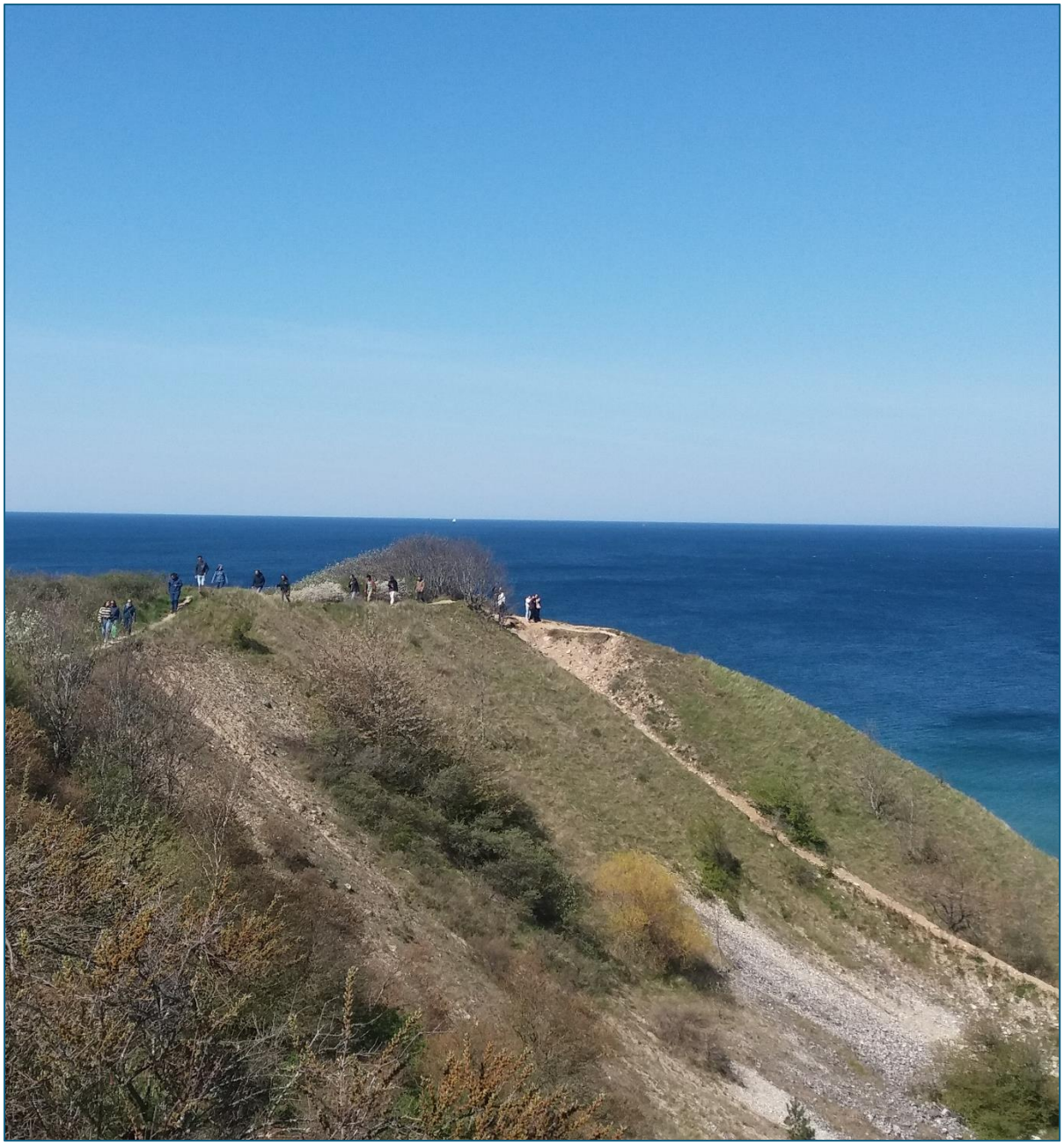

Odsherred Insights

Sustainable Transitions in Odsherred

3rd Edition

6 May – 14 May 2023

GHENT UNIVERSITY

DEPARTMENT OF GEOGRAPHY

UNIVERSITY OF COPENHAGEN

Roskilde Universitet

Introduction

Every year, students in the Master of Science in Geography and Geomatics of Ghent University (Belgium) undertake a research trip abroad. Since 2021, the destination of this project work has been Odsherred, Denmark, in collaboration with Roskilde University and the University of Copenhagen. This third edition took place from the 6th to the 14th of May 2023 in Udsigten.

Apart from excursions in Odsherred and the surrounding areas, the research trip has included an intensive geographic fieldwork project where students actively investigate the local spatial dynamics in the more rural area of Odsherred. The overall aim of this project work is to enhance students' scientific and intellectual competencies in geography through critical literature reviews, research design, fieldwork (e.g., surveys and interviews with locals), data collection, scientific analysis, and oral and written presentations. The topics investigated are all self-defined research projects, applying skills from other courses in a context abroad. The project work emphasises an interdisciplinary approach, covering different aspects (physical geography, landscape research, social and economic geography, as well as geomatics).

The students were assisted by teachers and researchers from Ghent University, the University of Copenhagen, and Roskilde University, as well as people from Geopark Odsherred, the Municipality of Odsherred, and local organisations and inhabitants. Below you can find an overview of the different research projects that were undertaken.

1. Travel satisfaction

- Noor Ghesquiere, Bavo Danneels, Maud Boghaert, and Paulien D'Hondt -

Taking the bus, train or car? Investigating the transport network and travel satisfaction in Odsherred, Denmark.

2. Recreational cycle network

- Emma Bekaert, Eva De Mits, Gil Glorieus, and Maud Vervaet -

Revolutionising cycling in Odsherred, Denmark: Creating a numbered-node cycle network to promote recreational bicycle use.

3. Future nature management

- Antoine Anneessens, Aag Bogaert, Ninke Fant, Nina Neutens, and Kobe Vervaecke -

Understanding the relation between past land use, soil, and biodiversity for future nature management around Hov Vig.

4. Solar energy

- Arthur Catteuw, Hannah De Cock, Loïc Dumortier, Lise Goossens, and Lore Lamote -

Solar energy in Odsherred: A dream or reality?

5. Viticulture

- Rune Van Severen, Simon Stael, Rémi Vandewalle, and Dries Coucke -

Viticulture in a changing Scandinavia: A case study of Odsherred and its surroundings, Denmark.

The 3rd Edition of the Odsherred Insights was made possible by the collaboration of many people from several organisations.

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Stakeholders that were involved:

The Municipality of Odsherred
Geopark Odsherred
All interviewed locals
Local organisations

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FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

TAKING THE BUS, TRAIN OR CAR?

INVESTIGATING THE TRANSPORT NETWORK AND TRAVEL SATISFACTION IN ODSHERRED

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Course: Integrated international project

Academic year: 2022 - 2023

UNIVERSITEIT GENT

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1 INTRODUCTION

When making a trip, several choices must be considered, for instance mode choice and route choice. These choices are determined by a set of different aspects such as comfort, price, duration of the trip, and how the transportation network is set up. This integrated international project will examine the travel behaviour of the people living or staying in Odsherred. The importance of this study can be found in different aspects. To outsiders, it seems Denmark is doing a good job in terms of evolution and further development of mobility, by offering, for example, shared micromobility and electric cars. However, its existence does not automatically mean it operates well. Therefore, it is important to investigate how satisfied the local people are with the offered services, in this case predominantly in terms of public transport, and especially in a more rural area. This study is distinguished by the fact that the transport network hasn't been academically investigated for Odsherred nor a lot of other more rural areas. Transportation studies are almost always located in urban areas. The fact that the study is mainly based on the respondents' input, makes the research study distinctive. It is considered to include both the residents of Odsherred and the tourists, since a lot of people own a summer house in the area, and their mobility pattern will probably differ from the locals. The main goal is to find out which transport modes are used and for what purpose, as well as the reason of this mode choice. The functioning of the transport network will be thus investigated. One of the subgoals is to detect the stated problematic points in the local transportation network. These points may be designated by the people as problematic points because of safety reasons, but also because of poor connection to other modes or a lot of congestion, for example. With a survey, both qualitative and quantitative answers are collected to get a better insight in this topic. Surveys are taken at different locations in Odsherred to reach a variated fraction of the people residing in the area. The commute routes of local residents will be investigated, in combination with the most used routes taken by tourists who stay in a summer house and frequently used routes by occasional visitors. In addition, the profiles of the users will be deducted by performing a cluster analysis. Furthermore, the spatial pattern of trips with different transport modes will be examined and finally, this report ends with a list of conclusions based on the collected quantitative and qualitative data.

KEYWORDS

Mobility, accessibility, transport network, commute, travel behaviour, public transport

2 RESEARCH GOALS AND QUESTIONS

This research aims to determine how well the transport network and transport modes offered in Odsherred function and how this can be improved according to different transport users in the area. An important subquestion to keep in mind is if there are significant differences between the needs of local residents and summer house owners (in terms of transport network optimization). Through a survey combined with a tool called TravelTrack, the goal is to determine how people like to travel around in this municipality and establish where they are not satisfied with the options/service that public transport offers.

Secondly, it could be interesting to investigate the different user profiles to which the respondents belong. This could give an insight into how the population of Odsherred is composed in terms of mobility. Finally, some proposals to improve public transport arrangements and other stated problems in the function of different transport modes will be formed.

In order to achieve these research goals, the main research question was framed as follows:

'How can insight into travel behaviour and appreciation be used to improve the transport network in Odsherred?'

To support this main research question, the following four subquestions are formed. They each contribute partly to be able to formulate an answer to the main question and make the research easier to understand:

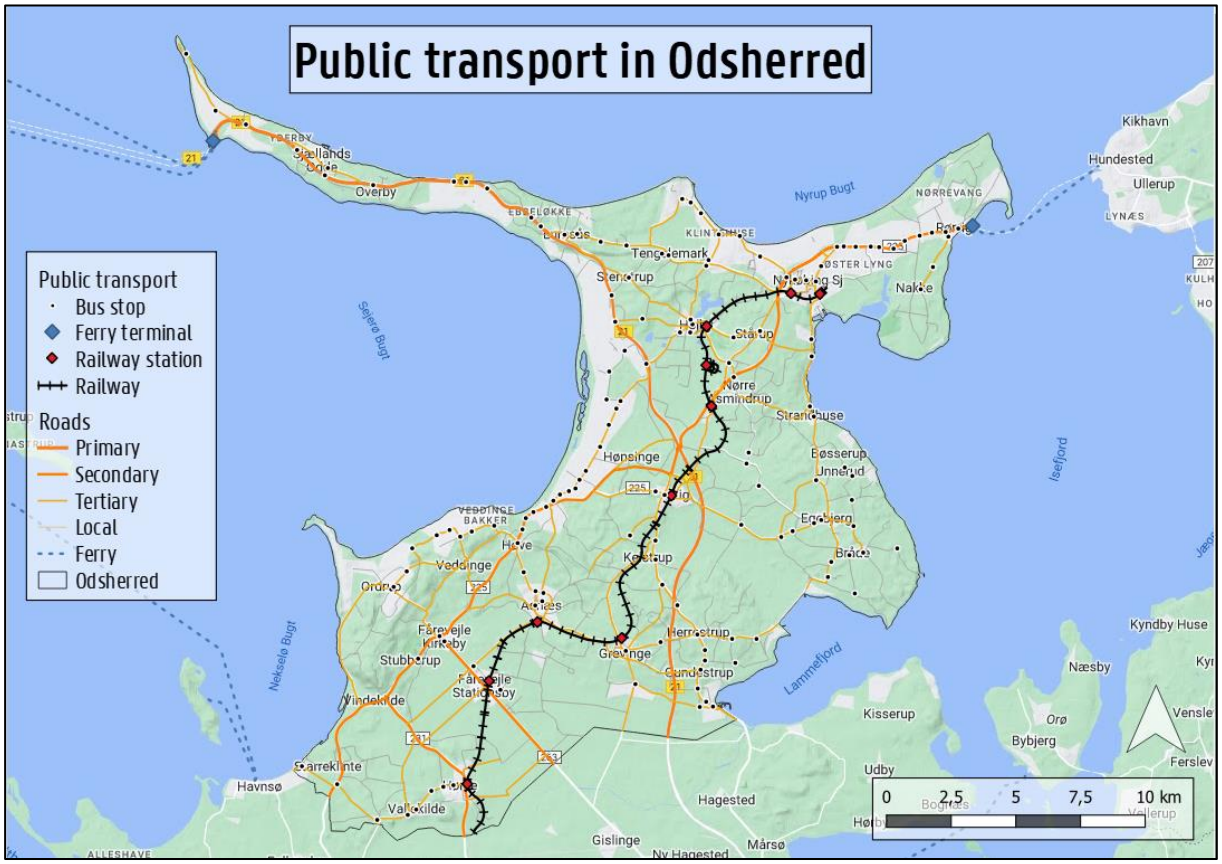
- *What is the difference between the appreciation of the transport network connectivity by local residents and summer house owners?*
- *What are the most common issues in the transport network, identified by the people?*
- *What is the spatial pattern of the transport modes?*
- *What are the user profiles among the respondents?*

3 THEORETICAL FRAMEWORK

Below, the current public transport network in Odsherred is visualized on a map (Map 1). The black line with regular small intersections, which represents a railway, immediately catches the eye. This is currently the only existing railway in the region. This train runs between Nykøbing Sjaelland and Holbæk, and passes each station twice an hour (https://www.odsherred.dk/da/bo-og-leve/trafik-i-hverdagen/trafik/offentlig-transport/, 2023). It's called the '510R Odsherredsbanen'. The ride consists of 15 train stops, with a total duration of 55 minutes. Next to this train, there are also busses adding to the public transport service in Odsherred. There are a few lines present that serve the residents and guests of Odsherred. The black dots on the map (Map 1) represent all the bus stops in the area. At first sight, it seems like there are a lot of bus stops in the area, but since the municipality extends over an area where the houses are quite widespread, bus stops are missing in several places. Furthermore, there are two ferry routes in Odsherred. These are Rørvig-Hundested and Odden- Aarhus/Ebeltoft Molslinjen (https://www.odsherred.dk/da/bo-og-leve/trafik-i-hverdagen/trafik/offentlig-transport/, 2023).

Map 1:

Public transport in Odsherred (own creation in QGIS, 2023).



The community is aware of the lack of bus stops and connectivity in some regions of the municipality. As a solution, the municipality of Odsherred provides a service known as Flextur. This public transport service is designed for citizens who do not reside in the neighbourhood from route-based public transport. It's also frequently used by people with limited mobility (Movia Trafik, 2023). Flextur is thus a demand-driven and address-oriented way of public transport, offering a tailored approach to public transportation. Because of this additional service, municipalities can focus their resources on running the fixed buses where the largest passenger numbers are, without disregarding the needs of other residents. It is important to note that Flextur differs from a conventional taxi service, as passengers often share the ride with others who have booked similar trips. Consequently, the most direct route may not always be followed.

As a means to enhance the convenience and appeal of public transportation in the country, Denmark introduced the Rejsekort in 2012 (H. Harboe & Riis, 2015). This card can be used on trains, metros, and buses. To obtain a personalized Rejsekort, individuals have to register on the website and have the possibility to load funds onto the card. From then on, traveling is possible with all three travel modes. To ensure accurate fare calculation, it is important to check in by the start of the journey and to check out again at the end. It's also possible to travel with multiple people using one Rejsekort. This card could be a first step towards MaaS (Mobility as a Service) in Denmark. In 2018, a master's thesis was published on this topic, which concluded that the Rejsekort should be complemented with an application that shows real-time information on available connections and delays (Gülsen & Atceken, 2018).

To make the public transport more attractive to younger people, there is also the Ungdomskort. This card is for everyone between 16 and 19 years old or people who are following an educational program. With this card, they can travel for free between their home and their school. Next to that, the card provides them with a discount on all their other trips in Denmark (Youth Card (Ungdomskort) - DOT, n.d.).

Public transport in Denmark is predominantly provided in urban areas, for the obvious reason that more people live here than in the rural areas. Therefore, many academic studies are reporting on how to improve public transport in more rural areas (such as Odsherred). Indeed, people in rural areas often rely on private or public transport to carry out their daily lives. Although there is no such example in Odsherred itself. Sama et al (2023) conducted a study in rural areas of India on the stated preferences of local people. That study concluded that tangibility and reliability are the most important factors for people to decide whether to use public transport or not. These include "buses are accessible to all categories of passengers", "buses are spacious, safe and

comfortable", "it is quite easy to get bus tickets", "passengers' interests come first" and "buses arrive on time". We will explore whether such factors are also crucial according to respondents in Odsherred in Denmark, a country that differs from India in many ways.

4 METHODOLOGY AND SOURCES

4.1 Before fieldwork

Mainly, three things needed to be developed to be able to perform our fieldwork. Firstly, we did desktop research on the current state of the transportation system in the area of Odsherred. The result of that can be found above on the map (Map 1) and the accompanying theoretical framework. Secondly, we needed to put together a survey, in which we ask some general, demographic questions and questions that are more related to people's mobility behaviour. UGent has a license for using Qualtrics, so we created our survey in this program (see appendix). Furthermore, we also needed a mapping tool, because in Qualtrics there's no option to point elements on a map, and as geographers, a spatial component to our research is important. Therefore Bart De Wit let us use a prototype of the 'TravelTrack' application for the mapping part of our surveys. To link the right survey to the right TravelTrack, we used ID's. The ID's work according to the following code: day – month - group – survey count. We'll split up into two groups on the field to reach more respondents, so the value for the group is either '1' or '2'. So for example ID 85101 refers to the first survey taken on the 8th of May (5) by group 1. These ID's are linked through a question in the survey as well as an input field in the TravelTrack. We soon noticed that there was some abundant information in the survey that could be already deducted from the TravelTrack, so we decided to delete for instance the question 'Where do you live?'.

During our brainstorming about which statistics we were going to use and calculate to get insight into the data, different ideas came up. First, we considered investigating the difference in frequency between car use and use of public transport between two groups (for instance tourists vs. residents) by performing t-tests. However, only 16 of the 81 respondents to the survey were tourists so it wouldn't be representative enough. Furthermore, we considered using age categories to compare answers between these different groups by performing ANOVA/t-tests. We realized that the kind of statistical analysis that can be performed is very dependent on the number and kind of data available.

4.2 During our visit in Odsherred

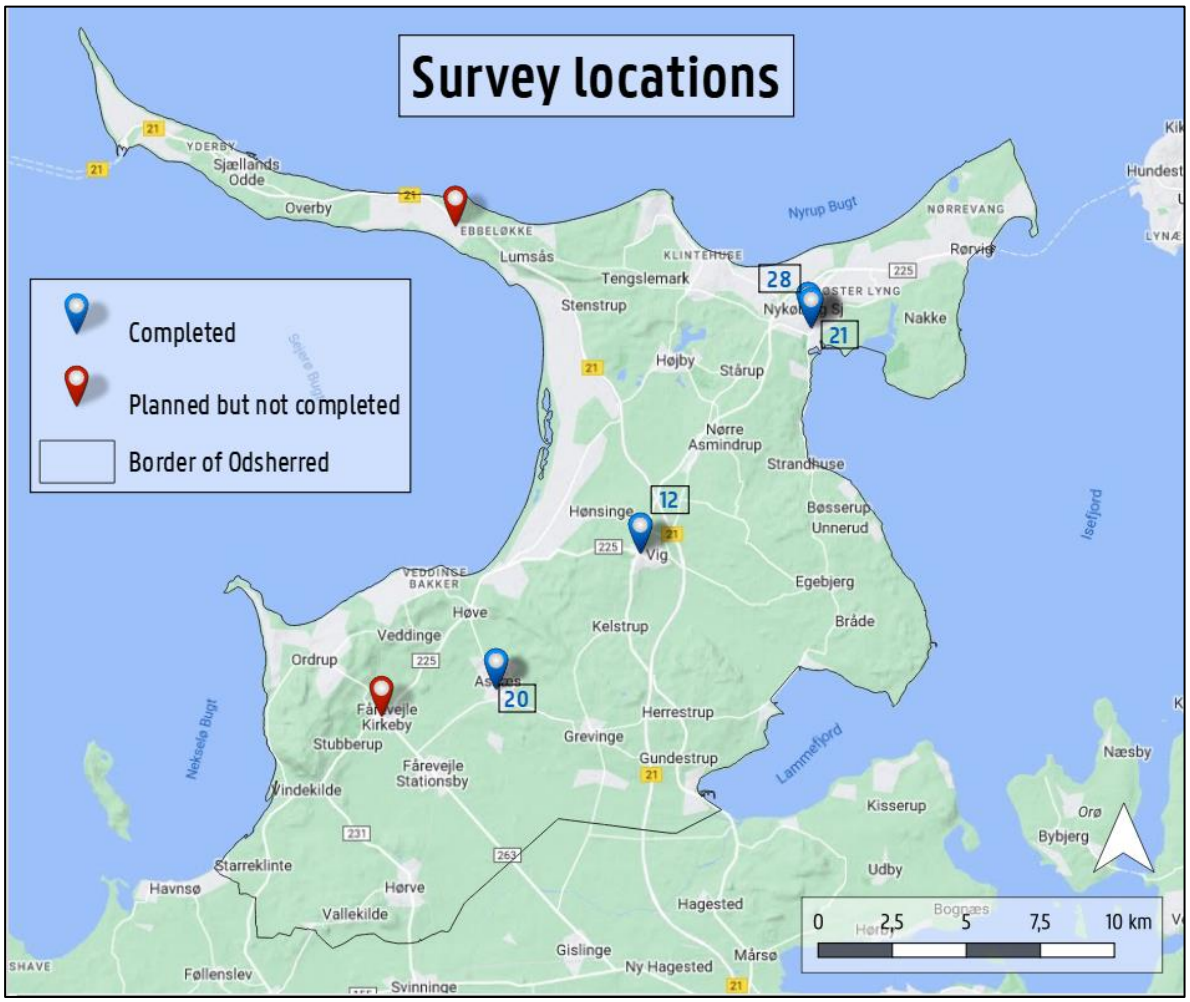
In this section, we will describe day by day how the field work developed. This way, it will become clear what we learned and how we adjusted our plans during the process. For example, the responsiveness was not always what we had hoped for, and that made us change locations more often than expected.

4.2.1 Day one

On the first day in Høve, we were able to finalize and test our survey questions in Qualtrics as well as implement the correct questions into the TravelTrack application. After that, we did some research about suitable locations to take our surveys. We tried to select different types of public places, like supermarkets, museums, sports centers, and shopping malls. The chosen locations are spatially distributed as shown in Map 2. In the second phase of the day, we went on the field for the first time. We visited two of the locations we selected in our online research, Vig and Asnæs, to check if they have real potential. This check was necessary because enough people must be willing to take the survey during the limited time of the fieldwork. For example, it soon became clear that there would not be enough people at the Odsherred Brandmuseum that we could interview, so we immediately decided to eliminate this location and focus on more crowded alternatives.

Map 2:

Survey locations in Odsherred (own creation in QGIS, 2023)



4.2.2 Day two

On day two, we tested our survey and the TravelTrack application for the first time in Vig, in front of the supermarkets. One person filled in the survey on a tablet, and the other person collected the information needed for the application. Soon we adapted our keyboard on the tablet to Danish since our first respondent already faced difficulties with the English keyboard when filling in his home address. We collected two responses and found that taking both the survey and TravelTrack took about five minutes. In the evening, we sought out whether the answers were properly recorded in the database. Furthermore, we also tried out other practical things that we'll need to execute when we have all of our results, for instance exporting the results in Qualtrics to a CSV file. After these try-outs, we could continue thinking about the possible statistical tests to perform with this kind of data, of both quantitative and qualitative nature. We again had to conclude that the answer to that question would depend on the amount and kind of data we would collect in the following days.

4.2.3 Day three

Day three was our first full day of fieldwork. Paulien and Noor first went to Nykøbing Sjaelland harbour, where it was very quiet and there were almost no people to interview. The local restaurant there is closed on weekdays and no tourists were encountered. Some time was lost walking to and from the harbour. Eventually, they lined up at the entrance of the supermarket Aldi. Later in the afternoon, they took surveys in front of Lidl, more towards the centre of Nykøbing Sjælland. There they took most of the surveys. That led to 19 surveys until 5 pm.

Maud and Bavo positioned themselves all day in the shopping street Algade, right in the centre of Nykøbing Sjaelland. Bavo started with the TravelTrack and Maud continued on another tablet with the Qualtrics questions. Everything seemed fine in TravelTrack, except for a ferry route they couldn't draw and no possible option to point the problematic points during a train route on the map. They collected 25 surveys from both older and younger people.

In the evening, we looked up our retrieved data in both the database and Qualtrics. In the database, we investigated the table Question_answers according to the table Questions to find out which question ID referred to which question. With the help of Bart de Wit, we also added two questions to the TravelTrack app because of a problem with train routes we experienced in the field, as discussed above.

After some consultation in the evening, we decided to go to a supermarket in Vig which has opening hours from 8 till 22h. Supermarkets that are open at such a late hour do not regularly exist in Belgium, so it seemed interesting to go get a look right before closing time. We noticed that people were less willing to answer our questions. Nonetheless, we managed to add another 6 surveys, which brings the total amount up to 50 surveys after this first full day on the field.

4.2.4 Day four

This day was planned similarly to the previous one but at different locations. We first drove to Vig, split up, and positioned at two supermarkets. After half an hour we collected only five surveys, so we decided to take the train to Asnæs. We had a good experience, using one Rejsekort for the four of us. In Asnæs we went to the mall and collected about twenty surveys. During our break, we came across two people collecting surveys for Movia, the largest mobility company in Denmark. One of them was Anette Enemark, head of mobility at Movia. She was very interested in the data we would collect and so we exchanged some of the information we already had after a few days. They were collecting surveys concerning the use of sharing bicycles In Asnaes for schoolchildren. This encounter proves that changing mobility is a topic in this region. This conversation also showed that not all projects are easily welcomed by the people.

After our visit to Asnæs, we wanted to take the bus to Fårevejle Kirkeby to reach a few people from a more rural area. There we experienced for ourselves that taking the bus in Odsherred is not always evident, since the bus we planned on taking was suddenly cancelled. Therefore, we decided to take the train once more to Nykøbing Sjælland and take the rest of the surveys at locations we already knew to be successful. We reached a total of 81 surveys.

4.3 After fieldwork: processing the data

To find an answer to the following subquestion: 'What are the profiles among the respondents?', we performed an Exploratory Data Analysis (EDA). With this analysis, the goal was to get insight into the dataset and detect patterns or valuable understandings. This analysis included calculating a similarity/distance matrix (based on the Gower distance) combined with a dendrogram to find out through hierarchical clustering (by performing a Hierarchical Agglomerative method) which people form a cluster and for what reason they are clustered together. The choice for using the Gower distance can be motivated as follows. This distance measure is useful

for comparing different observations (in this case for instance two people who took our survey), based on multiple variables of various kinds. As described underneath, we had variables of both numerical and categorical nature. The following steps describe the process from calculating this Gower distance to obtain eventually the distance matrix in Figure 1.

The first step was deciding seven important factors that make up the profile of a mobility user. These factors must be possible to deduct from the survey. The following factors were chosen:
Resident/tourist, gender (M/F) , age (numerical) , amount of cars (numerical) , public transport user (yes/no), which type of public transport used (train/bus/ferry), employment status (6 options). The answers for each person in the survey to these factors were extracted from Qualtrics as a CSV file (Table 1).

Table 1:

Part of the CSV file of the factors used for creating a distance matrix

	A	B	C	D	E	F	G	H	I	J
1	ID	Resident/Tourist	Age	Gender	Employme	Amount o	Public trar	Train	Bus	Ferry
2	85101	Resident	60	F	Employed	1	No	0	0	0
3	85102	Resident	37	M	Employed	1	No	0	0	0
4	95101	Resident	49	M	Unemploy	2	No	0	0	0
5	95201	Resident	17	F	Student	2	Yes	1	1	0
6	95102	Resident	64	F	Retired	3	No	0	0	0
7	95103	Resident	17	F	Student	2	Yes	1	1	0
8	95104	Tourist	31	F	Employed	0	Yes	1	0	0
9	95105	Tourist	70	M	Retired	0	No	0	0	0
10	95202	Resident	52	F	Employed	0	Yes	1	0	0
11	95203	Resident	66	F	Retired	1	No	0	0	0
12	95106	Tourist	64	F	Retired	0	Yes	1	0	0
13	95204	Tourist	68	F	Retired	0	Yes	1	0	0
14	95107	Resident	70	F	Retired	1	Yes	1	1	1
15	95108	Tourist	68	F	Retired	0	No	0	0	0
16	95205	Resident	50	F	Employed	2	No	0	0	0
17	95109	Resident	22	M	Employed	2	No	0	0	0
18	95110	Resident	15	M	Student	1	Yes	1	1	0
19	95111	Tourist	66	M	Retired	0	No	0	0	0
20	95112	Resident	51	M	Employed	1	No	0	0	0
21	95206	Tourist	38	F	Seeking o	0	Yes	0	1	0

Satisfaction with the transport

As is shown in Table 1, the type of public transport is divided into 3 different binary columns. 1 means they use the respective transport mode, 0 means they never do. The other columns are not adapted.

After creating the CSV file, the code for creating the Gower distance between all different records in the CSV file was compiled. The Gower distance refers to a similarity measure for categorical data (Gower, 1971). The two non-categorical factors (age and amount of cars) were normalised in this code between 0 and 1 by using min-max

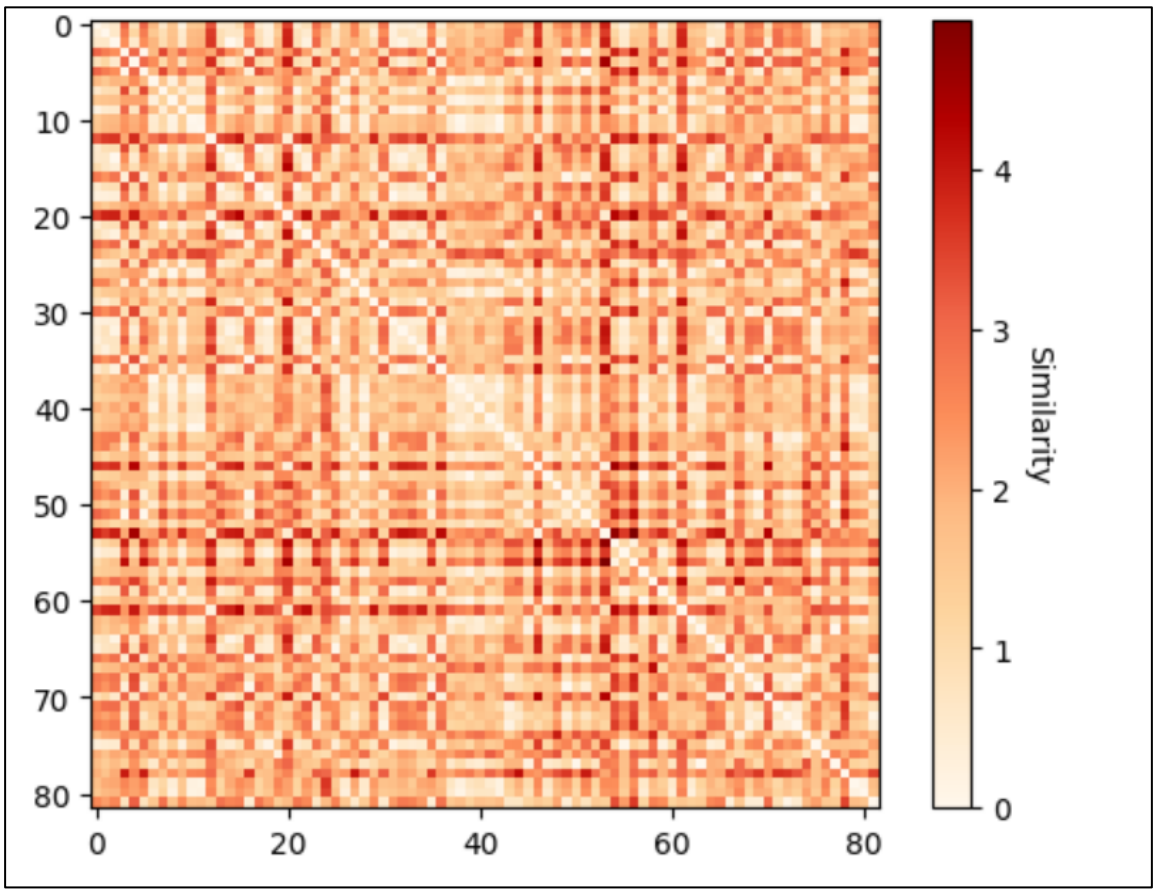
feature scaling. The Gower distance algorithm pairwise compares all the factors for a resident with each similar factor for another resident for all records in the file. All categorical factors are put in the dataframe as a column with binary values for each category (1: belongs to this category, 0: doesn't belong to this category). If for two ID's they are both male (binary both 0 or both 1), age is once 35 and once 34, employment status two times different (1 and 0 or 0 and 1 depending on which category has which binary value) the Gower distance (GD) will be the following for these two records using three factors:

GD = 1 (because same binary value) + 0,8 (normalized values) + 0 (different binary value) = 1,8
Comparing binary values between two records for one factor is called calculating the 'Dice distance'. This Dice distance therefore always is either 1 (if they have the same binary value) or 0 (if they have another binary value for the same factor).
The strength of this metric is that even if some values are missing for a certain variable, the Gower-distance can still be compared. Furthermore, this measurement shows at a glance the similarity between two records in the dataset in a numerical way. As described later in this paper, clusters are easily detectable when using this metric for creating a distance matrix. However, there are also some downsides to this method. All the different variables are pairwise compared with the variables for another record, and put into one single value. This causes some loss of information. Therefore, it can be hard to understand the exact meaning of the distance. Besides, since all variables are pairwise compared, it's a time-consuming process, so not recommended for large datasets.

After running the code in Google Colab and implementing the CSV file into this code, the following distance matrix was created (Figure 1), representing the Gower distances between all ID's. This matrix has a range of 81x81 according to the 81 respondents. Each intersection of two surveys has a color. The darker red the color, the higher the Gower distance between these two surveys and thus the more similar these two persons are for the seven factors that were taken into account. The diagonal axis is white, which refers to a score of 0 on the similarity scale since every point on this axis represents the intersection of two times the same survey. Logically, this needed to be dark red but the code of the algorithm only compares pairwise, which means the surveys aren't compared to themselves.

Figure 1:

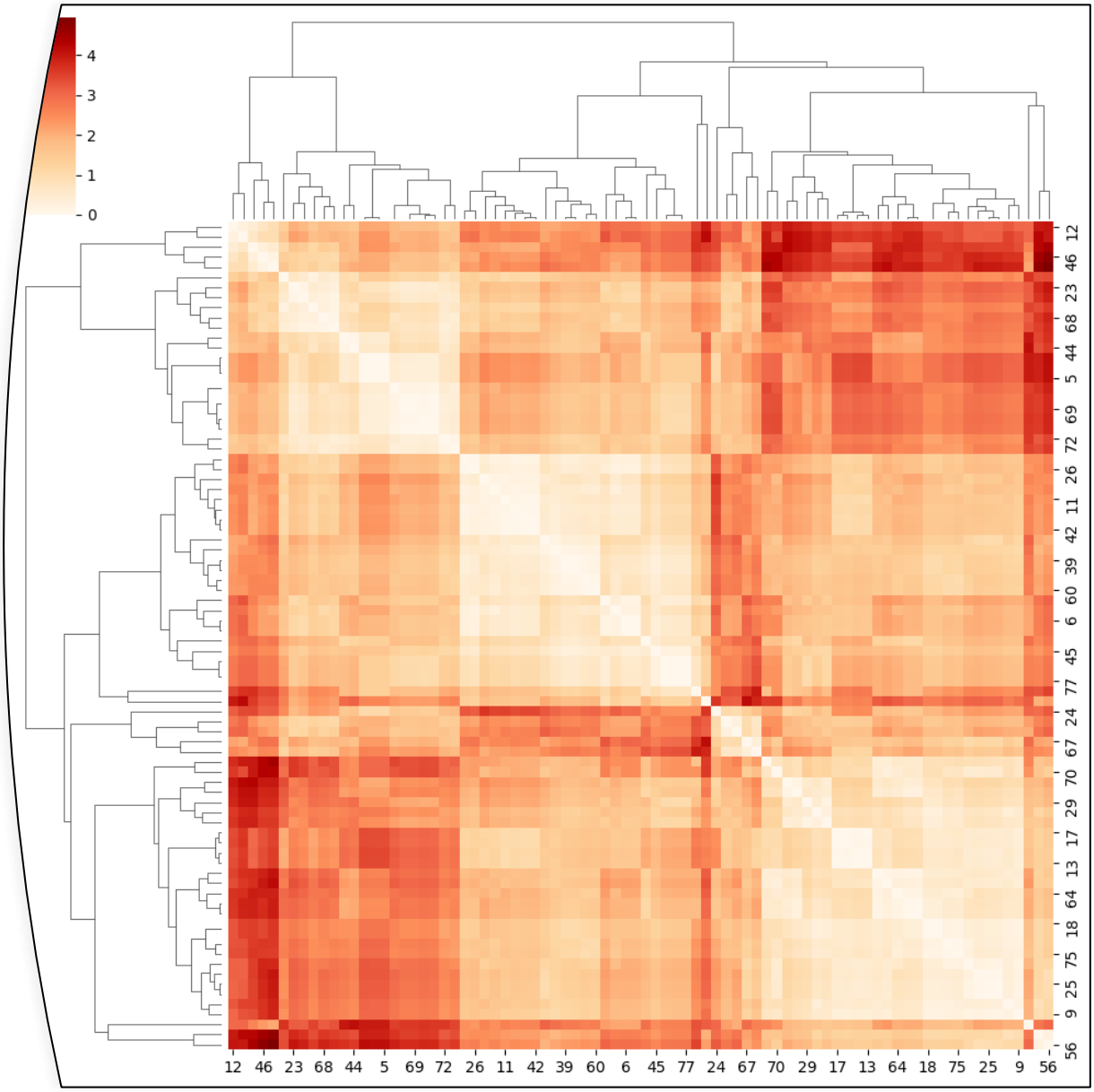
Distance matrix representing Gower distances



On Figure 2, the distance matrix of the data is shown in a different way, with a dendrogram linked to the matrix. On this visualisation, the range is still 81 x 81 but the axes are not numbered linear from 0 to 81. The numbering is deducted from the dendrogram. This means that each number (that refers to an ID) is first clustered with a number close to them before it's clustered with a number further away on the axis. For instance, 12 and 56 are the least similar, since they are only clustered in the last step. This is an additional benefit of this visualization. The data is clustered with average linkage and not Ward since Ward is only possible for Euclidian distances.

Figure 2:

Distance matrix combined with dendrogram

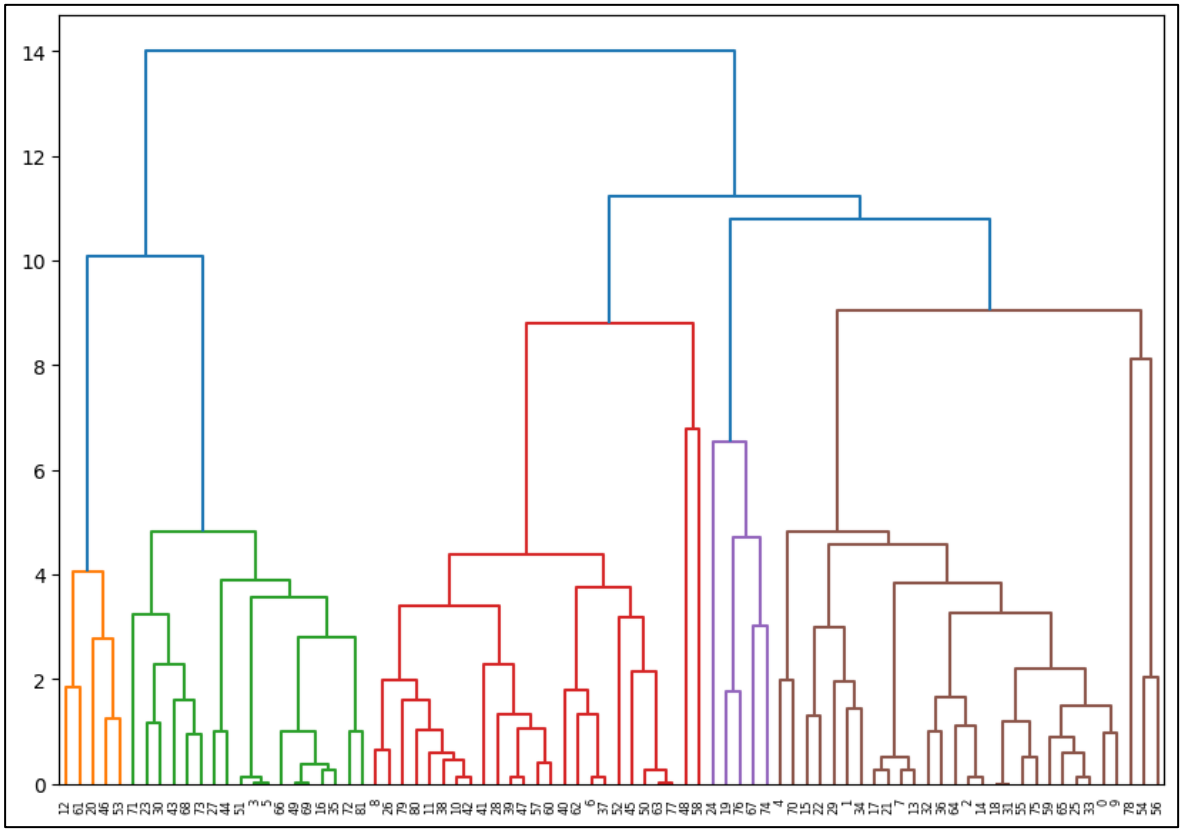


We thus performed a Hierarchical Agglomerative Clustering (HAC) analysis to get insight into the dataset. This is a useful method when executing an Exploratory Data Analysis (EDA) since natural patterns and clusters can be easily discovered and identified. Through this HAC, you can get a lot of insight into the dataset, outliers can be easily detected. This choice can be further motivated by the fact that we didn't define a number of clusters beforehand, but wanted to see the bigger picture and then select several clusters that showed useful information for our research. By using a dendrogram, you thus get a pleasant visualization that allows you to detect clusters by sight. In this case, we chose five clusters (Figure 3). This seemed natural since if you choose to

keep more clusters, the individual clusters would have less and less meaning. In this case, when you look for instance at the interviewees that have a red color in Figure 3 and slice the dendrogram at the height of 8 on the y-axis, the following occurs. Interviewees 8 until 77 on the x-axis are a group with high intra-similarity and next to them are two interviewees, 48 and 58 that have high intra-similarity. However, 48 and 58 are quite similar to interviewees 8 to 77 (inter-similarity) and have less meaning standing on their own in a cluster of just two respondents. This phenomenon is more limited when choosing five clusters in this example. Clustering aims to maximize intra-similarity and minimize inter-similarity. If you go for less than five clusters, the inter-similarity is relatively high.

Figure 3:

Coloured dendrogram



The last step of this EDA is to extract and define the clusters that can be detected from the dendrogram (Figure 3). The five colors all represent a different cluster, since we chose to divide the hierarchical dendrogram above the highest brown line. To find out what causes an interviewee to belong to a cluster, we wrote down the answers for each variable column-wise for each ID of that cluster. Then, the predominant variables in which the people were similar, quickly became apparent. Underneath, all clusters will be discussed:

a) The yellow cluster represents a small cluster of only five persons, using all three means of public transport (bus, train and ferry). Four of them are men, four of them are residents and 4 of them are retired. The sample is however too small to make conclusions in terms of employment status and other characteristics for this cluster.
b) The green cluster contains people who are either student or employed full-time, who all use both train and bus. For the other characteristics, there is no clear link.
c) The red cluster consists of 23 persons. They have in common that, in terms of public transport, they only take the train sometimes. Some of them own a car, others don't. All ages, working situations and genders can be found in this cluster.
d) The purple cluster is a small cluster like the yellow cluster and also consists of only five persons. Demographically, they differ a lot, but they all use the bus and not the train nor the ferry.
e) Lastly, the brown cluster is the largest cluster and contains 29 people. This cluster clearly represents the oldest generation. They are all older than 50 years, most of them even passed the age of 65. The majority of them are residents who never use public transportation. They often own at least one car.

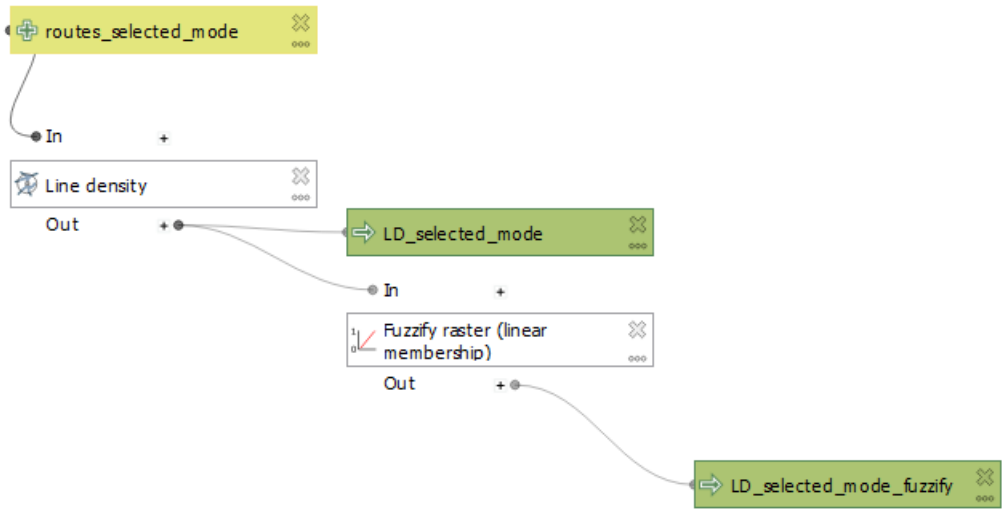
Unfortunately, there are also disadvantages related to Hierarchical Agglomerative Clustering. It's difficult to define the optimal number of clusters, this decision gives the process a subjective aspect and can give a distorted view. Furthermore, outliers can have a direct impact on the cluster determination process. One large outlier can influence the whole cluster.

To create heatmaps, a cartographic model (Figure 4) is given that represents the methods used in QGIS. Spatial data retrieved from TravelTrack can be used to make those maps. With the theory from the practical lessons in GIS: applications in mind, we already knew how to perform this analysis. However, the route's geometries are linestrings instead of polygons. Therefore, the function Line Density can be used for lines. This has been applicated to all routes of all modes, routes of cars, routes of bikes and routes by foot. Line density is an option within interpolation – such as heatmaps – but only used for line data. The line density algorithm calculates for every raster cell the number of lines within a specific perimeter or search radius. This perimeter can be installed by the user and is based on the coordinate system for units. Within this perimeter, every intersection of a line feature is being summed up and then divided by the total area of the perimeter. For these maps, we used a search radius of 150m and a pixel size of 200m. This to be as visible as possible on the displaying maps. The

search radius also needs to be more than half of the pixel size and 150m tended to give the most suitable display of the line density. Four vector layers can be selected as input layer. The total dataset of routes, the routes travelled by car, the routes travelled by bike and lastly the routes walked by foot. These three other layers can be created by using a 'Select by Expression', for example "mode" = "car", in the attribute table of the vector layer that contains all of the routes. On all four layers, the algorithm Line Density is used. In the final step, all of the layers are normalized by using the fuzzify algorithm with linear membership. This in order to make the maps inter-comparable because when the data is standardized, the minimum and maximum values are the same (0 and 1) for each map.

