Graduate thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Mihret Hailu Fenet

Comparison of Environmental Impact of Hydropower and Wind Power

Graduate thesis in Hydropower Development
Supervisor: Tor Haakon Bakken
Co-supervisor: Mahmoud Saber Kenawi
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Abstract

One of best way to reduce the effects of climate change is to increase electricity production from renewable sources, which offers an excellent prospect for low carbon emissions and greenhouse gas reduction, However, it is difficult to claim that renewable energy has no environmental impact. Because each renewable energy technology has its own environmental disadvantage, depending on the technology the impacts can be on aquatic or terrestrial biodiversity. This study compares the environmental footprint of renewal energy by selecting three hydropower plants named Grana, Litfossen, and brattset, and from the wind power plant, the selected wind farms are called Geitfjellet, Stokkfjellet and Hitra 1&2. The analysis is divided in to three-time step for hydropower and in two-time step for wind power plant to see the land use change through time. The first-time step is taken before the deployment of the project, the second time steps is 2-4 years after the construction and the third time step is long term after construction for each selected hydropower plants,

For wind power the time steps are divided in to two, before the construction and after the construction of wind farm. The selected technologies generate close to similar capacity of electricity in MWh.

The comparison of land use dynamics is done by getting raster image from satellite data and performing image classification, change detection in Arc GIS Pro to get the quantitative area of land use in different time step.

According to the case study results, a hydropower plant occupies more area than a wind farm. The average land occupation of wind power is computed as 0.019m2yr/kWh, whereas the average direct land occupation of hydropower is 0.159m2yr/kWh.

The indirect impact of the wind farm-related to deforestation and urbanization is smaller than the selected hydropower plant.

Preface

This study is given in partial fulfillment of the requirements for a Master of Science in Hydropower development at the Norwegian university of science and technology. This study was performed between January/15/2022, and July/05/2021. Professor Tor Haakon Bakken and Ph.D. candidate Mahmoud Saber Kenawi have supervised the work.

First and most, I want to thank God for helping me with everything through the process, and many people have contributed to this work. I want to thank my main supervisor Tor Haakon Bakken and co-supervisors Mahmoud saber Kenawi for their support during the entire semester, Their valuable advice, quick responses, and positive feedback have been highly appreciated. I also want to thank My friends, my mother, Bethlehem, and Alexander, Mone who have been with me throughout the process by motivating me to reach the final stage.

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Abbreviation

GWh……………………………Gigawatt hour

GIS……………………………. Geographical information system

HPP …………………………… Hydropower plant

KWH……………………………. Kilowatt hours

LCA …………………………. Life cycle assessment

LULC ………………………… Land use Land cover

MW …………………………... Megawatt

MWh …………………………. Megawatt-hour

NVE ………………………….. Norwegian Water Resources and Energy Directorate

PHES……………………………. Pumped hydroelectric storage

ROR………………………………Run off river

TWh ……………………………. Terawatt hour

WPP ………………………….... Wind power plant

1 Introduction

Energy is the capacity to do any kind of work, and it is the driving fuel of development. The amount of energy production is one of the indicators for the development of the country. There are two types of energy sources: nonrenewable and renewable energy, and they are primary resource to produce electricity. (U.S. Energy Information Administration, 2021)

nonrenewable energy is extracted from the earth. It is the source of energy from natural resources such as oil, natural gas, nuclear energy, and coal, the four primary nonrenewable sources. Moreover, it is a solid and stable energy output. Although it is an effective way of getting energy, it has massive consequences on the environment, among those radioactive waste from nuclear energy, oil slicks, and spills, effects on human health, emission of carbon dioxide, a greenhouse gas which is the leading cause of global warming. To solve the delinquent that happens because of the impact is shifting the technology to Renewable energy.

Renewable energy is the modern thinking of energy source that is naturally replaced and rapidly growing in the energy sector Around the world. Renewable energy reached about 29 percent of electricity generation in 2020. The main renewable energy sources are hydropower, solar power, wind power, geothermal, and tides. Hydropower is the most significant segment, with about 16.8 percent. (center for climate and energy solution, 2020)

Even though renewable energy sources have fewer environmental issues in terms of carbon emissions and greenhouse gas emissions, there are still some drawbacks to the environment regarding wildlife habitats and land occupation.

There have been some separate studies about the environmental impact of different renewable energy sources, but only a few studies compare renewable energy technologies with different indices. The case study presented in this thesis is planned to address the issue of the comparison of the environmental impact of renewable energy deployment between hydropower and wind power associated with the land use land cover. Hopefully, it will supply beneficial results to see the extent of land occupation between those two technologies.

1.1 Objective and Goal

The objective of this master thesis is to look the overview of the negative environmental impact of renewable energy related to land use dynamics

1.2 Scope

This study is directed within the following scopes

- General assessment on the land-use composition in the hydropower and wind turbine direct impact on the reservoir deployment and wind turbine installation and the surrounding the reservoir at 1Km distance from the reservoir shore of the existing reservoir
- Detailed assessment on the land-use changes for every 100 meters, within the100meters distance form reservoir shoreline and wind farm project area.
- Comparing the land occupation and electric production of hydro power and wind power.

1.3 Questions & Hypotheses

- What is the direct footprint of RE deployment?
- What is the most best energy system in terms of land occupation?
- How the land use dynamics behave due to Renewable Energy deployment?
- What are the accompanying impacts due to this dynamic change Deforestation, Urbanization?

1.4 Thesis format

This thesis is divided into five chapters. Chapter 1 is about the general concept of energy, research purpose, and goals.

Chapter 2 discusses the theoretical background of hydropower and wind power as well as an overview of the Environmental impacts of the technology.

Chapter 3 outlines the study area in Norway, the case study of hydropower plants and wind energy.

Chapter 4 is about material and methodology

Chapter 5 discusses the research findings (results) and how they correlate to the current literature. chapter 6 is about conclusions, limitations, research contributions, suggestions for future research directions, and highlights ways.

2 Theoretical Background

2.1 General concept of Hydro power and wind power

This part discusses the general concept of hydropower and wind power projects, their positive and negative effects on the environment, and the core principle of this study.

2.1.1 Hydro power

As the name indicates, hydropower is the generation of the electric city from the water; it is the technique of getting energy by converting mechanical energy to electric energy. The central concept in hydropower development is changing potential energy stored in the reservoir into mechanical energy, then converting this mechanical energy into electric energy.

The amount of energy that could get depends on the reservoir size, the head difference between the reservoir and the turbine, and turbine efficiency.

the hydropower plant has the following key components

- Water collection and storage
- Dam and intake
- Waterways (canals, tunnels shafts, penstock pipes)
- Power station
- Transmission

$$P = \eta \rho g h Q$$

Hydropower plants are categorized differently depending on their head, size, and availability of water; there are three types of hydropower plants.

Run-off river (ROR): - this type of hydropower plant works only when enough water is available. This plant's primary purpose is to use excess water, e.g., in flood situations during the rainy season. The facility to generate electricity is directly connected to the river or channels flowing water from a river divert by constructing intake across the river and the water through a canal or penstock to spin a turbine. Usually, a run-of-river project will have little or no storage, some seasonal storage Run-of-river provides a constant amount of electricity (base load), with some flexibility of operation for daily fluctuations in demand through the facility's water flow adjusts.

Pumped hydroelectric storage (PHES): **-** is a structure of two water reservoirs at different altitudes. The upstream reservoir operates in a similar way to regular hydropower. Except that they are refilled using a water pump and so serve as energy storage as well; The critical distinction is that PHES requires at least one additional, lower reservoir or a large and stable enough river from which to take water for pumping.

Storage(reservoir): This hydropower plant gives reliable energy throughout the year. The large dam built across the river and the substantial amount of area that is inundated when the reservoir is at its highest expected level when the water is stored it be capable of meeting the demand for electricity in the dry season to this kind of hydropower plant is standard in most countries in the world.

2.1.2 Wind power

Wind energy is one renewable energy source. It works by using a wind turbine to generate electricity city. The wind turbine's purpose is to change the kinetic energy that comes from the wind into electric energy by using aerodynamic force from the rotor blades. In the concept of wind power, cool air and warm air have an essential role. The sun shines on the land and the water, and land heats up faster than water. Warm air rise over the land, and cool air over the water moves in. (Energy.gov, n.d.)

Depending on the wind farm's location, there are two types of wind power: onshore and offshore. Even if wind can find everywhere on the Earth, the power of wind power to generate energy is different due to the rotation of Earth, the content of the air, and several physical forces that create a complex weather system, resulting in both geographical, annual, and daily variations of wind. The amount of power that can be collected from wind energy varies depending upon the size of the turbine and the length of its blades; there are two types of wind turbines horizontal and vertical. The most common one is the horizontal turbine.

component of wind turbine

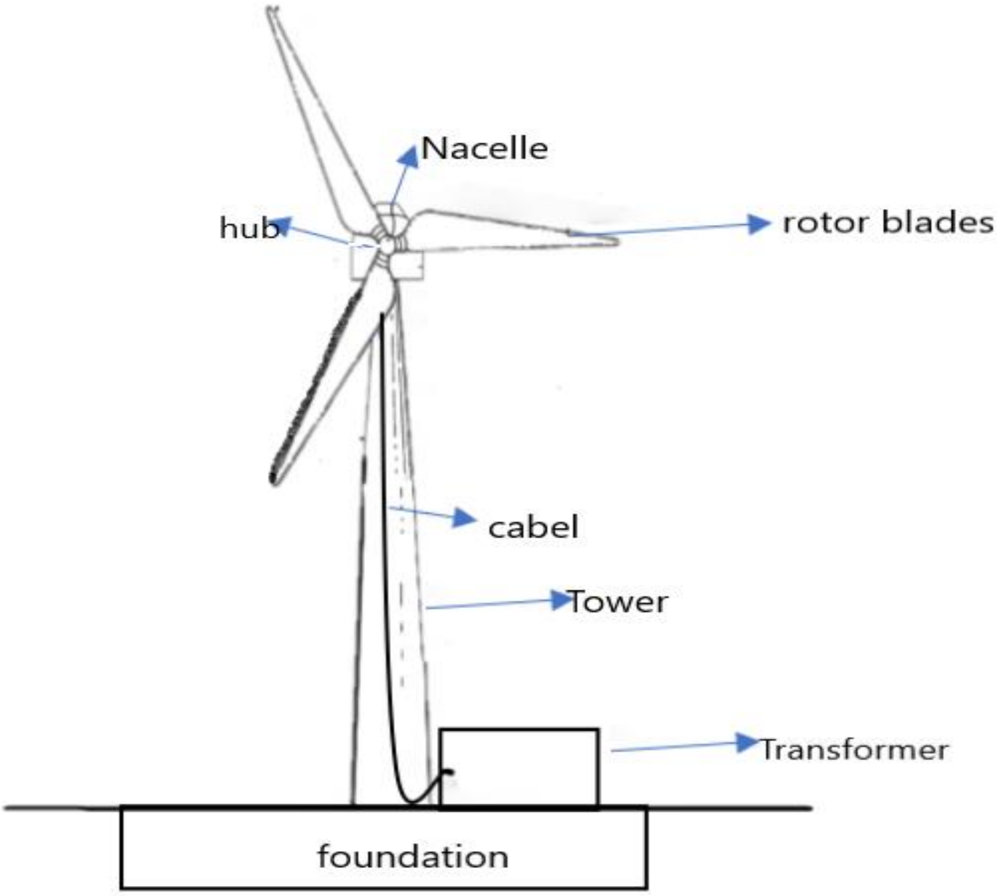


Figure 2-1illustration of the component of wind turbine (self-modified figure)

The production is proportional to the rotor's dimensions and the wind speed cube. Theoretically, when wind speed doubles, wind power potential increases by factor of eight.

2.2 Environmental impact

Environmental impact can be defined as the outcome that takes place due to the implantation of any project that could positively and negatively impact the environment. (Environmental effect, 2005)

2.3 Positive impact

The positive impact of the increasing practice of renewable energy has several benefits among those.

- Renewable resource indicates they will never run out.
- It will be replaced quickly, because it is a natural phenomenon, for example, wind energy, the wind blows regularly, water will always be available.
- the availability of stable energy supply with less price from fossil fuel, and in case of any natural or artificial damage it will be fixed within low maintenance cost comparatively fossil fuel
- Using renewable energy is a healthy choice for human life. This means that the reduced amount of pollution or the toxic substance to the environment deduct the health problems related to the emission of the toxic substance. Non-renewable energy such as natural gas or coal could lead to some health complications in the respiratory organs.
- The renewable energy industry also provides enormous job opportunities to the community and technological innovation.
- Recreation

2.4 Negative impact

Even if renewable energy is the best way of generating electricity with reduced environmental effects, it is still not entirely free from any drawbacks due to the deployment of the project, and the impact is different from one technology to another. This study focuses on hydropower plants and wind farms.

There is a different mechanism to assess the environmental impact of hydropower among those by distinguishing between direct and indirect effects. A direct impact directly causes a change in the nature of the river or a lake and affects ecology, E.g., Hydroelectric dams block migration routes for fish, preventing them from breeding and causing high juvenile mortality rates. However, indirect impacts change the physical or chemical environment and thereby change the quality of the habitats in that river or lake. (Bakken, Atle Harby, Håkon Sundt, & Audun Ruud, 2012).

Hydropower development causes direct and indirect effects through altered habitats and land-use change. The indirect impacts can lead to the weakening of the environmental conditions and biodiversity. The degree of influence varies for small-scale and large hydropower plants. The negative impact of small hydropower plants is comparatively fewer.

Alike hydropower plants, wind farms also affect the environment depending on the location of the wind turbine (onshore or offshore); the following things are the most common type of impacts observed. (Energy Efficiency & Renewable Energy, u.d.)

- Degrade habitats due to deforestation and urbanization; will have a direct impact on wildlife.
- Noise caused by the rotation of the blades
- birds killed because of the collision with wind turbines
- Aesthetics is controversial because people have different perspectives; some people accept the change and connect the idea to science and technological advancement, and others have difficulty taking and enjoying the difference when they see the landscape change. (The Aesthetics of Wind Energy, 2018)
- Land occupation by wind turbines

2.5 Essential terms of the land use analysis

LCA differentiates between land occupation and land transformation. The use of a land area for a particular purpose is characterized as land occupancy.

Land transformation is described as a change in land area to meet the needs of a new occupation process. The degree of modification, the duration of land occupation, and the recoverability of the impacted terrestrial environment all influence recovery to the original state. The period of the occupation process delays the recovery to the actual condition.

As described in the previous section development of hydropower and wind power plants has issues related to land occupation, this could be an underlying cause for the disturbance of local surroundings like landscape change, reduction of vegetational coverage, and damming of areas leading to change in the water-covered area.

This paper's emphasis will be on the land use adynamic, and in chapter five, there will be more discussion about land occupation in the selected case study and findings of the result.

3 Background

3.1 Hydropower in Norway

Hydropower is the primary power supply source for the electric city in Norway. Norway has 20 percent of the hydropower resources, and the system has a high storage capacity. It covers 50 percent of the water reservoirs in Europe; these reservoirs count to around one thousand hydropower reservoirs. Geographically, Norway has enormous potential for hydropower development. Amounts of precipitation, topography, and climate made the country suitable for producing Hydropower. The water stored in reservoirs, and kept for times with high demands, thus storing electricity, is an enormous benefit for the Norwegian electrical supply. Due to the ability to produce electricity at times with high demand through storing water in reservoirs, Hydropower is well-suited with other sources of primary power generation, adding to peak-load generation. Hydropower development has granted raising the country's economic benefit and increased income through job creation, infrastructure, and access to electricity. (EnergyNorway, n.d.)

