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Location investigation of a high-speed rail using cost surface analysis: Case study Hässleholm-Lund

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Master thesis, 30 credits, in Physical Geography and Ecosystem Science

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Nike Rosenström

Abstract

The urge for more sustainable and environmental-friendly transportation has never been as high as it is today. The demand will probably continue to increase as the knowledge about climate change continues to widen and as the expectations, of mitigation and adaptation measures, intensifies. One sector that is in great need of taking more mitigation and adaptation measures is the transport sector. The transport sector is one of the heaviest emitter's in the world. The most dominant emitter in the sector is by far the airplanes and the trucks used for freights. The focus is therefore to make the means of environmental friendly transport more effective and profitable for the public. A solution to this problem is the high-speed rail (HSR) that is being built and used in different parts of the world today.

The overall purpose for this project is to plan out where the best placement of an HSR would be between the cities of Hässleholm-Lund with extra focus on the nature and Swedish laws. The HSR is to be plotted with 6 different cost rasters based on 6 different scenarios, some of which avoids protected areas and some that avoids the agricultural land use types. These 6 scenarios are then combined with the slope to avoid the slopes that are steeper than 2 degrees. Which means that in total there are 12 different scenarios that makes up 12 different cost rasters. To conclude this work; using this method, the time variations will lie around 2 minutes, which in this case translates to about 15-20 % depending on which scenario. This research also shows that, with this method, it should be possible to save the protected areas without setting aside the important criteria and variables.

Keywords: Physical Geography • Ecosystem analysis • High-speed rail • HSR • Protected areas • Hässleholm-Lund • Cost surface analysis • CSA • Cost connectivity • Cost raster

Populärvetenskaplig sammanfattning

Påtryckningarna för en mer hållbar och miljövänlig transport har aldrig varit lika hög som den är i dag. Efterfrågan kommer troligen att fortsätta öka i takt med att kunskapen om klimatförändringar fortsätter att öka och när förväntningarna, om mildrings- och anpassningsåtgärder, intensifieras. En sektor som är i stort behov av att vidta mer begränsningar och anpassningsåtgärder är transportsektorn. Transportsektorn är en av världens största utsläppskällor. Den överlägset dominerande utsläppskällan i sektorn är flygplan och lastbilar som används för gods. Fokuset för denna rapport ligger därför på att göra de klimatvänliga transportmedlen mer effektiva och lönsamma för allmänheten. En lösning på detta problem är höghastighetstågen (HSR) som byggs och används i olika delar av världen idag.

Det övergripande syftet med detta projekt är att planera var den bästa placeringen av ett HSR skulle vara mellan städerna Hässleholm-Lund med extra fokus på naturen och de svenska lagarna. HSR spår ska planeras med hjälp av 12 olika kostnadsytor utgjorda av 12 olika scenarier, varav några undviker skyddade områden och andra undviker områden med lutningar brantare än 2 grader. För att summera denna rapport; denna metod visar att tidsvariationerna är runt 2 minuter, vilket i detta fall är omkring 15-20 % beroende på scenariot. Denna undersökning visar också att, med denna metod, borde det vara möjligt att skona de skyddade områdena utan att de viktiga kriterierna och variablerna läggs åt sidan.

Nyckelord: Naturgeografi • Ekosystemanalys • Höghastighetståg • HSR • Naturkyddsområden • Hässleholm-Lund • Kostnadsanalys • Kostnads-konnektivitet • Kostnadsraster • Skyddade områden

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Abbreviations

AHP – Analytical Hierarchy Process

CAB – County Administrative Board (Länsstyrelsen)

CSA – Cost surface analysis

EIS – Environment impact statement

GCP – Ground control points

HSR – High-speed rail

SDSS – Spatial decision support system

STA – Swedish Transport Administration (Trafikverket)

UN – United Nations

WTC – Wildlife-train collision

1. Introduction

The urge for more sustainable and environmental-friendly transportation has never been as high as it is today. The demand will probably continue to increase as the knowledge about climate change continues to widen and as the expectations, of mitigation and adaptation measures, intensifies. One sector that is in great need of taking more mitigation and adaptation measures is the transport sector. The transport sector is one of the heaviest emitter's in the world (European Commission, n.d.). The most dominant emitter in the sector is by far the airplanes and the trucks used for freights. In Sweden, the heaviest pollutant overall is the industry sector, but the transport sector is not far behind (Naturvårdsverket, 2019b). The overall goal in Sweden is to have net zero emissions by the year of 2045 and the European commission is aiming to be climate-neutral by 2050 for the Paris agreement's global climate action to be met (European Commission, 2018; Naturvårdsverket, 2019a).

To reach these goals the transport sector has to be more sustainable since the goals, in no way, would be reached if the transport sector looks like it does today. The flights across the world is increasing every day, up until the beginning of this year. At the same time people who are aware of the climate situation is always looking for new ways to travel more environmentally friendly and sustainable in their everyday life. To start small, one easy way to save up on emissions is if people would use the public transport more (here airplanes are not considered public transport), both for business travels but also for private travels. But for people to make that switch, the public transport needs to be more effective, i.e. travel the same distance in a shorter amount of time than the public transport does today. If the public transport could meet these conditions, it would make it easier for people to choose means of transport that are more sustainable. As it is now it is not effective enough to choose the environmental-friendly transportation over the more convenient means of transportation.

The focus is therefore to make the means of environmental-friendly transport more effective and profitable for the public. A solution to this problem is the high-speed rail (HSR) that is being built and used in different parts of the world today. This is also discussed to be built in Sweden. Trafikverket, the Swedish Transport Administration (STA), is currently conducting a location investigation of a planned HSR between

Hässleholm-Lund together with the consultancy firm SWECO (Trafikverket, 2019a; 2020a). This project can be linked to the United Nations, UN, 2030 Agenda for sustainable development, that was adopted in September of 2015. It has 17 Sustainable Development Goals and 169 targets that all countries and stakeholders should work towards (United Nations, 2015). Some of these goals are related to this project. For example, Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable. Goal 13: Take urgent action to combat climate change and its impacts. As well as Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. These goals are associated to this project since an HSR can be seen as a resilient infrastructure and a new innovation here in Sweden. It will also make the cities more inclusive, resilient and sustainable. The building of an HSR will also combat climate change and its impacts. And it is clearly linked to Goal 15, because depending on where SWECO and the STA choose to place the HSR, it might impact the Swedish terrestrial ecosystems, forests and biodiversity.

The planning of an HSR is not an easy task, there are several key parameters and criteria to consider before the building of an HSR even can begin. Land-use, land cover, populated areas, economics as well as road network, is only some of the things to consider in these projects. With these comes then the more technical issues of slope, curve radius and noise. Since the horizontal radius of the curves must not be less than 4 650 m, the curves cannot be too sharp (Trafikverket, 2018).

To find a good route that consider several of the factors above, this thesis is using a Cost Surface Analysis (CSA) to plan out the HSR route between the cities of Lund and Hässleholm in the south of Sweden. The analysis is made up by creating different routes depending on what land use is deemed most important to preserve. This will give an overview of how the route might look depending on what the authorities decides are the criteria to follow.

In consideration of the method used in this thesis it is important to know that no other report has been found where this exact method has been used. However, it is considered important to look outside the box and explore things that has not yet been done before, especially in science.

1.1. Aim of the study

The overall purpose for this project is to evaluate how different scenarios place an HSR between the cities of Hässleholm-Lund, with extra focus on the nature and Swedish laws. The reason why the focus lies on the HSR between these cities is because it is where one of Sweden's first HSR is planned to be built. The base of this project is to be as true to the real scenario as possible so that the methods and results can be considered in future similar projects. Since this field of study is quite unexplored, especially in Sweden, all studies in the field can have great impacts on how to conduct these types of projects in the future.

The HSR is to be plotted with 6 different scenarios, or groups, that are preserving different land use types. The groups are explained in the objectives and Figure 1 below.

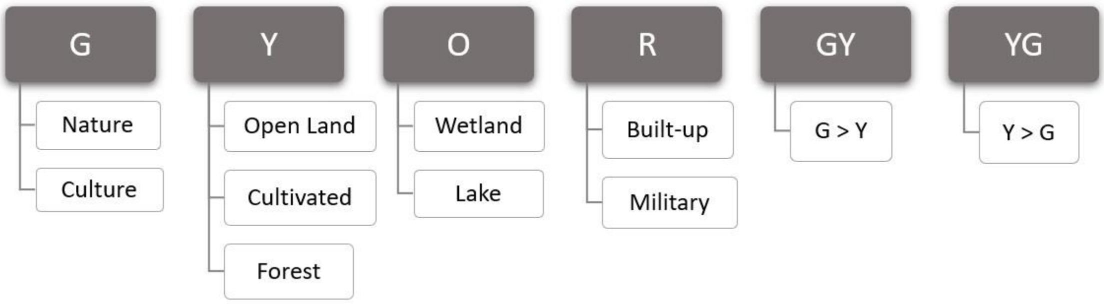

Figure 1. The first six groups and which land use that is preserved in that corresponding group. For group GY, G is multiplied by 0.65 before adding that to group Y that is multiplied with 0.35. Group YG, Y is multiplied with 0.65 before adding it with group G that is multiplied with 0.35.

Research questions

1. How does topography and land-use affect the location of the HSR corridors based on CSA?
2. How much of each land-use class are affected by the HSR corridor in the different scenarios?
3. Which HSR corridor is the best, when looking at length, intersections, number of farms affected, number of bridges required and conflicts?
4. What can be done to mitigate the barrier effect that the HSR form

Overall methodology

The first stage of the project is to use 6 different cost rasters in a CSA, therefore, different groups are presented which can be seen in Figure 1 above. The second stage is to combine all of the above mentioned groups with the slope.

The third stage is to conduct a barrier effect analysis since HSR often becomes a barrier for both people and animals (Borda-de-Água et al., 2017; Trafikverket, 2018). The analysis will be made up by intersecting the different routes with roads, rivers, power lines and hiking routes to see how many times each of the HSR routes are crossing any of these existing paths and discuss the mitigation through a literary review.

Limitations

Limitations of this study includes not taking certain parameters into account, such as contaminated soil, curve radius and the fact that the data used might not be the most recent or updated data available.

