Chapter 6

Project: Expansion of Transport System to Arlanda

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Icke-teknisk sammanfattning

Introduktion

Stockholms län är en av de snabbast växande regionerna i Europa, med en befolkning som beräknas öka från 2,3 miljoner till 2,6 miljoner människor till år 2030. År 2050 väntas befolkningen i Stockholms län uppnå närmare 3,4 miljoner invånare. I takt med den ökande befolkningstillväxten ökar även trycket på Stockholms flygplatser. Swedavia har tagit fram en vision för den framtida utvecklingen av Arlanda, med målet att flygplatsen ska bli en viktig knutpunkt för internationella flygresor och transfers. Visionen innebär en kapacitetsökning från dagens 24 miljoner passagerare till närmare 70 miljoner passagerare om cirka femtio år. En kraftig ökning av antalet flygpassagerare medför ett ökat tryck på den befintliga infrastrukturen för persontransporter, vilket kommer att innebära ett större behov av effektiva transportlösningar mellan Stockholm och Arlanda. Swedavia förutspår att det kommer krävas en ökad kapacitet för såväl järnvägstrafik som vägtrafik.

Syftet med denna strategiska miljöbedömning är att identifiera vilka möjliga alternativ som finns för att klara det framtida behovet av persontransporter mellan Stockholm och Arlanda, samt vilka betydande miljökonsekvenser dessa alternativ kan innebära. Målsättningen är att inblandade aktörer och intressenter ska få relevant information kring olika transportlösningar och dess miljöpåverkan, och rapporten kan med fördel användas som ett verktyg i framtida beslutsprocesser.

För att identifiera och bedöma de potentiella miljökonsekvenserna för de olika alternativen har fyra olika metoder använts. Geografiska informationssystem har använts för att skapa kartor över studieområdet, både i syfte att visualisera området samt att skapa en grund för delar av konsekvensanalysen av alternativen. Intervjuer med relevanta aktörer har utförts för att få expertinformation kring området. *Causal Loop Diagrams* och flödesscheman har skapats för att identifiera olika relevanta parametrar, för att undersöka kausalitet mellan dem och för att utvärdera eventuella kumulativa effekter. Slutligen skapades ett *impact matrix* för att illustrera vilka samt hur stora konsekvenser de olika alternativen medför.

Områdesbeskrivning

Området som studerats i denna miljöbedömning är sträckan mellan Stockholm och Arlanda, vilket motsvarar cirka 40 kilometer. Sträckan inkluderar både E4:an samt järnvägarna Ostkustbanan och Arlandabanan. Eftersom studieområdet är stort präglas det av många olika typer av landskap. Den södra delen av sträckan består huvudsakligen av industriområden och bostadsområden, medan den norra delen främst utgörs av jordbruksland och skogsområden. Två naturreservat är belägna i närheten av studieområdet - Fysingen och

Igelbäcken. Igelbäcken utgör en av Stockholms gröna kilar och fungerar därför som en viktig spridningskorridor, men är också ett uppskattat område för rekreation. Fysingen är en av Stockholms bästa fågelsjöar med närmare 100 häckande arter.

Nollalternativ

Nollalternativet avser det alternativ där Arlanda flygplats fortsätter utvecklas i dagens takt (en passagerarökning med cirka 5 % per år), och att Swedavia inte genomför de föreslagna expansionsplanerna.

Om Arlanda flygplats inte utvecklas enligt de föreslagna planerna kommer behovet av en höjd kapacitet i transportsystemet också att minska. Det finns däremot en risk att trycket på den existerande infrastrukturen ökar till följd av befolkningstillväxten, vilket kan leda till trafikstockning och trängsel.

Alternativ 1

Alternativ 1 presenterar ett scenario med en ökad effektivitet och kapacitet på järnvägssystemet mellan Stockholm och Arlanda. Ingen förändring i vägsystemet kommer att ske i detta alternativ. Ökad kapacitet och effektivitet innebär lägre biljettpriser, mer frekventa avgångar och fler tåg, vilket möjliggörs av en utbyggnation av järnvägen med ett nytt spår i varje riktning.

Utbyggnaden av två nya järnvägsspår på sträckan mellan Stockholm och Arlanda förväntas ha en stor påverkan på landskapsbilden då ett flertal bostadshus troligtvis kommer behöva flyttas när järnvägen expanderas. Både byggnationen och driften av de nya järnvägsspåren förväntas ha en mindre negativ påverkan på områdets luftkvalitet, vattenkvalitet och markkvalitet samt på dess kulturminnen. Positiva effekter förväntas däremot när det gäller utsläpp av växthusgaser. Tåg är ett klimatsmart resealternativ, och när fler passagerare väljer tåget istället för fossila färdmedel förväntas utsläppen minska.

Alternativ 2

Alternativ 2 presenterar ett scenario med en utvidgning av E4 med två körfält i båda riktningarna. Ingen förändring i järnvägssystemet kommer att ske i detta alternativ. Ett av körfälten kommer att reserveras för miljöeffektiva fordon som Flygbussar, skyttelbussar och taxibilar som drivs med förnybara drivmedel. De nya körfälten planeras i segmenten Häggvik - Rotebro, Rotebro - Glädjen samt Glädjen - Arlanda flygplats.

Utbyggnationen av de två nya körfälten förväntas ha stor negativ påverkan på områdets luftkvalitet, vattenkvalitet och markkvalitet, med negativa ekologiska konsekvenser som följd. Negativa effekter förväntas även när det gäller utsläpp av växthusgaser, då fler fordon på vägen leder till högre utsläpp av CO_2. En ökad vägtrafik förväntas också leda till högre bullernivåer, vilket i sin tur leder till negativa konsekvenser för både människor och djur som vistas i området.

Slutsats

En jämförelse mellan nollalternativet, alternativ 1 och alternativ 2 visar att utbyggnationen av järnvägen har en genomgående lägre miljöpåverkan än utbyggnationen av E4. Detta beror främst på den stora påverkan vägtrafiken har på miljön i jämförelse med tågtrafiken. De föreslagna järnvägsspåren kommer däremot ha en stor påverkan på det fysiska landskapet, då ett flertal hus som redan idag är belägna väldigt nära spåren kommer att behöva flyttas eller förstöras. Nollalternativet bedöms ha lägst miljöpåverkan, men på grund av den växande befolkningen kommer infrastrukturen behöva byggas ut oavsett om Swedavia genomför sina planer eller ej.

Trots att både Alternativ 1 och Alternativ 2 innebär en kraftig kapacitetshöjning inom respektive transportgren, kommer detta troligtvis inte att räcka för att tillgodose Swedavias långsiktiga utvecklingsplaner. Mest troligt kommer därför de båda alternativen behöva kombineras för att kunna täcka det framtida kapacitetsbehovet.

Non-technical Summary

Introduction

Stockholm County is one of the fastest growing regions in Europe, with a population estimated to increase from 2.3 to 2.6 million people by 2030. By 2050, the population in Stockholm County is expected to reach nearly 3.4 million inhabitants. Together with the increase in population, there is also an increase of travellers and flights at Stockholm airports. Swedavia has devised a vision for the future development of Arlanda Airport with the aim of making Arlanda a transport hub for international flights and transfers. According to this vision, the airport capacity would increase from today's 24 million passengers to nearly 70 million passengers in fifty years. Such a dramatic increase in the number of travellers would cause an increased pressure on the existing ground transport infrastructure and would create a higher demand for efficient transport solutions between Stockholm and Arlanda. Thus, the increase in capacity in both rail and road traffic would be an essential part of the future development of the transport system.

The purpose of this Strategic Environmental Assessment (SEA) is to provide stakeholders and decision-makers with possible options of how to meet the future transport demand between Stockholm and Arlanda. Therefore, this SEA aims to identify potential environmental impacts, find suitable solutions and propose mitigation measures to minimize adverse effects caused by transport system developments.

To identify and assess the potential environmental impacts four different methods have been used. Interviews with relevant stakeholders have been conducted to obtain expert information. An impact matrix was made to illustrate what the consequences are of the proposed options. Causal Loop Diagrams (CLD) were used to identify relevant parameters, investigate causality between them and evaluate cumulative effects. With Geographical Information Systems (GIS) maps were created for visualization purposes and as a basis for analyzing impacts of different options.

Study Area

The study area is the transport corridor between Stockholm and Arlanda with a length of approximately 40 kilometers. This area includes both road E4 and railways Ostkustbanan and Arlandabanan. The area is characterized by different types of landscape. The southern part of the corridor consists of mainly industrial and residential areas, the northern part is surrounded by agricultural land and forests. Two nature reserves are located close to the study area - Fysingen and Igelbäcken. Igelbäcken is an important area to connect Stockholm's different green areas and its biodiversity, but it is also an appreciated recreation area. Fysingen is one of Stockholm's best bird lakes with nearly 100 breeding species.