3.2 Wind power in Norway

Even if the history of generating electricity from wind power has been practiced in recent years, the development of wind farms has increased rapidly. Smøla wind farm is the first wind farm in Norway. The project began operating in 2002 with a 40MW installed capacity. And in recent years, the Investment in wind power has grown significantly. Currently, wind power contributes a large amount of electrical energy to the country. At the start of 2021, there were fifty-three wind farms with an installed capacity of 3 977 MW. This matches about 13.1 TWh in a regular year. In the year 2020, wind power is reported for 6.4 percent of total electricity production in Norway. A sum of 59.3 TWh of wind power was generated in the Nordic area. (energy fact Norway, 2021)

3.3 Study area

3.3.1 Hydro power plants

The study area is in Innlandet and Trøndelag country in Norway. In this study, there are three hydropower plants selected. The three hydropower plants are the existing hydropower projects constructed in 1989 along the Orkla river basin. The Orkla hydropower scheme consists of five power plants. The power plants are Ulset, Litfossen, Brattset, Grana, and Svorkmo, which have an overall installed capacity of 320 MW and a mean annual generation of 1,398 GWh. The power plants were allocated between 1982 and 1985. The power is transferred to the regional 132 kV and 66 kV grid, but this study only focused on Grana, Litfossen, and Brattset hydropower plants. Each power plant has the following installed capacity, respectively 75 MW, 75 MW, and 80 MW. (Torodd, Kjell, & Inge , 2021)

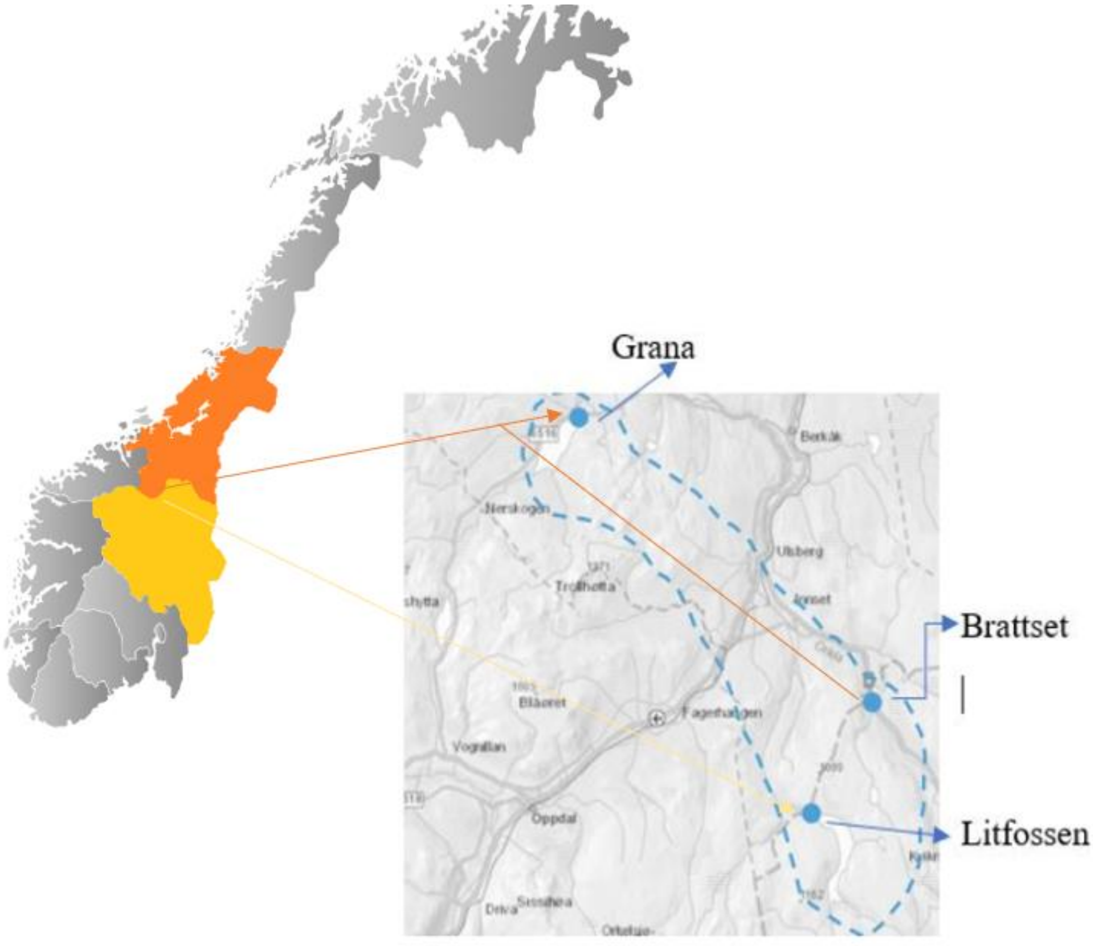


Figure 3-1hydropower plants study area

3.3.2 Wind power plant

The three wind power plants that are studied in this project are in Norway, Geitfjellet, Hitra1and 2 are part of the Fosen onshore wind farm, which is the largest European onshore wind farm and consists of six wind farm projects. Geitfjellet wind farm is in the Trøndelag region in Orkland municipality; it has forty-three turbines and was constructed in very recent time 2018. the installed capacity of this wind farm is around 180 MW, and the height of the tower is an 87-meter Rotor diameter of 136 meters.

Hitra wind farm is in the Trøndelag region in Hitra municipality; it is a two-phase project. The first project, Hitra 1, started operation in 2004 with twenty-four wind turbines and with a total capacity of 55MW. The second phase of this project construction starts in 2018 and contains twenty-six wind turbines with a 93.6 MW installed capacity. The rotor diameter and the tower height are the same as the Geitfjellet wind farm.

Stokkfjellet wind farm is in Selbu municipality, this project consists of 21 turbines, and it has an installed capacity of 88MW.

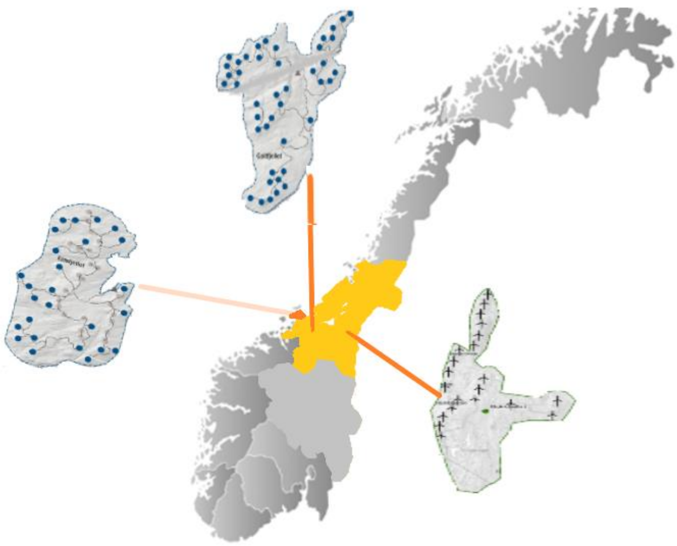


Figure 3-2 study area of wind farm

4 Materials and Methods

This section discusses the techniques, reasons, assumptions for selecting a case study, and procedures adopted in the study area.

Assumptions

The basis for this comparison of environmental impacts of the wind energy and hydropower plant should generate equivalent amounts of power (in MWh) without reflecting other aspects of the energy services offered, such as the extent to which electricity is controlled and supply reliability. Land Use Dynamics on Three Time Steps is used to identify the project's possible direct and indirect impact and to examine the total environmental effect throughout the period.

4.1 Data collection

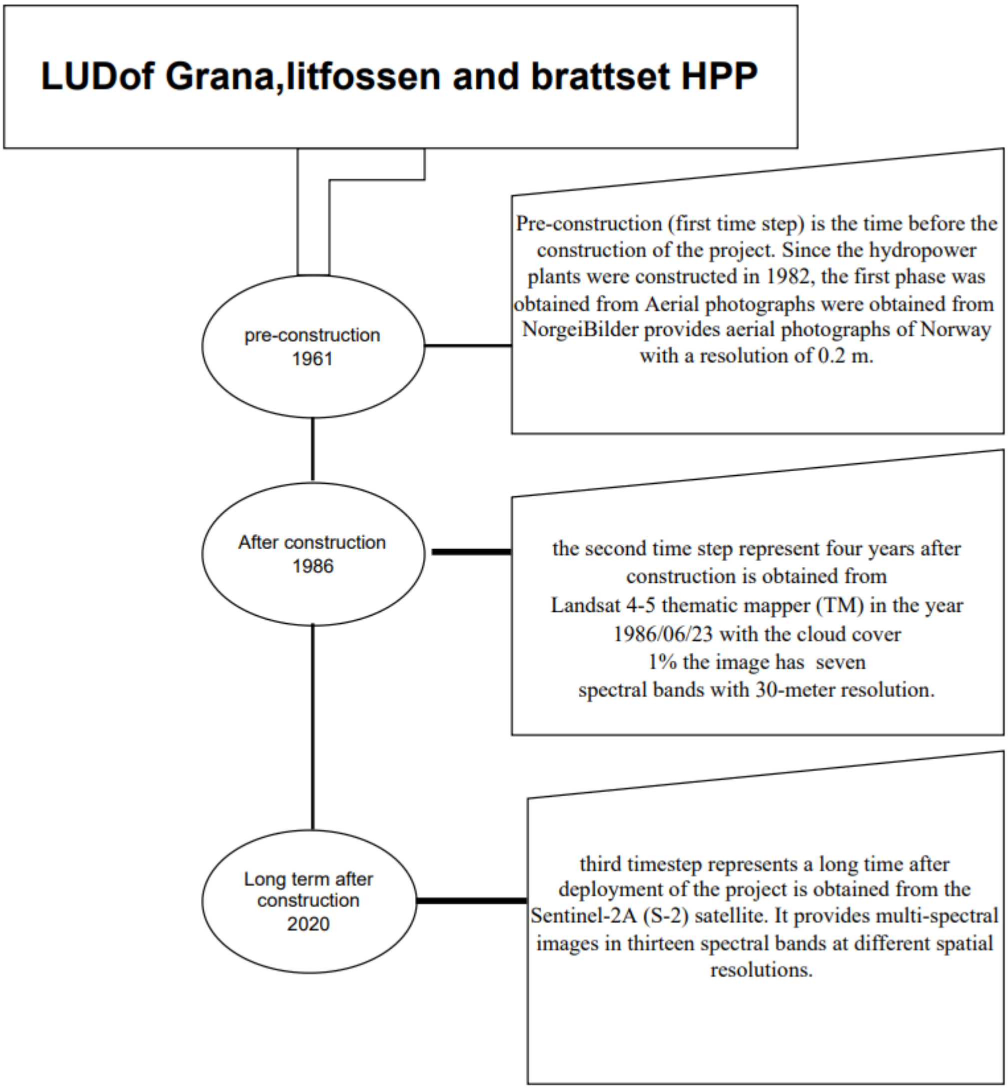


Figure 4-1illustrtion in data collection of hydropower

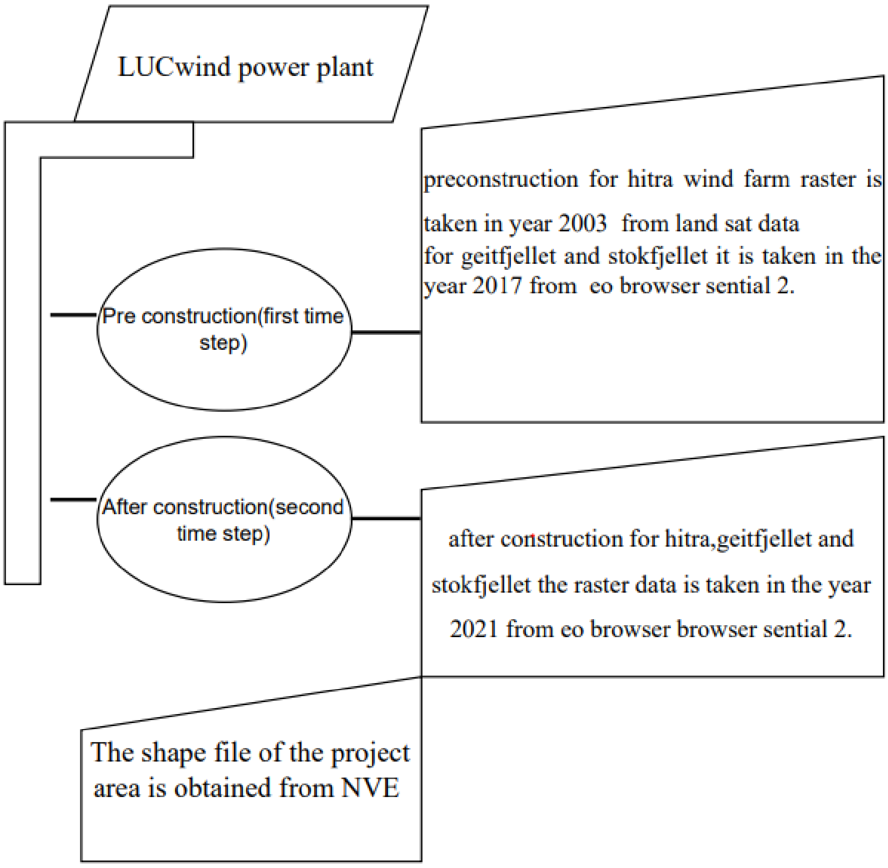


Figure 4-2 illustration in data collection of wind power

4.2 Satellite image Analysis

Esri develops valuable software for performing, managing, analysing, and mapping all types of geographical data. The leading software used in this research to perform the raster image analysis. Arc GIS PRO is the latest version of Arc map 10.3.

The following major steps are conducted to assess the land use land cover analysis of the study area: -

1. **Add satellite image in ArcGIS PRO**

The first thing in this process is downloading TIFF (raster Graphics image) data from the open data source. Before the file is downloaded, the following things should be cheek. Cloud cover is the important thing. It should be below twenty percent, and months of the year since the study's goal is to analyze the land use land cover change the availability of snow will affect recognizing the actual image. So, it must be filtered by months that are free from snow accumulation.

The next step is to add the valuable bands to arc GIS pro and merge the bands together and change the image's appearance by using different band compositions; this is helpful to get the actual color of the ground. The image is obtained from the red, green, and blue bands. Most of the time, band 3, band 2and band 1, in respective order, will represent the actual color of the image or natural color image. Not only is actual color enough to perform the land classification, but the false color is also essential because it allows visualizing near-infrared. The standard composition of false-color composites is band 4, band 3, and band 1 in respective order. Other indices also show the availability of vegetation in the area called (NDVI) and normalized difference water index (NDWI); those also help find the availability of the vegetation and water bodies in the area during sampling to classify data.

$$\mathrm{NDVI} = \frac{\mathrm{B4-B3}}{(\mathrm{B4+B3})},$$

$$\mathrm{NDWI} = \frac{\mathrm{B2-B4}}{\mathrm{B2+B4}}$$

2. **Sampling**

The next step after clear and visible image sampling of the class by using the training sample manager tool, it is one of the tools in image classification that is offered in the image analyst license; it is used to categorize different classification schema even if it has default classification schema since the classification schema in this analysis slightly different from default schema the new classification schema is added. For this five-classification schema more than 20 samples are taken from each class depending on the size of the area, the more class sample will enhance the accurate classification. (esri, n.d.)

Class name		**Description**
	vegetation	All kind of forest including marshlands
	waterbody	Any kind of water body including small ponds
	Urban	Roads, built-up areas
	Agriculture	Cultivated and cropland
	bare land	Exposed rocks,

Table 4-1 level 1 land use classification

3. Classification

Image classification is the main task in the process of finding the accurate land cover of the area. In Arc GIS pro, there are different three-way image classifications, such as manual classification, pixel, and object-based classification; however, in this study, the classification is done by a pixel-based method. In this method, there are two types of classification techniques those are: (Esri)

- Supervised classification
- unsupervised classification

The major difference between these two methods is supervised classification, as the name indicates the image is guided by a person who performs the image analysis or the training sample. In unsupervised classification, the software system analyses without a training sample.

Supervised classification is selected for this analysis, and the image is classified based on the training sample using a Support Vector Machine (SVM); this system is one of the most widely used classifiers, among other five classifiers. This method is chosen because it can classify large images with a smaller amount of error in the case of a variable amount or range of training samples.

After the image classification, the next thing performed in this analysis is pixel editing, which is used to edit the raster classified image; in case of misclassified class or pixel, it is helpful to edit the image**.**

4. Accuracy assessment

After the whole image classification, image improvement is made. Accuracy assessment is continued to check the precision of the classified image. The accuracy assessment tool is one of the crucial techniques to check whether the classified image is precise or not .by using random points from each class; the assessment is done between the classified image value and the actual ground truth. The classified value indicates the output of the classifier or what the results using the classifier show; ground truth reveals as the reference from the original image picked by the person by inspecting the original image by eye and determine what class is. And for the image is considered as accurately classified, the accuracy rate ranges between 1-100%.