Disposition

The following chapter includes theoretical background of the subject. It introduces the history of HSR, the Swedish Transport Administration's process for planning HSR, the Swedish laws connected to the project as well as previous studies in the field. Chapter three will include the methodology used to reach the aim in this investigation. The fourth chapter includes the result and the fifth chapter will analyze the results. Finally, chapter six will conclude the findings in this investigation as well as give some thoughts on further research.

2. Background

This part of the thesis provides a broad overall background of what is considered to be important to know before the analysis is explained

2.1. History of HSR

The evolution of HSR has been developed since the early 1960s in Japan where they first built an HSR that travelled up to 250 km/h. Since 1972 their HSR standard is from 300 km/h and other countries are now looking up towards 400 km/h (SJ, n.d.; Möllerström, 2018). The HSR concept is of course relative to timeline, steam-powered locomotives in 1830 that held a speed record of 50 km/h has nothing on todays 500-600 km/h speed trains that is being tested (Bharule et al. 2019). Only in the last 20 years the HSR has gone from meaning trains that travel around 200-250 km/h, to mean trains that travel at a speed of 320 km/h or more. From now on the concept of HSR in this thesis imply trains that travel at a speed of 320 km/h.

Europe

In Europe, the intention has for many years now been to connect the bigger cities in EU by building an HSR network to make it easier to travel between the countries. It has even been brought up in the UN where in 2019 a convention was made to engage countries in Europe and Asia when implementing railway projects along the main transport corridors in the region (United Nations, 2019). The Convention on the Facilitation of Border Crossing Procedures for Passengers, Luggage and Load-Luggage carried in international Traffic by Rail is open for signatures but is not yet in force (UNTC, 2019).

Sweden

There has not been any larger investments on infrastructure in Sweden since the 1950-60s even though the train passengers has doubled in less than 25 years (SJ, n.d.). In 2014 the government decided to start the planning of new main lines for HSR (Trafikverket, 2019b). It is not until 2018 that the government made the high-speed train a part of the infrastructure plan for 2018-2029 and in November 2019 the State Audit released a report on the government's suggestion (Sveriges Regering, 2018; Riksrevisionen, 2019; Trafikverket, 2019b). The report was made since this infrastructure investment is the biggest financial commitment in modern times (Riksrevisionen, 2019).

In the infrastructure plan, the Swedish railway is to be upgraded and some parts are going to support the HSR with a speed of 320 km/h. One of the parts that are going to be upgraded is the part between Hässleholm and Lund (Sveriges Regering, 2018; Riksrevisionen, 2019).

Railway infrastructure

Trafikverket, the STA is, as stated in the introduction, conducting a location investigation together with SWECO (Trafikverket, 2019a; 2020a). The idea is in the end that the HSR will go from Stockholm to Malmö and Gothenburg as well, Figure 2. The HSR will probably be connected to the European HSR network from Malmö through Copenhagen and out in Europe.

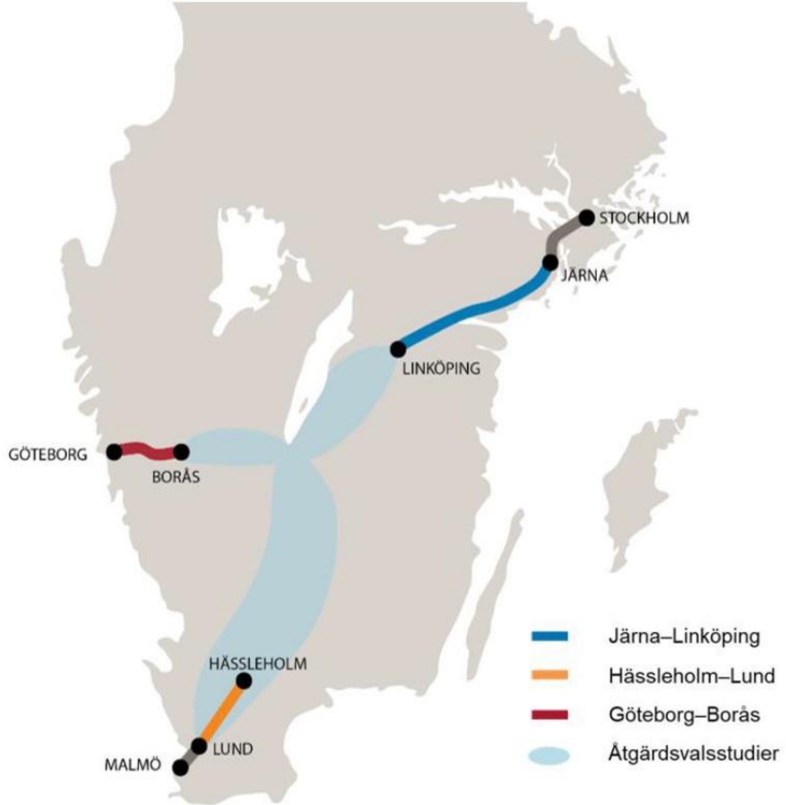

Figure 2. The planned HSR routes in Sweden. The orange line represents the route between Hässleholm and Lund, the blue shadowed area is a part of the action choice studies. Picture from Trafikverket (Trafikverket 2018).

The goal with the Hässleholm-Lund project is that it will contribute to the long-term sustainable transport system where the end goal is reached in a cost-effective way with the 8 target areas: travel time, health and safety, capacity and robustness, nature resourcing, station locations, energy effectiveness and climate neutrality, landscape and lastly, architecture (Trafikverket, 2020b).

The Swedish Transport Administration's process for planning HSR

The steps described here are the steps that the Swedish Transport Administration (STA) has written in the report called Planning description – Project Hässleholm-Lund (Planläggningsbeskrivning – Projekt Hässleholm-Lund) (Trafikverket, 2019b). Translated to English by the author of this thesis.

The first phase in planning a HSR is to write up a planning process that is regulated by the law on building railways (Lag (1995:1649) om byggande av järnväg). When writing the planning process, the STA produce consultation documents where they describe how the surrounding environment may be affected by the new HSR between Hässleholm-Lund. The consultation document was then discussed in 2018 and the different viewpoints were then compiled in a consultation report. The STA also adds the response to the viewpoints. These consultation documents and reports are then the basis for Länsstyrelsen, the County Administrative Board (CAB), to use when deciding whether or not the HSR can be assumed to have a significant environmental impact. The decision was made in January of 2019. This means that an Environment Impact Statement (EIS) (Sv. Miljökonsekvensbeskrivning) can be produced and that consultations shall take place with an extended consultation circle. The STA will therefore consult with the CAB, the region, the affected municipalities, other state authorities as well as the organizations and the general public that can be assumed to be affected.

The planning process will in this case contain 5 different phases. The 5 phases are: the consultation report for CAB to make an EIS (done in 2018), a location investigation (2019-2022), permissibility test (2022-2024), development of railway plan (2022-2026) and finally, approval test (2026-2028).

Phase two is where Trafikverket is at the moment in the planning of the route between Hässleholm-Lund, and this phase is the location investigation. This phase includes exactly what it sounds like, it is an investigation of the location where the HSR should be built. Different routes, or corridors, are studied and the ones that are being presented should all meet the final purpose of the HSR and appear reasonable to carry out in an overall assessment. The focus is to describe how the project could impact the public interests. The studied corridors will be ranked during the process.

According to chapter 17 in the Swedish Environmental Code (17 kap. Miljöbalken 1998:808), bigger road- and railroad projects have to pass through a permissibility test (Sv. tillåtlighetsprövning) done by the government before the plan itself is established and the final review is done. The permissibility test is done after the location investigation is finished and the test is only for the proposed corridor and not for the project as a whole. If the corridor is permitted, the HSR is to be constructed within that very same corridor.

When the corridor has been decided it is time for the exact route to be investigated, this is the development of railway plan. Here it is reported which land that needs to be used permanently and temporarily to build the HSR. Protective measures that the project is carrying out regarding, for example, noise and water protection, are also reported in the planning documents. The focus lies on individual interests and how individual property owners are affected by the project.

The fifth and final phase is the approval test (Sv. fastställelseprövning). This is done by the law and planning review department at the STA after the CAB has approved the plan. Approval testing means that the project’s impact on the environment, health, encroachment and inconveniences, to name a few, is tested in its entirety. Is it so that the STA concludes, by the time of the investigation, that it can be accepted and that the benefits to the public outweigh the inconveniences the project causes individual interest, then the plan is determined.

The decision can be appealed to the government.

2.2. Benefits for the socioeconomic and the environment

There has been some studies on whether or not an HSR would benefit the socioeconomic and the environment respectively. The studies have shown mixed results on if the HSR would in fact benefit both the socioeconomic as well as the environment. As stated by Blanquart and Koning (2017), “results show great variability as economic effects are conditional upon a set of other factors such as city size, industry structures, amenities, and distance from the urban core" (Blanquart and Koning, 2017).

According to the STA, there are also not enough benefits of the HSR for the socioeconomics here in Sweden. They have conducted some research and published a report that the government has studied and the National Audit Office (Riksrevisionen) is also stating that the numbers that the STA has shown is not beneficial enough to actually build an HSR (Riksrevisionen, 2019). According to the STAs report the economic benefit would only be 40% of the investment (ibid.).

Like the research on the benefits in the socio-economic sector, the research on the benefits for the environment is also mixed. Nobody can argue that the HSR is worse than flights or travelling by car, but there is however more to consider than only the pollution that is being set free at the moment of movement. One also has to consider the surrounding environment, how that is being affected by the barrier that the railway form with the interruption of land and habitats. Also, the pollution during the building of the railway itself with all the materials and such.

2.3. Previous studies

Most of the studies and reports published on this topic deals with the benefits and potential that might come with HSR's (Peters et al, 2014; De Rus et al, 2009; De Rus & Inglada, 1997; Van Wee, Van Den Brink & Nijland, 2003). De Rus et al (2009) makes an economic analysis of HSR in Europe, De Rus et al (1997) investigates the cost-benefit of the HSR in Spain while Peters et al (2014) analyzes the potential for HSR as part of the Multimodal Transportation System in the United States' Midwest Corridor. So far there has not been any signs that the actual placement of an HSR with the help of CSA has been done before. It seems that most of the researchers want to study if the HSR can have a positive effect on the economy and analyzes if the effects are good enough to start the planning of constructing an HSR or not.

