Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Geography

Astrid Seland

Assessing solar energy potential for cabins in high latitudes

A GIS method

Bachelor's thesis in Geography
Supervisor: Jan Ketil Rød
Co-supervisor: Gabriele Lobaccaro, Tahmineh Akbarinejad
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Preface

This thesis is written as a completion of the bachelor degree program in geography at the Norwegian University of Science and Technology (NTNU). The subject of the thesis is related to own interests in renewable energy sources and the green transition.

The first week of October 2022, Malin Bergset and I attended an international summer school at NTNU called URSA MAJOR. During one week, my group of international and Norwegian students got the opportunity to work with the issue of social acceptance of solar PV panels in cultural heritage areas. The work was done in collaboration with Helios, a project funded by the Research Council of Norway lead by the Department of Civil and Environmental Engineering at NTNU. Helios is working with the exploitation of solar energy in Nordic cities. The introduction to Helios brough about the opportunity to collaborate with the project. As I am very interested in the topic and as renewable energy and solar photovoltaic panels are also relevant for a geography student, this thesis is written as a collaboration with the Helios project and the Department of Civil and Environmental Engineering.

I would like to acknowledge and give the warmest thanks to my supervisor Jan Ketil Rød from the Department of Geography, NTNU. His help has been highly appreciated, especially regarding GIS and methodology. I would also like to give a special thanks to Gabriele Lobaccaro and Tahmineh Akbarinejad from the Department of Civil and Environmental Engineering, NTNU, for excellent help regarding academic writing. Your helpful inputs and time have been greatly valued and appreciated.

Abstract

The world is facing an enormous threat in the face of climate change, forcing policy makers to look to new and sustainable energy sources. Rooftop photovoltaics are estimated as one of the major contributors in the energy transition and for achieving climate goals. In this thesis, it has been investigated how rooftop solar photovoltaic technology can be a feasible solution in municipalities in high latitudes, using cabins in Oppdal as a case study. The thesis uses a GIS approach, calculating the solar radiation potential throughout a year. The thesis argues that solar photovoltaic panels may serve as a contributor to a more sustainable energy mix, despite the fluctuating availability of solar energy making it difficult to provide power during the winter months. Furthermore, the thesis concludes that GIS can be a suitable tool for calculating solar radiation, although calculation time can represent a limitation. The thesis can be used by policy makers to investigate the solar potential in their municipality as well as an initial step in a more in dept analysis of solar potential in high latitudes.

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List of abbreviations and nomenclature

Abbreviation	Definition
DEM	Digital Elevation Model
DSM	Digital Surface Model
EU	European Union
FKB	Felles Kartdatabase
GIS	Geographic Information System
EEA Agreement	Agreement on the European Economic Area
IPCC	Intergovernmental Panel on Climate Change
KPIs	Key Performance Indicators
PV	Photovoltaic
RES	Renewable Energy Sources
SDG	Sustainable Development Goals
SSB	Statistisk Sentralbyrå
UN	United Nations
ZEB-lab	Zero Emission Building Laboratory

Nomenclature	Definition
W	Watt
k	kilo
h	hour
m	meter

Table of figures and tables

Front page: Elfag. (2020). *Legg strøm på hytta*. https://www.elfag.no/legg-strom-pa-hytta/

1. Introduction

The world is facing an enormous threat in face of climate change. Both terrestrial and marine areas are getting warmer, and extreme events are increasing globally. The sixth report from the Intergovernmental Panel on Climate Change (Arias et al. 2021) describes a deteriorating climate affecting a number of vitally important areas, like ecosystem services, health and welfare (IPCC, 2022). There is a common goal among nearly all countries worldwide to limit global warming to 2 °C, preferably 1,5 °C. This goal is set in the international Paris Agreement, which also states that the wealthiest countries have a greater responsibility to fight climate change (UN, n.d., a). In addition, United Nations (UN) member states have committed to work against the UN sustainable development goals (SDG), presented in September 2015 (UN, n.d., a). Goal number 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all (UN, n.d., b). Embedded in this goal are five key arenas, whereas two focus on a rapid transitioning to decarbonized energy systems and to leave no one behind on the path to a net-zero future. Furthermore, target 7.2 states that by 2030, there should be a substantial increase in the share of renewable energy sources (RES) in the global energy mix. According to the UN (n.d., c), the world is not on track for achieving this goal, and therefore there is a need for more research contributing to how the world can transition towards a more environmentally friendly energy mix. Solar energy could be one solution to achieving this goal.

Norway is one of the 189 countries committed to the UN SDGs and the Paris Agreement. Furthermore, through the European Union (EU), the country has obliged to cut 50-55% of all greenhouse gas emissions by 2030 compared to the levels of 1990 (Regjeringen, 2022). Achieving these goals include transitioning to a sustainable society on all scales of governance. Norway is a vast country situated in high latitudes, with 356 municipalities with very different environmental conditions. A widespread phenomenon in nearly all the municipalities, is the use of cabins as secondary homes. As of February 2023, 448 805 secondary homes were registered, of which the majority were cabins (SSB, n.d., a). The widespread use of cabins in Norway represents an important field of study in light of climate change and RES in high latitudes. Many cabins are located in rural areas surrounded by nature. Oppdal municipality is one municipality in this category. The construction of cabins has received critique the past years due to destruction of land areas associated with the building process (Kaste, 2021). Thus, a quest for more sustainable cabins has arisen. As of 2022, solar power contributed to approximately 0.1% of the total Norwegian power production (NOU 2023:3, p. 54). Oppdal's

4142 cabins make the municipality an interesting area related to sustainable cabins with the use of solar photovoltaic (PV) panels.

This thesis consists of five chapters. The first chapter presents a background for the thesis, where an overview of the latest solar PV technology, trends and strategies for solar power production, and the importance of assessing solar energy on high latitudes is given. Thereafter, a methodology chapter presents how GIS can be used to calculate solar potential. The following results and discussion chapter presents the most viable cabin areas in Oppdal for the installation of solar PV panels, and examine the findings and how the solar energy produced can be utilized in Oppdal municipality's sustainable transition. Finally, the thesis concludes by summarizing the most important findings and recommendations for further studies.

1.1 Framework and aim of the thesis

Despite several international contributions regarding solar potential on rooftops, for instance INES' Solar Cadaster showing the potential for rooftop solar PV panels in Geneve and Oslo municipality's solar map showing the potential in Oslo, there is little research concerning the solar potential of cabins (INES, 2020; Oslo kommune, n.d.).

This thesis therefore aims to assess solar potential in rural areas of Norway, using cabins in Oppdal municipality as a case study. Within this framework, the hereby thesis has the ambition to address the following main research question and sub questions:

- What is the feasibility of solar energy exploitation on cabins in rural areas in high latitudes?
    - How can a geographic information system (GIS) identify the areas with the highest solar energy potential?
    - How can local solar energy production be a virtuous solution for rural municipalities in high latitudes with a widespread use of cabins?

The objectives for the thesis are:

- Create a solar map of Oppdal municipality, showing the most suitable areas for solar PV production on cabins and to present key performance indicators (KPIs).
- Develop a user-friendly communication approach using geographic visualization and KPIs to raise the public awareness about solar energy potential for cabins in rural areas.

Thus, the thesis can be used by municipalities to investigate how cabins in their region can be more environmentally sustainable, inspire municipalities to implement solar PV panels and raise the awareness of the general public on the available solar energy potential in the rural scale of cabins.

2. Background and theory

2.1 Solar potential in high latitudes

Solar power is a clean and abundant energy received by the Earth’s surface as energy carrying photons. Each year, the Earth’s surface absorbs approximately 7000 times more energy than the annual energy consumed by the world’s population (Bridge et al., 2018, p. 24). Today’s solar PV technology harnesses 15%-20% of the available solar energy and transforms it into electricity (Norsk solenergiforening, n.d.). Depending on available space, solar PV panels can be connected to matrixes of various sizes (Telang, 2013). Furthermore, the technology can be placed at the site of exploitation, without disturbing noise nor movement (Ulsrud, 2017, p. 327).

Several research papers highlight how solar PV panels would be a suitable solution in high latitudes. A literature review carried out in 2017 found that the efficiency of solar PV panels decreases linearly with increasing temperature (Mussard, 2017, p. 738). Furthermore, low temperatures during winter would in some cases partially compensate for shorter days. The research of Child & Breyer (2016, p. 530) concluded that solar PV panels are feasible in northern latitudes. Their conclusion is complimented by Adaramola and Vågnes (2015, p. 530) who monitored the annual insolation in a small-scale grid in Ås, Norway demonstrating that grid-connected system installations are technically feasible energy systems in high latitudes. In Antarctica, solar PV panels are utilized on the Wasa research station for power production, showing how solar energy can be utilized even in extreme temperatures at high latitudes (ASOC, 2010, p. 2). Less extreme examples can be found in Finland, where solar PV panels are mounted on the roof of two supermarkets in Turku, located at 60 °N and in Trondheim, Norway where a zero-emission building has installed solar PV panels on roof and facades in order to produce energy (Child et al., 2019, p. 2; SINTEF, n.d.).

2.2 International and national trends concerning solar energy

The international solar power production is expected to significantly increase in the coming years. In May 2022, the EU released a climate and energy security plan called REPower EU, where solar power is described as an important component in the making of a new, sustainable and energy independent EU. The plan involves a doubling of the solar energy capacity by 2025 compared to 2020, described in a separate Solar Energy Strategy (European commission, 2022, a). The strategy implies solar energy on different scales, however, the report states that up to 25% of the total energy demand in the EU may be covered by rooftop solar PV panels in the near future (European commission, 2022, b). Norway is committed to the EU through the Agreement on the European Economic Area (EEA agreement), and consequently has to co-operate with the EU on energy and climate matters. Furthermore, the country has agreed to participate in EUs climate legislation for the period 2021-2030 (IEA, 2022).

In February 2023, the Norwegian Commission of Energy released an official report encouraging production of solar power in Norway. The rationale was partly based on the adaptability of the technology and partly on global trends showing descending costs (NOU 2023:3, p. 17). According to the report, solar power is likely to compete with both wind and hydroelectric power in the future (NOU 2023:3, p. 103). The report was written and published by the national government, however also local governments are expected to take actions to fight climate change. In 2019, the Norwegian Ministry of Local government and Regional development put forward the plan for national expectations for regional and municipal planning for 2019-2023. The document established national expectations related to sustainable development in rural areas, and underpinned how municipalities have a central role in transitioning to a low-carbon society as well as adjusting to the changing climate (Kommunal- og moderniseringsdepartementet, 2019, p. 15). Additionally, the document emphasizes the importance of nature and recreation throughout the country, the role of municipalities to preserve these areas in planning processes, and how increased tourism and the usage of cabins represent a threat to this task (Kommunal- og moderniseringsdepartementet, 2019, p. 16-18).

2.3 GIS and solar energy

Several methods for assessing solar energy potential exists throughout literature. For instance, Liu et al. (2023, p. 3-6) proposed a methodology consisting of a 3D city model, meteorological data and the use of an empirical model. Koch et al. (2022, p. 4-9) had a different approach, using irradiation data in combination with an image filtering technique to classify feasible rooftop segments for PV installations. This thesis has a GIS-approach, using the software ArcGIS Pro. GIS are computer-based systems used for operating with spatial data (Rød, 2020, p. 14). A GIS provides the user with tools to collect, manipulate, analyze and present spatial data and their attributes, which enables advanced and complex analyses. The ability to analyze data and attributes in a spatial context makes GIS a sought tool in multiple situations, for instance related to planning and natural resource management (Boulos & Wilson, 2023, p. 2).

There are two main methods of representing data in a GIS; vector data and raster data. Vector data consists of points, lines and polygons and have their own unique attribute table containing properties associated with the spatial data (Rød, 2020, p. 24). Raster data is subdivided into discrete and continuous rasters, where discrete rasters usually represent phenomena with defined borders while continuous rasters represent phenomena which may vary (Rød, 2020, p. 36-37). Whereas a discrete raster holds pixel values of integers, continuous raster values might also be floating numbers.

2.3.1 Solar radiation analysis

Incoming solar radiation is defined as the sum of three components, shown in figure 1. The first component is direct solar radiation, which consists of uninterrupted solar radiation on its way to the Earth’s surface. Direct solar radiation is usually the dominating source of insolation (Rød, 2020, p. 234). Subsequently, diffuse solar radiation makes up the second component, and entails solar radiation spread by clouds, particles and other obstacles in the atmosphere (Rød, 2020, p. 234). Lastly, reflected solar radiation accounts for the final component. In snow covered areas, this component sometimes surpass the amount of direct solar energy and become dominant (Esri, n.d., a).

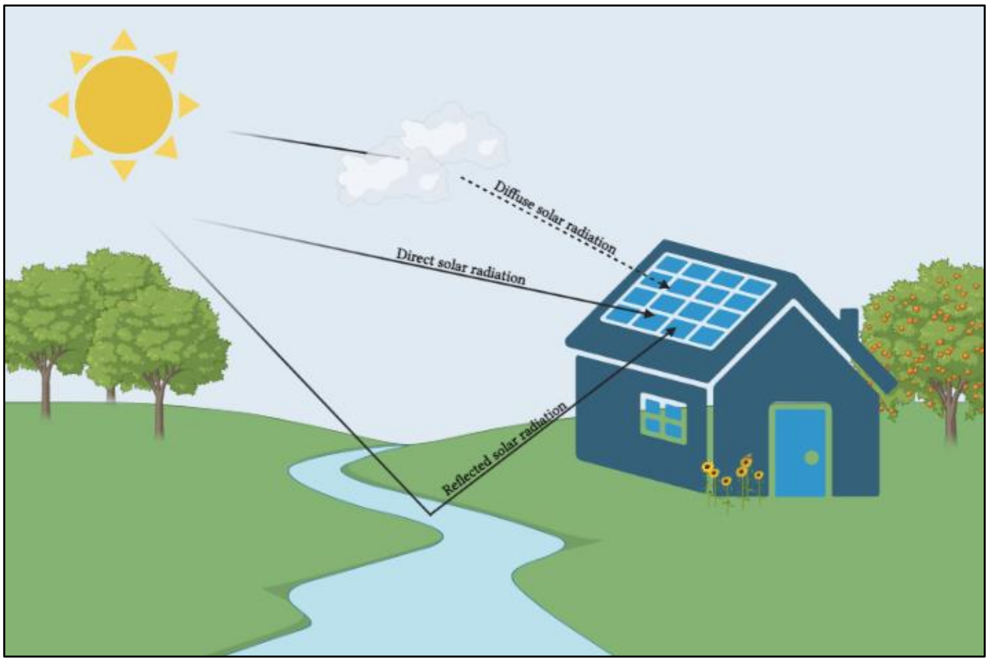

Figure 1: Solar radiation, three components

A solar radiation analysis done in a GIS is calculated as the sum of direct and diffuse solar radiation, as shown in equation 1 (Fu & Rich, 2000, p. 12).

$$Global_{tot} = Dir_{tot} + Dif_{tot} \qquad (1)$$

There are two different tools in ArcGIS Pro for performing a solar radiation analysis and both include four main steps, illustrated in figure 2.