If the accuracy rate change range is above 75% is acceptable, and in the case of this image analysis for all time steps, the accuracy rate range reaches between 75 to 99%.

$$\text{Accracy } \% = \frac{\text{truevalue}}{\text{totalsamplevalue}} * 100$$

5. **Area calculation**

After the classification of the image and accuracy assessment, the area calculation is done by using the” Calculate Geometry Attributes” geoprocessing tool to find the area of land cover before Dam Construction for the HPP and before the installation of the wind turbine and repeating the same step for the second and third timestep.

6. **Buffer analysis**

In arc GIS pro, a buffer analysis is performed to determine the indirect influence of the project's deployment to the surrounding area. The buffer analysis tool is used to establish a buffer zone surrounding the reservoir polygon for HPP and the total project area polygon for wind farms; by utilizing this tool and combining it with the python software, the area transformation is analyzed with a 100-meter difference in 1 km total buffer area.

7. **Change dictation**

One of the most basic functions of imaging and remote sensing is change detection. It is the process of comparing various raster datasets, often gathered for the same region at different periods, to assess the kind, amount, and location of change. This application is used in this analysis to compare the area transformation from (first time step to second time step) or vice versa Change dictation is useful method to assess the area transformation and it allow to show to which types of area transformed.

5 Result and discussion

In this chapter, evaluations and comparison of results are discussed regarding the direct and indirect land occupation and land transformation of hydro and wind power plants.

5.1 Direct and indirect LU of HP

The construction of any artificial structure could result in temporary and permanent disturbances of the natural area to different extent depending on the size, purpose, and duration of construction.

Temporary impact area: -these impacts are associated with temporary construction of access roads, storage, diversion work, and clearing of vegetation areas during the construction of the underground waterway. After the construction, these areas will have a chance to return to their previous state. The duration that the area to return to the natural state will depend on the extent of the loss and the type of area.

Permanent impact area: -this type of impact last for extended periods or until the life span of the project, such as dams, intake, waterways, powerhouses, and roads.

The land occupation of hydropower is mainly on the reservoir formed by hydroelectric development; it can vary widely, depending on the size of the hydroelectric generators and the land's topography. (union of concerned scientists, 2013)

Indirect impact area

In the land use context, the indirect impact is defined as an impact on the area surrounding due to indirect influence of the project, such as urbanization and deforestation; this idea could be related to the Non-invasive nature area, and it is also used to check the habitat degradation. The area is protected from artificial activities. Invasion-near areas are less than one kilometre from heavier technical installations. So, in this study, I tried to assess the impact of the hydropower reservoir and project area of the wind farm with the one-kilometre buffer zone.

5.1.1 Grana hydro power plant

Grana HPP has an underground powerhouse and underground waterway; since these structures are under the surface, they are not included in the analysis. Granasjøen Reservoir is a man-made lake that covers an area of approximately 6,64 km^2 with a volume of 144Mill. M^3 figure 5-2 shows the land-use change of Granasjøen reservoir indifferent time step.

Figure 5-1lay out of grana hydropower plant from (NVEAtlas)

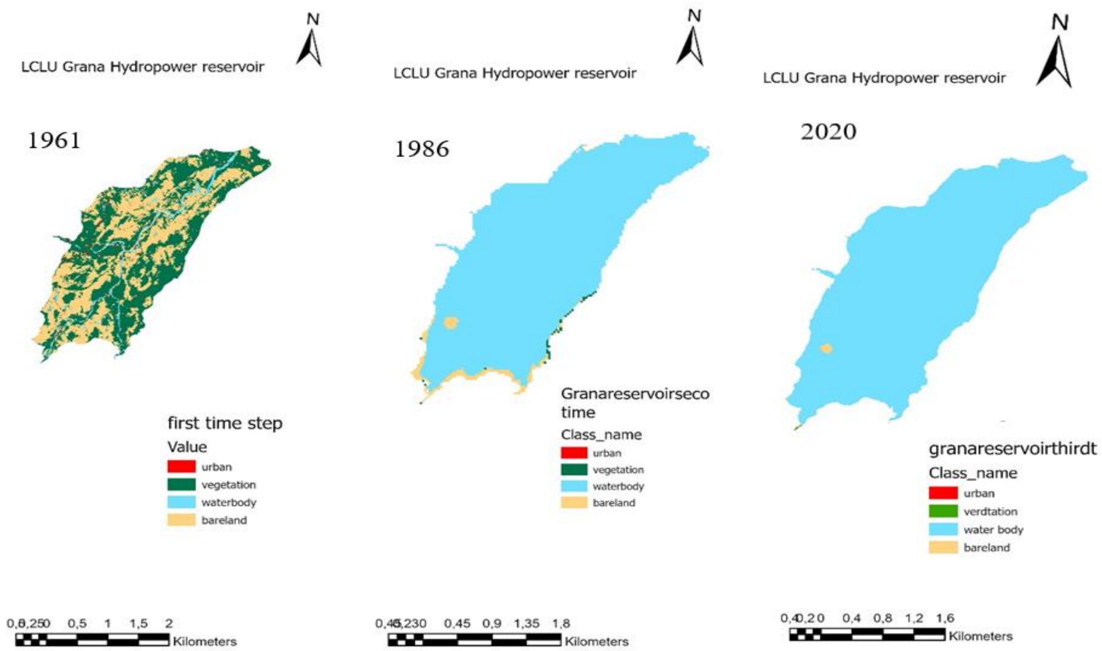


Figure 5-2 LCA Granasjøen reservoir

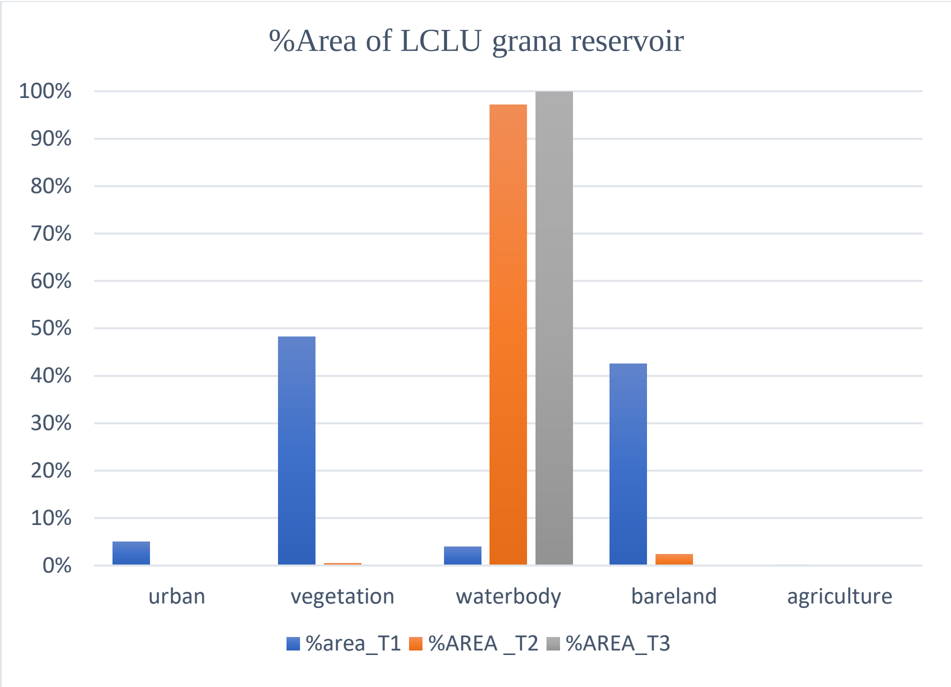


Figure 5-3percentage area of grana reservoir

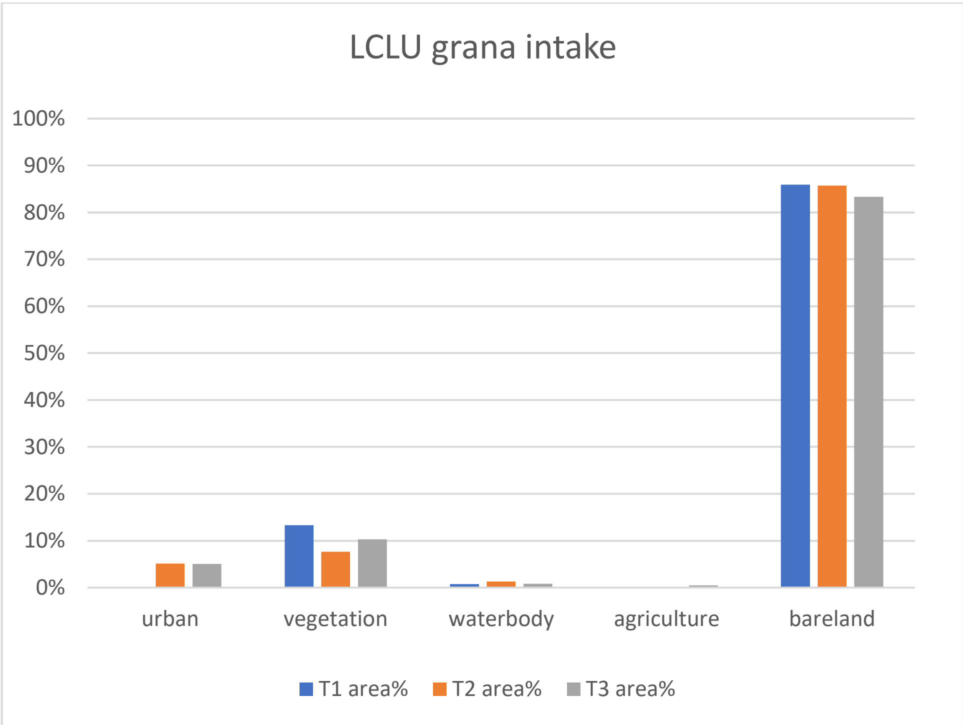


Figure 5-4percentage area of LCLU grana intake

Land Use transformation of reservoir and intake area

This reservoir area is identified in five classifications as described in Chapter 2. In the first time step the area was covered by vegetation it is about 48%, and the bare land covers around 42%of the total area and the percentage area of water body, urban and agriculture covers below 10% this shows deforestation is the main impact on the area

in the second and the third step, the general area is inundated by water; thus, 100% of the area is a water body.

Grana has three intakes, and the direct impact observed in this area is only due to the construction of the access road and the intake dam.

In the first-time step, the area did not have urban and agricultural areas; the area was covered dominantly by bare land and 12% vegetation.

The total change of the area in the intake is insignificant in all three-time steps; more than 80% of the site is still bare land.

Indirect impact area

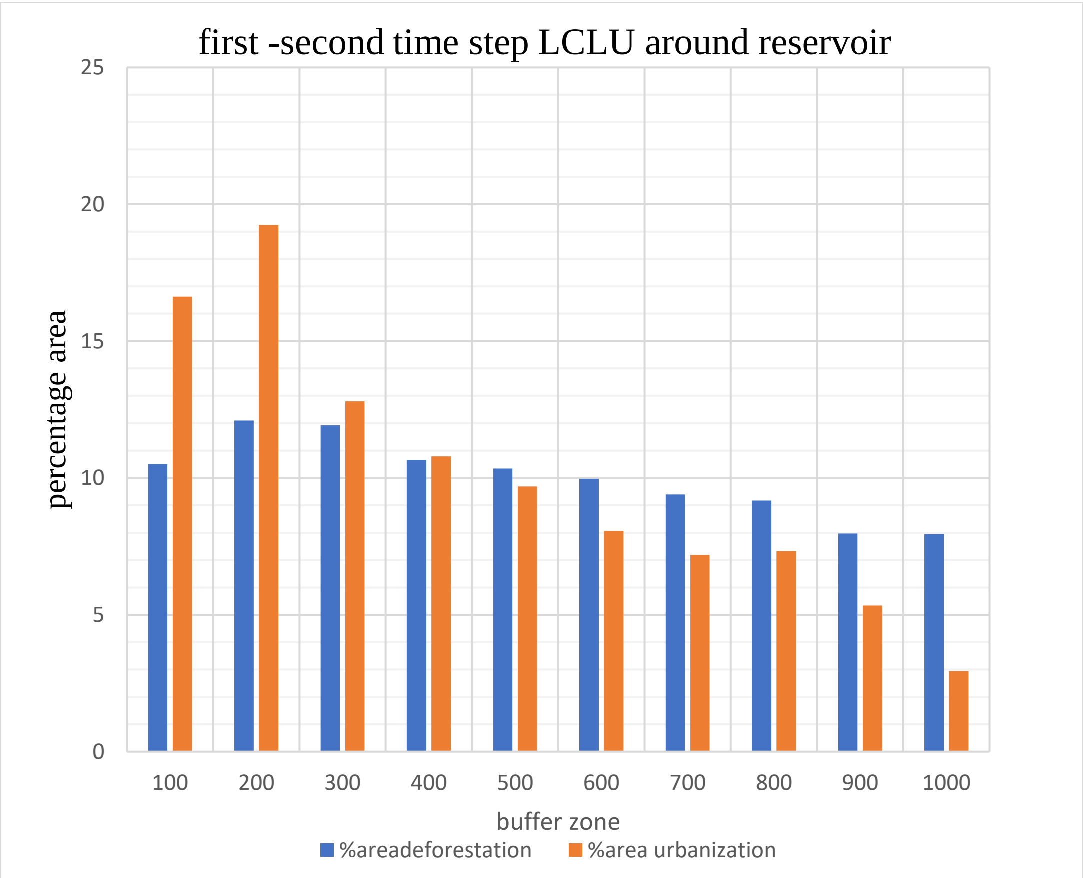


Figure 5-5 change of LU T1-T2 of around grana reservoir

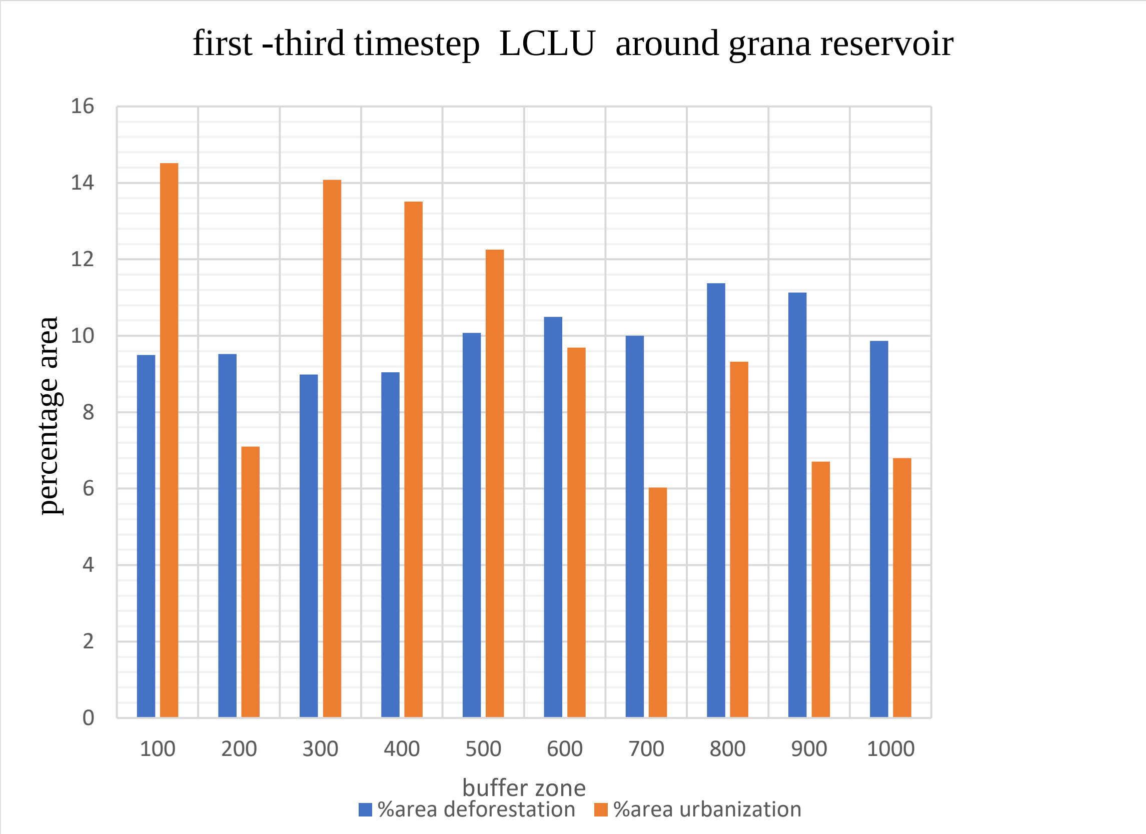


Figure 5-6change of LU T1-T3 of around grana reservoir

Figure 5-4 and figure 5-6 illustrate the result of the surrounding area of Granasjøen reservoir, area change from 1961 to 1986 and 1961-2021, respectively

Overall area difference

According to the results, the area of vegetation around the reservoir is getting reduced in the second time step; this could be the reason because of construction work around the reservoir cause damage, and the vegetation of the area get an increase in the third time step; this result explains after a long term the nature rehabilitated back.