There is however some published reports on how to optimize HSR routes with the help of a Spatial Decision Support System (SDSS) (Kim et al, 2014). Their aim was to find the most suitable location of a transport infrastructure with the use of SDSS (ibid.). Kim et al (2014) states that their method "provides a composite foundation for decision making to attain enhanced regional mobility, especially for a HSR" (Kim et al, 2014). They compare the routes by investigating the construction estimates, suitability scores and anticipated land acquisition fees (ibid.). The method is a bit more complex than the method used in this thesis, but it can be argued that both methods are built on the same ground.

2.4. Cost Surface Analysis

The cost surface analysis, CSA, is a tool used to analyze a chosen area and calculate the cost of going to the adjacent cells. The CSA simulates how to travel through a landscape by choosing the least costly path (ArcGIS Desktop, n.d.). This should not be confused with Euclidean distance. The cost can represent different things such as: energy expended, time, risk and money (ibid.). As a part of this analysis there is a tool called Cost Connectivity that was used here. The input in the Cost Connectivity is firstly a layer of the land cover classes with their respective weights, a cost surface, as well as the start and end points of the route that is being calculated.

The CSA result is a route that avoids the cells that has higher values and going through the cells that has lower values, i.e. cost less. The input in this analysis can be many different cost surfaces, this way, the results will be many different routes.

2.5. Noise

Farms and other settlements near the HSR will of course be affected by the noise of the HSR. Hanson (1990) stated that: "Typically, the noise impact corridor ranges between 200 ft (~60 m) and 1,000 ft (~300 m), depending on existing ambient noise conditions, train schedule, operating conditions, and guideway configuration.". Hanson (1990) also states that: "Noise impacts may extend out to distances of 500 ft (~150 m) on either side of the tracks in otherwise quiet residential areas.".

2.6. Swedish environmental law

When planning and building HSRs, there are certain things to take into consideration. One of the most important is of course the laws. But since this thesis focus on the environment and the protected areas, the only laws that will be mentioned here is the ones connected to the Swedish Environmental Code (Miljöbalken (1998:808)) and the Planning and Building law (Plan- och bygglagen (2010:900)), which is strongly interfered with the Environmental Code (Sv. Miljöbalken). There is also, as mentioned earlier, a general Law on Building Railways (Lag (1995:1649) om byggande av järnväg).

Sweden, amongst other countries, has its own environmental objectives as a part of the work that EU has been doing towards reaching the environmental goals for the region.

Sweden has one generation goal, 16 environment quality goals and lastly 6 way points, these goals are set up by the government to be able to contribute to the international goals that have been set. Some of these environment quality goals are: limited climate impact, a rich flora and fauna and living forests. These goals are very much affected by the building of an HSR and it is therefore, as stated earlier, a real challenge to even plan the building of an HSR.

2.7. Barrier effect

The HSR can act as a barrier for both humans and animals. This has been a problem in many countries all over the world and it is also a problem with roads and power lines (Fischer, 2003). It is therefore a good idea to learn about the problem with roads and powerlines and the studies on the impacts by those barriers (Borda-de-Água et al., 2017). The regular railway is of course also acting as a barrier and there have been studies that shows that here in Sweden the wildlife-train collisions (WTC) has increased during the past 15 years (Seiler & Olsson, 2017).

3. Methods

The CSA method used, to look at the cost of avoiding or not avoiding different land use types, was selected because of the connection to the Swedish environmental laws. The Swedish environmental laws are set up to preserve individual protected species, cultural important areas and nationally important areas. But in these types of projects, like building an HSR, where the possibility of disrupting anything that is protected under the Swedish environmental laws are quite high, it is a compromise between several interests. Therefore, this study also wants to examine how the costs might change depending on what to avoid in the building of an HSR. The idea for the method in this thesis was first thought of when reading the paper by Kim et al, (2014). The theory for both methods are to take as many factors into account as possible and come up with the best route for an HSR. The biggest difference is that the SDSS is a model and this thesis use ArcMap.

3.1. Study area

The study area is in between the cities of Lund and Hässleholm in Skåne, the southernmost province in Sweden, Figure 3. This study area was chosen since it is between these cities that one of the first HSR's in Sweden is being planned to be built.

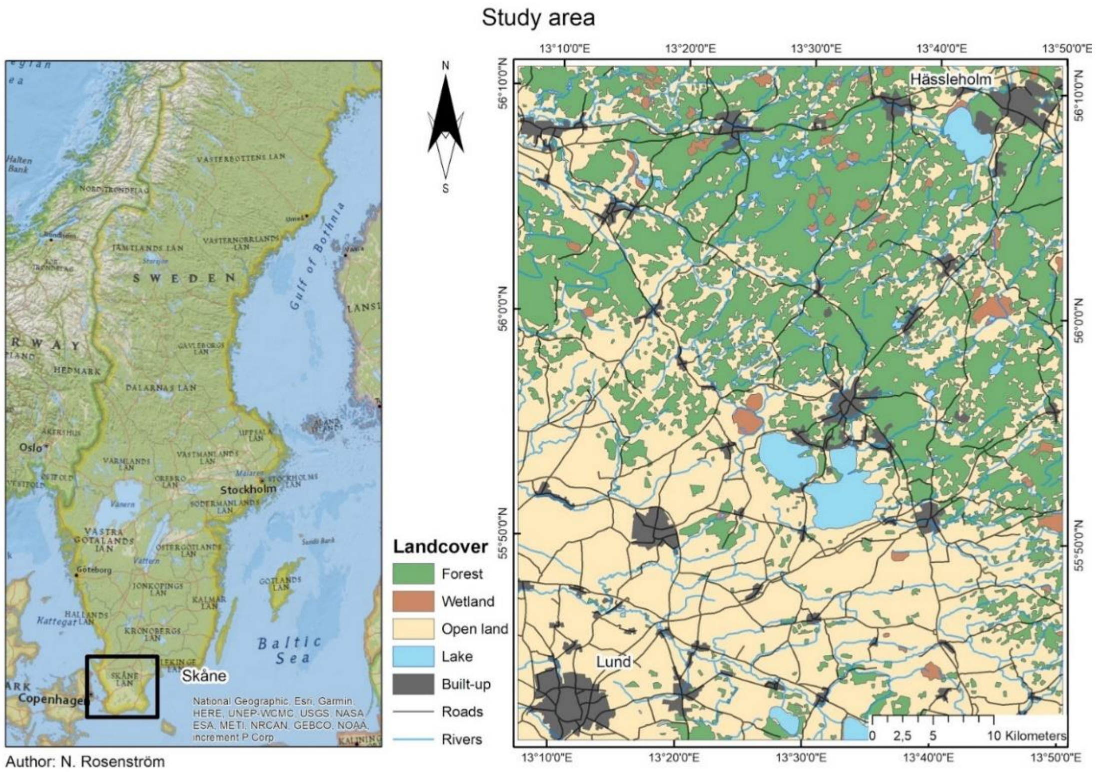

Figure 3: A visualization of where the study area is located in Sweden with a zoom in to the extent of the study area.

This part of Sweden is known to be quite flat compared to the rest, although, there are some horsts that stands out from the rest of the landscape. Some of these horsts are overlapping parts of the study area and will therefore, most likely, affect the analysis. The study area is mostly covered by forest in the north-east and croplands in the south-west. There are three bigger lakes in the area, one directly south of the city of Hässleholm and two in the middle of the area. There is also a military zone in the south that can be seen in Figure 10.

3.2. Data

The data used was retrieved from a geoportal where aerial photos, digital maps and other valuable information can be found.[1] The data used is however collected by © Lantmäteriet. The datasets that were downloaded are described in Tables 1-4.

Table 1. Fastighetskartan 1:5 000 - 1:20 000 and the different thematic- and position accuracy the different data classes have.

Fastighetskartan 1:5 000 – 1:20 000 Up to dateness: Varies, 2019	**Thematic accuracy**	**Position accuracy**
Land use	Large areas – High Small areas – Low	The position accuracy cannot be specified per land use but is related to the type of boundary line.
Protected areas	High	0-5 m
Built-up	Deviations can be found mainly with regard to the classification of "other" buildings	
Hike	Good	2-10 m
Rail	Good	2 m
Power	High	At most 5 m

Fastighetskartan has a good overall thematic accuracy, it would be preferred if the thematic accuracy could be a bit higher, but it can be argued that it is good enough. The position accuracy is on the other hand very high. It ranges between 0-10 m which is to prefer to get a good overall spatial accuracy. The up-to-dateness (Sv. aktualitet) is varied, but the data was updated in 2019.

[1] SLU geo database: Geodata Extraction Tool

Table 2. GSD-Terrängkartan 1:50 000 with the thematic- and position accuracy per class.

GSD-Terrängkartan 1:50 000 Up to dateness: High	**Thematic accuracy**	**Position accuracy**
Built-up	High	Good, not all buildings are however included
Wetland	Large areas – high Small areas – low	5-50 m
Hike	Good	5-10 m

GSD-Terrängkartan 1:50 000 is updated regularly and has a thematic and position accuracy that ranges between 5-50 m depending on the data class. The position accuracy is very good in some data classes, while in some other classes it could have been better. For the wetland for example, it would have been better to have maximum 5-10 m position accuracy instead of 5-50 m. The final result is only as good as its input, which means that the resulting HSR routes might deviate up to over 50 m in precision accuracy, and these errors might then result in completely different land types affected.

Table 3. The thematic- and position accuracy for GSD-Översiktskartan.

GSD-Översiktskartan Up to dateness: High, 2019	**Thematic accuracy**	**Position accuracy**
Protected areas	High	Due to cartographic generalization, position accuracy may vary
Built-up	Large areas – high Small areas – low	Due to cartographic generalization, position accuracy may vary
Military	An increase in the quality of the area is underway	Due to cartographic generalization, position accuracy may vary
Road	Generally high	Due to cartographic generalization, position accuracy may vary
Rivers	High	Mean error of 50 m

GSD-Översiktskartan is updated regularly and the data that can be downloaded is updated every week. The up-to-dateness is high, and the thematic accuracy is generally high for each data class. The position accuracy however is not very well described, it says that due to generalization, the accuracy is varied. It would have been good to specify this information a bit more.