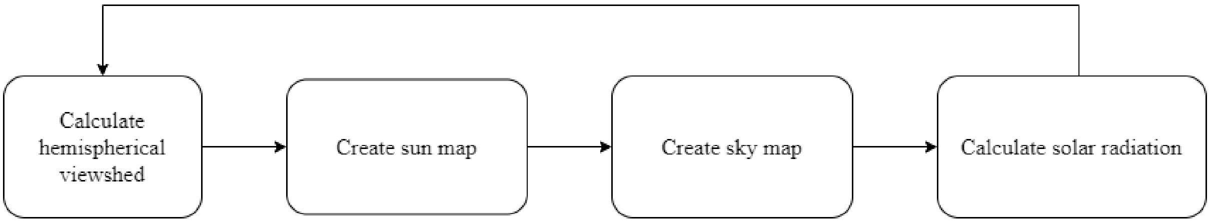

Figure 2: The four main steps of a solar radiation analysis, repeated for each cell.

First, a hemispherical viewshed is calculated for each cell in a digital surface model (DSM). By searching for sky obstructions in a predetermined set of directions, a raster representation is made representing visible and obstructed areas of the skyline. (Fu & Rich, 2000, p. 3). An illustration of this can be seen in figure 3. Direct solar radiation is considered when making a sun map in the second step. A sun map is a map showing the temporal variation of the sun’s position in the sky, based on parameters representing latitude, day of the year and time of the day (Rød, 2020, p. 235). Each sector in the resulting sun map holds a value representing the position of the sun at a specific time of year and day, as seen in figure 4 (Fu & Rich, 2000, p. 5-6).

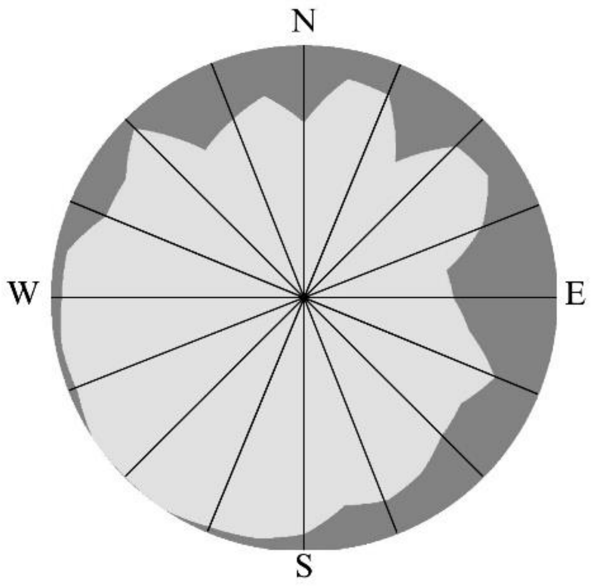

Figure 4: Sun map

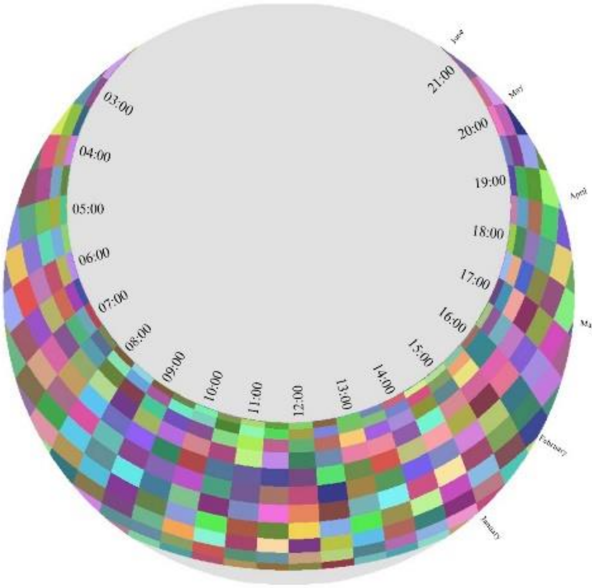

Figure 4: Hemispherical viewshed

Diffuse solar radiation can originate from any sky direction (Fu & Rich, 2000, p. 8). Step three is thus to make a sky map representing sectors of differing zenith and azimuth angles which are used for calculating diffuse solar insolation (Fu & Rich, 2000, p. 8; Rød, 2020, p. 237). A sky map can be seen in figure 5. Zenith angle is the angle from a viewpoint to a sightline, where 0° represents a vertical sightline and 90° represents a horizontal sightline. Azimuth angle represents the angle between the vertical line at the viewpoint and the projection of the sun-earth line in the horizontal plane (Rød, 2020, p. 235; Kalogirou, S. A, 2022, p. 1).

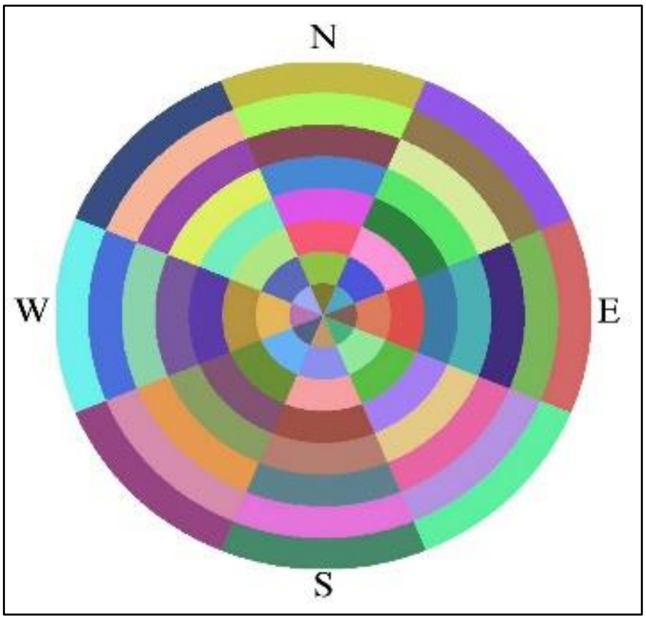

Figure 5: Sky map

Steps two and three are done while overlaying the hemispherical viewshed made in step one so that only visible areas in the research area are calculated, as shown in figure 6. Step four repeats the previous steps, creating an insolation raster representing the whole research area.

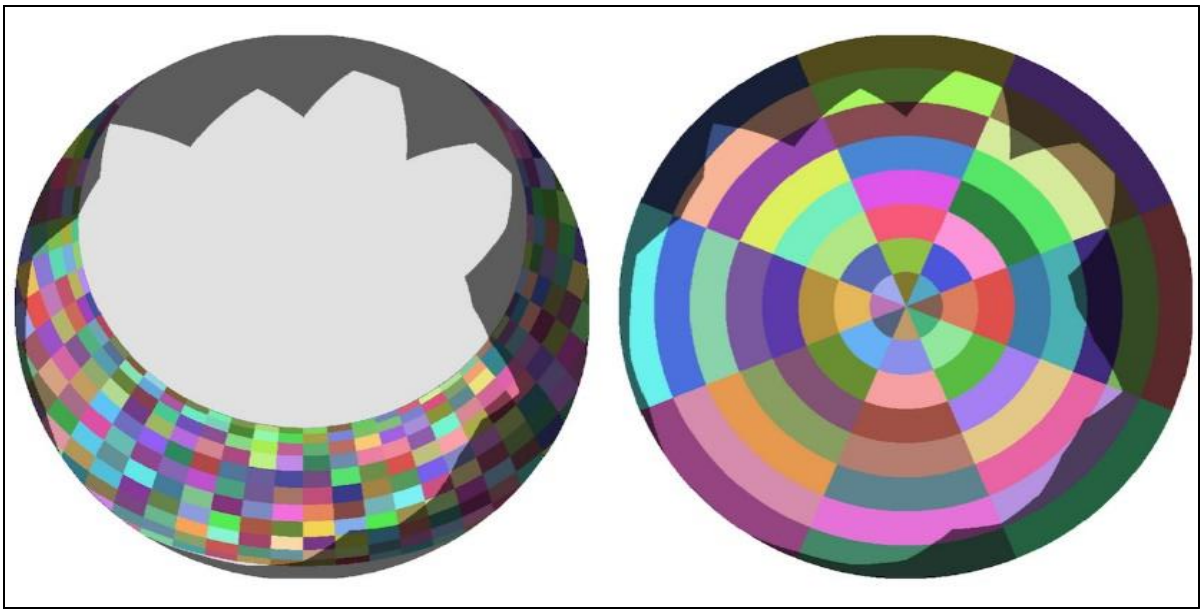

Figure 6: Sun map and sky map overlapped by a hemispherical viewshed

3. Materials and methods

This chapter concerns the methodology and materials used for investigating the solar potential on cabins in the rural area of Oppdal municipality. First, the case study will be presented, followed by data collection which entails both literature and spatial data collection. Thereafter, the «Area Solar Radiation» tool and a calibration of the tool is presented. Lastly, a large-scale analysis and a small-scale analysis is performed. A workflow is illustrated in figure 7.

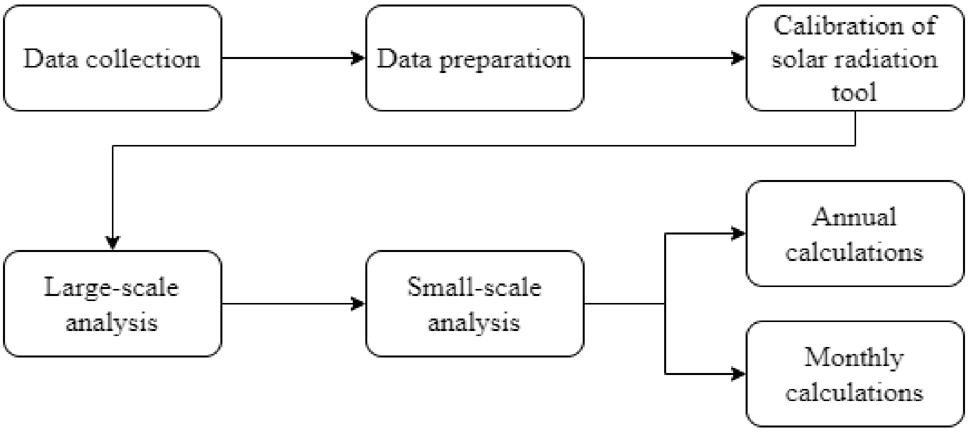

Figure 7: Workflow for the materials and methods

3.1 Case study

Norway is localized in high latitudes and experiences a fluctuating amount of solar radiation throughout the year. The country is elongated, reaching from 58° N in the south to 71° N in the north. Hence, the amount of solar radiation differs relative to location. Trøndelag county is located in the middle of Norway, and contains 38 municipalities and several national parks and nature reserves (Haugen, 2023). One of the municipalities is Oppdal municipality, shown in figure 8.

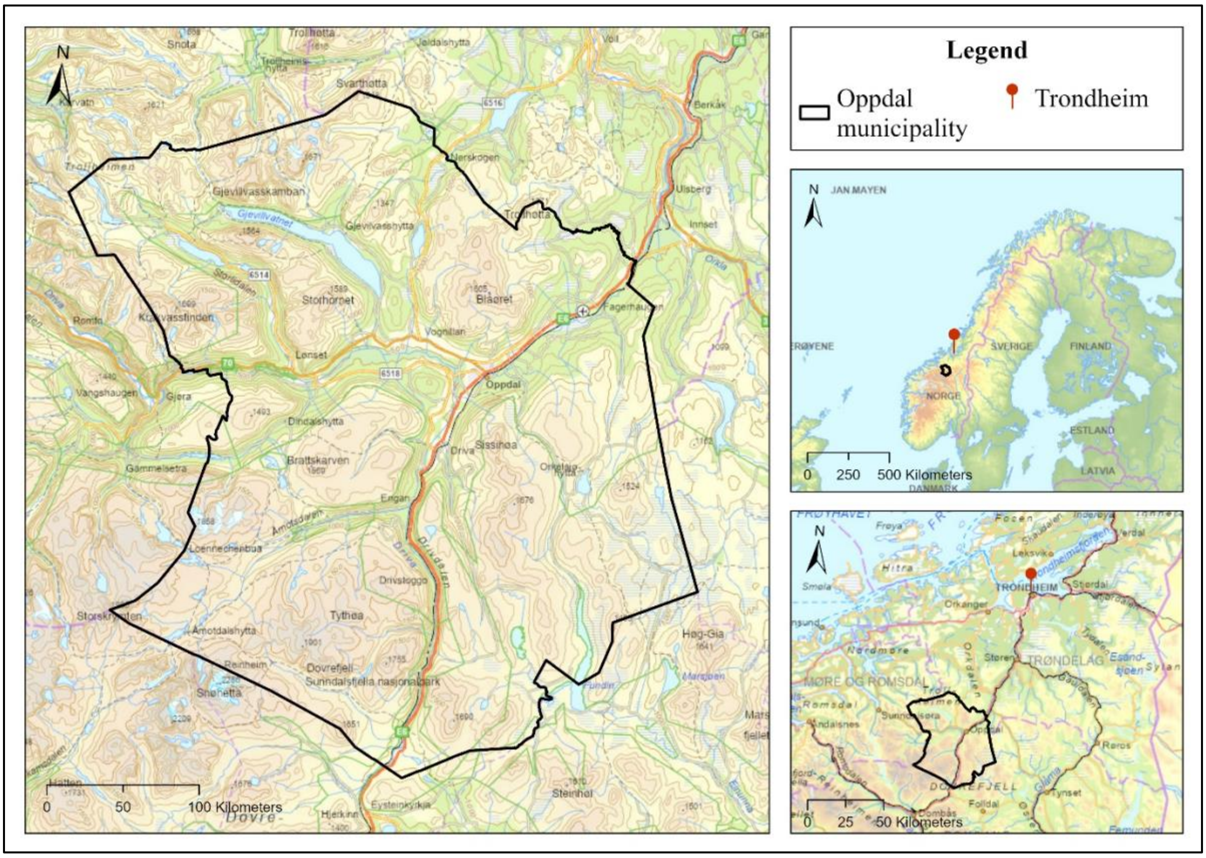

Figure 8: Oppdal municipality

Oppdal municipality is a rural municipality housing more than 7200 inhabitants, with a municipal center located 545 m.a.s.l. south in Trøndelag county. The municipality has a continental climate according to Köppens climate classification (Kottek et al., 2006, p. 260). Furthermore, Oppdal is characterized by large surrounding nature areas, with Trollheimen northwest and Dovre-Sunndalsfjella national park south. According to Statistisk sentralbyrå (SSB) (n.d., b) 4142 cabins were registered in Oppdal in 2022, implying a high share of leisure residents. This is reflected in Oppdal's master plan, claiming that the municipality wishes to be both an attractive travel destination and place of residence (Oppdal kommune, 2013, p.19). Additionally, the plan highlights the surrounding nature and its role in the municipality's vision of being a year-round travel destination characterized by valuable nature experiences (Oppdal kommune, 2013, p. 3).