NAME	URBAN	VEGETATION	WATERBODY	AGRICULTURE	BARE LAND
LCLU1961	0,070424137	9,229069674	0,188745685	0,293728472	6,647135871
LCLU1986	1,0053	7,8255	0,0234	1,8567	5,7177
LCLU 2021	0,072469916	9,219987804	0,182399153	0,292512365	6,667611677
T2-T1	0,9348758 63	1,403569674	0,165345685	1,562971528	0,929435871
T1-T3	0,002045779	0,009081871	0,006346532	0,001216107	0,020475806
T2-T3	0,932830084	1,394487804	0,158999153	1,564187635	0,949911677

Table 5-1 the overall area changes of around grana reservoir

5.1.2 Litfossen and brattset

Litfossen HP plant has an artificial reservoir formed by constructing a rockfill dam with a moraine core; the reservoir is known as Innerdalen, its volume is 153 Mill m3, and the primary intake is in the upper berth of the Orkla River. The power station and the waterways are underground; the headrace tunnel is 7,450 meters long, and the tailrace tunnel that is 90 meters in length. So, powerhouses and waterways are not included in the direct impact assessment. The direct impact of Litfossen is only because of the reservoir.

The connection between the Litfossen and Brattset power plants is due to the fact that after the Litfossen power plant generates electricity, the water flows to the Storfoss pond, which serves as an intake reservoir for the Brattset power plant, with a volume of 1.7 Millm3, even though the Brattset is run off the river or has seasonal storage. The system has the benefit of drawing water from the Innerdalen reservoir and having a larger installed capacity than any other hydroelectric plant in the Orkla river basin. (Torodd, Kjell, & Inge , 2021)

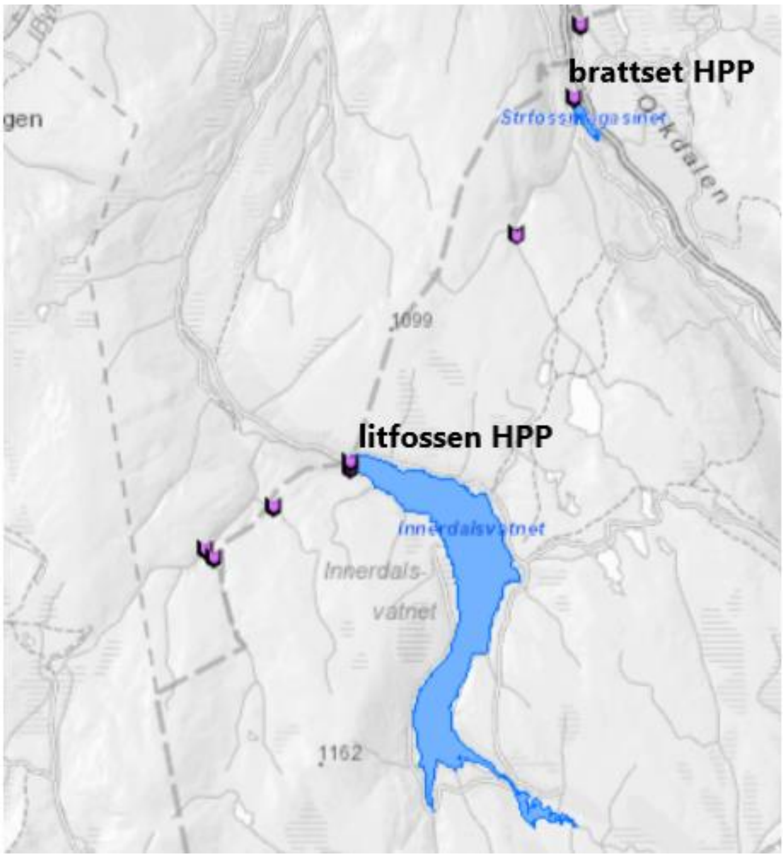


Figure 5-7ay out of Litfossen hydropower plant from (NVEAtlas)

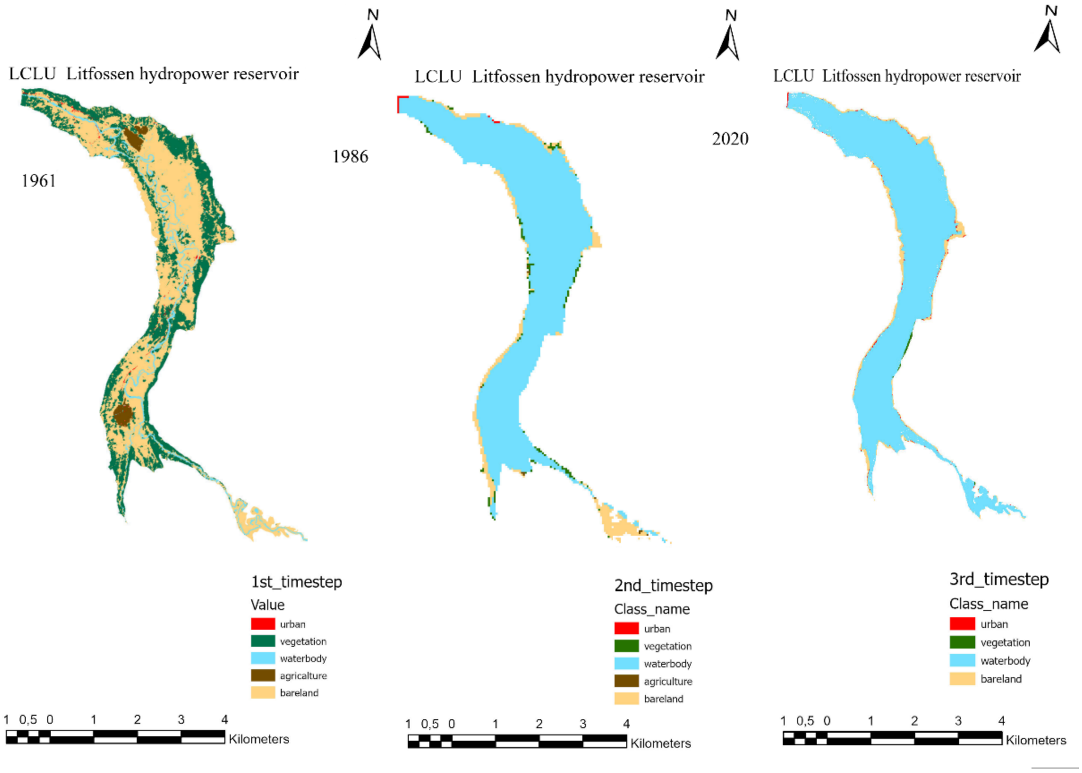


Figure 5-8Innerdalsvatnet reservoir

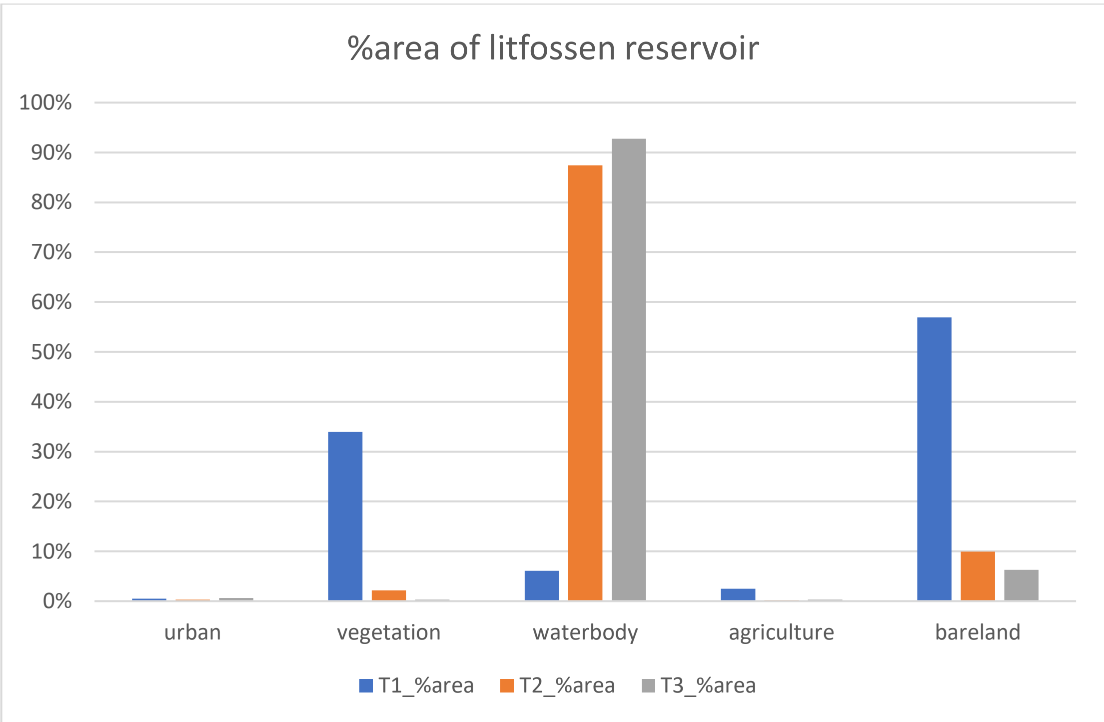


Figure 5-9 percentage area of Litfossen reservoir

Land Use Composition

Figure5-9 illustrates the percentage area of Litfossen in three-time steps; in the first-time step, vegetation-covered 34% of the area, bare land covered roughly 55% of the total area, and water bodies, urban areas, and agricultural covered less than 10%. This demonstrates that deforestation has had the most significant impact on the area; in the second time step, approximately 10% of the area is bare land; this may be the reason that the reservoir does not reach its total capacity; however, in the third time step, the entire area is inundated by water; nearly 100% of the site is water body.