The DEM used in this report has a spatial resolution of 2 m with a height accuracy of 0.1 – 0.4 m (Lantmäteriet, 2019). The product is based on a national laser scaling with more than 0.5 points per m^2. From this grid, a 2 m grid is then interpolated, using a bilinear method. It is of course desired to have as high pixel resolution as possible, meaning the detail an image holds should be as high as possible. But the pixel resolution is only as good as the spatial resolution, which should be as low as possible. In this case, the spatial resolution would be the best if it was closer to 1. But since this data layer was interpolated from the National height model with a 1 m grid, the data can be considered of good resolution for this purpose.

Table 4. The resolution for the DEM - GSD-Höjddata, grid 2+.

Data	Resolution	Source
DEM - raster	2 m	GSD-Höjddata, grid 2+

Everything that is included in each land use category is described in Table 5 below.

Table 5. What is included in each land use category, data taken from the downloaded datasets.

Nature	National park, nature reserve, natural heritage, bird protection, animal protection, biotope protection, building monument, building ban, archeological site, landscape image protection, mineral processing, mining permit, processing concession, railway plan, road plan.
Culture	Bigger ancient monument, bigger ancient monument without clear sign above ground, cultural-historical relic, other cultural-historical relics.
Open Land	Area for other open land where the height of the vegetation is less than 1.5 m. This includes former agricultural land, seed plantations, pastures, naturally growing meadows and grasslands etc.
Cultivated	Arable land, fruit and berry plantation.
Forest	Needleleaf and mixed forest (felled land also included), broadleaved forest (90-95% of the area must be covered by broadleaved trees),
Wetland	Area for normal marshland ("brown bog") and inaccessible marshland ("blue bog"), (peat-forming mire (bog and marsh) with rice tufts and vegetation-rich, firm coverings with root-forming cataracts and grasses. the ground is normally passable on foot. can either be forested, completely open or have a sparse layer of trees or scattered trees.) min area is 2500 sqm.
Lake	Water, lakes, bigger watercourses, dams.
Built-up	High buildings, low buildings, closed buildings (ex. parking houses), industry buildings, squares, holiday homes, small towns, urban areas, villages, farms.
Military	Military training area.

In Table 6, the information about everything that is included in the network categories, can be found.

Table 6. Exactly what is included in the network categories.

Railroad	Railway with single track, railway with double track, underpass/tunnel for railway, other (non-regular) railway.
Road	Road with width ≥ 7m, road with width ≥ 5m and ≤ 7m, underpass/tunnel, highway.
Hike	Walking trail, bike/park path, footpath, exercise tracks (elljusspår), underpass/tunnels.
Power	Power line distribution, regional, backbone network (stamnät), transformer station, pipeline, pipeline above ground for gas or liquid.

3.3. Methods

The methods described here is mostly performed in ArcGIS 10.5.1 and Excel.

Cost connectivity

It was considered important that the data to be used actually was the most accurate data, both when it comes to the spatial accuracy and the up-to-dateness, but also of course the classification. Therefore, an extraction of certain data was done from the different downloaded data layers based on what data was considered to be, the most, accurate, see Figure 4 below. Where it was found that the data differed, as for the protected areas and built-up areas for example, which was retrieved both from Fastighetskartan and GSD-Översiktskartan, both data layers were merged to create a new version for that land use. This was done to not lose any data.

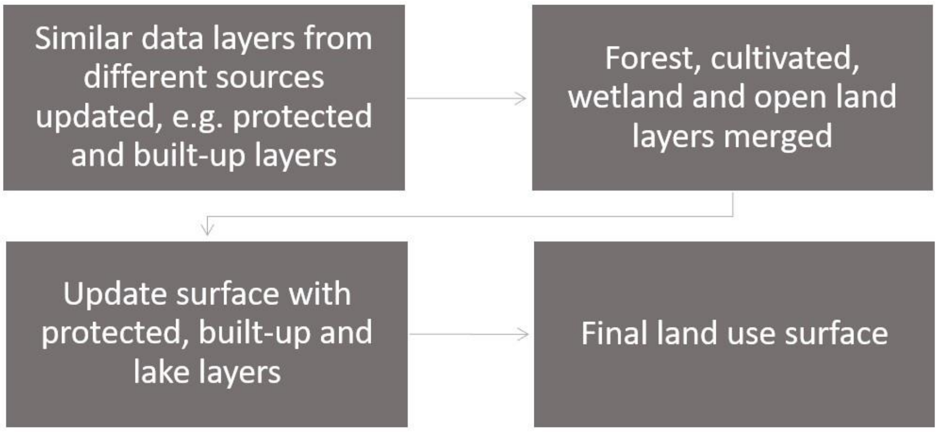

Figure 4. Flow chart showing the first steps to create a land use surface.

The data layers were merged to create the first surface. The nature reserve, culture reserve, lake and built-up layers were then added to the first surface to get an updated version of the surface with the protected areas as well, see Figure 4 above. The resulting land use surface act as the input in the detailed flowchart seen in Figure 5 below. The next steps can also be seen in the figure below.

It is essential to build topology to make sure that no gaps or overlaps exists in the surface. The topology was created with the latest updated surface. It was chosen to not have gaps, nor overlap. It was then validated to see exactly where these errors occurred. With the help of the clip function in the Edit toolbar, single features could be chosen and the data that coincides with the chosen feature would be clipped back to match the selected feature. This takes away the overlaps. Fortunately, the method to add together the different data made sure that there were no gaps.

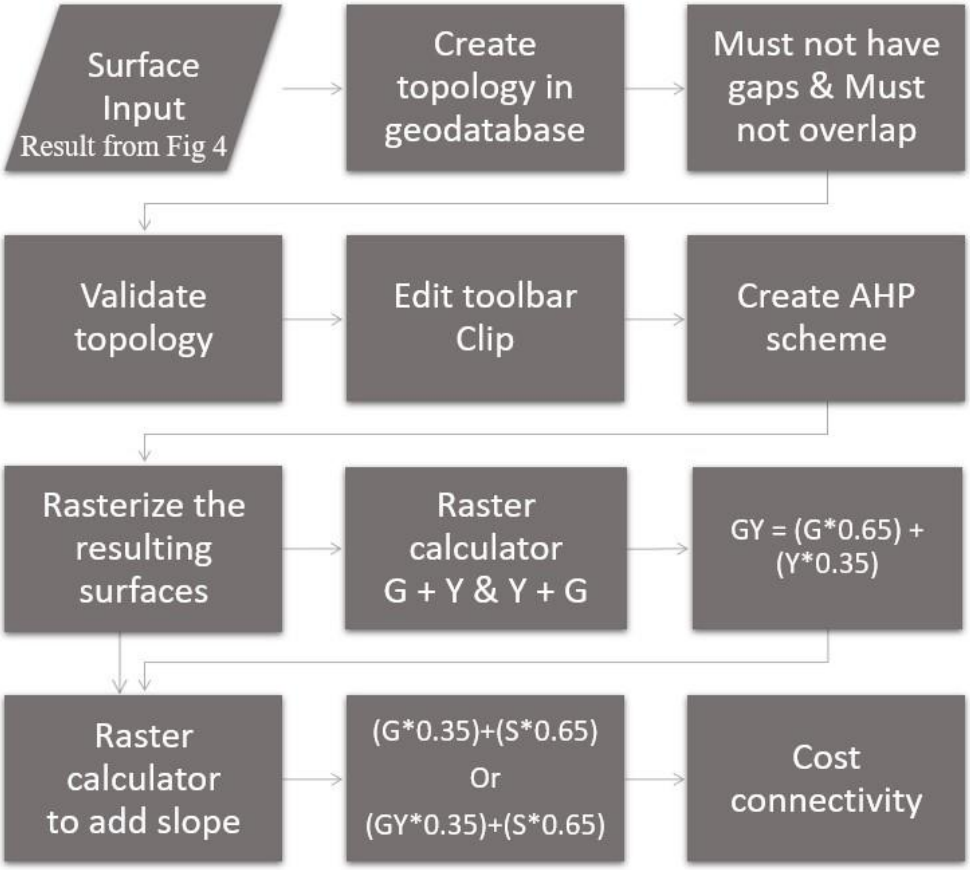

Figure 5. A detailed flow chart over the steps used in this method.

The classes in the vector layer were then grouped to prepare for an Analytic Hierarchy Process (AHP). In Figure 6 below the groups can be seen. In the first group, the Green (G), the natural and cultural reserves are grouped together to create a scenario that preserves the protected areas. The second group is the Yellow group (Y), which preserves the more agricultural classes, which in this case is the open land, cultivated areas and the forested areas. The third group is the Orange group (O), here the wetlands and the lakes are preserved. In the fourth and final group, Red (R), the built-up and the military zones are preserved. The resulting 4 surfaces were then rasterized. The maximum area was chosen as the cell assignment, which means that the feature that takes up the largest area within a cell will give its attributes to that cell.

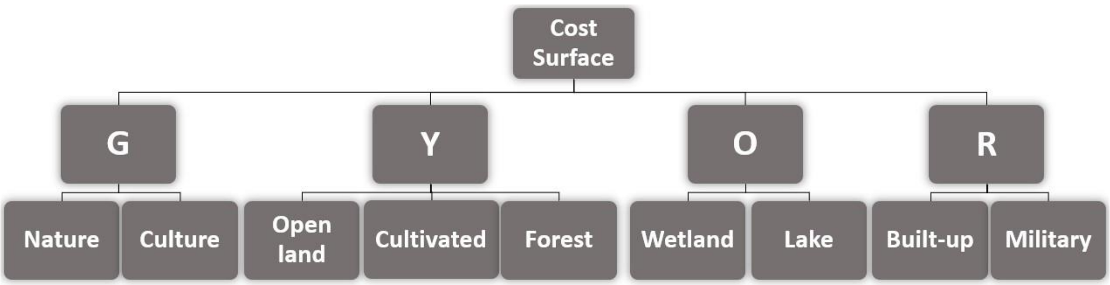

Figure 6. The AHP scheme.

For the first group, G, where the HSR should preserve the natural and cultural important areas, those classes were given values of 10. The remaining classes were given values of 1, these weights were given to the different land use classes to clearly separate the preserved groups from the unpreserved groups. The reason to why the classes were set to have a value of 1 or 10 was to get a broad span of the different values of the cells when one group were combined with another group or with the slope. If the values would have been 1 and 2, the span would not have been as broad and the different land use classes would not have been so easy to separate. Therefore, two completely different values, i.e. 1 and 10, was thought to clearly separate which classes that is more costly to travel through in a cost raster.