Figure 4:

Cartographic model of the project in QGIS (own creation in QGIS, 2023)

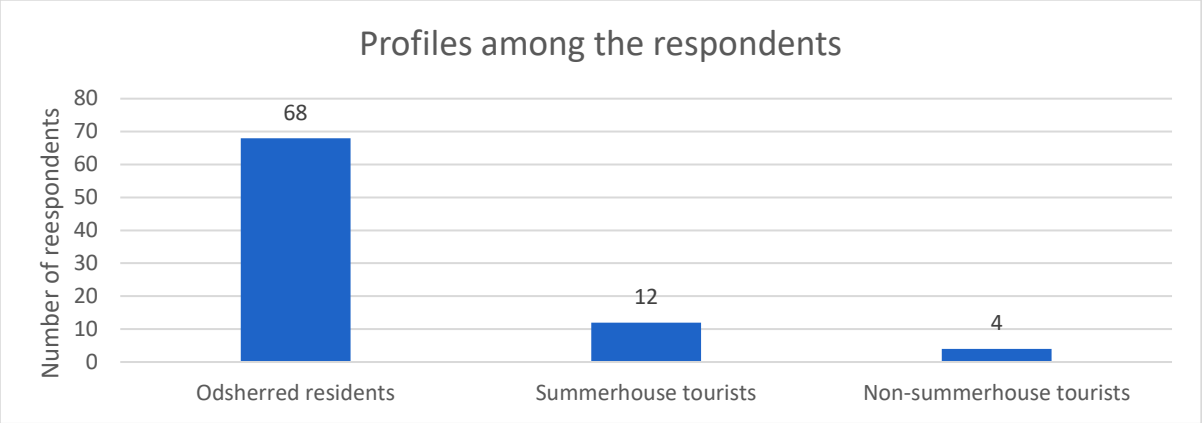


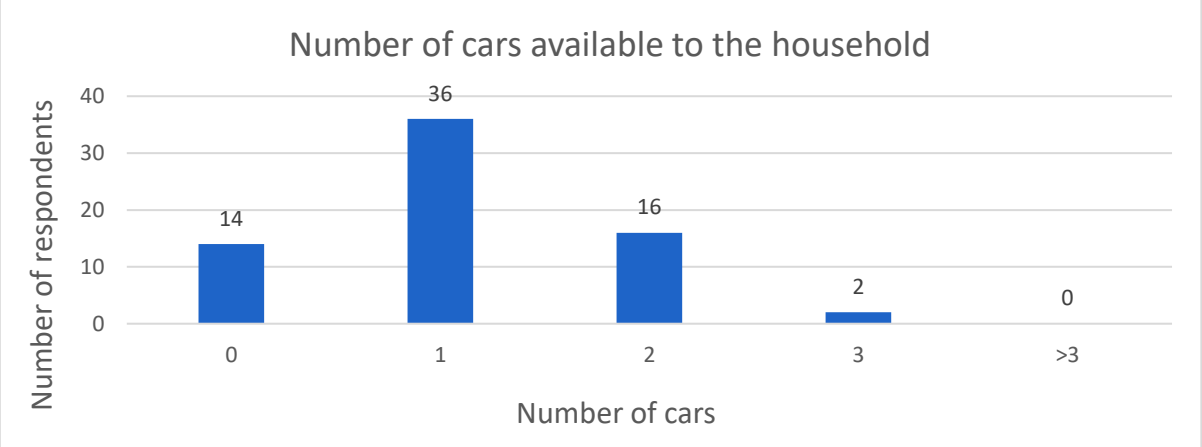
5 RESULTS

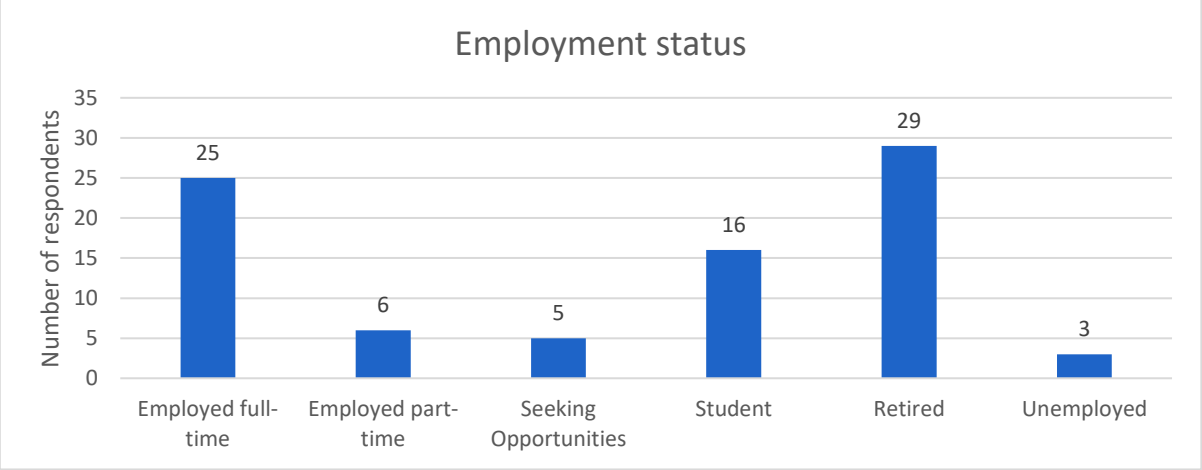
5.1 Graphs and statistics

Figure 5:

Bar charts obtained with data from Qualtrics







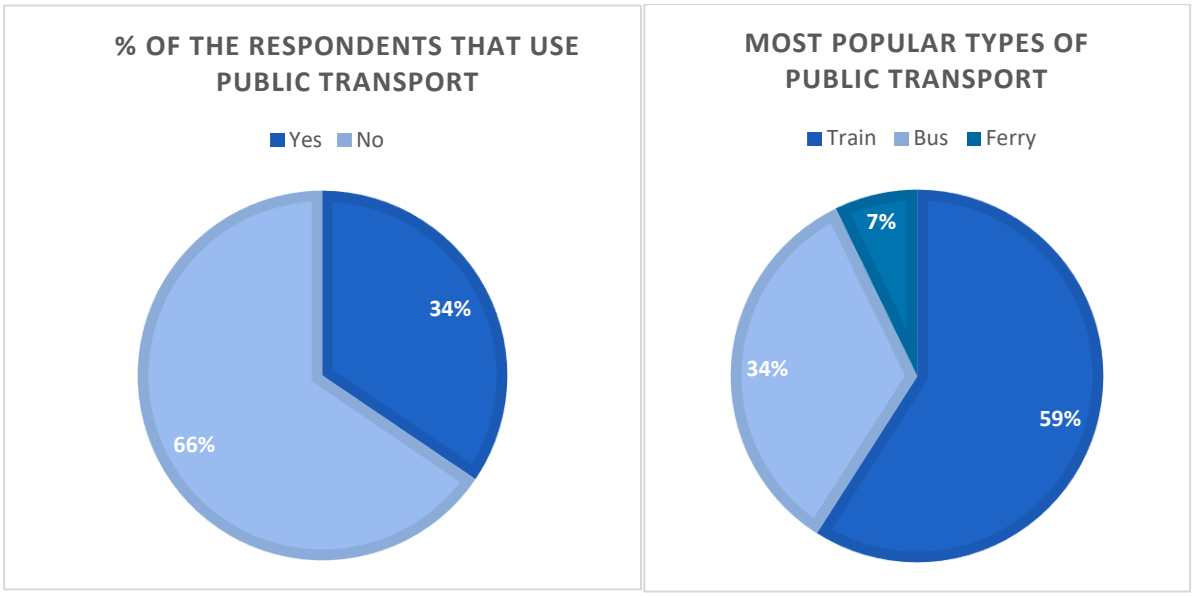
The above bar charts (Figure 5) are taken from the Qualtrics website. The first graph shows that through random street surveys, many more local Odsherred residents were surveyed than tourists (both summer house tourists and non-summer house tourists). This is more than likely because the surveys were conducted in May, and this is a period when tourism in the area is just getting going.

The second graph shows that most of the people we surveyed have 1 car at home. However, there are also 14 households without a car. That is 20.59% of the people who completed this question. In comparison to Flanders in 2021, there 22.9% of households do not own a car (statbel, 2022). So these percentages for Odsherred (according to our small survey) and Flanders match.

The last graph represents the employment status of those surveyed. It shows that we surveyed both full-time and half-time working people, as well as unemployed, students, and retirees. However, the distinction between the unemployed and those looking for a job was not easy to make.

Figure 6:

Pie charts obtained with data from Qualtrics

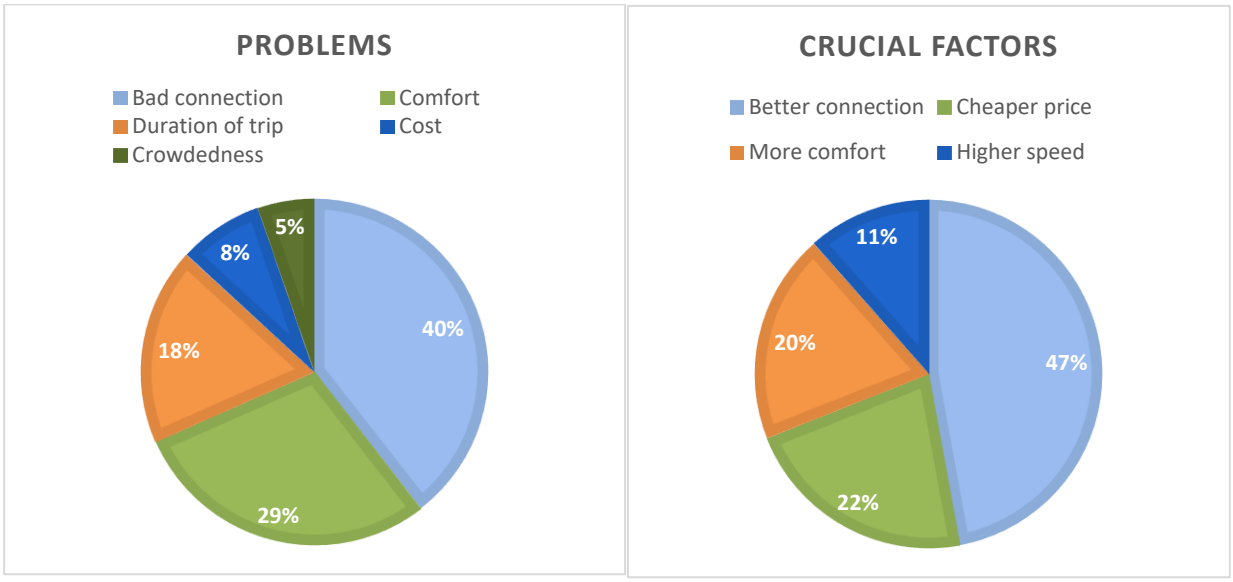


The left pie chart in Figure 6 illustrates the usage of public transport in Odsherred municipality. Based on the chart, it turns out that 65% of the population has used public transport at some point. The public transport system in this area contains buses, trains, and ferries. These 3 play a crucial role in facilitating the movement of people within this specific region. The percentage of 65% represents a substantial majority of individuals within the municipality who have experienced the convenience and benefits of utilizing public transport.

The right chart of Figure 6 illustrates that the train is more popular in Odsherred (59%) than the bus (34%) or the ferry (7%). The higher percentage of train usage suggests that people in the municipality find it more convenient, efficient, or preferable for their transportation needs compared to the other modes of public transport available. The following two charts (Figure 7) may help to clarify this.

Figure 7:

Pie charts obtained with data from Qualtrics



The left chart provides insights into the problems and pain points identified by respondents in Odsherred's transport network. Among the participants, the largest perceived problem is related to poor connectivity, accounting for 40% of the respondents. This issue primarily arises from bus stops being located far from where people live or infrequent bus schedules. As a result, individuals are more inclined to choose the train as their preferred mode of transport, as indicated in Figure 6. Apart from connectivity, other problems identified by respondents include comfort, which was cited by 29% of participants, and the duration of the trip, which accounted for 18% of the responses. These factors suggest that commuters in Odsherred value not only the convenience but also the comfort and time efficiency of their travel experiences.

According to respondents, the major characteristics that encourage people to use public transit more frequently are shown in the pie chart on the right of Figure 7. Improved connectivity to public transportation services is cited by 47% of survey respondents as the main factor that would encourage its use. The affordability of public transportation is therefore the second most important element, with 22% of respondents highlighting its importance. Several underlying reasons may contribute to an interpretation of these findings in the context of

the Odsherred municipality. Lack of accessibility to major areas (for example people who have no bus stop where they live), neighbourhoods, or locations within Odsherred may put off potential users (especially the summerhouse owners) of public transport since it makes it difficult for them to go where they need to go quickly. This may be the case in remote areas where many summer houses are located. People there are more likely to opt for the car to get around, and will ignore public transport. Cycling is more likely to be seen there as a form or recreation, rather than a mode of transport.

Additionally, the importance that a sizeable percentage of respondents gave to less expensive public transport emphasizes the financial considerations that go into commuter choice. When it comes to influencing people's transportation decisions, affordability is especially important for those who use public transport. However, quite a few people also indicated that the prices were doable. Furthermore, socioeconomic factors like household income may have an impact on the respondents' preference for less expensive transport. As already mentioned, the population of Odsherred is made up of a variety of groups. For people who rely significantly on public transport, cost becomes the declining factor when choosing their method of transport, and lower rates could greatly increase the appeal and viability of using public transport.

5.2 Heatmaps

In the following section, all of the produced heatmaps are shown. Map 3 shows all of the used roads in Odsherred. This means all of the modes combined (bike, foot, and car). On this map some outliers are also shown, by this we mean the long routes that lead to cities outside of Odsherred. For example to Kalundborg, Roskilde and Holbæk. Maps 4 – 6 show the line density of the roads by respectively bike, car and foot, for the region of Odsherred. On all four maps, the correlation between the density and the survey locations is highly visible. Nykøbing Sjælland has a lot more density than other parts of Odsherred because 60% of the surveys were taken in that city. The connection between Vig – one of the other survey locations – and Nykøbing Sjælland stands out in terms of density on the heatmap that represents car routes (Map 5). One of the explanations for this phenomenon can be the connection to the highway (21), which leads to Holbæk and Copenhagen. The heatmap of used roads by car is by far the most useful, because of the higher representation of roads. The reason behind this reasoning is the scale of our study area. Odsherred is so large that only car routes are represented well. Heatmap of routes by bike and foot are more useful when a study area of just a single city is used, for example only in Nykøbing Sjælland. In that case, more survey respondents are needed to obtain a good representation for the making of a heatmap. Heatmaps of bike and walking routes could have been useful if there were more respondents and more spatial distribution. This means we had to take more surveys in total and take them on more different places in Odsherred.

Map 3:

Heatmap of the used roads in Odsherred: total (own creation in QGIS, 2023)

Map 4:

Heatmap of the used roads in Odsherred: by bike (own creation in QGIS, 2023)

Map 5:

Heatmap of the used roads in Odsherred: by car (own creation in QGIS, 2023)

Map 6:

Heatmap of the used roads in Odsherred: by foot (own creation in QGIS, 2023)

6 DISCUSSION

Our research aims to determine how well the transport network in Odsherred functions and how it can be improved based on the preferences of local residents and summerhouse owners. The research goals and questions focus on understanding the differences in valuation, identifying common problems in the transport network, examining the spatial pattern of transport modes, and understanding the user profiles of the respondents.

The theoretical framework section provides an overview of the current public transport network in Odsherred, including the presence of a railway line, bus stops, and ferry routes. The Flextur service is discussed, as a demand-driven and address-oriented public transport for citizens who do not have access to route-based public transport. However, this service was not addressed by any of the interviewees. The Reisekort (for everyone) and Ungdomskort (for students) are also mentioned as means of increasing the convenience and attractiveness of public transport in Denmark.

Our project provides different insights based on graphs and statistics. First, the bar charts reveal important information about the respondents in Odsherred. The higher representation of locals compared to tourists in the sample is consistent with the timing of the surveys conducted in May, when tourism in the area is just beginning. The data relating to car ownership indicates that a significant percentage of respondents (20.59%) of respondents in Odsherred do not own a car. If we compare this with car ownership in Flanders (22.9%), this corresponds. This finding implies that Odsherred shares characteristics with other areas in terms of car ownership patterns, despite the municipality's unique context. The pie charts related to public transport report on the transport preferences of the population in Odsherred. The higher percentage of train use compared to buses and ferries suggests a preference for train travel among residents. This finding is valuable for policymakers and transport planners as it indicates that we need to focus on improving train services and connectivity to meet the demands and preferences of the population. The pie chart regarding public transport problems shows that poor connectivity is the top concern among respondents, followed by comfort and travel time. This finding suggests that addressing connectivity issues, such as proximity to bus stops and frequency of bus schedules, can positively impact public transport use in Odsherred. International examples of regions that have successfully addressed connectivity issues can provide valuable lessons and potential solutions for improving the transportation network in Odsherred.

The survey not only resulted in quantitative data, but also posed some open questions to which the respondents could answer freely. This way, they could give some more detailed motivation for or information about their previous answers. One of the last questions asked about what they wanted to change about the current transport system and why. The answers to that question were very diverse. Some of the most remarkable statements and contradictions will be listed here. Firstly, some people stated that the public transport is too expensive, while others said the prices are good or even cheap. The second remarkable finding from the open question was the bad service some people experienced. For the buses, many people said there was no bus stop near their home. Someone also said that there are delays weekly. Next to that the bussed would not come frequently enough and do not ride in the (late) evening. The findings towards the local train were slightly better, but also the train is not free of delays and some people said it was too dirty to take the train. A rather large group concluded that traveling by car is much more convenient than using public transport in this area. And lastly, there was a small subgroup of car users that had some small complaints about car use in this area. There seem to be some roads in a bad state, with potholes, and some roads have a high risk of crossing animals.

Regarding the data analysis methodology, the use of the Gower distance in combination with hierarchical clustering provided valuable insights into the profiles and clusters of the respondents. The clusters identified in the analysis represent different characteristics and behaviors associated with mobility patterns. Although the sample size may limit the generalizability of the findings, this approach opens avenues for future research to examine the profiles more deeply and compare them with international examples. By taking larger samples and performing comparative analyses, researchers can gain a better understanding of the mobility profiles and clusters in Odsherred, as well as their similarities or differences with other regions.

7 CONCLUSION

Using the responses that came from the surveys and the analyses conducted, it is possible to provide an answer to our preconceived research questions. To answer our main research question, the subquestions need to be answered first. Concerning a difference in appreciation of the transport network connectivity between the local residents and summer house owners, no valuable conclusions can be made. The reason for this is the low number of respondents who belonged to this latter class. These numbers make it impossible to make representative statements about the difference between the two groups. However, some findings were brought to us verbally by the respondents. The few interviewed tourists told us that they never use public transport and almost always take the car. They do bicycle, but only for leisure. Concerning the different user profiles among the respondents, a few clusters of people were detected during the exploratory data analysis. A distinguishable group of older people is rather conservative. They don't want to get rid of the car and try public transport, they don't see the benefits of the services. The most frequent users of public transport are students or people without a driver's license. Regarding existing issues in the transport network, a lot of negative or problematic insights were given, verbally or in terms that we used in the survey. The following aspects were frequently brought up by the respondents. They complained mainly about the fact that there were no buses late in the evening (past 10 pm or at some places past 8 pm), and not enough buses besides the peak hours. Furthermore, it was frequently mentioned that there was no bus stop in the neighborhood. In general, people were more satisfied with the train service than the bus service. Important to notice is that our study is very biased since the surveys were mainly taken in Nykøbing Sjælland, so conclusions for the whole region of Odsherred can't be made. In general, there can be said that there are more or less as many good aspects as points of improvement noticed by the local people for the transport network.

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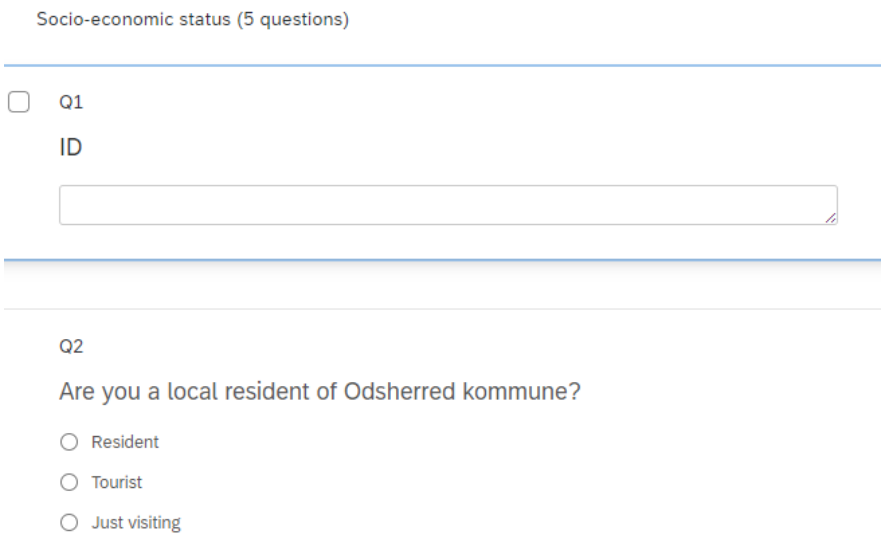
9 APPENDIX

9.1 Survey questions



Q3

Display this question

If Are you a local resident of Odsherred kommune? Tourist Is Selected

And Are you a local resident of Odsherred kommune? Just visiting Is Selected

Where do you live?

Q4

What is your age?

Q5

What is your Gender?

- M
- F
- X

Q6

What's your current employment status?

- ○ Employed full-time
- ○ Employed part-time
- ○ Seeking opportunities
- ○ Student
- ○ Retired
- ○ Unemployed

Q7

What is your monthly net income?

- ○ Less than 7500 DKK (€1000)
- ○ 7500 - 14 999 DKK (€1000 - 1999)
- ○ 15 000 - 19 999 DKK (€2000 - 2699)
- ○ 20 000 - 29 999 DKK (€2700 - 3999)
- ○ 30 000 - 39 999 DKK (€4000 - 5399)
- ○ 40 000 DKK (€5400) or more
- ○ I prefer not to answer

Q8

Display this question

If Are you a local resident of Odsherred kommune? Resident Is Selected

How many cars are available to your household?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ > 5

Q9

Display this question

If How many cars are available to your household? 1 Is Selected

And How many cars are available to your household? 2 Is Selected

And How many cars are available to your household? 3 Is Selected

And How many cars are available to your household? 4 Is Selected

And How many cars are available to your household? 5 Is Selected

And How many cars are available to your household? > 5 Is Selected

How frequently do you use a car?

- ○ Daily
- ○ Weekly
- ○ Monthly

Q10

Display this question

If How many cars are available to your household? 1 Is Selected

And How many cars are available to your household? 2 Is Selected

And How many cars are available to your household? 3 Is Selected

And How many cars are available to your household? 4 Is Selected

And How many cars are available to your household? 5 Is Selected

And How many cars are available to your household? > 5 Is Selected

For what purpose do you use a car?

- ☐ Work
- ☐ Leisure
- ☐ Family visit
- ☐ Groceries
- ☐ Other

Q11

Do you ever use public transport?

- ○ Yes
- ○ No

Q12

Display this question

If Do you ever use public transport? Yes Is Selected

How frequently do you use public transport?

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ Never

Q13

Display this question

If Do you ever use public transport? Yes Is Selected

Which type(s) of public transport do you use?

- ☐ Train
- ☐ Bus
- ☐ Ferry

Q14

Display this question

If Do you ever use public transport? Yes Is Selected

For what purpose do you use public transport?

- ☐ Work
- ☐ Leisure
- ☐ Family visit
- ☐ Groceries
- ☐ Other

Q15

Display this question

If Do you ever use public transport? No Is Selected

What's holding you back from using public transport?

- [ ] Duration of trip
- [ ] Cost
- [ ] Comfort
- [ ] Crowdedness
- [ ] Bad transport link

Q16

What would make you use public transport more often?

- [ ] Cheaper price
- [ ] Better connection
- [ ] More comfortable
- [ ] Higher speed

Q17

Are you in possession of the 'Rejsekort'?

- ○ Yes
- ○ No

Q18

Display this question

If Are you in possession of the 'Rejsekort'? No Is Selected

What's your opinion about this card?

Q19

Beside cars and public transport, which other mode do you use most often?

- ○ Bicycle
- ○ Walking
- ○ Shared vehicle

Q20

Display this question

If Beside cars and public transport, which other mode do you use most often? Bicycle Is Selected

For which purpose do you use a bike?

- [ ] Work
- [ ] Leisure
- [ ] Family visit
- [ ] Groceries
- [ ] Other

Q21

Display this question

If Beside cars and public transport, which other mode do you use most often? Walking Is Selected

For which purpose do you walk?

- [ ] Work
- [ ] Leisure
- [ ] Family visit
- [ ] Groceries
- [ ] Other

Q22

Display this question

If Beside cars and public transport, which other mode do you use most often? Shared vehicle Is Selected

For which purpose do you use a shared vehicle?

- [ ] Work
- [ ] Leisure
- [ ] Family visit
- [ ] Groceries
- [ ] Other

Q23

How satisfied are you with the transport connections?

Commute

Q24

Which aspects play a role in your choice of transport mode(s)?

- [ ] Comfort
- [ ] Speed/time
- [ ] Cost
- [ ] Service
- [ ] Family situation

Future in terms of mobility in Odsherred

Q25

Do you feel like there's a need for change in terms of mobility in the region?

- ○ Yes
- ○ No

Q26

Display this question

If Do you feel like there's a need for change in terms of mobility in the region? Yes Is Selected

Can you give a word of explanation (about missing connections, bus stops, train route,...)?

9.2 Data used to make the distance matrix

ID	Resident/Tourist	Age	Gender	Employment status	Amount of cars	Public transport user	Train	Bus	Ferry
85101	Resident	60	F	Employed part-time	1	No	0	0	0
85102	Resident	37	M	Employed full-time	1	No	0	0	0
95101	Resident	49	M	Unemployed	2	No	0	0	0
95201	Resident	17	F	Student	2	Yes	1	1	0
95102	Resident	64	F	Retired	3	No	0	0	0
95103	Resident	17	F	Student	2	Yes	1	1	0
95104	Tourist	31	F	Employed part-time	0	Yes	1	0	0
95105	Tourist	70	M	Retired	0	No	0	0	0
95202	Resident	52	F	Employed part-time	0	Yes	1	0	0
95203	Resident	66	F	Retired	1	No	0	0	0
95106	Tourist	64	F	Retired	0	Yes	1	0	0
95204	Tourist	68	F	Retired	0	Yes	1	0	0
95107	Resident	70	F	Retired	1	Yes	1	1	1
95108	Tourist	68	F	Retired	0	No	0	0	0
95205	Resident	50	F	Employed full-time	2	No	0	0	0
95109	Resident	22	M	Employed full-time	2	No	0	0	0
95110	Resident	15	M	Student	1	Yes	1	1	0
95111	Tourist	66	M	Retired	0	No	0	0	0
95112	Resident	51	M	Employed full-time	1	No	0	0	0
95206	Tourist	38	F	Seeking opportunities	0	Yes	0	1	0
95112	Tourist	65	M	Retired	0	Yes	1	1	1
95207	Tourist	64	F	Employed part-time	0	No	0	0	0
95208	Resident	32	F	Unemployed	2	No	0	0	0
95113	Tourist	24	M	Student	0	Yes	1	1	0
95114	Resident	12	F	Student	2	Yes	0	1	0
95209	Resident	76	M	Retired	1	No	0	0	0
95115	Resident	47	M	Seeking opportunities	0	Yes	1	0	0
95210	Resident	48	F	Employed full-time	2	Yes	1	1	0
95116	Resident	63	M	Employed part-time	1	Yes	1	0	0
95211	Resident	13	F	Student	1	No	0	0	0

95117	Tourist	33	M	Employed full-time	0	Yes	1	1	0
95118	Resident	51	M	Employed full-time	1	No	0	0	0
95212	Resident	60	F	Retired	2	No	0	0	0
95119	Resident	75	F	Retired	1	No	0	0	0
95213	Resident	25	F	Employed full-time	1	No	0	0	0
95214	Resident	17	M	Student	1	Yes	1	1	0
95215	Resident	68	F	Retired	2	No	0	0	0
95120	Resident	32	M	Seeking opportunities	0	Yes	1	0	0
95216	Resident	61	F	Employed full-time	0	Yes	1	0	0
95121	Resident	53	F	Employed full-time	1	Yes	1	0	0
95122	Resident	20	F	Employed full-time	0	Yes	1	0	0
95217	Resident	76	F	Retired	1	Yes	1	0	0
95123	Resident	65	M	Retired	0	Yes	1	0	0
95124	Resident	55	F	Employed full-time	0	Yes	1	1	0
95218	Resident	56	M	Employed full-time	2	Yes	1	1	0
95125	Resident	33	F	Employed full-time	1	Yes	1	0	0
95219	Resident	44	M	Seeking opportunities	0	Yes	1	1	1
95126	Resident	52	F	Employed full-time	1	Yes	1	0	0
95220	Resident	16	M	Student	3	Yes	1	0	0
95127	Resident	19	F	Student	1	Yes	1	1	0
95128	Resident	17	M	Student	1	Yes	1	0	0
95221	Resident	16	M	Student	2	Yes	1	1	0
95129	Resident	41	F	Employed full-time	2	Yes	1	0	0
105201	Resident	38	M	Retired	0	Yes	1	1	1
10502	Resident	63	F	Retired	1	No	0	0	0
105202	Resident	57	F	Retired	1	No	0	0	0
10503	Resident	80	M	Retired	1	No	0	0	0
105203	Resident	53	F	Retired	1	Yes	1	0	0
10504	Resident	18	F	Student	0	Yes	1	0	0
105105	Resident	71	M	Retired	1	No	0	0	0
105106	Resident	56	F	Employed full-time	1	Yes	1	0	0
105204	Resident	79	M	Retired	1	Yes	1	1	1
105107	Resident	39	F	Seeking opportunities	0	Yes	1	0	0

95108	Resident	15	F	Student	1	Yes	1	0	0
105109	Resident	53	M	Employed full-time	2	No	0	0	0
95110	Resident	80	F	Retired	1	No	0	0	0
105205	Resident	17	M	Student	1	Yes	1	1	0
105111	Resident	75	M	Retired	1	Yes	0	1	0
105112	Tourist	43	M	Employed full-time	0	Yes	1	1	0
95113	Resident	19	M	Student	1	Yes	1	1	0
105206	Resident	81	F	Retired	2	No	0	0	0
95114	Resident	70	F	Retired	0	Yes	1	1	0
95115	Resident	41	F	Employed full-time	1	Yes	1	1	0
95116	Resident	43	F	Employed full-time	0	Yes	1	1	0
105117	Tourist	75	F	Retired	0	Yes	0	1	0
105207	Resident	53	F	Unemployed	1	No	0	0	0
105118	Tourist	27	F	Employed full-time	0	Yes	0	1	0
95119	Resident	15	M	Student	1	Yes	1	0	0
105208	Just visiting	30	F	Employed part-time	0	Yes	0	0	1
105209	Tourist	72	F	Retired	0	Yes	1	0	0
105210	Resident	60	F	Employed full-time	0	Yes	1	0	0
105120	Resident	39	M	Employed full-time	1	Yes	1	1	0

9.3 Google Colab code for clustering

https://colab.research.google.com/drive/1W3kbbwxBszNhBEFkBYuS4j2uX86JpCtx?usp=sharing

FACULTY OF SCIENCES

REVOLUTIONISING CYCLING IN ODSHERRED, DENMARK: CREATING A NUMBERED-NODE CYCLE NETWORK TO PROMOTE RECREATIONAL BICYCLE USE

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1. INTRODUCTION

Cycling is very popular in Denmark, especially in larger cities like Copenhagen. The Danish capital city is often called one of the most bicycle-friendly cities in the world. Danes cycle a total of 8 million kilometres every day and large amounts of money are being invested to improve cycling infrastructure around the country. There is, however, still a lot of potential to increase bicycle use for recreational purposes in more rural areas like Odsherred where bicycle use has even decreased over the last decades (Cycling Embassy of Denmark, n.d.; Okraszewska & Jagielska, 2017; VisitDenmark, 2022). The passage of the second stage of the Tour de France 2022 through the southern part of Odsherred was a very big event for this rural region and showed that there was certainly enthusiasm for more recreational cycling and bicycle tourism. Currently, already around 35% of cycling trips in Denmark are leisure trips. Options for planning a cycle route remain nevertheless limited to the point-to-point network of national, regional and local cycle routes, which is very fragmented and mostly ill-suited for shorter cycling trips (Foreningen Dansk Cykelturisme, n.d., VisitDenmark, 2022).

The Belgian idea of a numbered-node cycle network, which enables people of all ages to easily plan a cycle trip of their own desired length along bikeable roads and is better suited for daytrips, has only recently been introduced in Denmark for four small pilot projects. One of the goals of the pilot projects is to determine the necessary criteria and methods to implement a nationwide cycle network in Denmark, a goal to which this project might contribute. A lot of research has been conducted in the fields of bikeability and designing cycling infrastructure, but the creation of numbered-node cycle networks and networks for recreational cycling in general have received little attention in scientific literature. In this project, an attempt is made to create a numbered-node cycle network for the Danish municipality of Odsherred using both GIS and verification in the field. The numbered-node cycle network could make it easier for visitors to explore Odsherred Geopark and its interesting sights and landscapes by bike. The main research question in this project is ‘How can a recreational numbered-node cycling network be created in Odsherred?’. This question will be answered with the aid of three sub-questions: 'What is the current situation regarding cycling infrastructure and recreational cycling in Odsherred and Denmark?', 'Which data and parameters should be taken into account when creating a numbered-node cycle network?’ and ‘How accurate is the resulting network?’.

2. THEORETICAL FRAMEWORK

2.1 Bikeability

Scientific literature about designing recreational cycle networks along existing road networks is (almost) non-existent. Most publications focus on commuter cycling instead of recreational cycling and provide criteria to design bicycle-friendly new infrastructure or optimise existing infrastructure. The concept of bikeability is regularly used in this context. Bikeability can be defined as the extent to which an environment is convenient and safe for cycling and is often summarised in five key principles. These are safety, comfort, directness, cohesion and attractiveness (Fonseca et al., 2023; Venema, 2019). The five principles are especially useful for designing new bicycle infrastructure, but also give an indication of how bicycle-friendly existing routes are. They are not equally important and priorities might be different for different kinds of users. Recreational users will, for example, emphasise attractiveness of a route and pay much less attention to directness than commuters do. Safety on the other hand is a principle that is important for all kinds of users and is often considered the most important principle (Venema, 2019). Based on an extensive literature study, Wysling and Purves (2022) have defined bikeability as being mostly affected by the speed limit on a road, the presence of separated cycling infrastructure and the slope of the road. The five bikeability factors are, however, influenced by many more factors than these three. An overview is provided below.

The safety principle means that conflicts between cyclists and road users should be kept to a minimum in order to avoid accidents. Cyclists are vulnerable road users and collisions with motorised vehicles can have serious consequences. The safety of a cycling route is often evaluated by describing the traffic speed, the traffic volume, the presence street lighting or the number of accidents that have occurred. Street hierarchy can also be used as a proxy for traffic volume. The number of accidents is a typical metric that quantifies actual safety, while behaviour of cyclists is influenced much more by perceived safety, which is much harder to measure (Fonseca et al., 2023; Venema, 2019).

Comfortable cycle routes limit inconvenience and delay. Important indicators for the comfort of a cyclist are the width of cycling infrastructure, the type and quality of the road surface and the slope of a route. Hills might provide nice viewpoints, but can be difficult to climb for less experienced cyclists when the slope of the hill gets to steep. Most scholars agree that slopes exceeding 5% should be avoided, unless this gradient is attained over a

very short distance. Gradients up to 3% are seen as perfectly suitable for cycle networks, while gradients of over 4% can be considered difficult for cyclists. (Fonseca et al., 2023; Manton & Clifford, 2013; Venema, 2019; Wysling & Purves, 2022). Other factors that influence the comfort of a cyclist, such as the weather, are harder to control. The directness principle means that a cycle route should be as short as possible and detours should be avoided (Venema, 2019). The directness of a cycle route is especially relevant for commuter cycling, but less important for recreational users. Research also shows that tourists clearly prefer to use roads with dedicated cycling facilities and are willing to take long and time-consuming detours to be able to use segregated cycling infrastructure (Deenihan & Caulfield, 2015; Fonseca et al., 2023).

In order to be cohesive, cycle routes must be easy to find and the transitions between different types types of infrastructure must be as smooth as possible. Additionally, the infrastructure quality and signage should be consistent along the whole route. Cohesion makes sure that the effort needed to cycle a certain route is similar throughout and that a seamless connection between origin and destination is provided (Fonseca et al., 2023; Venema, 2019).

Attractiveness is a more subjective principle than the others and might be interpreted very differently by different persons. Some people will emphasise social safety or liveliness when describing attractiveness, while many others think more of the aesthetics of the surroundings of a route (Fonseca et al., 2023; Venema, 2019). In general, cyclists find minor roads more attractive than roads that carry much motorised traffic, which can mostly be attributed to noise and air pollution. The surrounding landscape also contributes to attractiveness. Most people prefer to cycle through a diverse and varied landscape instead of a monotonous one. Open landscapes that provide panoramic views and green areas such as forests are also appreciated by many people (Venema, 2019).

2.2 Bicycle Tourism and Numbered-Node Cycle Networks

A setting that is considered bikeable might not only persuade locals to use their bikes more often but can also attract tourists that want to cycle. Bicycle tourism contributes to the income of local businesses and can also contribute to the economic development of rural areas. It brings the advantages of tourism to a certain region, while only having a minimal impact on climate change and the environment compared to other forms of tourism. In addition, bicycle tourism and recreational cycling do not increase traffic congestion and are beneficial for public health (Manton & Clifford, 2013; Okraszewska & Jagielska, 2017; Piket et al., 2013; Venema, 2019). In Belgium

and The Netherlands, most recreational cyclists and bicycle tourists use the numbered-node cycle networks since the roads in these networks are often considered to be among the most bikeable routes in a certain region.

Hugo Bollen, a Belgian mining engineer with a passion for walking and cycling, came up with the idea of a numbered-node cycle network in the early 1990s. He suggested to create a network of cycle routes along bikeable roads where each intersection of the routes (a node) is assigned a number. Signs at every intersection display these numbers to indicate the route towards other nearby intersections. A route along the network can thus be cycled by following a series of numbers. The first numbered-node cycle network opened in 1995 in the Belgian province of Limburg as an attempt to attract more tourism to a region that was severely affected by the closure of the last coal mines in Belgium (Reymen, 2017; Witman, 2013). The idea quickly spread to the rest of Flanders and the first network in the Netherlands was inaugurated in 1999. Nowadays, numbered-node cycle networks can be found in most of Belgium and the Netherlands and parts of Germany, France and Croatia (Colas, 2023; Reymen, 2017; Witman, 2013). Hugo Bollen also set up a similar concept for walking tours, which require a denser network of trails and roads. This opened at the same time in 1995 and spread to regions outside of Limburg as well but has been slightly less successful than its cycling equivalent (Reymen, 2017).

Numbered-node cycle networks are popular due to their ease of use. Cyclists can plan their trip with a paper map, a website or an information sign they come across and just have to write down or memorise the numbers of the nodes they want to include. They no longer have to stop at each junction to take a look at the map and just can follow the signs along the road. For clarity, these signs have a uniform style and contain only the essential information: a bike symbol, node numbers and arrows giving directions. Signs are always located on the right side of the road and normally have the same height. One sign is placed about ten metres before the junction, one at the junction itself and one behind the junction to confirm you are going in the right direction (Colas, 2023; Reymen, 2017; Witman, 2013). A numbered-node cycle network offers more freedom and flexibility than signposted fixed routes. Rather than relying on individual signposts that can become confusing when there are many different routes, a numbered-node network allows cyclists to create and modify their own routes. Large information signs at important junctions show an overview of the network and allow people to shorten or lengthen their route. This kind of cycle network allows people of all ages, including elderly people and families with young children, to adapt the route according to the weather and their own wishes, needs and capabilities and gives them the opportunity to enjoy a pleasant day out on the bike (Colas, 2023; Foreningen Dansk Cykelturisme, n.d.; Reymen, 2017; Witman, 2013). A numbered-node cycle network is mostly used for a regional

bicycle trip and is less suited for long-distance bike tours, which are still signposted separately in Belgium and the Netherlands (Witman, 2013).

2.3 Numbered-Node Cycle Network in Denmark

Inspired by the Belgian example, there is now a project to create numbered-node cycle networks in Denmark as well. The project is called 'Recreative Network of the Future' and is coordinated by Danish Cycling Tourism, a non-profit association aiming to promote and develop recreational cycling and bicycle tourism in Denmark. The association was established in 2014 and already coordinates the development of the EuroVelo long-distance cycle routes in Denmark (Foreningen Dansk Cykelturisme, n.d.). The existing national, regional and local cycle routes in Denmark are focussed on long-distance trips and are mostly over 20 years old. In this period, signposts have disappeared or have become unreadable. Moreover, these routes are incoherent and not well connected to each other and no longer respond to the needs of most cyclists. Over 80% of recreational cyclists in Denmark make daytrips from their home, summerhouse or hotel and want to get back to the same place on the same day. This requires cycle routes that allow loops instead of cycle route that go from one point to another. In 2020, Danish Cycling Tourism therefore received funds from the Danish national government to carry out a pilot project on creating a numbered-node cycle network as part of a government support package for the tourism sector during the COVID-19 pandemic (Foreningen Dansk Cykelturisme, n.d.). Four locations were included in the project: the southern part of the island of Bornholm, around the Præstø Fjord in Zealand and around Sønder Omme and Vejle in Jutland. The networks at these locations are all very small and only contain a few nodes. They are mainly intended to select a suitable design for the signposts and related information platforms and to determine the criteria and methods that should be used to define a numbered-node cycle network (Foreningen Dansk Cykelturisme, n.d.). The network will be based on the existing infrastructure, but there will be space for recommendations about improvements to the infrastructure too. Each road segment in the pilot project areas is assigned a so-called recreative value, a score between 1 and 9 based on several measurable criteria which fit in with the five principles of bikeability. The creators of the network acknowledge that this score can never be fully objective and that every individual might experience a cycle trip differently. A full list of criteria has not been published yet (Foreningen Dansk Cykelturisme, n.d.; Knudepunkter, n.d.).

There is now a dedicated website about the project for a numbered-node cycle network in Denmark (https://knudepunkter.dk/) and a platform for cyclists that want to use the networks was launched recently in four languages (http://en.cykel.net/). Danish Cycling Tourism would like to expand the network beyond the four

pilot project locations to the whole of Denmark and proposes a total length of 20 000 km with 5000 nodes. Creating a nationwide numbered-node cycle network fits into several strategies and policies for tourism from the Danish national government. Additionally, promoting cycling for active holidays and recreation is also a major part of Denmark's national bicycle strategy (Foreningen Dansk Cykelturisme, n.d.; Okraszewska & Jagielska, 2017). The existing national long-distance cycle network in Denmark will be integrated into the numbered-node cycle network but continue to exist separately. Danish Cycling Tourism estimates that creating a cycle network for the entire country will cost about 100 million DKK, while the yearly costs for operation and maintenance are estimated to be around 6 million DKK (Foreningen Dansk Cykelturisme, n.d.). These costs are seen as reasonable since it is expected that creating a numbered-node cycle network will increase the number of recreational cycle trips. This would not only greatly benefit public health and encourage better use of existing bicycle-friendly infrastructure, but also bring economic benefits through higher income for local businesses and higher income from taxes (Foreningen Dansk Cykelturisme, n.d.).

3. METHOD

Hugo Bollen made the first numbered-node cycle network in the 1990s by selecting potentially suitable roads on a topographic map. He subsequently got on his bicycle to verify the routes in the field and to check whether adaptations to the network or the cycling infrastructure were necessary (Reymen, 2017). This research project followed a broadly similar approach and started with a desktop analysis in GIS instead of using paper maps, before moving on to terrain work in Odsherred in May 2023. The aim of the GIS part was to create a suitability map of road segments that were eligible to be included in the network. First, some constraints were set to remove unsuitable roads from the dataset. A constraint is a characteristic that makes a location completely unsuitable. This location is thus not considered in the rest of the analysis. Factors represent criteria that can impact the suitability of a location either positively or negatively. In this project, six different factors were taken into account and weighted with the Analytic Hierarchy Process (AHP) developed by Thomas Saaty (1990) to combine them into a suitability map of the road network. Some local domain experts were interviewed to determine the exact weights for the AHP heuristic. In this manner, a street with high suitability will get a higher score and could potentially be an important connection in the numbered-node cycle network. The qualitative fieldwork was employed to verify whether the used data was correct and whether the suitability map reflected the situation on the terrain. The result of the desktop analysis and fieldwork is a digital static map of a possible numbered-node cycle network in Odsherred. Cyclists could use this map to plan a cycle route. The next paragraphs will explain the study area, software and data and all the followed steps in more detail.

3.1 Study Area

The study area for this project is the municipality of Odsherred on the Danish island of Zealand (Figure 1). Odsherred municipality has an area of about 355 km² and a coastline of around 155 kilometres (Werther, 2022). The municipality became the first Danish Geopark in 2014 because of the geological and cultural heritage of the region. The ice-age landscapes and coastline draw many tourists. During the summer season, the regular population of 33 000 are joined by up to 100 000 visitors. Odsherred has around 25 000 second homes, the largest number of second homes of any Danish municipality, and tourism provides one third of the private sector jobs in the municipality (Werther, 2022).

Figure 1: Location Map of the Study Area.

3.2 Data and Software

All the data on which the study is based is shown in the table below (Table 1). These are primarily from OpenStreetMap (OSM). All data was used to create the suitability map except the Belgian node network. That was used to compare the density of the obtained network in Odsherred with the density of that of Belgium. The software that was used for the spatial analysis in this project is QGIS. To create the webtool which was used for the fieldwork, a script was written in Notepad++ based on HTML, CSS, PHP and JavaScript. A connection was made with a databank, accessible via PgAdmin, to save the input data from the form.

Table 1: Sources of the Used Data.

Name	Type	Source
Road network Odsherred	Shapefile (vector)	OpenStreetMap
Land use	GeoJSON	OpenStreetMap
Existing cycle routes	GeoJSON	RouteYou
Existing cycle routes	GeoJSON	OpenCycleMap
Odsherred boundaries	Shapefile (vector)	GADM - Database of Global Administrative Areas
Viewpoints	GeoJSON	OpenStreetMap
Windmills	GeoJSON	OpenStreetMap
Ruins	GeoJSON	OpenStreetMap
Churches	GeoJSON	OpenStreetMap
Castles	GeoJSON	OpenStreetMap
Public toilets	GeoJSON	OpenStreetMap
Digital Elevation Model	TIFF	Datafordeler
Cycle nodes Belgium	Shapefile (vector)	RouteYou
Dead ends check	FME Workspace	RouteYou (personal communication)

3.3 Suitability Map

First, some constraints were put on the road network of Odsherred, which was downloaded from OpenStreetMap, to exclude roads that were deemed completely unsuitable for the numbered-node cycle network. More specifically, motorways, highways and roads where cycling is not allowed were removed from the dataset. In addition, dead end streets were eliminated by using the GRASS v.clean toolset in QGIS to remove dangles with a length shorter than 2000 m. In the following steps, work continued with this reduced road network. Six measurable factors that are relevant to recreational cycling were selected based on the five principles of bikeability and the scores for these factors were calculated for all the remaining roads. Afterwards, the basic statistics of each factor layer were calculated in QGIS to get better insights in the meaning of the scores and the study area.

3.3.1 Assessing Key Factors and Scores for Each Category

The existing cycle routes in Odsherred were selected as the first factor. These routes were downloaded from RouteYou and OpenCycleMap and then overlaid on the road network. Road segments along which an existing route runs, got a score of 1. If there was no existing cycle route, the score became 0.

Car speed limit is the second factor, and it was used as an indicator for cycling safety. The road network downloaded from OpenStreetMap has an attribute which contains this information. Road segments with a speed limit equal to or higher than 80 km/h got a score of 0. A score of 0.5 was assigned to road segments with a speed limit of 60 km/h and 70 km/h. All roads with a speed limit of 50 km/h or less got a score of 1. The idea behind these scores is that high-speed roads are not desirable and less safe for cyclists.

The third selected factor is road type, and this factor is also based on the road network attribute data from OpenStreetMap. Roads are categorised as primary, secondary, tertiary, residential and so on. This factor was used as a proxy for the traffic volume of roads because traffic data was not available for free. Table 2 shows the road categories, their meaning and the corresponding scores assigned to the road segments. Roads with a dedicated bike lane got a higher score of 1.1 because these are the most desirable.

Table 2: Road Segment Scores Based on Road Types (Bron: OpenStreetMap Wiki, 2023).

Road Type Category	Description	Assigned Scores
Cycleway	Road section reserved for cyclists	1.1
Living_street	Residential streets where pedestrians have priority over cars, speeds are kept very low	1.1
Residential	Often lined with housing	0.9
Unclassified	Often link villages and hamlets	0.9
Path	A non-specific path which can be used, if mentioned, by pedestrians, horse riders, cyclists or farmers	0.8
Track	Roads for mostly agricultural or forestry uses	0.8
Tertiary and tertiary_link	Often link smaller towns and villages	0.7
Secondary and secondary_link	Often link towns	0.5
Footway	For designated footpaths, i.e., mainly/exclusively for pedestrians. If mentioned, bicycles are also allowed.	0.4
Primary and primary_link	Often link larger towns	0.3
Service	For access roads to, or within an industrial estate, camp site, business park, car park, alleys, etc	0.1
Steps	For flights of steps (stairs) on footways	0.1

The fourth factor is an indicator of the natural environment. For this, land use data was obtained from OpenStreetMap, and scores were added based on how desirable it is to cycle through a particular environment. The desirability is of course subjective, but there are some general tendencies that were taken into account. Very few people like to cycle through industrial areas, for example. A very low score was therefore assigned to industrial areas, while more natural areas like grassland or forests got higher scores and are thus more preferred for the cycle network (Table 3). The openness of the landscape associated with the type of land use was also taken into account to a lesser extent. Open environments got a slightly higher score than closed environments, e.g., forest compared to grassland. To add this land use score to the corresponding road segments, a buffer was drawn around each land use parcel and attached to the segments by using an intersection. It was calculated how much of the surroundings of the segment was of each score, that share was multiplied by the score and the sum of these was the final score. When a road segment passes for example through 90% farmland and 10% residential areas, the final score would be 0,9 * 0,8 + 0,1 * 0,5 = 0,77.