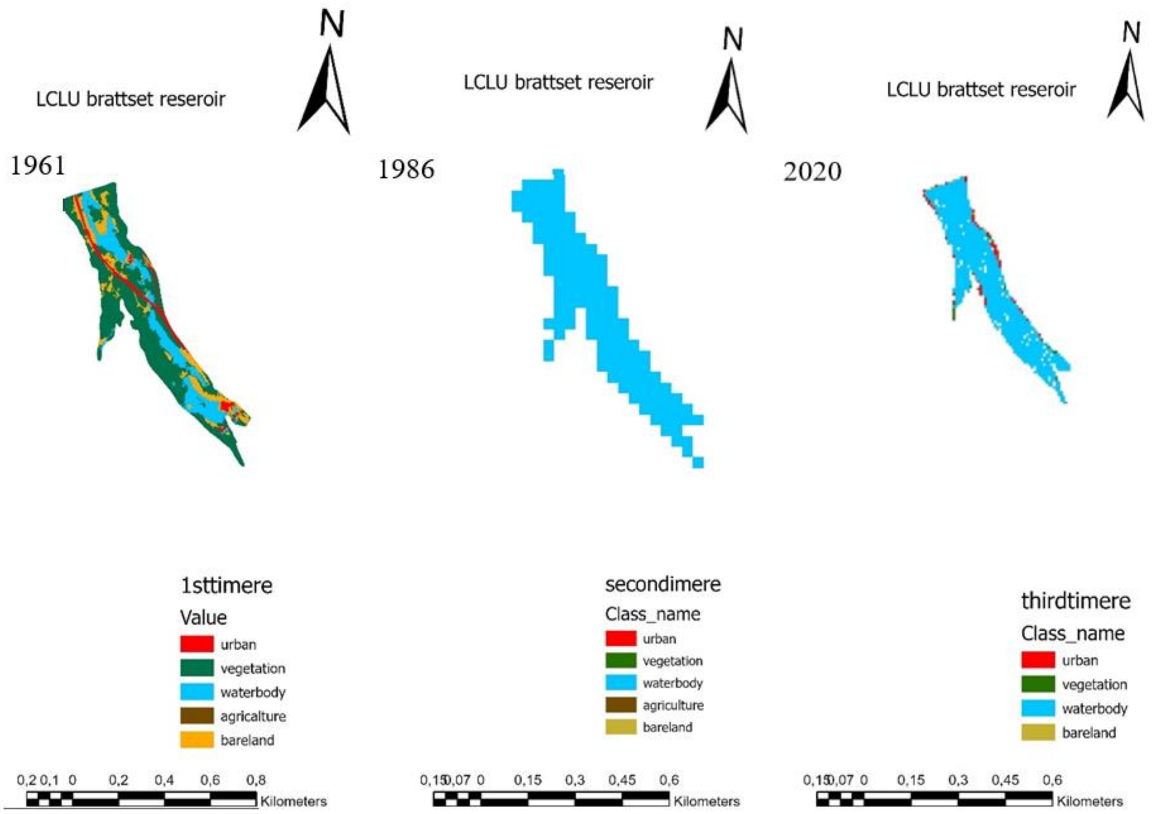


Figure 5-10 LCA Strfossmagasinet reservoir

Indirect impact area

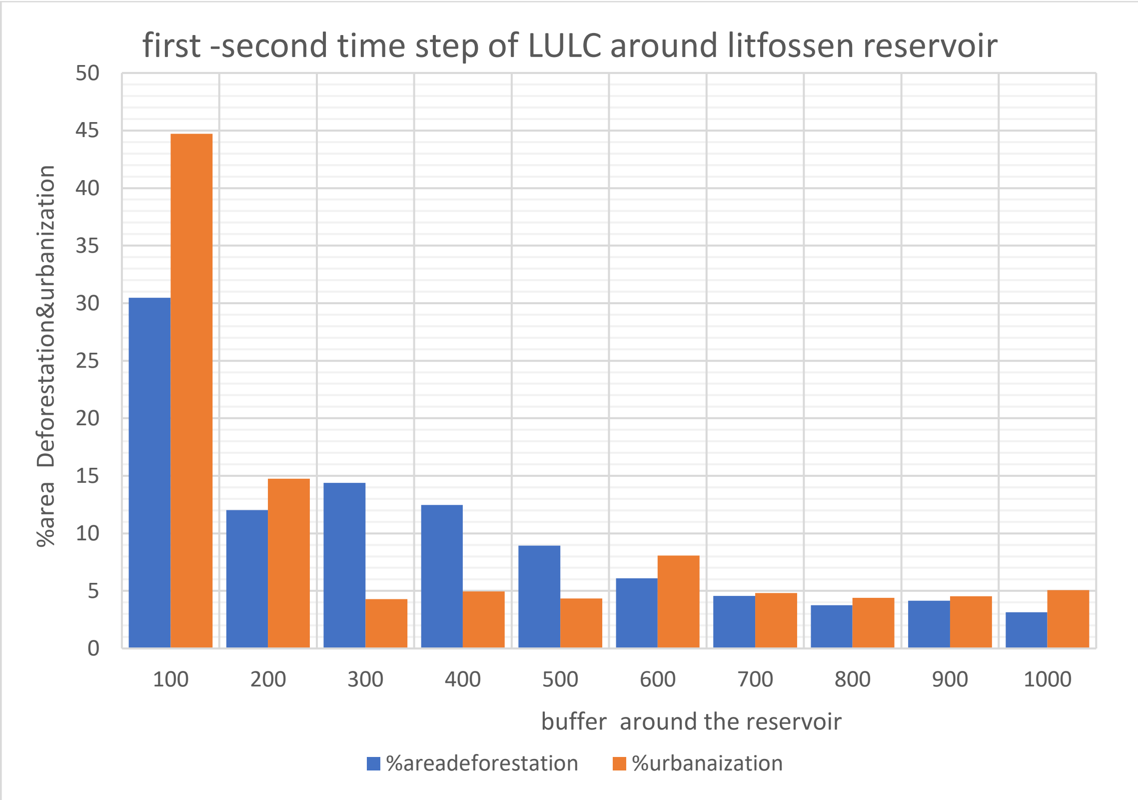


Figure 5-11 change of LU T1-T2 of around nnerdalsvatne reservoir

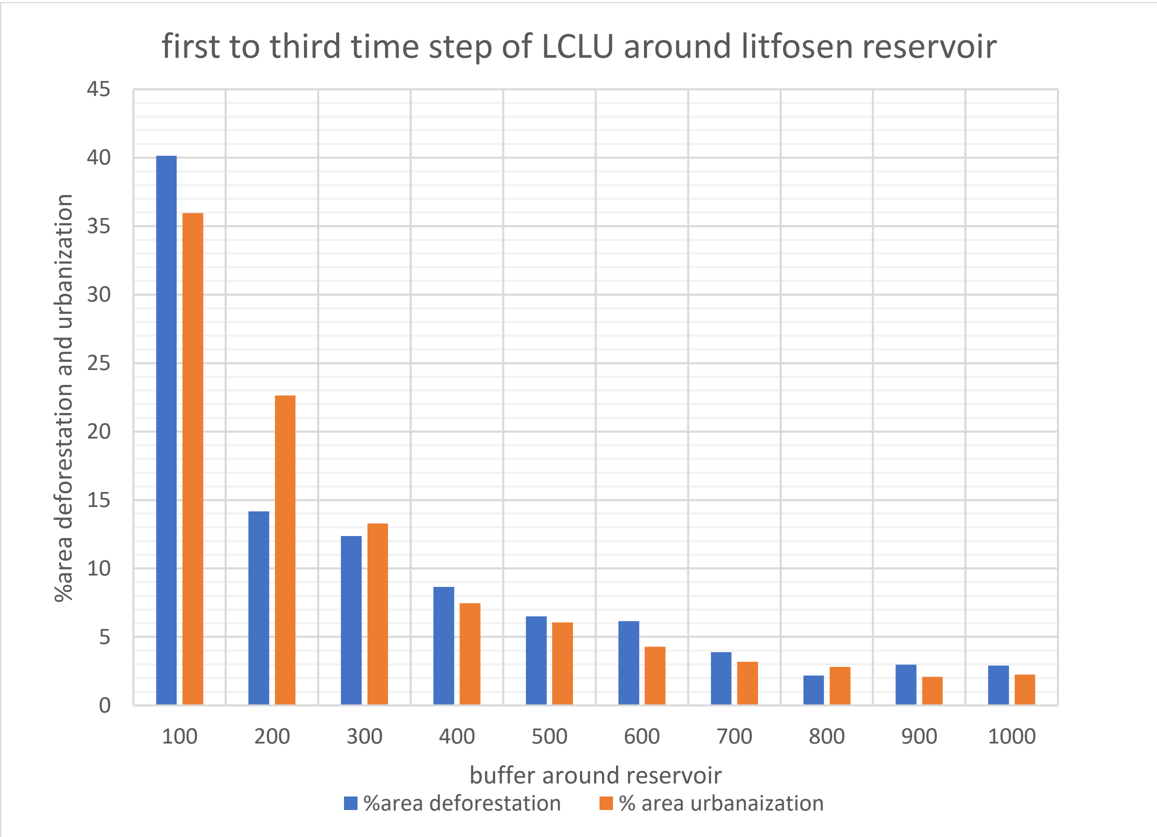


Figure 5-12change of LU T1-T3 of around nnerdalsvatne reservoir

The land use in the region surrounding Litfossen changed because of the dam's construction. The results indicate that the vegetation around the reservoir is deteriorating in the second time step because of damage from the dam's construction, but the area is not returning to its natural state after a considerable amount of time or when it checked in long term evaluation, as the results indicate the area within 100 to 300 meters of the reservoir as the region becomes more urbanized and deforested.

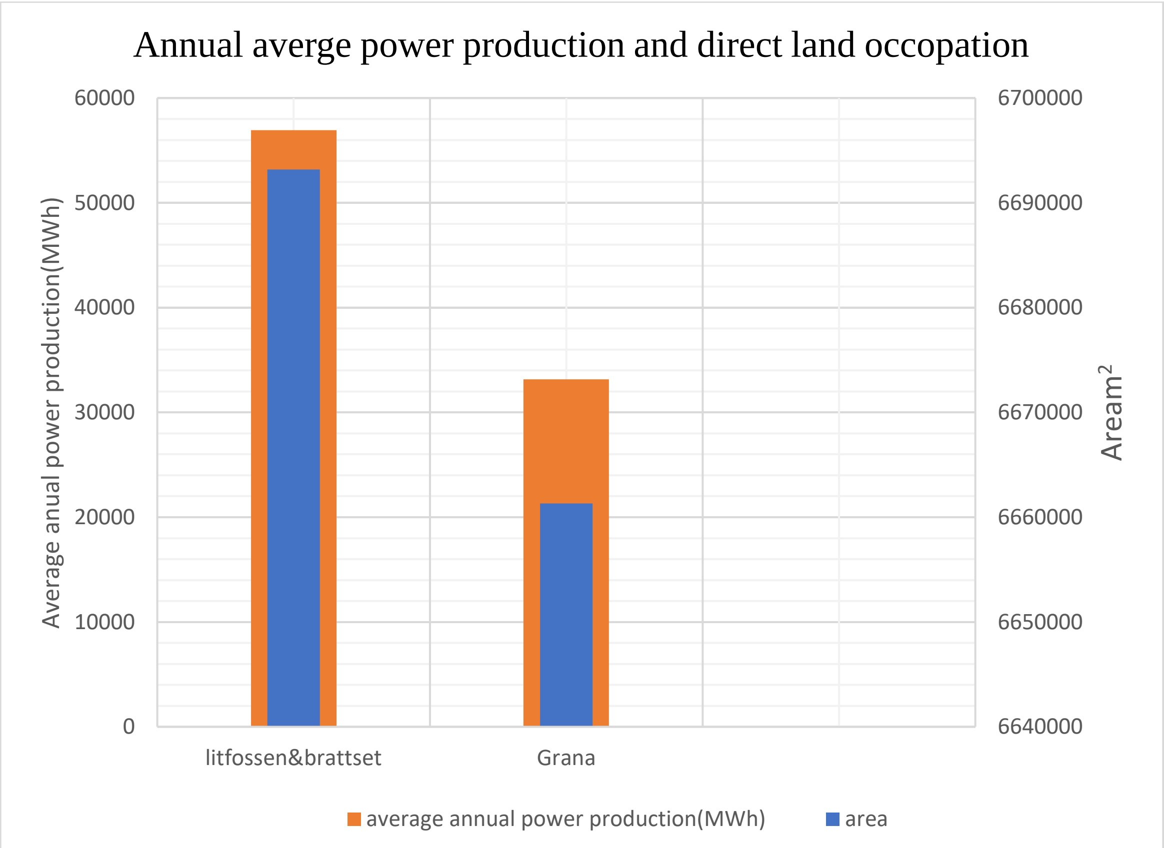


Figure 5-13annual average power production & land occupation of HPP

Litfossen and brattset are used as the combined system in evaluating direct land occupancy of hydropower. Because brattset is run on river hydropower and only has small storage, but it benefits from the upstream Litfossen reservoir and produces more electricity than Litfossen, considering brattset intake small pond as its solitary direct impact will misrepresent the actual effect, so the direct land occupation of Litfossen and brattset are merged as one system. So compared to the Grana hydropower plant, the two combined systems take a large area and produce more electric power.

Summary of indirect impact area of hydropower

The result obtained after the evaluation of the indirect impact assessment of the surrounding area of all the selected hydropower reservoirs the percentage area of urbanization and deforestation is below 50%, depending on the distance from the reservoir; the magnitude of effects is different. The more it gets closer to the reservoir, less than 500m there is deforestation observed, and urbanization due to the construction of access road for the dam the far we go from 500-1000m the change is insignificant.

5.2 Wind power plant

The land occupied by wind power plants is due to the following structures

- turbine pads
- access roads
- substations
- service buildings, and other structures

During the construction of the structure listed above, the land must be clear around each turbine. While land change around a turbine pad and roads, this alteration represents a potentially substantial degradation in ecosystem quality.

A wind farm's land occupation depends on the size and number of wind turbines. The number of wind turbines that will be installed will depend on the nominal power for each wind turbine. It is calculated that the nominal performance for each wind turbine will be between 2 and 4 MW. Larger turbines usually involve a greater distance between the turbines and thus a relatively less direct land use. In general, larger turbines will require less road. (impact assesment of hitra2, 2010)

Direct impact area

Wind turbine pads, access roads, substations, and other facilities that physically occupy land space are considered the direct impact of the wind farm.

Total impact area

The direct impact of the wind farm is measured in terms of the overall area of the wind farm, which is designated in project documentation as "project area, border." This region is not generally defined and is frequently determined by the individual project developer; this will vary amongst developers.

Indirect impact area

This is the 1 km buffer around the project boundary considered to evaluate the influence of the wind farm on the surrounding neighbourhood.

5.2.1 Getfjellet wind power plant

In Geitfjellet wind farms the direct impact

Estimated land use (UTBYGGINGSPLANENgetfjellet, 2010)

Direct impact	Area in km^2
Internal and access roads	0.466
Wind turbine and assembly sites	0.053
Transformer station and service building	0.002
Total	0.521

Table 5-2 Estimated land use

Direct impacts are internal and access road, wind turbines and assembly, transformers

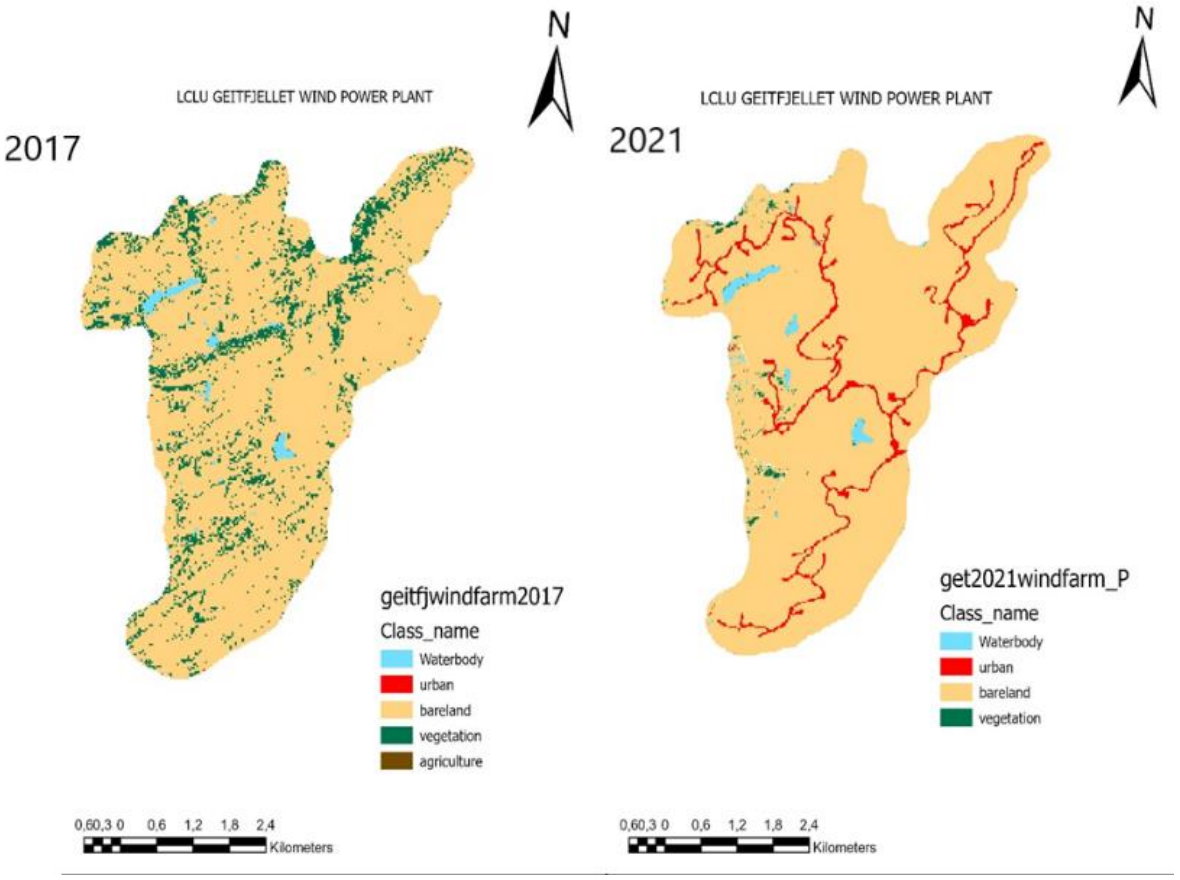


Figure 5-14LCA geitfjellet wind farm

		geitfjellet T1-T2windfarm				
	urban	vegetation	waterbody	Berland	Agricultural	total area(km^2)
T1_2017	0.01	3.15	0.35	21.80	0.00	25.3
T2_2021	1.35	0.30	0.35	23.27	0.00	25.3
difference	1.34	2.85	0.00	1.47	0.00	

Table 5-3 direct LU change of geitfjellet wind farm

Indirect impact

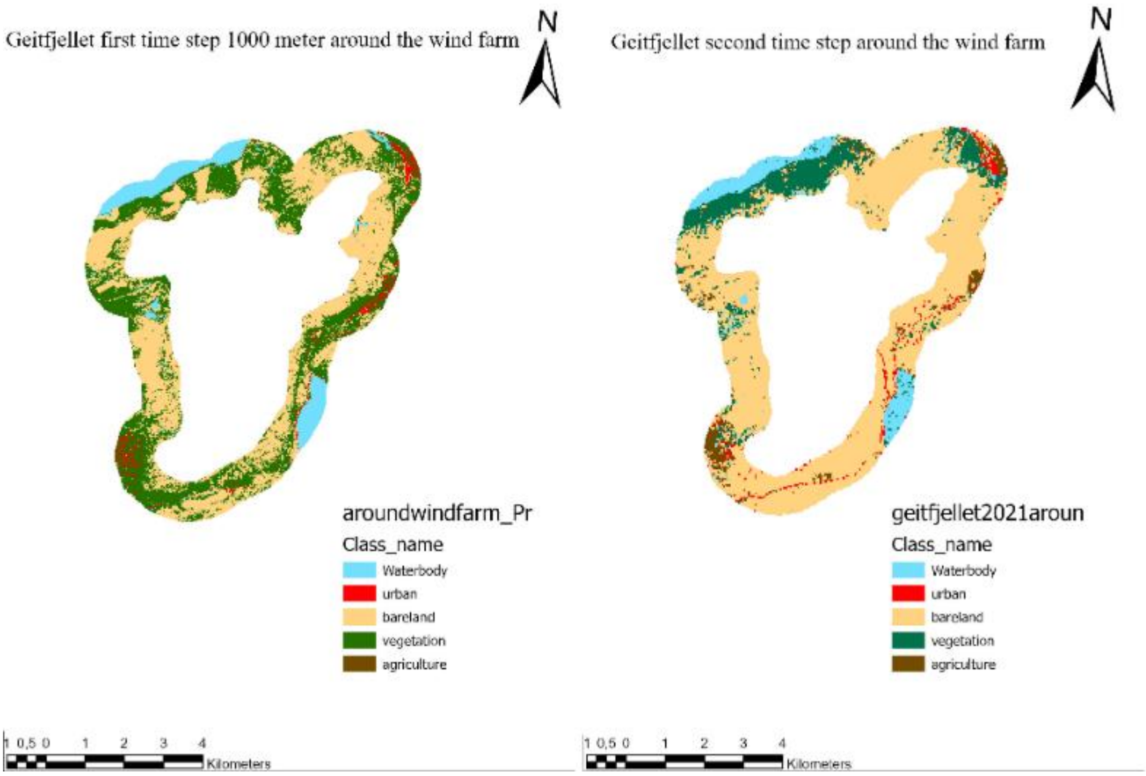


Figure 5-15LCA around geitfjellet wind farm

geitfjellet T1-T2 1000m around Wind farm						
	urban	vegetation	waterbody	Bare land	Agricultural	total area(km^2)
T1_2017	0.60	11.39	2.5	14.44	0.54	29.5
T2_2021	0.80	4.12	2.5	20.67	1.4	29.5
Difference	0.19	7.27	0.0	6.23	0.89	