Zero Option

The zero option refers to the scenario where Arlanda Airport continues to develop at the present rate with an increase of travellers of about 5 percent per year. Swedavia's plans on airport expansion are not implemented and the existing transport infrastructure is overloaded with passengers due to an increase in population in Stockholm region.

Option 1

Option 1 presents a scenario with an increased efficiency and capacity on the rail system between Stockholm and Arlanda. This option includes lowering ticket prices, more trains and frequent departures which includes an addition of new rail tracks to the existing system. No change regarding the road E4 will occur in this option.

The addition of two new rail lanes on the stretch between Stockholm and Arlanda is expected to have a major impact on the landscape image. Several residential buildings would need to be moved if the railroad would be expanded. Both the construction and operation of new railways are expected to have a minor negative impact on the area's air, water and soil quality as well as its cultural heritage. Positive environmental impacts are expected in terms of reducing the greenhouse gas emissions due to the use of electric fueled trains instead of fossil fueled cars.

Option 2

Option 2 presents a scenario where road E4 is broadened with two lanes in both directions. One lane in each direction is reserved for public buses, airport shuttles and taxis powered by renewable fuels. The new lanes are planned to be constructed in the segments Häggvik - Rotebro, Rotebro - Glädjen and Glädjen - Arlanda Airport. No change in the rail system will occur with this option.

The development of the two new lanes is expected to have a major negative environmental impact on the area's air, water and soil quality. Negative effects are also expected when it comes to greenhouse gas emissions, as more vehicles on the road lead to higher CO_2 emissions. Furthermore, increased road traffic will most likely lead to higher noise levels, which in turn leads to negative consequences for both humans and animals in the area.

Conclusions

A comparison between the Zero Option, Option 1 and Option 2 shows that the expansion of the railway has a consistently lower environmental impact than the broadening of the E4. This is due mainly to the big impact road traffic has on the environment compared to the railway traffic. The proposed railway tracks will on the other hand have a big impact on the physical landscape, since several houses that today are situated close to the tracks will have to be moved or destroyed. The zero alternative is estimated to have the lowest environmental impact, but because of the growing population the existing infrastructure will have to expand whether Swedavia implements their plans or not.

Even though both Option 1 and Option 2 will amount to a large increase in capacity within the two transport sectors, this will probably not be sufficient to meet Swedavia's long-term development plans. A combination of both options is most likely needed to meet a 70 million capacity requirement.

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6.1. Introduction

6.1.1 Purpose and Goals

The purpose of this Strategic Environmental Assessment (SEA) is to find suggestions on how to expand the transport system between Stockholm City and Arlanda airport and to evaluate possible environmental impacts from the proposed options in this chapter. The aim is that through evaluating environmental impacts from the proposed options, this SEA can provide decision-makers with a recommendation of different options that would cover the increasing need for capacity within the transport system, and also be the most sustainable and environmentally friendly option. Therefore, the main goals of this report are:

- To propose options on how to meet the increased transport demand that comes with an increasing amount of airborne passengers.
- To examine the different options' possible environmental impacts.
- To provide suggestions on how to mitigate possible environmental impacts.
- To provide different suggestions of how to follow up and monitor future developments.

6.1.2 Why SEA?

A Strategic Environmental Assessment (SEA) is a process that aims to ensure that environmental aspects are considered and evaluated on a strategic level regarding policies, plans and programmes (Naturvårdsverket, 2010). The SEA ensures that the possible environmental consequences of a plan are included, and it should work as a tool for efficient decision-making for a sustainable development (Glasson *et al.*, 2012). The expansion of Arlanda airport will lead to an increased demand for efficient transports, which can be solved in a variety of ways. Thus, a SEA is important to address different transport options and its possible environmental impacts. The difference between an SEA and an EIA is explained in table 6.1.

Table 6.1. Main differences between an EIA and SEA (Amended from Glasson et al., 2012).

EIA (Environmental Impact Assessment)	SEA (Strategic Environmental Assessment)
Applies for a specific project	Applies for policies, plans and programmes
Executed late in the decision-process, reactive	Executed early in the decision-process, proactive
Mainly quantifiable/mappable	Mainly descriptive
Often covers a small geographical area	Often covers a large geographical area

6.1.3 Boundaries

6.1.3.1 Geographical Boundary

This SEA focuses on the transport corridor between Stockholm and Arlanda airport, namely road E4 and the railway system (figure 6.3). The transport services we consider are SL commuter trains, the Arlanda Express, Flygbussarna Airport Coaches (Flygbussarna), one SL bus line, taxis and privately owned cars (figure 6.2). The report only focuses on the stretch between Arlanda airport and Stockholm, excluding all other surrounding cities.

6.1.3.2 Passenger Boundary

In this report there is no set time boundary since it is not possible to know when Swedavia will reach the goal of having 70 million passengers per year at Arlanda airport. Instead, we have chosen to concentrate on the capacity of the transport system in terms of its ability to serve all the people travelling between Stockholm and Arlanda airport. In 2016, Arlanda airport had more than 24.7 million passengers (Swedavia, 2017, oral communication), out of which 4.4 million passengers were transfer passengers (Swedavia, 2017a, email communication). Swedavia estimates this number to rise up to 35 million by approximately 2025 and to 70 million in possibly fifty years or more. However, those numbers are based on Swedavia's visions rather than actual calculations and include a great amount of uncertainty.

6.1.4 Assumptions

Due to the uncertainties of what capacity will be needed in the future transport system, there is a lack of official plans for future expansions. Since this SEA is not evaluating a proposed plan, it is not possible to suggest alternative ways of how to carry out the plan or project. Instead options for how the desired development could be realized are created. Therefore, the term 'option' is used in this report, instead of the term 'alternative', which is normally used in this context. Furthermore, various assumptions have been made to be able to present well-estimated options and their impacts. These assumptions as well as what this SEA excludes due to its boundaries is presented below.

Amount of Ground Based Travellers

- Due to Swedavia's goal of Arlanda airport becoming a transfer-hub, we assume that the percentage of transfer passengers will increase over time. As of today, the fraction of transfer passengers is 18 percent (Swedavia, 2017a). Therefore, the following assumptions have been made:
    - When Arlanda airport has 35 million airborne passengers, we assume that 80 percent are ground based travellers and 20 percent are transfer passengers. This equates to 28 million ground based travellers per year, travelling to and from Arlanda airport.
    - When Arlanda airport has 70 million airborne passengers, we assume that 60 percent are ground based travellers and 40 percent are transfer passengers. This equates to 42 million ground based travellers per year, travelling to and from Arlanda airport.

- 90 percent of ground based travellers will travel from Arlanda airport to Stockholm, or the other way around. In 2016, the number of people living in Uppsala was about 10 percent of the amount of people living in Stockholm Metropolitan area (SCB, 2017b). Assuming the same population increase throughout this SEA's timeline, we can estimate that the proportion of ground based travellers coming to Stockholm will be 10 percent less than the total number of ground based travellers (already excluding transfer passengers). According to this calculation, there would be 25 200 000 ground based travellers per year on the stretch between Arlanda airport and Stockholm (about 69 thousand people per day) when Arlanda airport has 35 million airborne passengers. And if Arlanda airport would have 70 million airborne passengers, there would be 37 800 000 ground based travellers per year on the stretch between Arlanda and Stockholm (about 103 thousand people per day). Out of theses ground based travellers, 60 percent or 22 680 000 travel with public transport and 40 percent or 15 120 000 travel with car.

Additional Assumptions

- Regarding our options, we assume that Bromma Stockholm Airport will still be in operation throughout the report's timeline.
- We assume that people living in urban areas will not be negatively affected by urban development concerning the change in visual landscape. This is based on the assumption that people already living in urban areas won't be affected by additional urban development.
- We assume that it is more environmentally friendly to travel by taxi than with a private car since the biggest taxi companies in Stockholm (Taxi Stockholm, Sverigetaxi and TaxiKurir) have an almost hundred percent fossil free taxi fleet. Furthermore, it could be more efficient to travel by taxi since parking is not needed.
- Within our options we do not consider the possible extension of Roslagsbanan to Arlanda airport. Though it is discussed in section 6.7.3.
- Bus line 538 from Rotebro to Arlanda airport is excluded since it takes a longer time to travel with this bus than with the bus line 583 from Märsta.
- Regional trains operated by SJ are considered, but not privately owned regional train companies.
- In this report, electromagnetic fields generated by electric currents in the railway system are excluded due to continuing uncertainty in regards to human health problems (Banverket, 2003).

6.1.5 Identification of Significant Environmental Parameters

The relevant environmental parameters were identified using the method of system thinking through Causal Loop Diagrams (CLD), and this is considered the most significant method for this project (Figure 6.12). The environmental parameters are also connected to related National Environmental Objectives since the future development of these significant parameters could contribute to the outcome of the environmental objectives. The impacts of different options on each parameter is described in detail in the environmental baseline (chapter 6).