Table 3: Road Segments Scores Based on Land Use.

Land Use Category	Assigned scores
Flowerbed	1.0
Grass	1.0
Greenfield	1.0
Heath	1.0
Meadow	1.0
Orchard	1.0
Village_green	1.0
Vineyard	1.0
Water	1.0

Land Use Category	Assigned Szcores
Basin	0.9
Farmland	0.8
Farmyard	0.8
Forest	0.8
Scrub	0.8
Residential	0.5
Industrial	0.1
Landfill	0.1
Other types of land use	0.5

The fifth factor is the slope of the road. The gradient of the roads was calculated in QGIS from the Digital Elevation Model. The fuzzy raster small membership algorithm was used to assign the scores. In that way, roads with slopes less steep than 4% got the best scores. Steeper slopes got much lower scores.

Finally, places of interest were added as a factor. Roads located along those sights got a score of 1, other roads got a score of 0. This was done by creating a buffer of 50 meters around the road segments. For this project, viewpoints, windmills, ruins, castles, churches and public toilets obtained from OpenStreetMap were selected as places of interest. Only those places that were relevant for Odsherred and present in the area were included.

3.3.2 Analytic Hierarchy Process - Creation of Weighted Factors Using the Likert Scale

In the next step, the six factors were weighed against each other. To get an idea of the appropriate weight for each factor in the cycle network, local experts were asked to fill in a symmetric Likert scale for each combination of two factors (Appendix 8.2). The respondents put a symbol on the range between extremely favouring factor 1 and extremely favouring factor 2. This symbol indicates the relative importance. To ensure that everyone had an equal understanding of the factors, the same explanation of each factor's interpretation was given before completing the Likert scale. The distance, rounded to an integer, between the centre point and the indicated point on the scale was used as a respondent's importance score. If a respondent preferred the second mentioned factor

more than the first, his score was inversed. In this way, all scores could be standardized to a value in function of the first mentioned factor.

The following example should clarify the method. As shown in Figure 2, a respondent had to choose on the Likert scale between car speed limit (factor 1) and natural environment (factor 2). A respondent that put a mark in the middle of the scale considered both factors to be equally important. When a respondent considered factor 1 to be more important, that person would put a cross on the left side of the scale (black). The distance between the midpoint and the cross was then measured. If this length was for example 5 cm, the respondent's score became 5. This means that the domain expert found factor 1 five times more important than factor 2. If the respondent thought that factor 2 was more important, he would have put a cross on the right side of the Likert scale (blue). The score would have been 1/5 = 0.2 in that case.

Figure 2: Likert Scale for the Combination of Car Speed Limit and Natural Environment.

After this, the median was taken of all pairwise scores. These medians were used in the AHP to find the global weight for each factor for the cycle network. The factor with the highest weight is the most influential one for choosing the road segments that should be part of the numbered-node cycle network.

3.3.3 Combining Factors to a Suitability Map

In the end, the scores of each road segment for each factor were multiplied with the corresponding weight from the AHP. By adding up those factor layers, each road segment got a final suitability score, which could be visualised in a suitability map.

3.4 Qualitative Control in the Field

The aim of the field work was to check whether the used OpenStreetMap data was correct and to clarify the meaning of the land use types and road types defined in OpenStreetMap. Besides, the fieldwork also had to provide a picture of how safe and bicycle-friendly a particular road segment is. In addition, it had to give an impression of the surrounding landscape. Therefore, a web application (http://we12s016.ugent.be/student2023/giglorie/gip/gip.php) was designed to consistently rate different survey points (Figure 3, Figure 4). Then, the territory of the municipality of Odsherred was traversed by car. A small part of the municipality was surveyed by bicycle to reach roads that were not accessible by car (Figure 5). For 173 randomly chosen sample points spread out over the whole municipality, several questions that are related to the six factors were answered (Figure 5).

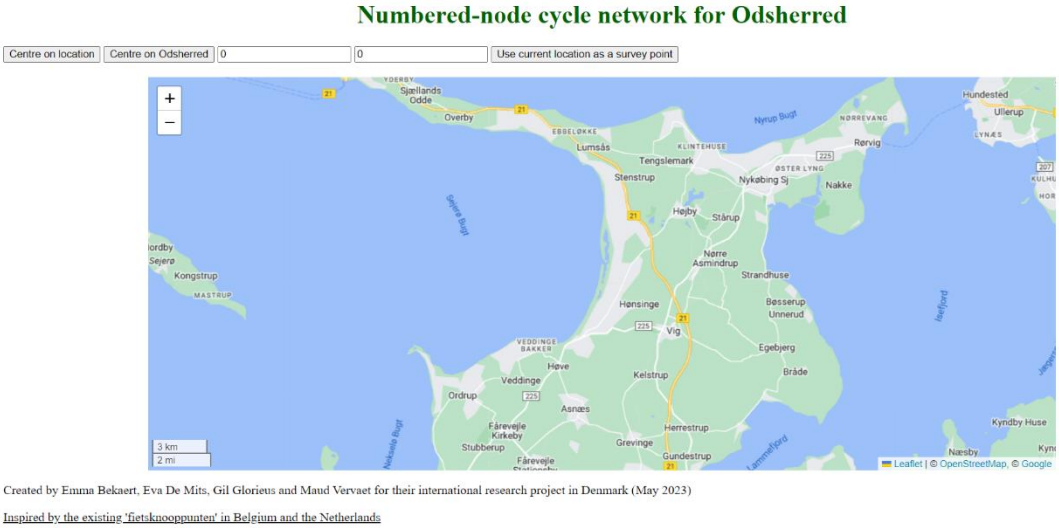

Figure 3: Web Application Used for the Field Work: Retrieval of Coordinates.

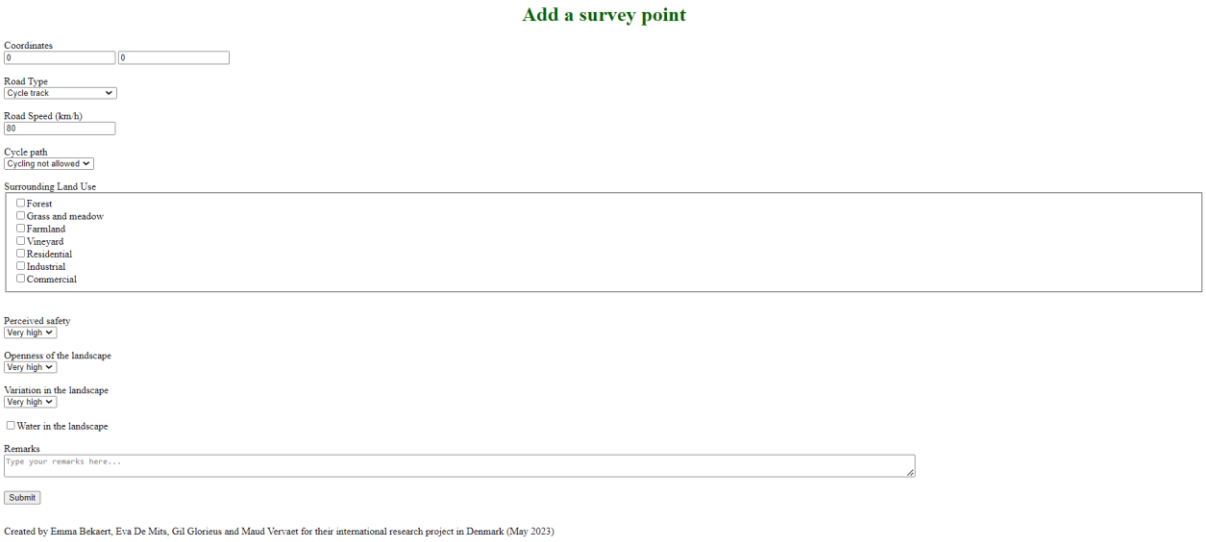

Figure 4: Web Application Used for the Field Work: Characteristics of a Survey Point.

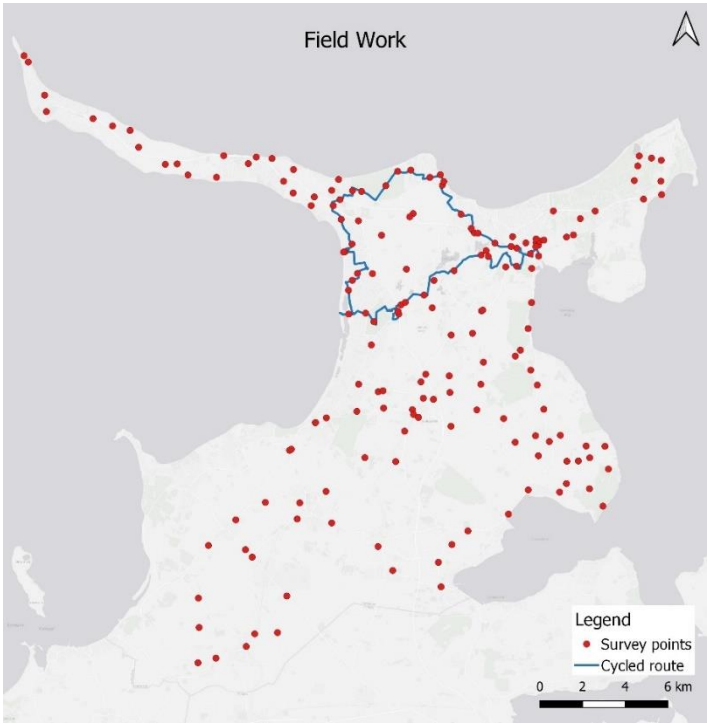

Figure 5: Location Map of the Field Work: Cycled Route and Survey Points.

To validate the input data from OpenStreetMap with our own observations, an error matrix was made for the speed limit, land use and road type. The survey points and the OSM data were compared with one another for these factors. For the other factors it was not possible to compare them in a similar way. The error matrices have been built up manually using the same visualisations for the corresponding categories of the survey points and the road network that is based on OSM data. The matrix then shows the number of observations in each class

and the agreement or discrepancy with de OSM data. The rows represent the classified data from the fieldwork, while the columns contain the different classes per dataset of OSM data. The diagonal shows the number of points were the field observations matches the OSM data. The User's Accuracy then measures the amount of times that the user has assigned the corresponding OSM value to a survey point by dividing the diagonal cell entry by the row total of a certain class. The Producer's Accuracy determines the amount of times that the OSM data has been classified correctly. Therefor the diagonal cell entry is being divided by the column total.

3.5 Creating the Numbered-Node Cycle Network for Odsherred

Finally, the cycle network itself could be manually created. The geometries were acquired by copying and pasting the relevant road segments from the OpenStreetMap roads enhanced with our final scores. While choosing the right road segments, the following aspects were kept in mind:

1. The final score of the segments should be as high as possible. In practice, this score was visualised on a colour ramp from red to green, and red or orange roads were therefore avoided. If there was no alternative to including a less suitable road, the separate factor scores were analysed to find out the reasons behind the low score and to assess whether this could be tolerated or not.
2. The routes should make no overly big detours and they should be connected to the rest of the network.
3. If possible, each village should have a part of the network passing through or near them. This ensures that cyclists can easily use those population centres as a resting place or a starting point where they can park their car there or take public transport.
4. The network should have a density close to the density of the numbered-node cycle network in Flanders. A too dense network is hard to use for cyclists as it provides them with too many options, but a network with very big gaps is not very useful either.

RouteYou has several methods to check the geometries of recreational networks. They provided us an FME script to ensure that there were no gaps between the network segments. The script checks where the dead ends are located and returns those as a point layer. The numbered nodes were obtained in QGIS by dissolving all the road segments, splitting them where they touch each other and then extracting the intersections as points. Some points were added manually, for example at the dead ends near the ferries. The numbers were added to the points as a new field that was filled with the row number.

3.6 Interviews - Questioning the Possibility of Implementing a Numbered-Node Cycle Network

The first objective of contacting local domain experts was to let them fill in the Likert scale to assess the different factors, which directly contributes to the creation of the cycle network. Furthermore, the possibilities and potential challenges associated with implementing a numbered-node cycle network in Odsherred, or in Denmark in general, were explored. The topics below have been covered for this purpose. The entire list of interview questions can be found in Appendix 8.1.

- The current state of the cycling infrastructure and network;
- Cycling in Odsherred;
- Potential for a numbered-node cycle network;
- Recommended Points of Interest (POIs).

The contact information of interesting individuals or instances to reach out to was obtained via Andreas Aagaard Christensen, who is a professor at Roskilde University and was also involved in this project. Due to his knowledge of the area and engagement with the project, he was also chosen as the first person to interview. Furthermore, people from VisitOdsherred and Geopark Odsherred were contacted for interviews. VisitOdsherred and Geopark Odsherred are two entities that contribute to the promotion, preservation, and development of tourism in the municipality of Odsherred. VisitOdsherred provides touristic information about the attractions, events and activities for visitors that would like to explore the area. They work closely together with Geopark Odsherred, an organisation that is dedicated to the development and maintenance of projects within the UNESCO Global Geopark framework. Geopark Odsherred aims to promote sustainable development, geological education and conservation of the region's geological sites. The organisation was created when Odsherred was certified as the first Danish UNESCO Geopark in 2014. In addition to engaging with these organisations, locals who have extensive knowledge and experience with cycling in the area have been contacted as well. These include the owners of Udsigten, a bicycle-friendly hostel and café situated in Høve, and people from the bicycle rental service Sayjes in Nykøbing Sjælland. We also asked some supervising teachers with domain expertise to fill out the Likert scales.

4. RESULTS

4.1 Suitability Map Using Weighted Factors

4.1.1 Scores Assigned to the Road Segments by Factor

For each of the factors, the scores assigned to the road segments were visualised with equal intervals. In that way, the road segments can be compared with each other for each factor, because there is no difference in importance yet. For the natural environment factor, the overall scores are relatively high (Figure 6). The median value is 0.680 and the mean value is 0.680. This means that the municipality of Odsherred is mainly characterized by natural and open types of land use (e.g., forest, grassland, farmland, water…). These environments are considered as pleasant to cycle through and are thus the most suitable for the numbered-node cycle network.

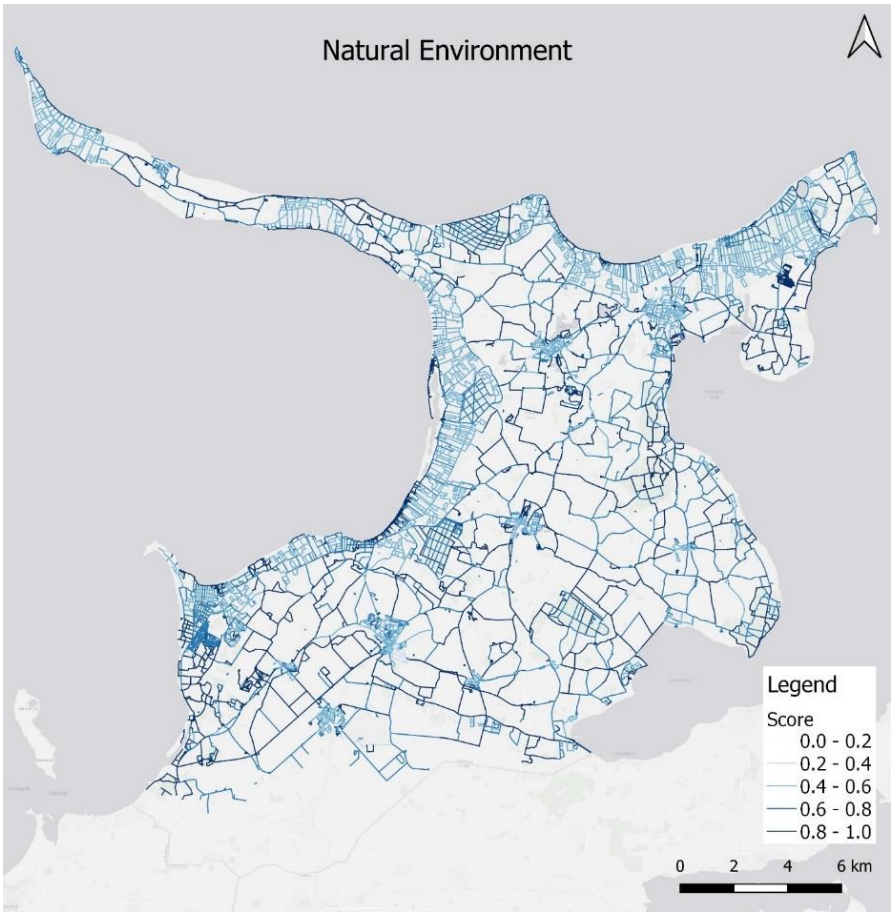

Figure 6: Road Segment Scores Based on the Natural Environment.

Figure 7 shows road segments in the vicinity of places of interest with a score of 1. The median value of all scores is 0.000 and the mean value is 0.019. This means that few roads pass near any of the sights that were included in the analysis. The low value may be due to the fact that only 56 sights were included in the analysis and the buffer was only 50 m.

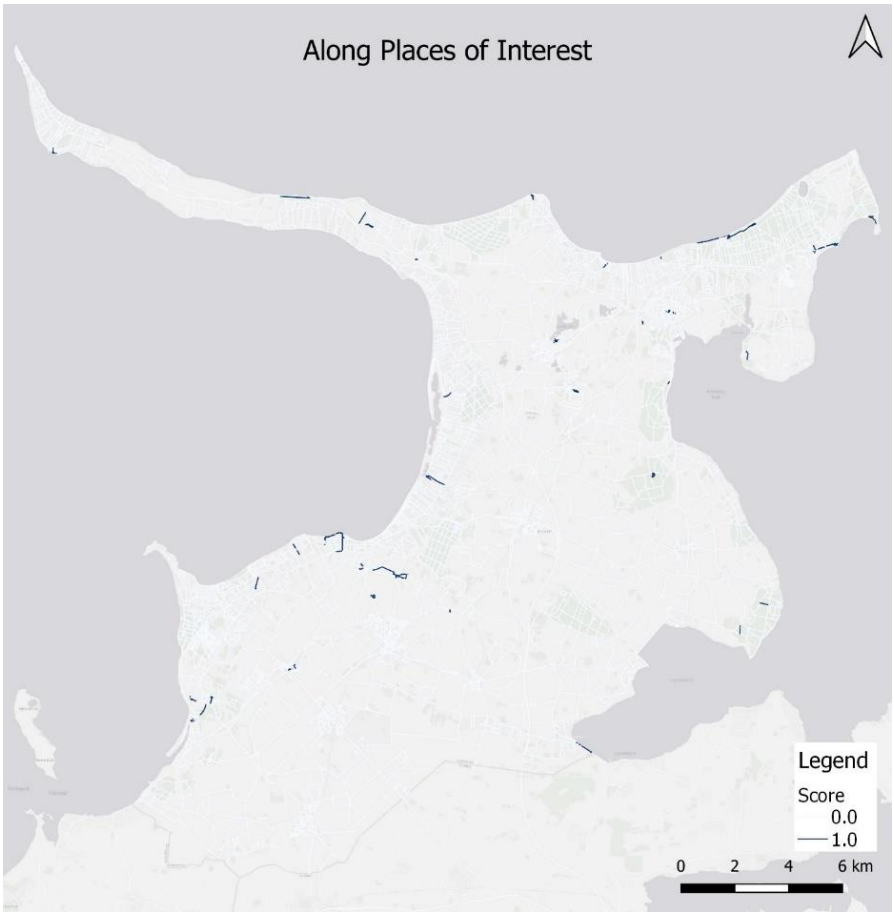

Figure 7: Road Segment Scores Based on the Proximity to Places of Interest.

For the road types, the overall scores are very high (Figure 8). The median value of all scores is 0.800 and the mean value is 0.707. This means that the municipality of Odsherred is mainly characterized by cycleways, living streets, residential streets, paths, tracks and unclassified streets. These roads are normally bicycle-friendly and therefore very suitable for the cycle network.

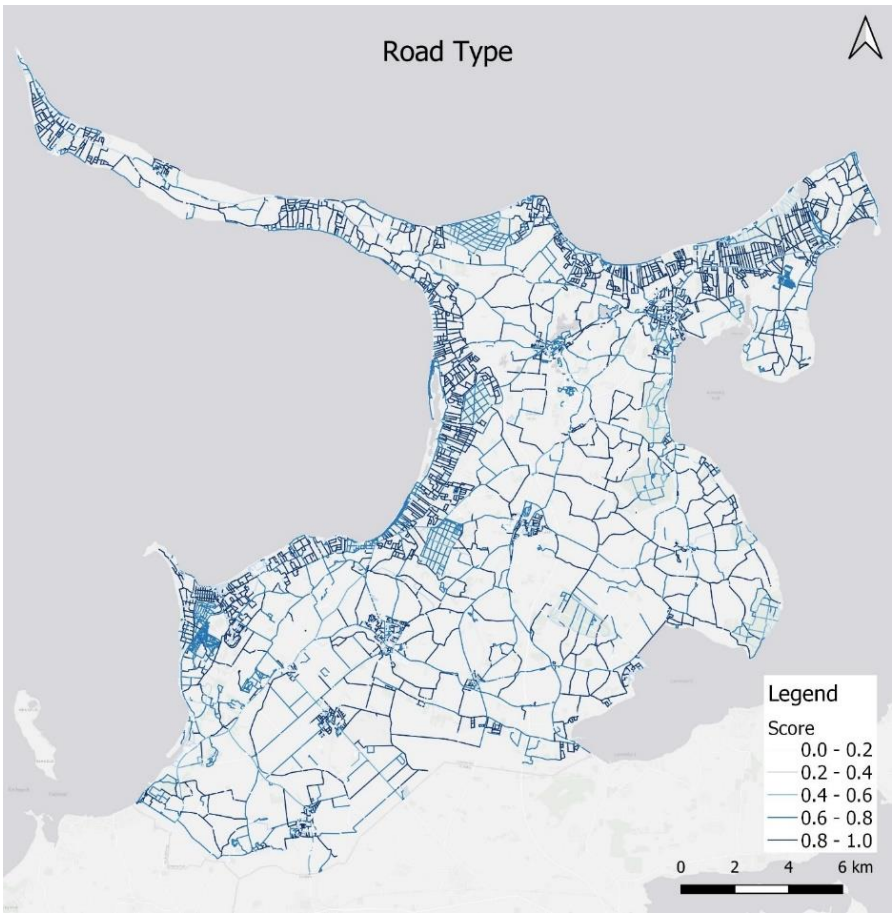

Figure 8: Road Segment Scores Based on the Road Type.

Figure 9 shows the scores assigned to the road segments based on the slope percentage. The median value of all scores is 0.904 and the mean value is 0.741. This means that most gradients are less than 4%. In addition, the darkest blue, and thus the highest scores, predominates on the map, indicating that mostly flat roads are prevalent in the municipality. These roads are desirable additions to the cycle network.

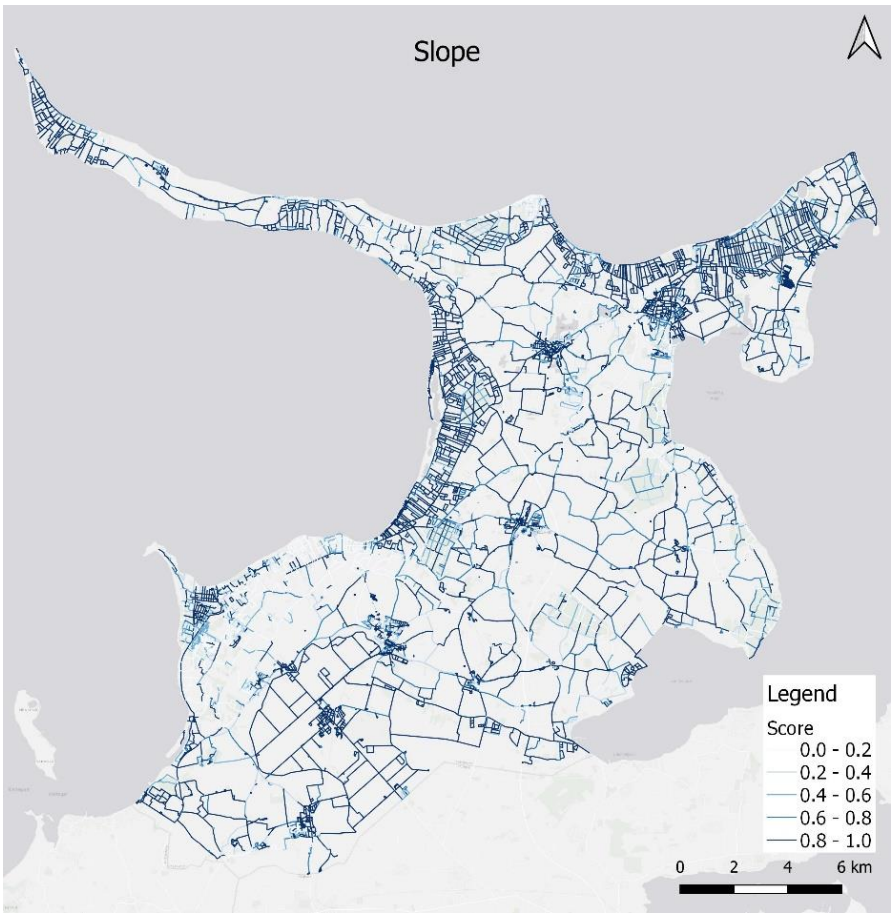

Figure 9: Road Segment Scores Based on the Slope.

Figure 10 shows the scores assigned to the road segments based on the car speed limit. The median value of all scores is 1.000 and the mean value is 0.912. Thus, the maximum speed on most roads in Odsherred is 50 km/h or less. This result could be expected since the largest roads were already filtered out of the road network through the constraints.

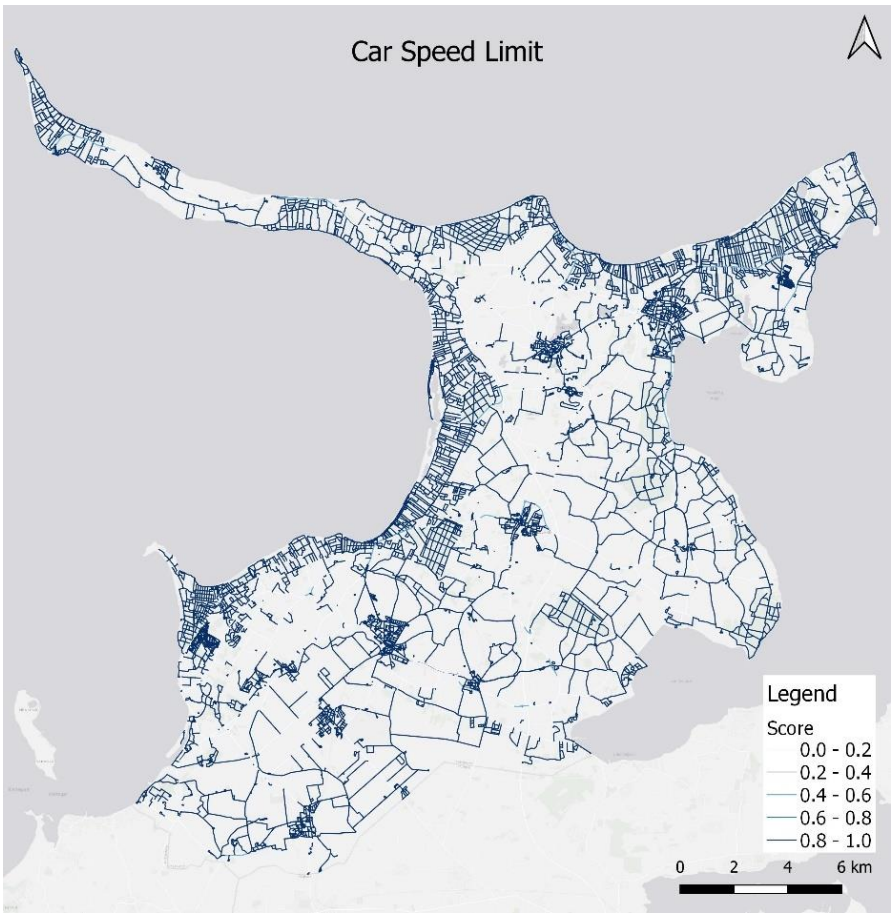

Figure 10: Road Segment Scores Based on the Car Speed Limit.

Figure 11 shows road segments along which existing RouteYou and OpenCycleMap bicycle routes run marked with score 1. The median value of all scores is 0.000 and the mean value is 0.460. This means that along most roads in Odsherred no existing routes pass. Nevertheless, the map shows a quite good coverage of the municipality based on existing cycle routes. This may be due to the fact that many roads lead to summer house areas. This is especially the case in the northern and western parts of the municipality.

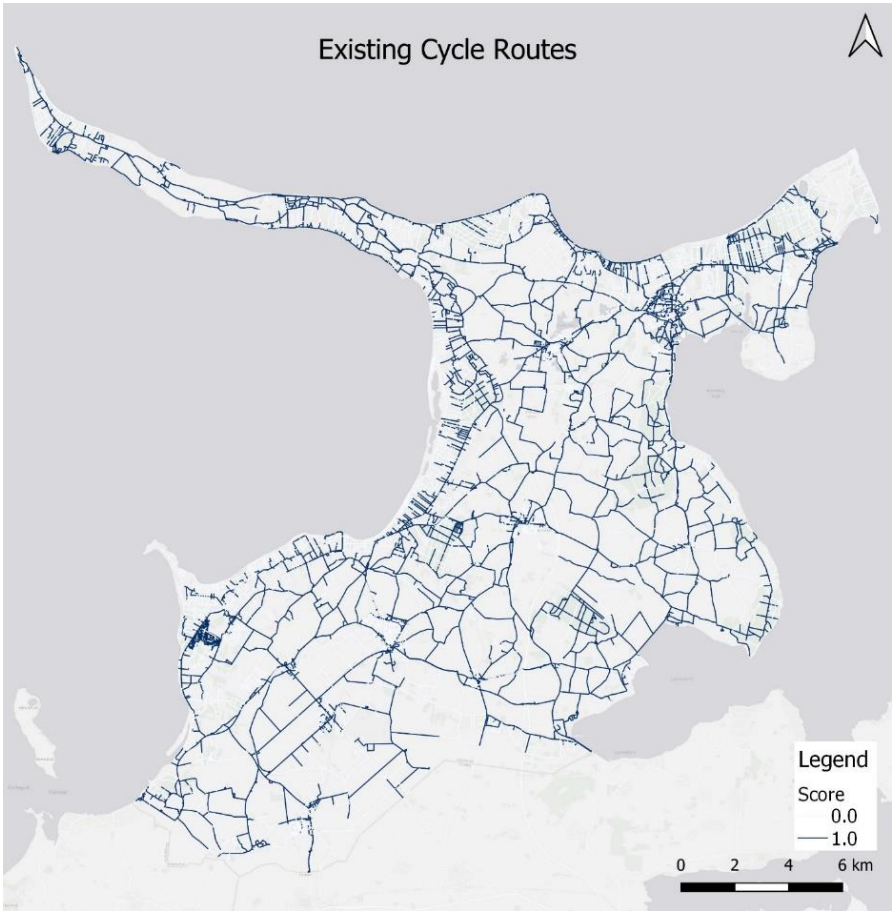

Figure 11: Road Segment Scores Based on the Presence of Existing Cycle Routes.

4.1.2 Analytic Hierarchy Process

Factor 1	Factor 2	Person a	Person b	Person c	Person d	Person e	Person f	Person g	Person h	Person i	Person j	Person k	Person l	Person m	Average	Median
Natural environment	Existing cycling routes	7,000	6,000	6,000	6,000	2,000	2,000	2,000	7,000	6,000	6,000	0,333	7,000	1,000	4,487	**6,000**
Car speed limit	Existing cycling routes	7,000	7,000	7,000	3,000	4,000	0,500	0,167	7,000	6,000	0,167	0,167	4,000	4,000	3,846	**4,000**
Car speed limit	Natural environment	1,000	4,000	1,000	0,333	0,250	3,000	0,143	0,143	0,200	0,167	0,200	7,000	7,000	1,880	**0,333**
Road type	Existing cycling routes	5,000	4,000	7,000	4,000	3,000	0,167	5,000	1,000	6,000	6,000	1,000	4,000	0,200	3,567	**4,000**
Road type	Natural environment	3,000	4,000	0,250	0,333	0,200	0,167	0,250	0,333	0,200	0,333	1,000	7,000	1,000	1,390	**0,333**
Road type	Car speed limit	0,167	4,000	1,000	4,000	1,000	0,167	6,000	5,000	0,167	3,000	1,000	5,000	0,250	2,365	**1,000**
Interesting places	Existing cycling routes	6,000	5,000	4,000	2,000	0,200	3,000	5,000	7,000	6,000	7,000	0,333	7,000	4,000	4,349	**5,000**
Interesting places	Natural environment	0,167	1,000	0,167	0,167	0,333	1,000	1,000	1,000	0,167	1,000	0,333	7,000	1,000	1,103	**1,000**
Interesting places	Car speed limit	0,143	4,000	0,250	1,000	0,200	5,000	2,000	1,000	6,000	6,000	1,000	1,000	1,000	2,199	**1,000**
Interesting places	Road Type	0,167	1,000	0,250	0,200	0,200	6,000	4,000	1,000	0,200	4,000	0,500	1,000	4,000	1,732	**1,000**
Slope	Existing cycling routes	5,000	1,000	1,000	0,500	3,000	6,000	0,143	2,000	6,000	6,000	3,000	7,000	1,000	3,203	**3,000**
Slope	Natural environment	1,000	0,250	0,167	0,143	0,333	2,000	0,143	0,333	0,167	0,333	3,000	7,000	0,250	1,163	**0,333**
Slope	Car speed limit	1,000	0,167	0,143	0,500	1,000	2,000	7,000	4,000	5,000	5,000	3,000	1,000	4,000	2,601	**2,000**
Slope	Road Type	7,000	0,200	1,000	0,333	1,000	1,000	0,143	1,000	5,000	6,000	3,000	1,000	1,000	2,129	**1,000**
Slope	Interesting places	7,000	0,333	0,250	2,000	2,000	2,000	0,143	0,167	0,200	0,500	3,000	5,000	0,250	1,757	**0,500**

Figure 12: Results of the Likert Scale.

Figure 12 shows the scores of the interviewees based on their Likert scales. The meaning behind each score greater than 1 (tinted blue), is that a respondent preferred the first mentioned factor. Any score less than 1 (tinted red), represents a preference for the second factor. A score of 1 indicates that the respondent had no preference for either of the two factors and considers them to be equally important. Then, the average and median of each

pairwise combination was calculated. The median was selected for further use in the AHP because it emphasizes the preference for a particular factor as opposed to the average values. Figure 13 shows the results of that AHP and the final weights of the factors. Natural environment receives the greatest weight and thus emerges as the most important factor in the model. This factor will thus have the most influence on which road segments will be part of the cycle network.

original matrix

	F1	F2	F3	F4	F5	F6	∑
F1	1,000	0,167	0,250	0,250	0,200	0,333	2,200
F2	6,000	1,000	3,000	3,000	1,000	3,000	17,000
F3	4,000	0,333	1,000	1,000	1,000	0,500	7,833
F4	4,000	0,333	1,000	1,000	1,000	1,000	8,333
F5	5,000	1,000	1,000	1,000	1,000	2,000	11,000
F6	3,000	0,333	2,000	1,000	0,500	1,000	7,833
∑	23,000	3,167	8,250	7,250	4,700	7,833	

calculation

							average
F1	0,043	0,053	0,030	0,034	0,043	0,043	**0,041**
F2	0,261	0,316	0,364	0,414	0,213	0,383	**0,325**
F3	0,174	0,105	0,121	0,138	0,213	0,064	**0,136**
F4	0,174	0,105	0,121	0,138	0,213	0,128	**0,146**
F5	0,217	0,316	0,121	0,138	0,213	0,255	**0,210**
F6	0,130	0,105	0,242	0,138	0,106	0,128	**0,142**
							1,000

final weights of the factors

Factors			
	F2	Natural environment	0,325
	F5	Points of interest	0,210
	F4	Road type	0,146
	F6	Digital Elevation Model	0,142
	F3	Speed limit	0,136
	F1	Existing routes	0,041

Figure 13: Analytic Hierarchy Process.

4.1.3 Suitability Map

By multiplying the factors with their corresponding weights and adding them up, all road segments got a suitability score. This results in the suitability map shown in Figure 14. The mean value of the scores is 0.574 and the median value is 0.570. This means that the roads in Odsherred have an average suitability for creating a cycling network. Roads with the highest scores are shown in green and are the most suitable as opposed to the red road segments. Road segments with a bad score below 0.3 are rather short and can only be found in the northwestern part of the municipality. The southwest has the most roads with a score between 0.3 and 0.5. The most suitable roads are scattered throughout the municipality, which is very useful for creating the cycle network.

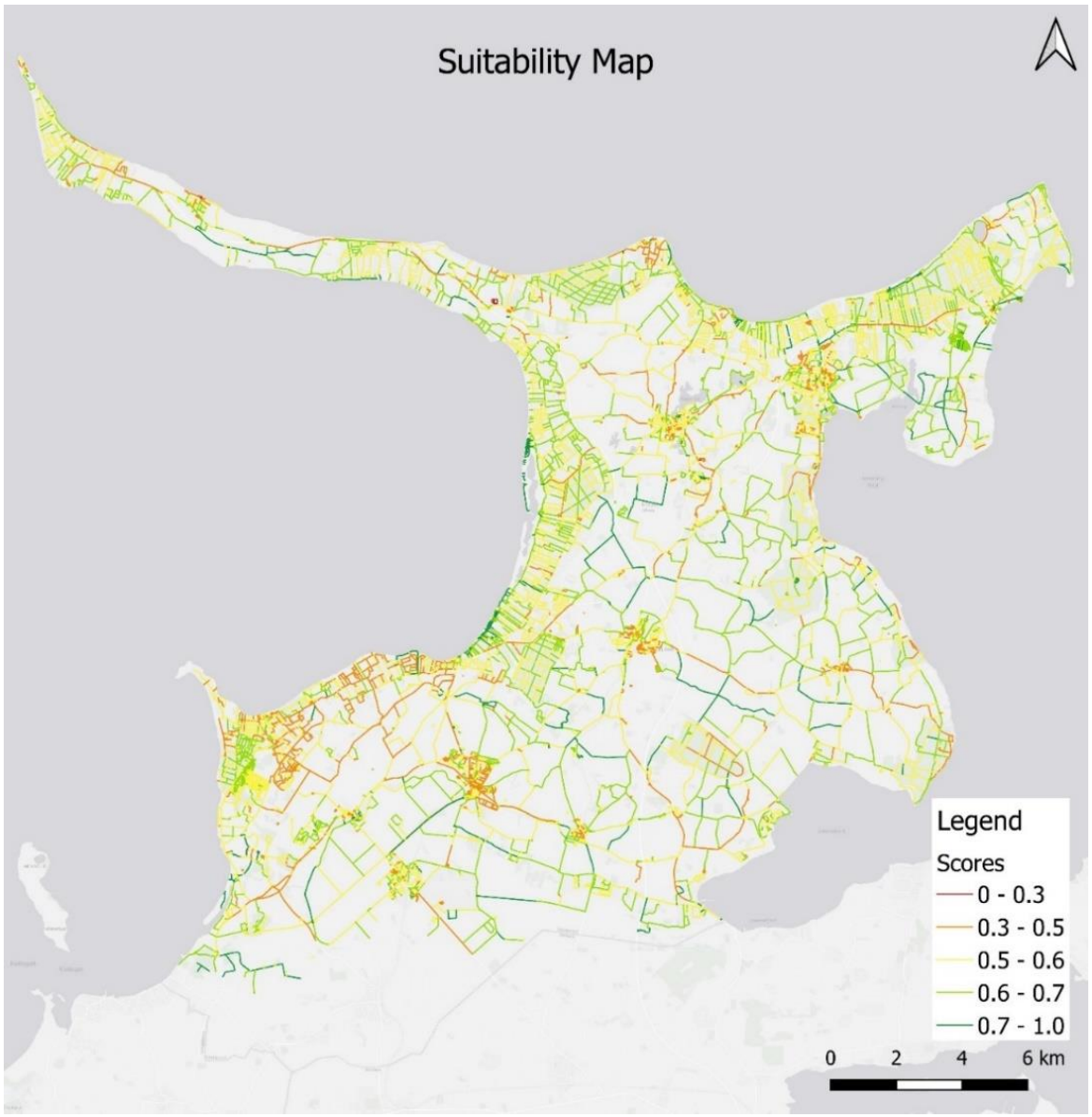

Figure 14: Suitability Map.

4.2 Qualitative Control in the Field

During the terrain work, different speed limits have been determined for the surveyed points. These speeds limits are compared with the speed limit that is assigned to the road network in OSM. In Figure 15 the error matrix for the car speed limit has been visualised. In total only 55% of the observations done in the terrain effectively correspond with the assigned car speed limit in OSM. For the speed limit of 0 km/h the producer's accuracy is only 20%. Only 16 out of 80 observations corresponded with the value in OSM data here. When the first column and row would not be taken into account the total accuracy goes up to 85%.

Car Speed Limit (km/h)		Reference Data										
		0	20	30	40	50	60	70	80	90	Total	User's accuracy
Classified Data	0	16	0	0	0	0	0	0	0	0	16	100%
	20	11	3	0	0	0	0	0	0	0	14	21%
	30	5	0	0	0	1	0	0	1	0	7	0%
	40	3	0	0	2	0	2	0	1	0	8	25%
	50	7	0	0	0	21	0	0	1	0	29	72%
	60	4	0	0	0	1	5	0	0	0	10	50%
	70	1	0	0	0	1	0	3	1	0	6	50%
	80	32	0	0	0	1	3	1	45	0	82	55%
	90	1	0	0	0	0	0	0	0	0	1	0%
	Total	80	3	0	2	25	10	4	49	0	173	
	Producer's accuracy	20%	100%	/	100%	84%	50%	75%	92%	/		**55%**

Figure 15: Error Matrix for Car Speed Limit.

In Figure 16 the road types are compared with those assigned to the road network in OSM. The overall accuracy is 78%. In total 78% of the observations done in the terrain effectively correspond with the assigned road type in OSM. The accuracy of roads where cycling is not allowed or not suited for cycling have the lowest accuracy. Adding more sample points would get better insights in this result.

Road type		Reference Data							
		Cycling not allowed	Not suited for cycling	Cycle track	Residential or other	Tertiary	Primary or secondary	Total	User's accuracy
Classified Data	Cycling not allowed	1	0	0	0	0	0	1	100%
	Not suited for cycling	0	4	0	0	0	0	4	100%
	Cycle track	0	4	5	1	1	0	11	45%
	Residential or other	1	0	3	56	1	0	61	92%
	Tertiary	0	0	0	16	44	1	61	72%
	Primary or secondary	0	0	0	0	10	25	35	71%
	Total	2	8	8	73	56	26	173	
	Producer's accuracy	50%	50%	63%	77%	79%	96%		**78%**

Figure 16: Error Matrix for Road Type.

Figure 17 shows the error matrix for land use types. During the terrain work, different types have been determined for the surveyed points and are compared afterwards with the land use types in OSM. In total 98% of the observations done in the terrain effectively matches with the data from OSM. This is a very high percentage which therefore implies a high accuracy of the OSM data.

Land use		Reference Data								
		Forest	Grass and meadow	Farmland	Vineyard	Residential	Industrial	Commercial	*Total*	*User's accuracy*
Classified data	Forest	*70*							*70*	100%
	Grass and meadow		*44*	1		2			*47*	94%
	Farmland			*25*					*25*	100%
	Vineyard			1	*0*				*1*	0%
	Residential					*28*			*28*	100%
	Industrial						*1*		*1*	100%
	Commercial							*1*	*1*	100%
	Total	*70*	*44*	*27*	*0*	*30*	*1*	*1*	*173*	
	Producer's accuracy	100%	100%	93%	/	93%	100%	100%		98%

Figure 17: Error Matrix for Land Use.

4.3 Numbered-Node Cycle Network for Odsherred

As mentioned in section 5.3, the resulting numbered-node cycle network was created using, among other things, the density of the network compared to that of Flanders. These densities are shown below in Figure 18 and Figure 19 respectively. Both networks have cells (the smallest loops that can be made in the network) that are less than 6 km in width and vary in size because of the terrain (water bodies and steep slopes), the accessibility and the interestingness of the surroundings. The density of the obtained network is comparable to the density of the Belgian network. Figure 20 shows the final numbered-node network.

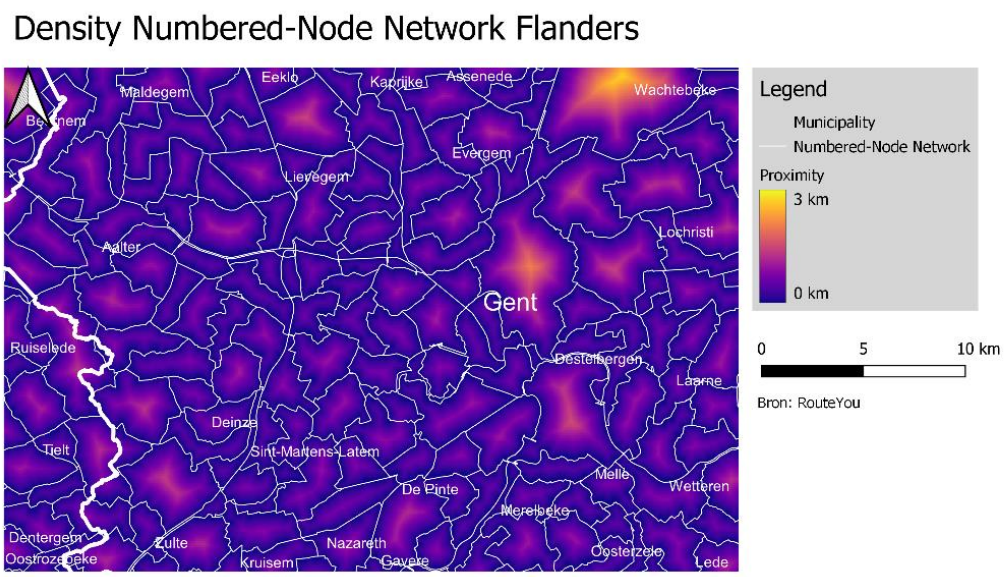

Figure 18: Density of the Numbered-Node Cycle Network in Flanders.

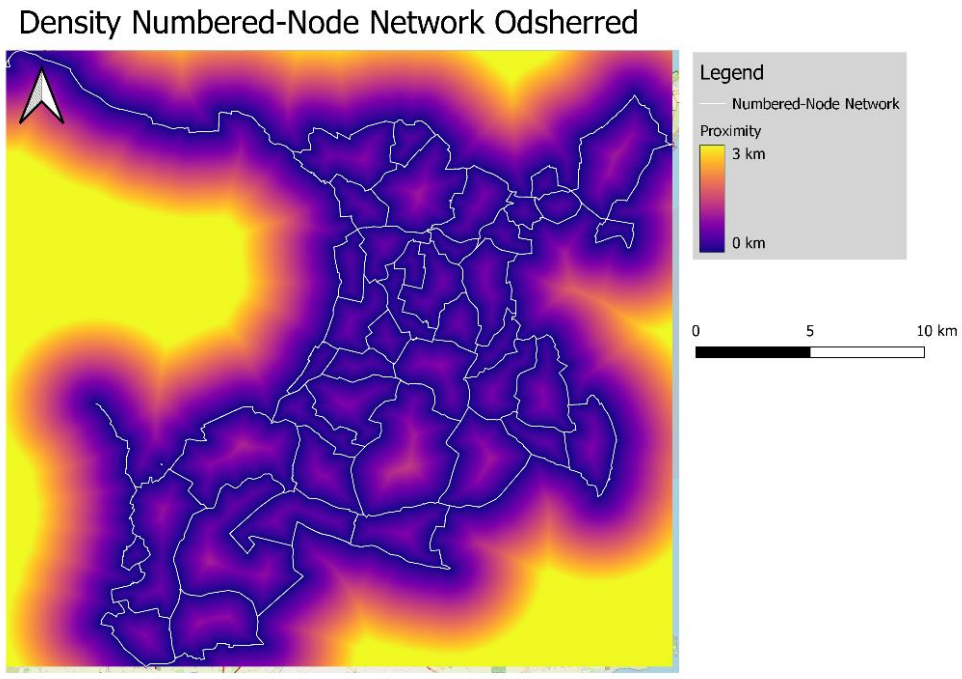

Figure 19: Density of the Numbered-Node Cycle Network in Odsherred.