Table 5-4geitfjellet indirect impact

5.2.2 Stokkfjellet

Direct impact

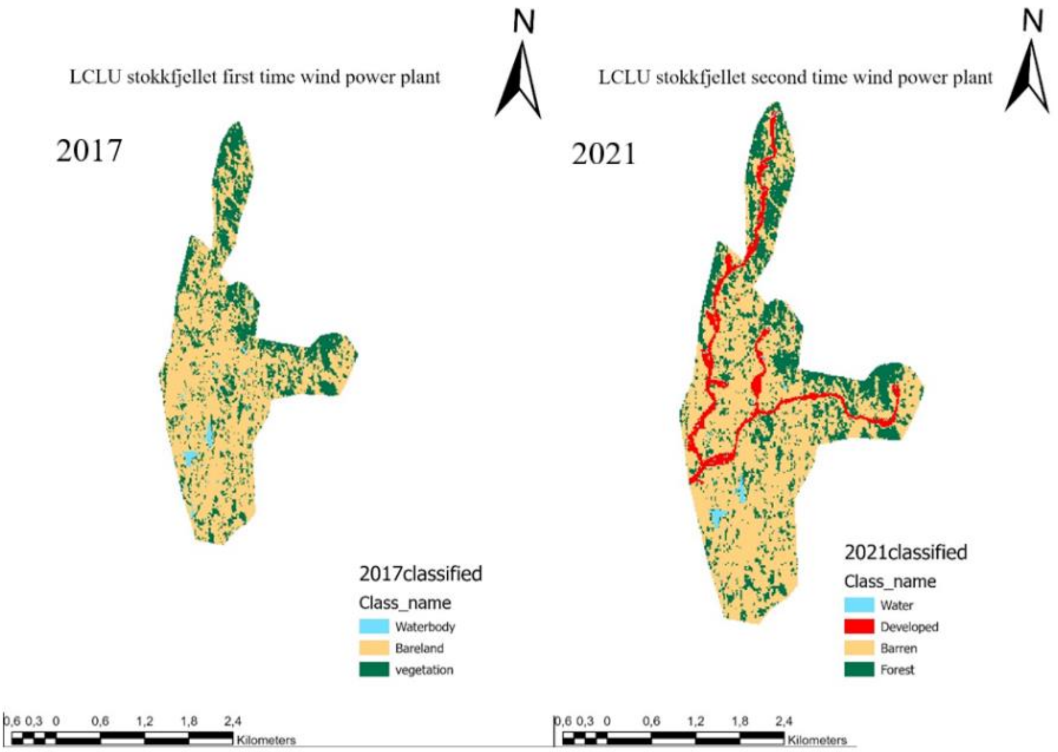


Figure 5-16LCA stokkfjellet windfarm

Stokkfjellet T1-T2windfarm						
	urban	vegetation	Waterbody	bare land	agriculture	total
T1_2017	0.00	1.660102	0.075615	4.037438	0.00	5.8
T2_2021	0.463974	1.506856	0.055653	3.746874	0.00	5.8
diff	0.46	-0.15	-0.02	-0.29	0.00	

Table 5-5 direct impact of Stokkfjellet windfarm

In Direct impact

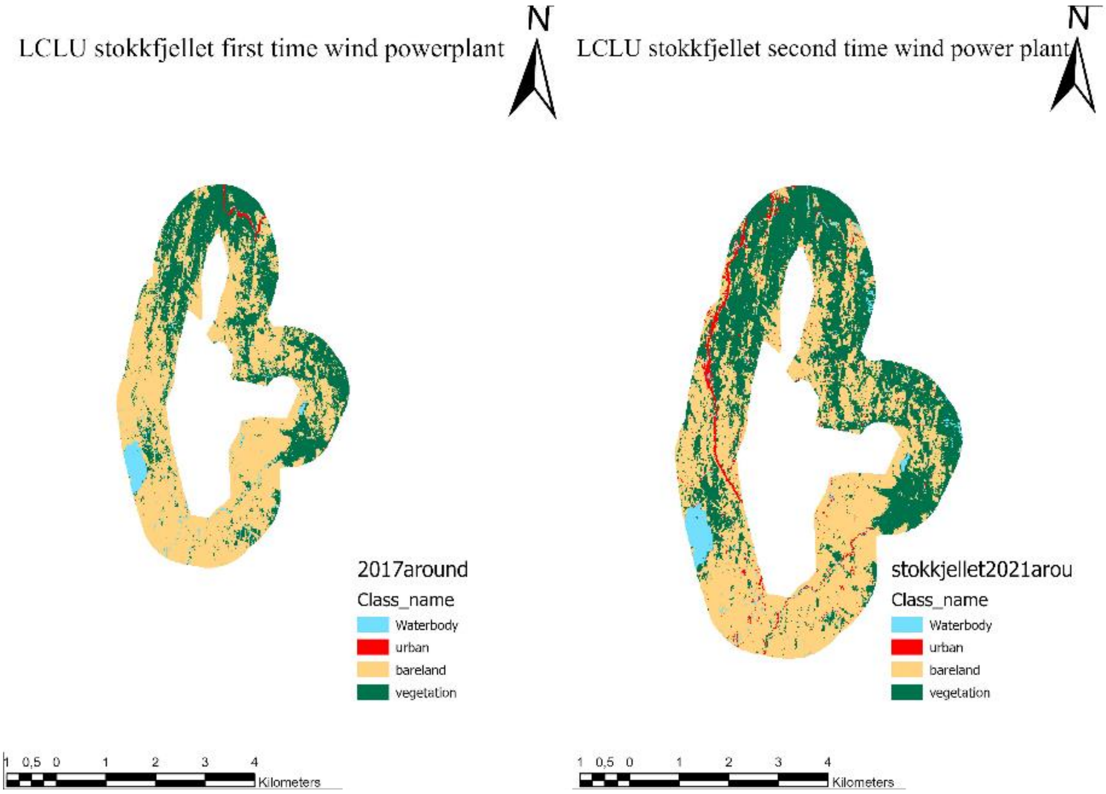


Figure 5-17LCA around of Stokkfjellet wind farm

stokfjellet T1-T2 1000m around windfarm						
	urban	vegetation	waterbody	bare land	Agricultural	Total area km^2
T1_2017	0.07864	5.87216	0.630327	11.059954	0.00	17.6
T2_2021	0.523861	7.254402	0.56802	9.276247	0.00	17.6
diff	0.45	1.38	-0.06	-1.78	0.00	

Figure 5-18 indirect impact of Stokkfjellet wind farm

5.2.3 Hitra 1 and 2

Direct impact

The Hitra wind farm will be built in two phases, according to the project land use report. A zoning plan governs the existing Hitra 1 wind farm. The zoning plan's boundaries cover a larger area than the direct area occupancy (direct land use). Hitra 2 is defined as primary direct land occupation. The estimated land use for Hitra2 is shown in the table below. (impact assesment of hitra2, 2010)

Direct impact	Area in km^2
Internal and access roads	0.134
Wind turbine and assembly sites	0.044
Transformer station and service building	0.0025
Total	0.1405

Table 5-6 estimated land use of hitra2

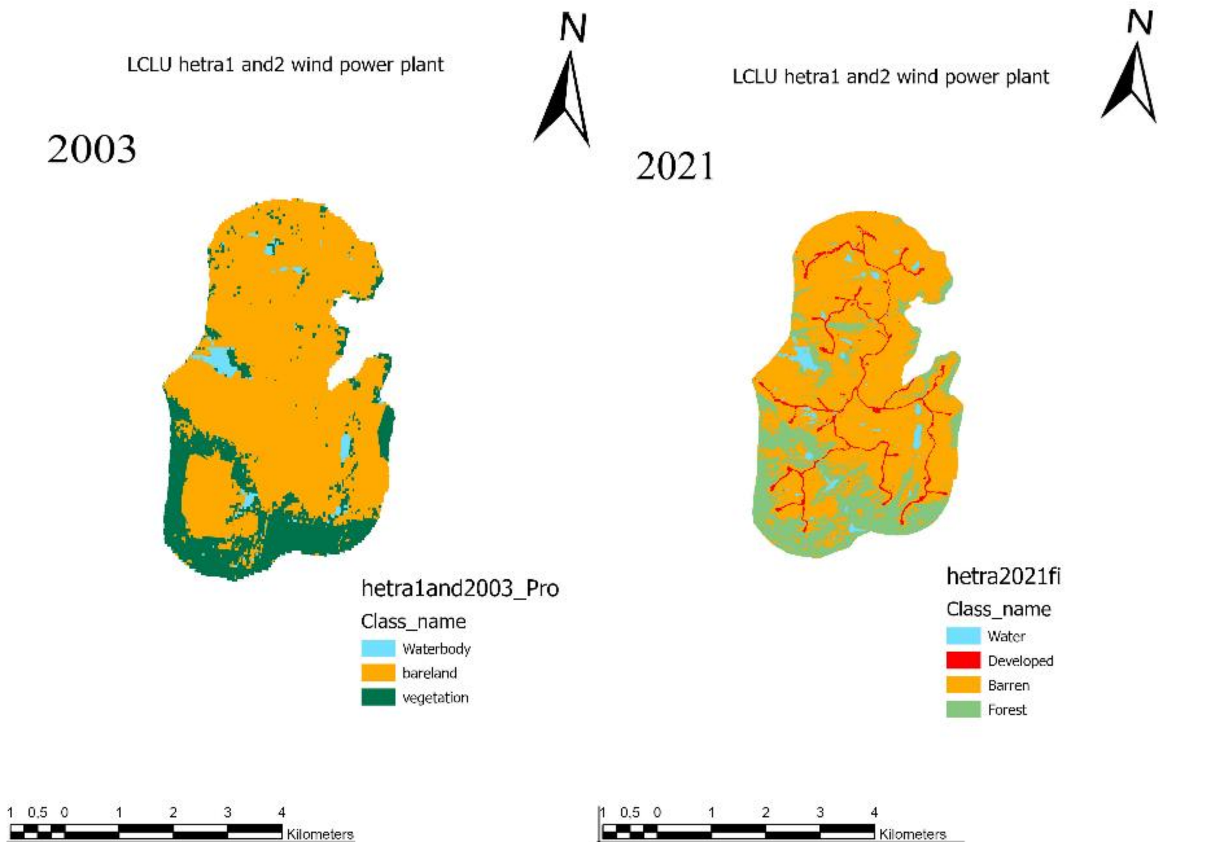


Figure 5-19LCA of hitra1 and hitra2 wind farm

hetra1and hetra2 T1-T2windfarm						
	urban	vegetation	waterbody	bare land	Agricultural	total
T1_2003	0.00	3.80	0.41	13.4	0.00	17.6
T2_2021	0.74	3.96	0.4	12.5	0.00	17.6
difference	0.74	0.16	0.04	-0.93	0.00	

Table 5-7 direct impact of Hitra wind farm

Indirect impact

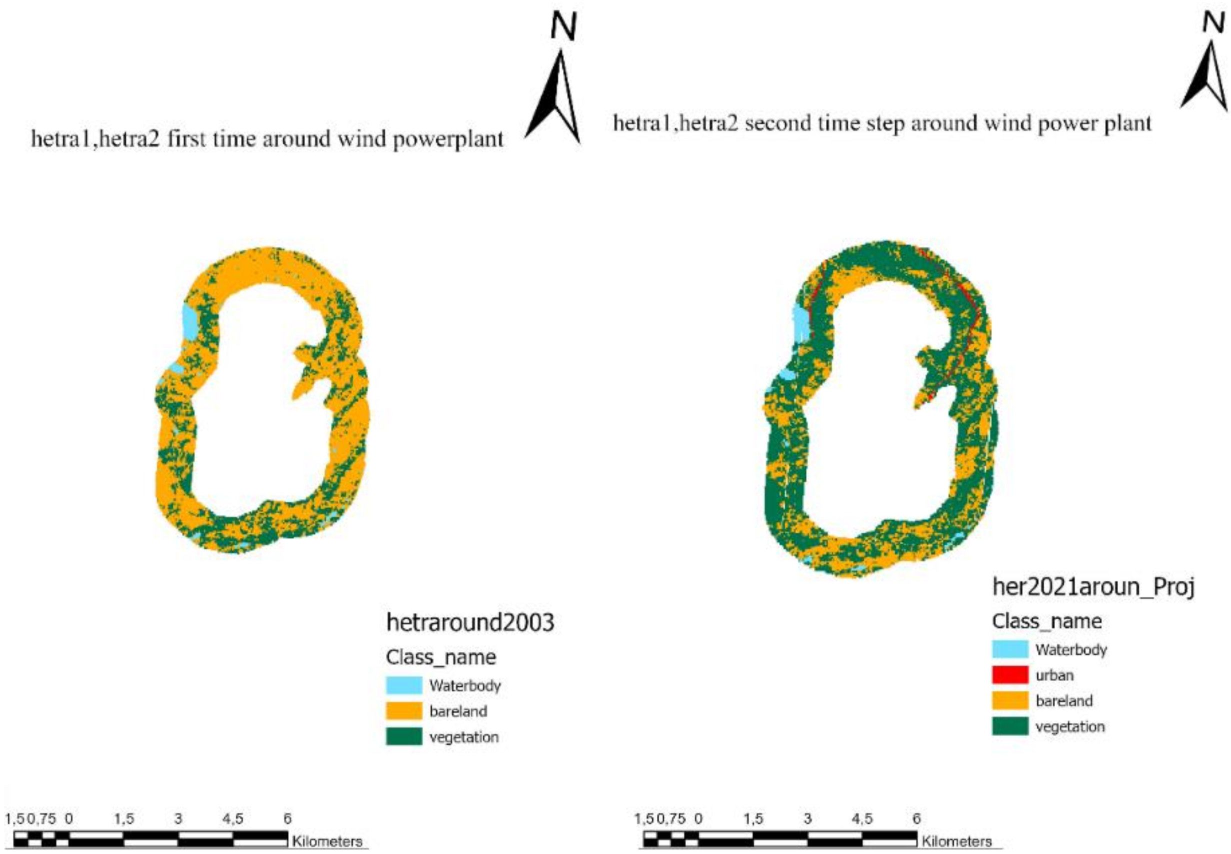


Figure 5-20LCA around hitra1&hitra2 wind farm

hetra1 and hetra2 1000m T1-T2 around windfarm

	urban	vegetation	waterbody	bare land	agriculture	total
T1	0.0	5.764	0.6834	13.8837	0.0	20.3
T2	0.2612	12.4	0.6	6.8845	00	20.3
difference	0.26	6.64	0.08	7.00	0.00	

Table 5-8indirect LU change of hitra1&2 wind farm

The total impact area is not included as the direct impact area but the general land use change of the selected wind farm is showed below.

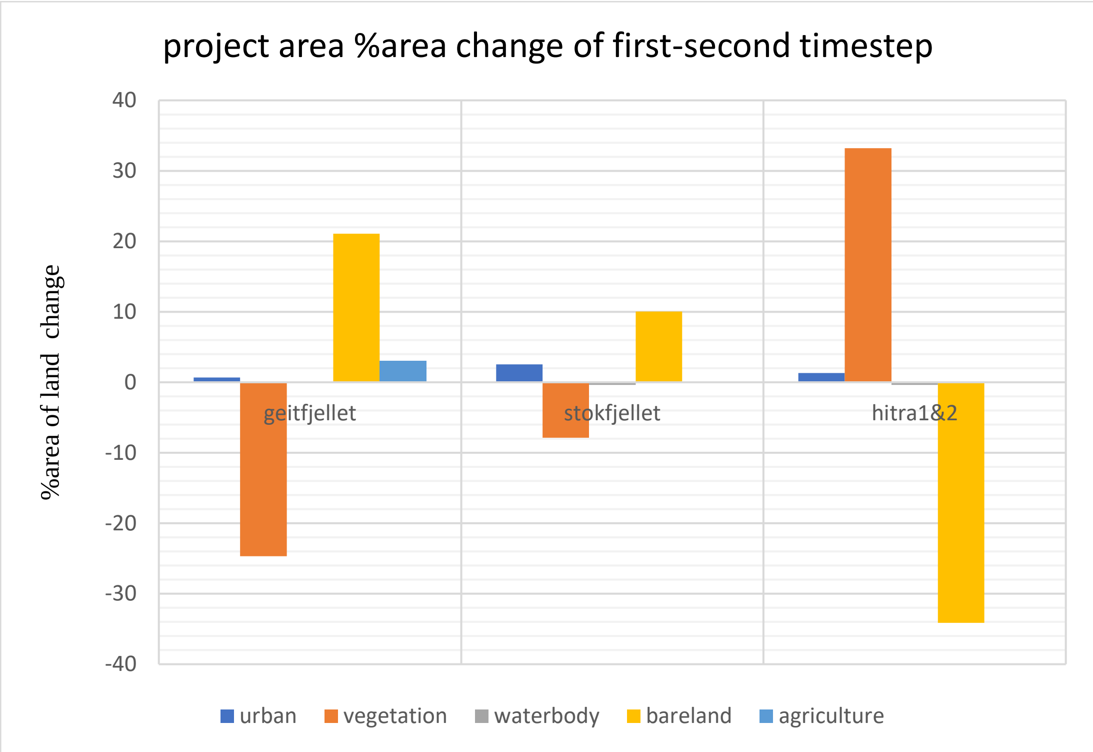


Figure 5-21 percentage area changes of WPP project area

In the assessment of wind energy, the result indicates that most direct impacts are associated with roads, turbine areas, and substations and the urban area, the estimated land use for Geitfjellet and Hitra 2 wind farm is underestimated in the project plan. so, the direct land occupation for this project is taken from calculated area.