As a municipality in Norway, Oppdal has a responsibility to face climate change. Their three main goals for the period 2019-2030 are:

1. Become a low emission society by 2050
2. Increase energy efficiency and the use of RES

3. Become a climate resilient and secure society in a changed climate era (Oppdal kommune, 2021, p. 5).

Their official climate plan for 2018-2029 includes a separate chapter dedicated to sustainable cabins, claiming that new areas for cabins should be developed as green areas with limited area use, joint solutions and compact as well as energy efficient buildings (Plankontoret, 2019, p. 12).

3.2 Data collection

Two main methods are used for collecting data for the thesis; a literature review and collection of spatial data.

3.2.1 Literature review

Previous literature concerning solar PV panels in rural areas was collected through a brief literature review, shown in figure 9. Literature found on the scientific databases Scopus and Web of Science were used and considered reliable. Suitable keywords were used to find relevant literature, mainly «Solar radiation», «rural», «high latitude», «cabins» and «GIS climate change». The publication date was set to after 2000 to exclude irrelevant literature due to the rapid development regarding solar PV panels. However, when there was little to no literature found for the given years, the date was adjusted back in time. Thereafter, literature was excluded based on the relevance of their title. Whenever the title referred to a field of study considered irrelevant, the article was excluded. The abstracts of the remaining articles and the most relevant articles were read. Ten articles found through the literature review were used in the thesis.

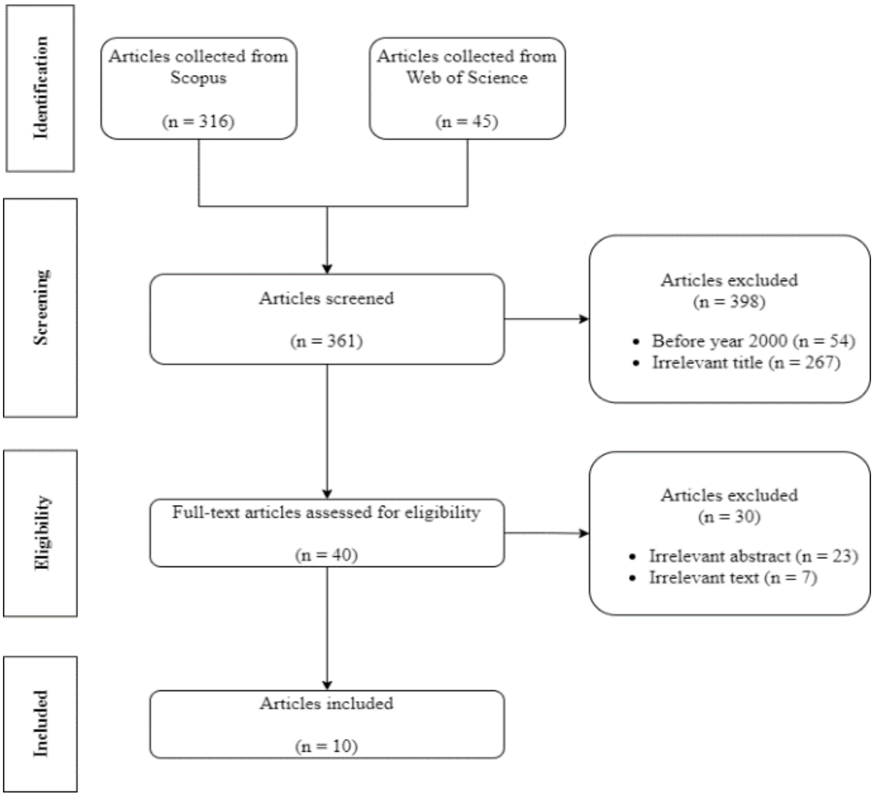

Figure 9: Literature review

3.2.2 Collection and preparation of spatial data

The desktop GIS application ArcGIS Pro was used to perform a solar radiation analysis. Additionally, the software was used to prepare data for the analysis and to visualize the results. The following spatial data was collected; research area in Oppdal and Trondheim, cabins in Oppdal, buildings in Trondheim and a DSM covering the research areas. Additionally, information about the amount of incoming solar radiation at a given roof was needed to perform a calibration of the solar radiation tool. This was collected from the Zero-Emission Building Laboratory (ZEB-lab) in Trondheim. The data collected is summed up in table 1.

Table 1: Spatial data collection

Spatial data					
Type of data	Spatial layer	Spatial representation	Resolution	Production year	Data source
DSM	DSM large-scale analysis	Raster, continuous	10 m	2021	Høydedata
DSM	DSM small-scale analysis	Raster, continuous	1 m	2021	Høydedata
DSM	DSM calibration	Raster, continuous	1 m	2021	Høydedata
FKB-data	Cabins	Vector, polygons	1 mm	2020	GeoNorge
FKB-data	ZEB-lab	Vector, polygons	1 mm	2020	GeoNorge
Basisdata	Oppdal municipaliy	Vector, lines	1 mm	2020	GeoNorge

A vector layer of Oppdal municipality was created by importing a feature class containing polygons representing municipality borders in Trøndelag from GeoNorge. Oppdal municipality was selected and extruded to a new feature layer and named «Oppdal». Thereafter, Felles kartdatabase (FKB) data representing buildings in Oppdal and Trondheim was downloaded from GeoNorge as two separate vector layers and imported to the geodatabase. FKB-data include all buildings in a given area, hence cabins in Oppdal had to be extruded to a new vector layer. «Select by Attributes» was used to select all buildings with the building type 161 in the attribute table. Building type 161 is the unique building type code assigned for cabins. The selected cabins were exported to a new layer named «Cabins», consisting of 4126 cabins.

A building with a known amount of received solar energy was needed for a calibration of the solar energy tool and collected from the ZEB-lab in Trondheim. The ZEB-lab is a research arena for the development of zero emission buildings, where facades and roofs are covered in solar PV panels, and thus data considering solar insolation is closely monitored (SINTEF, n.d.). The ZEB-lab is located in an urban environment 120 km north of Oppdal municipality. A calibration using data from Trondheim will therefore lead to errors when transferring the script to Oppdal. Yet, the data from the ZEB-lab was considered valuable, as it was difficult to get other calibration data from a location closer to the research area[1]. The ZEB-lab was highlighted in the attribute table for the buildings representing Trondheim, and exported to a new feature class. The new layer was named «zeb_lab».

Three DSMs representing the research areas were ordered from Høydedata and uploaded to GIS as several smaller raster tiles. A DSM was chosen over a digital elevation model (DEM) as the DSM represents the surface height of natural and human made features, while a DEM represent ground levels. As this analysis is interested in the amount of solar radiation arriving at the roof of buildings, as well as how nearby elements like vegetation and other buildings will block and affect the insolation, it is better to use a DSM than a DEM (Rød, 2020, p. 230). Two DSMs covered Oppdal municipality, one with a one-meter resolution and one with a ten-meter resolution. The third raster covered Trondheim and had a resolution of one meter. «Mosaic to New Raster» was used to merge the raster layers to three continuing DSMs. Thereafter, the appropriate rasters were clipped to «Oppdal» and «zeb_lab» with «ClipRaster» and named «dsm_lsa» and «dsm_zeb».

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[1] Several cabin associations in Oppdal municipality were contacted and asked whether cabins in their association had installed solar PV panels. As none of the associations answered, the best option for calibration was to use the ZEB-lab in Trondheim.

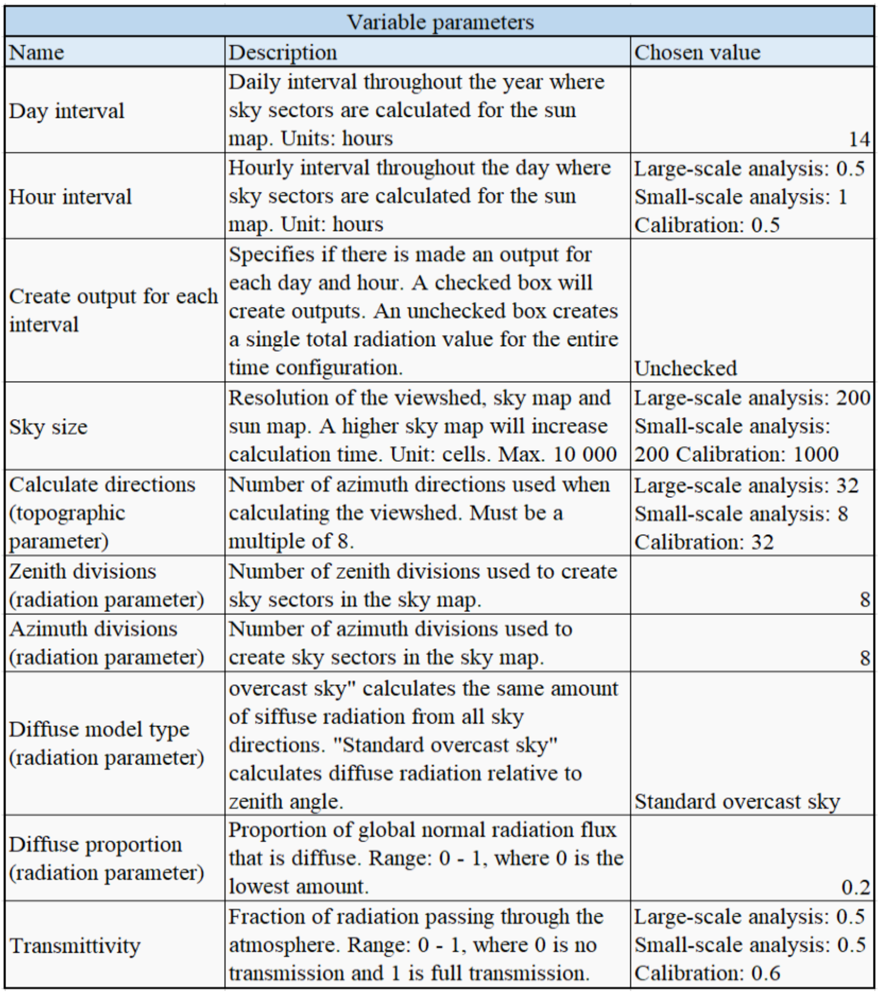
3.3 Area Solar Radiation

The «Area Solar Radiation» tool was used for calculating incoming solar radiation. The tool was chosen because it considers shadows and obstacles when calculating solar radiation. «Area Solar Radiation» takes 13 parameters which can be subdivided as constant or variable parameters. Constant parameters have to be set to a certain value based on the chosen research area and time configuration, while variable parameters may have values chosen from a pool of possibilities.

3.3.1 Constant and variable parameters

The constant parameters are *input surface raster*, *latitude*, *time configuration*, *z-factor* and *slope and aspect input type*. *Slope and aspect input type* was set to «From surface raster» to receive a more precise result, while time configuration was set to the respective time interval for the calculations, hence one year, one month and one day. Subsequently, the variable parameters were set according to table 2.

Table 2: Variable parameters



Variable parameters		
Name	Description	Chosen value
Day interval	Daily interval throughout the year where sky sectors are calculated for the sun map. Units: hours	14
Hour interval	Hourly interval throughout the day where sky sectors are calculated for the sun map. Unit: hours	Large-scale analysis: 0.5 Small-scale analysis: 1 Calibration: 0.5
Create output for each interval	Specifies if there is made an output for each day and hour. A checked box will create outputs. An unchecked box creates a single total radiation value for the entire time configuration.	Unchecked
Sky size	Resolution of the viewshed, sky map and sun map. A higher sky map will increase calculation time. Unit: cells. Max. 10 000	Large-scale analysis: 200 Small-scale analysis: 200 Calibration: 1000
Calculate directions (topographic parameter)	Number of azimuth directions used when calculating the viewshed. Must be a multiple of 8.	Large-scale analysis: 32 Small-scale analysis: 8 Calibration: 32
Zenith divisions (radiation parameter)	Number of zenith divisions used to create sky sectors in the sky map.	8
Azimuth divisions (radiation parameter)	Number of azimuth divisions used to create sky sectors in the sky map.	8
Diffuse model type (radiation parameter)	overcast sky" calculates the same amount of siffuse radiation from all sky directions. "Standard overcast sky" calculates diffuse radiation relative to zenith angle.	Standard overcast sky
Diffuse proportion (radiation parameter)	Proportion of global normal radiation flux that is diffuse. Range: 0 - 1, where 0 is the lowest amount.	0.2
Transmittivity	Fraction of radiation passing through the atmosphere. Range: 0 - 1, where 0 is no transmission and 1 is full transmission.	Large-scale analysis: 0.5 Small-scale analysis: 0.5 Calibration: 0.6

Day interval was set to 14 and *hour interval* was set to 0.5 for the large-scale analysis and 1 for the small-scale analysis. The rationale for these values is mainly calculation time, but the values are also set with regards to the changing seasons in Norway. Thus, the model got enough time between each interval to limit calculation time while considerations regarding the season's variability and weather conditions were preserved. *Sky size* was set to 200 to save calculation time for the large-scale and small-scale analyses and to 1000 for the calibration. 200 is considered a sufficient sky size for a year-long calculation with larger daily intervals using a whole DSM as in the case of this calculation (Esri, n.d., b).