- **Physical landscape:** The visual aspects and the use of the landscape, including infrastructure and settlements as well as nature areas.
- **Noise and vibrations:** Unwanted sound and vibrations deriving from road traffic, trains and construction sites.
- **Air quality:** The condition of the atmosphere and the concentration of air pollutants in the area, including particles (PM10 and PM 2.5).
- **Soil quality:** The soil conditions in the area and possible soil contaminations.
- **Water quality:** The chemical, physical and biological characteristics of the water bodies in the area, including both surface water and groundwater.
- **GHG emissions:** The contribution to the emissions of greenhouse gases from the transport sector.
- **Biodiversity and connectivity:** Valuable nature, biodiversity (i.e. flora and fauna) and important ecosystems and habitats in the project area.
- **Risk and safety assessment:** Risks involving road- and railway traffic which is a threat to both human health as well as the environment due to human accidents and chemical leakage from traffic accidents.
- **Socio-economic factors:** The number of employees in the surrounding municipalities and the job opportunities related to the project. Also refers to the health of the inhabitants around the area of Arlanda airport.

6.2. Project Description

6.2.1 Background

The Draft Masterplan for Arlanda airport, initiated in 2014 by Swedavia, has a planning framework for the next 30 years. A new Masterplan proposed in 2017 oversees development of the Arlanda airport for an even longer time, until 2070. This long-term Masterplan, expected to be finished in 2019, outlines the significance of the transport system upgrade, stating that developments which are required to facilitate the forecast growth of traffic demand are necessary. A Draft Masterplan, outlining the structure and focus points for the new long-term Masterplan was published in 2017, this document is the starting point for this report.

As stated in section 6.1.3.1, Arlanda airport can be reached from Stockholm city center by using the Arlanda Express train, commuter trains, Flygbussarna, SL bus number 583, taxi or private car. The public choice in using these alternatives is influenced by factors such as travelling time, ticket prices, frequency of service, reliability, regularity and punctuality. The distribution of different types of transport are shown in figure 6.1.

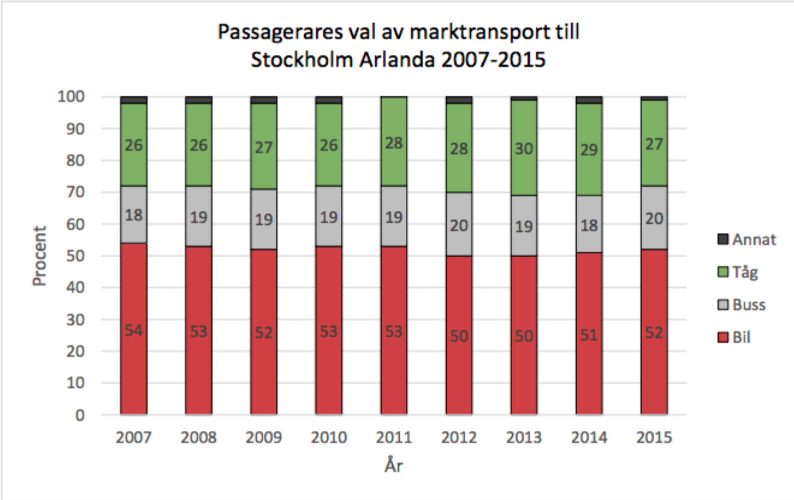


Figure 6.1. The distribution of passengers' choice of means of transportation to Arlanda airport between 2007-2015 (Swedavia, 2015).

The percentage of passengers travelling to Arlanda airport by car and bus are increasing, while the passengers travelling by train slightly decreased between 2014 and 2015. The number of passengers travelling with Arlanda Express decreased by 1,8 percent between 2014 and 2015 (Arlandabanan Infrastructure, 2015).

The vital part of the transport system development is to make means of transportation more accessible while meeting the capacity requirements. This requires the collaborative work with Trafikverket (Swedish Transport Administration), Länsstyrelsen i Stockholms Län (County Administrative Board of Stockholm), several municipalities and other stakeholders. Ticket price and travel time do influence the choice of transport mean. Current prices of a standard non-refundable adult one-way ticket and estimated travel times on the Stockholm-Arlanda airport stretch are presented in table 6.2.

Table 6.2. Ticket prices and travel times on transport routes included in the project.

	Arlanda Express (Stockholm C ↔ Arlanda airport)	**Flygbussarna: All lines**	**SL: commuter train (Stockholm C ↔ Märsta) + Bus (Märsta ↔ Arlanda airport)**	**SL: commuter train (Stockholm C ↔ Arlanda airport)**	**SJ: regional train (Stockholm C ↔ Arlanda airport)**
Ticket price	280 SEK	Online: 99 SEK At station: 119 SEK	30 SEK	150 SEK (Station fee included)	175 SEK
Travel time	20 minutes	45 - 50 minutes	1 h 2 minutes	37 minutes	19 minutes

Figure 6.2. Different transport alternatives for passengers travelling between Stockholm and Arlanda airport, the top left image shows the Arlanda Express (Gkika, 2014), the top right image shows a flygbuss (Solna Gate, 2015), the bottom left image shows a commuter train (SLL, 2016), and the bottom right image shows mainly car traffic on the E4 (Omnibuss, 2009).

6.2.1.1 Proposed Plan

In Swedavia's Draft Masterplan (2017), a general description of the future transport system is explained. According to Swedavia, the demand for mobility and transport is expected to increase as the airport expands. The Draft Masterplan states that Arlanda airport is likely to expand to a capacity of at least 35 million passengers within 10 years, and to a future capacity of 70 million passengers in at least fifty years. These years however are only used as a reference point, and it's rather the capacity itself which is being planned for, and not for those plans to occur within a specific time limit.

The future expansion of Arlanda airport means that transport volumes to and from the airport will increase, placing very high demands on efficient transports, urban planning and technology development. Swedavia predicts that an increased capacity is required for railways and road networks as well as internal transport and parking. Furthermore, an airport shuttle bus is proposed, to provide free and easy access between Stockholm and Arlanda airport. For a sustainable transportation, it is important that different modes of transport are joined in one interchangeable system where trains, buses and cars are accessible and reliable choices for public.

6.2.2 Site Description

The transport corridor that connects Stockholm City with Arlanda airport is located in Stockholm County in a peri-urban area. Highway E4 and the railway delimit the area from the west and from the east, respectively (figure 6.3). The transport route is surrounded by urban, industrial and natural landscapes. Closer to Stockholm, the landscape is characterized by a strong exploitation of the land. Many office buildings, houses, small villas, shopping centers, parking lots, bridges and other urban formations are located close to both the E4 and the railway system. Further to the north, the landscape becomes more open with a mix of forest patches, agricultural fields, meadows, small farm buildings and fields for domestic animals. The rural-urban areas include Häggvik, Rotebro, Bredden, Glädjen, Rosersberg and Märsta.

Many indications point towards a growing amount of traffic north of the Häggvik traffic junction (figure 6.8). This is due to exploitations in the municipalities of Sigtuna, Upplands Väsby and Sollentuna, together with the expanding area called Airport City Stockholm. Another factor that will increase the traffic pressure on the E4 north of Häggvik is the implementation of the Stockholm bypass that is planned to open in 2026 (Trafikverket, 2017b).