The graph below shows the land use per annual average production; the site shown in this graph does not include the general project area, only land occupation of the sum of road, turbine station, and other facilities related to the wind farm. According to the result, geitfjellet higher land occupation and highest average annual power production.

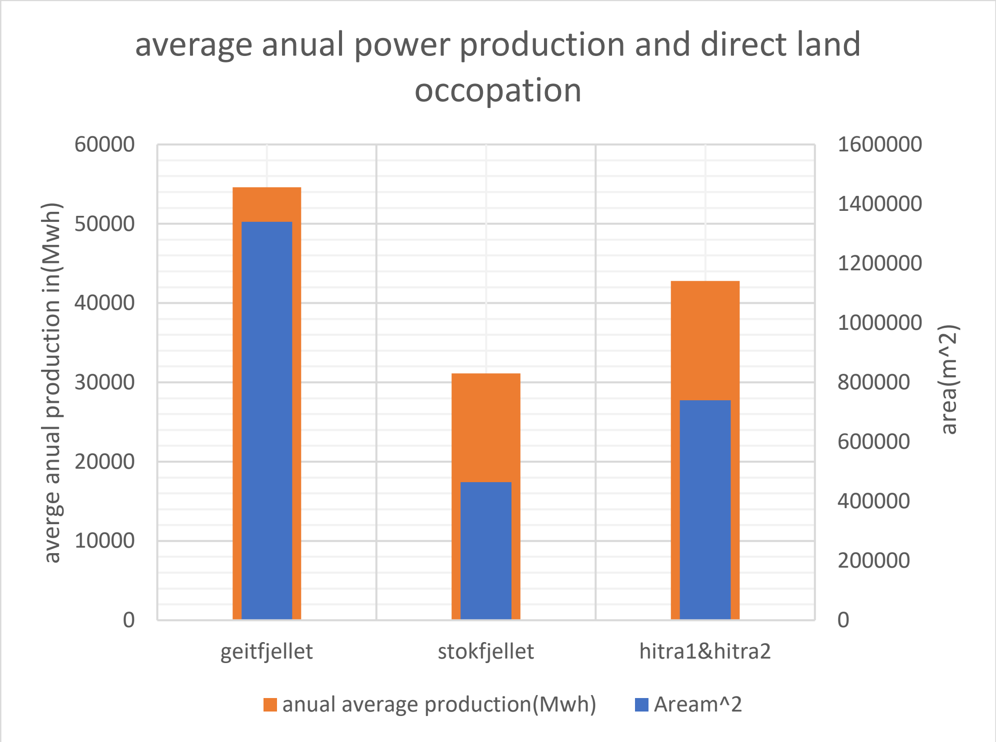


Figure 5-22annual average power production & land occupation of WPP

Total indirect impact of wind power plants

Except for the geitfjellet wind farm, the land near Stokkfjellet and Hitra has been vegetated, indicating that the wind farm building may not have the same indirect influence on other wind farms; there may be other variables associated with this varied location.

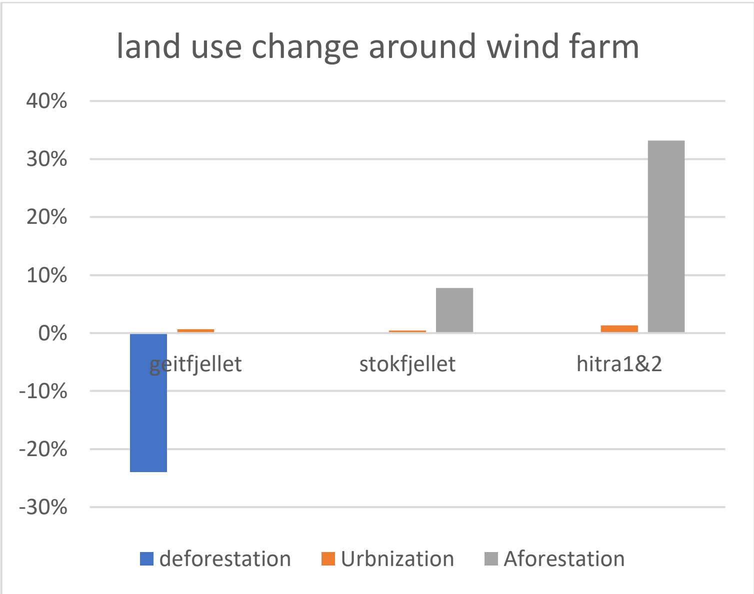


Figure 5-23 indirect land use change of wind powerplant

5.3 The result of a land use comparison WPP and HPP

Net land occupation calculated in the equation below (Martin Dorber,Roel May,and Francesca Verones, 2019)

$$\text{Net land occopation} = \frac{\text{direct land occopation}(m^2)}{\text{average annual electricity production}(Mwh)}$$

In comparing the direct land occupation of HPP and WPP, the following result is obtained as shown in the graph (fig 5-24)

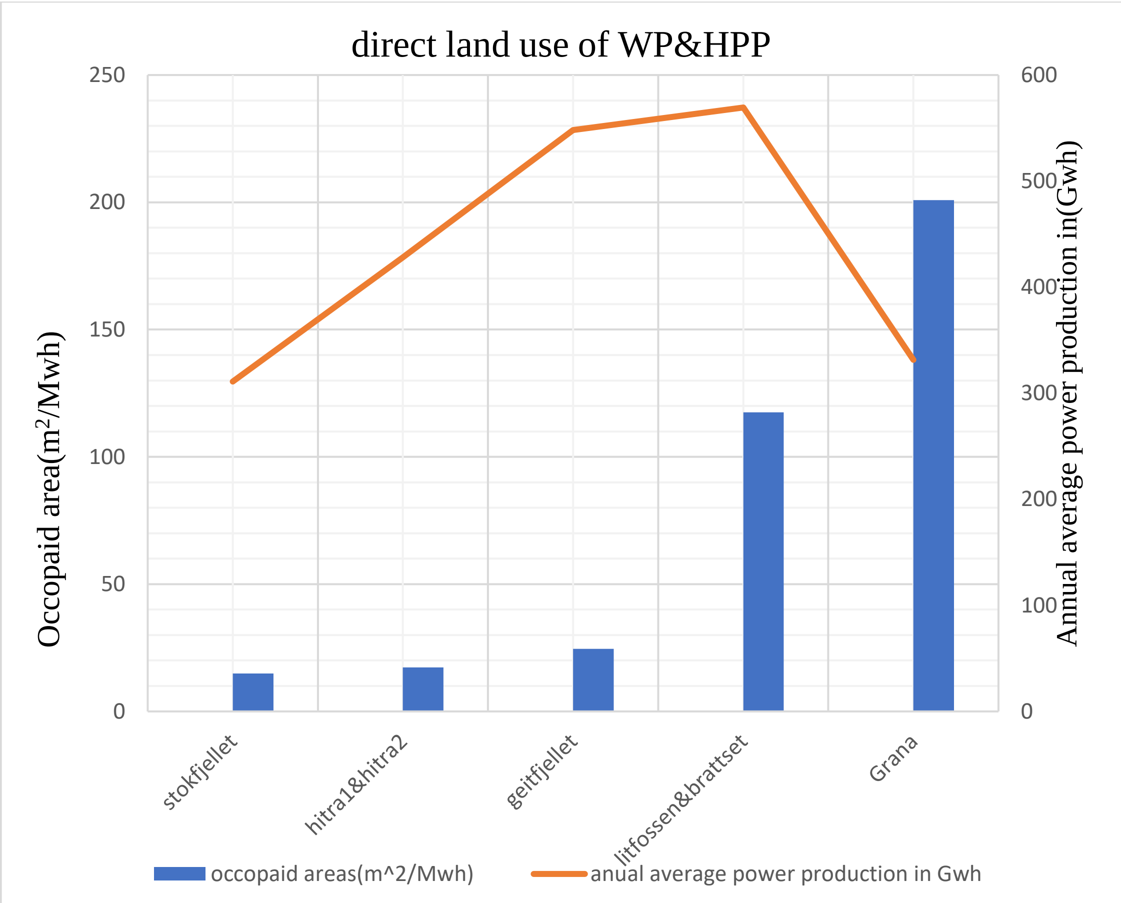


Figure 5-24land use occupation per unit production of HPP&WPP

6 Conclusion

This study described the intensity of land occupation and land-use changes of selected wind power and hydropower plants. The parameters of land occupation and land-use change are effective ways to compare the environmental impact of the two different renewable energy technologies. There are two primary indicators of land use that are discussed in this study, direct impact, and indirect impact. The research indicated that both types of primary indicators of land use have temporary and permanent environmental impacts.

Direct and indirect impacts were observed through varied timesteps that extended to forty years post the deployment of the hydropower project. According to the image analysis, the following results obtained at Grana, Litfossen& Brattset hydropower plants have shown significant direct land-use change during reservoir construction of approximately 40% for Grana and 34% for Litfossen and Brattset of vegetation area inundated by water. This construction also contributed to indirect impact through the additional construction of an access road and other facilities that caused the destruction of the surrounding vegetation. However, it was observed that in all the hydropower plants, the surrounding vegetation recovered from the initial damage.

Wind farms showed a different relationship between direct and indirect impact. The image analysis result shows that the direct effect of wind farms was mostly caused by the construction of an internal road, wind turbine installation, and other facilities, this leads the percentage area of urbanization to increase from 0 to 5.8% on average, and the average deforestation in the project area of a wind farm is 4.34%.

According to the indirect impact assessment, the result determined that the construction of wind farm have varied impact on the area surrounding, there is afforestation in stokkfjellet and hitra1&2 wind farms surrounding, but in Geitfjellet, 24% deforestation is observed. The primary transformation in the surrounding area was due to the construction of an access road.

Finally, the result of the case study shows that wind power plants take less area to produce approximately the same capacity of electricity. The average direct land occupation across all investigated wind power plants was calculated as $0.019m^2$·yr/kWh, for hydropower's average direct land occupation was $0.159m^2$ ·yr./kWh.

6.1 Limitation and uncertainty

This thesis has the following limitation

- The parameters that are taken in this study do not cover all the environmental impacts assessment of energy project such as aesthetic view, Noise pollution, wildlife.
- In the comparison of the WPP and HPP the variation of the energy throughout the year is not considered.
- Satellite image is not enough to quantify or to rank which renewable technology are useful in terms of social activity, so the social issue related to recreation or other activity is not assessed.
- Since the construction of wind farms that are selected in this study are constructed recently long-term evaluation is not done.

Bibliography

(2021, December 13). Retrieved from U.S.Energy Information Adminstration : https://www.eia.gov/energyexplained/what-is-energy/

AS, T. (n.d.). Retrieved from https://tronderenergi.no/vind/stokkfjellet: https://tronderenergi.no/vind/stokkfjellet

Bakken, T. H., Atle Harby, Håkon Sundt, & Audun Ruud. (2012). Development of small versus large hydropower in Norway. Trondheim, Norway: SINTEF Energy Research.

center for climate and energy solution. (2020). Retrieved from https://www.c2es.org/content/renewable-energy/#:~:text=Globally%2C%20renewables%20made%20up%2029,was%20added%20globally%20during%202020.

Energy Efficiency & Renewable Energy. (n.d.). Retrieved from https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects

energy fact Norway. (2021, 05 11). Retrieved from https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/#wind-power

Energy.gov. (n.d.). Retrieved from wind energy technology: https://www.energy.gov/eere/wind/how-do-wind-turbines-work

EnergyNorway. (n.d.). Retrieved from https://www.energinorge.no/om-oss/in-english/#:~:text=Norway%20is%20a%20major%20energy,such%20as%20windpower%20and%20biomass.

Environmental effect. (2005). Trondheim: NTNU.

esri. (n.d.). Retrieved from ArcGISPRo: https://pro.arcgis.com/en/pro-app/latest/help/analysis/image-analyst/training-samples-manager.htm

esri. (n.d.). Retrieved from Overview of image classification: https://pro.arcgis.com/en/pro-app/2.8/help/analysis/image-analyst/the-image-classification-wizard.htm

(2010). impact assesment of hitra2. stattkraft.

Joan Alcla Joseph Blandol,Mohd. Azizul Hafiz Jamian and Jayasilan . (2020). AN ASSESSMENT OF LAND USE SURROUNDING HYDROPOWER RESERVOIRS USING REMOTE SENSING IN SARAWAK, MALAYSIA . Journal of Sustainability Science and Management, 67-78.

(2010). Konsekvensutredninger. stattkraft .

Martin Dorber,Roel May,and Francesca Verones. (2019). Modeling Net Land Occupation of Hydropower Reservoirs in Norway. Trondheim, Norway: Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU).

Paul Denholm, Maureen Hand, Maddalena Jackson, and Sean Ong. (2009). Land-Use Requirements of modern wind power plant in united state. NREL is a national laboratory of the U.S. Department of Energy.

stattkraft . (n.d.). Retrieved from https://www.statkraft.com/about-statkraft/where-we-operate/norway/geitfjellet-wind-farm/

The Aesthetics of Wind Energy. (2018). nexus media news.

Torodd, J., Kjell, E., & Inge , H. (2021). Norway's hydroelectric development. oslo,Norway: Norwegian Water Resources and Energy Directorate (NVE).

union of concerned scientists. (2013, mar 5). Retrieved from https://www.ucsusa.org/resources/environmental-impacts-hydroelectric-power#toc-land-use

(2010). UTBYGGINGSPLANENgetfjellet. stattkraft.

APENDIX

APPENDIX A: Description of the master thesis

APPENDIX B: Maps and GIS results

NTNU **Faculty of Engineering**

Norwegian University of Science and Technology **Department of Civil and Environmental Engineering**

M.Sc. Thesis in

Water Resources Modelling and Engineering

Candidate: Mihret Hailu

Title: Comparison of environmental impact of hydro power and wind power

1 BACKGROUND

Initiated by extensive plans to develop onshore wind power in Norway it has been an intense debate in media about the environmental impacts related to the development of different renewable electricity technologies. Development of wind power in Trøndelag and Norway has experienced intense local and regional resistance.

It is, however, difficult to find scientific evidence supporting that some technologies have a smaller environmental footprint than another, by systematically comparing the environmental performance of off-shore wind power, on-shore wind power, small and large hydropower as well as refurbishment and extension of existing hydropower plants. This study aims at selecting a number of existing renewable electricity project (hydropower and wind) and systematically compare their environmental footprint, i.e., with respect to selected environmental indices, such as, e.g., land use occupation, impacts on wilderness areas, habitat degradation, and other relevant environmental indicators. The study can be divided into the following activities:

Literature review on studies comparing environmental performance between electricity technologies

Selection of case studies for a comparing environmental performance (in Norway or abroad) and analytical approach

Carry out an analysis (GIS-based analysis) of the environmental impacts/develop based on the selected case study and analytical approach

Do a ranking of the environmental performance/footprint of the different renewable technologies

2 MAIN QUESTIONS FOR THE THESIS

Key questions to be addressed in the thesis can be carried in the following steps.