In the second group, Y, the open land, cultivated areas and the forested areas were given the values of 10 while the other land-use and land cover classes were given the value of 1. This was done to have a good separation of the classes that the HSR either were going to be encouraged to go through or to be avoided. This creates cost layers that is then used to create the final cost surfaces.

Two mixed classes were also tested, these two classes were two different versions of the Green (G) and Yellow (Y) groups with the help of the Raster calculator. In the first run weights were used, the Green group were multiplied by 0.65 and the Yellow multiplied with 0.35 and they were then added together to form the group GY (Green > Yellow). The second run was the opposite. The Yellow group was weighted by multiplying it by 0.65 and the Green group was weighted by multiplying by 0.35, and then added together to form the group YG (Yellow > Green).

All 6 of the different groups were then combined with the slope, see Figure 7 below. The slope was derived from the DEM to be able to set a maximum value of the gradient to 2 degrees since that is what can be the maximum slope for an HSR (Trafikverket, 2018). For example, the Green group and the slope were added together in the raster calculator after the Green group was given a lower weight and were therefore multiplied by 0.35 and the Slope was given a higher weight by multiplying it by 0.65, forming the group GS (Green + Slope). The same was done for the two mixed groups. Meaning that the GY group was multiplied by 0.35 and then combined with the slope that was multiplied by 0.65, creating the group called GYS (Green > Yellow + Slope). Figure 8 and 9 is an example of how this combination might have looked like.

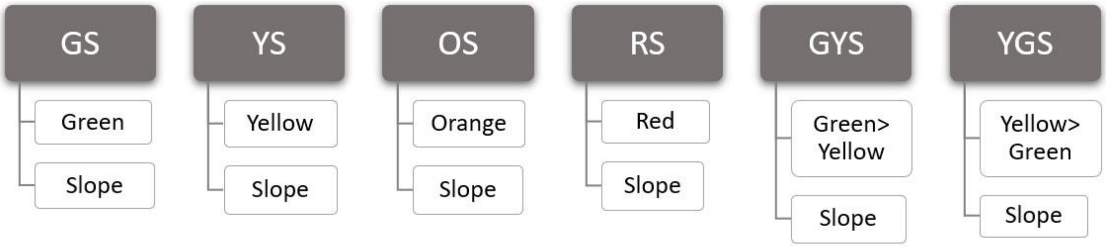

Figure 7. The groups combined with the slope.

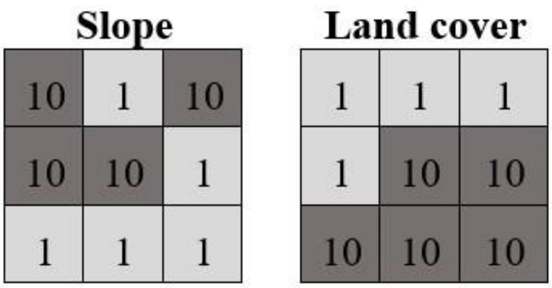

Figure 8. The input layers where the cells have gotten weights of either 1 or 10.

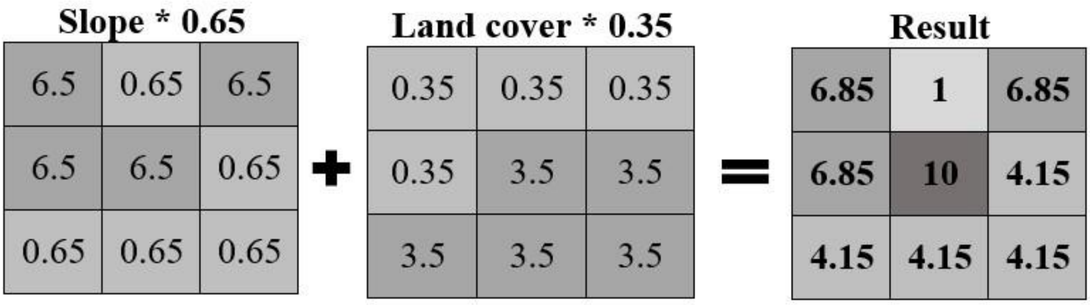

Figure 9. How the previous Figure 8 look like when the layers have been multiplied by 0.65 and 0.35 respectively and how the resulting cost raster could look like.

After completing these steps there should be a total of 12 different cost surfaces, 6 with only land-use taken into account, meaning group G, Y, O, R, GY and YG. And additional 6 different with the slope taken into account as well, GS, YS, OS, RS, GYS and YGS. These 12 different cost rasters are then used in the cost analysis.

The Cost Connectivity analysis needs to have a feature dataset that decides between what points the connection should be made. The other input was therefore a start and end point, which in this case is made up by a point vector layer of the city of Hässleholm as well as the city of Lund, to mark the start and end points of the HSR.

To know exactly how much of each land-use the different scenarios affect, a buffer-zone of 25 m on each side was created for each group. The data was then transferred to Microsoft Excel where graphs and plots were created to better analyze the result.

Another buffer zone of 300 m were also created to be able to extract the affected farms and smaller houses nearby the HSR that might be affected by the noise. The buffer zone was set to 300 m on each side of the rail, since Hansson (1990) stated that the noise impact corridor ranges between 200 ft (~60 m) and 1,000 ft (~300 m). This was done to make up for the fact that wind speed, ambient noise and other factors might affect how far away the noise can be heard. This buffer zone was also used to extract intersections with other conflicts such as churches, chapels, castles, emergency hospitals, towers and wind turbines.

Barrier effect analysis

The barrier effect analysis was conducted through a literary research of how the HSR has been affecting the animals in different countries. This is done to get an overview of how the HSR, as a barrier, might affect the Swedish wildlife, how the movements might change and possible mitigations.

Apart from the literary research, an intersect was also done with the routes from the 12 groups to see how they intersect with the roads, rails, rivers, powerlines and hiking routes. This was done to get an overview of how many times the HSR would be a barrier for the already existing infrastructure.

The HSRs effect on the animals is much harder to predict. There has to be much research on all the possible animals in the area and their movements throughout at least one year. Since this was not possible at the time there will be some mitigation measures debated later in the discussion section.

It should also be mentioned that the HSR of course also act as a barrier for the flora as well. It is not only the humans and animals that is affected by the barrier.

4. Result

In this section, the results from the CSA as well as the results from the barrier effect analysis will be presented.

4.1. Cost Surface analysis

In Figure 10 (A and B), the first 4 groups, i.e. G, GS, Y and YS, can be seen. To the left in the figure (A) it can be seen that group G, that does not take the slope into account, is a bit straighter than GS that do take the slope into account. The same is not however the case with the groups Y and YS to the right in the figure (B). They both follow a quite meandering path.

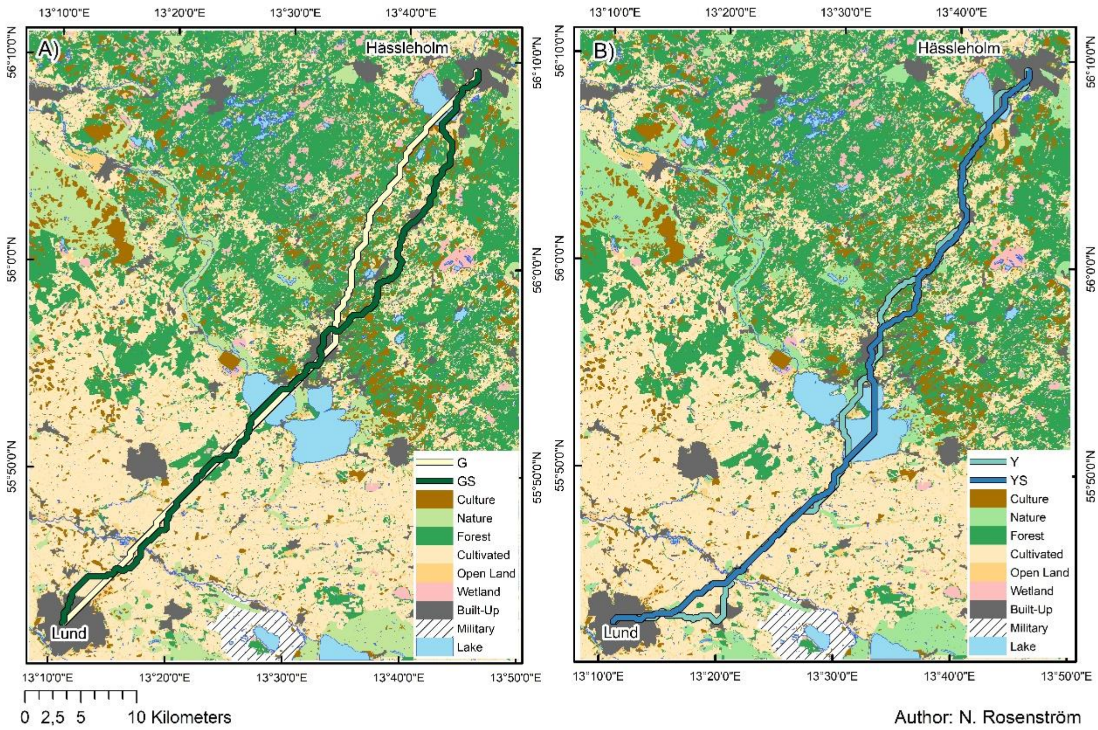

Figure 10. A) The HSR route for the Green and Green + Slope groups. **B)** The HSR routes for the Yellow and Yellow + Slope groups.

In Figure 11 below, the groups O, OS, R and RS can be seen. To the left, group O is a bit more straight than group OS that follows a path to avoid a slope steeper than 2 degrees. It is seen quite clear that these two groups avoid the lakes and water as far as they can. Group R is no exception, it is also much straight forward than group RS.