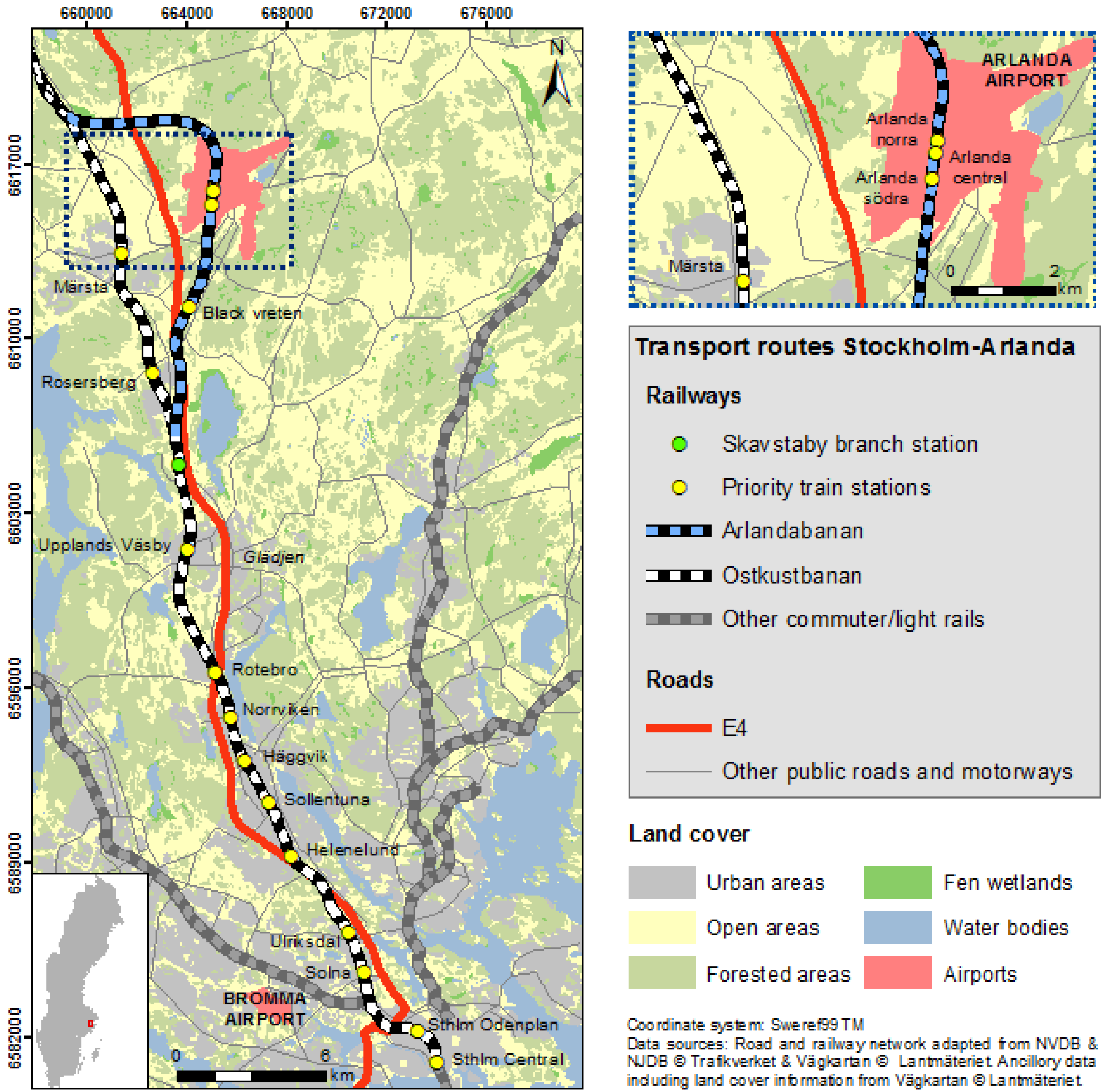


Figure 6.3. Map showing the study area including the main infrastructure facilities from Stockholm Central Station to Arlanda airport as well as the current land cover.

6.3. Methods

In order to establish and evaluate the impacts on the environment due to the proposed options in this SEA, four methods have been used and are described below. In addition to these methods, a literature review has been carried out. The basis for it builds on the Draft Masterplan from Swedavia (Swedavia, 2017), a national plan from Trafikverket for the future Transport system (Trafikverket, 2017b) and the Stockholm County Council's regional development plan for the Stockholm region (Stockholms läns landsting, 2017a). Aside from these; scientific articles, reports, websites and books have been used in order to gather information about the project area, its environmental condition, and the transport system.

6.3.1 Interviews

A number of stakeholders were contacted and asked to be interviewed in order to get their expert opinions. Due to the short project time, public hearings were not possible. The purpose of the interviews was therefore to obtain expert information rather than to find the public opinion on the questions in hand. A list of the interviewed stakeholders can be found in Appendixes, table 6.6. Unfortunately, it was difficult to get in contact with some of the identified stakeholders as well as find time for an interview due to the time constraints of the project. Only a few stakeholders actually replied with answers to the interview questions.

6.3.2 Causal Loop Diagram (CLD)

In the system dynamics methodology, a problem or a system can be represented as a causal loop diagram (CLD). A CLD is a diagram that visualizes the causalities between different parameters in a system. In this case, the system consists of the effects on the transport system between Arlanda airport and Stockholm City due to Swedavia's future goal of having 35 million passengers per year. This method was used to be able to identify the environmental and social parameters that would be affected by the development of the transport system, and also what cumulative impacts that may arise because of it.

However, all of the systems within the project are not dynamic. The construction phase of the project is not a dynamic system, since feedbacks and loops are not present. Therefore, a flowchart of the construction phase was used to show the interactions between the systems parameters. The operational phase of the project is a dynamic system, and therefore a CLD was created.

How to read a CLD

The arrows are assigned different polarities (+ or -), depending on what the causal relationship is between two parameters. If the relationship entails a change in the same direction it is assigned a positive polarity (+), for example; the more cars on the road, the more noise and vibration. But, if the relationship entails a change in the opposite direction it is assigned a negative polarity (-), for example; the more green technology used, the less GHG emissions are released. Due to the size of the original CLD we divided it up by phase: one for the construction phase and one for the operation phase. The decommissioning phase is not considered. Also, to simplify the reading of the CLD's the polarities were assigned different colors. The arrows with a positive polarity are green, and the arrows with a negative polarity are purple.

6.3.3 Impact Matrix

An impact matrix is used to get a clear overview of the magnitude of the impacts each option will have on the various environmental parameters (table 6.3). A five-grade scale, reaching from major positive impact to major negative impact, is used to classify the magnitude of impacts. Each grade on the scale is represented by a specific colour (table 6.3). The impact matrix is based on a matrix constructed by Ekologigruppen AB (Kloth *et al.*, 2011). The timeline in this impact matrix stretches to whatever year Arlanda airport will have 35 million passengers per year, which could be in the mid 2020's according to Swedavia. An impact matrix is further used to assess how different transport options contribute to relevant environmental objectives (table 6.5).

Table 6.3. Definitions of impact matrix grade-scale (modified from Kloth *et al.*, 2011). The matrix classes are used to assess and compare the impacts of different options on the environmental and socio-economic parameter.

++	**Major positive impact**	*Major positive impact on national, regional or municipal interests and objectives. Alternatively, improvement on currently exceeded environmental quality standards, national guidelines or environmental thresholds.*
+	**Minor positive impact**	*Positive impact that does not constitute a major positive impact*
0	**No impact**	*No notable impact.*
-	**Minor negative impact**	*Negative impact that does not constitute a major negative impact.*
--	**Major negative impact**	*Major negative impact on national, regional or municipal interests and objectives. Alternatively exceeding environmental quality standards, national guidelines or environmental thresholds; or clearly worsen currently exceeded environmental quality standards, national guidelines or environmental thresholds.*

6.3.4 Geographical Information System (GIS)

Through ArcGIS, a GIS software, we have created four maps to illustrate and analyze the project area. Figure 6.3 is a comprehensive map, showing the important transport routes between Stockholm and Arlanda airport that we will focus on in this report. Figure 6.9 is an overview of the groundwater and surface water bodies in the area, intended to provide a backdrop for analyses of water quality.

Further maps are created for the two options proposed in this report, the railway option (figure 6.6) and the road option (figure 6.8). An intersection analysis was done in ArcGIS to determine what physical features fall within our proposed expansion zone for roads and railways respectively. This analysis includes any potential overlap with buildings, recreational areas, as well as areas protected under Swedish law such as nature/culture reserves and ancient relics (although we have chosen not to include smaller cultural relics). Groundwater protection areas will be excluded from this analysis as those areas are vast and visually represented in figure 6.9. Train sidings and spurs running adjacent to the main lines in some sections are also not included in the analysis, in case of further expansion of the railway potential new locations for these tracks needs to be studied.

Transport network data used for analysis originates from Nationella vägdatabasen (NVDB) & Nationella järnvägsdatabasen (NJDB), although cartographic generalization was done for visualization purposes based on Vägkartan from Lantmäteriet, which also provided further data of land cover digitized at a scale of 1:100 000. Data regarding potentially vulnerable areas (buildings and protected areas like nature reserves and ancient relics) come from Fastighetskartan. Vatteninformationssystem Sverige (VISS) was used as a data source for localisation of ground water bodies and surface water bodies.

6.4. Options

The suggestion of alternatives is a vital aspect of both EIA's and SEA's because that is when other ways of achieving the planned activity are considered (Glasson *et al.*, 2012). Since this report is a SEA, the proposed options are formulated on a more comprehensive level than they are in an EIA, as these options are assessed early in the planning process (*ibid.*).

The strategically assessed options presented below suggest different developments in the area to be able to achieve the passenger capacity that Swedavia wants at Arlanda airport in the future. These options' most significant environmental impacts are assessed and the mitigation measures that could limit them are explored. The options will deal with the following factors: location, operating processes, design, size, types of technology, and the zero option where the status quo remains.

6.4.1 Zero Option

The amount of passengers flying to and from Arlanda airport has increased with approximately 5 percent per year during the last 5 years (Swedavia 2017b). The zero option refers to the option in which Arlanda airport will have a continued development as per the status quo, without Swedavia implementing the proposed plans regarding increasing Arlanda airport capacity to 35 million passengers in mid-term perspective and to 70 million passengers in a long-term perspective. This zero option would most likely lead to less demand for the transport system to increase its capacity to be able to transport that amount of passengers to Arlanda airport.

Still, the transport system needs to increase its capacity to be able to avoid traffic congestion, due to the present and estimated future population increase in the project area. A growing population will also increase the already high demand for residences, which will probably have a negative effect on the environment. It could also lead to a need for expanding the road system and public transport with more roads, bus- and trains stops, and maybe new routes within public system.