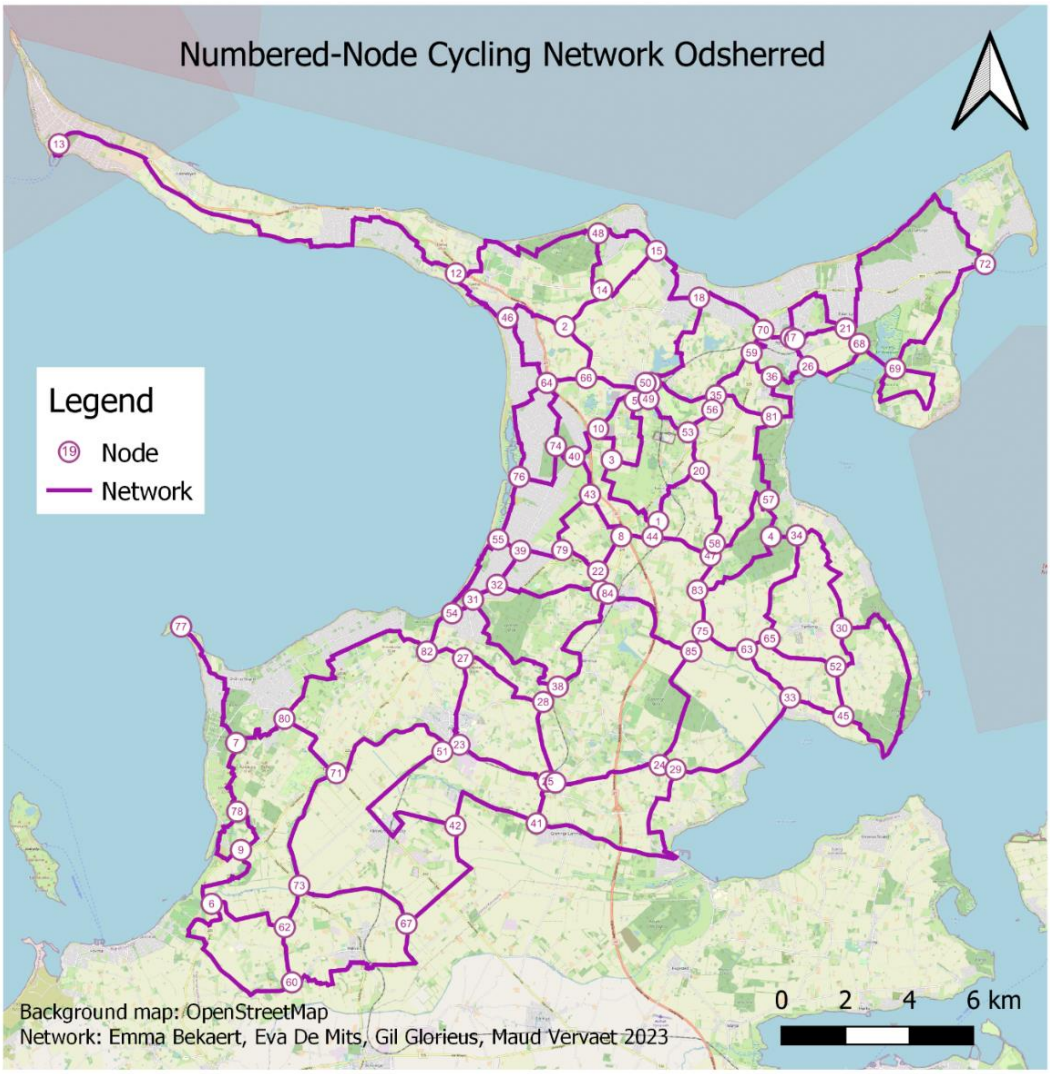

Figure 20: Numbered-Node Cycle Network for Odsherred.

4.4 Interviews

During the interviews with various stakeholders, the possibility of implementing a numbered-node cycle network in Odsherred has been examined. The insights gathered from these interviews shed a light on the current situation in the municipality and on the feasibility and potential challenges for a cycle network there. The key results from the interviews are summarised in the following paragraphs.

4.4.1 The Current State of the Cycling Infrastructure and Network

The present state of the infrastructure and road network was generally regarded as very good, well-developed, and safe for cyclists. Only the person commenting from a parent's perspective believed that the present infrastructure falls short of meeting children's safety needs, due to a lack of separate bike lanes on their way to school. These would be more prevalent in Denmark's cities' immediate environs. Apart from this, the roads were considered safe to cycle on. The attitude of Danish drivers also plays a role in this, since they are known to be attentive to more vulnerable road users such as pedestrians and cyclists. This could be partly attributed to the education system for getting a driver's license and to the policy in which drivers are held responsible for nearly all accidents involving cars and cyclists.

Presently, there is no numbered-node cycling network in the area yet, but there are multiple routes already designed. Examples would be the Geopark Bjerg Grand Prix route, the daisy route, the ice age route, and national cycling routes. At this moment, more routes are created using digital tools, but they are not visible on the road.

4.4.2 Cycling in Odsherred

A significant number of recreative cyclists and race cyclists come to Odsherred, particularly from Copenhagen. In Odsherred itself, a car culture is also present though. The interviewees emphasised that there is huge social inequality in the region and some people can't afford to buy a bicycle. Over the past five years, the cycling landscape in Odsherred has transformed, mainly due to three major developments. First, the Geopark Bjerg Grand Prix has attracted many racing cyclists. In addition, the Tour de France (2021) has given an extra boost to

recreational cycling in Odsherred. And finally, the COVID-19 pandemic has also contributed to changes in cycling behaviour.

4.4.3 Potential for a Numbered-Node Cycle Network

In the current situation, there is no such network present in the municipality of Odsherred and the current cycle routes have been perceived as boring by one of the respondents. A great value would be placed on the variation in landscapes and interesting elements during cycling. The current cycling routes do not always go through the most noteworthy places. The numbered-node cycle network on the other hand would enable cyclists to follow a designated route that highlights the unique characteristics of the area. The idea of creating such a network has thus been met with positive responses from the interviewees. However, the placement of signage poses a challenge due to rules determined by national nature authorities. Although digital tools are currently used to create routes, these are not visible on the road. For public roads or private roads, getting permission to place signage is not too difficult. But for private roads that are commonly owned, all residents have to agree, which takes considerably more time. Since this would be the situation in the areas with summer houses, this poses a considerable problem for the implementation of such a network in Odsherred. For further initiatives in the implementation of a numbered-node cycling network in Odsherred, contacting the Dansk Cykelturisme organisation has been recommended.

4.4.4 Recommended Points of Interest (POIs).

Points of Interest (POIs) can enlarge the overall cycling experience and highland the special elements of the area. In Odsherred, several special elements have been identified as valuable POIs to let a route pass by. It is regarded as more interesting when aspects of historical heritage, scenic viewpoints, or special natural characteristics are incorporated into the cycle network. In Odsherred, burial mounds are important archaeological sites that showcase the region's history. Also, mills are characteristic and charming elements, and several viewpoints in the hilly landscape are also worth it to pass by with a bicycle. Furthermore, services like public toilets or bars have been mentioned to take into account.

5. DISCUSSION

5.1 Limitations of the Method

The proposed bicycle network was created based on six factors chosen from the scientific literature. However, there is a degree of subjectivity in this research. For example, we chose which specific sights to include in the suitability analysis. For the study area, this amounted to only 56 points. Thus, more points of interest could be put into the analysis, or less attention could be paid to them even though they emerged as an important factor in the AHP. In addition, the more desirable types of environment and landscapes in a bicycle network were chosen with a low scientific base. As an indicator of landscape type, land use was used with natural and open landscapes being preferred. However, this does not take into account the diversity of landscape along the route. This could be calculated via the Shannon index, but this could also present problems of scale on very short segments. Nevertheless, it can be concluded that a solid network was created using the chosen factors. Besides, the density of the created network is in the same order as the density of the Flemish network. The fieldwork allowed the results obtained from the desktop analysis to be validated. Moreover, it provided relevant insights to ultimately determine which roads would be included in the network.

The choice was made to work with data from OpenStreetMap. In that manner, the method is reproducible and other data layers can easily be used, or the study area can be adjusted. However, it must be taken into account that this is open data and managed by a community. This results in data that is not always reliable. For the car speed limit a large number of segments have not yet been assigned a certain value in OSM, which results in a lot of 0-values that should be taken into account. Besides, only 55% of the recorded sample points match the actual car speed limit. On the other hand, the accuracy for road type and land use type was much higher. In addition, the data does not include information on road obstacles or their accessibility. Private roads were not considered for example and roads that are (temporarily) closed could not be included in the model. Another possible problem is that the resolution of the used digital elevation model was fixed at 25 m. If a model with a finer resolution were used, the slope could have been determined more accurately and this could have affected the eventual model.

For the AHP, 13 (local) domain experts were surveyed. This small number of respondents makes the study not fully representative. It is nonetheless useful information since the experts had extensive knowledge about the

current Danish cycling culture and landscape experience. What stood out in the results is that the Belgian domain experts gave less importance to the gradient than the local experts. For the car speed limit, the opposite could be noticed. This is a factor that should be weighted more heavily according to the Belgian experts than for the Danish experts. This is an interesting contrast that also emerged during the interviews and can be explained by the fact that motorists in Odsherred are very aware of cyclists on the road.

5.2 Future Research

The obtained results are in line with expectations. Nevertheless, there is room for improvement. For example, additional factors could be included in the suitability analysis such as road surface substrate, intersections, private roads, landscape variety and traffic density. According to Wysling and Purves (2022) cyclists may perceive intersections as stress points and less safe. By determining the number of intersections on a route or assigning lower scores to road segments that end at complex intersections with high degrees of centrality, this can be included as a factor in the analysis. In addition, they believe that the area and width of bicycle infrastructure has a greater impact on cycling enjoyment than the type of infrastructure. Finally, traffic volume and mixes are not currently included in the model, but are approximated through the car speed limit. Adding those factors could make the network even safer. All those factors could be weighted in advance with a large group of cyclists. By surveying more people, such as experts, local residents and bicycle tourists, the numbered-node cycle network could be even better tailored to the users' needs. In addition, some factors may be correlated with each other. No correlation analysis was performed in this study, but this may be interesting toward future research.

6. CONCLUSION

This project focussed on the creation of a numbered-node cycle network for the Danish municipality Odsherred. Using OpenStreetMap data and a selection of six different factors (natural environment, car speed limit, road type, slope, existing cycle routes and points of interest) a suitability map was created to find the most suitable road segments. The desktop analysis has been combined with a qualitative control in the field, allowing for the creation of error matrices to analyse the quality of the input data and the suitability map itself. Next to this, interviews were conducted to question the potential for such a network in Odsherred.

The subjectivity in choosing factors, reliability issues with the data and the limited representativeness of the small number of respondents to the AHP survey are the main problems with the method used in this research. Potential improvements to the project could be the inclusion of additional factors and a correlation analysis in the suitability analysis, and the extension of the survey to a larger and more diverse group of participants. Furthermore, it can be concluded from the interviews that there is an interest for a numbered-node network, but the Danish regulations regarding signage installation pose a significant obstacle for the actual implementation of this.

Despite these limitations, this project shed light on the development of a numbered-node cycle network and this has led to a map for a possible cycle network for Odsherred. The project has hereby paved the way to smooth and pleasant cycling experiences in Odsherred.

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8. APPENDIX

8.1 Interview questions

Icebreaker and introduction

- Can you please introduce yourself?
- What is your connection or involvement with cycling in Odsherred?

Introduction to the research

- Are you familiar with the concept of cycling node networks that exists in Belgium/the Netherlands?

The current situation of the cycling infrastructure and network

- How would you describe the current state of cycling infrastructure in Odsherred?
- Are there any existing cycling networks or routes in the region?
- What are the strengths and weaknesses of the current cycling infrastructure and network?

Cycling in Odsherred

- Who are the primary users of the cycling infrastructure in Odsherred? Are they mainly tourists, locals, members of cycling clubs?
- Have you noticed any changes in the composition or behaviour of cyclists in the region over time?
- What makes cycling popular in Odsherred? Why do people cycle here?

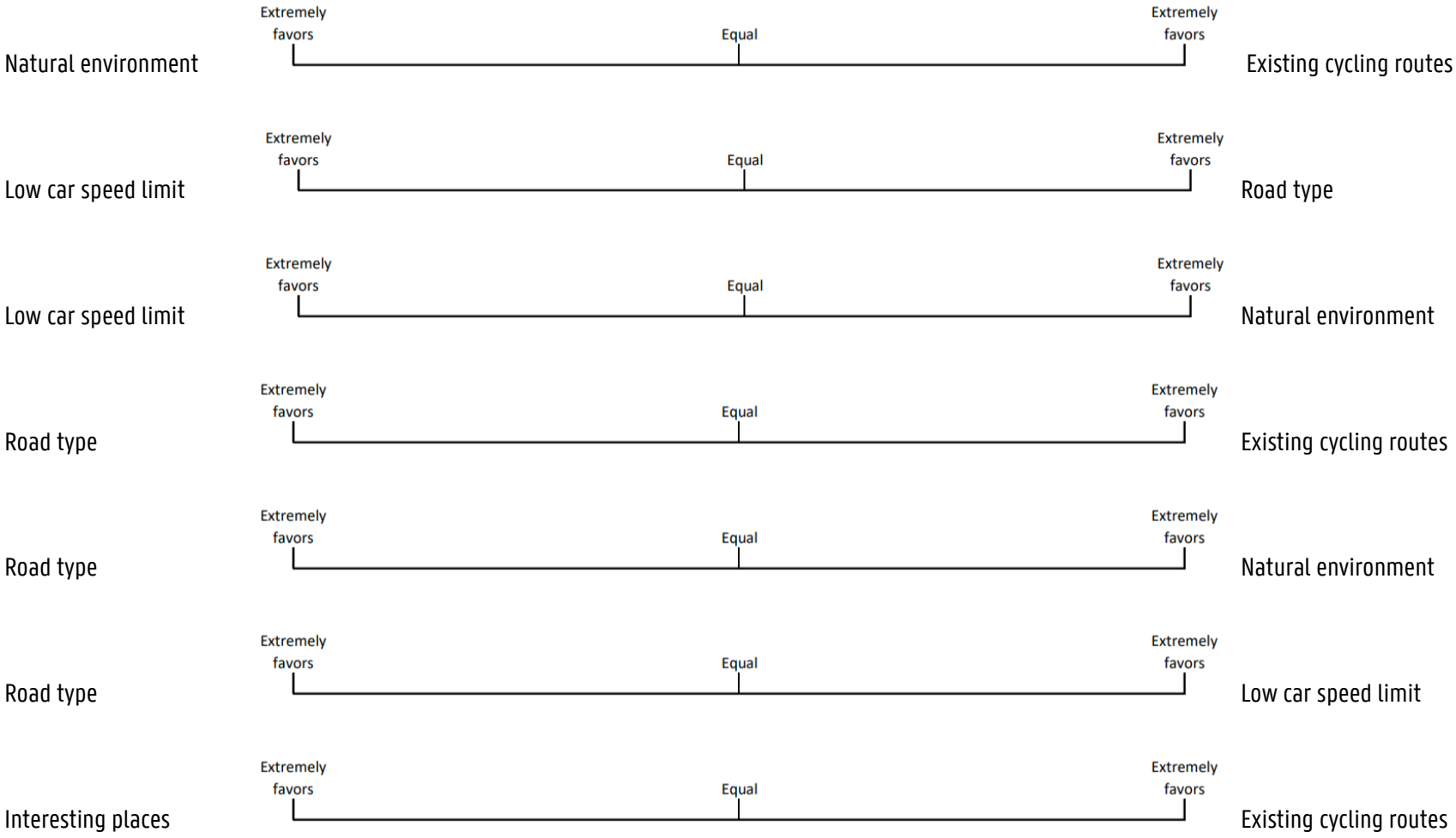
Potential for a numbered-node cycling network

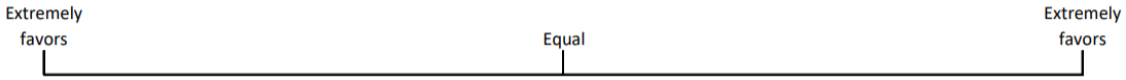
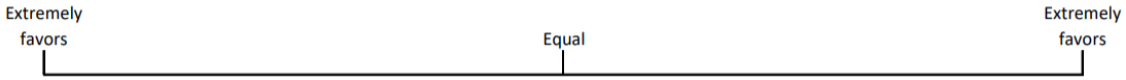
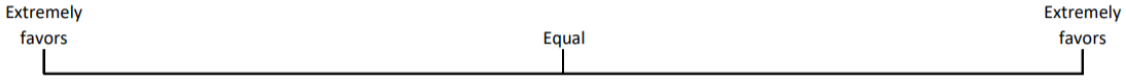
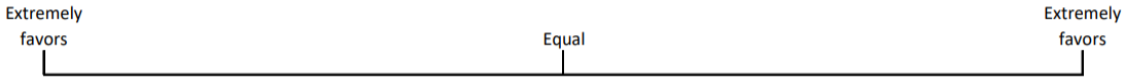
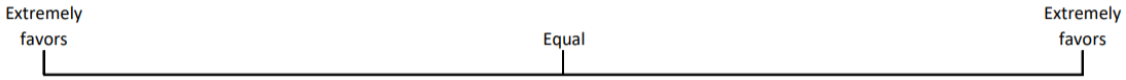
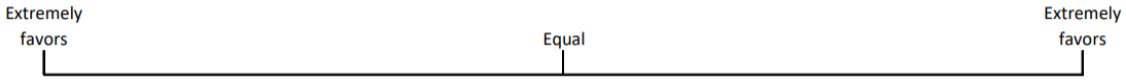
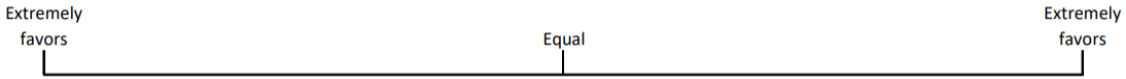
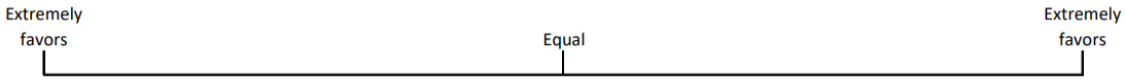
- In your opinion, would there be potential for the installation of a numbered-node cycling network in Odsherred? Why or why not?
- How do you think such a network could benefit the local community and attract more cyclists?

Recommended Points of Interest (POIs)

- Are there any special places in Odsherred that you would recommend to include as points of interest in the cycling node network?

8.2 Form Likert Scales



Interesting places		Natural environment
Interesting places		Low car speed limit
Interesting places		Road type
Weak slope		Existing cycle routes
Weak slope		Natural environment
Weak slope		Car speed limit
Weak slope		Road type
Weak slope		Interesting place

FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

UNDERSTANDING THE RELATION BETWEEN PAST LAND USE, SOIL AND BIODIVERSITY FOR FUTURE NATURE MANAGEMENT AROUND HOV VIG

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CONTENT

1 INTRODUCTION

The preservation of nature is an important topic that has been receiving increasing attention in recent decades. Nature preservation has an important function in the preservation of ecosystems and their biodiversity. The influence of human activities often has negative effects on nature that disturb ecosystems and causes a loss of biodiversity. To better understand how to manage and protect nature, appropriate research is necessary. In the study three aspects are examined: historical land use, soil and biodiversity. By means of a historical analysis of land use, borehole measurements, and measurements of biodiversity we want to gain insights that will help with the implementation of effective nature conservation practices. This implementation will also be aligned with the current nature policy in Denmark in the form of the national and local visions on Danish landscape policies. Finding the relationship between the historical analysis of land use, soil and biodiversity for future nature management in the study area is the main research question of this study. The study area is located within the nature reserve of Hov Vig and its surrounding region. Given the rich history of this area, it is interesting to explore how the landscape has evolved throughout history. The historical analysis focuses on land use which is mapped on the basis of historical maps and aerial photographs from different time periods. This allows land use trajectories to be determined. These trajectories provide insights in how the landscape has developed and changed over time. The interactive tool CLUE (Change in Land Use Explorer) is used to determine this in an analytical way, including calculating the Hamming distance, Levenshtein distance, time depth and classifying all the different trajectories. In this research only the time depth metric is used. This metric illustrates the dynamic or static nature of the land use in a particular patch of the study area. In addition to the historical analysis, at least one soil sample (mostly two samples) is taken for each land use class to investigate whether there is a relationship between land use and soil characteristics. Biodiversity measurements are also conducted at the same locations as the soil samples. This approach enables the identification of the relationship between historical land use, soil characteristics, and biodiversity. By utilizing this information and reflecting on past and present management decisions, the aim is to improve future nature conservation objectives.

2 THEORETICAL FRAMEWORK

2.1 Study area

The study area for this research is located in the east of Denmark, more specifically in the municipality of Odsherred, in the region of Zealand (figure 1). The total size of the study area is 42,65 km^2. In the north, the area is bordered by the summerhouses and the city of Rørvig, in de east and south it is bordered by water. The western boundaries consists of the buildings from the city of Nykøbing Sjælland. The focus of the research is on biodiversity, land management, soil and land use. That is the reason why the area does not include densely populated areas. The study area (figure 1) includes the nature reserve Hov Vig, a bird reserve protected area since 1979. This has a central location in the research area. The western part consists of a poldered area and the eastern part is called the peninsula of Nakke, which was formed after the ice ages.

Figure 1: Study area

2.2 Historical context

2.2.1 Odsherred

To understand the landscape of the study area, it is very important to know the history of the area. Especially for this study area, which is located in the geopark of Odsherred. A geopark is an area with a unique geology and contains relicts of the past that were important for the development of the environment. It is supported by UNESCO world heritage (Geopark Odsherred, 2018).

The contemporary landscape of Denmark was created during and after the last ice age (LIA). This period is also known as the Weichselian (Odsherred kommune & niRas, 2012). During this cold period the icecaps consisted of ice and snow, became bigger and reached Hov Vig and its surroundings. The icecap deposited some clay sand and gravel in the area (Odsherred kommune & niRas, 2012). An example is the town 'Nakke', this village is built on a higher area with sediment that was deposited by the icecap. These areas became islands in the sea due to a rising of the land (figure 2). Although the icecap melted after this cold period, several relicts can be found in the contemporary Danish landscape. Moraines, fjords, depressions and hills constructed due to glacial deposits are examples of these relicts. Depressions were created due to erosion and the huge force of the icecap (Odsherred kommune & niRas, 2012).

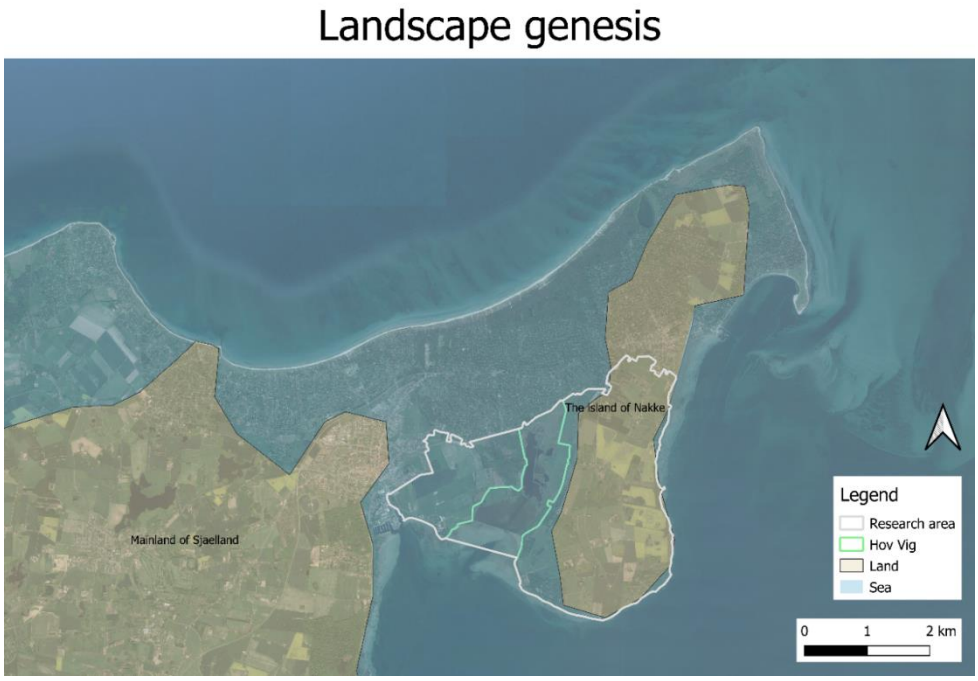


Figure 2: Landscape genesis phase 1

In the next phase, a cover sand ridge was formed which connected the island of Nakke with the Mainland of Zealand (figure 3). Nowadays the summerhouses are constructed on this cover sand ridge (appendix 4).

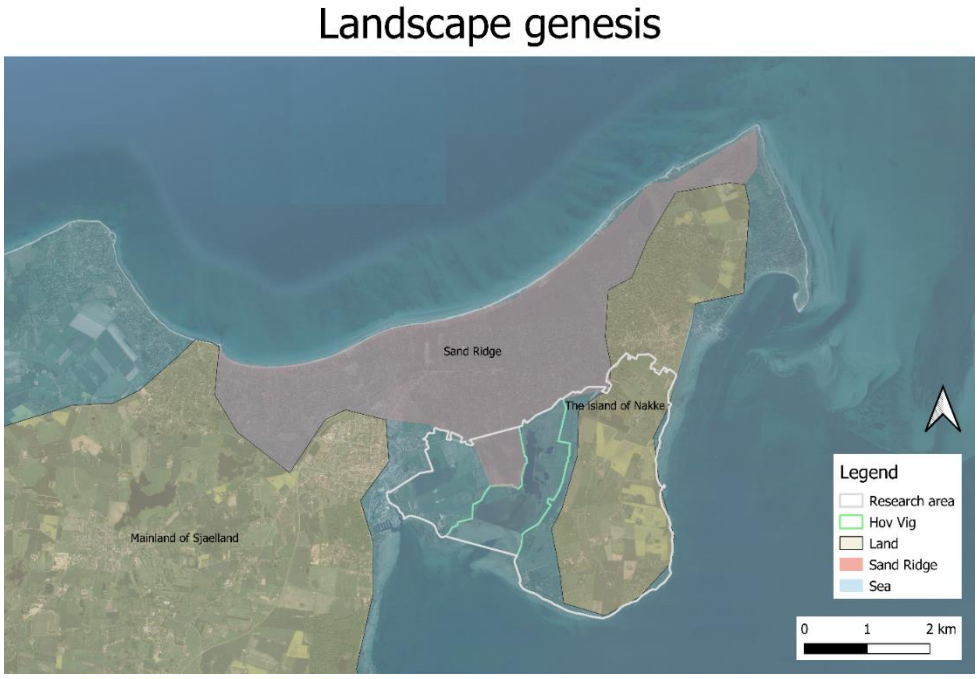


Figure 3: Landscape genesis phase 2

Since the bronze age, the landscape had a high population because the fjords, bays and coves became accessible (Naturstyrelsen B, *s.d.*). The introduction of humans in the landscape had a big influence, especially in the last century due to the expansion of the agricultural landscapes and an intensification of the agricultural areas in Denmark. As a result, big rectangular plots made their introduction in the landscape (Odsherred kommune & niRas, 2012). Another effect is the origin of the monoculture which means there is only one species growing in a field at a certain time. This concept is also observed in other European countries. Because of agricultural expansion, a lot of semi-natural habitat types disappear. There was also afforestation, agricultural abandonment and intensification on soils. All those elements and especially the glacial landscape were the basis for the diversity of landscape elements, but also for the variety of the fauna and flora in Denmark, which caused an important natural historical value (Odsherred kommune & niRas, 2012).

2.2.2 Hov Vig and surroundings

2.2.2.1 Hov Vig

The large structure in the middle of the study area is Hov Vig (figure 4), a protected nature reserve with 267 registered bird species that can be observed in the Hovvigvej, a dirt road which splits the area into two parts. The water is kept at the right level and refreshed for the different water birds with approximately 10km of channels (Rørvig Guide, 2022). One of the largest colonies of cormorants in Denmark can be found and admired here with the help of several bird towers and hiking trails. Furthermore, there are wetlands, reed forests and pastures situated in the study area (Naturstyrelsen A, *s.d.*).

Hov Vig has a rich history with the first people making their way to Nakke about 15 000 years ago (Naturstyrelsen B, *s.d.*). Many different people inhabited the area over the years, including the Vikings. In the 16th century, sand drifts, intensive grazing and population growth destroyed the land. These, in combination with an earlier uplifting of the land, formed the shallow wetland next to Hov Vig. In the mid-19th century, Denmark lost a war against Germany and because of that, Denmark lost large pieces of their land. To regain some of the land, the idea rose to dam Hov Vig for agricultural activities. In 1902, a violent storm caused the dam to break and flooded the area again. The dam was repaired later, but the water was not drained again. In 1979, the state purchased the area and made it a protected Natura 2000 area. (Naturstyrelsen B, *s.d.*).

2.2.2.2 Slettemose

To the southeast of Hov Vig, there is a pasture which is called Slettemose (figure 4). The area is difficult to cultivate and has been used for grazing through the years, allowing Slettemose to maintain its character as pasture. In 1995, it became in the possession of the state except for the farm which is privately owned. The unique fauna and flora are preserved, including horses and other grazing species and returning species such as frogs, snakes and buzzards (Naturstyrelsen C, *s.d.*).

The green area next to Slettemose, Enebærheden, used to be a moorland grazed by cows, but is now covered by juniper. Also the forest apple, oak and rose has been spreading through the area. Now, the idea rises to make the juniper grow further over the moorland where the cows and horses are grazing (Naturstyrelsen C, *s.d.*).

Through Slettemose, there is a stream forming a green arm in the area. This used to be an arm of a fjord which dried out during the Viking area. At the bottom of the stream, there were pipes that were removed to mimic the landscape of the 19th century (Naturstyrelsen C, *s.d.*).

2.2.2.3 Nakke Skov

Nakke Skov is a young forest that was planted in 1994 by the state and includes several tree species such as beech, oak, ash, wild cherry, pine, red elm, and Douglas fir (figure 4). The forest extends with arms of oak and apple trees into the grazed land surrounding it. Some lakes in the forest that had dried up were refilled (Naturstyrelsen C, *s.d.*).

In the north of Nakke Skov, near the town of Nakke, there is an opening between the two arms of the forest. The only bull of the town grazed here until the 18th century. This bull, as the father of all calves in the area, was extremely well cared for and his condition was inspected regularly (Naturstyrelsen C, *s.d.*).

2.2.2.4 Ringholm Skov

This forest is mainly composed of mixed hardwood in combination with conifers, the proportion of which is decreasing due to storm damage and aging. Over time, beech, oak and ornamental trees (nobilis) have been planted. The ornamental trees are of good quality. This is because they grow on poor sandy soil which results in many short branches for each tree. A part of the forest is inhabited by a much smaller colony of cormorants than in Hov Vig. The birds reduce the proportion of birch in the forest due to their high level of fertilization (*N.N.*, 2007).

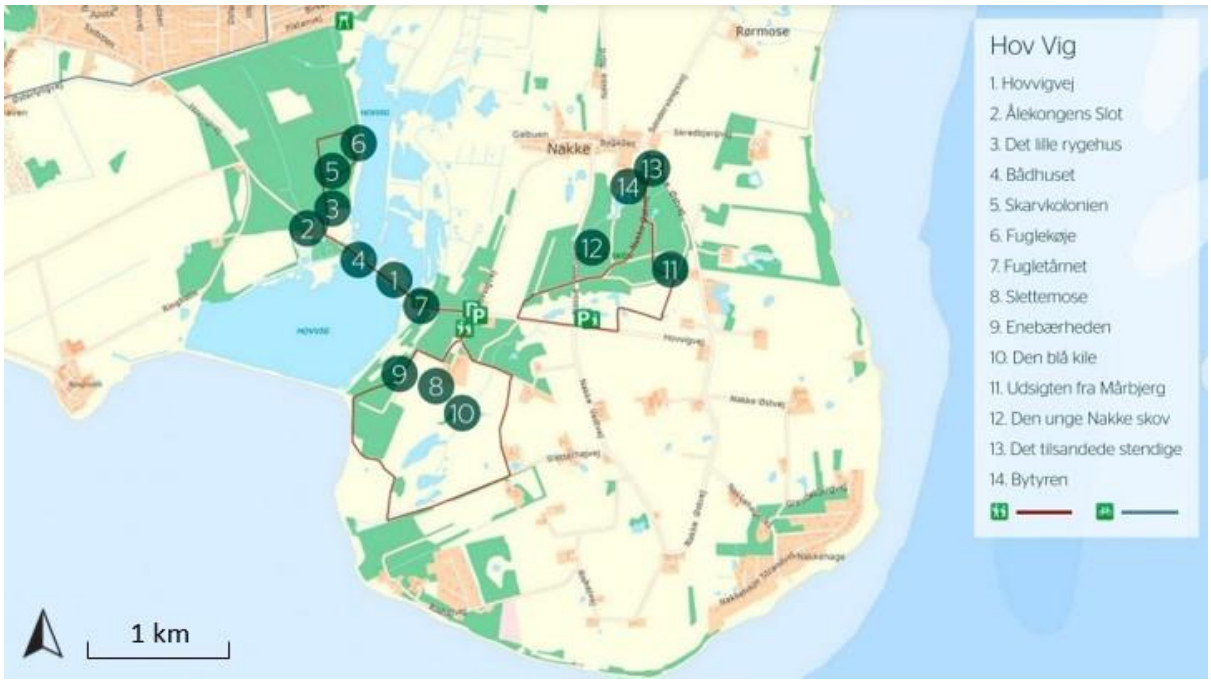


Figure 4: Nature areas

2.3 Policy context

Enhancing the biodiversity in nature areas in combination with the ecological significance of agricultural landscapes is currently a subject with a lot of interest in Denmark. This has led to both national and local plans and visions to improve the natural value of Danish landscapes (Odsherred kommune, 2017). Furthermore are such projects beneficial for climate change ("Danish Nature Policy", 2014).

2.3.1 Denmark

There are three general visions at the national level to improve the natural value of Denmark. First of all, more nature should be created and these nature areas should be better connected. In addition, initiatives for wild animals and plants should be strengthened. Finally, nature experiences and outdoor activities should take place to improve and promote a sense of community. In this study, the focus is particularly on how to applicate the first two visions in Hov Vig and its surrounding areas. According to the Danish Nature Policy (2014) this can be achieved by creating more forest in the area, making the aquatic environment cleaner, better protecting of valuable nature areas, doing efforts against invasive species and helping

endangered species. In addition, it is important that possible changes in the area are attractive propositions for farmers and that everyone has the opportunity to use nature (Danish Nature Policy, 2014).

2.3.2 Odsherred

The city of Odsherred has less nature than the national Danish average, as a result of which creating nature and counteract fragmentation by making connections between nature areas is important (Grüttner et al., 2021 & Odsherred kommune, 2017). More specifically, Odsherred executes the plans and visions of the Danish government for example by leaving dead wood and leave trees standing when they are cut to create life for birds, insects, plants and fungi. Furthermore, a goal is to create more wild nature, by making areas untouched. The municipality ensures grazing because this is an important factor to benefit for flowers, plants and butterflies. In addition, Odsherred contributes to the creation of bogs and lakes by allowing natural depressions to swamp and old ditches are stopped, as a result of which water can stay in the forest. Moreover, the municipality tries to take care of old trees and forests and let trees grow where they feel best. Finally, Odsherred takes care of heats, bogs, grasslands with burning, livestock and hay sledding, whereby they protect germinating seeds, roots, small animals and fungi (Naturstyrelsen D, s.d.).

2.3.3 Natura 2000

Hov Vig, a part of the study area, is situated in a Natura 2000 bird protection area. The protection of the area takes place on both the national and the municipality level. The Danish Agency for Water and Nature Management, also known as the Danish Environmental Protection Agency, describes objectives for 252 designated protection areas in several plans. Municipalities like Odsherred are responsible for the implementations of these plans. This includes establishing grazing to improve habitats for shovelers, regulation of water levels to preserve waterlogging in the meadows in spring and promoting the development of the reed beds in Hov Vig (Odsherred kommune, 2017).

2.3.4 Geopark

As a geopark, Odsherred focuses on the relation between the geology, landscape, local production history of culture and art. There are many sights and resources in Odsherred that highlights these relations (Geopark Odsherred, *s.d.*). Between 2019-2024, the geopark has some points they want to work on in the context of managing the geopark. The geopark wants more people to know what they can find in a geopark, what the meaning of the geopark is... They also want to preserve the landscape. More specifically, they want to build a platform for sustainable development with a connection between growth, identity and environment. They want to do that by making the strength of the geopark available for the local people by using the landscape, art, cultural history and food (Geopark Odsherred, 2018). Because the study area is situated in Geopark Odsherred, this vision is important to keep in mind during the analysis of the gathered data.

2.4 Biodiversity

2.4.1 Which biodiversity?

When biodiversity is measured, it is important to clarify what definition of biodiversity is used. Biodiversity can firstly be divided into phylogenetic diversity, functional diversity and taxonomic diversity. Phylogenetic diversity measures the phylogenetic difference between species. Functional diversity is about the functions and/or traits the species have in an ecosystem. Taxonomic diversity is simply the amount of species that are present. The last form of diversity is used in this research. A second way to split biodiversity, is into alfa-, beta- and gamma-diversity. Alpha-diversity is simply the diversity in the study area. Beta-diversity is the difference between two study areas. Gamma-diversity is the overall diversity in a wider area where the study areas are in (Magurran, 2021). The alpha- and gamma-diversity is used in this research.

When measuring taxonomic diversity, the simple thing to do is to count the amount of different species encountered in the study area. This is species richness. However, this does not show the whole picture. The second component is evenness. This is a measure to the relative apportionment of abundances among species. Perfect evenness for example means

that all species are present in the same amount in the study area (Rousseau & Van Hecke, 1998). This way a species that is on the brink of collapse can be shown more clearly.

2.4.2 Not all species are equal

When the species are counted, it will be important to determine which organisms are present. It makes a big difference if a species is endemic (the species lives only in one certain place) or also has other habitats. One other thing to look for is if the species is invasive in Denmark. Invasive plants or animals can harm local ecosystems and drive other species to extinction. For this reason it is also necessary to check if the species is endangered.

Lastly, it is important that an ecosystem is as varied as possible so all functions and niches are fulfilled. This means that an ecosystem that has 100 different plants from the same family that roughly realize the same niche is not as diverse as an ecosystem that contains 50 different plants from different families. A proposed solution for this is to only count the families (Harper & Hawksworth, 1994).

2.4.3 Problems with measuring biodiversity

One of the problems with measuring biodiversity is that the amount of diversity increases with sampling effort. This means that someone who counts all species in an area will have a higher species richness if they search for 2 hours then if they search for 1 hour. It will thus be important to spend roughly the same amount of time and effort on each research point (Magurran, 2021).

A second problem is that not every species is going to be as easily observed. Firstly, there is the biodiversity in the soil. These organisms are vital to live above the ground but are not easily found. Bigger mammals like rabbits or mice are never going to be found on a one meter square area because they are going to run away. The amount of insects that will be observed are going to depend on the weather and the time of the year. A possible solution for this is to just count the plants. As there is data on how many species of plants, insects, mammals… there are in Denmark, the total amount of species can be extrapolated and estimated.

2.4.4 How to calculate evenness

To express the evenness of species two indices can be used: the Shannon index and the Simpson's index. Simpson's index uses following formula:

$$p_i = d_i / \sum_i d_i$$

$$D = \sum_i p_i^2$$

$$diversity\ metric = -\ln D$$

The first formula produces the proportion of individuals of species d_i of the total amount of species. The second formula adds all those proportion squared up. The last formula takes the natural logarithm of this. If there is low evenness and thus a few species dominate, this will result in low values.

The Shannon index uses the first formula and the following one formula:

$$H = \sum_i p_i \ln p_i$$

The results are similar: high values means that no species dominate and low values means that there are a few species in high abundance (Van Strien et al., 2012).

3 RESEARCH QUESTIONS

The study area has changed a lot throughout the centuries (paragraph 4.1). The landscape was created by the icecaps and the impacts of erosion, sediment and the sea. After that, the population of humans increased and there was an intensification of the agriculture in Denmark. These changes in the landscape caused a decrease in biodiversity and endangered species. The monoculture and increasing of the agricultural fields are the reasons that a lot of species disappear in the study area. The last years, the government tried to improve the ecological value in Hov Vig and the surrounding to increase the biodiversity again. Therefore, it is important to get an inside in the relations between the landuse, soil and biodiversity. So

the main research question is: “What is the relation between the past land use, soil and biodiversity for future nature management around Hov Vig?”

This question was split up into different subquestions.

- *‘What are the landscape trajectories of the area explaining the landscape genesis of the area?’*

  To get an answer to this question a historical analysis of the past land use is done using maps, arial images and a field observation. Changes from 1840 until now were observed using eight time periods. The result of this question is a series of maps that shows the changes in the landscape and a time depth map which shows how dynamic or static a certain patch in the study area is.

- *‘Which soil types are characteristic for the area?’*

  This research question has the aim to analyze the soil profile based on the stratified sampling method based on the time depth map where each class has at least 2 soil samples. So, the soil samples can give valuable information about characteristics of the soil.

- *‘What are the current characteristics of biodiversity?’*

  To get an answer to this subquestion, an identification of vegetation types and their ecological characteristics has to be done. Furthermore it is important to determine the ecological value of the vegetation types.

- *‘How can the insights in landscape from the past land use, soil and biodiversity improve the future nature management objectives?’*

The aim of this question is to reflect on past, current and future management decisions by interviewing the forestry of the area and taking this information into account during this study.

4 METHOD

4.1 Historical analyses of the past land use

The method consists of four parts. The first subject is a historical analyses with mapping of the trajectories of the land use. In the study of landscape management, it is important to investigate the dynamics and development of the landscape over time because current landscape characteristics are linked with ancient processes that build the contemporary landscape. To investigate this link in the study area, a Landscape Change Trajectory Analysis (LCTA) is applied. In this analysis, change trajectories are constructed to establish relationships between current and past landscape patterns (Käyhkö & Skånes, 2008). The current patterns of the study area and changes visible in the trajectory analysis provide a better explanation for the current physical conditions in the landscape.

First, a sequential spatial datasets of the study area is needed. The data in this study consists of historical maps and aerial photos from various years (1840-1899, 1901-1945, 1931, 1953-1976, 1972, 1995, 2003, and 2023). This spatial data spans a few centuries, providing a broad and comprehensive view of the landscape over time. The land use of each spatial dataset is mapped as accurately as possible using a uniform legend (table 1) that allows the comparison of land use across all time scales.

Table 1: Uniform legend

10	Forest
20	Agricultural area
30	Wetland
40	Water
50	Residential area
60	Coastal landscape

Once the land use mapping is completed for the eight spatial datasets, the datasets are converted into raster images. The resolution of 20x20 meters of the raster images provides the best trade-off between the level of detail and computer processing. This resolution is chosen to minimalize the slivers and maximalize the level of detail. All the raster images are overlaid in chronological order, so that the change in land use over time can be determined. For each pixel, a change trajectory is created that captures the sequential succession of land use classes over time. These changes in trajectories can help better understand landscape changes.

After obtaining the trajectories, the pixels are divided into clusters. These clusters can be determined in different ways. In the beginning, the plan for this research was to use three different measures: the Hamming distance, the Levenshtein distance and the time depth. Pixels that are assigned to the same clusters exhibit the same patterns according to these measures. These measurements are calculated using a python code that allows the user to determine the number of clusters that should be calculated. In the end, only the time depth was used because there was a fault in the code of the Hamming distance and the Levenshtein distance. The time depth measure gives an indication on how long the current landscape has been maintained and can provide important indications of the biodiversity in the landscape. The interactive tool called CLUE was provided to us for the measuring of these different metrics and is explained in section 4.2.

For this study, eight clusters were chosen because there are seven possible changes and the eighth class means that there is no change in land use over time.

4.1.1 CLUE – Change in Land Use Explorer

After creating the raster images for each historical period, they can be utilized to analyse patterns over time. For this research, the interactive tool CLUE (Change in Land Use Explorer) was employed for this purpose. This tool provides the code to determine the Hamming distance, the Levenshtein distance, and the time depth. This code was executed in Python. The functioning of the code is explained in the following steps:

1) The first step is to install and import several required packages, such as python-Levenshtein, rasterio, numpy an scipy.
2) The generated raster images (TIFF files) that are stored on the local disk can now be read and resampled if necessary. Resampling is performed to ensure that the raster files all have the same resolution and dimensions.
3) After resampling, each image is stored in a 3D array.
4) Then, for each corresponding pixel, the Hamming distance (which determines the frequency of change) and the Levenshtein distance (which indicates the number of edits in the sequence) are calculated. Each set of values is stored in a matrix of the same size as the generated raster images.
5) The time depth is also calculated for each corresponding pixel. This is done using the 'calculate_time_depth' function, which indicates how long the current land use has existed.
6) To cluster the pixel values, the K-means clustering method is used. Eight clusters are chosen because of the seven possible changes and the option that there is no change in land use. Each value is assigned to the nearest cluster center.
7) Then, each value is assigned to a cluster label.
8) Labelled arrays are created with the same height and width as the original rasters.
9) Obtaining the metadata from the original rasters, such as type, height and width to update the formed arrays.
10) Saving the labelled arrays as a GeoTIFF-file to the local disk.
11) When opening the GeoTIFF-file in QGIS, eight classes are visible. Then, each class must be interpreted because there is no logic order from more static to dynamic for example. The interpretation is done by looking at the cartographic sources and search for where the change occurred.

4.2 Soil samples

The second subject to consider is the soil. This part required some fieldwork. For each cluster that was defined by the trajectories of the time depth map, soil samples had to be taken. For each cluster, at least one soil sample was taken, preferably two. In total 21 soil samples were

taken. These soil samples will be taken at the same place as the measurements of the biodiversity. This will be discussed in paragraph 6.3.

Figure 5: Soil sample

The soil samples are taken with an Edelman drill that can take a soil sample of 10-15cm. That means that for each soil sample it is necessary to penetrate different times into the ground. The different parts are laid on the ground next to the drill-hole in the right order so that it is possible to analyse the structure of the soil . The characteristics of each layer are studied and typed on a tablet in an especially prepared survey (appendix 1). The survey was created with the tool *ArcGIS survey123*. Through this survey, the exact location can be stored with the GPS on the tablet and all the information of the soil samples can be gathered in a table. The soil samples are categorised in one of the seven categories that are qualitative determined on the basis of the different variables (table 2): loam above clay, sand above loam, sand, sand above clay, clay above sand, sand with boulders and loam above a layer of sand and clay. Those categories will be used to link the soil characteristics with biodiversity, past land use and current land use (table 8).

Table 2: Variables to determine the soil types

Name variable	**Explanation**	**Level of measurement**
Layer 1	The texture of the layer closest to the surface	Categoric
Layer 2	The texture of the layer under layer 1	Categoric
Layer 3	The texture of the layer under layer 2	Categoric
Admixture	Material outside of sand, clay or silt that is in the soil	Categoric
Depth admixture	Depth at which these other materials occur	Ratio (cm)
Depth groundwater	Depth at which the groundwater was found	Ratio (cm)

4.3 Biodiversity

The last phase of the study studies the biodiversity of the area. This part has two subphases.

First, there is the measurement of biodiversity. This will be done by picking a spot in the same area as the drill-hole. This spot is chosen by throwing a stone random into the area. This will ensure that a random sample of the biodiversity will be taken. Then two folding rulers are laid on the ground. These will form the border of the 1 m^2 that will be studied. Within this square all species of plants that are growing on the ground will be counted and determined by name. Different resources were used to help determine the plant species, like plant books and the Obsidentify app. After the field work was completed, an additional confirmation was conducted to verify the occurrence of the plant species in Denmark. When there were some dominant species in the square, the percentage was taken. This information was all written down.

Secondly, there is a survey with questions that help contextualize the area around the 1 m^2. This context is important because you cannot determine a patch based on 1 m^2. For example, in a forest there is a high chance that the 1 m^2 will not contain any trees. Thus, you would not know if there is a forest and which trees there are in this forest if you would just read the findings within the 1 m^2.

Figure 6: Biodiversity square

This survey contains questions about the soil, the topography, the openness of the landscape, the dominant vegetation species and the ground layer coverage (appendix 2).

All of this information will be put in a table in the same way as the soil samples. With the information of the field (table 3), four different vegetation types are determined: agriculture, open grassland, watery landscape, closed grassland and closed landscape. These will be used to determine connections between the soil characteristics, past and present land use (table 8).