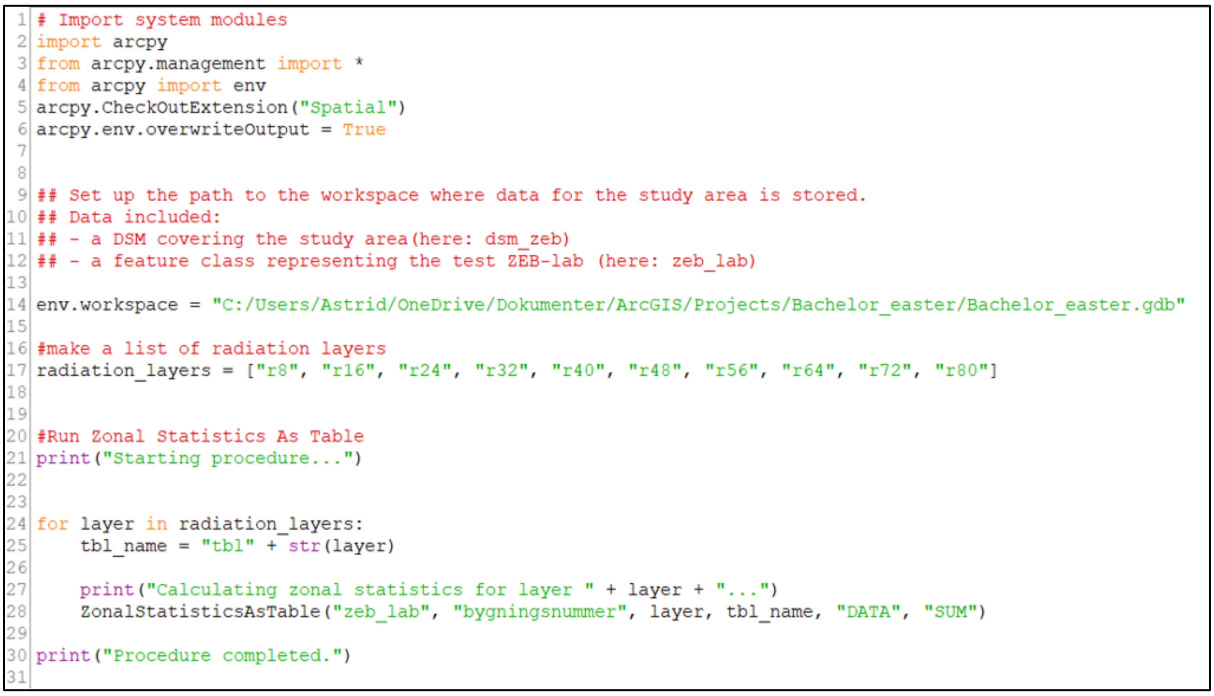
The final variable parameters can be subdivided into two groups; topographic and radiation parameters. The variable topographic parameter is *calculate directions*. The more complex the topography and detailed the input surface raster, the higher number of directions are recommended. The topography of cabin areas in Oppdal is defined by hills and rough grounds, while the resolution of the DSM is ten meters for the large-scale analysis and one meter for the small-scale analysis. The optimal number of directions is therefore to be decided in the calibration of the solar energy tool. *Zenith* and *azimuth divisions* are radiation parameters. Both were set to 8 to save calculation time. *Diffuse model type* was set to «Standard overcast sky» for a more precise result. *Diffuse proportion* was set to 0.2, representing clear sky conditions, as the air quality in Oppdal is considered good and there are few particles in the atmosphere affecting the insolation (Miljødirektoratet, n.d.). *Transmittivity* was set to 0.5 for a generally clear sky, based on meteorological data showing that Oppdal had 102 days of precipitation in 2022 meaning a relatively clear sky.

3.3.2 Calibrating the tool

In order to optimize the analysis, a calibration of the «Area Solar Radiation» tool was done using GIS and Python. Python was used to optimize the process and thus save time. The calibration was done with regards to the topographic parameters. Atmospheric parameters will change from day to day and in the future caused by a changing climate. The transfer value of the calibrated model is thus greater in calibrating the topographic parameters. There are three topographic parameters, however only *calculation directions* is a variable parameter and was thus chosen for calibration. The calibration was done for March 1st 2023 for the ZEB-lab in Trondheim, which was characterized by a clear sky. *Diffuse proportion* was therefore set to 0.2

and *transmittivity* was set to 0.6 to mimic atmospherical conditions. The remaining parameters were set according to table 2.

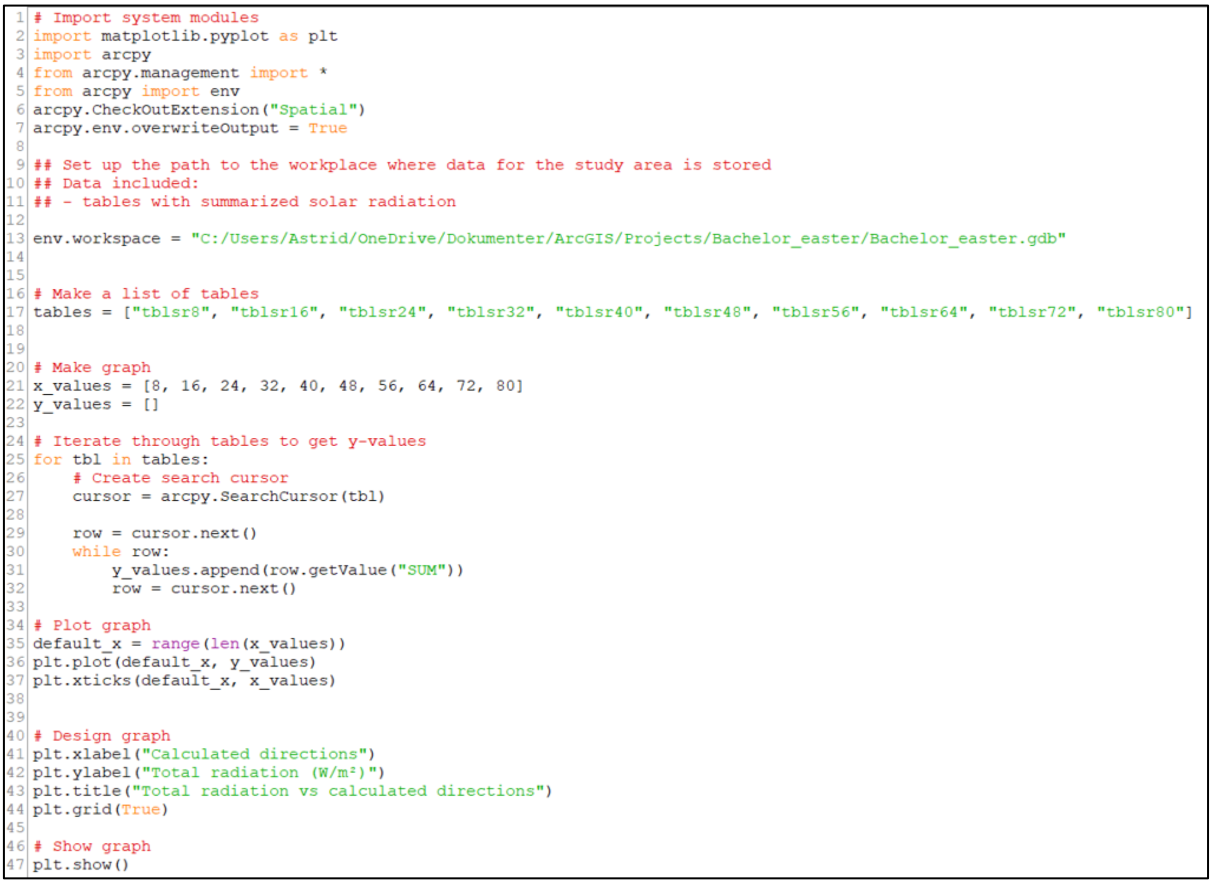
The «Area Solar Radiation» tool was run once for the following values for *calculation directions*; 8, 16, 24, 32, 40, 48, 56, 64, 72, 80. This resulted in ten new layers, named rX, where X represents the value for *calculation directions*. Thereafter, the total sum of all pixels covering the ZEB-lab was calculated finding the total insolation for each variable, using the python script in figure 10.



```
# Import system modules
import arcpy
from arcpy.management import *
from arcpy import env
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True


## Set up the path to the workspace where data for the study area is stored.
## Data included:
## - a DSM covering the study area(here: dsm_zeb)
## - a feature class representing the test ZEB-lab (here: zeb_lab)

env.workspace = "C:/Users/Astrid/OneDrive/Dokumenter/ArcGIS/Projects/Bachelor_easter/Bachelor_easter.gdb"

#make a list of radiation layers
radiation_layers = ["r8", "r16", "r24", "r32", "r40", "r48", "r56", "r64", "r72", "r80"]


#Run Zonal Statistics As Table
print("Starting procedure...")


for layer in radiation_layers:
    tbl_name = "tbl" + str(layer)

    print("Calculating zonal statistics for layer " + layer + "...")
    ZonalStatisticsAsTable("zeb_lab", "bygningsnummer", layer, tbl_name, "DATA", "SUM")

print("Procedure completed.")

```

Figure 10: Python script, zonal statistics

The script resulted in ten tables named tblrX, X representing the value for *calculation direction*. A graph was made to visualize the results from the varying numbers for *calculate directions*, using the python script in figure 11. The graph is shown in figure 12.



```
# Import system modules
import matplotlib.pyplot as plt
import arcpy
from arcpy.management import *
from arcpy import env
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

## Set up the path to the workplace where data for the study area is stored
## Data included:
## - tables with summarized solar radiation

env.workspace = "C:/Users/Astrid/OneDrive/Dokumenter/ArcGIS/Projects/Bachelor_easter/Bachelor_easter.gdb"


# Make a list of tables
tables = ["tblsr8", "tblsr16", "tblsr24", "tblsr32", "tblsr40", "tblsr48", "tblsr56", "tblsr64", "tblsr72", "tblsr80"]


# Make graph
x_values = [8, 16, 24, 32, 40, 48, 56, 64, 72, 80]
y_values = []

# Iterate through tables to get y-values
for tbl in tables:
    # Create search cursor
    cursor = arcpy.SearchCursor(tbl)

    row = cursor.next()
    while row:
        y_values.append(row.getValue("SUM"))
        row = cursor.next()

# Plot graph
default_x = range(len(x_values))
plt.plot(default_x, y_values)
plt.xticks(default_x, x_values)


# Design graph
plt.xlabel("Calculated directions")
plt.ylabel("Total radiation (W/m²)")
plt.title("Total radiation vs calculated directions")
plt.grid(True)

# Show graph
plt.show()
```

Figure 12: Python script, graph

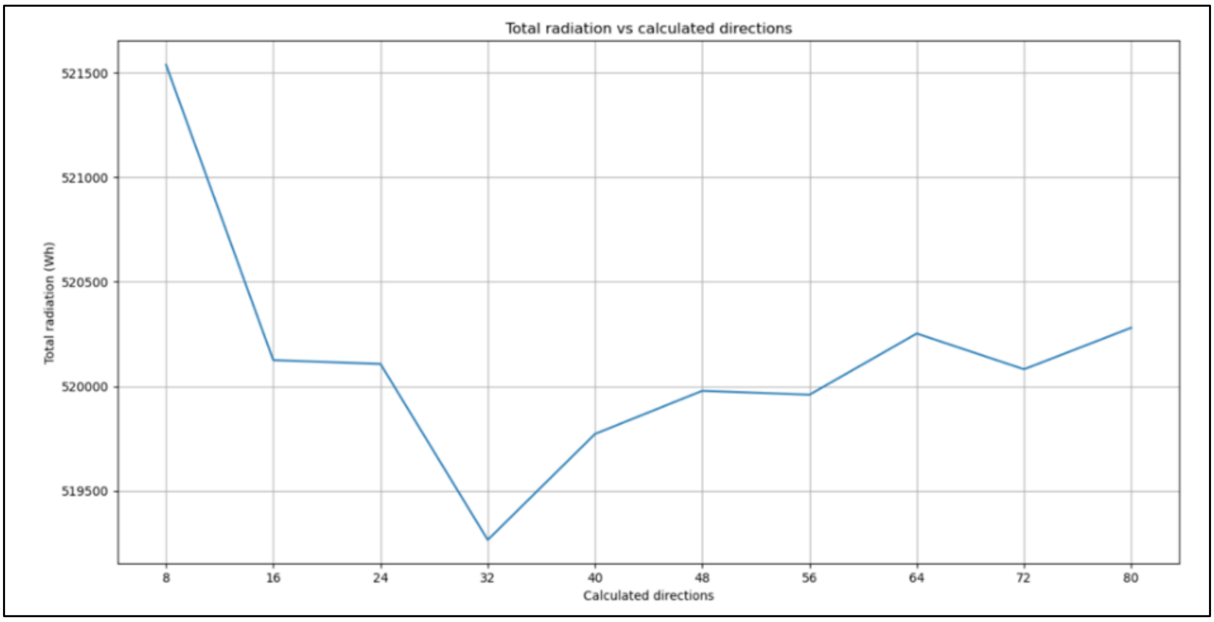


Figure 11: Outputs for calculated directions

A pyranometer installed on the roof of the ZEB-lab registered a total of 895.3513 W/m² on March 1st 2023. This number was multiplied by the area covering the ZEB-lab in GIS, that is 597.287 m², resulting in a total daily solar radiation of 534 781 W. None of the values used for *Calculated directions* resulted in a total insolation of 534 781 W. However, the value 8 is the closest to the correct value, and thus this value was used for the small-scale analysis. Neither the user manual made for «Area solar radiation» nor Esri's documentation state how many directions are possible to calculate (Fu & Rich, 2000, p. 34; Esri, n.d., b). Therefore, only values ranging from 8 to 80 were tested. However, two random calculations of solar radiation were done using 104 and 160 as input variables to check how values outside of the chosen range would influence the results. The total amount of insolation did not exceed the output calculated by using the value 8.

3.4 Analysis

The analysis of Oppdal municipality consists of a large-scale analysis, performed using a DSM with a resolution of ten meters, and a small-scale analysis using the calibrated tool and a one-meter resolution DSM based on the results from the large-scale analysis.

3.4.1 Large-scale analysis

A large-scale analysis of Oppdal municipality was performed to gain insight into which cabin areas in Oppdal are most feasible for the exploitation of solar energy. An uncalibrated version of «Area Solar Radiation» was used to calculate the insolation, using a DSM with a resolution of ten meters and parameters according to table 2. Additionally, the same DSM as the input raster was set as snap raster in the environments tab, ensuring that the extent of the resulting total global radiation raster match the cell alignment of the input raster (Esri, n.d, b). The resulting total global radiation raster was clipped to «Cabins» by using the tool «Clip Raster».

