,94 daa, while the temporary area affected averages 42,56 daa. The term "temporary land occupation" is relative to the area affected e.g. the installation Kvåle-Luster (Figure 14) has a temporary area usage of 12,5 daa. The area affected was mostly agricultural fields that were quickly restored after construction. By comparison, a dense forest cut down as “temporary land occupation” may take decades to fully regrow. We have compared hydroelectric power plants that are defined by NVE as small-scale hydropower, and we have seen that the numbers vary greatly from temporary to permanent land occupation. The definition of small-scale hydro is based on its installed capacity, and the impacts of each plant may vary greatly, even within similar ranges of capacity. The idea of an average value for land occupation by small hydro has a limited meaning, as the land occupation appears to be dependent on a variety of factors that do not necessarily tie directly to their production (Kelly-Richards et al., 2017).

Discussion 5: Red-list species affected by expansion of small hydropower

The results for red-listed species within a 100m distance of potential hydropower sites show that expanding hydropower does not come without consequences, however these results have their limitations. The majority of registered red-list species found within the 100m buffer are from the animalia kingdom, mainly lynx and wolverine but also one case of wolves. Assessing whether or not expanding hydropower has a direct effect on these species is impossible without an in-depth knowledge of their specific habitats and behavior. There is no way of knowing if the observations are made in their habitat or if they are simply passing through when observed without proper field work. The other observations of fungi and plants are easier to rely on as they do not migrate. It is also shown in the (NVE, 2015) report that there were far more red-listed observations around planned hydropower projects than what was given in the concession applications, with more than double the observations of red-listed moss and lichen in the evaluation project (NVE, 2015). There are also limitations to consider here without proper field-work; whether the observed plant or fungi are dependent on nutrients from the river in question; if the species are still present at all and the case of duplicate reports which may affect the frequency of observations in our results. Artsdatabanken contain millions of observations, but the data for Norway is still quite patchy, making analysis based on this data somewhat unreliable.

Conclusion

This thesis considers three parameters to give an understanding of what environmental impacts the expansion of small-scale hydropower will have in Sogn & Fjordane. These parameters are the land occupation of small-scale hydropower, the loss of INON by hydropower expansion, and the disturbance of red-list species through hydropower expansion.

Our selection of parameters is not the only environmental impacts by small-scale hydropower, but they are selected to give an understanding of the scope of the impacts and may serve as a proxy for quantifying the effects as long as there are no better indicators.

Changes in INON, land occupation and impacts on red-list species are a small portion of total environmental impacts related to small-scale hydropower. They still serve as an indicator to what we can expect if we continue in the direction of small hydropower expansion that started in 2002. We recognized that visible changes in the landscape vary by site, the construction method and type of land occupied. A shortcoming of this study is that the INON classification only considers the distance to nearest human encroachment, and does not take into account the natural values and services provided by an area. Through statistical analysis of the potential hydropower sites we identified a loss of 956 149,79 daa INON, reducing the amount of INON area in Sogn & Fjordane by 5,13 percentage points. The expansion will claim 1 144 daa INON per MW of the potential small-scale hydropower. This result, coupled with the histograms for infrastructures, gives an idea of how much land will be affected by new hydropower. This too has its shortcomings in that the infrastructure are measured in a straight line, while roads in reality are winding for practical reasons, especially in a mountainous region like Sogn & Fjordane. Taking infrastructure into account in a realistic manner, with slopes and turns, would significantly improve upon these results. Such a detailed analysis is possible but was beyond the scope of this study due to time limitations. Another aforementioned improvement would be to assign to each hydropower site an actual area (instead of treating it as a point) prior to measuring the distance to INON, as buildings in reality are not just a single point from which you measure center-out. We've stated earlier that for small hydropower the resulting difference may not be that significant, but for increased accuracy, adding an area would improve the quality of the research.

Our results for land occupation by small-scale hydropower bases itself on information supplied by the applicants for small hydropower concessions. These numbers have been found in this thesis to vary from our assessment based on our analysis of visible impacts of small hydro. This points to some underestimation of the affected area in the application documents. The result is supported by the findings in the report by NVE in 2015. In the report they found that the environmental impacts of planned hydropower projects were significantly higher than what was stated in the original application for concession, concerning flora and nature types (NVE, 2015). We also found that within 100m of the potential hydropower sites, 19 critically endangered and 64 endangered species were observed. Although these results are very limited and cannot be generalized as is, the threat that small hydropower poses to endangered species are in line with the conclusions of (Bakken et al., 2014). Knowing that a concession is not a reliable source to evaluate actual environmental impact is important to bring forward in the discussion of expanding small-scale hydropower.

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