Table 3: Variables to determine the vegetation types

Name variable	Explanation	Level of measurement
Number of species	The total number of species that were found within the square meter.	Interval
Dominant species 1	The name of the species that occurs the most (outside of grass).	Nominal
Dominant species 2	The name of the species that occurs the second most (outside of grass).	Nominal
Percentage of grass	Percentage of area that is covered with grass within the square meter.	Interval
% soil	Percentage of area that is not covered with anything in the general area.	Ordinal
% grass	Percentage of area that is covered with grass in the general area.	Ordinal
% herbs	Percentage of area that is covered with herbs in the general area.	Ordinal
% wooded area	Percentage of area that is covered with woodlands in the general area.	Ordinal
% crops	Percentage of area that is covered with crops in the general area.	Ordinal
% water	Percentage of area that is covered with water in the general area.	Ordinal
Number of layers	The amount of vegetation layers of different height in the landscape where grass is layer 0.	Interval
Open or closed landscape	Indicates if the landscape is open or closed (with percentage)	Categoric
Shannon index	Value of the evenness of the species within the square meter.	Interval
Biodiversity score	Value of the biodiversity of the general area.	Categoric

4.3 Land management

For a better understanding of the nature reserve (of Hov Vig) the forestry was interviewed (appendix 4). On the other hand, a walk through the study area was educational for the land management.

4.4 Combining all the factors

When all the data is collected, everything can be put in one big table (table 4). This table contains the different variables for each measuring point. This gives a clear overview of all the information about vegetation types, soil types, time depth and the evaluation of the biodiversity.

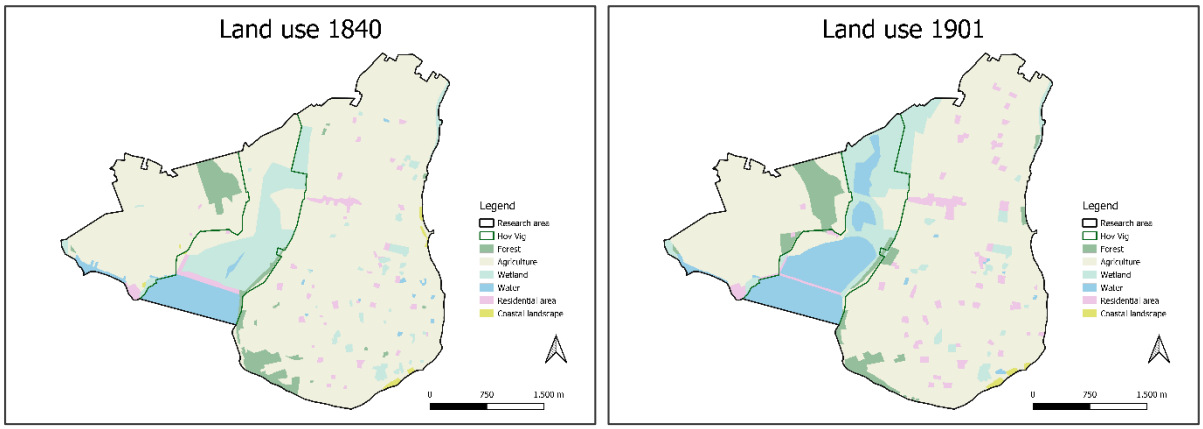
Table 4: Combination table

Name variable	Explenation	Level of measurement
Time-depth	Number of changes of land use derived from the mapped land uses over time.	Ratio
Vegetation type	Categories of biodiversity derived from the biodiversity variables in table 3.	Categoric
Soil type	Categories of soil characteristics derived from the soil variables in table 2.	Categoric
Evaluation biodiversity	Value of the biodiversity of the square meter and surroundings, based on the biodiversity variables in table 3.	Categoric

5 RESULTS

5.1 Historical analysis of the past land uses

The research consist of three parts. The first part consists of a historical analysis of the past landuse. A sequence of maps showing the evolution of the landscape in function of six classes (figure 7) is made. Agricultural areas, wetlands, forests, water, residential areas and coastal landscapes are shown on the maps.



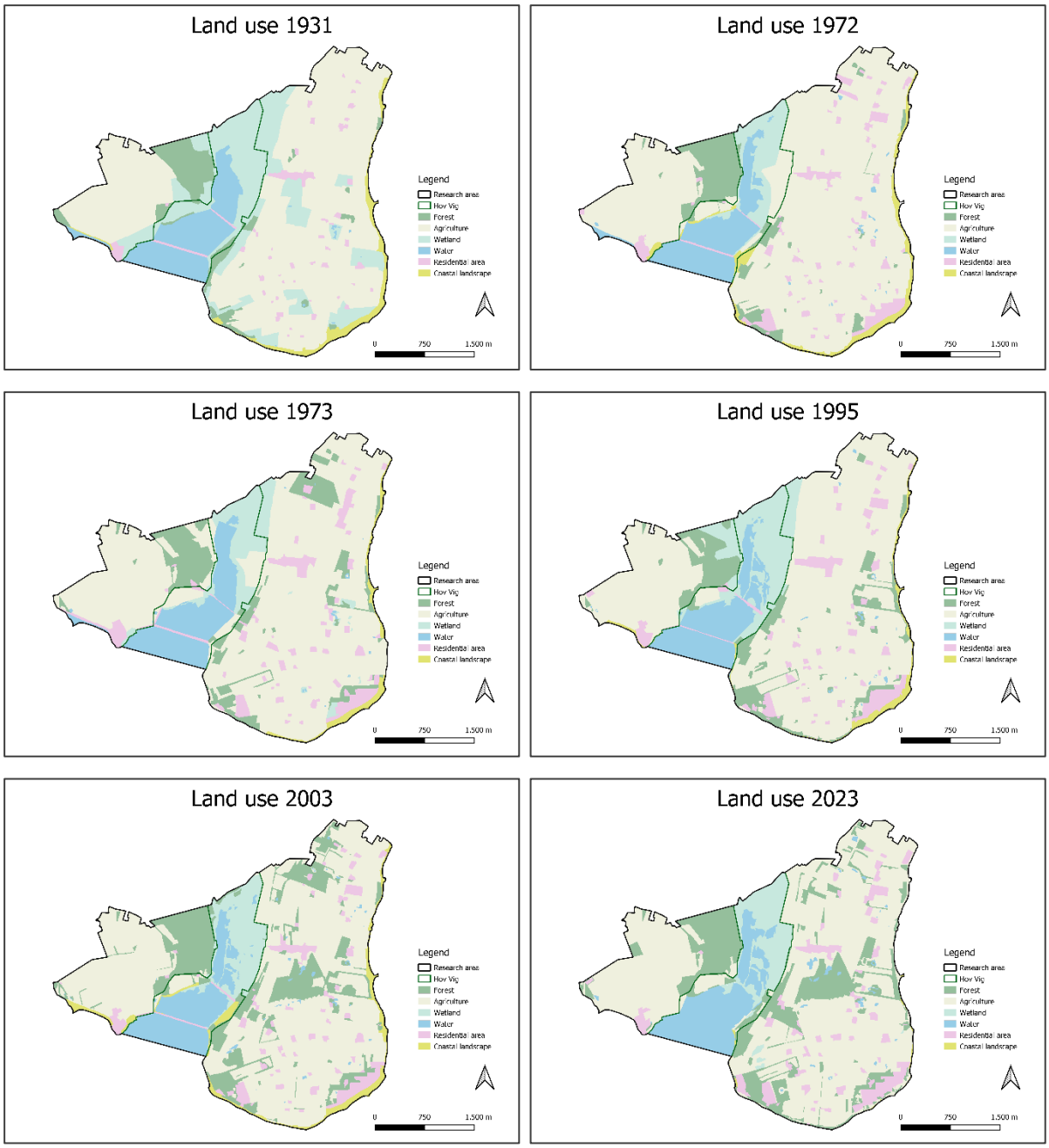


Figure 7: Sequence maps of land use

Based on figure 7, an overview is generated (figure 8) showing the share of land use types from 1840 until now. The share of agricultural areas is the biggest in the study area, but a decrease is observed between 1840 and 2023. The rise of more forest and residential areas is the reason for this decrease. The amount of wetlands is more variable depending on the situation with the dams. The results of the maps show that the dates does not match with the reality. On the map of 1901, the situation that is described in the literature as the flood and breach of the dam in 1902 is visible.

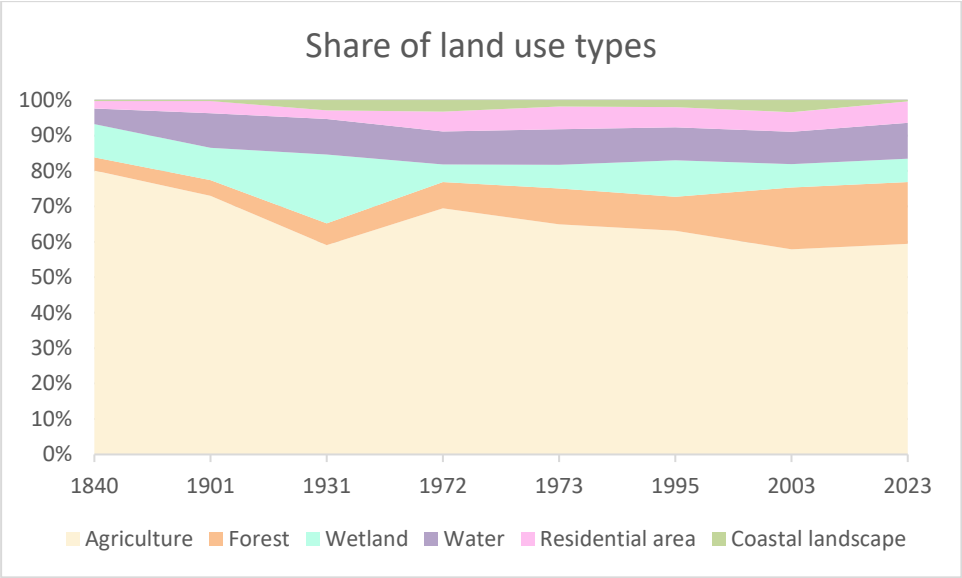


Figure 8: Share of land use types

The end result of the historical analysis of the past land use is the time-depth map (figure 9). The darker the color on the map, the more dynamic the area is, the more the land use has changes over time.

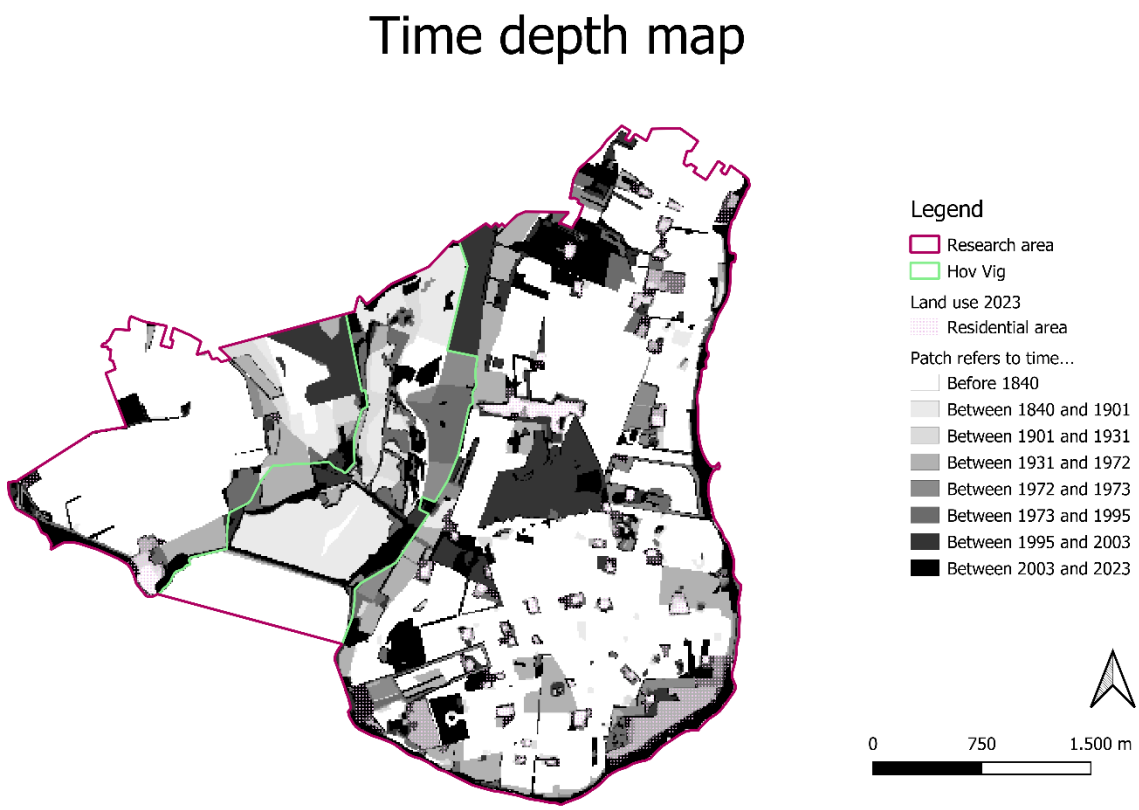


Figure 9: Time-depth map of land use

5.2 Soil samples

The second part of the study contains the soil samples. 21 samples were taken in the study area and they were catalogued (according to the different variables of table 5) in seven classes (soil types in table 8): loam-clay, sand-loam, sand-clay, loam-sand-clay, sand, sand with boulders and clay-sand. The soil samples and types are visualised in figure 10. The location of the soil samples is chosen using two indicators. The first indicator is that there must be at least one sample in each class of the time depth map, but preferable there are two samples in each class. The second indicator is that it has to be in the core of a patch because the edge can have some disturbances due to traffics on roads for example.

Table 5: Table with all the soil samples characteristics

ID	Layer 1	Layer 2	Layer 3	Admixture	Depth of admixture (cm)	Depth groundwater (cm)
1	Loam	Clay				150
2	Loam	Clay		Parts of shells	150	
3	Sandloam	Sand		Stones	130	
4	Loam	Sand	Clay			68
5	Sand	Clay		Limestone	205	
6	Humus	Clay	Sand	Stones	81	
7	Humus	Sand				30
8	Black sand	Sand	Sand			
9	Humus	Sand				10
10	Peat	Sand				20
11	Fine sand	Fine sand	Clay			50
12	Loam	Sand		Stones	30	40
13	Sandloam	Sand		Stones	50	
14	Loam	Sand		Stones	30	40
15	Humus	Sand				20
16	Humus	Sand		Plants	14	32
17	Loam	Clay		Sand		
18	Clay	Sand		Stones	70	
19	Sand	Sand		Stones	60	
20	Loam	Clay		Stones	0	10
21	Loam	Clay		Parts of shells	150	

Points 2 and 21 were close to each other, so the same characteristics were used.

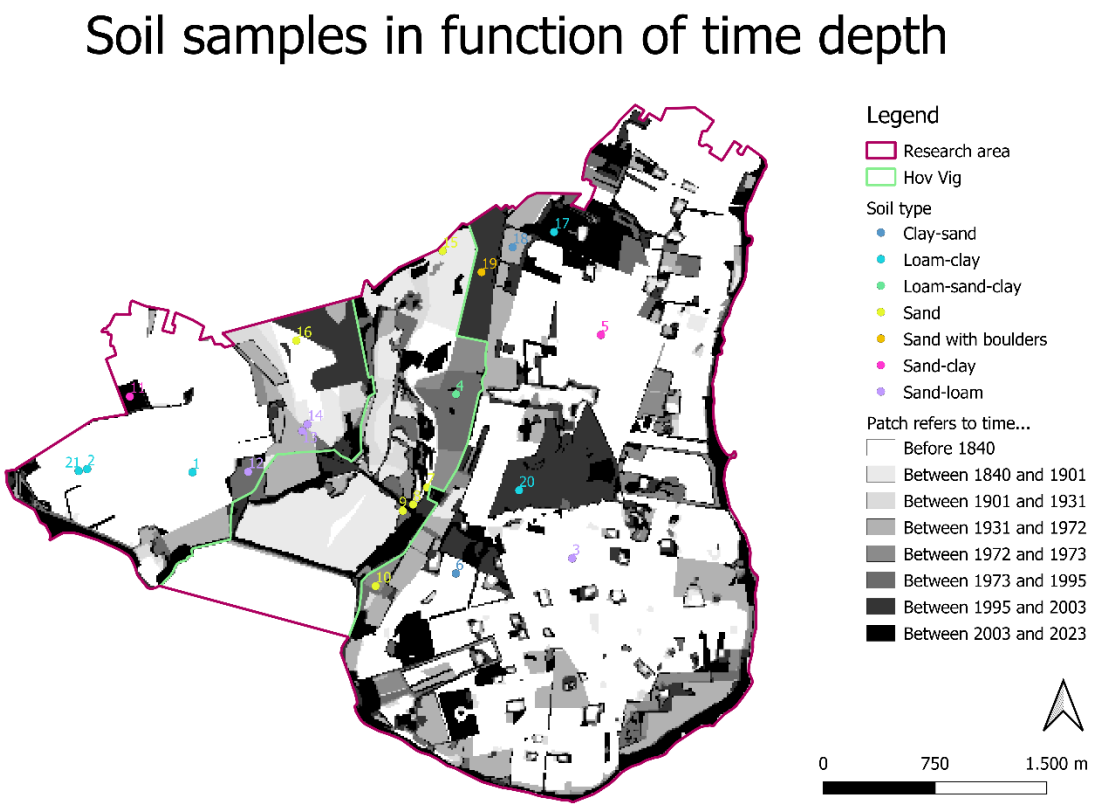


Figure 10: Soil samples in function of time-depth

5.3 Biodiversity

The third phase of the study consists of a biodiversity evaluation. The biodiversity was measured on each place where soil samples were taken. It was important to take this sample in the core of a patch, because of vegetation disturbances in the edges of patches. The evaluation of the biodiversity was divided into four classes: not valuable, less valuable, valuable and very valuable as shown in figure 11.

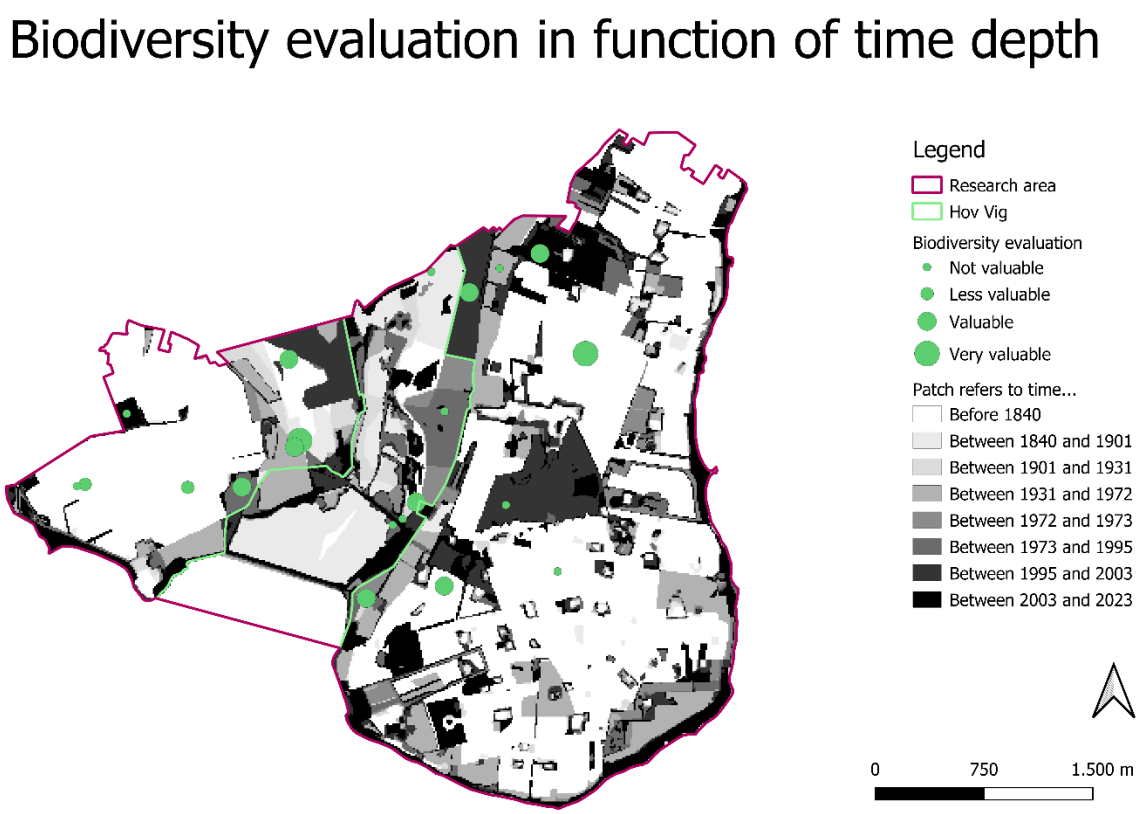


Figure 11: Biodiversity evaluation in function of time-depth.

Table 6 shows the different variables that were measured while taking a sample. These were then combined into six categories (vegetation types in table 8): Watery landscape (with herbaceous vegetation of common reed and water dock), open grassland (with mostly herbaceous vegetation and different species of flowers), closed grassland (with mostly mosses and trees), closed landscape (covered with bare soil and few herbs, grasses and trees) and agriculture.

Table 6: Table with all biodiversity characteristics in the area

ID	% grass environment	% bare soil	% gras	% herbs	% wooded area	% crops	% water	# layers	Open/ closed lanscape
1	99	25-50	0	0-25	0	25-50	0	0	Open
2	100	0	75-100	0	0	0	0	0	Open
3	90	0	75-100	0-25	0	0	0	0	Open
4	80	0	75-100	0-25	0	0	0-25	1	Open
5	30	0	75-100	25-50	0	0	0	0	Open
6	90	0	75-100	0-25	0	0	0-25	1	Semi-open
7	50	0	0-25	0-25	0	0	75-100	3	Semi-open
8	0	0	0	25-50	0	0	25-50	2	Closed
9	0	0	0	0-25	0	0	50-75	2	Closed
10	50	0	50-75	0-25	0-25	0	0	3	Semi-closed
11	40	0-25	50-75	0	25-50	0	0	2	Closed
12	20	0	50-75	0-25	25-50	0	0	4	Closed
13	85	0	50-75	0-25	75-100	0	0	2	Closed
14	0	50-75	0-25	0	25-50	0	0	3	Closed
15	80	0-25	50-75	0	0	0	0-25	0	Open
16	80	0	50-75	25-50	25-50	0	0-25	3	Closed
17	0	50-75	0-25	0-25	25-50	0	0	3	Closed
18	98	0	75-100	0-25	0	0	0-25	1	Semi-open
19	98	0	75-100	0-25	0	0	0	0	Open
20	0	75-100	0	0-25	0-25	0	0	1	Semi-closed
21	10	0-25	50-75	0-25	0-25	0	0	2	Semi-open

Table 7: Table with all biodiversity characteristics inside the 1 m^2

ID	# species	Dominant species 1	Dominant species 2	Shannon-index	Biodiversity score
1	3	Anthemis arvensis (field chamomile)	Thelypteris palustris (marsh fern)	-0.736	Not valuable
2	0				Not valuable
3	4	Taraxacum officinale (dandelion)	Cerastium (mouse-ear)	-1.172	Less valuable
4	2	Argentina anserina (silverweed)	Unknown	-0.649	Less valuable

5	9	Geranium molle (dovesfoot geranium)	Anthoxanthum odoratum (sweet fernal grass)	-1.729	Very valuable
6	4	Plantago lanceolata (ribwort plantain)	Bellis perennis (daisy)	-0.694	Valuable
7	2	Phragmites australis (common reed)	Rumex hydrolapathum (water dock)	-0.540	Valuable
8	2	Phragmites australis (common reed)	Rumex hydrolapathum (water dock)	-0.451	Less valuable
9	2	Phragmites australis (common reed)	Rumex hydrolapathum (water dock)		Less valuable
10	4	Moss	Juniperus communis (common juniper)	-1.409	Valuable
11	1	Kindbergia praelonga (common feather-moss)	Betula (birch)		Less valuable
12	6	Sphagum (bog moss)	Pinus sylvestris (scots pine)	-1.466	Valuable
13	3	Selaginella krausiana (krauss' moss)	Cytisus scoparius (common broom)	-0.803	Valuable
14	1	Dryopteris dilatata (broad buckler-fern)	Different bug species		Very valuable
15	1	Phragmites australis (common reed)			Less valuable
16	2	Sphagum (bog moss)	Betula pubescens (cowny birch)		Valuable
17	8	Taraxacum officinale (dandelion)	Equisetum arvense (field horsetail)	-1.8278	Valuable
18	4	Ranunculus acris (meadow buttercup)	Lathyrus pratensis (meadow vetchling)	-1.2105	Less valuable
19	6	Potentilla reptans (creeping cinquefoil)	Luzula campestris (field wood-rush)	-1.3913	Valuable
20	2	Veronica hederifolia (ivy-leafed speedwell)	Galium aparine (cleavers)	-0.2573	Less valuable
21	6	Galium aparine (cleavers)	Senecio	-1.784	Less valuable

5.4 Knowledge of the local forestry

In the interview (appendix 9.4), several interesting points were discussed that can contribute to a better understanding of the relationship between past land uses, soil and biodiversity for future nature management. Two dams were constructed in Hov Vig, each serving different purposes (local forestry, personal communication, 11 may 2023). The first dam was flooded through a storm. The dam was never built up and now it is providing an opportunity for birds to inhabit the area and find food due to the lower water level. The second dam was constructed to protect Nykøbing Sjælland from seawater.

The management of Hov Vig aims to expand the nature area and establish corridors to connect with other valuable areas (appendix 9.4). When purchasing land, they have certain conditions. Firstly, they prefer to wait for the landowners to approach them for selling their land. Secondly, they find land with sandy soil more appealing, as grasslands on sandy soil tends to exhibit higher biodiversity compared to clay soil. This is because dominant grass species do not thrive as well in sandy soil, allowing other plants to flourish. Additionally, the land should be accessible to locals for birdwatching and nature walks.

In addition to expand the reserve, various management adaptations have been implemented to enhance biodiversity in Hov Vig (appendix 9.4). One important measure is the preservation of dead trees, as they provide habitats for a wide range of insects. Glacier stones that were previously removed from agricultural lands have been reintroduced, creating opportunities for reptiles and birds. Previously, the grass and flowers were regularly cut, but these plants play a significant role in supporting biodiversity, in particular butterflies and other insects. Lastly, water pipes that were previously installed for drainage of the agricultural area have been removed to allow the reestablishment of natural lakes.

5.5 Summary

In table 8 all the measure points have got a time-depth, vegetation type, soil type and evaluation of the biodiversity from the results in the previous tables. When the time-depth is 0, which means that there weren't any changes of land use since 1840, the vegetation type is

mostly agriculture or open grassland. However not all the open grassland vegetation types are that old (see points 3, 18 and 19). For the other time-depths, it is impossible to find any pattern because there aren't enough samples for each time stamp. Correlations between vegetation types and soil types are easier to find. Watery landscapes are always on a sand soil type, closed grassland or landscape are mostly on sand or sand with loam or clay soil types, agriculture is to be found on loam-clay soil types and open grassland can be found on every soil type. The evaluation of biodiversity does not seem to have a pattern matched with the other variables. Agriculture vegetation types are mostly evaluated least valuable. The other measure points have every type of evaluation for every time-depth, vegetation and soil type.

Table 8: Summary of biodiversity, soil, past and present land use.

ID	Time-depth	Vegetation type	Soil type	Evaluation biodiversity
1	0	Agriculture	Loam-clay	Not valuable
2	0	Agriculture	Loam-clay	Not valuable
3	1973	Open grassland	Sand-loam	Less valuable
4	0	Open grassland	Loam-sand-clay	Less valuable
5	0	Open grassland	Sand-clay	Very valuable
6	0	Open grassland	Clay-sand	Valuable
7	0	Watery landscape	Sand	Valuable
8	1901	Watery landscape	Sand	Less valuable
9	1973	Watery landscape	Sand	Less valuable
10	1972	Closed grassland	Sand	Valuable
11	2003	Closed grassland	Sand-clay	Less valuable
12	1973	Closed grassland	Sand-loam	Valuable
13	1931	Closed grassland	Sand-loam	Valuable
14	1840	Closed landscape	Sand-loam	Very valuable
15	1840	Watery landscape	Sand	Less valuable
16	0	Closed grassland	Sand	Valuable
17	2003	Closed landscape	Loam-clay	Valuable
18	1931	Open grassland	Clay-sand	Less valuable
19	1995	Open grassland	Sand with boulders	Valuable
20	1995	Closed landscape	Loam-clay	Less valuable
21	0	Agriculture	Loam-clay	Less valuable

The end result is a synthesis map showing the relations between the historical analysis of the past land use, the soil samples and the biodiversity evaluation (figure 12). This result shows that agricultural areas has less biodiversity than grasslands. Certainly grasslands that aren't

dynamic have very valuable biodiversity. Sand in the soil seems to be an indicator of a valuable biodiversity. The reason could be that there are less agricultural activities on sandy soils.

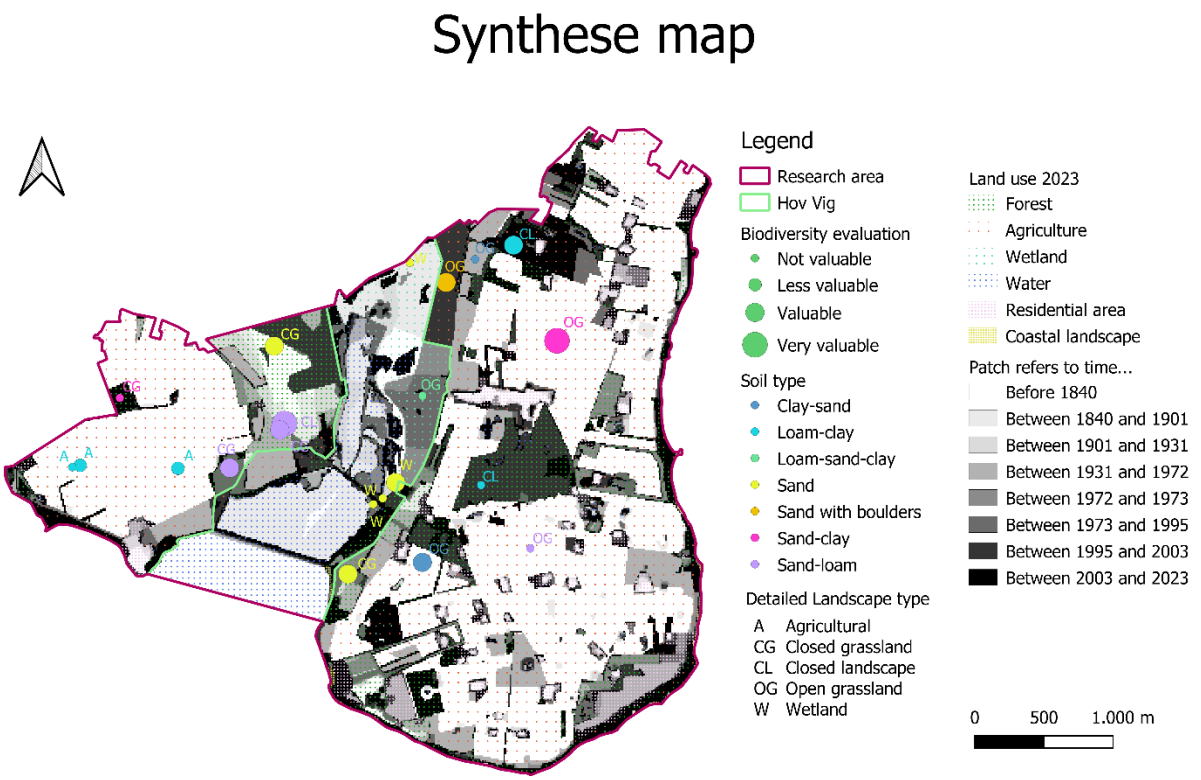


Figure 12: Synthesis map

6 DISCUSSION

6.1 Uncertainties in the interpretation of historical maps

Working with historical maps and arial images can cause some uncertainties while studying the land use. Uncertainties can occur with topographical maps because of the selection of features and the simplification of the reality. Secondly, by mapping the land use of land cover, the features are divided in different categories depending on the aim of the map. So, this categorization is not an objective representation of reality. Therefore, it is important that every definition in the legend is well understood for each of the maps that were used in the research. Unfortunately, this information is not available for all the maps that were used and this can cause a potential source of error and uncertainty.

Besides the topographical map, there are other data sources that can cause potential errors. First of all, the interpretation of a map can differ from that of an aerial image because there is a difference in information. An example is that in some of the topographical maps the coastline with the beach was not visible and so it was not mapped. But that doesn't mean that this type of land use was not present in the landscape.

Finally, there also some sources of uncertainty through the interpretations and digitalisation of the historical data by different individuals. It is important to acknowledge that the interpretation of the land uses of each person can be different. Just like the grade of details that has been digitalised.

Thus, it is important that the results of historical studies of the development of land cover/land use should be interpreted with caution.

6.2 Unequal time intervals in the time series

When conducting the historical analysis, it is important to note that the length of the time interval can vary significantly between the different data points used. For example, the interval between two consecutive observations may exceed 60 years, while it may be less than 20 years between two other observations. These variations necessitate careful interpretation of the analysis. Shorter time intervals are capable of providing a more detailed insight into temporal changes. Therefore, it is crucial to take this into account during the historical analysis. This variation in time intervals is also important when calculating the Hamming distance, Levenshtein distance, and time depth. Long time intervals can lead to the omission of rapid changes, resulting in inaccurate outcomes.

6.3 Uncertainties and problems by the fieldwork

The measurement of biodiversity, the recognition and determination of the different types of plants was a challenge because of the researchers' lack of knowledge. On the other side, some questions in the survey about biodiversity were very subjective. The answers on those question will be different depending on the person who is filling in the survey. For example, the degree of openness or the spatial distribution of the vegetation is subjective. Some of the

questions in the survey were estimated, for example 'What percentage of the ground layer coverage is filled with grass?'

Other uncertainties can occur by taking the soil samples. It was sometimes very difficult to recognize the types of the soil. The reason was that often soil types were a combination of different soil textures so it was difficult to characterize the samples. Secondly, there was also a lack of information because it was not always possible to drill through the stones until the water level was reached.

Finally, for the terrain work there were some problems with accessibility of the measuring points. First of all, the study area contains a lot of areas with water. Therefore, it is sometimes difficult to reach the wet places. Besides the problems with accessibility through water there are a lot of forbidden areas in the nature reserve. Those areas are created to protect the fauna and flora in the area and there cannot be disturbances.

Figure 13: Example of a forbidden area

6.4 Possible errors in the processing and interpretation of the data

In this research there were only 21 measure points. This number of points was too low and makes quantitative analysis of correlations impossible. Therefore, the soil and vegetation types were determined qualitative, just like the division of valuable or not-valuable vegetation types. Those results are subjective and can be different for other researchers which causes a certain potential error.

So, the method of this research can definitely work but more samples are essential to make more conclusions.

6.5 Valuation of biodiversity

As earlier mentioned, each research point received a biodiversity score ranging from not valuable to very valuable. There was however no uniform way to assess this. For example,

point 21 received a less valuable score despite having six different species and having a Shannon-index score of -1.748. Point 14 which had only one plant species is seen as very valuable. This discrepancy is because of the environment that is taken into account and the fact that point 14 is the only spot where there are an extraordinary amount of insects found. The biodiversity scores are thus largely based on observations and not solely on the numbers that were written down. This of course has the drawback that the biodiversity scores are not reproducible or comparable when someone else does the same research. This notwithstanding, the data assembled to observe the biodiversity is reproducible.

Another problem is the biodiversity in the nature reserve. The points 4, 7, 8, 9 and 15 are all inside of Hov vig and none received a very valuable score. This is because there are not many species of plants present. It can however not be denied that these places are incredible valuable as a bird sanctuary. This shows that the used way of measuring the biodiversity does not show the whole picture and extra information and context is always important.

Lastly, the status of the found species are relevant to mention. None of the species found are threatened and only 2 out of the 26 plants encountered are not native to Denmark. Ivy-leafed speedwell (Veronica hederifolia) is native to South Europe but is naturalized in Scandinavia. Gazonmosvarentje (Selaginella kraussiana) is native to South East Africa and is an invasive species.

6.6 Land management

With all the results of the historical maps, the fieldwork, the policy context and the visions for the future, there are some conclusions that can be made about the land management and nature expansions in the area. There will be a mainly focus for the nature reserve of Hov vig and possibilities to improve and expand this protected area. In the past, they introduced some new forests in the area for economic reasons. These forest are not part of the original vegetation. Unfortunately, these conifers caused more fragmentation in the landscape and they are not very optimal for the conservation of endangered species and the biodiversity in this area which goes against the policy discussed in paragraph 2.3. To minimalize those effects it would be interesting to make some steppingstones of grasslands in those forests. These

stepping stones need a smaller area than corridors and can already increase the biodiversity significantly.

The increase of the fauna and flora is one of the goals for Denmark and Odsherred. To achieve those goals, it is interesting to buy areas with sand in the underground. In those sandy areas, the dominant species of grass will not grow that fast. Therefore, other species have the chance to grown which is positive for the amount of biodiversity. Further, the government wants to invest in areas were the groundwater table can raise and pools can be introduced again. This kind of management is needed to achieve the Natura 200 goals. In the north, the summerhouses and cover sand ridge prevent an expansion of the nature reserve. All those things take time and are examples of long-term management plans.

Besides all these plans, there are some things that can and should be done at short notice. In the past, the government removed all the dead or sick trees. Nowadays, they do not do that anymore and the biodiversity increases on those places. Further, the grasslands and roadsides should not be mowed in during spring. This is the period with a lot of flowers, bees, butterflies and those area are actually very valuable for those species. On the first side, it looks like the policy of the Natura 2000, which said that there is a need of grazing some area, is a contradiction with the policy of Denmark and Odsherred that have the opposite opinion. However, it actually is important to understand the area so that there is grazing and mowing on the right places. Also the conservation of the wooden edges are elements that are positive for the fauna and flora.

7 CONCLUSION

Hov Vig is a beautiful nature reserve that is very important as a bird sanctuary. Therefore the biodiversity in and around Hov Vig must be maximalized. To achieve this, the area must be well understood before certain measures can be taken. This research tried to understand the relationship between the past land use, current land management, soil and biodiversity in and around Hov Vig. For the past land use eight different maps from different time periods were created. Then the interactive tool CLUE was used to gain a time-depth measure. The soil was studied by making drill-holes on positions that were determined beforehand. In these same locations the biodiversity was measured by counting all the species in a square meter.

Someone who was working for the forestry in the area was interviewed for information about the land management. It is important to note that each of these measurements comes with uncertainties.

As there were only 21 points that were measured, no statistical analysis could be done. Therefore the following conclusions were obtained by a qualitative approach. It is firstly notable that grassland has more valuable biodiversity than agriculture. Secondly, sandy soils have mostly more biodiversity than clay and loam soils. This falls in line with the idea that there is more agriculture on the clay and loamy grounds. It also follows the plans of the land management to develop the sandy soils as nature. This correlation could also be because only the sandy grounds get developed as nature. It is therefore no surprise that the most valuable places are stable grasslands on sandy soils. Any further conclusions are hard to make because of the low amount of measuring points. It would be interesting to use the same method with more data points so statistical analysis can be used. It is probable that more relations can be found this way.

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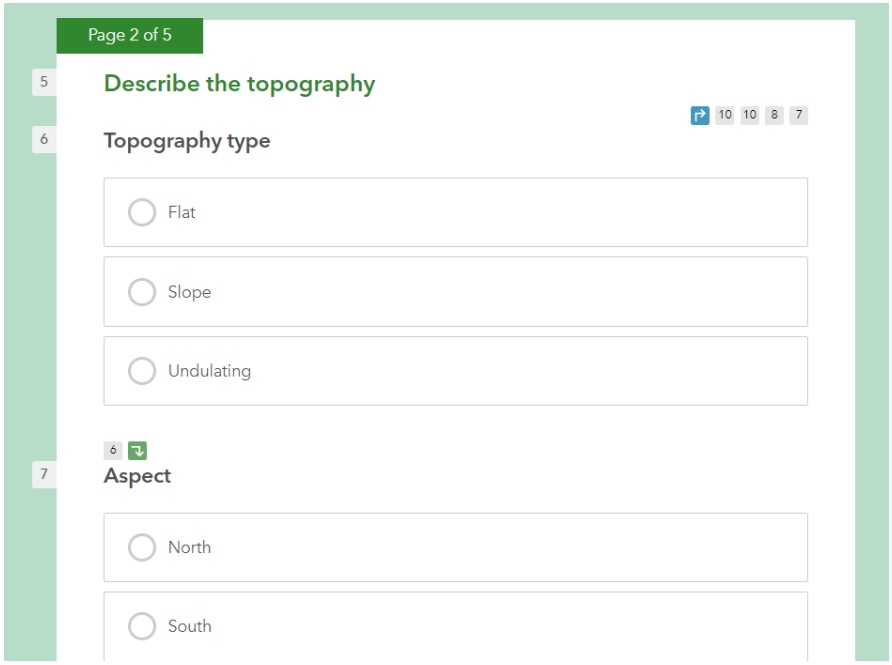
9 APPENDIX

9.1 Soil survey

https://survey123.arcgis.com/share/9084717fbc1342539abc9e20b0937b3b

9.2 Biodiversity survey

https://survey123.arcgis.com/share/97bfaacf6bd84410a292815f71a86045



Figuur 1: Survey biodiversity

9.3 Python code (CLUE)

```
import os
import numpy as np
import rasterio
from rasterio.enums import Resampling
from scipy.spatial import distance
from scipy.spatial.distance import hamming
import Levenshtein


folder = "C:/Users/ninan/Documents/GIP/tifs"
filepaths = [os.path.join(folder, f) for f in os.listdir(folder) if f.endswith('.tif')]


# Read raster data and resample if necessary
datasets = []
resampling_factor = 1
for file in filepaths:
    with rasterio.open(file) as src:
        new_width = int(src.width * resampling_factor)
        new_height = int(src.height * resampling_factor)
```

```
        data = src.read(
            1,
            out_shape=(new_height, new_width),
            resampling=Resampling.nearest
        )
        data = data.astype(int)
        datasets.append(data)

# Stack the resampled rasters along a new axis to create a 3D array
stacked_datasets = np.stack(datasets, axis=-1)
print( np.unique(stacked_datasets))
#print(len(stacked_datasets[0]))
#print(len(stacked_datasets[1]))
#print(len(stacked_datasets[2]))

# Calculate the Hamming distance matrix for the corresponding cells
hamming_dm = np.full((stacked_datasets.shape[0], stacked_datasets.shape[1]), fill_value=-1)
for i in range(stacked_datasets.shape[0]):
    for j in range(stacked_datasets.shape[1]):
        if stacked_datasets[i, j, 0] != 0:
            hamming_dm[i, j] = hamming(stacked_datasets[i, j, :],
                                       [stacked_datasets[i, j, 0]] * stacked_datasets.shape[2]) * \
                               stacked_datasets.shape[2]

# Calculate the Levenshtein distance matrix for the corresponding cells
levenshtein_dm = np.full((stacked_datasets.shape[0], stacked_datasets.shape[1]), fill_value=-1)
for i in range(stacked_datasets.shape[0]):
    for j in range(stacked_datasets.shape[1]):
        if stacked_datasets[i, j, 0] != 0:
            seq1 = ''.join(map(str, stacked_datasets[i, j, :]))
            seq2 = ''.join(map(str, [stacked_datasets[i, j, 0]] * stacked_datasets.shape[2]))
            levenshtein_dm[i, j] = Levenshtein.distance(seq1, seq2)
```

```
# Calculate time depth for each cell in the 3D array
def calculate_time_depth(sequence):
    current_land_use = sequence[-1]
    time_depth = 0

    if current_land_use == 0:
        return -1

    for land_use in reversed(sequence):
        if land_use == current_land_use:
            time_depth += 1
        else:
            break

    return time_depth



# Calculate time depth for each cell in the 3D array
time_depth_array = np.full((stacked_datasets.shape[0], stacked_datasets.shape[1]), fill_value=-1)
for i in range(stacked_datasets.shape[0]):
    for j in range(stacked_datasets.shape[1]):
        time_depth_array[i, j] = calculate_time_depth(stacked_datasets[i, j, :])

#amount of clusters
k = 8

from sklearn.cluster import KMeans

# Flatten the arrays and filter out -1 values
filtered_time_depth = time_depth_array[time_depth_array != -1].reshape(-1, 1)
filtered_levenshtein = levenshtein_dm[levenshtein_dm != -1].reshape(-1, 1)
filtered_hamming = hamming_dm[hamming_dm != -1].reshape(-1, 1)

# Perform K-means clustering on the filtered values
```

```
n_clusters = k  # Change this to the desired number of clusters
kmeans_time_depth = KMeans(n_clusters=n_clusters).fit(filtered_time_depth)
kmeans_levenshtein = KMeans(n_clusters=n_clusters).fit(filtered_levenshtein)
kmeans_hamming = KMeans(n_clusters=n_clusters).fit(filtered_hamming)

# Get the cluster labels for each value
time_depth_labels = kmeans_time_depth.labels_
levenshtein_labels = kmeans_levenshtein.labels_
hamming_labels = kmeans_hamming.labels_



import numpy as np
import rasterio
from rasterio.transform import Affine

# Function to create a labeled array from the flattened labels
def create_labeled_array(original_array, labels):
    labeled_array = np.full(original_array.shape, -1)
    labeled_array[original_array != -1] = labels
    return labeled_array

# Create labeled arrays with the same shape as the original rasters
time_depth_labeled = create_labeled_array(time_depth_array, time_depth_labels)
levenshtein_labeled = create_labeled_array(levenshtein_dm, levenshtein_labels)
hamming_labeled = create_labeled_array(hamming_dm, hamming_labels)

# Open the original raster to get its metadata
input_filepath = "C:/Users/ninan/Documents/GIP/tifs/1840.tif"
with rasterio.open(input_filepath) as src:
    metadata = src.meta.copy()

# Update metadata based on the resampled shape and data type of your arrays
metadata.update(
    dtype=rasterio.int32,
```

```
    height=time_depth_labeled.shape[0],
    width=time_depth_labeled.shape[1],
    transform=Affine.translation(metadata["transform"].c, metadata["transform"].f) *
Affine.scale(metadata["transform"].a / resampling_factor, metadata["transform"].e /
resampling_factor),
)

# Save the labeled arrays as GeoTIFF files
with rasterio.open('C:/Users/ninan/Documents/GIP/tifs/output/time_depth_labeled_12.tif', "w",
**metadata) as dst:
    dst.write(time_depth_labeled.astype(rasterio.int32), 1)

with rasterio.open("C:/Users/ninan/Documents/GIP/tifs/output/levenshtein_labeled_12.tif", "w",
**metadata) as dst:
    dst.write(levenshtein_labeled.astype(rasterio.int32), 1)

with rasterio.open("C:/Users/ninan/Documents/GIP/tifs/output/hamming_labeled_12.tif", "w",
**metadata) as dst:
    dst.write(hamming_labeled.astype(rasterio.int32), 1)
```

9.4 Interview

Antoine (A) and Ninke (N) talked with a local forestry (F). The interview was written down.

F: Originally this area was part of an old fjord. The landowner created a dam over here and all the water was pumped out of the area. Hundred years ago the area was flooded and the owner kept the water in the area. Since than this is a water area with a lot of birds because the water level is very low which is optimal for the birds. The birds can eat everywhere. This line here that it is a bird reserve, out there people are not allowed to walk there. And that is quite unique. 40 years ago bought this area, and it is expanding. Now 900m² of land is owned by Danish government.

N: You bought different lands in different time periods. Is there a difference in biodiversity?

F: The last ground we bought was from a farmer that had only heath. So it is poor area with not a lot of nutrients. Those areas have mostly sand and this sort of ground is good for nature. Here grass will not grow that well and will not dominated that much. So other plants have a bigger change to grow and during the summer there are a lot of flowers.

A: So you can say that clay soil is better for agriculture than sand?

F: Yes because there grow not so many flowers and there is less biodiversity. You can see there are a lot of flowers on the poor, sandy landscape.

A: Yesterday we were talking with another guy and he told us that Denmark is second country on least biodiversity. Is that true?

F: I know it was bad but not that bad. You can see here that the flowers are all cut.

N: By the government?

F: No by the locals, yesterday they cut all the flowers because they thought that is was more beautiful. And went to talk to them and they said there made a big mistake and they have apologize.

N: Are there some other contradictions between locals and management of the reserve?

F: they don't agree always like the examples with the cows. Over there, you can see a pool with water.

A: Is it difficult to stay wet because it is sand ground?

F: No, in the past they drained those area and took the water away with some plastic pipes. Because on agriculture ground to much water is not good. Now we cut of the pipes so the water can raise again. We try to give the water back to the nature. This area is flat. But on the topological maps you can see the old lakes and so we can recreate the lakes depending on those maps.

A: When we were walking yesterday in the area there were some white trees. How do they excist?

F: That is because of the shit of the birds. There are very toxic and the trees die.

N: Yes it was very interesting that under the trees there is no vegetation at all.

F: Yes that is because the shit is very strong and all the tree die. It is very clever of the birds. When the tree die it is easier to built a nest. Now there are 600 pairs of cormorants. That is less than in the past.

N: what is the reason?

F: There is not enough food for a bigger group of birds. Humans don't like them, because there are damage the trees and there are black. They make a lot of noise and they stink.