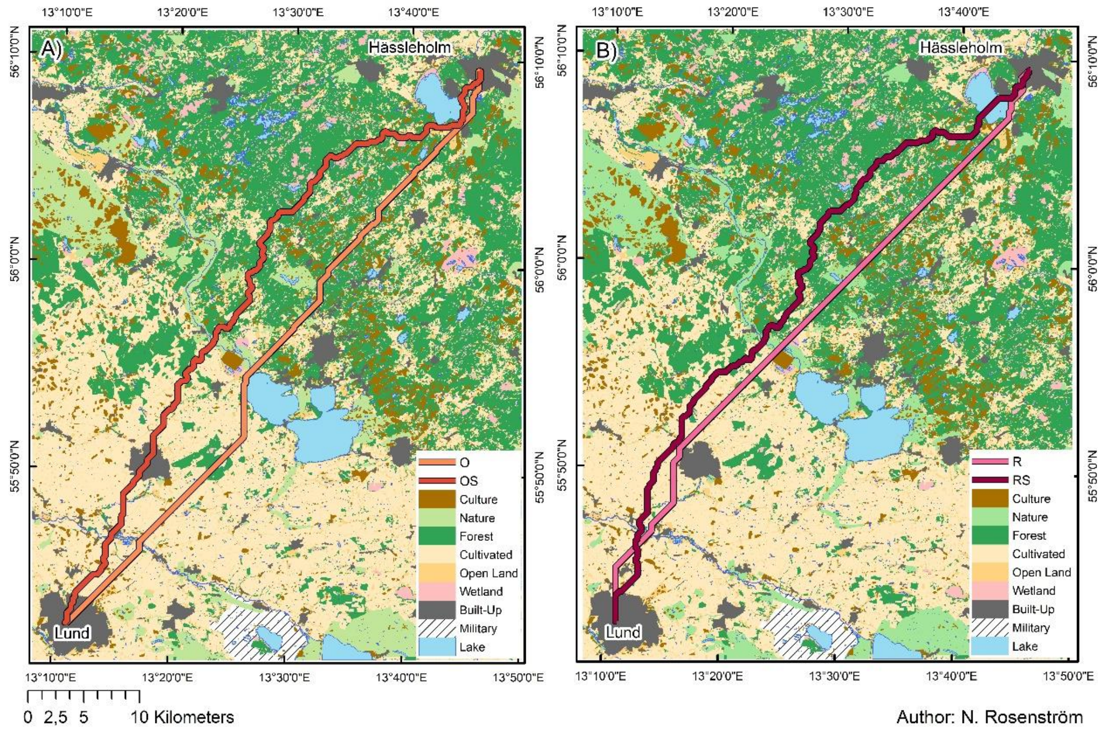

Figure 11. **A)** The HSR route for the Orange and Orange + Slope groups. **B)** The HSR routes for the groups Red and Red + Slope.

In Figure 12 below, the four mixed groups can be seen. The map to the left shows the groups where G has a higher weight and is multiplied by 0.65 and then added with Y that is multiplied by 0.35, i.e. group GY. Also, the group GYS is visible. To the right the groups YG and YGS can be seen.

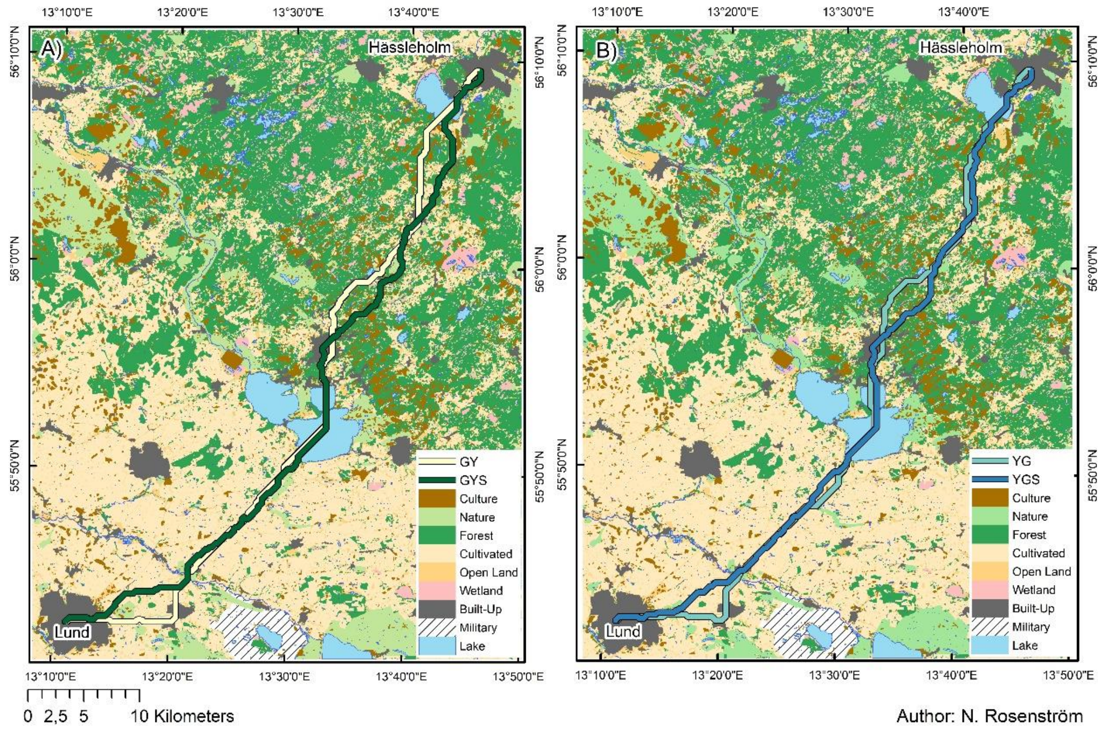

Figure 12. A) The HSR route for the Green > Yellow and Green > Yellow + Slope groups. **B)** The HSR routes for the groups Yellow > Green and Yellow > Green + Slope.

In Table 7, the different groups' length in km can be seen.

Table 7. The length in km for the different groups.

Scenario	G	GS	Y	YS	O	OS	R	RS	GY	GYS	YG	YGS
Length (km)	65	73	76	73	65	76	65	75	72	74	73	72

In all the groups the length of the route gets longer when the slope is added, except for groups with Y. With the groups Y-YS, YG-YGS it is the opposite. Y is 3 km longer than YS and YG is 1 km longer than YGS.

The time difference lies around 2 minutes from the fastest to the slowest route.

The results from the 25 m bufferzones can be seen in Figure 13 and 14 below. The distribution of affected land-use classes within 25 m in each direction for the 12 different routes. As seen in Figure 13 the land-use class that is affected the most is the cultivated- and built-up areas. The forested areas are also quite affected. The least affected land use classes are in general the wetland and the natural and cultural reserves. Groups G, O and R are the groups that has the lowest total hectares of affected land, this is because they have the shortest routes of 65 km each. All the other groups has a length that is longer than 70 km.

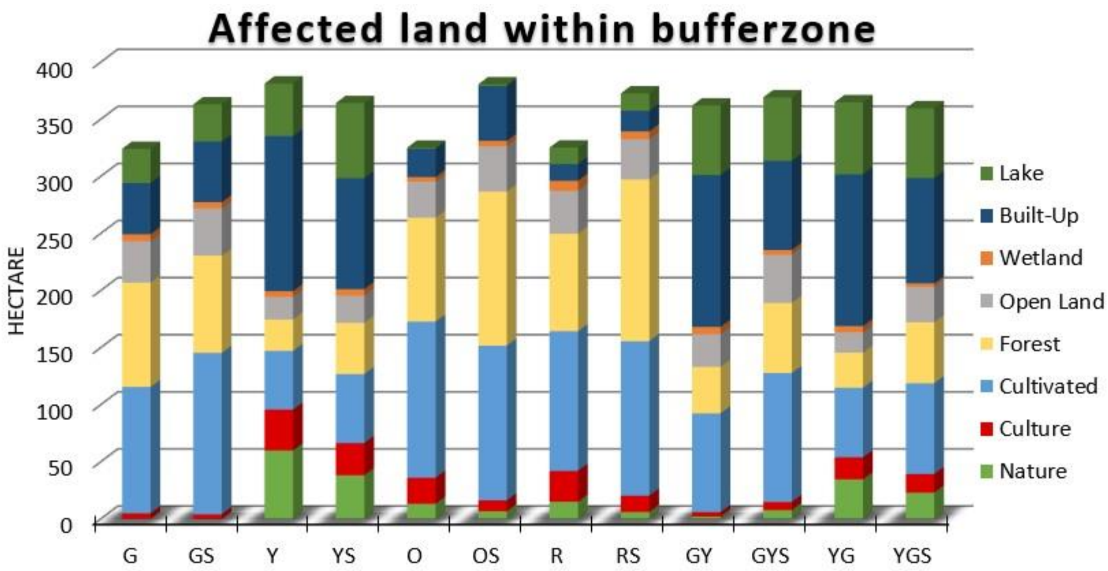

Figure 13. The affected land within the 25 m buffer zone for each group.

In Figure 14 the affected land within the 25 m bufferzone is shown in another type of graph to make it easier to read the number of hectares per land use class per group.

Also here it is visible that the land use classes that are most affected are the cultivated, forested and built-up areas.

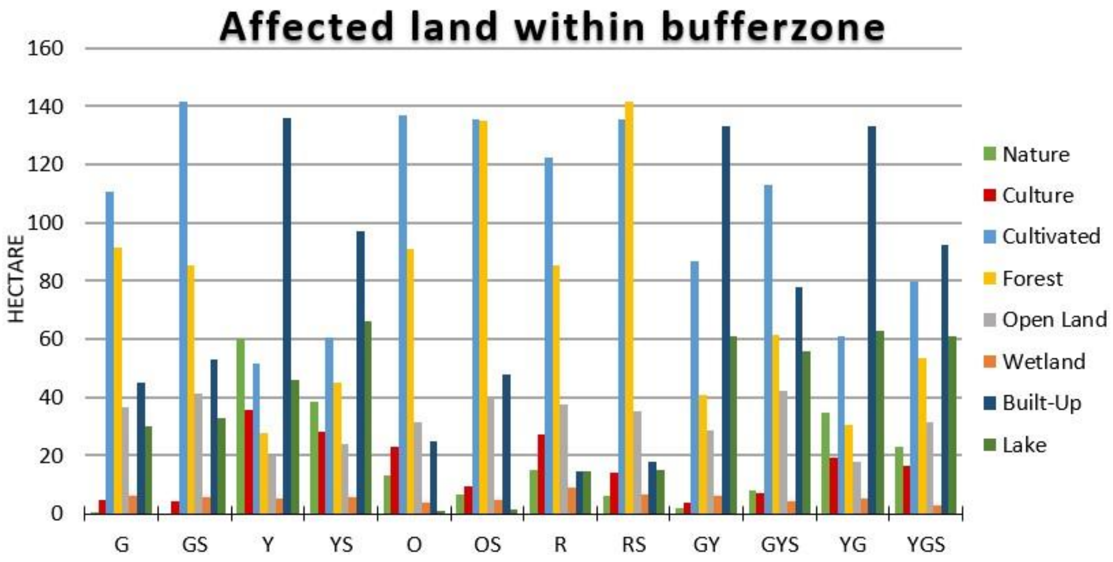

Figure 14. A graph showing the distribution of land-use classes within the 25 m buffer zone for each group.