Three areas were investigated based on the large-scale analysis, named area A, B and C. Area C was chosen as the most interesting area for implementation of solar PV panels on the roof of cabins due to the high amount of solar radiation combined with a large number of cabins. The chosen area had 1013 cabins, while the two remaining areas consisted of 519 and 466 cabins.

3.4.2 Small-scale analysis

Two small-scale analyses were performed on area C, an annual and a monthly analysis, both for the year 2022. Two new polygon layers were created and named «area_ssa» and «areaC», representing area C and surrounding elevated areas that may serve as obstacles to solar radiation. Subsequently, the one-meter DSM was clipped to «area_ssa» using the tool «Clip Raster» and named «dsm_ssa» and the cabin-layer was clipped to «areaC» using the tool «Clip» and named «cabins_ssa».

The calibrated version of «Area Solar Radiation» was used to calculate annual and monthly solar radiation. As for the large-scale analysis, the same DSM as the input raster was used as snap raster in the environments tab. The parameters were set according to table 2. Dates representing the respective months were set as start and end date of the month and the calculation was run once for each month. In total, the tool was run 13 times, once for the annual analysis and once for each month.

The resulting raster layers were clipped to «cabins_ssa» using «Clip Raster» and the tool «Zonal Statistics as Table» was used to summarize the pixel values for each roof. Thereafter, «Join Field» was used to import the summarized values from the table created in the previous step to «cabins_ssa» and given the name «SUM_X», where X represents the respective month or year. The resulting attribute table contained the summarized annual and monthly global solar radiation for cabins in area C.

Dust, dirt, snow and other particles might accumulate on the solar PV panels. The summarized monthly radiation was thus multiplied by the soiling factor for Trondheim municipality, a factor representing the amount of solar energy lost due to particles covering the solar PV panels' surface (Maghami et al., 2016, p. 1309). As the soiling factor is based on Trondheim Municipality while the study area is located south of Trondheim at a higher altitude, the soiling factor for December through March was altered. Meteorological data shows that the study area experienced a mean temperature below 0°C in December, January and February in 2022, as well as a normal temperature of -1.8°C in March (Yr, n.d.). It is thus assumed that solar PV panels will be totally covered by snow, preventing the panels from producing electricity during these months. The soiling factor was thus set to 100. Three new fields were added for each month in the attribute table for «cabins_ssa», using the tool «Add field». «Calculate field» was used to adjust each monthly sum to the soiling factor for solar modules mounted on surfaces with a slope in the range of 0°-15°, 15°-25° and 25°-40°. Tools used for data processing is shown in figure 13.

Figure 13: Tools used for processing results

4. Results and discussion

This chapter presents results from the large-scale and small-scale analyses. Furthermore, the most viable cabin areas for the use of solar PV panels in Oppdal municipality are presented with KPIs. The findings are discussed in a chapter 4.2, in addition to limitations to the study.

4.1 Results

4.1.1 Large scale analysis

The amount of annual solar radiation received in Oppdal ranges from 46 kWh/m² to 1035 kWh/m² and is shown in figure 14.

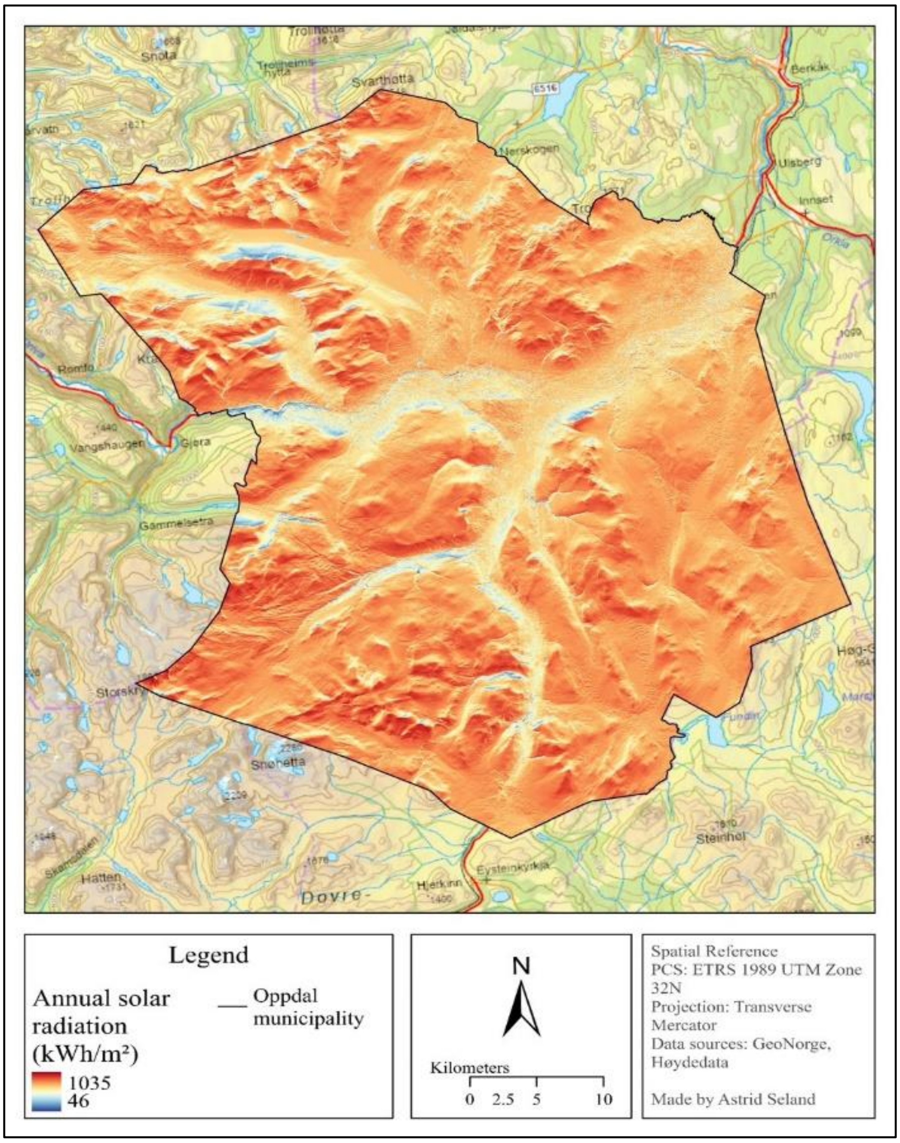


Figure 14: Large-scale analysis, Oppdal municipality

When clipped to areas representing cabins, the annual solar radiation ranges from 240 kWh/m² to 860 kWh/m². Three areas stand out based on two factors; amount of annual solar radiation and number of cabins. The three areas are named Area A, B and C in figure 15. The areas mainly consist of cabins with an annual amount of received solar radiation over 850 kWh/m², and are thus in the uppermost interval of the insolation received on all the examined cabins. There are several areas outside of the chosen areas receiving a large amount of annual solar radiation, for instance cabins placed northeast of area B around Bjørklia and cabins placed west of Ångardsvatnet. Thus, other areas might also be well suited for solar PV panels.

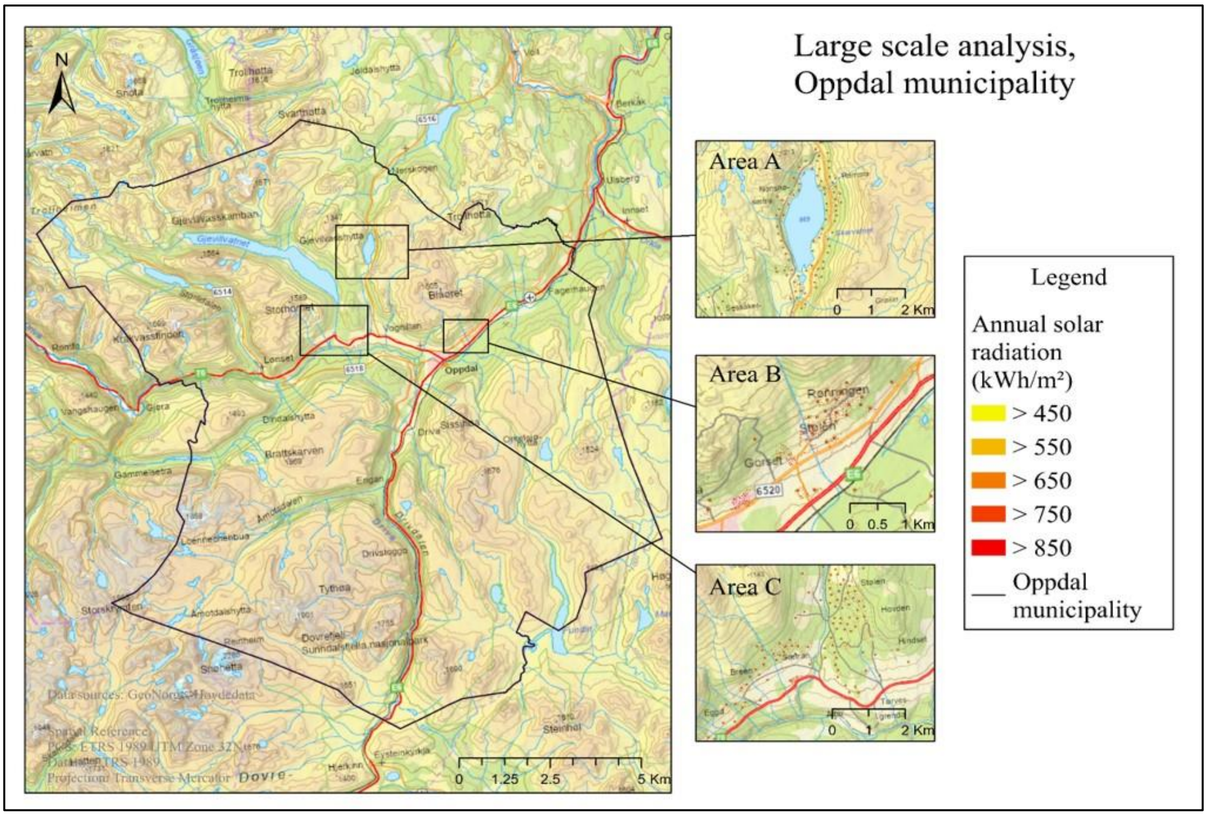


Figure 15: Areas of interest, Oppdal municipality

4.1.2 Small scale analysis

The annual solar radiation on cabin roofs in Area C ranges from 0.077 kWh/m² to 1 773 kWh/m², as shown in figure 16.

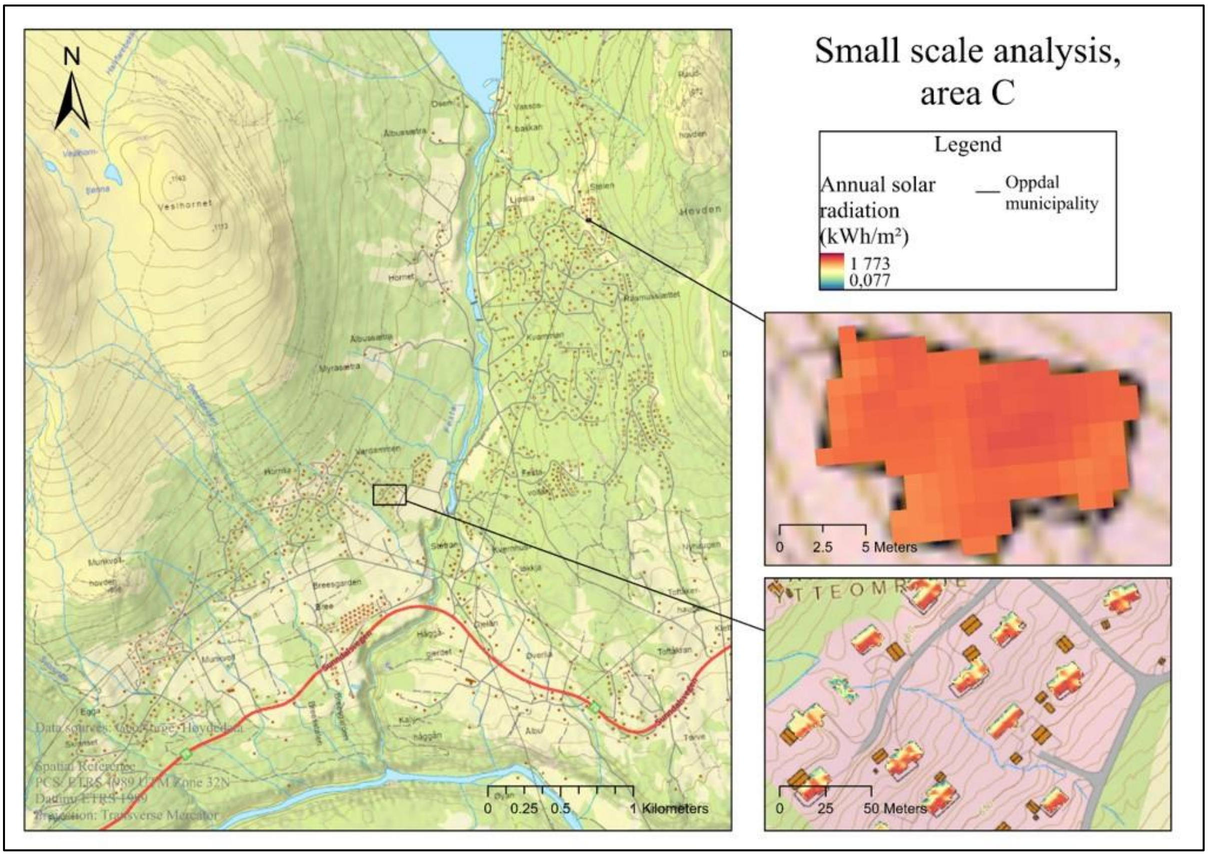


Figure 16: Area C. Inset map 1 shows a cabin receiving a large amount of annual solar energy. Inset map 2 shows an area receiving more than 1500 kWh/m2.

All months are considered in the annual small-scale analysis. The part of the roof facing south to southeast is the most suitable location to place a solar PV panel in order to receive the highest amount of solar radiation. The total annual solar radiation received on each roof is also affected by the size of the roof.

The annual solar radiation for the total roof of each cabin varies from 23430.63 kWh to 454 483.7 kWh, with an annual mean insolation of 124 729.2 kWh as shown in figure 17. 439 cabins in area C receive over the average amount of annual solar radiation.