N: So many birds were shot?

F: Yes like 40 years ago there were barely some cormorants in Denmark. Also the humans think that it is there fish but we are equal with al the other species on earth.

A: Are there some positives aspects that the birds have?

F: Yes, there living small fish in water but there is also water plankton in the water that clear the water and light on the water. So that the water plants can grow. The fish is eating the water plankton so the water isn't clear anymore. The young birds eat those fishes. In other places the humans have to take out of the fish for more biodiversity in the water and clear water. But here the nature do itself. The dead trees have more insects than living trees, so it is important that dead trees are not removed. Before that they used it for forestry.

N: We had a questions about the forest. There are like a lot of new forests. Is it just in the new ones that there forestry?

F: Yes

A: Why is there more wood?

F: The government wanted to increase forest. So in Denmark there more trees were planted

A: Would it be a here wood area?

F: no, we need some open spaces.

A: What are interesting grounds for nature reserve?

F: Places where it is possible to create water and lake... It is also important that there is access to the reserve for humans so they have opportunities to experience the area by walking.

F: Here a lot of people go by the bike or walk in the area but they are afraid of the cows. That is the reason why we built a fence. So you can walk without connect with the animals. That is a problem in Denmark that the people are afraid. There is almost 300m² in the same fence with all the cows.

N: Those stones in the area, what are these?

F: In the past sort of those stones were removed by the farmer.

A: Those are from glaciers?

F: Yes, the ice was here and they deposited all the stones that were here. So now we bring the stones back to the area. And it looks a bit strange know, but in a couple of years, those stones are natural and there are a habitat for some reptiles so they can hide under the stones.

A: yesterday we took some soil samples, maybe I can show you on the map? And in our samples there were a lot of stones. Is this from the glacier like these stones?
F: No, this was an island (Nakke) and water flues through the area but then there was a sort of dike caused by deposited of the clay and the water couldn't go through. In that time there were a lot of stones deposited. Those are now still present in the soil.
N: Can you walk with the cows? Or is it forbidden?
F: No it is allowed to walk there. It was a big issue to create possibilities to get among the cows. The locals are afraid. The cows have a big area where they can walk. They can walk even to the water.
N: So there are many fence in the area? Like more in the south there is also one.
F: Yes, an electric one, it make it easier for persons with a handicap. The gate will automatically open.
N: In that way there is also some wooded area with some plants that you can eat. What kind of land was it before the nature reserve?
F: Is was always natural. Also those plants and they spread further in the area. There are not many places where we have that kind of plants.

F: This part here are a hill and an open sea. This was filled up with clay and land was raised through isostasy and sand was blowing on the Nord side. Here you have a forest and church those were created to stop the sand from blowing into the area. In the past everything until Nykøbing Sjælland was under water, that is the reason that there wasn't a hill on those places. The second dam make sure that the area do not flood today.
A: And is it an idea to cut the trees and let the sand blow again?
F: No, that is not an option. Otherwise the whole sand would destroy to many houses.
A: And is it possible to buy some summerhouses?
F: No that is not possible because the houses cost too much. So it is not possible to make a corridor.
A: And to expand the area, how can you buy areas?
F: We don't go out and said you have to sell it. We have to be patient and wait until the landowners come to use.
A: thank you, it was very interesting

SOLAR ENERGY IN ODSHERRED: A DREAM OR REALITY?

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ODSHERRED KOMMUNE

UNESCO Global Geopark Odsherred

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1 INTRODUCTION

The global transition towards renewable energy sources is essential to move away from the unsustainable and costly fuel-based energy system but also necessary towards a future that is powered by local and affordable renewable energy sources (Couture & Leidreiter, 2014). Denmark plays a leading role in this transition, with already 50% of energy supplied by wind and solar power in 2020. By 2030, the Danish Government set the goal to develop an electricity system that will be completely independent of fossil fuels (Denmark, s.d.). However, a further diversification of energy sources is necessary to achieve this target as it ensures greater stability, reliability and sustainability in the energy system.

This research will focus on solar energy and how it is or can be implemented in the Odsherred commune in East Denmark. The Danish Ministry of Climate, Energy and Utilities (2019) predicted an increase in wind power, biogas and the use of heat pumps by the year 2030. However, the estimate trajectory of solar power anticipates only a small rise and this is striking, since the need for a further diversification of renewable energy. The amount of solar power compared to wind power is also remarkably lower. These factors both indicate that solar energy research can provide interesting information.

The following sections will be covered in this report. Firstly, the current energy situation in Odsherred and Denmark will be sketched, embedded in a theoretical framework of the current regulations about solar farms, the advantages and disadvantages of solar power, the different types of solar energy producers and other examples of energy landscapes. Next, a suitability map will deliver valuable information about the theoretically suitable places for solar farms in Odsherred. Thereafter, multiple interviews with stakeholders and farmers will be carried out to receive more detailed and recent information. These steps will then be combined into a discussion.

2 THEORETICAL FRAMEWORK

2.1 Study area

The main study area consists of the Odsherred commune, located in the north of the province Sjælland (Zealand). The municipality of Odsherred has existed since 2007 by merging three local authorities: Dragsholm, Trundholm and Nykøbing-Rørvig (Werther, 2022). Odsherred is divided into twelve parishes (Figure 1): Odden, Højby, Nykøbing, Rørvig, Nørre Asmindrup, Vig, Egebjerg, Fårevejle, Asnæs, Grevinge, Vallekilde and Hørve. The region is a rural area and is characterised by forest, nature and sandy beaches (Sørensen & Vidal, 2004). Furthermore, the Odsherred commune, spanning across 355 km², earned the distinction of being recognised as a Global Geopark by UNESCO in 2014. The landscape is very valuable due to the presence of three distinct end moraines called the *Odsherred Arches* at the core of the Geopark, which were formed during the latter part of the Weichselian ice age

approximately 17,000 years ago. Together with the glacial depressions and meltwater plains, they represent a classical geomorphological example of a glacial landform, only equalled by a few other places in Europe (UNESCO, 2021).

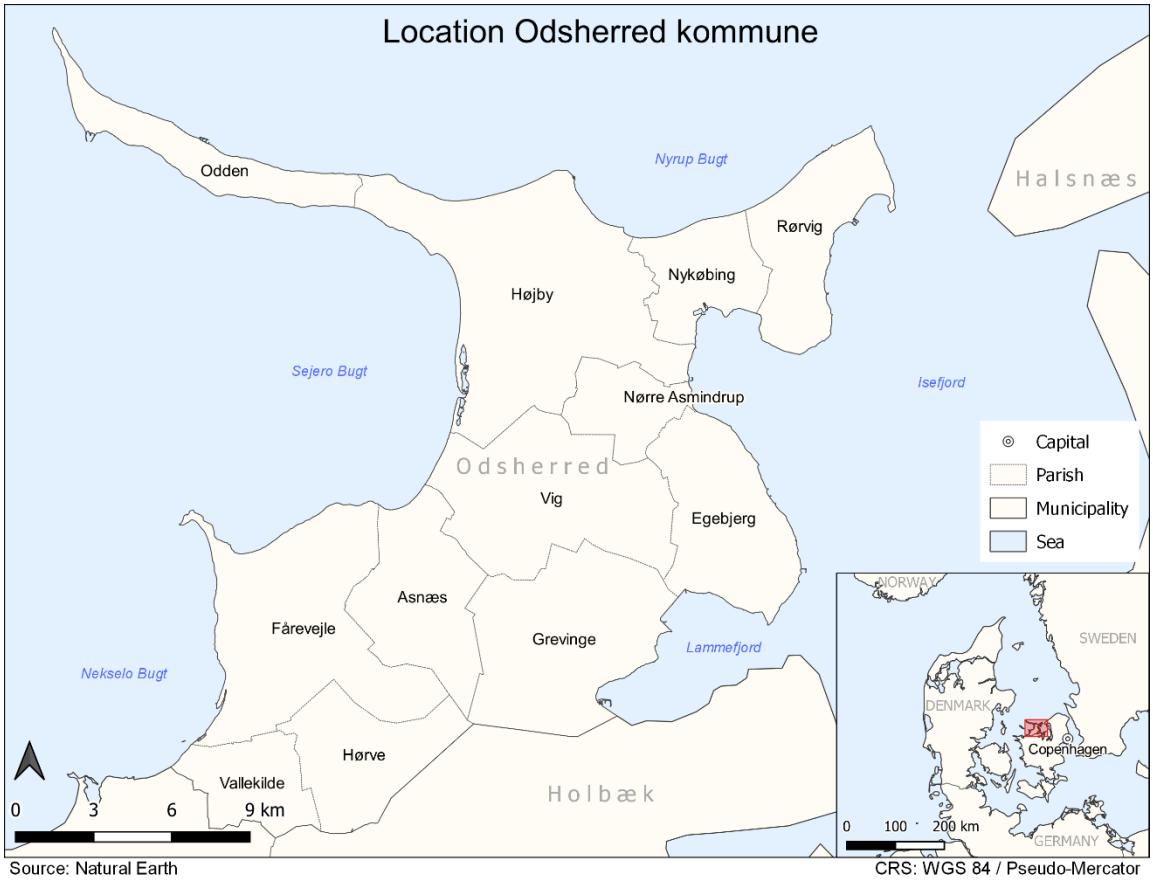

Figure 1: Location map of Odsherred commune, Denmark. (own production)

The municipality serves as a gateway to the ferry link between Zealand and Jutland and is conveniently accessible from Copenhagen, either within a one-hour drive or a train ride of thirty minutes. With its accessibility, Odsherred has become a popular and attractive holiday destination for tourists. The municipality houses the largest number of second homes and holiday houses in Denmark, most of them are situated near the coastline. Agriculture also plays an important role in the region. However, Odsherred's local production sector is limited, and the economy is characterised by small businesses that are very reliant on tourism. It is also faced with problems as the population is declining and educational levels are low. Young people are leaving the region to move to the cities, while older people stay to enjoy retirement in the relatively sunny area (Sørensen & Vidal, 2004; Wherther, 2022).

2.2 Solar energy

In this part, we first of all look at the current energy consumption and production in Odsherred and which part of this electricity is generated by solar cells. Furthermore, we will look at the future opportunities.

2.2.1 Current situation in Odsherred

There are several solar farms in the municipality of Odsherred and its surroundings. Figure 6 (situated in '3.2. Field work') shows the location and types of solar farms in the area. Not all solar farms in Odsherred produce electricity, there is also a heating plant. Because of the number of solar farms in Odsherred, we can conclude that not all energy can be produced by solar panels. This means that there are other sources. To get a better view of the energy distribution in Odsherred, it is useful to request data of the electricity production and consumption. The Energi Data Service (2023) was consulted as it provides good insights into this topic. To conduct this analysis, data from the last seven years (2016-2022) was utilised, with 2016 serving as the initial year of available data. It was first checked whether there were any differences over the years, for example wind turbines that were added or power plants that were dismantled, as these changes can cause significant differences. Based on the graph in Figure 2 and online research, there is no found evidence of changes in the capacity of electricity production. In Odsherred, electricity is produced in three ways: onshore wind turbines, solar power and decentral power plants. In this period, solar power and wind power stayed relatively stable compared to decentral power plant electricity generation. Overall, there is a slightly upward trend concerning electricity production.

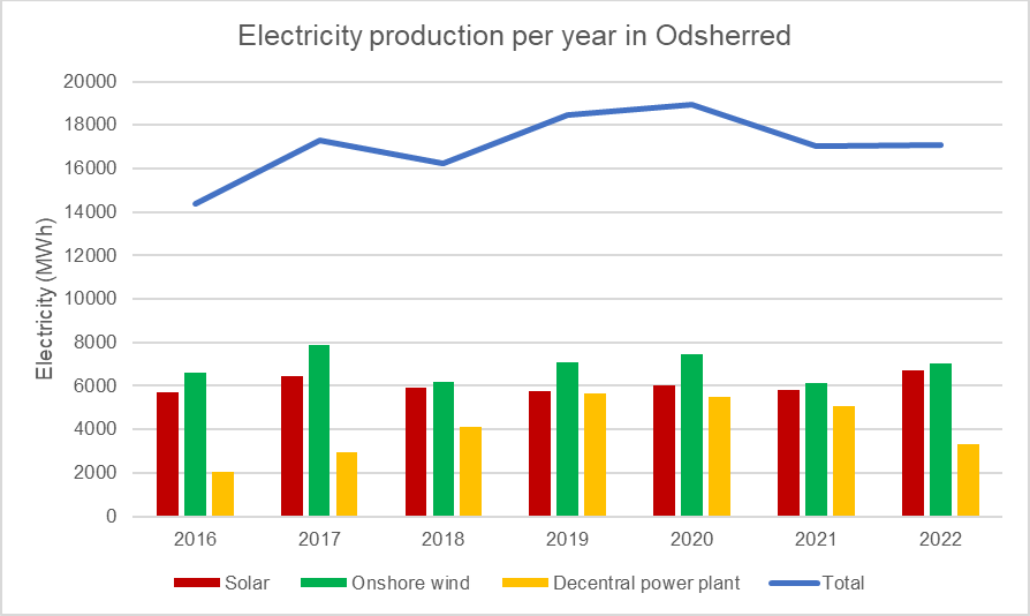

Figure 2: Electricity production in Odsherred per year from 2016 to 2022 (Energi Data Service, 2023)

According to the Energi Data Service (2023), Odsherred consumed 232 146,6 MWh of electricity in 2022, while only producing 17 111,6 MWh. This indicates that the municipality generated a mere 7.37% of its total electricity consumption, relying heavily on other regions for electricity production. Figure 3 illustrates the monthly electricity production in Odsherred, averaged over the 2016-2022 period. Wind and solar energy production are dependent on the weather. In sunnier periods, solar cells will produce more electricity. The same applies to wind turbines as they need wind to produce electricity (Nuttal, 2020). These trends are clearly visible in the graph. In dark winter months, electricity production by solar cells reduces to under 100 MWh, while these months are likely to be windier and therefore wind turbines produce more. During winter season, these shortages are compensated by decentral power plants (DPP). These DPPs are defined as a wide range of suppliers of electricity or heat based on coal, oil, gas, biogas and wood burning and in some cases it concerns wind turbines (Energi Data Service, 2023; Law BEK nr. 565).

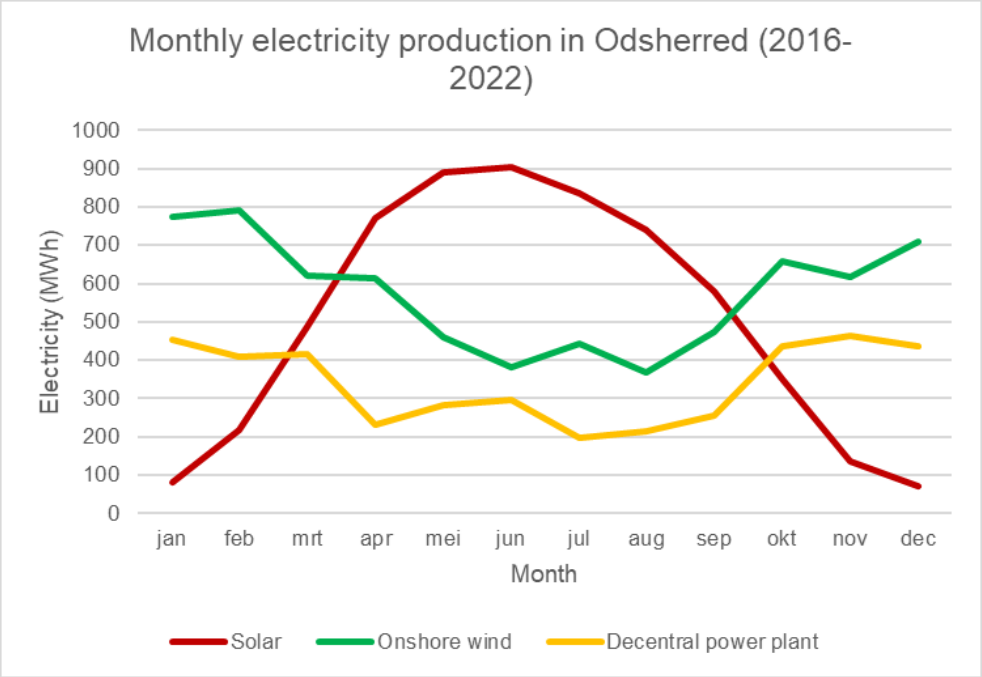

Figure 3: Monthly electricity production in Odsherred, averaged over 2016-2022. (Energi Data Service, 2023)

2.2.2 Denmark's energy transition: to 100% renewable energy

Denmark plays a leading role in terms of green energy production. Since 2020, 50% of electricity in Denmark is supplied by wind and solar power and numbers are rising (Denmark, s.d.). The Danish Government has the objective to reduce greenhouse gas emissions by 70% in 2030, in order to achieve the goal of net zero emissions by 2050. The focus here is mainly on the further development of large-scale offshore wind, although the further roll-out of solar photovoltaic (PV) and onshore wind is suggested as well. The Danish electricity system is already undergoing a development comprising an

increasing amount of renewable energy production from mainly intermittent wind and solar power sources, together with a decreasing central and decentral power plant production capacity. With an expanding level of electrification, the predicted increase in energy demand must be taken into account, as more cars and heating systems will run on electricity. However, there is an important issue of the security of electricity supply. Renewable energy producers like solar and wind power are highly fluctuating sources of energy, as the amount of sun and wind depends on the weather and season. Therefore, the diversification of energy sources is important (Danish Ministry of Climate, Energy and Utilities, 2019).

The implementation of solar farms in Odsherred suits Denmark's greater framework to reach net zero emissions by 2050 (Danish Ministry of Climate, Energy and Utilities, 2019). As mentioned before, the region of Odsherred is one of the sunniest in Denmark. Figure 4 shows the PV-power potential in Denmark. This PV-power potential is based on the amount of solar energy reaching an area, also known as insolation. According to the Global Solar Atlas (2018), Odsherred is a good place to produce solar energy compared to the rest of the country. This creates more opportunities to develop solar farms in Odsherred. However, there are several counteracting reasons concerning the opportunities, which will be discussed later.

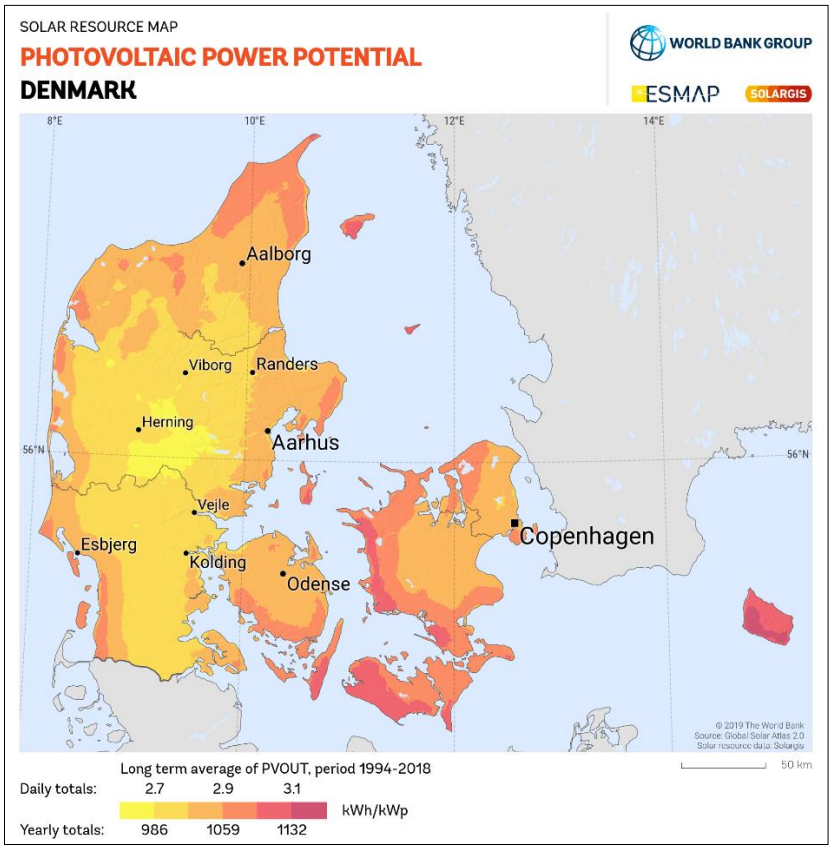

Figure 4: Photovoltaic-power potential in Denmark from the period 1994 – 2018 (Global Solar Atlas, 2019)

2.3 Advantages and disadvantages

2.3.1 Advantages

Solar power provides numerous benefits, making it an increasingly popular choice for energy generation. For instance, solar power is cost-effective and a cleaner and more sustainable energy source that can significantly reduce greenhouse gas emissions and help combat climate change. These advantages will be discussed in detail below.

According to the website Greenmatch (2023), the biggest advantage to solar power is that it is a source of renewable energy. Here, it is important to remember that we can receive solar power daily in any part of the world and that this resource is infinite. This is what makes this source of energy so interesting (Greenmatch, 2023). A second advantage to solar power is that it causes energy bills to fall, unlike other energy sources. The exact drop in the bill depends on the size of the solar system and the consumption of heat or electricity. With a larger solar system, the price can drop significantly due to the size of the it. In some cases, an excess may even be granted if more energy is generated in the solar system than consumed. In this way, solar power can be beneficial for farmers and companies (Greenmatch, 2023). The third advantage is that it can be used for different purposes. Solar power can be used to generate electricity as well as heat. In this way, solar power can be useful in different applications (Greenmatch, 2023).

Solar energy systems usually do not require that much maintenance. Occasionally things need to be renewed, but these are not major costs (Greenmatch, 2023). A final advantage to solar power is that it will strengthen towards the future. The technology regarding generating and storing the energy keeps advancing, which could make this an even more interesting source of energy in the future (Greenmatch, 2023).

2.3.2 Disadvantages

Besides a lot of advantages, there are also some disadvantages. For instance, solar power is weather-dependent and can have a distracting appearance in the landscape. The most common disadvantages are discussed below.

A first disadvantage according to Greenmatch (2023) is that the initial cost of purchasing solar panels is relatively high. This includes paying for solar panels, wiring batteries to store the generated electricity and the cost of installation. As this technology is constantly evolving, this cost may decrease in the future (Greenmatch, 2023). A second drawback to solar power is that it depends on weather conditions. For instance, less energy can be generated in the solar panels if it is cloudy or rainy. It should also be taken into account that no energy can be generated during the night (Greenmatch, 2023). Solar energy can

be used directly during the day. It can also be stored in large batteries, from which electricity will be used at night. These batteries provide a good solution for supplying energy at night, but are very expensive (Greenmatch, 2023). A solar farm also requires a lot of space. It will most likely be placed in rural areas where biodiversity is high and therefore will disrupt the local ecosystem, harming the animals and plants that live there (Mollick, 2023).

Solar energy is a lot less polluting than other non-renewable energy sources. Despite this, solar panels are often associated with pollution. For instance, making and installing the solar system would emit greenhouse gasses. Also, some toxic materials and hazardous products are used during the manufacturing of solar photovoltaic systems. This gives solar panels a more negative connotation (Greenmatch, 2023). The last disadvantage of solar energy is its appearance. Many people experience the panels as ugly and disturbing. People may find this as a major problem concerning the disturbance of the landscape (Solvari, 2023).

2.4 Regulations around renewable energy

2.4.1 Legislation

In Denmark regulations around solar energy are found to be falling under renewable energy policies. Renewable energy regulations are described under the act ‘Promotion of Renewable Energy and the Electricity Supply Act’, which is not only relevant on national level but also implies EU regulations (Schmith *et al.*, 2022). This act regulates renewable energy-related actions, like developing, financing, operating and selling the energy. Therefore, the main goal of this regulatory framework is to decrease dependency on fossil-based energy while ensuring that the supply takes into account security, economy and environment. Equal access to this renewable energy is also an important component of the act. However, the act does not implement regulations on local scale and would therefore benefit from multiple future amendments.

2.4.2 Promotion and the future

Denmark actively promotes the use of renewable energy. Schmith *et al.* (2022) mention that the country established numerous stimulants (which are regulated by the previously described act) in order to encourage renewable energy production. One of these stimulants is the implementation of cheaper tariffs (Res Legal, 2018). These occur in the form of tenders, when installing solar photovoltaics (or wind-generated energy installations). The subsidies can be divided into those tariffs as price supplements to ensure a fixed revenue that is independent to the actual market and financial support towards the construction costs of new renewable energy facilities (Schmith *et al.*, 2022).

Nevertheless, subsidies related to renewable energy are decreasing, especially when it comes to solar energy (Schmith *et al.*, 2022). Since 2020, Denmark no longer provides financial support for the establishment of new solar farms within the country. Wind energy is also affected by this decrease, as wind farms nowadays have to indemnify the state for their location in some areas at sea. This is a consequence of the ability of renewable energy to be competitive on the market and therefore started to match fossil-generated electricity prices. Another downside is described by the Danish Ministry of Climate, Energy and Utilities (2019) as the uncertainty concerning the security of electricity supply, due to the highly fluctuating amount of generated energy having a solar (and wind) origin. This is partly reflected by Figure 5, which visualises an only moderated predicted growth of the share of solar energy in the total of renewable generated energy. Although in the coming years, the extra new capacity of the electricity sector is expected to be mostly coming from solar photovoltaics in combination with wind and solid biomass (Danish Ministry of Climate, Energy and Utilities, 2019).

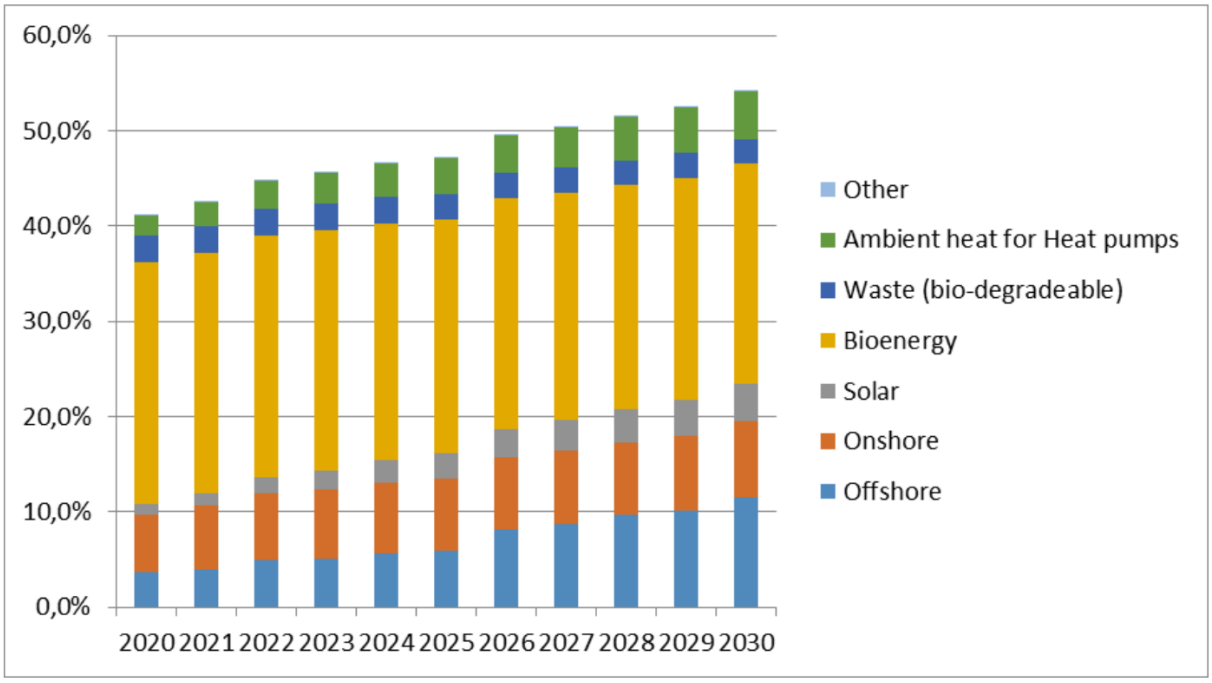

Figure 5 : Predicted shares of individual renewable energy technologies (Danish Ministry of Climate, Energy and Utilities, 2019)

On the other hand, Schmith *et al.* (2022) define promising news, as in 2020 the Danish government established 'The Climate Act', which requires the making of a national climate sub-target every fifth year with a perspective for the following 10 years. These plans always must be environmentally more ambitious than its predecessor. Furthermore, the Local Government of Denmark accentuates the importance of establishing a strategic energy plan by Danish municipalities, within the context of a renewable energy transition (Danish Ministry of Climate, Energy and Utilities, 2019). The government also supported the making of an external fund directed to multifunctional land distribution, which can be favourable to the installation of solar energy-devices.

2.4.3 Solar energy embedded in EU regulations

In December 2022, the European Union created a framework concerning council regulation to accelerate the deployment of renewable energy (Regulation 2022/2577). Since the invasion in Ukraine in February 2022, Russia drastically reduced the supply of natural gas to the EU and energy prices are soaring. This situation endangers the economy and threatens the security of electricity supply. Therefore, the EU came up with a plan to append quick transformations in the energy network. The fast development of renewable energy sources can help to mitigate the effects of the current energy crisis. However, there are still some stumbling blocks preventing a quicker implementation of renewable energy. According to T. Kjær, professor in energy planning at Roskilde University, the building of a solar plant could theoretically be done in two months.

In reality, obtaining the necessary documents in Denmark can be a time-consuming process (Kjær T., personal communication, 10 May 2023). This is because of the dop-down system in place, where each level of authority must approve the request before it can proceed to the next level. This system causes difficulties, as the municipality must first seek approval from the next level, who then seek approval from the next level, and so on, resulting in significant delays. As a result, it can take a very long time for the documents to pass through the various authorities and be approved, as stipulated in the regulations. In the best case, the building permit will only be obtained after three to four years but it can take up to five or even thirteen years.

A solution would be a faster system that can be done in a shorter time (Kjær T., personal communication, 10 May 2023). The current long-term approach is having a negative impact on the rapid implementation of solar farms in Odsherred, as well as on the quick transition to renewable that the EU has in mind. He proposes a new schedule that combines different steps and significantly speeds up the process of applying for a building permit. With this new approach, various steps can be combined, allowing for a more efficient process. This will help Odsherred to quickly implement solar farms and move towards a more sustainable energy future in line with the EU’s goals.

2.5 Types of solar energy producers

2.5.1 General solar energy producers

Solar power is a multi-purpose renewable energy source that can be used in various ways. Three major types of solar energy technologies can be distinguished: PV, concentrating solar-thermal power (CSP) and a heating liquid system. PV are the best-known form of solar panels. When the sun shines on such a solar panel, the PV cells absorb energy from the sun's rays into the panel. This energy creates

electrical charges that move in response to an internal electrical field in the cell, causing electricity to flow (Energy.gov, n.d.).

The second form is CSP. CSP-systems use all kinds of mirrors to reflect the sun's rays. The solar rays are then concentrated in a receiver that converts the solar energy into heat. This heat can be used to produce electricity, or it can remain stored in the form of heat for later use. The CSP-system is primarily used in very large power plants (Energy.gov, n.d.).

A third system is a heat system that heats a liquid in tubes. These tubes are mounted on the back of the solar panels (Christensen A., personal communication, 8 May 2023). Through a heat pump, the heat obtained from the liquid is distributed to the various households living near the panels. These panels are heavier than those working with photovoltaics. As a result, the panels cannot be mounted on roofs and require an area where they can be installed.

2.5.2 Agrophotovoltaics

In the context of this research, it is interesting to explore the potential of multi-functional land use, also called agrophotovoltaics (APV). APV is a technique where solar PV power and agriculture can coexist on a piece of land (Mulhern, 2020). Although both crops and solar panels need the energy of the sun for photosynthesis and electricity or heat production, their proximity provides several advantages.

The coexistence of crops and solar can be beneficial for each other. Sun relief can boost the productivity of certain crops. The shading of an installation reduces evaporation from crops, which can lead to up to 40% higher crop yield (Mulhern, 2020). In the other way around, the proximity of crops can be profitable for electricity production. When keeping climate change in mind, soil and air temperatures are highly likely to rise. These warmer temperatures can negatively affect the productivity of PV solar panels. "*The ground shading and increased evaporation provided by a healthy layer of undergrowth can cool the solar panels, increasing their energy output*" (Dreves, 2019). Flourishing vegetation can therefore boost the energy production from solar cells.

2.6 Energy landscapes

An energy landscape transition is also being considered in Belgium. The Waasland region, for example, wants to produce 100% climate-neutral energy by 2040. This also involves considering the use of solar energy. For instance, they are also thinking about the use of solar fields. These solar fields make use of PV panels. These fields would have a minimum area of 1 km². This would have a yield of 90 000 MWhe, equivalent to the electricity consumption of 26 000 households. They estimate that these panels would have an operation of 1 000 hours per year. These panels will be installed in the Waasland region

on vacant sites, as they say no other business is possible under the panels (Provincie Oost-Vlaanderen, 2021).

They are also considering the second type for solar power generation, CSP-systems. Here they want to use 1 km² fields of mirrors, which concentrate the sun's rays and can generate heat up to 400°C as a result. This heat could be used to generate 130 000 MWhw of electricity, or the heat consumption of 5 600 households. These mirrors could also produce about 1 000 hours per year at full load and where again nothing is considered possible under the mirrors (Provincie Oost-Vlaanderen, 2021). So Denmark is certainly not the only country considering a transition to 100% renewable energy. Belgium is also thinking about this scenario.

3 METHOD

Our method consists of three main components. Firstly, we did a comprehensive desktop study, which involved conducting a literature review on the topic and collecting relevant data for the multicriteria evaluation. These findings were used to develop a suitability map, which was then used in the fieldwork. The second phase involved the fieldwork, which included site visits to existing solar farms or renewable energy companies and interviews with various stakeholders. This stage gave us an understanding of the practical aspects of implementing and managing solar farms, as well as insights into the perspectives of different stakeholders. Finally, we combined the insights gained from the desktop study and fieldwork to develop a comprehensive analysis of the topic. The components will be discussed in more details bellow.

3.1 Desktop study

3.1.1 Literature overview

At first, we started looking for information about the study area of Odsherred commune. This information was retreated from scientific papers and websites like UNESCO, that talked about the Geopark of the Odsherred commune. We also looked for sources about renewable energy, solar energy, clean energy and the definition of solar farms in our literature research. This was done to define the importance of our study, which can be found in the introduction. After a general search for solar energy and solar farms we took a closer look at solar energy in the study area. We looked for the current situation in Denmark and Odsherred specifically. In addition we also added an overview of the regulations that already existed on solar energy in Odsherred. Following this, we looked at the advantages and disadvantages of solar energy. It is important to have a critical view on the topic to not automatically assume that solar energy is always the better option.

Our search for solar energy led us to different ways concerning the generation of solar energy. These types of producers are further discussed in ‘2.4. Types of solar energy producers’. Lastly, other energy landscapes were examined to make a full comparison between different areas. We found an area in Belgium that is going through an energy landscape transition right now. This is a great example to look at different methods that are being used and is therefore great for comparison with the study area of Odsherred.

We read scientific papers on solar energy transition in different study areas to get a better understanding on how Odsherred could create more possibilities of implementing solar energy. These papers gave more insight on which methods were useful and how we could approach the analysis. Kırcalı & Selim (2021) for example performed a multicriteria analysis to create a site suitability overview for solar farms in Antalya, Turkey. Their final product was a suitability map of the study area, indicating where solar farms would be pleasant. The approach of Kırcalı & Selim (2021) would also suite the first part of our analysis, so we decided to use a multicriteria evaluation as well. The data they used was categorised into geography, solar parameters and logistics and although we had to make slight changes, the categories gave us a good understanding on which data and variables we should use.

3.1.2 Multicriteria evaluation

Multi-criteria evaluation (MCE) is a commonly used method for comparing and evaluating different alternatives based on multiple criteria or factors. This approach is particularly relevant in the context of solar farm suitability evaluation, where factors such as proximity to main roads, proximity to substations, slope, aspect and insolation levels can significantly impact the feasibility and profitability of a solar farm project.

Proximity to main roads and substations are crucial factors to consider when evaluating the suitability of a location for a solar farm, as they determine the ease of connecting the solar farm to the power grid and the associated costs. Similarly, insolation levels play a key role in determining the potential energy output and financial viability of a solar farm, this also applies to slope and aspect. Insolation and aspect can be correlated with each other.

To employ MCE in solar farm suitability evaluation, it is important to standardise each factor. In this case, linear standardisation, which involves rescaling the factors to a range of 0 to 1, has been used to allow for direct comparison and evaluation. For the standardisation of the slope, a non linear method was used.

Once the factors have been standardised, a weighted linear combination method is used to calculate a suitability score for each location, with weights assigned to each factor based on their relative importance. For instance, a higher weight may be assigned to proximity to main roads if it is considered

more important than insolation levels. Several possibilities exist for assigning weights to the factors. The first option is to allocate higher weights to main roads and substations, assuming that economic factors are the most significant. The second option involves assigning equal weights to all factors, thus considering them to be of equal importance. Finally, there is the possibility of assigning higher weights to physical factors, such as insolation, slope and aspect.

First, a map was created with equal weights. This was because there is no particular preference for certain weights. The literature does not really make a distinction in this regard. Then, a second map was also created. This was because new insights were gained during the fieldwork. Economic factors were particularly important in this case. This is because Odsherred does not exhibit a great variety of physical factors, and money plays a crucial role.

3.2 Field work

Like mentioned before, our fieldwork consisted of two different methods. We were going to visit existing solar farms in the area and do interviews with different stakeholders. We started looking for possible stakeholders first, who would be involved in the solar energy image of Odsherred. Before we left for Denmark, we could only contact one person, named Rasmus Kruse Andreasen. He is a landscape manager at the Odsherred municipality who specialises in climate adaptation, water planning and other environmental cases. We planned a meeting with him in Roskilde to talk about the current regulations of solar energy and get his opinion about our suitability map. This also required to prepare some interview questions. After contacting our first stakeholder, we tried to contact several solar farms in the area of Odsherred but unfortunately, they did not answer our emails. So, we left to go to Denmark with only one interview planned.

Arriving in Denmark, we searched the area through Google Maps satellite images and found a couple more solar farms in Odsherred and the Kalundborg commune (Figure 6). Our plan was to drive to these solar farms and see if we could find the owner and ask this person some questions. This tactic led to having an interview with a farmer who owns a solar farm and is planning to expand. We also visited the heat plant of Nykøbing and asked the manager some questions concerning his solar farm. We also had some interviews with people living close to a solar farm and we questioned their opinion about the farm. Andreas Aagaard Christensen, professor at Roskilde University, recommended a colleague, named Tyge Kjær, that specialises in Energy Planning. So, we contacted him and set up a meeting to talk about the current energy planning in Odsherred and Denmark in general.

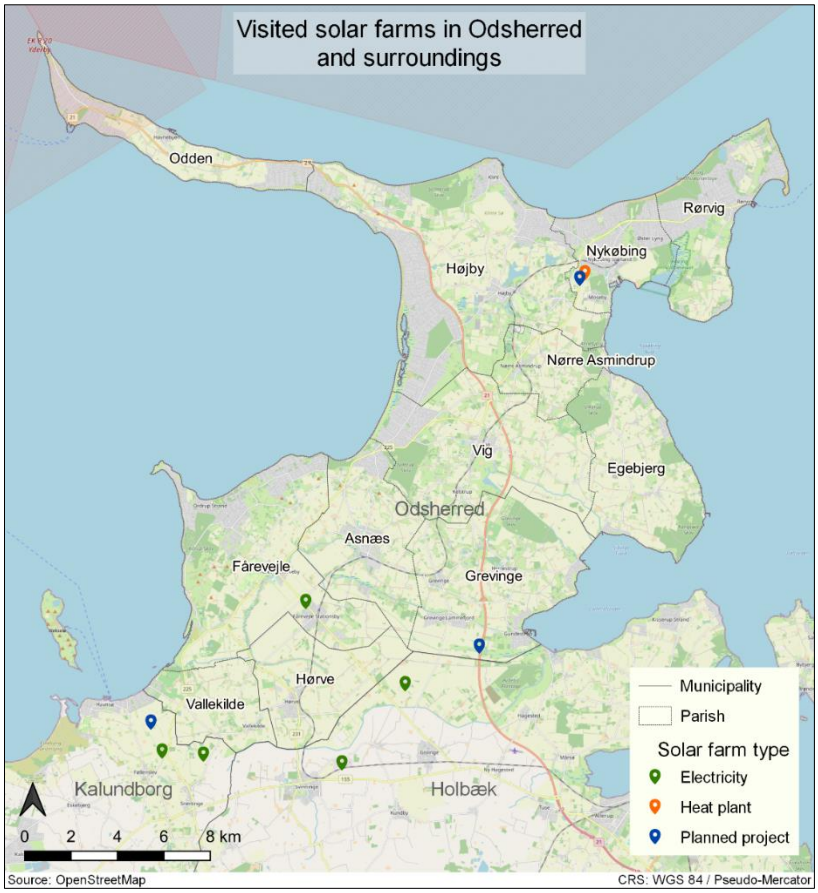

Figure 6: Location of visited solar farms. (own production)

4 RESULTS

4.1 Suitability map

Below, the results of the suitability map are presented. As mentioned, an initial map was created where all factors were assigned equal values. Figure 7 depicts this suitability map. For the analysis, only agricultural lands were considered. Agricultural land was chosen due to its ease of conversion for solar panel installations, whereas other land uses, such as buildings, would require extensive modifications. The first suitability map reveals a favorable distribution of suitable locations, particularly around Asnæs and centrally near Vig. Good locations can also be found on the Sjælland Odde peninsula. In the east of Odsherred is also a big area where the suitability is less favorable.

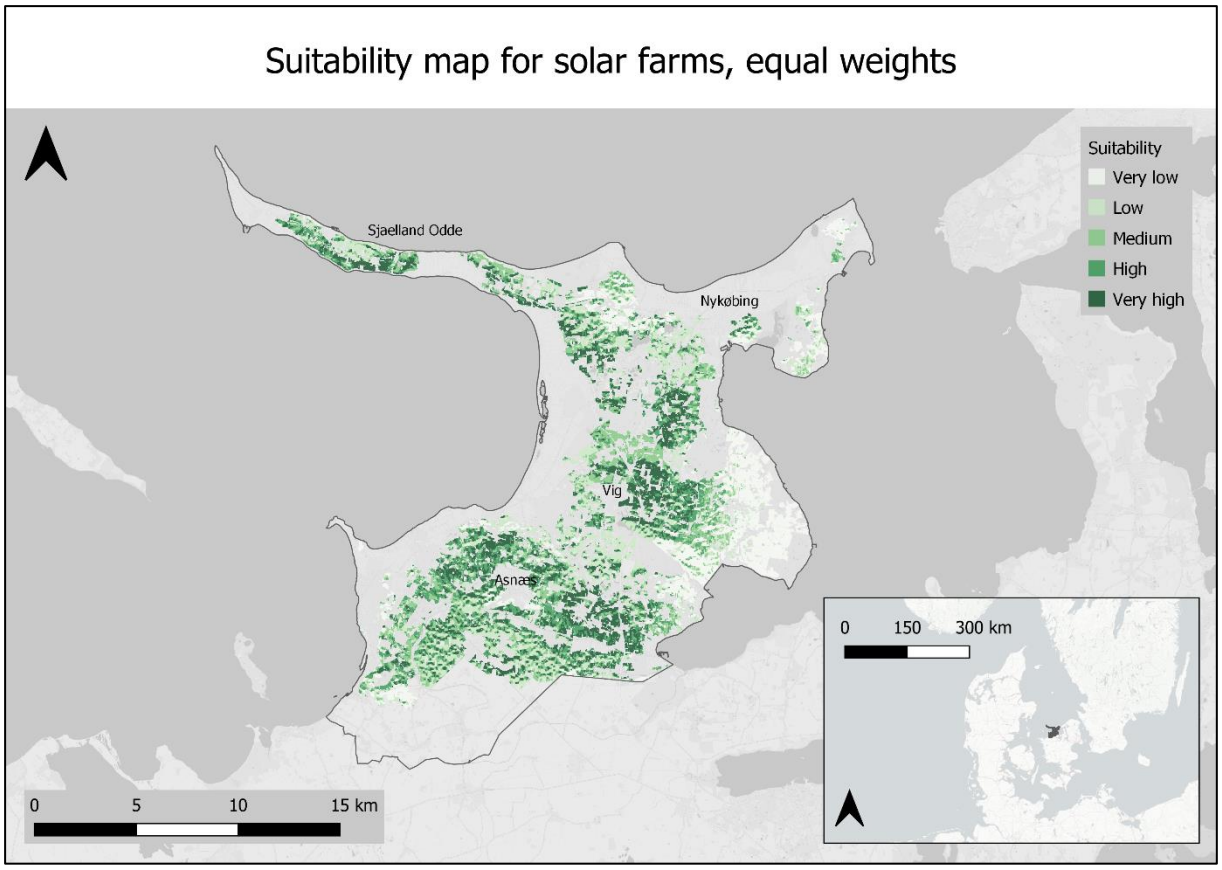

Figure 7: Suitability map where the factors have equal weights. (own production)

Through the conducted fieldwork, it has become evident that economic factors play a more significant role. Figure 8 displays the suitability map where these factors have more power, revealing optimal locations around Asnæs and Vig, particularly in the northwest of Asnæs. When comparing the two maps, slight differences can be observed. Thus, it can be observed that in the northwest of Asnæs, the suitability is less favorable compared to equal weights. Similarly, the same trend is observed in Sjælland Odde, where there is also higher suitability when using equal weights. However, when economic factors are prioritised, it is evident that there is a better suitability in central Odsherred (north of Vig) compared to equal weights. The usefulness of the suitability map is demonstrated by a forthcoming project. A project is planned in a location with a very high suitability according to the map. The new project is situated in the southeast of Odsherred and will be further discussed below.

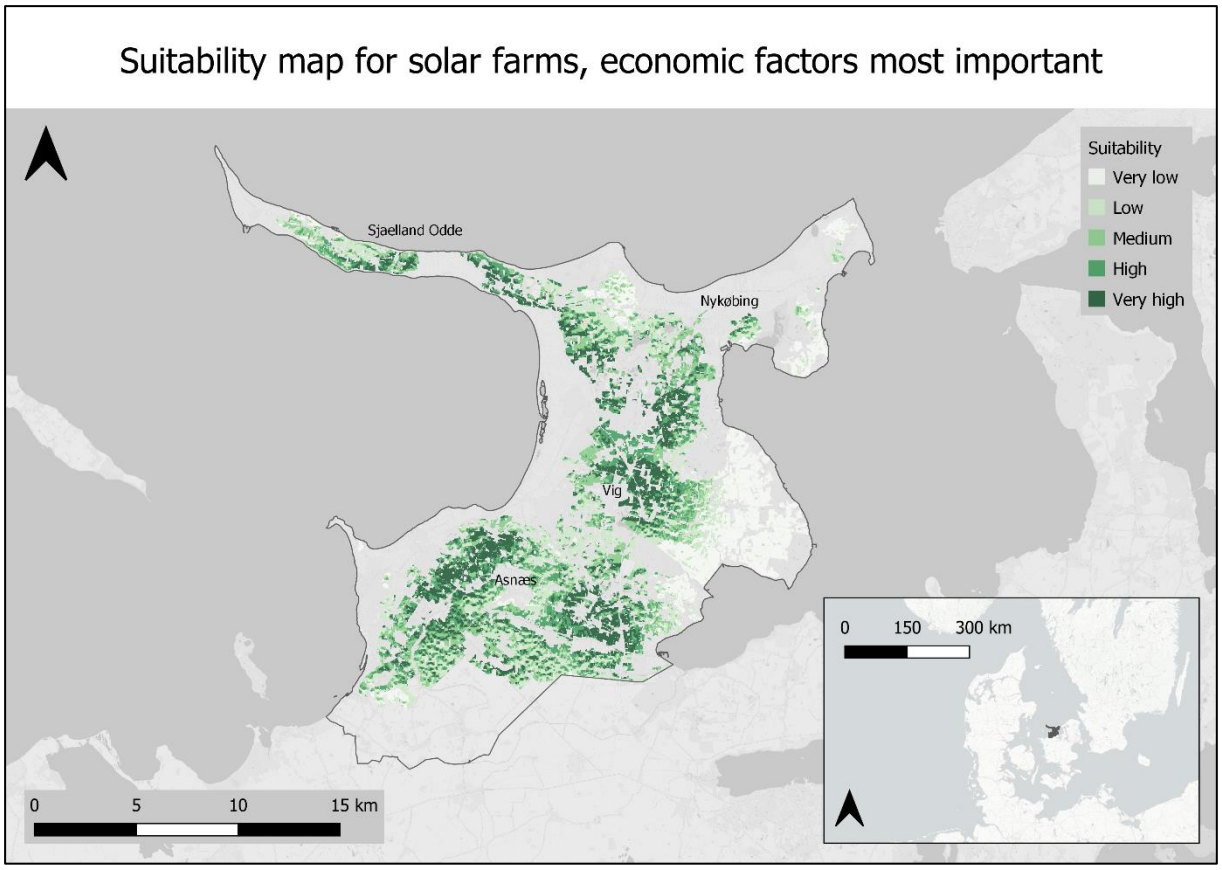

Figure 8: Suitability map where the economic factors are most important. (own production)

4.2 Insights form interviews

4.2.1 New project in Odsherred

The municipality of Odsherred is planning a new photovoltaic solar plant to cope with the rising electricity demand in its area (Rasmus Kruse Andreasen, personal communication, 9 May 2023). It will serve approximately 39 000 households, producing 175 million kWh per year, and it will have a lifetime of 30 years. The solar plant will be built in a rural area with a low population density and the land use is agriculture at the moment. The biggest goal the municipality has with this project is to maintain nature as much as possible and implement elements to contribute to the community.