In addition, a better infrastructure connectivity between cities in the Mälardalen region may increase job opportunities since it creates the possibility for people to live far away from their jobs (East Midlands Development Agency, 2006). This could lead to an increase of people travelling by car and public transport to and from the project area, and possibly more traffic congestion.

6.4.2 Option 1 - The Railway Option

Option 1 entails both an increase in efficiency and capacity regarding the railway system between Stockholm city and Arlanda airport. No change in the road system will be present within this option (E4). An increase in efficiency could involve lower ticket prices, more frequent departures and number of trains, more train carts per train and more efficient technologies regarding both the railway and the trains.

This option's increase of capacity is based on Trafikverkets plan to expand the railway section on Ostkustbanan between Solna municipality and Uppsala with two additional tracks (Trafikverket, 2016). See schematic in figure 6.4. In this SEA we only focus on the railway section between Solna municipality and Märsta station, since it is not physically possible to expand the railway system between Stockholm City and Solna municipality. More specifically our analysis is focused after the train depot near Solna station where 6 tracks become 4, and the potential for expanding the number of tracks moving forward to Märsta station is large.

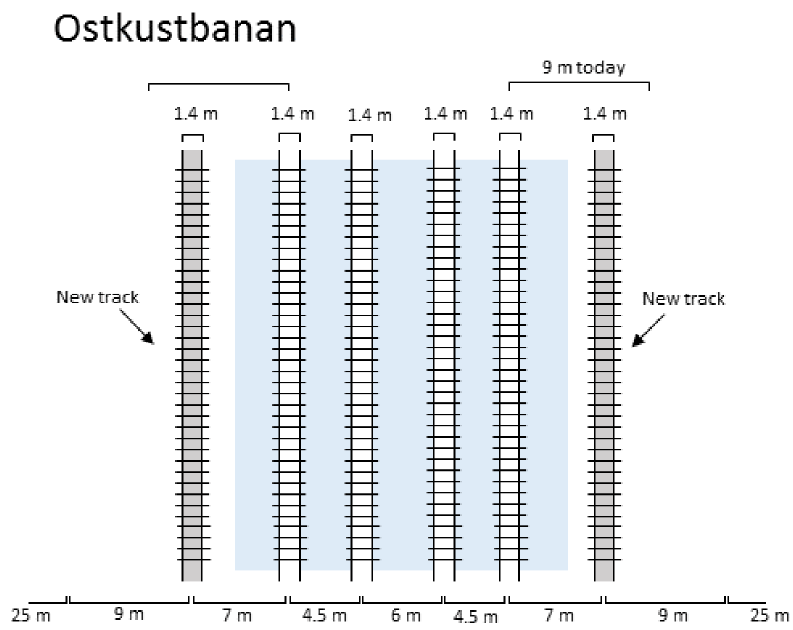


Figure 6.4. Schematic figure showing addition of two new tracks on either side of existing tracks for Ostkustbanan

At Skavstaby branch station trains going directly to Arlanda switch to Arlandabanan, a train line which currently has two tracks. How many additional tracks Arlandabanan will be expanded with as well as the location of those tracks is currently up for debate (Trafikverket, 2016).

However, for the purpose of this report we will assume that Arlandabanan is expanded with two additional tracks, which is visualized in figure 6.5.

The efficiency regarding all trains (commuter- regional- and long distance trains as well as Arlanda Express) could be increased by reducing ticket prices so that more people will see trains as an option instead of taking their car or a taxi. In the railway option, the frequency of departures will increase. The amount of trains in operation can also increase, together with the number of carts that are attached to each train. Efficiency within this option also means that design of the inside of trains should be spacious in order to fit as many passengers as possible.

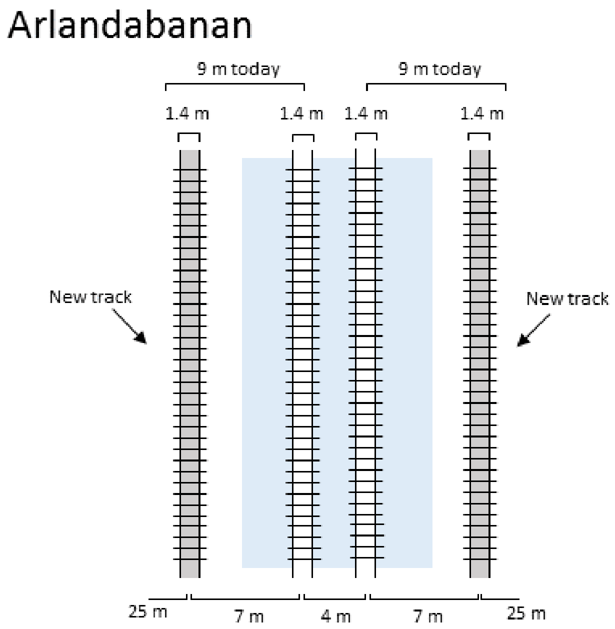


Figure 6.5. Schematic figure showing addition of two new tracks on either side of existing tracks for Arlandabanan

Within this option, improvements in technology are also considered. The use of more efficient and environmentally friendly technologies could lead to less environmental and health impacts. For example, more efficient engines and less friction between train and the railway track will lead to less particles tearing from the tracks. Furthermore, the implementation of trains that partially run on solar power could save a lot of energy and contribute to a more sustainable transport system. As of today, travelling by train is more environmentally friendly than travelling by car. The reason for this is that trains operating between Stockholm City and Arlanda airport run on green electricity, while car traffic contributes to greater greenhouse gas emissions. Thus, car traffic counts as a less environmentally friendly way of travelling.

The bus route of the SL bus line 583, operating between Märsta station and Arlanda terminal 5 is also included in this option (figure 6.6). This is due to the fact that one of the routes available to Arlanda airport is by commuter train to Märsta station and then bus 583 to Arlanda terminal 5. This is currently the cheapest way of travelling from Stockholm to Arlanda airport. Since the frequency of departures of the commuter trains is a possibility within this option, it should also be considered that bus line 583 needs to increase its departures which could lead to impacts on environment along the bus route.