1. Selection of study area for the comparison of environmental impacts, and selection of indicator(s) for comparison
2. Review of relevant literature for the selected study
3. Collection/compilation of map-based data for the analysis
4. Preparation and processing of data in GIS.
5. Calculation of relevant indices (land use/occupation) for the selected region/renewable technologies and discussion of the results
6. Assess the calculated impacts between the different renewable technologies in the case study sites
7. Assessment of the assumptions, limitation and uncertainties in the methodology and calculations, and

3 SUPERVISION, DATA, AND INFORMATION INPUT

Professor Tor Haakon Bakken will be the main supervisor of the thesis work, with Mahmoud Saber Kenawi as the co-supervisor. Discussion with and input from colleagues and other research or engineering staff at NTNU, power companies or consultants are recommended, if considered relevant. Significant inputs from others shall be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The report shall be typed by a standard word processor and figures, tables, photos etc. shall be of good report quality, following the NTNU style. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references. All figures, maps and other included graphical elements shall have a legend, have axis clearly labelled and generally be of good quality.

The report shall have a professional structure and aimed at professional senior engineers and decision makers as the main target group, alternatively written as a scientific article. The decision regarding report or scientific article shall be agreed upon with the supervisor. The thesis shall include a signed statement where the candidate states that the presented work is his/her own and that significant outside input is identified.

This text shall be included in the report submitted. Data that is collected during the work with the thesis, as well as results and models setups, shall be documented and submitted in electronic format together with the thesis.

The thesis shall be submitted no later than 05th of July 2022.

Trondheim 15th of January 2022

Tor Haakon Bakken

____

Tor Haakon Bakken, Professor

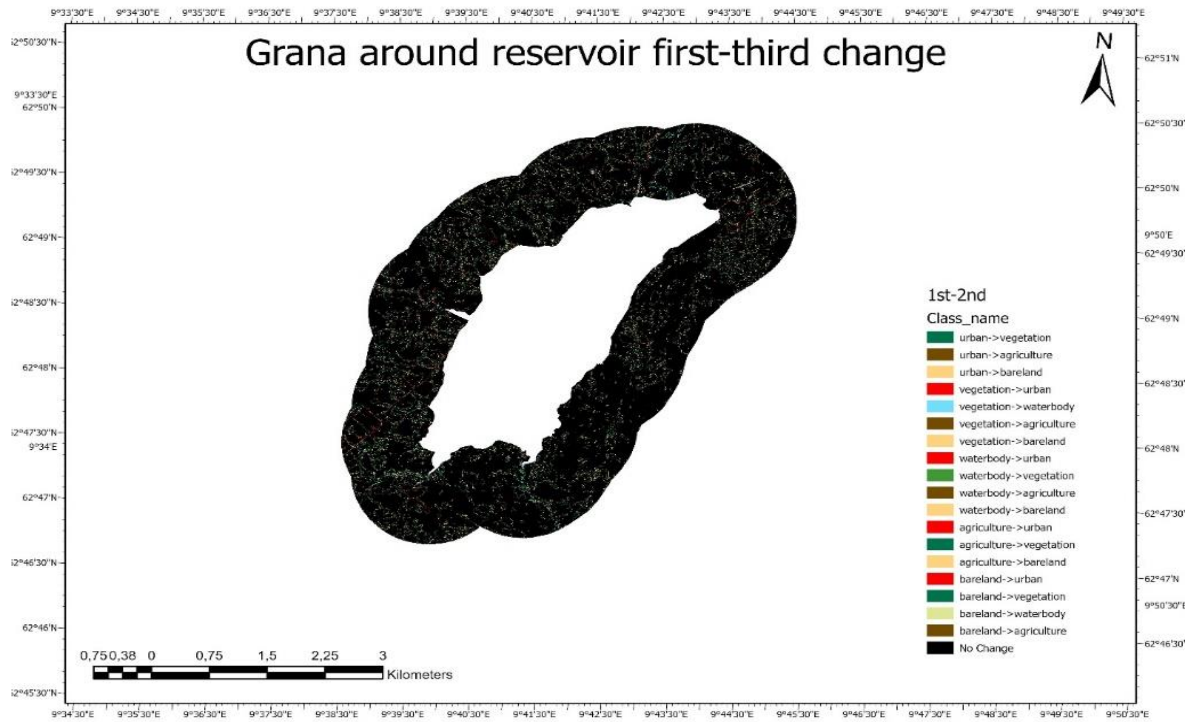
accuracy assessment confusion matrix

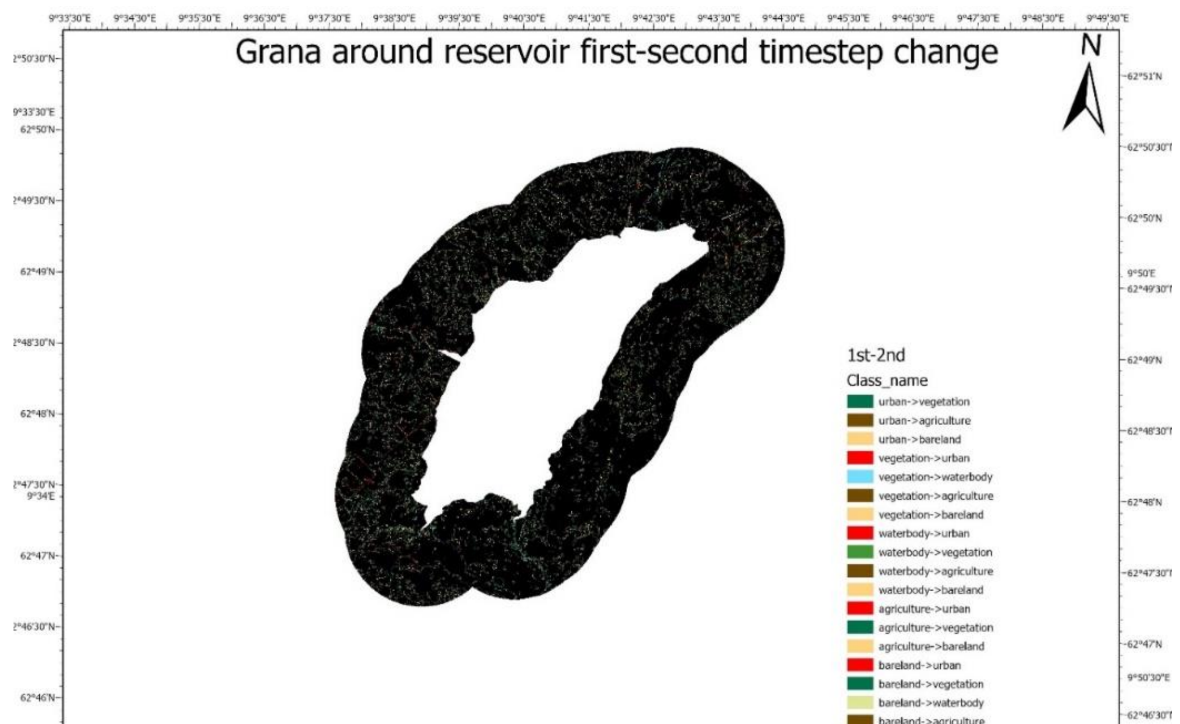
		geitfjellet 2021						
OBJECTID *	ClassValue	waterbody	urban	bareland	vegetation	Total	U_Accuracy	Kappa
1	waterbody	50	0	0	0	50	1	0
2	urban	0	50	0	0	50	1	0
3	bareland	0	0	50	0	50	1	0
4	vegetation	0	0	1	49	50	0,98	0
5	Total	50	50	51	49	200	0	0
6	P_Accuracy	1	1	0,980392	1	0	0,995	0
7	Kappa	0	0	0	0	0	0	0,993333
		2017						
OBJECTID *	ClassValue	waterbody	bareland	vegetation	Total	U_Accuracy	Kappa	
1	waterbody	67	0	0	67	1	0	
2	bareland	0	67	0	67	1	0	
3	vegetation	0	11	56	67	0,835821	0	
4	Total	67	78	56	201	0	0	
5	P_Accuracy	1	0,858974	1	0	0,945274	0	
6	Kappa	0	0	0	0	0	0,91791	

		stokfjellet2021						
OBJECTID	ClassValue	waterbody	urban	bareland	vegetation	Total	U_Accurac	Kappa
1	waterbody	47	2	1	0	50	0,94	0
2	urban	0	46	4	0	50	0,92	0
3	bareland	0	0	50	0	50	1	0
4	vegetation	0	0	3	47	50	0,94	0
5	Total	47	48	58	47	200	0	0
6	P_Accurac	1	0,958333	0,862069	1	0	0,95	0
7	Kappa	0	0	0	0	0	0	0,933333
			2017					
OBJECTID	ClassValue	waterbody	bareland	vegetation	Total	U_Accurac	Kappa	
1	waterbody	66	1	0	67	0,985075	0	
2	bareland	0	67	0	67	1	0	
3	vegetation	0	13	54	67	0,80597	0	
4	Total	66	81	54	201	0	0	
5	P_Accurac	1	0,82716	1	0	0,930348	0	
6	Kappa	0	0	0	0	0	0,895522	

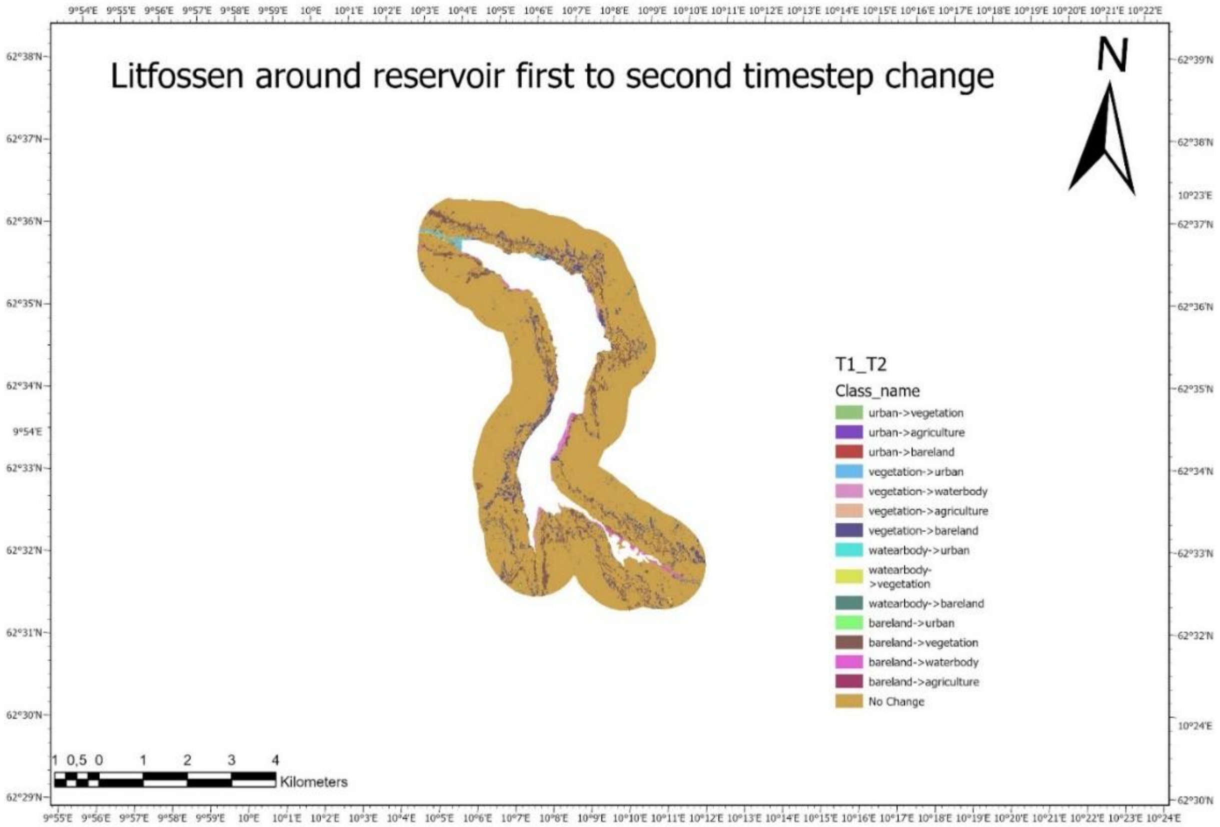
	hitra 1&2 2021							
OBJECTID	ClassValue	waterbody	urban	bareland	vegetation	Total	U_Accurac	Kappa
1	waterbody	10	0	0	0	10	1	0
2	urban	0	9	1	0	10	0,9	0
3	bareland	0	0	142	0	142	1	0
4	vegetation	0	0	5	40	45	0,888889	0
5	Total	10	9	148	40	207	0	0
6	P_Accurac	1	1	0,959459	1	0	0,971014	0
7	Kappa	0	0	0	0	0	0	0,937409
	hitra1&2 2003							
OBJECTID	ClassValue	waterbody	bareland	vegetation	Total	U_Accurac	Kappa	
1	waterbody	10	0	0	10	1	0	
2	bareland	2	150	0	152	0,986842	0	
3	vegetation	1	9	33	43	0,767442	0	
4	Total	13	159	33	205	0	0	
5	P_Accurac	0,769231	0,943396	1	0	0,941463	0	
6	Kappa	0	0	0	0	0	0,849154	

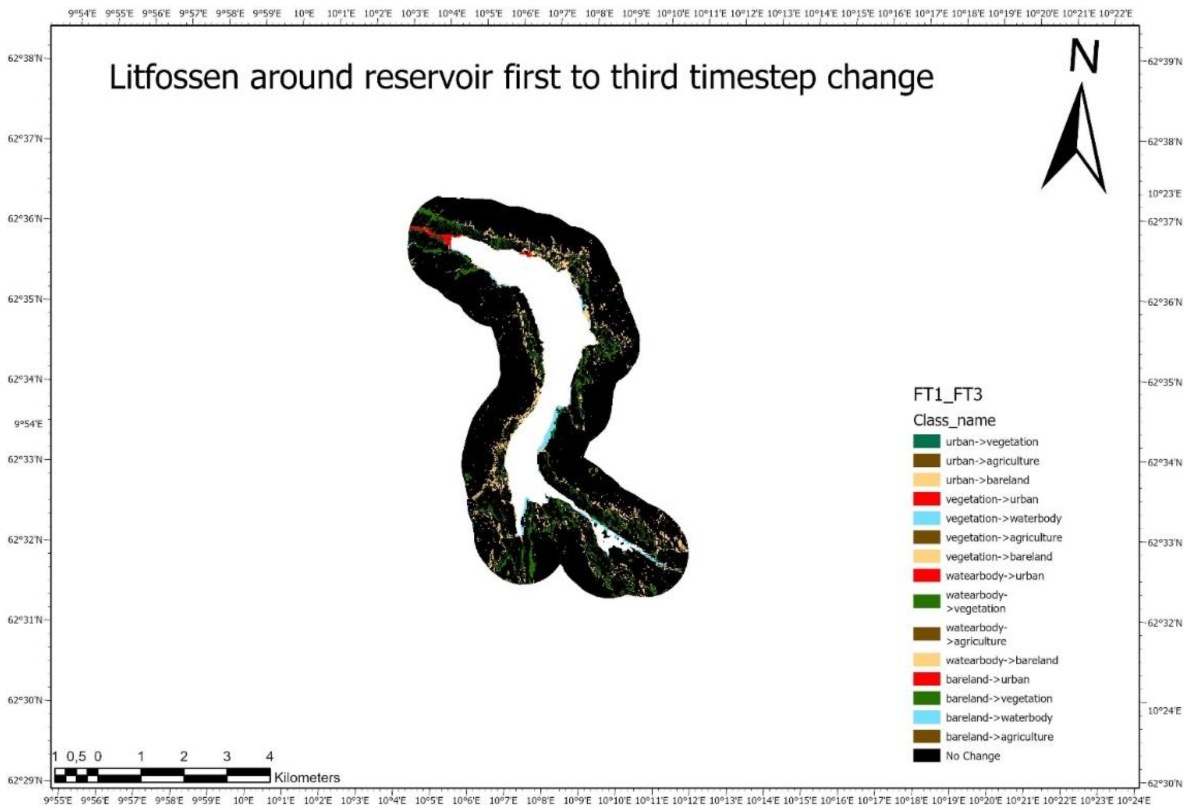
indirect area change of grana reservoir





Indirect impact of Litfossen





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