The landscape in Odsherred has an important value because it has been designated as a geopark. It must therefore be ensured that the project causes the least amount of disruption to the landscape. One way the municipality is implementing this, is by creating a nature belt around the solar panels. This belt will be made up by trees and shrubs that block the view from the outside. Underneath the solar panels grass and herbs will be planted and the presence of grazing animals will also be made possible. The area contains a couple of protected natural habitats, where building panels will not be possible. These

pieces of land will also be surrounded by a five-meter perimeter of no infrastructure to maintain these habitats. The project will also give back to the community. The panels will be treated to be anti-reflective, so surrounding residents and passers-by are not bothered by the reflecting light. They will also make sure there will be no noise pollution from the installations or activities.

4.2.2 Odsherred's habitants' opinion

According to the findings of the multiple interviews, a general view on the opinion of the residents of Odsherred could be constructed. It would seem that the majority of the inhabitants have a more negative view on the implementation of new solar farms in the commune. This seemed to be mostly due to their visual look, that disturb the typical landscapes present in Odsherred. Interviews with inhabitants showed that they are closely related to the cultural aspect of the land and do not want the eye-catching glance of the solar panels interfering with the landscapes. Next to the appearance, some residents also claim that the panels produce a 'zooming' sound, that is annoying. Although when on terrain, this sound seemed to be of minimal noise and would therefore only be audible to inhabitants very close to the panels. From an interview with a resident habituating nearby the large solar farm of Europ in Svinninge, information was acquired concerning a financial devaluation of his house by 75% since the installation of the solar farm. An interesting insight was the occurrence of the 'Not in My Backyard' phenomenon (NIMBY) during interviews with residents. This phenomenon happens when people are supporters of the project as long as it is not implemented nearby their residential infrastructure. The main reason for this resistance is mainly due to the not matching embedding of the solar panels in the landscape surrounding because of its visual aspect. During an interview with a resident nearby a small-scale solar farm, the resident formulated that the farm was located behind her garden and was hidden by high trees and numerous bushes. Therefore, she was not affected by the striking looks of the solar farm in the surrounding landscape and was not bothered by it. She also mentioned that she supported this solar-way of producing energy. When asking her what her opinion would be if the solar would be located in front of her house and thus visible, she stated that she would not be pleased by it due to the appearance and would be suite bothered. Consequently, some inhabitants seem to be enthusiastic about solar farms, as long as they are not affected themselves by their visual aspects.

A possible solution concerning this problem would be to engage people that would go on terrain in order to explain the way these solar farms work and are embedded in the municipality (Kjær T., personal communication, 10 May 2023). The goal of this initiative is to not only make the inhabitants feel like consumers of the products of these solar farms but also make them feel like producers and important parts of the development towards a greener future.

4.2.3 Multifunctional potential of solar farms

Following from the interest of a farmer willing to install more solar panels on his land, multiple suggestions to combine solar farming with other activities were proposed by the Belgian company 'IZEN'. As having large grazing animals is not possible without installing costly raised solar panels, photovoltaics made of translucent material would allow greater solar radiance through the panels and would therefore allow more options for possible types of vegetation to be cultivated under the panels. These types of translucent panels are more expensive but seem to be more cost effective than building raised solar panels. Other possibilities aiming more towards increasing biodiversity could be the seeding of different flower species (e.g., Hairy tare, Tansy, Dove foot geranium) flowering for two to three months, which can be beneficial for pollinators. Consequently, it would augment biodiversity significantly more than homogenous, monocultural agriculture and these species are also suitable to grow in the semi-shaded micro-climates created by the panels. Another possibility of combination would be the planting of fruiting trees north of the solar panels, which also profit birds and insects as a food source. The trees could also be home to bird boxes and beehives. IZEN laid the emphasis on making the new solar farm multifunctional in such a way that it can be combined with recreational features for residents as well as biodiverse-supporting infrastructure. E.g., establishing a corridor in the middle of the solar farm designated to the transit of wild animals (Figure 9), building a watch tower at the corner of the field for residents to enjoy the view or creating walking trails for hiking.

Figure 9: Corridor for animals to pass. (Khaled et al., 2022)

Other possible alternatives could be:

- Bike roads between the solar panels
- Adventure trails going through the solar park
- Creating patches of different ecological habitats (e.g., little ponds, small rewilded pieces of land)
- Recreational infrastructure (e.g., playgrounds)
- Resting places (e.g., picnic)

By implementing some of the previous multifunctional options, stakeholders with high interest but low influencing capabilities (indicated in Figure 10) are given the chance to be implemented in solar project. This results in a more unified relation between solar energy and its social and ecological surroundings. A good example is the way the solar heat plant of Nykøbing combines its solar panels with residential recreation in addition to a small pond (which stimulates biodiversity in the plant). Inhabitants are able to walk between the solar panels and lunch on the grass patches as they are publicly accessible. Next to this, the pond is home to breeding frogs and in spring it serves as a habitat for the newborn frogs. The occurrence of the more unified relationship could partly solve the NIMBY-phenomenon, by implementing features that connect inhabitants to the solar farms.

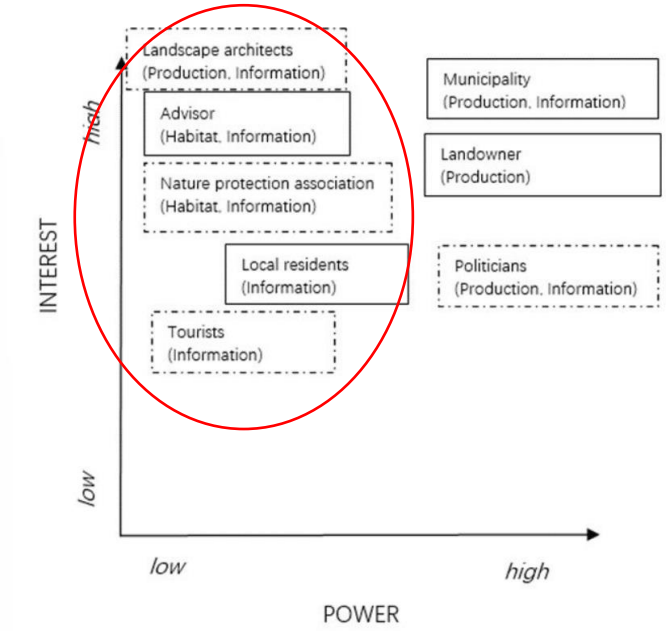

Figure 10: Power and interest graph for certain people. (Khaled et al., 2022)

Concerning the managing of the land, sheep grazing can be a good alternative in order to preserve the biodiversity in the area. This concept was proposed by IZEN as a maintaining method for the new large solar farm of the farmer but is not new, as the method is already applied on the already smaller established solar farm on the farmer's land (Figure 11). The concept of sheep grazing was also seen in the solar heating plant of Nykøbing Sjælland, where sheep were indeed used to keep the grass down between the solar collectors (although they were not present at the time of our visit because of construction works). In addition, the farmer also planned to utilize sheep for grazing purposes. Although he described the relevance of the sheep as not too important, as they were still a better option than doing nothing with the land under the solar panels.

A last possibility with high potential would be cultivating the land for agricultural purposes. The farmer showed some interest towards this concept (although he mentioned he will probably not implement it). Crops could be cultivated between the solar panels rows by installing moveable solar panels that could

rotate in a vertical position in order to create passage for harvesting machinery. However, this type of panels are being tested and still needs research before being put on the market.

Figure 11: Sheep grazing between solar panels. (own production)

4.2.4 Barriers in the current regulations

Several barriers seem to be present in multiple aspects of the situation. The implementation of new EU regulations requires Denmark to formulate new regulations on national and regional level. However, to this day there is a lack of regulations concerning all municipalities in the country. To coop with the transition to renewable energy reliance, the municipality of Odsherred decided to install district heating in a number of places.

Another barrier can be found in the ownership of solar farms, as they are still a private matter in Odsherred. Most farms are owned by private big landowners and are therefore not property of the commune. This implies that the majority of the produced electricity is sold on an open market, which in most cases means being consumed in Germany. Habitants in the neighborhood will therefore only experience the disadvantages, as they will not be able to use the generated electricity. In addition, new solar farmers do not seem to receive money from the government anymore. 10 years ago, private owners could benefit from a fee during the first 10 years after building and thus owning a solar farm. Therefore, although most people included in the interviews said solar farms are more profitable than agriculture, the starting cost can be considered too high for ‘normal’ people.

At last, East Denmark (Sjælland) seems to have a harder time transitioning to more renewable energy, because of its location on a profitable gas highway running through Norway, Denmark and Germany. West Denmark (Jutland) is closer to getting renewable energy, because of its more independent characteristic. The prices of general electricity are also lower in Sjælland than in the western part of Denmark, so people do not want to change to solar energy as it would be considered as a private investment. Everything was 'working fine before', so changing to renewable energy was not necessary until the Russian-Ukrainian war started. This war made electricity prices go up significantly, so people wanted to find a way to save money. Renewable energy was one of these options. Since prices are going down again this year, there will not be a big request for solar energy anymore, with the mindset of saving money.

5 DISCUSSION

5.1 Suitability map

When creating a suitability map for potential solar farm locations, various factors were taken into account. Below will be discussed what the interviews taught us about our suitability map and the used factors. One significant consideration is the slope of the land, which is important in mountainous or hilly areas. However, in Odsherred, the slope is not a major concern as our stakeholders mentioned that it is never too steep to build a solar farm. Therefore, it is possible to adjust the solar panels to achieve the optimal angle.

Another important factor that was not included in the suitability map, is the proximity of people living near potential solar farm locations. From interviews conducted, it was discovered that people who live close by might be the biggest constraint for building a solar farm due to NIMBY, BANANA (Build Absolutely Nothing Anywhere Near Anything), and CAVE (Citizens Against Virtually Everything) principles. For example, in Odsherred, which is a Geopark, people do not want to see the landscape drained by big installations. Additionally, people may not be sufficiently informed about the benefits of solar farms, and the presence of a solar farm may lower house prices in the surrounding area. Furthermore, noise complaints are a common issue for solar farms, and farmers are implementing measures such as building nature borders around the farms with wildflowers, trees, and insulation to mitigate the noise.

Connection to the substation is a crucial factor since people have to pay for their own connection to the grid if their solar farm is not yet connected. Therefore, locations near high voltage substations are preferred.

Most plausible locations for solar farms are large estate farms, which are owned by individuals with substantial financial resources who want to invest. Physical and economic factors of the area do not

matter as much in these cases. However, the minimum size for a profitable solar farm is 20 hectares, so smaller areas are not useful for this purpose. So, the size of parcels would have been interesting to include in the suitability map.

Lastly, it seems that some stakeholders believe that solar farms should be placed on wetlands or polluted sites that are not suitable for other land uses. Solar panels can also be placed near drinking water resources since other land uses might pollute them. In summary, a suitable solar farm location can consider various factors such as the slope, proximity to people, connection to the substation, parcel size, and existing land use, but new regulations and a new mindset are needed.

6 CONCLUSION

In conclusion, the municipality currently has several solar farms, but they contribute to only a small percentage of the total electricity consumption, indicating a reliance on other sources. The electricity production in Odsherred is primarily generated by onshore wind turbines, solar power, and decentral power plants. While solar and wind power remained relatively stable, decentral power plant electricity generation showed fluctuations. Denmark aims towards a transition of 100% renewable energy, with a focus on offshore wind and the expansion of solar photovoltaic and onshore wind power. Solar farms in Odsherred align with Denmark's goal of achieving net zero emissions by 2050. Solar power offers advantages such as being a renewable energy source, reducing energy bills, versatility in applications, low maintenance, and ongoing technological advancements. However, there are also disadvantages, including the initial high cost of solar panels, weather dependence, the need for space for solar farms, potential environmental disruption, pollution associated with production, and aesthetic concerns.

Based on the findings of our fieldwork, the importance of physical and economic factors in determining a suitable location for a solar farm is overshadowed by public opinion and land availability. While our suitability map indicates more ideal areas than others, the process of establishing a solar farm is more complicated. Current regulations cause challenges, requiring landowners to navigate several steps before commencing construction. As a result, future solar farm locations primarily depend on landowners with sufficient resources to invest in the project, with less focus on specific land characteristics.

Currently, there is scepticism among the public of Odsherred regarding solar farms due to concerns about their impact on the visual appearance of the landscape. Preserving scenic views and adhering to the NIMBY phenomenon are significant considerations for locals. However, our research reveals that existing solar farms in Odsherred partially embrace multifunctionality. Although they have yet to adopt the crops method, these solar farms incorporate activities such as grazing sheep and other functions. Interviews have highlighted the importance of considering nature preservation and the well-being of the surrounding communities for solar plants. By further developing multifunctionality, solar farms have the

potential to contribute more to the local community and potentially address the NIMBY issue. To minimize NIMBY reactions, it is crucial to effectively communicate and collaborate with local residents.

To conclude, this study highlights the significant potential for solar energy in Odsherred, indicating a clear demand for further development within the municipality.

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8 APPENDIX

8.1 Interview guide – Rasmus Kruse Andreasen

8.1.1 What do we do?

We are master students in geography from Ghent University and we are doing a project concerning solar energy in Odsherred. A global transition towards renewable energy forces to look for new ways of gaining sustainable energy. Denmark plays a leading role in this transition, with already 50% of energy supplied by wind and solar power in 2020. However, a further diversification of energy sources is necessary to achieve a complete transition.
This report studies the possibilities of implementing solar energy in the Odsherred kommune. In the first place, we sketched the current energy situation in Odsherred (and Denmark), by looking at literature concerning the current regulations about solar farms, the available solar energy sources and the pros and cons of solar panels. Next, we created a suitability map with valuable information about the theoretically suitable places for solar farms in Odsherred. Thereafter we looked into the multifunctional aspect that could be a possibility to associate with these solar farms. We will go a bit more into detail in these last two components in our last questions.

8.1.2 General questions

- Could you tell us a bit more about yourself and your function at the municipality of Odsherred?
- As a member of the centre of Bussiness, Technology & Culture of Odsherred, could you give us an insight of what this centre stands for within the municipality?
- As our project covers the embedding of solar farms within the municipality, we would be courious to know if and how solar farms are handled by this department?

8.1.3 Solar energy situation in Odsherred

- The Danish Ministry of Energy underlined the importance of establishing a strategic energy plan by Danish municipalities, within the context of a renewable energy transition. Did Odsherred established such a plan and if yes, what are the main goals and components of it?
- To which extend do you think Odsherred's policy about solar farm can become a suitable renewable energy source the same way wind energy for example became for Odsherred?
- We have already found one solar farm dedicated to heating in Nykobing. Could you tell us about the motivation for installing this infrastructure and why it was chosen to be a heating one instead of a electricity-producing one?
- Are there other solar farms in the municipality?
- Are there any forms of usage of solar farms in combinations with other land uses (e.g., agricultural crops, sheep grazing)?

Figure 12: Crops growing under solar panels (Google Images, n.d.a)

Figure 13: Sheep grazing under solar panels (Google Images, n.d.b)

8.1.4 Statistics and funding

- According to a document made by the Danish Ministry of Climate, Energy and Utilities, the government supported the making of an external fund directed to multifunctional land distribution, which can be favourable to the installation of solar energy-devices. Do you know if this external fund concept was carried out and if yes, did Odsherred benefit from this fund?
- Was the installation of the solar farms subsidised by the Danish Government?
- Does Odsherred has some kind of plan concerning the storage of solar- and wind-produced energy, as they are highly fluctuating sources of energy (e.g., wind turbines are dependent on the weather, solar panels produce significantly less during winter months) and thus energy storage will assure more certainty towards secure energy amounts?

8.1.5 The renewable energy future of Odsherred based on our suitability map

During our preparatory research we produced three suitability maps for the installation of new solar farms in Odsherred based on a Multicriteria Evaluation-method. Factors determining the outcomes of the maps were closeness to the road network, closeness to substations, insolation, slope and aspect. The more suitable a factor is for a solar farm, the higher of a suitability value it has.

Economic	**Physical**
Closeness to the road network	Insolation
Closeness to substations	Slope
	Aspect

Table 1: Economic and Physical factors used in the suitability map (own production)

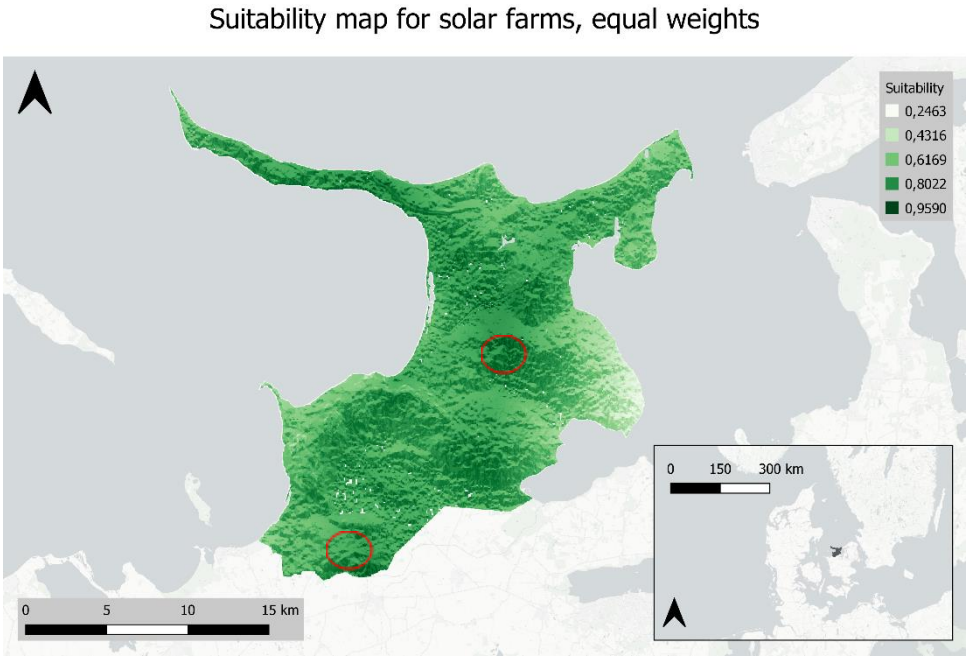

Figure 14: Suitability map for solar farms, equal weights (own production)

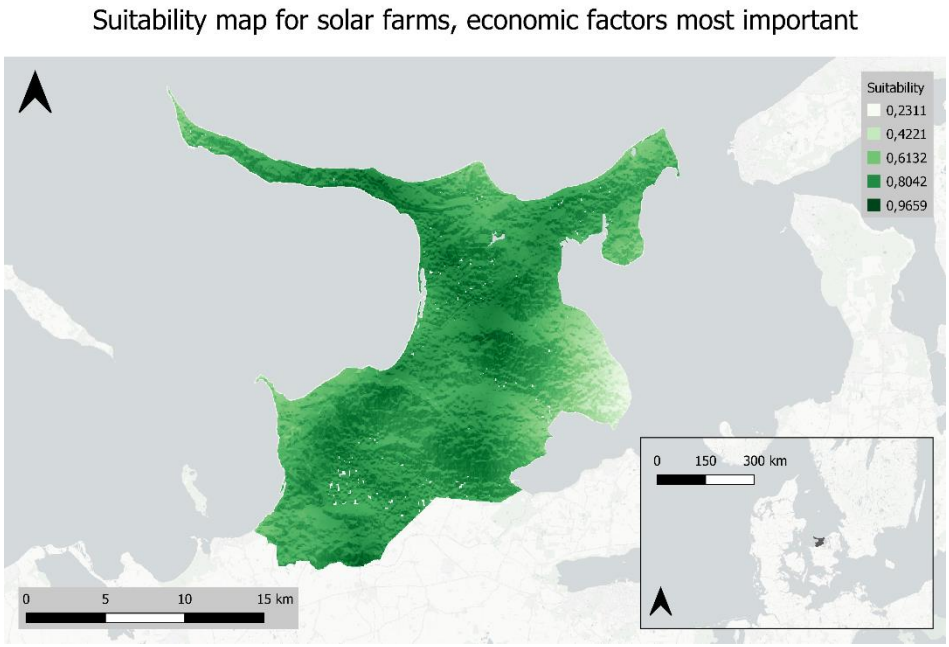

Figure 15: Suitability map for solar farms, economic factors most important (own production)

These are two examples of the kind of areas that result the best in the suitability analysis. Does this match with the kind of areas you have in mind to put solar farms on?


Figure 16: Suitable place for solar farming (Google Earth, n.d.a)


Figure 17: Suitable place for solar farming (Google Earth, n.d.b)

Figure 18: Suitable place for solar farming (Google Earth, n.d.c)

Figure 19: Suitable place for solar farming (Google Earth, n.d.d)

How does the resulting map stand against real plausible locations that could be designated towards producing of solar energy?

What do you think of the importance of each factor included in our suitability map? Are there any factors that should weigh more than others?

Are there any factors not included in our evaluation, that would also be important for a suitable place to build a solar farm?

8.2 Interview with Rasmus Kruse Andreasen

These notes were made during the interview.

Date: 9 May 2023

To understand the current and future situation of solar farms in Odsherred, a word of explanation is needed from the commune itself. In an interview with Rasmus, employee at the commune around energy and water, he told us more about this. He started with an overall sketch of Odsherred's current situation. This showed that there is only one solar farm and that it serves as a heating system. The commune itself has no solar farms to generate electricity. He said that the Odsherred commune was ashamed of these issues, as the nearby communes do rely more on renewable energy.

In the future, they plan to build a large solar farm of about 140 hectares. The rules do not specify anything around the installation of solar panels. Thus, they are now mainly placed on the land of large landowners who are themselves interested in placing them on their property. The panels will be located in southern Odsherred. These areas lend themselves to this because they are owned by large landowners and they have the perfect plots for this. In doing so, he explained that maintaining any sheep could cause higher costs, making this less interesting for the landowner.

They note that there is a need for legislation around the installation of solar farms. For instance, each commune has its own small regulation on solar farms, but they want to design an overarching legislation that takes into account the regulations of the different communes. These plans are not yet for in the near future and there did not seem to be much of a rush behind them. In doing so, he explained that, in his opinion, it is not about finding suitable land, but about landowners deciding what to do on their land or not. Also, the solar fields are owned by a private company, so making overarching regulation makes less sense.

The various possible locations for installing the solar fields were then reviewed. Based on the suitability map, some possible locations were found. Rasmus, on the other hand, did not find these locations equally suitable. For instance, in 2 of these places, he said, there are many opponents now against windmills and biogas and it is not a good idea to install panels here. Thus, according to him, it is not possible to draw up a map or regulations based on the factors discussed earlier, as the placement of solar fields mainly depends on neighbours and landowners. This causes a lot of suitable spaces to be left out. They also do not want to force the landowners into this, with many not thinking of the possibilities. Contrary to our literature, he explained that the electricity extracted by the solar fields does not go to nearby households or homes, but is sold on an open market. Also, the bypassed houses often receive money as compensation for installing the solar panels. This can amount to sums of €1000 a month.

He feels that the suitability map should also take into account the opinions of local residents, as this is a big factor in holding up the plans. Another factor to be included is the coastline, which is partly protected and where no panels can be placed in this area. The distance to substations is not a main factor, according to him, as there is willingness to make new connections in the power grid to get the energy from the solar farms onto the grid. Here, the landowners themselves are responsible for making arrangements with the power grid. The commune does not intervene in this.

He does definitely see the potential of multi-functionality of the solar fields. For instance, he says they plan to scatter flower seeds between the panels in their new field and put sheep that can graze in the grass. He says it is not a complete replacement, but it is compensation for taking up the land. That way, it is better than doing nothing. Similarly, he sees it as a dichotomy, since on the one hand they want to protect nature and put more effort into biodiversity, and on the other they are taking natural land to put solar panels on.

It further discussed the situation of the opinion of Odsherred residents. According to him, the residents fear that the installation of the panels will cause parts of the geopark to disappear. The residents are apparently very conservative about their landscapes and do not want them to change. This often makes them in opposition to plans for new solar fields.

8.3 Farmer solar farm

8.3.1 Interview notes

These notes were made during the interview.

Date: 9 May 2023

A farmer who owns a solar farm in Føllenslev was interviewed. The solar farm produces 398 kW and was built in 2013. The decision to install the solar panels was motivated by a fiscal benefit offered by the government. Initially, a price of 17.3 euro cents per kWh was paid for the first ten years, which was higher than the market price. After this period, the market price was paid. The farmer also owns three wind turbines. There are sheep grazing in the solar panel field, and they do not pose any issues with the panels. This demonstrates a good example of multifunctionality, as the grass is kept short and sheep can be kept. However, the farmer is hesitant to combine the solar farm with crops as this technology is still in its pioneering phase.

When the solar farm was installed in 2013, there was not much opposition from the local residents. The solar panel field is not highly visible from public roads. Currently, the farmer has planned a significant expansion and intends to convert almost all of his agricultural land into a solar farm. This is expected to generate higher revenue than cultivating crops. In general, the new solar farm has received positive feedback due to the decision being made at a time when energy prices are high. However, there have been some complaints from nearby residents who own summer houses. To address their concerns, the farmer plans to plant bushes and trees around the solar farm.

The new solar farm will serve multiple functions beyond energy production. A wildlife passage will be established in the center of the plot to allow animals such as a deer to move from one side to the other. This serves as compensation for biodiversity. Additionally, walking paths and an observation tower will be installed among the solar panels. The connection to the power grid is scheduled for 2026, requiring the construction of a new connection line. The farmer will bear the full cost of this infrastructure, but it is considered a worthwhile investment.

8.3.2 Extra information provided via mail

Following from the interest of a farmer willing to install more solar panels on his land, multiple suggestions to combine solar farming with other activities were proposed by the Belgian company ‘IZEN’. As having large grazing animals is not possible without installing costly raised solar panels, photo voltaics made of translucent material would allow greater solar radiance through the panels and would therefore allow more options for possible types of vegetation to be cultivated under the panels. These types of translucent panels are more expensive but seem to be more cost effective than building raised solar panels. IZEN laid the emphasis on making the new solar farm multifunctional in such a way that it can be combined with recreational features for residents as well as biodiverse-supporting infrastructure. E.g., establishing a corridor in the middle of the solar farm designated to the transit of wild animals or building a watch tower at the corner of the field for residents to enjoy the view.

8.4 Mrs. Hansen

These notes were made after the interview.

Date: 9 May 2023

Lives on a farm with solar panels. She is very happy with the solar panels because they are behind the house and not visible that way and because she will get free electricity from this as the panels are her cousin's. She did say she is not in favour of large solar panel fields because they 'drain the landscape'.

8.5 Interview local resident large solar farm Svinninge

These notes were made after the interview.

Date: 9 May 2023

The individual we interviewed operates a catering company located adjacent to the solar farm just outside Svinninge, where he also resides. In the vicinity, there are also wind turbines. We inquired about his opinion regarding the solar farm, to which he expressed dissatisfaction due to the significant devaluation of his property by 75 percent following the establishment of the photovoltaic field. Apparently, the government did not heed the concerns of the residents and proceeded with the approval of the solar farm. Furthermore, he experiences considerable noise disturbance from the facility. Efforts are being made to address this issue, including frequent meetings with the solar farm's owner, Europ. Several modifications have already been implemented, such as the planting of trees to create a barrier between the houses and the solar panels. Additionally, a new insulation system has been installed.

8.6 Woman who lives near solar farm

These notes were made after the interview.

Date: 9 May 2023

The woman has no problem with the solar farm as she cannot see the solar panels from her home. If the solar panels were in view, she would complain about them. Consequently, she knows many people who are unhappy with the panels because, in her opinion, they are very ugly.

8.7 Interview teacher school Fårevejle with solar panels

These notes were made after the interview.

Date: 9 May 2023

We interviewed a teacher from Odsherreds Efterskole, a school that possesses a small plot of solar panels for internal use. These panels have enabled the school to become almost entirely self-sufficient in terms of electricity. The school is actively engaged in promoting renewable energy and was among the pioneers in the area to adopt solar panels. The teacher himself is a strong advocate of solar panels, although he understands the perspective of those who oppose them. Recently, people have become more supportive of solar panels due to the conflict in Ukraine, as they offer potential savings on energy bills.

According to the teacher, people encounter fewer issues with solar panels compared to wind turbines. The teacher, who resides adjacent to the solar panels, does not experience any noise disturbances from them. However, he acknowledges that individuals tend to have more concerns about wind turbines. Their towering height, noise emissions, and shadow flickering contribute to a greater opposition. In contrast, solar panels operate silently and have a lower visual impact on the landscape. Additionally, the municipality is actively transitioning to a new district heating system based on waste incineration, indicating a genuine interest in shifting towards greener energy sources.

8.8 Klaus Hansen – Nykøbing Sjælland Varmeværk

These notes were partly made during the guided tour and completed afterwards.

Date: 10 May 2023

The heating plant has two installations: a gas-powered heat pump in the centre of Nykøbing, and an installation with heat-generating solar panels on the edge of the built-up zone, in the southwest of the parish. The heat pump has been operating since 1960 but is outdated. There is a transition to replace the installation to one with solar panels, allowing the gas-pump to phase out. The solar panels were installed in 2014 and expanded in 2019. The produced heat will be transported through a district heating system, which thery are currently developing in Nykøbing. Energy in Denmark is divided into two regions: Jutland and Sealand. Jutland is at a disadvantage because it is poorly connected to the energy network in Europe, while Sealand serves as a kind of electricity highway from Norway and Sweden to Germany and the rest of Europe. This might be the reason why people in Sealand are reluctant to adopt solar panels, as the excess energy generated will be put on the electricity network and distributed across Europe.

Around the year 2000, many solar farms were established due to substantial government subsidies. The installation in Nykøbing got around 65 million Danish kroner and covers an area of 14 ha. The project acquired 14 ha of land through a public auction following the death of a single man, the owner of the ground. The location of the land was ideal for the installation of the solar panels. However, there have been a few complaints from owners of summer houses regarding the panels.

Sheep are grazing between the panels to keep the grass short and to prevent high grass from shadowing the panels. It costs the company no money and the shepherd has free access to grassland for his sheep to graze, it is a win-win situation for both. A very small part of the panels is shaded by the tower, this is a mistake.

The heat farm currently produces 7 MW while also consuming 2 MW of electricity. These 2 MW are powered 90% by solar and wind energy and are needed to run the 5,5 bar water pumps to be able to circulate the liquid that is stored inside the panels, to “harvest” and store this heat. The installation consists of 200 km of pipeline and holds 6 million litres of water. Nitrogen is taken from the atmosphere to prevent oxygen from reaching the water, as this will cause the pipes to rust. For this reason, the water is also kept basic. The farm is in favor of installing more solar panels to generate this 2 MW of electricity and becoming merely independent, but space is a constraint. They are considering purchasing batteries in the future to store excess energy. There is an ongoing expansion project of 4000 m² that faced some difficulties in obtaining approval. There were some comments regarding the appearance of the solar panels and the current building housing the heat pump, although it weren’t complaints. However, this is needed to produce sustainable heat and to buffer the moving of many people to Nykøbing. To minimise nuisance to local residents, trees and wildflowers are placed around the solar farm.

Once the new part of the solar farm is installed, 90% of the heat needed in Nykøbing will come from the solar plant, which is expected to be completed by the end of 2023. The remaining 10% will be provided

by a combination of gas and electricity pumps. This electricity heat pump is important to ensure energy supply in a period when there is little sunlight reaching the earth and will take over in that case. However, there is already a special water tank that make it possible to produce heat earlier than standard tanks.

8.9 Tyge Kjær – RUC

These notes were made during the interview.

Date: 10 May 2023

Notes were not kept separately as insights obtained from the interview were directly incorporated in our results.

FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

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UNIVERSITEIT GENT

1 INTRODUCTION

As viticulture in Southern Europe becomes increasingly complicated due to climate change, new opportunities arise in more northern regions that are becoming more suitable for winemaking (Fraga et al., 2021; Jones et al., 2022). These regions, which were once considered to be beyond the limits of viticulture, are now witnessing a rise in the number of vineyards that are producing wine at a higher capacity each year (Olsen et al., 2011; Toldam-Andersen & Becker, 2015). Denmark is a prime example of this growing Northern winemaking industry. Since 2000, the country has been recognized by the European Union as a wine-producing nation, which has made it legally permitted to commercially sell wine and has led to the establishment of the first vineyards in the country.

This study aims to gain insight into the present state of viticulture in Denmark, specifically in the region of Odsherred and its surroundings. We seek to explore the reasoning behind the location of vineyards and the various factors that played a role in the decision-making process. Potential sites for future vineyards are also predicted using a random forest algorithm.

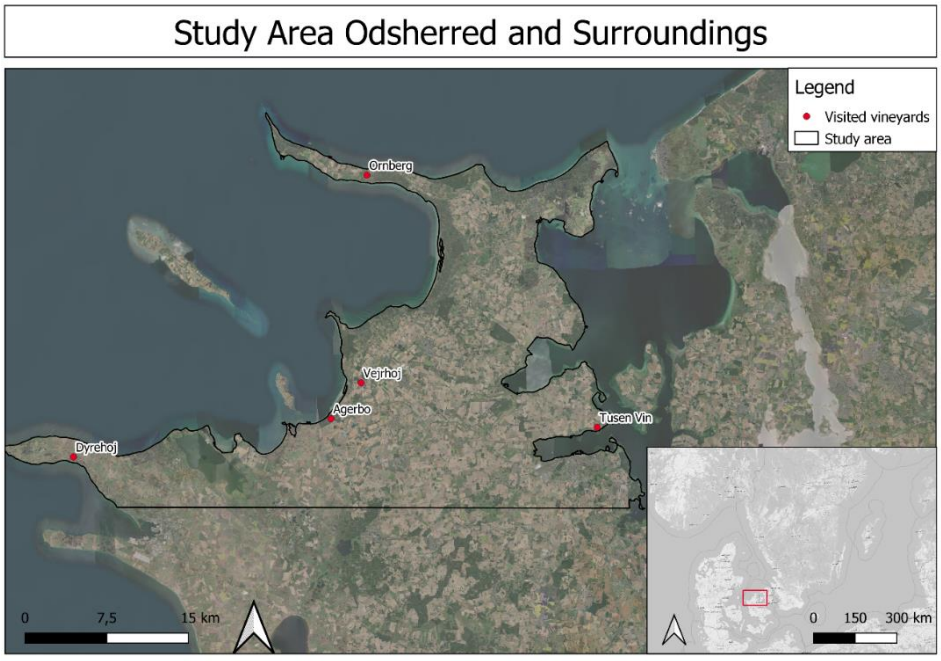
As part of this research, a literature review and structured interviews with five viticulture farmers were conducted on-site. The farmers' expertise helped in refining the prediction model and parameters utilized in the study. Additionally, these interviews provided greater insight into the motivations behind practicing viticulture and the significance of local climate and geography. Furthermore, the farmers' perspectives on the future of viticulture in the context of climate change were also included in the analysis. While the method developed in this study could have practical applications in other areas, it's worth noting that the key factors of importance may vary.

2 THEORETICAL FRAMEWORK

2.1 Study area

Odsherred is a municipality located in the north-western part of Sjælland, Denmark, covering an area of 355 km². The region is renowned for its geopark status, which UNESCO granted it in 2014, making it the only geopark in Denmark. This designation signifies that the area has a geological heritage of global importance (Werther, 2022). The landscape is primarily composed of glacial structures that emerged around 17,000 years ago during the latter part of the Weichselian period. Subsequently, postglacial and coastal processes have shaped the terrain of Odsherred, which is still undergoing continuous transformation today (UNESCO, n.d.). Our study area contains the whole of Odsherred and the northern parts of Kalundborg and Holbeek. We included these parts because they contained additional vineyards, which were important training data for our model.

The climate is mild and generally warm and temperate. Precipitation is significant in this area, even during the driest periods. The yearly average precipitation is 790 mm. The summer months are the wettest, and the winter is the driest. Average annual temperatures are around 9.3°C (Climate-Data.org, 2023). The proximity to the coastline also results in Sjælland being a windy area.



Map 1: *Study area, Odsherred and surroundings in QGIS*.

2.2 Literature

2.2.1 The Role of Climate and Climate Change

Grapevines have a prolonged cultivation history in Europe since the second millennium B.C. (Droulia & Charalampopoulos, 2022). Today, grapevines are primarily considered to be one of the most important crops in all of Europe, underscoring their fundamental socio-economic role. Europe leads the world in terms of wine production and vineyard area and is home to some of the most influential and prestigious wine regions and wines (Fraga et al., 2012). These are especially predominant in Italy, France, and Spain, which consist of the world's top wine-producing countries. These countries have a long winemaking tradition and have a well-adapted climate for growing grapes.

Climatic conditions are an important factor in the growth of vines. The microclimate of vines is influenced by the mesoclimate of the vineyard and the macroclimate of the wine area. They decide the terroir or immutable characteristics of an area and are crucial in the overall possibility of making wine. The climate essentially controls the canopy microclimate, the physiology, and development of the vine, and the quality and quantity of the product, therefore playing a dynamic role in a specific terroir. According to Droulia and Charalampopoulos (2022), many individual atmospheric parameters such as solar radiation, wind, and humidity affect vine growth and productivity. Certain thermal and hydrological conditions appear to be the most important.

Due to climate change, vines are facing increasingly warm and dry growing conditions (Droulia & Charalampopoulos, 2022). However, the vine is a plant of Mediterranean origin, which is well adapted to these conditions. Yet, higher temperatures shift phenology and the ripening period to a time in the season which is less favourable for the production of quality wine and increasingly dry conditions lead to yield reduction (Schernewski, 2011; Jones et al., 2022). These warm and dry conditions imply that the taste of grapes will alter. Among other things, the sugar content will be higher, maturity will differ, and this results in a wine that tastes different. Not only will the temperature change, but the precipitation will be impacted. Climate change projections provide evidence for significant changes in both the growing season temperature and precipitation in the coming decades (Fraga et al., 2012). Not adapting accordingly could end up in a loss of big yields. Although grapevines have several survival

strategies, mounting evidence for significant climate change in the upcoming decades urges adaptation and mitigation measures to be taken by the winemaking sector (Fraga et al., 2012).

However, climate change is creating opportunities in more northern European regions that have now become, more, feasible locations for practising viticulture. One of the often-mentioned consequences of recent global warming is prolonged growing seasons and fewer days with sub-zero degrees in higher latitudes (Menzel et al., 2001; Bertin, 2008). Recently, Jones and Schultz (2022) examined potential latitudinal shifts in winemaking due to climate change. They concluded that many new regions are emerging at higher latitudes while existing cool climate regions are becoming more suitable as the climate changes. This development and the intensive breeding of new resistant varieties means that the limit for grape growing is moving northwards (Tate, 2001). Thereby, some stress factors jeopardizing winemaking in southern Scandinavia have been reduced, and serious wine producers can now be found as far north as Norway at roughly 60°N (Olsen et al., 2011).

There are a growing number of locations in Denmark where cold-weather grapes can thrive. In each of these zones a microclimate exists and the vineyards receive an average of 100 extra days of sunlight each year (Hartman, 2020: Independent, 2021). The warmer average temperatures combined with technological advances in horticulture and these microclimates, have made Danish winemaking possible.

Though making wine in Northern Europe is possible due to climate change, viticulture is restricted by growing seasons that are shorter than those in Central or Southern Europe. The higher latitudes of these regions produce longer day lengths and, therefore, a high photosynthetic adaptive capacity that is an important asset and limiting factor. However, despite summer warmth that is increasing the suitability to grow vines, variability in low winter temperatures at these latitudes will remain a risk and yearly weather variability will have a big impact on the yields (Jones & Schultz, 2016; Karvonen, 2016). A cold summer could be detrimental for northern vineyards, and the role of extremes in the scope of climate change is not to be underestimated.

2.2.2 Current State of wine culture

A prime example of the rising winemaking possibilities in Northern Europe is Denmark. Currently, there are more than 100 venerable producers across Denmark, with the bulk concentrated along the warmer coastlines of Sjælland, Funen, and Jutland (Independent, 2021). This recent surge of winemaking in Denmark is a relatively new cultural phenomenon. Traditionally, Northern Europe has not been recognized for its ability to produce wine due to its suboptimal climate conditions (Bentzen & Smith, 2009). Despite this, Northern winemaking is not a unique occurrence; in the Bronze Age, a period of warmer temperatures existed, potentially allowing for winemaking, evidenced by the discovery of grape seeds from that era (Persson, 2017). In addition, temperatures during the Medieval Warm Period were 1 °C warmer than today, and vines were grown in areas north of today's traditional wine regions. According to Olsen et al. (2011), the cultivation of vines for wine production in Scandinavia dates back to some medieval monasteries. Due to the harsh and unstable climate, the wines produced were of poor quality. In small, well-shaded gardens, vines were often planted on south-facing walls. Despite these precautions, successful ripening of the grapes was highly uncertain, especially during the so-called Little Ice Age (1500-1800 AD) when the growing season was short. Furthermore, the few grape-growing activities on Danish soil ended with the expulsion of Catholic monks from Protestant Scandinavia in the 16th century (Olsen et al., 2011). These historical periods show the role of climate change as a key limiting factor in viticultural possibilities.

The recent Danish viticulture can be characterized by numerous hobby farmers who started growing wine in the early 1990s, leading to the founding of the Danish Vineyard Association (DVA) in 1993 (Toldam-Andersen & Becker, 2015). Due to pressure from the Danish government, the EU Wine Regulations were revised in the year 2000 to make commercial production of wine legal in Denmark. As a result, Danish commercial winemakers were allowed to produce "Vin de Table" with no geographical origin on the label. At the same time, Danish regulations were also being implemented. Thus, a new wine-producing country was born. However, Danish producers do not enjoy the same EU subsidy regime as older wine-producing countries.

An industry has been emerging since then with, according to the DVA, about 98 commercial producers in 2015 and about 1300 members as hobby growers. The 20 largest producers have about 60% of the total area (Toldam-Andersen & Becker, 2015). Furthermore, due to the rapid development of production, Denmark asked for permission to produce 'vin de table' with a geographical indication on the label, which means that the year of harvest and grape variety could be announced on the label. The EU Commission accepted this request in 2007 and hereafter Danish wines can carry the label 'regional wine' from Jutland, Funen, Zealand (where Odsherred is situated) or Bornholm (Bentzen & Smith, 2009).

2.2.3 Grape varieties

In line with other wine-producing countries, there are strict regulations for commercial wine production in Denmark, as listed by The Danish Agricultural Ministry (2008). Commercial wine producers are only allowed to use grape varieties which have been accepted (Bentzen & Smith, 2009). In Denmark, 48 European and Baltic grapevine varieties have been approved for growing (Karvonen, 2016). The grown varieties are typically limited to hybrids or very early ripening cultivars (Jones & Schultz, 2016). These grapes are adapted to the northern climate and must be resilient to cold temperatures and harsh conditions. The research by Jones & Shultz (2016) tells us that there are risks in growing grapes in these areas. The short growing season is challenging, which is typically shorter than seven months. The inland cooler climates have an even greater risk of low temperatures impacting the yield, with spring or fall frost being an active threat. On the other hand, the more northern areas close to the coastline have more precipitation. This needs to be avoided during the growing season because it increases the risk of diseases in the stocks (Jones & Schultz, 2016).

Modern technology made it possible to make new grape varieties that are more resilient to the cold conditions of the north. These are hybrid cultivars specifically made for the northern climate and have a high degree of resistance to viticultural important fungal diseases. They considerably reduce plant protection measures or even make them unnecessary and can contribute to more environmentally friendly viticulture. New fungi-resistant grapevine varieties for example Solaris and Helios are cultivated in northern climates and can be used for commercial wine production (Schernewski,

2011). Of these two, Solaris, is the most dominant one in Odsherred. The grape was created in 1975 at the grape breeding institute in Freiburg, Germany. Basler (2003) states it is a very resistant, hardy variety, suitable for northern marginal winemaking climate. It is well suitable to replace traditional grape varieties like Müller-Thurgau. In Denmark, a high number of cool climate cultivars are being tested with the blue cultivar 'Rondo' as the dominant one. Among the green cultivars, 'Solaris' is the most important. Red wine production has initially been very dominating, but a shift with more focus on white wine, rosé and sparkling wine has been seen in the last years (Toldam-Andersen & Becker, 2015).

Something that these grapes have in common is that they are new fast-maturing vine varieties that can take advantage of the long periods of sunlight and strong solar radiation of the summer months (Karvonen, 2016). Research by Jones & Shultz (2016) shows that within established or emerging cool climate-producing regions worldwide, the varieties being grown are similar, but also show some variation due to regional interests or climate extremes.

2.2.4 Economic potential

Environmental factors play an important role in determining grape quality and yield. Additionally, depending on these circumstances (and other elements like market access) profitability for growers in some regions can be driven by optimizing yields and reducing production costs, while in other regions it can be driven more by producing higher-quality grapes for higher-priced wines (van Leeuwen et al, 2019). The Danish wine industry has so far been favoured by a positive interest from media and consumers with wines being sold at relatively high prices (mostly 15-30 Euro). On this basis, Danish wine can be regarded as a low-produced, higher-priced niche wine. According to Schernewski (2011), northern viticulture is more labour-intensive due to the varieties bearing more risk and having a lower sugar content in the grape than traditional grapes. This means that bottles will be more expensive and there will be fewer volumes of bottles. On the other hand, a significant share of the commercial area is still very young and prices are expected to decrease when fully established (Toldam-Andersen & Becker, 2015). On top of that, Danish wine is regarded as a niche product, which influences its high price. In a region where wine production is not common, newly

established wineries have the benefit of being regarded as an attraction and their wine can be sold as a niche product. Visitors, tourists, collectors, and the increasing wine-interested audience are willing to pay a higher price per bottle than for a comparative product from a traditional German wine region (Schernewski, 2011).

According to Berni et al. (2005), the main features characterising wine demand in Denmark can be described as a notable and continued growth in consumption from 1980 onwards. Followed by an increasing trend in the consumption of higher quality wines and lastly a strong orientation towards certain typical wines which are highly valued especially where they have a specific identity distinguishing them from international varieties (Berni et al., 2005). National-grown wines fit this trend and are popular for their niche outlook. Next to wine-producing countries like Italy, France and Greece, Denmark belongs to the very top of wine-consuming countries resulting in a high demand for wine. The nationwide production of wine could play a significant role in national consumption and see a new shift in Danish wine demand. However, Danish wine still is hardly more than a local attraction with a niche focus. The same is true for several recently established wineries in northern Germany (Schernewski, 2011)

2.2.5 Environmental Advantages

The Danish wine industry is still relatively small compared to other countries, but it is growing rapidly, and many people see it as an opportunity for economic growth and tourism. In addition to economic benefits, there are also environmental benefits to growing grapes and producing wine in Denmark. Compared to many other crops, grapevines require less water and are generally less susceptible to pests and diseases, which means that they can be grown with fewer pesticides and herbicides. Furthermore, the cultivation of grapes can help to reduce soil erosion and improve soil health, which can have a positive impact on the local ecosystem.

3 METHOD

3.1 Research Questions

The goal of this study, as stated in the introduction, is to get a better understanding of the current situation regarding viticulture in Odsherred. Our study wants to find the reasoning behind the location of vineyards in our study area and which factors that influence this. On top of that, we want to predict possible future locations of vineyards and the impact of climate change. To reach this goal two research questions, each having a sub-question were formulated.

Research questions:

Q1: Why are vineyards located where they are?

SQ1: What are the factors that influence this?

Q2: What are possible future locations of vineyards?

SQ2: How does climate change play a role in this?

To answer these questions as comprehensively and completely as possible, two different methods are used. We adopt a qualitative approach where on-site interviews with five farmers are conducted combined with an intensive cartographic survey to construct a prediction map.

3.2 In-depth interviews

To answer the question of why vineyards are located where they are (RQ1) and what are factors that influence this (SQ1), in-depth, interviews were conducted with Five vineyard owners in Odsherred and surroundings. Thirteen potential interviewees were contacted of which five were willing to participate in our research. They are geographically spread out and are ranging from small to largescale production. The interviews were structured with open questions. The interview had three main parts: a) understanding the reasons for practicing viticulture, b) gathering information on implemented techniques and c) future outlook on viticulture. The important physical parameters in viticulture, as stated by the farmers, are used to redefine the variables used in the Random Forest Algorithm. On top of that part c of the interviews helped in understanding their experience and outlook on climate change (SQ2).