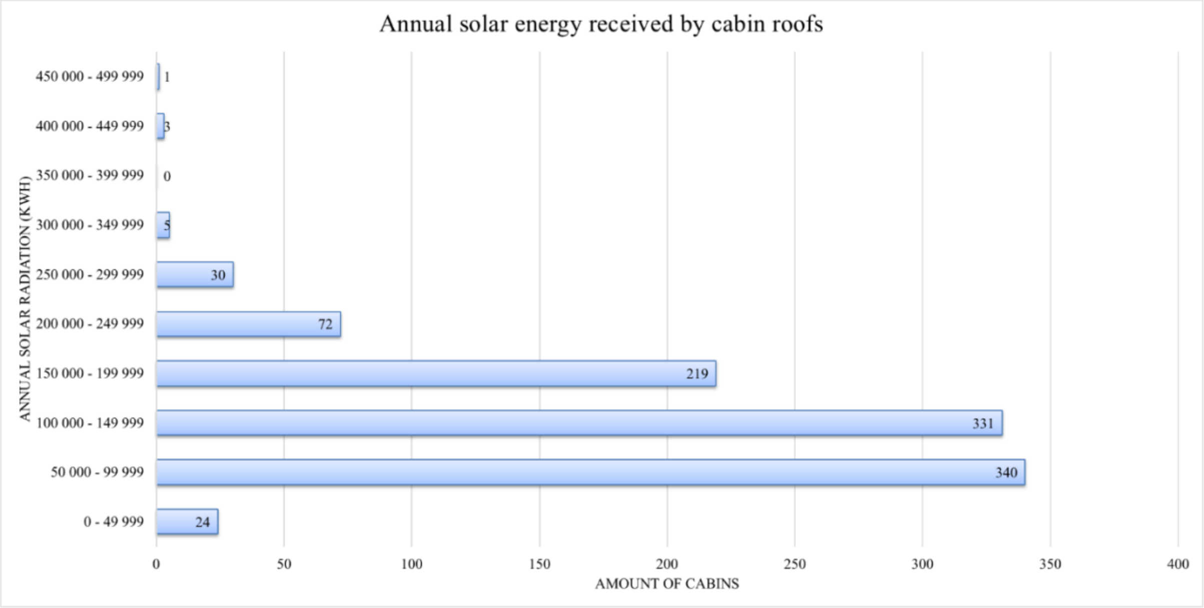


Figure 17: Annual solar radiation.

4.1.3 Monthly variations

The monthly calculations show a great temporal variety in insolation. Most solar radiation is received in June, while least solar radiation is received during December, as shown in figure 18.

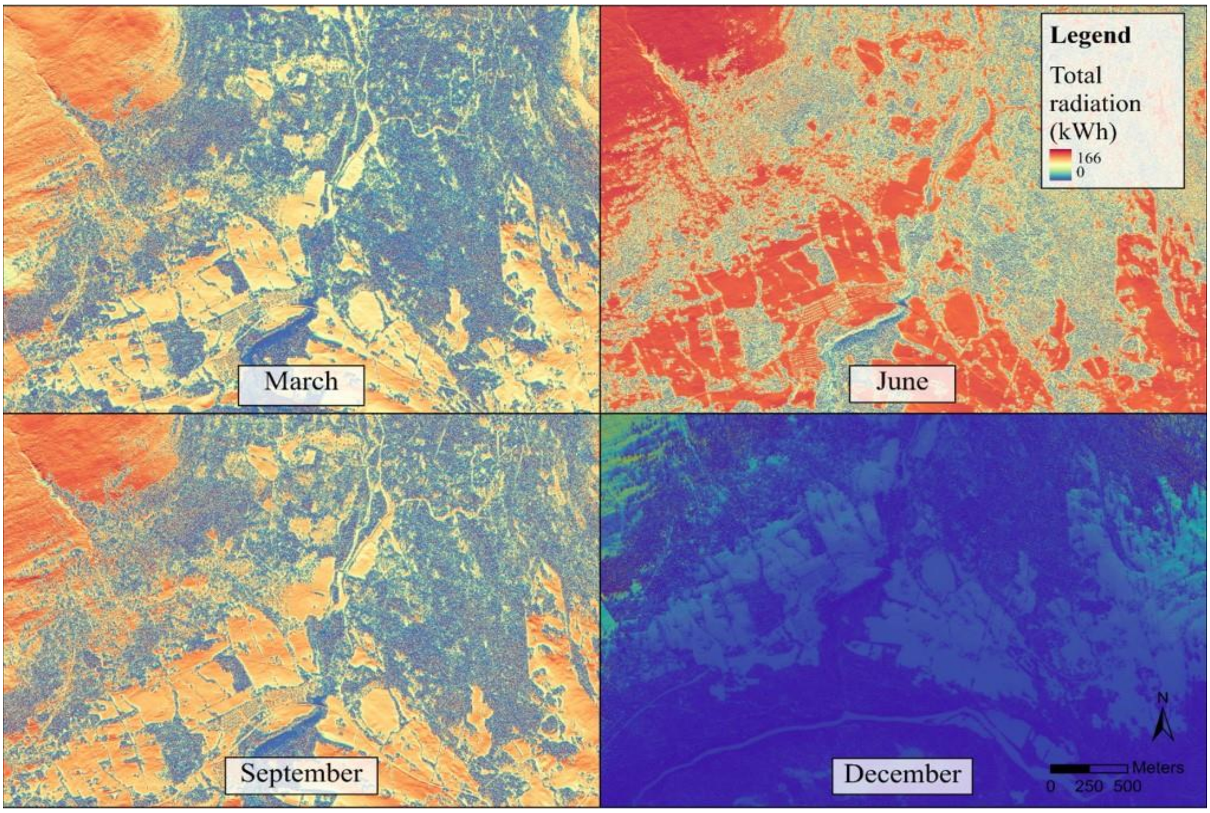


Figure 18: Monthly variations

The monthly solar radiation received on the most feasible, the least feasible and an average cabin in area C is shown in figure 19. The mean solar radiation surpasses 10 000 kWh in May, June and July and 5000 kWh during April and August. The most feasible cabins receive more than 40 000 kWh of solar radiation during June and July, and more than 10 000 kWh from April to September. During October and November, the solar radiation decreases rapid.

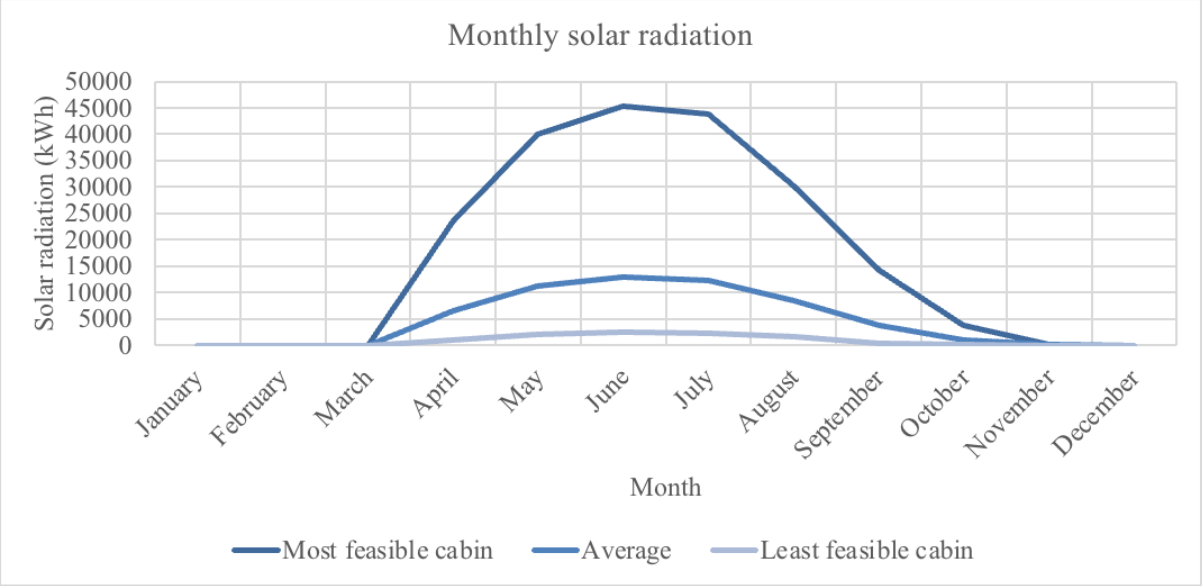
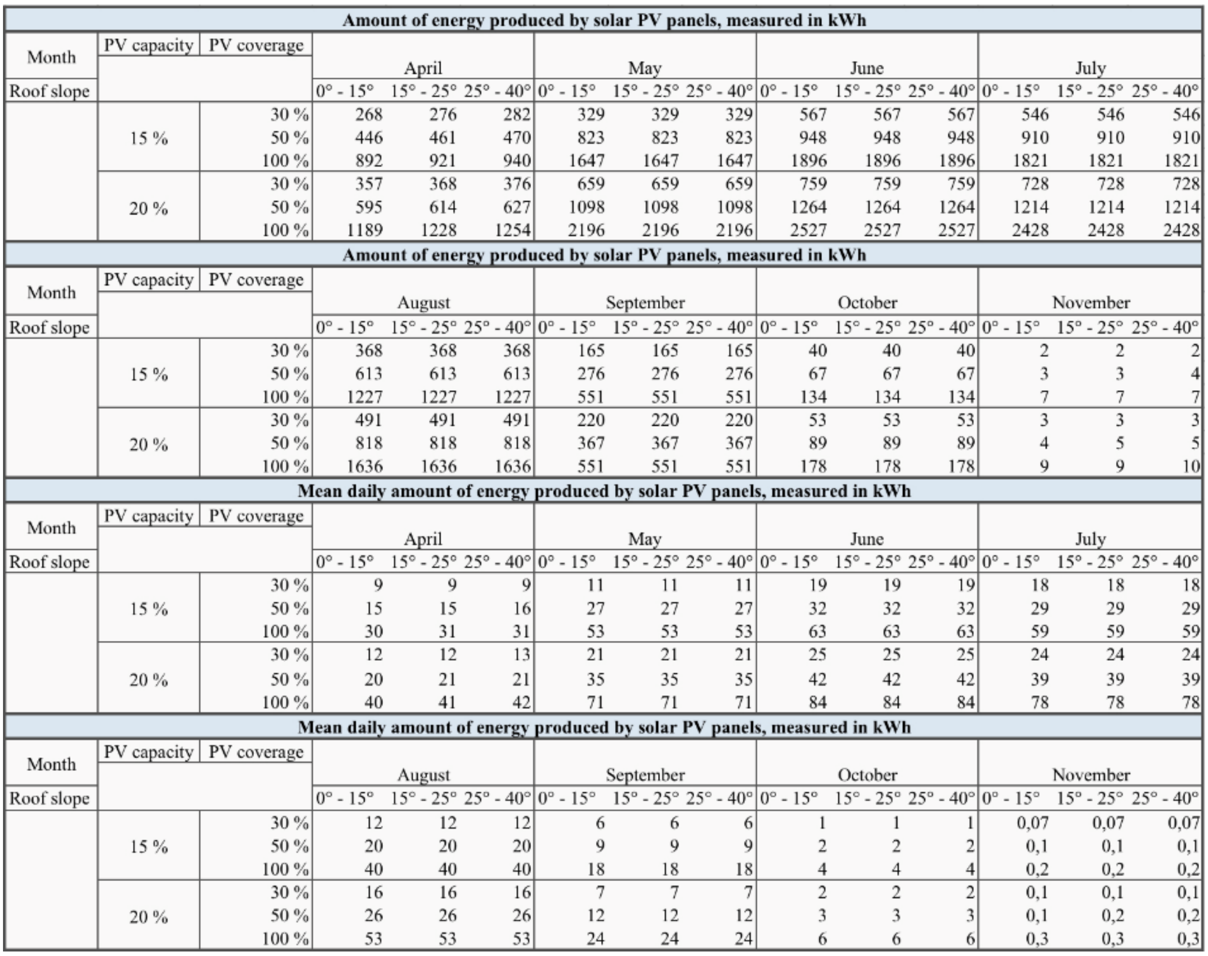


Figure 19: Monthly solar radiation.

4.1.3 Key performance indicators

The following KPIs are calculated using the mean value for the months April through November. December through March are not evaluated, as the soiling factor is set to 100 and thus no solar radiation is received. Numbers are collected from the monthly small-scale analysis. Three different scenarios concerning solar PV panel coverage on roofs are considered, namely 30%, 50% and 100% coverage. The numbers are adjusted according to indicative values for the soiling-factor for solar modules with a roof slope in the range of 0°-15°, 15°-25° and 25°-40° (See Appendix for values). An average solar PV panel is able to capture 15%-20% of the total solar radiation, and thus numbers are given for a solar PV panel with an efficiency of 15% and 20% (Norsk solenergiforening, n.d.). Table 3 shows monthly and daily values for solar radiation in area C in April throughout November.