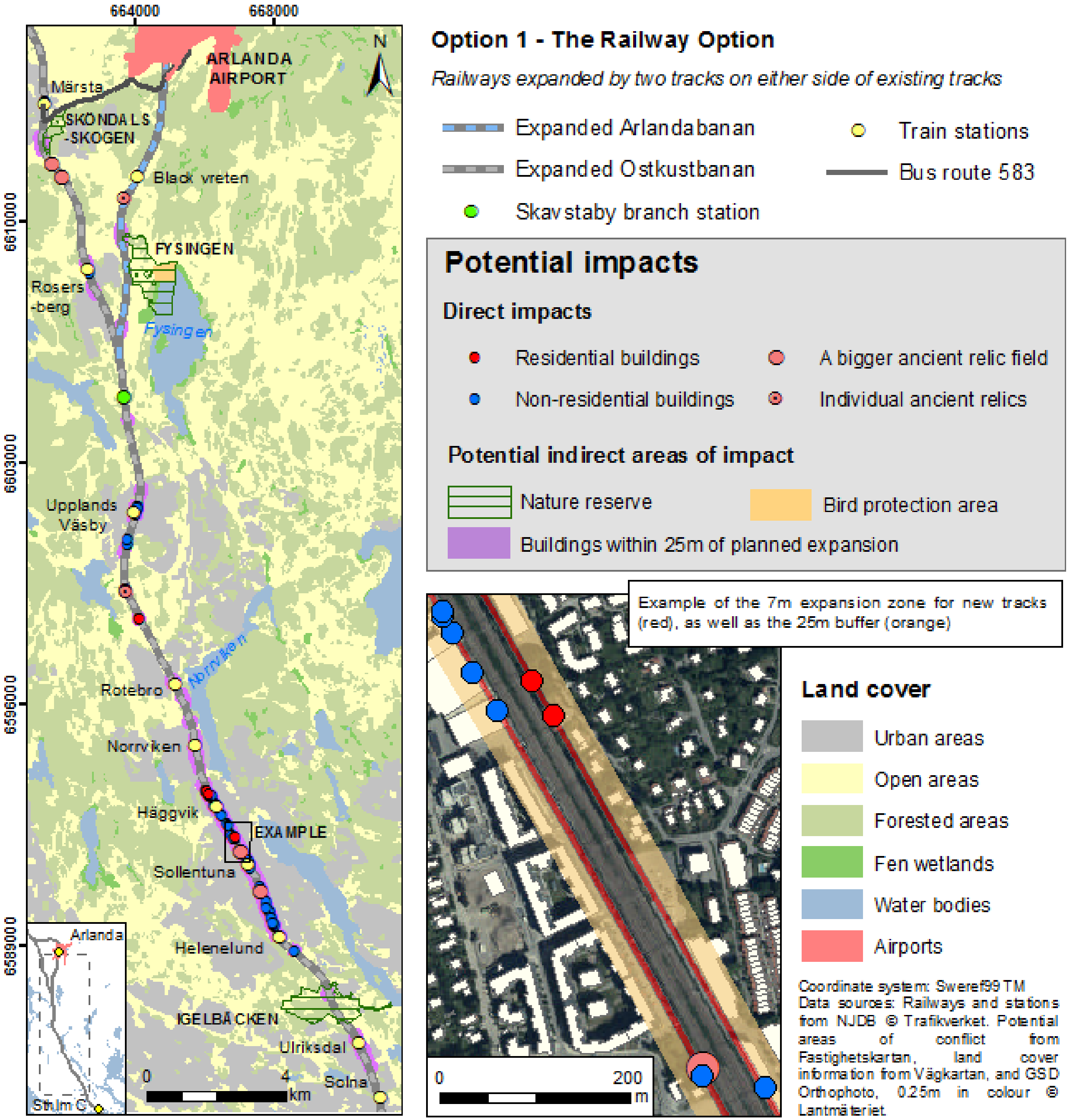


Figure 6.6. This intersection map shows expansion of the railways from 4 to 6 tracks along Ostkustbanan, and an expansion from 2 to 4 tracks along Arlandabanan, and how this impacts existing building infrastructure and areas of cultural and natural interest

6.4.3 Option 2 - The Road Option

Option 2 entails no change in the railway system, but an expansion of the E4 between Stockholm and Arlanda airport with two more lanes in both directions (figure 6.7). Also, suggestions for how to increase the efficiency within the road transport system are put forward. The expansion of lanes would be constructed where it is physically possible. The new lanes at E4 would be added in the segments of Häggvik – Rotebro, Rotebro – Glädjen and Glädjen – Arlanda airport (figure 6.8).

The traffic volume on the E4 is currently close to maximum capacity (Trafikverket, 2017d). To avoid traffic congestion and encourage more efficient and sustainable transport solutions, one of the lanes in each direction should be reserved for public transport and more environmentally friendly transportation means. This entails Flygbussarna buses, taxis and airport shuttle buses provided by Swedavia. This environmentally friendly lane will from now on in the report be referred to as the green lane.

The efficiency regarding Flygbussarna buses is increased through lowering of prices so that more people choose bus travel instead of private cars, and also the frequency of departures shoud be increased, and if needed also the amount of buses in operation. To promote public transport, Swedavia would in this option implement a free airport shuttle bus between Arlanda airport and Stockholm City. It could potentially be free since the internal transport at Arlanda airport, which is managed by Swedavia, is free. Although the amount of departures would not be as frequent as the Flygbussarna buses to avoid conflict due to economic competition. Efficiency within this option also means that the design of the buses should be spacious in order to fit as many passengers as possible.

Within this option, use of new technology is also considered. Use of renewable fuels such as biodiesel, and green electricity have low or no emissions of greenhouse gases. Renewable fuels can also have low emissions of other pollutants such as NOx, PM2.5, PM10 and others. New engine technology could clean the exhaust from vehicles that still emit high levels of pollutants (Weber & Amundsen, 2013). Carefully chosen road surface coating reduces noise and particle emission from road tear. Conscious choice of tire type could also reduce particles from road tear.

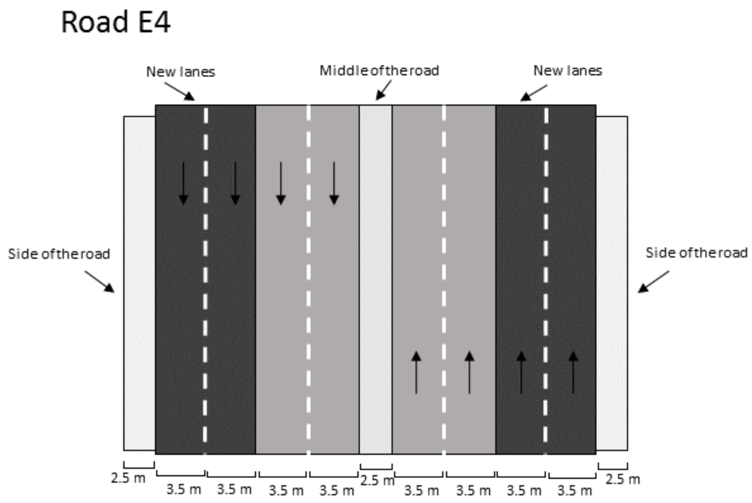


Figure 6.7. The schematic figure shows that two additional lanes would be constructed in each driving direction. The measures for the width of the lanes is based on Trafikverket (2004).

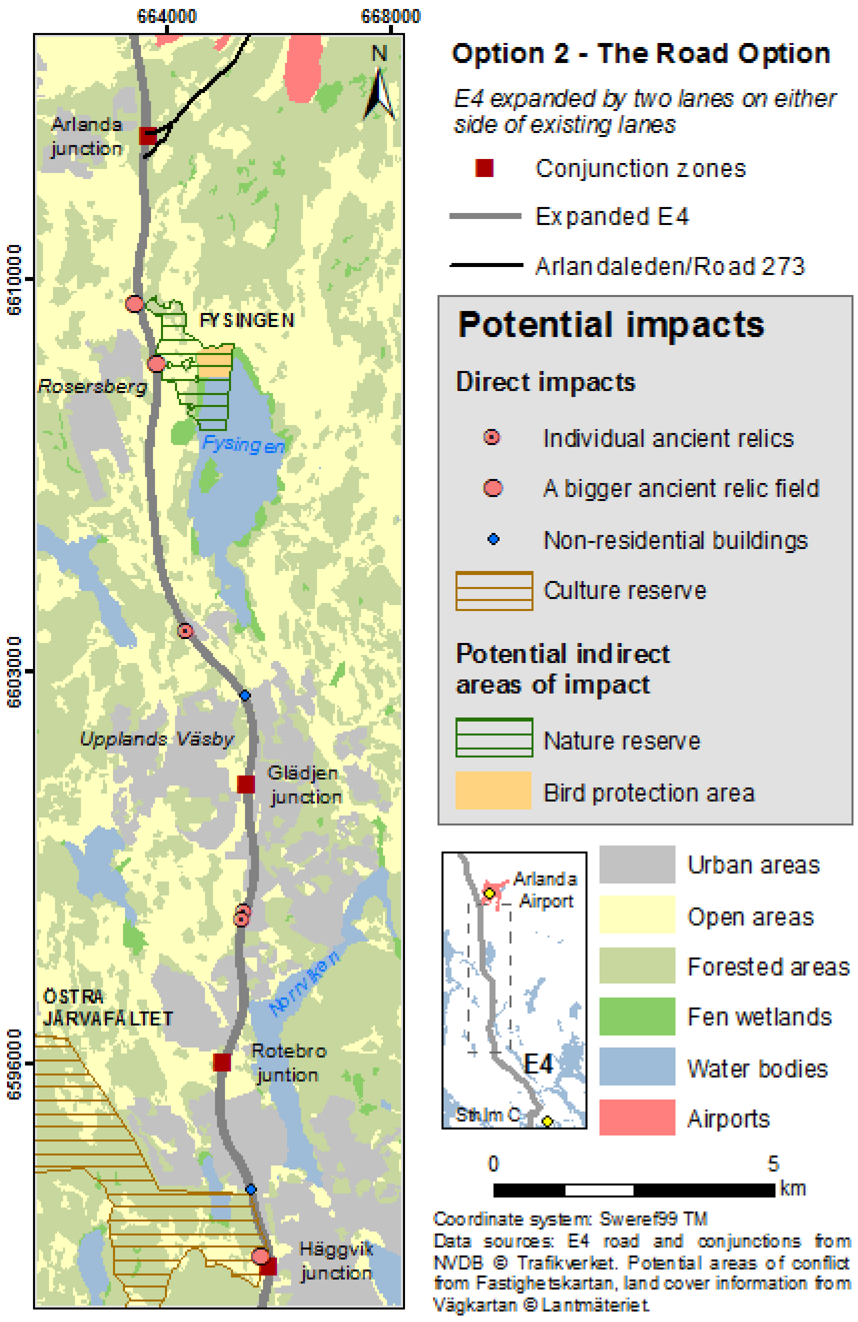


Figure 6.8. This intersection map shows expansion of the E4 from 4 to 6 lanes, and how this impacts existing building infrastructure and areas of cultural and natural interest

6.5. Environmental Baseline, Effects and Impacts

6.5.1 Physical Landscape

6.5.1.1 Baseline

The southern half of the area between Stockholm and Arlanda airport is an urban landscape. This stretch of E4 passes through several Stockholm districts and shopping areas, and several office buildings and residential areas are located close to the road. In the northern half, the landscape is dominated by fields, farmlands and minor forested areas. Basically, the railway passes through the same landscape as the E4. However, they are not entirely parallel, and the railway leaves the urban area a bit earlier than the E4 does (figure 6.3).