4.2. Barrier effect

The results from the literature study on the barrier effect shows that there are a lot of research on the types of barriers that the HSR act as and also mitigation measures that can be taken into account when building HSRs. As stated by Borda-de-Água et al. (2017), the impact on biodiversity can be divided into 4 different main topics: "mortality, barrier effects, species invasions and environmental disturbances, with the latter ranging from noise to chemical pollution.".

Carvalho et al. (2017) lists different types of mitigation measures and some of those are: crossing structures, structures that restricts wildlife access to railways as well as habitat and wildlife population management. The crossing structures can be everything from wildlife underpasses or overpasses to amphibian or reptile tunnels. The wildlife over and under passes can be constructed specifically for animals and wildlife to cross over or under linear infrastructures. These are called anything from eco ducts, green bridges and landscape connectors depending on how big the structures are (Carvalho et al, 2017).

The structures that restricts wildlife access to railways is one of the best and most efficient ways to reduce the wildlife mortality by railways. They prevent all types of crossings and even force flying animals to cross above the trains and the wires

(Carvalho et al, 2017). Some of these structures are physical barriers, sound signaling and exclusion fences. The physical barriers can be as simple as trees, while the sound signaling is a way to warn the animals when a train is approaching. The exclusion fences has been the most common and most effective way to limit the animal contact with railways. It is probably also the most cost-effective technique to alleviate wildlife mortality by trains in the long run (ibid.).

There is of course also barriers to narrow the noise impact corridor, as Hanson (1990) states: "noise impact corridor can be narrowed considerably with the use of wayside noise barriers.". Which means that the 300 m buffer zone to find the farms and settlements that might be affected by the noise, actually can be mitigated quite well by building noise barriers.

What is important to consider when building any of these structures is that there might be some negative impacts as well. As Carvalho et al. (2017) states: "moreover, some structures may reduce animal movement, disrupt landscape connectivity, or have negative implications for erosion and grazing.".

Table 8: All the intersections that the different routes have with roads, rivers, powerlines, rails and hiking routes.

Scenario	Hike	Power	Rail	River	Road	Total
G	25	13	8	6	15	**67**
GS	32	15	9	8	24	**88**
Y	55	22	11	7	43	**138**
YS	47	15	12	8	28	**110**
O	36	20	8	10	16	**90**
OS	24	16	11	13	26	**90**
R	25	18	8	10	18	**79**
RS	15	14	9	10	12	**60**
GY	44	21	7	8	38	**118**
GYS	39	21	8	7	32	**107**
YG	59	22	5	7	44	**137**
YGS	36	18	10	8	27	**99**

The results from the intersect analysis can be seen in Table 8 above. It can be seen that the intersections for the different groups ranges between a total of 60-138 where it is group RS that has a total of 60 intersections and group Y that has a total of 138 intersections. The number of intersections with hiking routes are the lowest for group R that has 15, and the highest for group YG that has a total number of 59 intersections with hiking routes. For the powerlines the numbers ranges from 13 for group G to 22 for the groups Y and YG. The intersections with the already existing rail ranges from 5 for group YG to 12 for group YS. The intersections with rivers ranges from 6 for group G to 13 for group OS. And lastly, the intersections with roads are ranging from 12 for group RS to 44 for group YG.

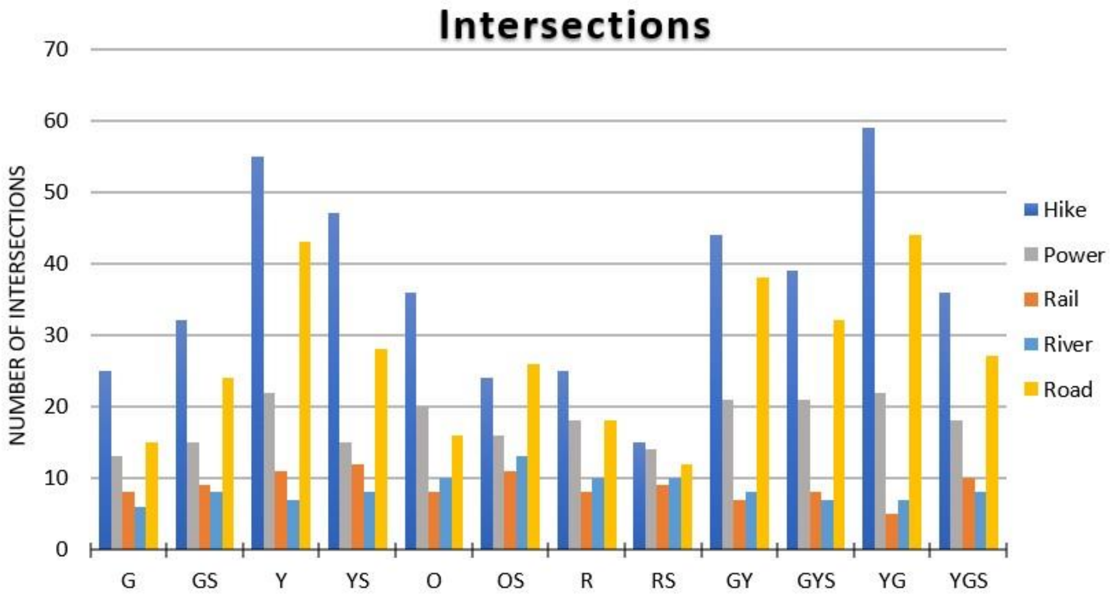

Figure 15. The distribution of intersections for each group.

In Figure 15 above, the intersections can be seen in another format. From this graph it is visible that the most intersections occur with hiking routes and roads. The least intersections occur with rivers and the existing rails.

Table 9 below shows the criteria length, number of intersections, number of farms and settlements within 300 m buffer zone, number of bridges required over lakes as well as other conflicts. The conflicts can be intersections with churches, chapels, castles, emergency hospitals, towers and wind turbines within 300 m of the HSR. It is a resulting table for all the different analyses made for each group.

Table 9. The results for the different criteria, length, affected land within 25 m, number of intersections, number of farms within 300 m, number of bridges required as well as number of conflicts for each group.

Scenario	Criteria	Length (km)	Affected land (ha)	Intersections	Farms	Bridges	Conflicts
G	Preserve natural & cultural areas	65	324.0	67	63	2	1
GS	G + Slope	73	363.1	88	88	3	2
Y	Preserve open land, cultivated & forest	76	381.3	138	83	5	4
YS	Y + Slope	73	364.2	110	54	4	3
O	Preserve wetland & lake	65	325.1	90	74	0	2
OS	O + Slope	76	380.6	90	109	0	2
R	Preserve built-up & military	65	325.2	79	78	4	2
RS	R + Slope	75	372.6	60	108	1	2
GY	G>Y	72	362.0	118	82	4	5
GYS	G>Y +Slope	74	369.2	107	72	3	2
YG	Y>G	73	364.8	137	74	4	4
YGS	Y>G + Slope	72	359.6	99	53	4	2

In Table 10 below it can be seen which group that performed best in each category. The column to the far right shows the best total, i.e. which group that performed the best in most categories or was mentioned most frequently in that row. So, in the first run YGS had the best numbers, i.e. shortest length, least number of intersections etc., in most categories while in the second run group YS performed the best. In the third run it was group GYS that performed best. However, group GS performed the best when looking at the number of times it is even mentioned in the table, so the number of times it placed top three. It performed the best in the top three runs in 5 out of 6 categories. While YGS only performed the best in 4 out of 6 categories in the top three runs.

Table 10. The group that is the best, second best and third best performing in each category.

Place	Length	Time	Intersects	Farms	Bridges	Conflicts	Best total
1	YGS	YGS	RS	YGS	OS	**GS**, YGS, OS, RS, GYS	YGS
2	**GS**, YS	**GS**, YS	**GS**	YS	RS	YS	YS
3	GYS	GYS	OS	GYS	**GS**, GYS	-	GYS

5. Discussion

In the following section the results from the analysis will be discussed.

5.1. Results

The aim of this thesis was to see where the best placement of an HSR were between the cities of Lund and Hässleholm. The method used, to create an AHP diagram, to group two or three different land use types to be able to compare different scenarios to each other was a nice way to get an overview of how the HSR might affect the different land use classes depending on how it will be built. It is also a good way to show the amount of different land use classes that will be affected by the HSR in one way or another. The intersections with hiking routes, existing rails, roads and rivers was a nice way to show how the HSR in fact act as a barrier to not only people, but animals and plants as well. The buffer zone used to retrieve the farms and other settlements was a nice way to show how many of the nearby homes that might be affected by the noise.

5.2. Cost connectivity

The results from the cost connectivity are showing that the time factor on this short route is a bit varied. The differences between the scenarios are around 2 minutes and that, in this case, is around 15-20 %. The time factor is very important when you add together the whole distance from Stockholm to Malmö. The whole idea with HSR is that it should be possible to travel that distance in a much shorter time than what is possible today. It is in that way you connect the cities and make it possible to commute between the biggest cities in Sweden without spending too much time travelling. To conclude research question 1, the travel time was in this scope varying a bit, since it differed about 2 minutes. In 4 out of 6 group pairs (G/GS=1, R/RS=2 etc.) the group that took the topography into account has a longer travel time than the group that did not include the slope and it is also a bit longer. This means that the topography affects the HSR in the way that the route becomes a bit longer since it has to avoid areas that has a slope greater than 2 degrees. Since the route becomes longer, the travel time is of course also affected. The land use type that affects the time the most is the land use types included in group Y, this means that mostly the cultivated and forested areas affect the time. This might of course also be because that the study area consists mostly of cultivated and forested areas.