Table 3: Monthly variations



Amount of energy produced by solar PV panels, measured in kWh														
Month	PV capacity	PV coverage	April			May			June			July		
Roof slope			0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°
	15 %	30 %	268	276	282	329	329	329	567	567	567	546	546	546
		50 %	446	461	470	823	823	823	948	948	948	910	910	910
		100 %	892	921	940	1647	1647	1647	1896	1896	1896	1821	1821	1821
	20 %	30 %	357	368	376	659	659	659	759	759	759	728	728	728
		50 %	595	614	627	1098	1098	1098	1264	1264	1264	1214	1214	1214
		100 %	1189	1228	1254	2196	2196	2196	2527	2527	2527	2428	2428	2428

Amount of energy produced by solar PV panels, measured in kWh														
Month	PV capacity	PV coverage	August			September			October			November		
Roof slope			0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°
	15 %	30 %	368	368	368	165	165	165	40	40	40	2	2	2
		50 %	613	613	613	276	276	276	67	67	67	3	3	4
		100 %	1227	1227	1227	551	551	551	134	134	134	7	7	7
	20 %	30 %	491	491	491	220	220	220	53	53	53	3	3	3
		50 %	818	818	818	367	367	367	89	89	89	4	5	5
		100 %	1636	1636	1636	551	551	551	178	178	178	9	9	10

Mean daily amount of energy produced by solar PV panels, measured in kWh														
Month	PV capacity	PV coverage	April			May			June			July		
Roof slope			0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°
	15 %	30 %	9	9	9	11	11	11	19	19	19	18	18	18
		50 %	15	15	16	27	27	27	32	32	32	29	29	29
		100 %	30	31	31	53	53	53	63	63	63	59	59	59
	20 %	30 %	12	12	13	21	21	21	25	25	25	24	24	24
		50 %	20	21	21	35	35	35	42	42	42	39	39	39
		100 %	40	41	42	71	71	71	84	84	84	78	78	78

Mean daily amount of energy produced by solar PV panels, measured in kWh														
Month	PV capacity	PV coverage	August			September			October			November		
Roof slope			0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°	0° - 15°	15° - 25°	25° - 40°
	15 %	30 %	12	12	12	6	6	6	1	1	1	0,07	0,07	0,07
		50 %	20	20	20	9	9	9	2	2	2	0,1	0,1	0,1
		100 %	40	40	40	18	18	18	4	4	4	0,2	0,2	0,2
	20 %	30 %	16	16	16	7	7	7	2	2	2	0,1	0,1	0,1
		50 %	26	26	26	12	12	12	3	3	3	0,1	0,2	0,2
		100 %	53	53	53	24	24	24	6	6	6	0,3	0,3	0,3

The following KPIs are investigated:

- Average power consumption per month, measured for a 120 m^2 cabin (800 kWh)
- Charge a Tesla Model Y to full capacity (75 kWh)
- Heat up a hot water tank of 2500 liters (25 kWh)
- Two hours of heating and using a sauna (7-9 kWh)
- Shower for 10 minutes (5.6 kWh)
- Run a dishwasher (1 kWh)
- Heating up a jacuzzi (150-250 per month kWh during summer, 300 kWh/month during winter)

The average cabin in area C has a size of 127.3 m^2. According to Strøm.no (2019), a cabin of this size requires a little more than 800 kWh of electricity per month. Table 3 indicates that 51 scenarios are able to provide enough electricity to fully cover a month use of electricity. April through August has the most potential to cover the electricity use, however it will require a large coverage of high-capacity solar PV panels during April and August. Four scenarios where 50% of a cabin roof with a slope of 15°–25° is covered by solar PV panels with an efficiency of 15% are shown in figure 20.

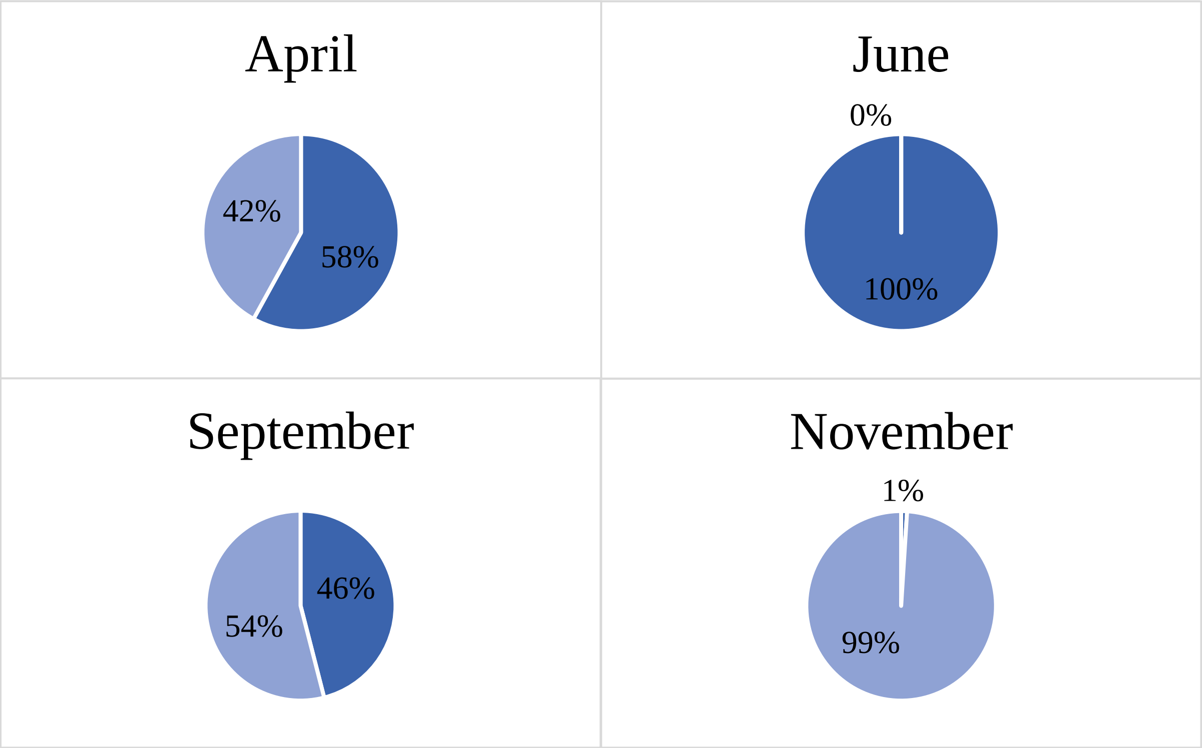


Figure 20: Percentage of electricity use covered by solar energy. Dark blue represents solar energy, while light blue represents remaining energy demand.

In 2022, Tesla Model Y was the most sold car in Norway (Norsk elbilforening, 2023). Tesla Model Y has a battery capacity of 75 kWh and is sold with a charger with a capacity of 11 kW (Norsk elbilforening, n.d.). An average cabin is thus only able to charge a Tesla Model Y from 0 to 100% in the scenario where 100% of their roof is covered by solar PV panels with a capacity of 20% in the months of June and July. Table 4 describes scenarios where 50% of a cabin roof with a slope of 15°-25° is covered by solar PV panels with an efficiency of 15%.

Table 4: Charging time, Tesla model Y

Month	Charging time	Prosentage of battery charged
April	1 hour, 22 minutes	20 %
May	2 hours, 27 minutes	36 %
June	2 hours, 55 minutes	43 %
July	2 hours, 38 minutes	39 %
August	1 hour, 49 minutes	27 %
September	49 minutes	12 %
October	11 minutes	2,70 %

Several cabins would be well suited to heat up a hot water tank during the summer months, as well as using a sauna, shower and running the dishwasher (TrøndelagKraft, n.d.; Sunwind, 2022; Hadeland, 2022). However, several of the scenarios allow heating up a jacuzzi during summer, but not after September (Norgesenergi, 2022).

4.2 Discussion

4.2.1 Solar energy potential in high latitudes

The solar analyses calculated for area C indicate several scenarios producing a sufficient amount of energy for completing everyday tasks. The feasibility for exploitation depends on the aim of implementing solar PV panels. Presuming that the goal is to produce electricity for everyday tasks, several cabins are considered feasible during April through October. All scenarios from April through September as well as the most promising scenarios calculated for October will for instance produce enough energy for running the dishwasher or taking a ten-minutes shower. More energy-intensive tasks, like heating up a hot water tank, will not be feasible during September nor October using only solar produced energy. Furthermore, only six scenarios showed cabins able to fully charge a Tesla model Y. Presuming that the goal is to cover a cabins' total electricity usage will result in a lower feasibility. The total energy requirement for a 120 m^2 cabin is met in 54 of the 144 calculated scenarios, not including December through March. Furthermore, scenarios are calculated for an average cabin in area C. Most cabins deviate from the average, and will thus produce an altering amount of energy depending on roof area.

Future cabin construction might optimize solar energy exploitation by taking advantage of spatial varieties affecting the amount of energy received by each cabin. The total solar radiation received depends on factors like cabin location, roof orientation and roof size deciding the amount of solar PV panels possible for the given roof. Thus, constructors can localize, orientate and size new cabins in order to receive a feasible amount of solar energy according to predefined energy goals.

4.2.3 Fluctuating energy density in high latitudes

Due to the fluctuating energy density of solar radiation and the low power density of solar PV panels, the temporal variations pose a critical issue regarding usable energy throughout the year. The power density of solar PV panels might increase in the future due to innovations in technology. The fluctuating energy density in high latitudes is however not changing. Innovative technology concerning energy storage and transfer might contribute to solve parts of the issue the coming years due to the high quest for solar energy exploitation from the EU. Assuming that up to four months of solar exploitation will be spoiled due to snow coverage, energy stored from excess days might not be sufficient. The low power production during winter might be prevented by removing snow from cabin roofs during winter months. However, monthly trends show a rapid decrease in the amount of received energy after September. To reach the goal of becoming a low emission society by 2050, Oppdal municipality therefore has to supplement with other climate actions. In order to be in line with the municipality’s master plan and the national expectations for regional and municipal planning, the actions should not conflict recreation areas. Despite, power produced from solar PV panels on cabin roofs can contribute to the green transition in Oppdal municipality, especially during summer. The implementation would also contribute to the municipality’s goal of an increased use of RES.

4.2.2 Solar PV panels as a green energy solution for rural municipalities

The plan for national expectations for regional and municipal planning presents clear expectations for rural municipalities in Norway to contribute to a low-carbon society (Kommunal- og moderniseringsdepartementet, 2019, p. 15). As this is also the goal for Oppdal municipality, planners and policy makers might further investigate how local solar energy can be a virtuous solution for developing a more sustainable society while also preserve important nature areas in the municipality.

The installation of solar PV panels on cabin roofs will result in several small and widespread RES landscapes. As the place of energy exploitation is the respective cabin, the RES landscape requires very little transportation infrastructure which may present an advantage for Oppdal municipality as they aim to preserve nature areas. By utilizing existing roofs, the RES landscapes avoid some of the problems concerning competing land use. Even though Oppdal municipality has large surrounding nature areas, the areas are mainly used for recreational activities. Oppdal municipality market itself as a year-round travel destination where valuable nature experiences are in focus. Hence, small RES landscapes on cabin roofs are not conflicting with their marketing strategy. As Oppdal municipality is looking to increase the use of RES in their energy mix, the small RES landscapes of roof mounted solar PV panels might pose a better solution than other RES like windmills and hydroelectric power plants which require larger RES landscapes for harnessing and transporting energy. Additionally, windmills and hydroelectric power plants are more visible where they are installed compared to roof-integrated solar PV panels.

The small amount of transportation infrastructure is associated with a scenario where each cabin is its own RES landscape. Hence, if the municipality decides to expand the RES landscape to include all cabins harnessing solar energy, the resulting RES landscape will take up more space. A micro grid could for instance enable the transfer of electricity surplus to larger complexes like Domus Oppdal or Aunasenteret, but would require the construction of more infrastructure.

4.2.2 KPIs and solar maps as a source of information

As of May 2023, Oppdal municipality does not have any regulations stating that solar PV panels should be mounted on cabin roofs. It is therefore up to each cabin owner to decide if they want to install the panels. The spatial variations in insolation in addition to the lack of regulations concerning installation of solar PV panels calls for user friendly tools for informing the common public about solar potential.

The solar maps can be used to inform cabin owners about the potential of their cabin. They can both be used by the municipality to inform owners of the most feasible cabins and for other cabin owners to examine their cabin’s potential. However, the maps are not detailed enough to provide owners with specific numbers. For this, more advanced maps or tables should be made. Furthermore, the maps are based on assumptions which might not be transferable to all cabins. The solar maps can thus be used as a tool to arouse the curiosity of cabin owners. The same can be said about the KPIs presented. Even though the KPIs make the solar radiation numbers more understandable, they might not be exact for each cabin. However, they can be used as a tool to increase interest and to relate numbers to everyday life. The different scenarios take into account the slope of the cabin roof as well as to which degree the roof will be covered with solar PV panels, making it easier for each cabin owner to address a suitable solution.

As the installation of solar PV panels have the potential to increase the amount of RES in the local energy mix of Oppdal municipality and to contribute to both national and international climate goals, policy makers may have an interest in contributing to the installation by incentivizing solar PV panels. Enova, an organization working for a national green transition, is already supporting households producing their own power (Enova, n.d.). Thus, Oppdal municipality might not need to incentivize the installation to a large extent. However, the municipality could be in charge of spreading information about Enova’s support and the benefits of solar power production to local cabin owners, for instance by using solar maps and KPIs.

4.3 Limitations to the study

The analysis contains several limitations which may influence the results. The limitations and error sources can be subdivided into three main categories; GIS software, calibration of the tool and spatial data.

4.3.1 GIS software

A major limitation associated with GIS software is calculation time. Calculating the annual solar radiation using the described parameters for area C, using a one-meter resolution DSM used approximately 48 hours, while calculating monthly solar radiation required more than 24 hours per month. The analyses were simplified to reduce calculation time. Reduction was partly done by dividing the analysis into a large-scale and a small-scale analysis, and partly by adjusting the parameters. For instance, a value of 8 was used for both zenith and azimuth divisions despite inserting a higher value would make the analysis more accurate.

Another limitation is associated with the tool’s parameters. The tool has 13 parameters which affect the output raster to a varying degree, and it is thus important that these are set as correct as possible. With a calculation time of 1 year, parameters like *Diffuse proportion* and *Transmittivity* will vary. Thus, the model represents a simplification of reality. A way of minimizing errors associated with varying atmospherical parameters could be to run the tool four times for each of the two main analyses, once for each season. For each analysis, the parameters should be set according to atmospherical values characteristic for the respective season.

Lastly, GIS software does not measure reflected solar energy. The analysis is performed at high latitudes where snow is common during winter. As snow has an albedo of almost 0.9, a large amount of radiation will be reflected. However, as the solar PV panels are places on roofs with surfaces facing upwards, reflected radiation might not impact the total solar radiation as much as for a standalone or facade PV panel facing downwards.

4.3.2 Calibration

The calibration of the tool was done to achieve a more realistic result. However, the calibration process showed that the provided values might be slightly too low. Furthermore, the value 8 was chosen for *calculation directions*. The value has a lower resolution than higher values, as the resolution increases linearly with the value. Therefore, the total radiation measured with the value 8 might be imprecise. An alternative solution could be to investigate which atmospherical parameters result in a mean value of the ten values used for calibration that is closest to the numbers for the ZEB-lab. Thereafter, the value closest to the mean value could be used for *calculation directions*.

Another possible error source associated with the calibration of the tool is the calculated numbers for the total insolation on the ZEB-lab. The calibration was performed based on numbers from a pyranometer placed on the roof of the building. The pyranometer calculates solar radiation for one m^2. This number was multiplied by the whole area representing the roof in the FKB-data in GIS with the assumption that this is the correct area and that each m^2 receive the same amount of solar radiation. The area representing the roof of the ZEB-lab is the horizontal area. However, the roof of the ZEB-lab has a slope and is thus a larger area than indicated in the FKB-data, which will affect the calibration.