6.5.1.2 Zero Option

Stockholm is expected to have a large increase in the city's population in the next few years (SLL, 2017a). This leads to an increased development of urban areas and an increase in infrastructure. Densification of current urban areas and further urbanization of rural areas will then be necessary. However, the impacts of the Zero option would have no noticeable impact on the physical landscape since it does not include any construction of new roads or railways.

6.5.1.3 Option 1

The expansion of the railway will have a major negative impact of the physical landscape along the southern half of the railway stretch. Many buildings and residential areas are located close to the tracks between Solna and Rotebro, and according to a report from Trafikverket (Trafikverket, 2016) and from this report's GIS-analysis, several buildings will be negatively by the proposed plan (figure 6.6). As can be seen in the map an expansion of 7m in either direction to make room for new tracks puts the railway on a collision course with many existing buildings that would need to be torn down.

The northern half of the railway stretch primarily consists of agricultural landscapes and forests, and no major intrusions in the landscape are needed to expand the railway. Thus, the expansion of the railway north of Rotebro will have much less of an impact on the physical landscape (figure 6.6)

Mitigation Measures

Many residents in the area will be negatively affected by the proposed railway plan. Although the railway will be expanded in the most efficient location to prevent severe intrusions, several houses located close to the railway might still be demolished. This requires mitigation measures such as restoration and compensation, including direct payments to the owners of the land where the railway will be expanded.

6.5.1.4 Option 2

Expanding the E4 with two additional lanes will have a minor negative impact on the physical landscape. In urban areas, the new lanes will collide with a few buildings, and it might also require reconstructions of the surrounding shopping areas and parking spaces (figure 6.8). In rural areas, the construction of lanes will imply some intrusions in the landscape and loss of green space. However, according to the assumption in section 6.1.4, most people living in urban areas will not be negatively affected by additional urban developments regarding the factor of visually pleasing landscape. Thus, the visual landscape in the rural areas will not be greatly affected by the new lanes, since the area where the road would be expanded is located next to the existing road.

Mitigation Measures

The additional lanes on E4 will not involve major intrusions of existing residential areas, although a few buildings and shopping areas might be affected. As mentioned in section 6.5.1.3, mitigation measures such as restoration and compensation might be needed for the landowners affected by the expansion. To prevent changes and to minimize the adverse impacts of the visual rural landscape, alternative designs of the road and its surroundings could be considered. Tree planting, slope recontouring and other improvements are efficient methods to compensate for unavoidable adverse impacts connected to the road expansion.

Summary of Possible Impacts Connected to the Physical Landscape

Zero Option

The Zero option will most likely have *no impact* on the physical landscape since it does not include any construction of new roads or railways.

Option 1

The expansion of the railway will most likely have a *major negative impact* of the physical landscape along some railway sections and *minor negative impacts* along others due to the interference between the proposed railway and the existing buildings in the area.

Option 2

The expansion of E4 with two additional lanes will have a *minor negative impact* on the physical landscape in the urban areas due to the interference between the road and the existing buildings. The rural areas will not be greatly affected by the expansion.

6.5.2 Noise and Vibrations

The Swedish parliament and government have set the target values for traffic noise in proposition 1996/97:53. The following targets are listed in the proposition and should normally not be exceeded when constructing new, or reconstructing already existing traffic infrastructure:

- 30 dB(A) equivalent level indoors.
- 45 dB(A) maximal level indoors during nighttime.
- 55 dB(A) equivalent level outdoors (at the facade).
- 70 dB(A) maximal level on a patio connected to a house.

The occurrence of noise and vibrations from rail-based traffic depends on what type of train is used, the speed of the train, how long the train wagons are and how many trains are connected to each other at the same time (Trafikverket, 2017a). Levels of noise and vibrations also depend on factors such as railway structure, different types of track components, the condition and maintenance of the railway tracks, and the soil conditions on the ground where the rails are built (*ibid.*).

A doubling or halving of the train speed means that the noise level will either increase or decrease by around 4 – 10 dBA (Naturvårdsverket, 2016). A doubling or halving of the train length or the traffic volume will generally mean a 3 dBA higher or lower general noise level (*ibid*).

Boverket's report *'Buller i Planeringen'* (2008) describes that exposure from multiple noise sources at the same time – for example from road and rail traffic – increases the overall experience of disturbing noise. The reason for this is that noise from different sources has different characteristics. The disturbance also increases if vibrations are present at the same time. Usually, the feeling of noise disturbance is stronger if the environment is perceived as unsafe or stressful (*ibid.*).

6.5.2.1 Baseline

The main sources of noise between Stockholm and Arlanda airport are the road E4 and the railway tracks for commuter trains, the regional trains and Arlanda express. According to noise maps of the area, the noise levels are > 65 dBA in direct connections to the E4, and >55 dBA in surrounding areas closely connected to the road (appendix figure 6.13).

Appendix figure 6.14 shows that the rail based traffic spreads noise in the same manner as car based traffic at the same decibel levels, albeit with a slightly lower distribution area than with car traffic (Trafikverket, 2012).

6.5.2.2 Zero Option

Following the zero option, there would be no additional noise from the construction and widening of the road E4 or for expansion of the railway tracks. The increase of operations noise would be lower in the zero option than in option 2, since a wider road would lead to more people travelling by car. No expansion of the railway tracks would mean that the train departures would be the same as today and would therefore keep the same noise level.

6.5.2.3 Option 1

With additional railway tracks being built, more noise and vibrations will occur during the construction phase. The construction machines together with the vehicles needed to transport materials back and forth from the construction sites will also create noise and vibrations. Seen in figure 6.6 is an example of a residential area where many buildings are found within a 25m from the planned expansion, and noise and vibrations could be a big issue for the residents of this area.

This construction will most likely not only take place during daytime, but also during late evenings and nights. Both the noise and vibrations can have negative impacts on the sleep cycle for people that live close to areas that are affected by those disturbing factors.

There will also be an increase in operation noise due to more frequent departures from Stockholm and Arlanda airport. Trains can cause specific noises, such as curvature noise, braking noise, noise from railway bridges and gears and slams from loose wagon parts. When the train wheel is rolling on the railway track it is not rolling evenly. This irregularity is the source of vibrations in the wheel and in the tracks - those vibrating structures will in turn cause so called rolling noise (Trafikverket, 2017a).

With a higher number of flight departures, there will be a need to increase the departures of bus 583 between Märsta and Arlanda airport. This will lead to increased noise levels around the buildings situated close to the bus route. If houses are placed close enough, the residents will also sense vibrations from the buses.

Mitigation Measures

As cities expand in size, noise management becomes more complex. In Stockholm, many of the current development projects are exposed to high levels of noise from for example traffic or industries. If noise issues

are submitted early in the planning process, it is easier to find good solutions of how to handle them. With help of thoughtful placement and design when constructing buildings and traffic infrastructure, high levels of noise can be prevented - or at least restricted (Trafikverket, 2016). A new type of quiet brake block made out of composite material could reduce the noise from trains very efficiently (SVT, 2017). According to the Swedish Transport Administration, a switch from the current brake blocks to the composite ones would have the same effect as building noise walls around the entire Swedish rail network (*ibid.*).
Polishing the rails can be another way of reducing the noise level around the railway tracks (Stockholms Stad, 2013). Rail squeal can be a problem when the weather is dry (*ibid.*). The squeal especially appears in rail curvature (*ibid.*). The noise from rail squeal is more or less frequent, although it varies in strength (*ibid.*). Since the issue is erratic, it is not taken into account when making noise calculations. SLL (2017) is actively working to minimize rail-screech with lubrication equipment and friction modifiers. Wheel dampeners can also be implemented (*ibid.*).

6.5.2.4 Option 2

If the E4 is broadened with two more lanes and additional bus traffic is implemented, the levels of noise will increase dramatically during the construction phase. When constructing a road, the levels of noise considered as most disturbing originates from pilework, sheet piling, boring and blasting. The removal of waste material from road construction sites with help of heavy transport vehicles may also be a source of additional noise along transport routes (Trafikverket, 2017). The construction of new bus stops and transport nodes will also increase the noise levels in the surrounding areas.

When the E4 was widened in the Stockholm area during an earlier stage, Trafikverket had to erect an embankment and two-meter-high noise screens along the construction site in order to handle the guideline values of 55 dBA along the facade on a number of properties close to the construction site (Trafikverket, 2016).

The addition of new lanes and bus routes together with an increase in population will most likely increase the traffic on the E4. Previous studies show that expansion of highly congested roads only provides temporary congestion reductions, since broader roads allow more vehicles (Litman & Colman, 2001). In a long-term perspective, expanded roads generate a significant amount of traffic, leading to even more congestions. This phenomenon is called induced traffic (*ibid.*).