The results from the affected land within the 25 m buffer zone is quite interesting, see Figure 13 and 14. Because only group G were to preserve the natural and cultural protected areas, but those areas are quite preserved in the rest of the groups as well. It is only in groups with Y, i.e. Y, YS, YG and YGS, that those areas are exploited a bit more. In Figure 13 and 14 for example it can be seen in group Y that the natural reserves are the second most exploited land use type.

Group Y was the group that would preserve the open land as well as the cultivated and forested areas. The cultivated areas are however the third most affected land in group Y. But it is the group that preserves the cultivated area to the largest extent. Group Y does however preserve the forested area and the open land the best together with group YG.

Group O, that were to preserve the wetlands and lakes do preserve the lakes very good compared to the other groups. This can also be explained by looking at Figure 11 and Table 9. It can be seen that group O avoids the lakes and in Table 9 it is also cleared that the group does not need any bridges to travel through the landscape. The affected wetland is however a very small for all the groups and is best preserved in group YGS. This can be seen as a lucky circumstance since building on wetlands is of course not an easy task in itself. Since the soil and the seasonal dynamic changes the whole base layer of where the HSR should be built, it is not sure that this can be done in a cost effective way. The groups that affects the most lakes are quite a few, it is mostly in group YS, GY, GYS, YG as well as in YGS. This can be explained by looking at Figure 10, 11 and 12. In those figures it can be seen that the 5 beforementioned groups travel through eastern Ringsjön, which is the largest lake in the area.

For group R, that were to preserve the built-up areas and the military area, clearly was the best group to preserve the built-up areas. The second best group to preserve the built-up areas is group O and OS, with group G and GS not far behind. The military area lies in the very south of the study area, and this of course makes it quite impossible to not preserve it. It should also be stated that in reality there should not even be any questions about preserving the military areas, it goes without saying that the HSR should not be built to go through a military area. And luckily, none of these groups do go through that area.

The 4 different groups that were combined in different ways with G and Y, i.e. GY, GYS, YG and YGS, were quite similar in the matter of protecting the lake. Both GY and YG do however affect somewhat more of the lakes than GYS and YGS. But when it comes to preserve the land use types that group G and Y was created for, these combined groups are doing a mediocre work. But since these land use types are the ones that take up almost the entire area, it would be impossible to spare them all and only build the HSR on wetland, lakes and in the built-up areas. The land use that is the most exploited in these groups are the built-up and the cultivated areas.

When looking at Table 10, three things are certain, 1: the best group overall, when looking at the groups including the slope, that has the lowest numbers in all the criteria, is group YGS. It has the lowest number both length-, farm- and conflict wise in the first run. 2: when looking at which group that has the best numbers in a top three list it turns out that group GS is the best since it places top three in 5 of the 6 different categories. 3: This would in theory mean that group GS is the best performing when looking both length wise, number of intersections, number of bridges required and conflicts. The only criteria that GS does not perform in a top three is when it comes to the number of farms in a 300 m buffer zone around the rails. In the farms category there is only two other groups that performs worse than group GS with its 88 farms, and that is group RS and OS with their 108 and 109 farms respectively.

The reason why the groups in Table 10 only included the groups that takes the slope into account is the reason that the slope is a constraint in reality. So even though the groups that does not include the slope is straighter and might seem cheaper. However, it is in fact only with group G/GS, O/OS, that the group that does not include the slope, is performing better than the corresponding group that does include the slope, see Table 9. For the rest of the groups they either perform equally better or worse than the groups that include the slope. For some groups, the ones that includes the slope is even performing better. As for group Y/YS, GY/GYS, YG/YGS, the groups taking the slope into account is performing better in all categories or perform the same in one or two categories.

When looking at the overall results it shows that group GS is in fact performing the best, with this method, maybe not the best in all categories, but overall, when looking at the top three in Table 10.

The loss in biodiversity and habitats will in the long run cost a lot more than it will if the HSR is built on other types of land cover. There is however also a loss when it comes to the deforestation that has to take place in order to build the HSR on forested land. Since the forests can be seen as carbon sinks, the deforested land will rather be seen as a carbon source. Therefore, the emissions from the permanent deforestation is of course adding to all the other emissions that comes with building a railway.

The 2030 Agenda does state that we should protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests and halt biodiversity loss. This is of course done best by leaving the protected areas as they are and not exploit them for any purpose. But, it also states that we should build resilient infrastructure, foster innovation as well as make cities inclusive and sustainable. These are also goals that can be met by the building of this HSR. The 2030 Agenda goals are therefore quite hard to live up to, because on the one hand they promote the building of new innovative infrastructure, but they also on the other hand state that the land and ecosystems should be left alone. It is therefore very important to weigh the advantages and disadvantages and figure out which direction that is the right direction.

What is not taken into consideration in this analysis is the cost of buying cultivated and forested land from the farmers or landowners. There is of course a cost in that as well, but the idea was that it should be more costly to buy out the areas that are protected under the environmental laws as natural or cultural important areas. Because in order to build or exploit those areas there is always a whole procedure to even explore if the area could be saved for these exploiting purposes.

One problem that has not been discussed is the problem of how the weight is set to correspond to the cost, but that the cost of exploiting the forested or the agricultural areas is not taken into account here. This is first of all due to the fact that the prices changes a lot between each year and it also depends on who is the owner of the land and what is being grown or produced there.

For future research it might therefore be a good idea to investigate even more if any kind of numbers and costs can be retrieved so that an even better weight scale can be made.

5.3. Benefits

Even though the results from other studies points to how different the socio-economic benefits are for different countries there is also a report on the socio-economic benefits for this exact project here in Sweden. That report does state that the benefits does not even make up for 40% of the invested money (Riksrevisionen, 2019). That report does also state that even though some of the calculations might be over- or underestimated, the overall conclusion is still that the HSR is very socio-economically unprofitable (ibid.).

The best scenario is of course if the HSR can have a redistribution effect so that the passengers who would usually travel by plane, is instead travelling by train. With this redistribution, the effects on the environment would in the long run be better. Especially if habitat and landscape mitigation would be executed during the building of the HSR. The benefits are of course not only attached to how the socio-economic is affected by the HSR but the overall benefits from the decrease in pollution and how the greenhouse gases are affected by the decrease of aviation travels. It is in the long run those changes that will be beneficial in the future.

5.4. Barrier effect

The results from the literature research on barrier effects shows that this is a problem that should really be taken seriously. There are however a lot of mitigation techniques and research on the best and most cost-effective way to mitigate wildlife mortality by railways. Thankfully the already existing railways and roads are also having the same problem of being a barrier and therefore the hope is that a lot can be learned from those types of projects as well.

The buffer zone of 300 m that was used to discuss how far the noise could travel can of course also be mitigated by the barriers, and if any barriers are to be used, the noise level is most probably not going to reach out 300 m.

As for the result from the intersect analysis, the thing to think about a bit extra here is how to make these intersections as human- and animal friendly as possible. One really great solution is the eco ducts or wildlife passages that was described by Carvalho et al. (2017). They are great for both flora and fauna and they would not be risking the movement of the animals at all as fences might do. It is also the best alternative to make sure that animals does not suffer from entrapment or that the gene flow is affected (Holderegger & Di Giulio, 2010).

5.5. Sources of errors

The sources of errors in this analysis is first of all of course the data used. The data has a varied precision, and this might of course affect the resulting routes. It would have been better to use data from e.g. Naturvårdsverket. The other thing is the fact that the Update tool, that was used to combine the first land-use layers and land cover layers, might have overrun some of the data so that it is not completely true to how the landscape looks like right now. The best option would be to have as recent data as possible so that the input is as true as it can be. What comes out as a result is only as good as the input data. It would therefore be good to evaluate the accuracy by going out in the field and collecting ground control points, GCP's, and compare to the final land cover map that is produced. By doing this, you know how well your data corresponds to the real land cover and also create a user-producer accuracy matrix.

Another source of error is of course the rasterization of the land use layer. This rasterization was controlled in the way that the maximum area was chosen as the cell assignment. This means that the feature that covers the largest area within a cell will give the cell its attribute. In this report it was thought to be the best option, but it does not however take away the fact that some of the features will take on a larger area while some features will get a smaller area than in the polygon layer. This means that the accuracy of the surface will decrease even more.

5.6. Limitations of this study and future research

Some things are simply too big or too complicated to be considered under the scope of this project. These things are of course thought to be important for further improvements of similar projects. Future studies are therefore strongly encouraged to take as many of these things into consideration. Contaminated soils, soil types, buffers around the constraints would be really good to incorporate in the future.

It would also be nice to have real numbers on costs, i.e. for tunnels and bridges or other types of intersect as well as the land acquisition costs. This would give a much better overview of what these kinds of projects costs or might cost depending on what mitigation strategies are being used.

6. Conclusion

This thesis tests different scenarios to see which land-use types and criteria that is the most important to include when planning an HSR route. It is thought to be good to use as many criteria and variables as possible. Contaminated soils, soil types and other kind of data that can enhance this method should be included in further research.

The first research question is answered in the discussion and the travel time is varying about 2 minutes. It is clear that the topography does affect the travel time. It is also clear that the land use that affect the travel time the most is included in group Y, meaning cultivated and forested areas which is also the land use types that the study area consists the most of.

The second research question can be answered by looking at Figure 13 and 14 in the result section. It is also scrutinized in the discussion. The land use type that is affected the least is the wetlands and the land use type that generally is affected the most is the cultivated and forested areas.

Research question three is answered by Table 9 and 10 in the results section. It is also debated in the discussion that since group GS were top three in most categories it should be the best scenario when looking at length, intersections, number of farms affected, number of bridges required and conflicts.

The research question number four is concluded in the small literary research about how HSRs act as barriers for both humans and animals. The result show that there are loads of different mitigation measures to consider when building an HSR. These mitigation strategies have both pros and cons, but according to the available reports discussed here, the mitigation should not be a problem. It is rather the costs for the different mitigation strategies that decides how good or bad the resulting mitigation measures are.

The method used here investigates how the routes differ depending on what types of land-use to avoid. It is however a disappointment to not have been able to use real numbers and costs for this analysis. But for the time of this thesis it just was not possible to get into all the steps and bureaucracy to get the costs that is needed to do this analysis. It is therefore encouraged to continue these types of researches to further improve this method.

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