4.3.3 Spatial data

The third main category of limitations considers data used for the analyses. The DSM used in the large-scale analysis has a resolution of ten meters which is not very detailed when it comes to solar analysis as it might not cover obstacles like trees and elevation changes on roofs. Consequently, the analysis done with the lower resolution DSM is not precise and the area chosen from the large-scale analysis might not be the one best suited. Furthermore, the one-meter resolution DSM used for the small-scale analysis is the most precise DSM available from Høydedata. However, some roofs have smaller elevation changes, so that features like chimneys might not be covered by the DSM.

5. Conclusion

This study employs GIS to examine the feasibility of solar PV panels on cabin roofs in high latitudes. Results indicate that several cabins are able to produce a sufficient amount of energy to power daily activities during summer. During winter, the received amount of solar radiation is not sufficient for powering daily activities, and thus not a feasible solution. Solar energy can however serve as a contribution to a more sustainable energy mix, powering a green transition. In this manner, solar PV panels can be one of several solutions for rural municipalities when creating a more sustainable municipality.

The thesis further investigated how GIS software can support the creation of a map to identify areas with the highest solar potential in Oppdal municipality. The findings suggest that GIS can be an effective tool for calculating annual solar radiation. However, simplifications were done to reduce calculation time and thus the results may be affected. Nevertheless, the current study is an initial step in investigating the solar potential in high latitudes.

Further research could investigate how the average electricity use on cabins shift relative to the shifting seasons and the fluctuating solar energy potential. Furthermore, the social acceptance of solar PV panels on cabin roofs and how implementation could be done in a socially accepted manner could be investigated, Lastly, the economic aspects and life cycle assessments concerning solar PV panels on cabin roofs should be considered.

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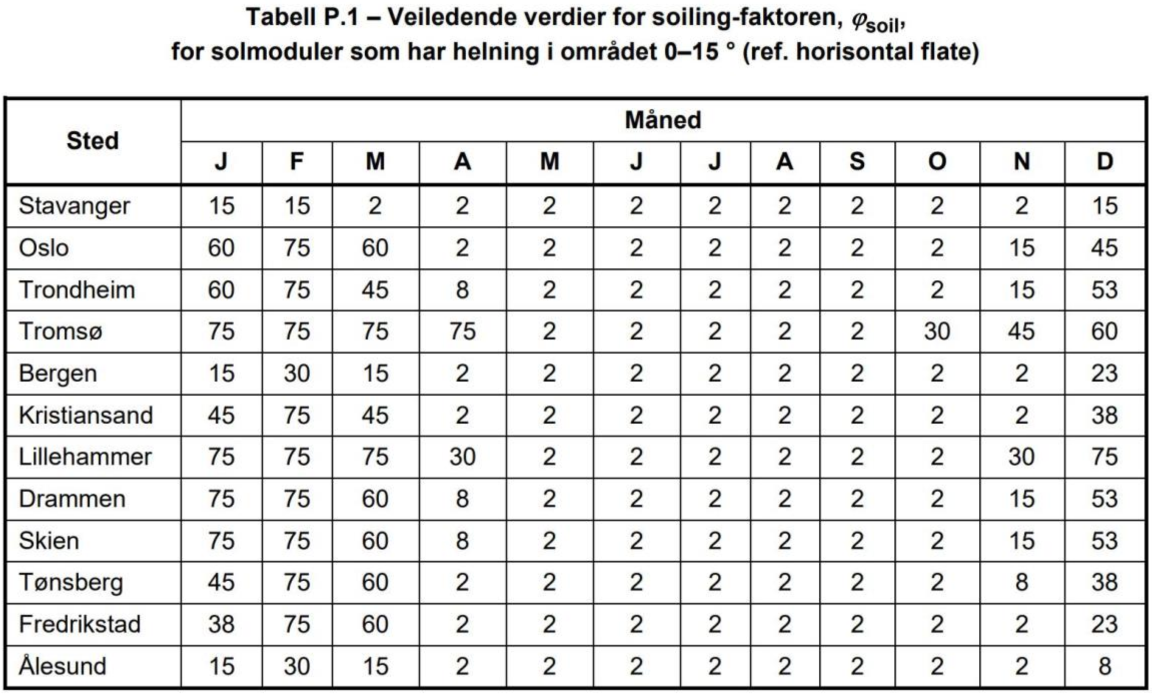
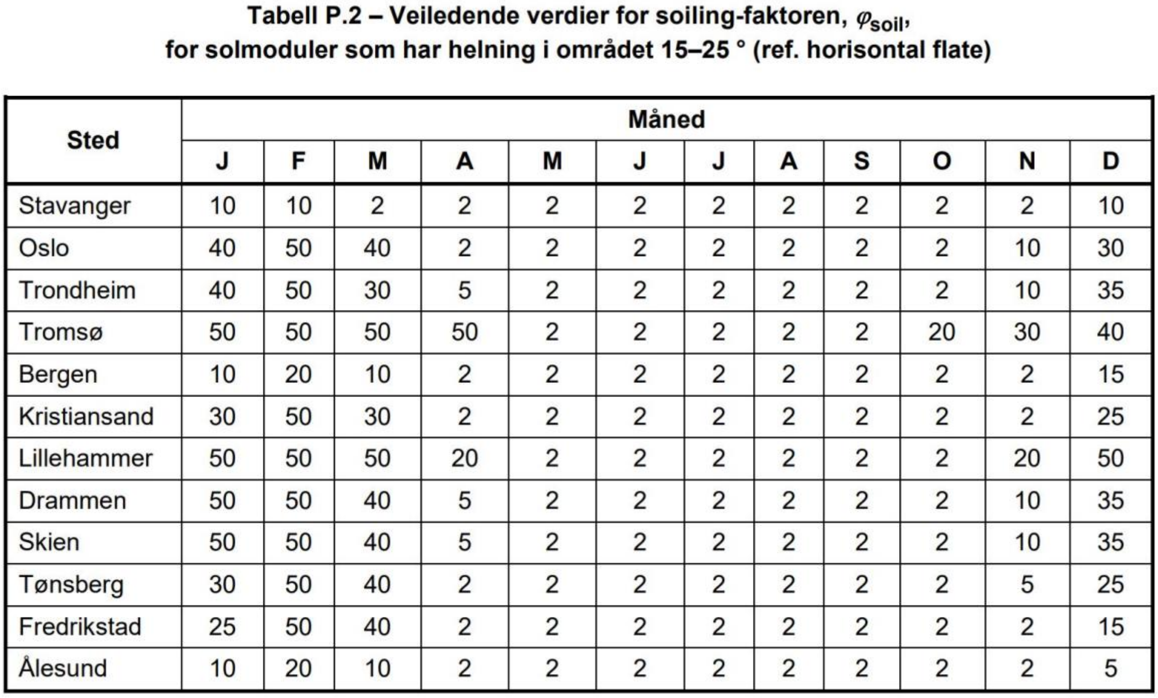
Appendix



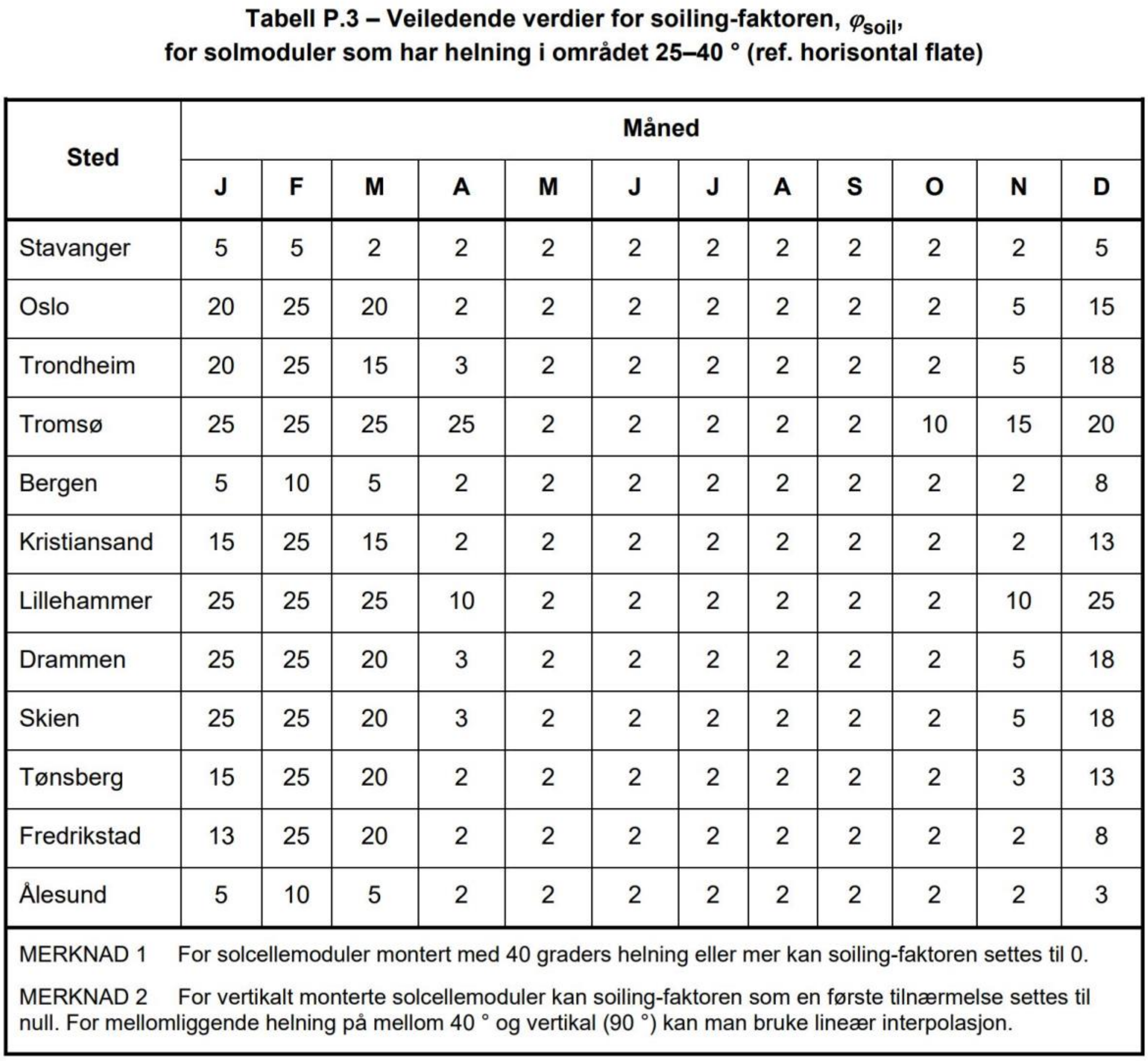
Tabell P.1 – Veiledende verdier for soiling-faktoren, φ_{soil}, for solmoduler som har helning i området 0–15 ° (ref. horisontal flate)

Sted	Måned											
	J	F	M	A	M	J	J	A	S	O	N	D
Stavanger	15	15	2	2	2	2	2	2	2	2	2	15
Oslo	60	75	60	2	2	2	2	2	2	2	15	45
Trondheim	60	75	45	8	2	2	2	2	2	2	15	53
Tromsø	75	75	75	75	2	2	2	2	2	30	45	60
Bergen	15	30	15	2	2	2	2	2	2	2	2	23
Kristiansand	45	75	45	2	2	2	2	2	2	2	2	38
Lillehammer	75	75	75	30	2	2	2	2	2	2	30	75
Drammen	75	75	60	8	2	2	2	2	2	2	15	53
Skien	75	75	60	8	2	2	2	2	2	2	15	53
Tønsberg	45	75	60	2	2	2	2	2	2	2	8	38
Fredrikstad	38	75	60	2	2	2	2	2	2	2	2	23
Ålesund	15	30	15	2	2	2	2	2	2	2	2	8



Tabell P.2 – Veiledende verdier for soiling-faktoren, φ_{soil}, for solmoduler som har helning i området 15–25 ° (ref. horisontal flate)

Sted	Måned											
	J	F	M	A	M	J	J	A	S	O	N	D
Stavanger	10	10	2	2	2	2	2	2	2	2	2	10
Oslo	40	50	40	2	2	2	2	2	2	2	10	30
Trondheim	40	50	30	5	2	2	2	2	2	2	10	35
Tromsø	50	50	50	50	2	2	2	2	2	20	30	40
Bergen	10	20	10	2	2	2	2	2	2	2	2	15
Kristiansand	30	50	30	2	2	2	2	2	2	2	2	25
Lillehammer	50	50	50	20	2	2	2	2	2	2	20	50
Drammen	50	50	40	5	2	2	2	2	2	2	10	35
Skien	50	50	40	5	2	2	2	2	2	2	10	35
Tønsberg	30	50	40	2	2	2	2	2	2	2	5	25
Fredrikstad	25	50	40	2	2	2	2	2	2	2	2	15
Ålesund	10	20	10	2	2	2	2	2	2	2	2	5



Tabell P.3 – Veiledende verdier for soiling-faktoren, φ_{soil}, for solmoduler som har helning i området 25–40 ° (ref. horisontal flate)

Sted	Måned											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Stavanger	5	5	2	2	2	2	2	2	2	2	2	5
Oslo	20	25	20	2	2	2	2	2	2	2	5	15
Trondheim	20	25	15	3	2	2	2	2	2	2	5	18
Tromsø	25	25	25	25	2	2	2	2	2	10	15	20
Bergen	5	10	5	2	2	2	2	2	2	2	2	8
Kristiansand	15	25	15	2	2	2	2	2	2	2	2	13
Lillehammer	25	25	25	10	2	2	2	2	2	2	10	25
Drammen	25	25	20	3	2	2	2	2	2	2	5	18
Skien	25	25	20	3	2	2	2	2	2	2	5	18
Tønsberg	15	25	20	2	2	2	2	2	2	2	3	13
Fredrikstad	13	25	20	2	2	2	2	2	2	2	2	8
Ålesund	5	10	5	2	2	2	2	2	2	2	2	3

MERKNAD 1 For solcellemoduler montert med 40 graders helning eller mer kan soiling-faktoren settes til 0.

MERKNAD 2 For vertikalt monterte solcellemoduler kan soiling-faktoren som en første tilnærmelse settes til null. For mellomliggende helning på mellom 40 ° og vertikal (90 °) kan man bruke lineær interpolasjon.

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