3.3 Prediction map

In order to calculate possible future locations of vineyards, a prediction map is made using the Random Forest algorithm. This can be integrated into the Knowledge Discovery in Databases (KDD) process, which involves a series of steps for discovering valuable patterns and knowledge from data (Sharma, 2022). It is a programmed and analytical approach to model data from a database to extract useful and applicable 'knowledge'. Data mining forms the backbone of KDD. It utilizes several algorithms that are self-learning in nature to deduce useful patterns from the processed data (Sharma, 2022).

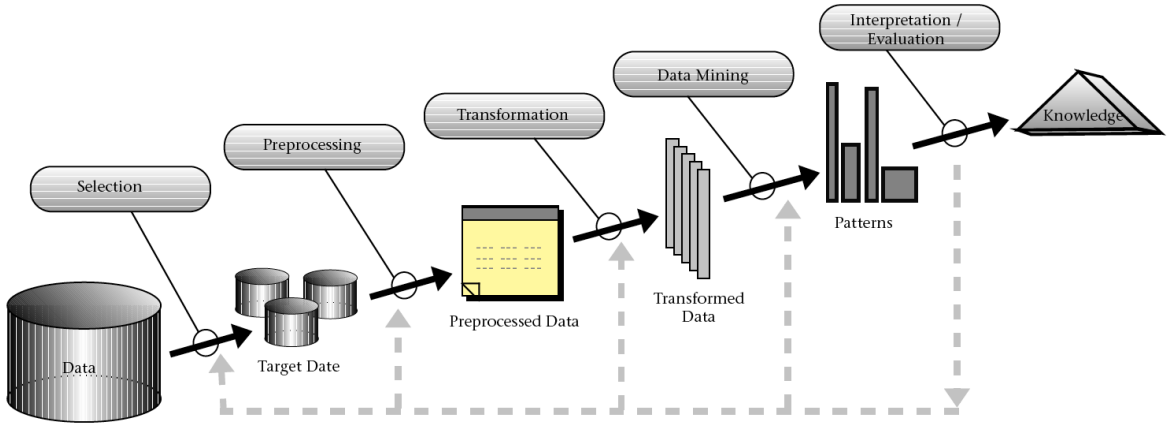


Figure 1*: The Knowledge Discovery in Databases (KDD) process.*

The algorithm is first explained after which the used variables are defined. These are based on the literature study and certain assumptions, which are critically analysed in the discussion. Lastly, the followed workflow in Jupiter Notebook is described.

3.3.1 Random Forest Algorithm

The Random Forest algorithm is an ensemble learning method in the machine learning world. It is a combination of multiple decision trees that work together to make predictions. The algorithm uses a bootstrap sampling technique and aggregation to generate more accurate and robust predictions (Chaudhary, n.d.). When training a Random Forest algorithm, multiple decision trees are created, with each tree trained on a random subset of the training data. At each split in a tree, a subset of the available

features is chosen randomly. This creates diversity among the trees in the ensemble. For a prediction by the Random Forest algorithm, the new data point is passed through each tree in the ensemble, and each tree makes an individual prediction. For classification problems, the prediction that occurs most often in the trees is taken (Chaudhary, n.d.).

The Random Forest algorithm has several advantages. It can handle complex relationships between features, such as interactions and non-linear relationships. It is robust against overfitting because it uses aggregation, resulting in an average or consensus of the predictions of multiple trees. In addition, it handles missing data and outliers well. The Random Forest algorithm is widely used in various fields, including image classification, healthcare forecasting, financial forecasting and more (Chaudhary, n.d.). It is a popular and widely used algorithm because of its flexibility, reliability, and ability to make good predictions in different scenarios.

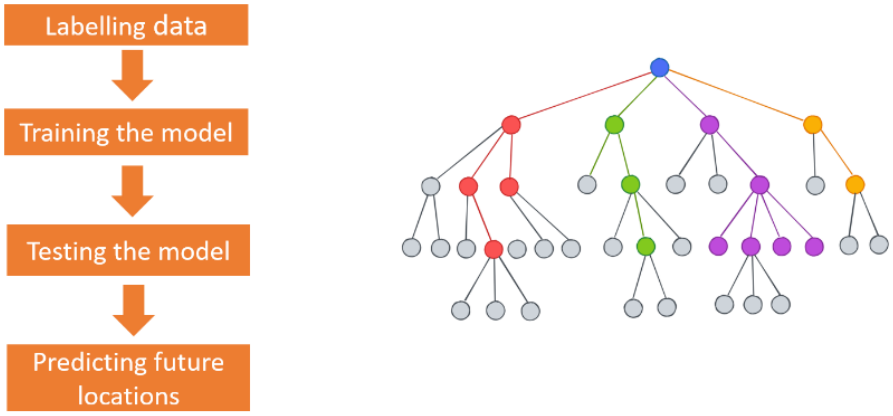


Figure 2*: Four-step process of the Random Forest algorithm.*

Because of the reasons listed above, The Random Forest Algorithm is chosen for this research and applied in a four-step process (see Figure 2). The first step in our process involves labelling data because the Random Forest algorithm is a supervised method. Here we label the data to know where there are already existing vineyards. For this, we use Google Maps to search for vineyard locations and mapped them on the orthophoto layer in QGIS. This less accurate method was chosen because no governmental data of existing vineyards was at our disposal.

Next, we train the model using the Random Forest algorithm, which is a classification method based on decision trees. In this case, our goal is to classify areas as either potential future vineyards or areas not suitable for vineyards (binary classification). We base our decisions on specific variables we have chosen, such as dominant soil type and sun exposure. Ultimately, the model provides a binary outcome: yes (vineyard) or no (no vineyard).

Once the model is trained, we move on to the testing phase. We assess the accuracy of the model and compare the predicted outcomes with the actual values by evaluating the different goodness-of-fit values, such as accuracy, precision, and recall. This step helps us evaluate the model's performance and identify any differences from the reality of the existing vineyards.

If we are satisfied with the accuracy and precision of the model, we proceed to the next stage: predicting future vineyard locations. Here, we apply the trained model to the entire study area to predict whether a location is suitable for viticulture or not. However, it's important to note that this is an iterative process. We continuously revisit previous steps, adjusting parameters and refining the model until we have a robust and reliable outcome.

3.3.2 Variables

We chose for six subdivisions to make the prediction map via Random Forest Algorithm. The subdivisions are split into 11 variables and listed in table 1. These variables are used in the Random Forest algorithm and based on certain assumptions. Our aim is to predict suitable cells in our study area that are sufficient for grape growing by digitizing existing vineyards.

The first subdivision is wind exposure which is calculated by SAGA, 'terrain analyses. This is called the wind exposure index and is calculated by combining the slope and aspect from the digital terrain model (DTM). We opted for this technique because it gives less noise than the two variables used by themselves. On top of that wind exposure has more relevance for the research as it is crucial in drying grapes for preventing frost. The result of the wind exposure algorithm is a raster where if the value

is greater than one, the location will catch the wind. When the value is lower than one, the location is sheltered from the wind. The exact minimum value is 0,87 and the maximum is 1,23. We divided the original values by two, so the values vary from zero to one. The final product has a resolution of 10×10m.

The second subdivision, sun, is split into two variables: sun hours and total insolation. The variables were calculated by SAGA, 'Potential incoming solar radiation'. The input is the days when the grapes grow and the insolation model. The map has a resolution of 10×10m. The Total insolation is the radiation incoming by the sun, expressed in kW/h. We opted for these variables because it takes the aspect into account and a minimal amount of sunlight is crucial for viticulture (Karvonen, 2016). If we opted for slope and aspect, we would have covariance between the variables. The resulting map has a resolution of 10×10m.

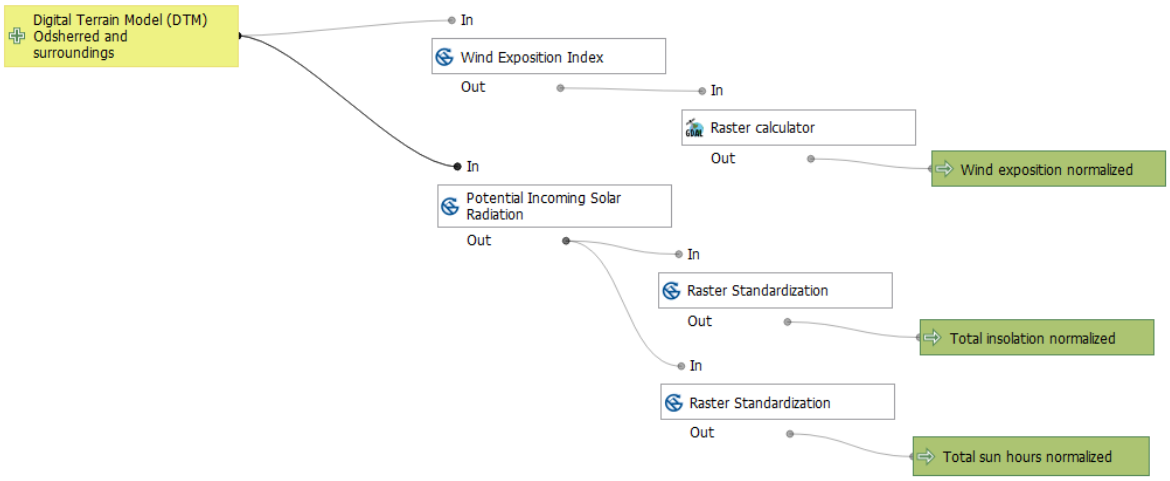


Figure 3*: Cartographic model of wind exposition, total insolation, and total sun hours.*

The next subdivision is the distance to the sea. This parameter is chosen because the sea has a buffering effect against temperature changes and protects the surrounding areas against the development of frost. According to a local expert, the sea north of Odsherred is colder, resulting from the Baltic Nordic water flow. The western and eastern located bodies of water are more enclosed by land and less affected by this flow and thus are hotter. The areas mean that it would be better for viticulture. We combined this into one map with the distance to each coastline, by using proximity analysis and Euclidean distance. The closer to one of the coastlines, the higher the

value for that given variable. Values range from 0 to 1. The map has a resolution of 10×10m.

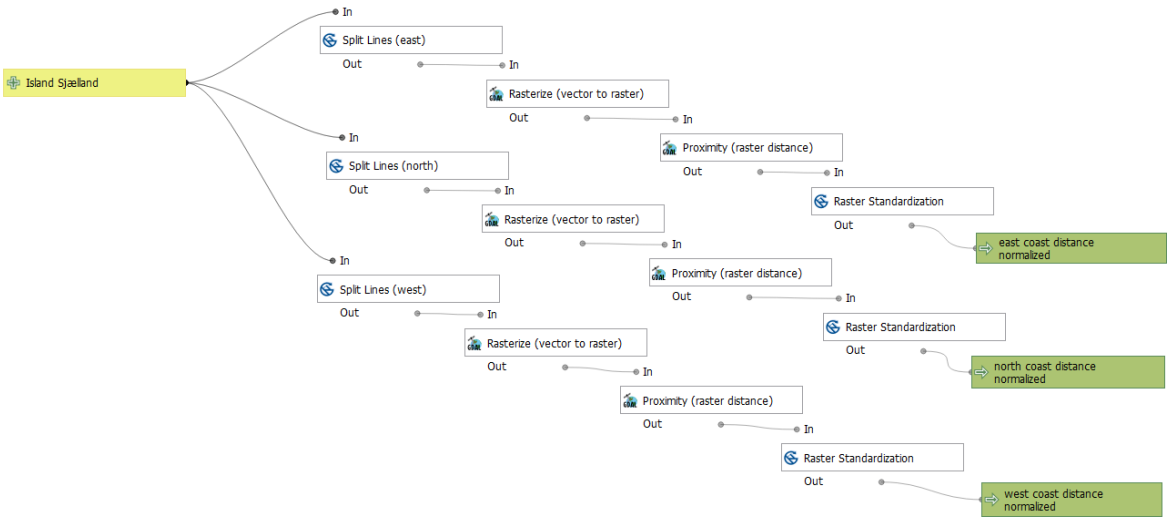


Figure 4: *Cartographic model of east coast distance, west coast distance, and north coast distance.*

The next subdivision is land use and was originally a categorical map. This subdivision was chosen because not every land use is adequate for the development of a vineyard. We used a raster calculation on the original categorical map so that the cells with value '212000' represent the category: 'Agriculture, intensive, permanent crops'. These include vineyards and other agricultural types. The newly given values are given the value one and the rest of the cells have a value of zero (binary raster). The resolution of this map is 30×30m.

Figure 5: *Cartographic model of land use binary raster.*

The last subdivision is soil as it plays a significant role in the quality, taste, and possibility of making wine (Mackenzie & Christy, 2005; Belda et al, 2017). Although soil and climate are both major environmental components in wine production, the

latter is of greater importance for the development of yield components, vine phenology, and grape composition (van Leeuwen et al., 2019). The soil is divided into six variables: clay, silt, fine sand, coarse sand, humus, and carbon. For each variable the percentage is given in the top 30 cm of the soil, this is the A-horizon. The resolution of this map is 30×30m.

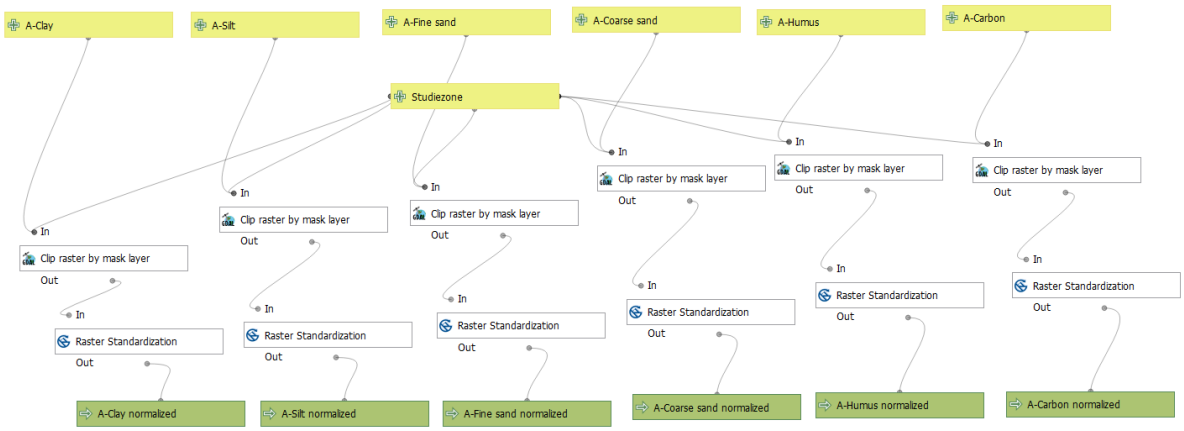


Figure 6*: Cartographic model of all the soil types.*

Table 1: *all subdivisions and variables used in the Random Forest algorithm with their resolution.*

General variables	Subdivision	Resolution (m)	Remarks
Wind	Wind exposure	10	>0.5: catches the wind <0.5: shelters from wind
Sun	Sun hours	10	
	Total insolation	10	In kW/h
Sea	Distance to the East Coast	10	Warmer
	Distance to the West Coast	10	Warmer
	Distance to the North Coast	10	Colder
Land use	Land use	30	1 = Agriculture, intensive, permanent crops (vineyards) 0 = the rest

Soil type (top 30 cm of soil)	Clay	30	
	Silt	30	
	Fine sand	30	
	Coarse sand	30	
	Humus	30	
	Carbon	30	

3.3.3 Point grid

This point layer contains all the attributes for each raster at that location and is exported to a CSV file. This CSV file will later be used as input to the algorithm's Python script. The point grid results in a 20×20 m format on which we sample the grid values. We chose this resolution to get a good resolution and keep the processing time as fast as possible. The result is a grid containing gridded vineyards as training data.

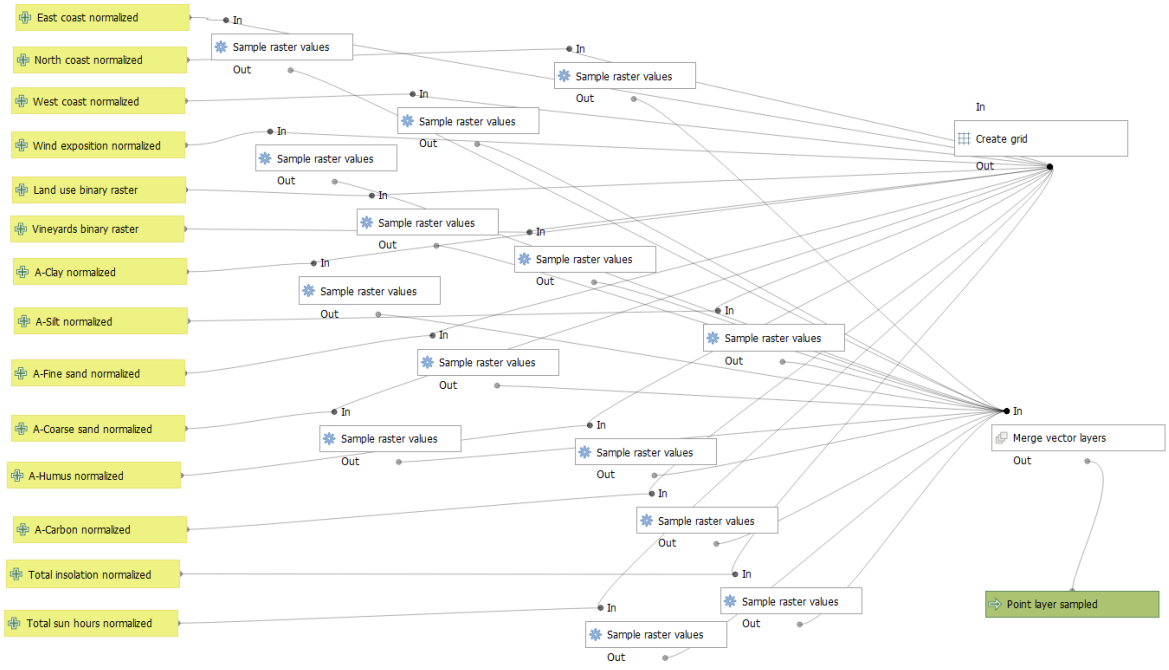


Figure 7: *Cartographic model of all variables for creating the point grid.*

3.3.4 Random Forest algorithm in Jupyter Notebook

We performed the algorithm in Jupyter Notebook. Hereunder, there is a step-by-step explanation of the workflow of the Random Forest algorithm. Validation is important to know if the results of the algorithm are good enough. Evaluations are executed to validate the model.

1) Importing the necessary libraries and modules to perform Random Forest classification and evaluate the performance of the model.

```
[ ] import pandas as pd
    import numpy as np
    from sklearn.model_selection import train_test_split
    from sklearn.ensemble import RandomForestClassifier
    from sklearn.metrics import accuracy_score, confusion_matrix, classification_report
```

2) Connecting with the google drive.

```
from google.colab import drive
drive.mount('/content/drive')
```

3) The CSV file is read using read_csv(). The dropna() function is used to remove all rows in the dataset that contain empty or missing values. The result is assigned to the variable data_clean.

```
[ ] path = "/content/drive/MyDrive/test11.csv"
    data = pd.read_csv(path, delimiter=",")

    print(len(data))
    data_clean = data.dropna()
    data_clean.head()
    print(len(data_clean))
```

```
1849792
1778376
```

4) X represents the set of features (independent variables) that will be used to make predictions, and y represents the target variable (dependent variable) that we want to predict. By separating the features and the target variable, you can use them to train a machine-learning model.

```
[ ]  # Extract features and target
     X = data_clean.drop(['fid','id', 'X', 'Y', 'wijn41','kulstof1','gsand1', 'humus1'], axis=1)
     y = data_clean['wijn41']
```

5) These essential steps involve training the model, making predictions, and evaluating its accuracy and performance using metrics like the confusion matrix and classification report.

```
[ ]  random_state = 42

     # Train the model
     rf = RandomForestClassifier(random_state=random_state, n_estimators=67, max_depth=17, min_samples_split=5, max_features=5, class_weight='balanced_subsample')
     accuracy_scores = []

     X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.3, random_state=42)

     rf.fit(X_train, y_train)

     y_pred = rf.predict(X_test)

     # Evaluate the model
     accuracy = accuracy_score(y_test, y_pred)
     conf_matrix = confusion_matrix(y_test, y_pred)
     report = classification_report(y_test, y_pred)
```

```
Accuracy: 0.9998219349856518
Confusion Matrix:
 [[533238     87]
 [     8    180]]
Classification Report:
              precision    recall  f1-score   support

         0.0       1.00      1.00      1.00    533325
         1.0       0.67      0.96      0.79       188

    accuracy                           1.00    533513
   macro avg       0.84      0.98      0.90    533513
weighted avg       1.00      1.00      1.00    533513
```

Figure 8: *classification report with the different evaluation values and the confusion matrix.*

During the evaluation of our trained model, we rely on various goodness-of-fit values as seen in the report (see figure 8) to assess its performance. To gain a more detailed understanding of the model's performance, we utilize a confusion matrix. This matrix provides a tabular representation that summarizes the model's classification performance based on correct and incorrect predictions. It consists of four key values:

True Negatives (TN)	False Positives (FP)
Samples that are correctly predicted as negative by the model. It indicates that the model accurately identifies the absence of a vineyard (n=533 238).	Samples that are incorrectly predicted as positive by the model. This means the model wrongly identifies the presence of a vineyard when it's not actually present (n=87).
False Negatives (FN)	**True Positives (TP)**
Samples that are incorrectly predicted as negative by the model. This means the model fails to identify the presence of a vineyard when it is present (n=8).	Samples that are correctly predicted as positive by the model. This means the model correctly identifies the presence of vineyard (n=180).

One important metric used for this purpose is accuracy, which measures the overall correctness of the model's predictions. It is calculated by dividing the number of correctly classified samples by the total number of samples. In this case, it’s the following:

(TN+TP) / (TN+TP+FP+FN) = 533 418 / 533 513 = 0,99982

As seen above, this indicates a high level of accuracy, which suggests an overfitting of the model, because it’s almost perfect. This is due to the significant number of non-vineyard samples (0 values) compared to vineyard samples (1 values). Predicting the absence of a vineyard (TN) is relatively easy, as reflected in the high count of true negatives (n=533 238) compared to the other values. This results in an almost perfect accuracy.

Because we have numerous 0 values, it is more informative to examine the evaluation metrics for the 1 values, such as precision, recall, and F1-score. These evaluation criteria provide a better assessment of the model's performance specifically for the positive class (presence of vineyards) and consider the data's imbalanced nature, as seen below:

- Precision: This is calculated with following formula: TP / (TP + FP). It measures the proportion of correctly predicted positive sample points (TP) out of all samples predicted as positive (TP + FP). In our case, there is a precision of 67%. This means

that 67% of the predicted vineyards are correctly classified as they match with the existing vineyards.

- Recall: This is somewhat linked to precision, but recall concentrates on the percentage FN rather than the FP and is expressed as TP / (TP + FN). The recall in our case is much higher (96%) than precision, because of the low number of FN (n=8).

- F1-score: This is a score that combines precision and recall: (2 * precision * recall) / (precision + recall). The F1-score for the trained model is 79%, which is reasonable as it falls between the values of precision and recall. The F1-score provides a balanced evaluation of the model's performance, where both the false positives and false negatives are considered.

6) These steps involve filtering the data, extracting the features for the filtered points, making predictions using the trained model, and adding the predictions to the filtered dataset.

```
# Filter the data for points with 0-vineyard value
zero_vineyard_data = data_clean[data_clean['wijn41'] == 0]
zero_vineyard_data.head()
print(len(zero_vineyard_data))

# Extract features for points with 0-vineyard value
zero_vineyard_X = zero_vineyard_data.drop(['fid','id', 'X', 'Y', 'wijn41','kulstof1','gsand1', 'humus1'], axis=1)
zero_vineyard_X.head()

# Make predictions for points with 0-vineyard value
zero_vineyard_predictions = rf.predict(zero_vineyard_X)

print(zero_vineyard_predictions)

# Add predictions to the filtered dataset
zero_vineyard_data['predicted_vineyard'] = zero_vineyard_predictions
```

7) These steps provide the counts of zeros and ones in the predictions, indicating the predicted distribution of vineyard values for the points that initially had a vineyard value of 0. The code output indicates that there are 1.777.406 points with a predicted vineyard value of 0 and 285 points with a predicted vineyard value of 1 among the points that initially had a vineyard value of 0.

   We want to have as many “ones” as possible in our new vineyards, but the more vineyards we have, the lower the precision of the “ones” in the classification report

(step 5) will be, which results in a less robust model. So, it's all about finding a balance between these two.

```
[ ]  num_zeros = zero_vineyard_predictions.size - np.count_nonzero(zero_vineyard_predictions)
     num_ones = np.count_nonzero(zero_vineyard_predictions)

     print("Number of zeros:", num_zeros)
     print("Number of ones:", num_ones)

     Number of zeros: 1777406
     Number of ones: 285
```

8) By running this code, the zero_vineyard_data DataFrame, along with the predictions, will be exported and saved as a CSV file at the specified location.

```
[ ]  # Export the DataFrame to a CSV file
     output_file = '/content/drive/MyDrive/output10.csv'
     zero_vineyard_data.to_csv(output_file, index=False)
```

4 RESULTS

4.1 Results of the interviews

There were five vineyard owners who were willing to participate in an interview. Four vineyard owners are already in the business for over a decade and the other one is a brand-new vineyard. They range from a farmer who saw an opportunity to pensioned people looking for a productive pastime. Different incentives brought them into the world of viticulture, some economical and others as a leisure. Two started as a hobby, but one got economically feasible. Also, they come from a big variety of backgrounds: farmers, PhD in fermentation, pensioned economist… Only one person was looking for a specific place that had an ideal location to grow grapes, the others organically rolled into viticulture. The professional vintners chose their location far more strategically than the hobbyist vintners. The hobbyists work on the fields they already have and don't really want to upscale their vineyards. The professionals expanded their field and picked the best parcels to grow the wine and not the parcels they had at hand.

The grape variety that every vineyard uses on their fields is Solaris. This is a resilient grape variety that did not exist 30 years ago. The development of hybrid grapes like

Solaris in combination with a warmer climate makes it possible to grow vines in Denmark. The contemporary vintners say that they are the second generation that can develop wine in Denmark, but the first who can make it economically feasible. They are grateful that the first generation pioneered and explored Danish winemaking. There is still some curiosity in making wine. Most current vintners have a few stocks of other varieties to test the grapes on how they do in the Danish environment and to be able to produce different wines.

Table 2: *information about the visited vineyards.*

Owner	Why?	When?	Output?	Grape?
Vineyard 1	As a hobby	2012	1,200 bottles	Solaris, Cabernet Cantor
Vineyard 2	As a hobby	2009	20,000 bottles	Solaris, Muscaris, Fukaris
Vineyard 3	Professional Already farmer	2008	35,000 (+ 15,000) bottles	Solaris, Souvignier Gris, Muscaris
Vineyard 4	Professional Already farmer	2007	15,000 bottles	Solaris, Sauvignon Blanc, Fenix
Vineyard 5	Professional Passion for fermentation	2020	(15,000 bottles) Prediction for next year	Solaris, Muscaris, Cabernet Cantor, Souvignier Gris

When asked about why their field can grow grapes in the Danish climate, they answered: “it is possible because of the microclimate”. This is also what the literature told us. The research of Hartman (2020) told us that the opportunity of viticulture in the more northern region would be possible, but that in the current locations a microclimate exists. Microclimate is hard to predict and explain, but the vintners told us that the proximity to the sea has a significant impact on climate. When frost occurs from May on, it is detrimental to the growth. The seas act like a buffer, frost only strikes the inland of Sjælland. Also, sun exposure, wind, and topography… play a role in the microclimate. One of the vintners told us that his college only one kilometre more land inward has frost, and he does not due to the proximity to the sea.

Another important physical factor is the wind. The amount of wind is also significant. Too little, and the stocks will be too wet and susceptible to diseases. Too much wind and the temperature will be too low for the stocks. Therefore, the vintners place bushes around the parcels. They must manage these bushes because they can’t grow too big, which would impact the wind circulation too much. Also, the sun is a big factor in

growing the grapes. The total sun exposure is an influential factor, that is another reason for not letting the bushes grow. Having a slope is also good, because the cold air will descend and not stay around the crops. Preferably, this slope is orientated to the south, so that there is more solar exposure.

Furthermore, the vintners told us what factors are less important than we first thought. The soil does not matter that much. We visited a vineyard that had a sand soil with clay and stones, sand with loam, and just sand. One of the vintners told us that you can even grow grapes on a clay soil, but that a lot of crop management would be needed. A second factor that is less essential than we first thought is the slope. We visited the vineyard on flat surfaces and more hilly terrain. The slope is useful so that there is more sun exposure and the cold air subside. It is also possible to grow on a flat surface, but the plants will be more susceptible to frost and diseases. But, this can be mitigated with proximity to the sea, spraying sulphur, and wind circulation.

A final factor that one of the vintners told us is the handcraft. This is something we can’t put in our model. To grow grapes in Denmark, a lot of crop management is necessary and this is a labour intensive process. Knobs must be removed so that the sugar content will be high enough to make wine. Knowing what stocks need to be managed and how much relies on the know-how of the vintner.

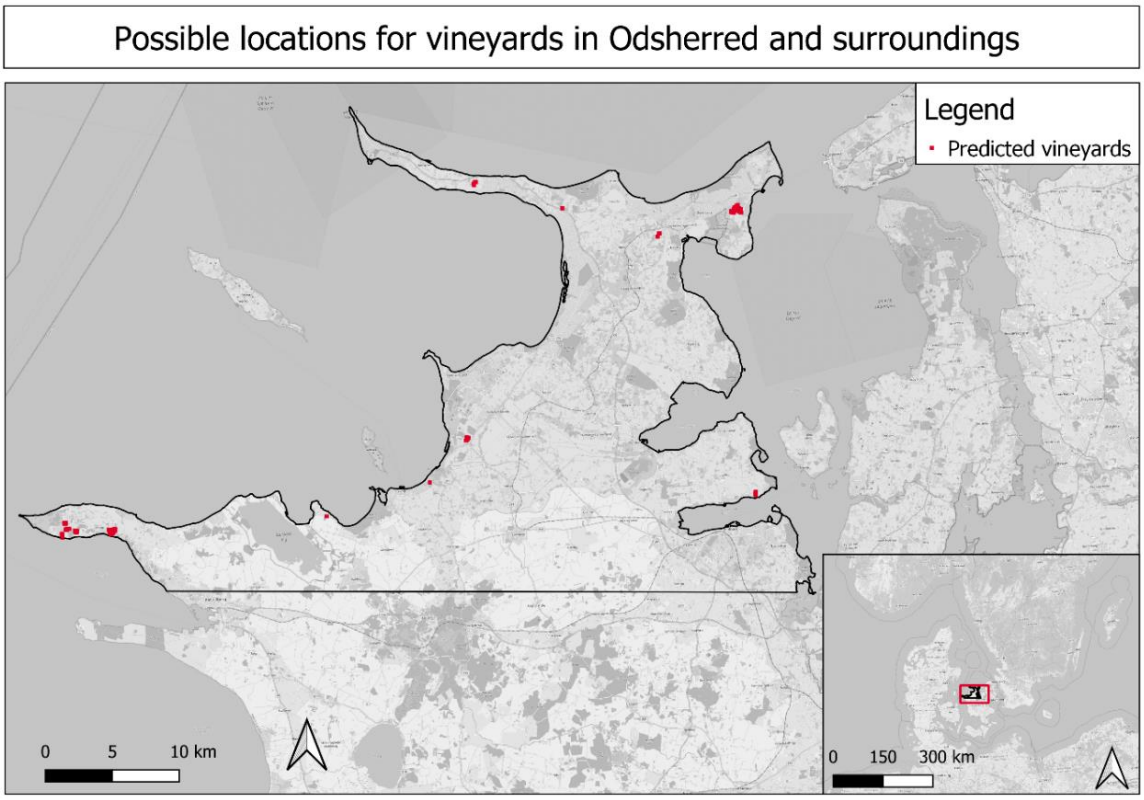
We asked about their future outlooks on viticulture in Denmark and further climate change. Hotter summers mean that the harvesting of the grapes will be earlier, but in the experience of the vintners we do not see a trend in earlier harvest over time as it depends on the year. They do find the temperature rise something positive for their grapes. On the other hand, the increase in extreme events like droughts, and extreme precipitation… are seen as something harmful to their stocks. Also, the introduction of more hybrid varieties, which will be more resilient to the Danish climate, will be welcomed with open arms. One of our interviewees said: “Adaption is key”, this will be necessary for all farmers with the changing climate.

In the literature study, we cover the advantages of the Danish wine culture. One of the advantages was that it is rapidly growing and focused on tourism. This is correct, with the different winemakers helping each other out. Because of the small scale and

interest from people, there is no competition between the vineyards. The vintners as it happens are helping each other out. The bigger vineyards lend out their bigger machinery to the smaller ones. They want to have more and bigger vineyards around them, so they can have more wine tourism around them. The largest share of the wine is sold in the shop of the vineyard, so wine tourism would be great for each of the vineyards.

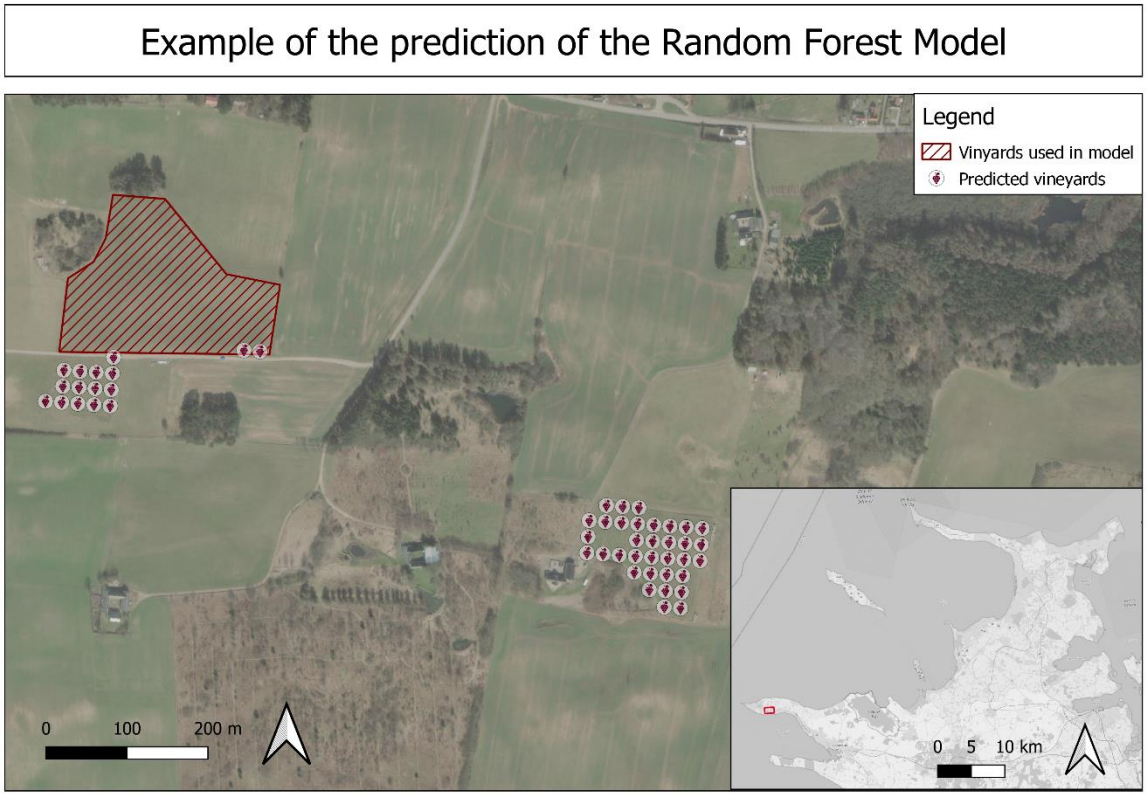
4.2 Results of the Random Forest algorithm

In map 2, you can see a map displaying all the predictions of potential vineyards from our Random Forest model. As you can clearly observe, all the vineyards are located close to the coast. This strategic placement near the coast serves the purpose of minimizing frost temperatures, which can be harmful to vineyards (Leolini et al., 2018; Nemani et al., 2001). Coastal areas often experience a milder climate compared to inland regions. The proximity to the ocean brings several benefits to vineyards. Firstly, the large body of water acts as a heat sink, absorbing and releasing heat slowly, which helps to moderate temperature fluctuations. This prevents freezing temperatures during the nights, reducing the risk of frost damage to the grapes (Leolini et al., 2018; Nemani et al., 2001). Additionally, coastal regions tend to have more maritime influences, such as fog and cool breezes. The cool breezes from the ocean help to maintain a more moderate and consistent temperature throughout the growing season, allowing the grapes to ripen gradually and develop complex flavours. For example, well-ventilated vineyards with good air circulation help reduce the risk of fungal diseases by allowing foliage and grape clusters to dry quickly after rainfall or dew formation (Vineyard owners, 2023).



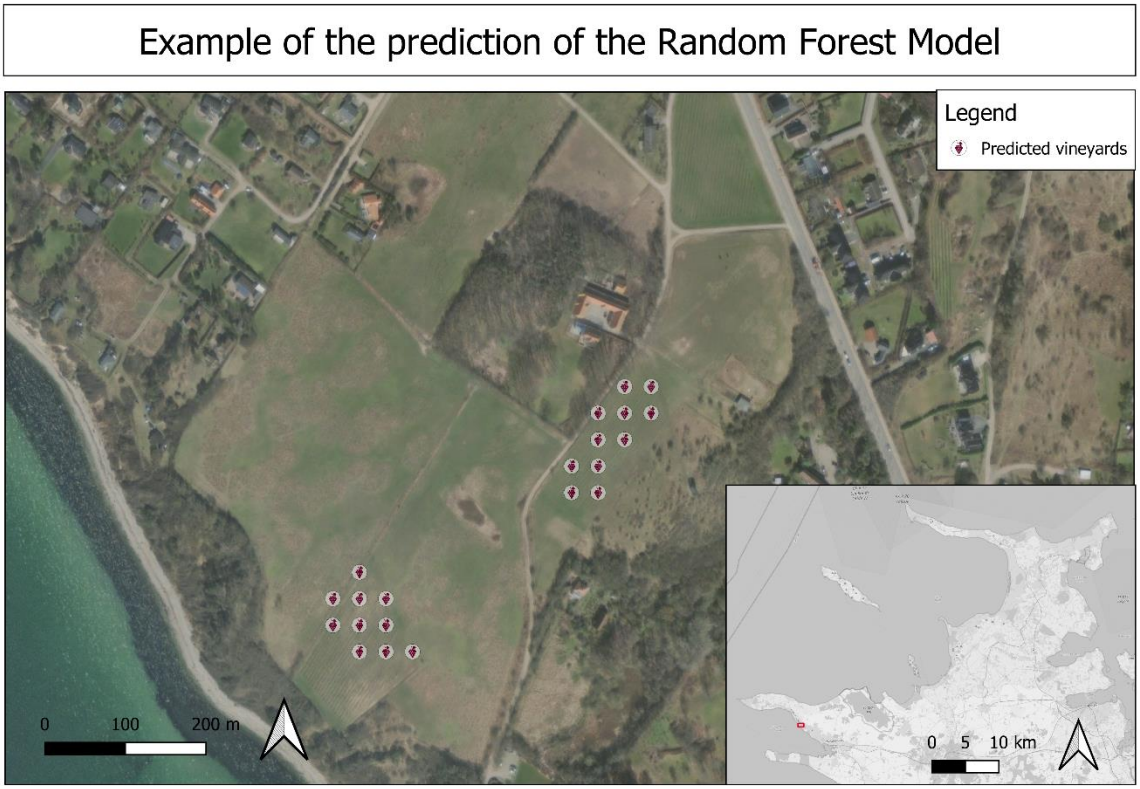
Map 2: *Possible locations of future vineyards*

On map 3, you can see an example of a prediction from the Random Forest algorithm. The Bordeaux coloured vineyard areas represent existing vineyards that were used in the model. The dots with the grape logo are predicted vineyards. When we looked at the predicted area on Google Maps, we discovered that this plot was an existing vineyard field that we had forgotten to include in our Random Forest model. From this, we can conclude that the model predicts realistic results.



Map 3: *Example of a possible location for a future vineyard*

On map 4, you can see a second example of the output from the Random Forest model. The model predicted another field where vineyards were already present from the Stub vineyard. Only a portion of the vineyard was included in the model. The predicted vineyard was located about 100 meters away and was overlooked. This is once again a good example that the model is realistic. On the map, you can clearly see that to the south of the vineyard, there is the sea. The model also predicted an area south of the existing vineyard, which is now a horse meadow when viewed through Google Street View.



Map 4: *Example 2 of a possible locations of a future vineyard*

Figure 9: *Screenshot of the predicted vineyard from the model.*

In Figure 10 and 11, you can see a third example of the random forest algorithm. The potential vineyard was mapped in an area that is now an orchard. This is because we chose the land use variable to predict vineyards where the land use class is "Agriculture, intensive, permanent crops." We will discuss this further in the discussion.

***Figure 10 and 11**: Ground validation as a screenshot of Google Maps and model output.*

5 DISCUSSION

During the processes of the research, we stubbled against points of contention. First, this study examined a limited number of firms, in a limited geographic area, with a limited number of variables. This results in a lot of biases. The following topic are the parts we could have done differently or potentially better.

5.1 Selected variables were good but not sufficient

We decided to run the Random Forest model without including the variables coarse sand, carbon, and humus as sub-variables of the soil because the interviews revealed that these variables are not important. From the interviews, it was found that the Solaris grape can thrive in different soil types. Therefore, we made the decision to exclude these variables. As for the land use variable, we chose to predict vineyards only in areas where the land use class is "Agriculture, intensive, permanent crops" because all existing vineyards were classified under this category. However, this approach proved to be too strict as it provided a lot of locations where for example orchards were present, while excluding other areas.

The interviews gave a better understanding of cultural, physical, and political influences and incentives, which aren't included in the Random Forest Algorithm. These factors could explain variations in the prediction model and reality. The hobbyist vintners that already lived on the fields will probably have less suited parcels than the professionals looking for an optimal parcel to grow grapes.

5.2 Output with continuous values

In our study, we used a Random Forest algorithm for the task of binary classification, distinguishing between samples labelled as 0 (no vineyard) and 1 (vineyard). However, it is worth noting that we could have also employed Random Forest with regression, which would have allowed us to predict continuous values ranging from 0 to 1, indicating the likelihood of a potential vineyard for each sample point. An interesting output could be one that can show all values above 0.8. These locations could potentially form clusters for good location.

5.3 Is microclimate even modellable?

Modelling microclimate can be challenging due to its highly localized and dynamic nature. Microclimates are influenced by various factors such as topography, vegetation, buildings, and nearby water bodies, which can create unique temperature and wind patterns in small-scale areas. While it is difficult to capture all the details of microclimates in a model, it is possible to incorporate some macro-level factors that indirectly influence microclimate and the terroir of the vineyard. For example, variables like elevation, proximity to water bodies, and land cover types can provide insights into the potential variations in microclimate.

5.4 Spatial resolution could be finer

Using finer-grained data for spatial resolution, such as terrain roughness on DSM (Digital Surface Model) at a 40 cm resolution and the thermal band (band 10) of Landsat to capture vegetation colour, can potentially provide more detailed information to improve the model. Here's how these variables can help:

Terrain Roughness on DSM: Terrain roughness refers to the variations in elevation within a specific area. By incorporating terrain roughness data at a higher resolution (40 cm), the model can capture more nuanced information about the local topography. This can be particularly useful for identifying microclimate variations related to slopes, valleys, or other terrain features that influence air circulation, temperature gradients, and local wind patterns.

Colour of Vegetation (Thermal Band): The thermal band of Landsat captures the thermal radiation emitted by objects on the Earth's surface. This includes vegetation, which exhibits different thermal properties based on its health, moisture content, and other factors. By considering the colour of vegetation as indicated by the thermal band, the model can potentially detect variations in vegetation health or moisture stress, which can have implications for microclimate patterns. This information can help map microclimates more accurately.

By incorporating these fine-grained variables into the model, the model's ability to capture microclimate variations is expected to improve. However, it is important to ensure that the data is reliable, properly processed, and appropriately scaled to match other variables in the model. Additionally, the availability and accessibility of high-resolution data should be taken into consideration when implementing these improvements.

5.5 Leave certain regions out of the analysis

Leaving certain regions, such as urban areas, out of the analysis can have both advantages and disadvantages when it comes to modelling.

Excluding certain regions can reduce the size of the dataset, which may result in faster training and inference times, especially if the excluded regions contain a large amount of irrelevant or noisy data. Urban areas often have unique characteristics and dynamics that can introduce additional complexity and noise to the model. By excluding them, you can potentially reduce the impact of these factors on the analysis and improve the model's performance. By focusing on specific regions that are more similar in terms of the target variable (e.g., vineyard suitability), you can create a more homogeneous dataset, which may lead to better model performance.

Urban areas can contain valuable information and patterns that are relevant to the analysis. By excluding them, you might miss out on important insights or potential correlations that could improve the accuracy and robustness of the model. Ultimately, the decision to exclude certain regions from the analysis should be based on a thorough understanding of the problem domain, the specific goals of the analysis, and

the availability of data. It is important to carefully evaluate the trade-offs and consider the potential impact on the model's performance and generalizability.

5.6 Selected training data

The Random Forest Algorithm needs training data. This was selected manually by looking at satellite images and looking them up on Google Maps. We included all the data that could be found. This had some advantages and drawbacks. The main advantage was that it worked as a validation. We did the test and gave us potential vineyards, and some of these parcels were already existing vineyards that we forgot to include in the training data. We then knew that the results could be trusted. The drawbacks are that it was labour-intensive and we forgot some training data. By forgetting some training data, we lost some information. Another drawback is that we selected some apple orchards as vineyards. This could lead to some misinterpretations.

An alternative was to use a detailed land use dataset. The different land uses have a specific code. Vineyards have the ‘530’ code. This would be a faster and less labour-intensive method to select the training data. The dataset would be stronger, and this is desirable for the Random Forest algorithm.

5.7 Wine is complex

We started off by thinking that you need sun, a good soil, and slope to the south to grow grapes. Now we know that to grow grapes you require a lot more than that. The more we delve into the literature or talked with local vintners, the more complex wine became. The microclimate is case specific and a lot of factors can influence it. To understand the question: “why is this vineyard located here?”, you need to understand the microclimate. But, as our research show, it is not a set of parameters that show these places, nor do we know if it is even possible to split it into parameters.

6 CONCLUSION

We see in the case of Odsherred that the location of most vineyards wasn't specifically chosen. In 4 of the 5 vineyards that we interview, different reasons were at play to settle at the location. Only later, they realized that their land was also suitable for viticulture.

There are two different factors that influence the location. First, the location is heavily influenced by physical factors such as the soil and climate of the area. As stated in the literature, climate is more important than soil (Van Leeuwen 2020). We found that this is indeed true, as vines are very resilient plants and, if taken care of properly, they can grow on very different soils. We found that, for Odsherred, distance to the sea was one of the most important factors, as this limits the development of frost, which is the biggest danger to viticulture. Second, the motivation for how they started and why they made wine also played a role in where they are located. There is a difference between those who started it out as a hobby during their retirement and those who had economic incentives. Niche theory is applicable to all types of vineyards as this industry is very small, though in the Danish wine industry you have mass producers and small players. We found that the microclimate plays the most important role. It is possible to grow and make wine in Denmark, but this is heavily dependent on the microclimate of the area. Only a limited number of locations are suitable for grape cultivation. These parcels could be occupied with vineyards if the interest and demand rise. In the future the economic perspective will grow as per the vineyard owners.

Possible future locations were correctly identified by our prediction model. There is room for more vineyards in Odsherred and the whole of Denmark. The curiosity for Danish wine is growing, and the future is perceived as looking bright. The owners we talked to only saw more vineyards as a positive evolution that could put Danish wine more on the map. The clustering of vineyards in proximity also creates other advantages, such as the sharing of facilities and wine tourism.
As stated above, microclimate is by far the most important factor. Modelling this microscale is very difficult, and the model we provide is based on data of a lower resolution. The computational power required to achieve a higher resolution is not

possible. In addition, microclimate depends on many factors that interact and influence each other. This makes both computation and modelling even more difficult. The use of thermal bands could help us find the optimal microclimates, this was covered in the discussion.

Furthermore, climate change was regarded as a generally positive evolution by the vineyard owners. This rise in temperature made it possible for wine to grow in Denmark. A further increase in extreme weather patterns is considered to be a negative consequence. This makes winemaking more difficult, as one extreme event can destroy the entire yield or give the process a setback of a few weeks.
The combination of more resilient hybrid vines that didn't exist 30 years ago, in combination with a rise in temperatures makes viticulture in Denmark possible. The pioneer generation who experimented with these grape varieties cleared the way for a new generation for vintners that made it economically viable. These will only become better and better as more varieties will be able to grow in Denmark and a longer wine tradition will evolve. Danish wine is here and it's getting better and better.

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