Mitigation Measures
One of the most important factors for lowering road traffic noise emissions is the asphalt (Stockholms Stad, 2013). A road made with newly coated asphalt will reduce the noise with 2-3 dBA compared to old asphalt (*ibid.*). Asphalt consisting of smaller stones will also have impact on the noise levels. According to the Stockholm City environmental plan, the standard pavement should be made with a maximum of 11 mm rock-size (*ibid.*).

When broadening the E4, a lot of the ground sediments will have to be removed. If the soil is not contaminated, it could be used for the construction of noise walls along the road (Stockholm Stad, 2016). Additional noise walls that have to be built should be covered in vegetation - both to make them more visually pleasing, but also as an ecosystem service that will help purifying the air along the E4 (*ibid.*). Vegetation could be used as absorbent on roofs and facades on buildings close to both the E4 and the railway tracks. Additional trees and bushes should also be planted for their noise reduction abilities as well as air purification abilities (*ibid.*).

Summary of Possible Impacts on the Levels of Noise and Vibrations

Zero Option
The zero option will most likely have a *minor negative impact* on noise emissions and vibrations, since the population in the Stockholm region will grow, leading to more traffic than today.

Option 1
The expansion of the railway will most likely have a *minor negative impact* on noise emissions and vibrations, since noise and vibrations from both construction and operations will increase.

Option 2
The expansion of the E4 will most likely have a *major negative impact* on noise emissions and vibrations, since noise and vibrations from both construction and operation will increase.

6.5.3 Air Quality

Combustion of fuel and tear from roads and tires lead to emissions of various types of particles. Particles are characterized by their size, particulate matter with a diameter less than 10 µm (PM10) and particulate matter with a diameter less than 2.5 µm (PM2.5) (Naturvårdsverket, 2017a). Both PM10 and PM2.5 can lead to several negative health effects such as cardiovascular diseases and lung diseases (*ibid.*). Combustion of fuel also leads to emission of the pollutant nitrogen dioxide (NO_2) (Naturvårdsverket, 2017b). NO_2 emissions have a negative effect on human health since they can cause irritation in the respiratory systems. The emissions also affect the environment in a negative way since NO_2, together with sunlight and other organic chemical compounds, form tropospheric ozone. Tropospheric ozone has several negative impacts on human health and plant life and it contributes to the greenhouse effect (Naturvårdsverket, 2017c).

6.5.3.1 Baseline

PM10 and NO_2 are the two types of air pollution that is the most difficult to keep on a safe level in Stockholm. The limit for the annual mean values for PM10 and NO_2 is 40 µg/m^3, but the target according to the environmental objectives is 15 µg/m^3 for PM10 and 20 µg/m^3 for NO_2 (SLB, 2017).

In the area between Stockholm and Arlanda airport, the average levels of both PM10 and NO_2 are relatively high. The levels of PM10 exceeds the annual limit value in several places, especially in the area around E4 in Upplands Väsby (SLB, 2017). The annual limit value of NO_2 is also exceeded in several places along the E4 between Stockholm and Arlanda airport (*ibid.*). The environmental objective of 15 µg/m^3 is far from being reached along the entire stretch of the E4 between Stockholm and Arlanda airport for both PM10 and NO_2.

The railway system is fueled by renewable electricity and has therefore no emissions of NO_2. However, there can be emissions of PM10 as a result of train track tear. Particles are released from both tracks, wheels and brakes (Gustafsson *et al.*, 2006). In tunnels, such as the tunnel under Arlanda airport, high levels of PM10 can accumulate (Trafikverket, 2012). The levels of PM10 at the station Arlanda C have been measured to be 5 times higher than the limit daily mean value of 50 µg/m^3 (Gustafsson *et al.*, 2006). However, railway tunnels are not governed by the limit daily mean value. Limit levels of PM10 are not exceeded where the railway tracks are above ground (*ibid.*).

6.5.3.2 Zero Option

The proposed population increase in Stockholm will lead to a demand of increased transportation infrastructure regardless of whether or not the plans to develop Arlanda airport are implemented. Hence, the zero option would have a minor negative impact on the air quality, since a larger population will lead to more vehicles. An increase in the amount of vehicles will lead to an increase of PM10 emissions from road and tire tear. It will also lead to more traffic congestion, which in turn leads to increased emissions. The estimation of the amount of NO_2-emissions depends on the expected development in fuel technology. According to a prediction from Trafikanalys (2017), 50 percent of the cars in 2030 will be electric hybrids or electric cars, and 40 percent will be fueled by diesel (biodiesel included) or gasoline. Electric cars have no emissions of NO_2. However, when considering electric cars, it is also important to take into consideration if the electricity powering the car originates from renewable sources or not. Electricity from fossil sources worsens the air quality at the location of the production and contributes to climate change (Lindström *et al.*, 2017). The use of Biodiesel could actually increase NO_2-levels depending on the type of biodiesel. HVO is an example of a type of biodiesel with relatively low NO_2-emissions and FAME is an example of a type of biodiesel with high NO_2-emission (*ibid.*). This suggests that the zero option would increase the amount of NO_2-emissions. However, the development of vehicle fuel use remains uncertain.

6.5.3.3 Option 1

Option 1 proposes a number of ways to increase the capacity and the efficiency of the railway system. One of the proposals is to expand the railway system with additional tracks. Both PM10 and NO_2 will be emitted during the construction of new railway tracks, which could have a negative impact on the air quality in the area. There would also be an increase in PM10- levels as a result of an increase in railway departures on existent tracks and from trains on the new track once they are operational. Since the levels of PM10 inside the tunnel under Arlanda airport caused by railway traffic are already very high, it is likely to assume that the levels could be hazardously high as a result of option 1. An increase in amount of departures for bus line 583 could slightly raise the levels of PM10 and NO_2 along its route. However, the buses on the route use fossil free fuel (Arriva, 2017). HVO-diesel is the most common fuel for buses in the area (Arriva, 2017). Since HVO-diesel has relatively low levels of NO_2-emissions, as discussed in section 6.5.3.2, and it is only an increase frequency for one bus line, the increase is probably so small that it is insignificant. The congestion on the roads would probably decrease slightly as a result of more people taking the train. However, this decrease would only be noticeable for a short period of time since more people use cars as a means of transportation when the roads are less congested (Litman & Colman, 2001). Thus, the impact from traffic is estimated to be the same as in the zero option.

Mitigation Measures

It is possible to reduce the release of PM10 from railway tracks, wheels and brakes by constructing them of durable materials. The largest release of particles happens when a train brakes (Gustafsson *et al.*, 2006). Thus, one possible mitigation measure of PM10-pollution could be to plan the brake process of trains in a way that releases the least amount of particles (*ibid.*). For example, when approaching a tunnel, the brake process could start outside the tunnel if possible. Good ventilation is also a measure to reduce the levels of PM10 in the tunnels.

6.5.3.4 Option 2

A broadening of E4 with two additional lanes will have a major negative effect on air quality. During the construction of the two lanes, there will most likely be an increase in occasional traffic congestion on the road, since construction work could obstruct the traffic. This would lead to increased traffic emissions localized to the construction areas, which would worsen the air quality. Heavy machines used during the constructions also emit pollutants, which contribute to a worsened air quality. After the construction, when the new lanes are in operation, there will be less traffic congestion. However, more people will most likely travel by car as a result of the temporarily high accessibility, leading to even more congestions in a long-term perspective (Litman & Colman, 2001). This would increase the emissions even further. If the relative distribution of fuels remains the same as discussed in section 6.5.3.2 in 2030, the emissions of nitrogen dioxide (NO_2) would increase to very high levels. The limit values of both NO_2 and PM10 are exceeded in the baseline at parts of the E4. Option 2 indicates that the limit level could be exceeded or greatly exceeded on the full stretch between Stockholm and Arlanda airport. The green lane reserved for public transport, taxis and car pools promotes the use of other means of transport other than private cars. This has a positive impact on the air quality, since fewer cars means less emission of pollutants. However, the significance of this decrease compared to the overall increase of pollutants by traffic emissions caused by the road expansion is probably not very large. But if none of the suggested lanes would be a green lane, the air quality would be even worse than assumed in this option.

Mitigation Measures

It is possible to reduce the emission of NO_2 by installing extra catalytic exhaust cleansing in the engine of the car (Naturvårdsverket, 2017d). One example of such a system is Selective Catalytic Reduction (SCR), which converts NO_2 into other substances. However, a problem with this method is that laughing gas, which is a very powerful greenhouse gas, is a byproduct of the process (Trafikverket, 2017c). It is necessary to conduct further research into improving the exhaust cleansing technology. A way to mitigate emissions of PM10 is to decrease the use of studded tires during winter time and to use highly durable road coating (Gustafsson, 2004). Another mitigation measure is to use fuel that emits as low levels of NO_2 as possible.

Summary of Possible Impacts Connected to the Air Quality

Zero Option

The zero option will most likely have a *minor negative impact* on the air quality due to an increased amount of PM10 and NO_2, caused by a higher pressure on the current transport system.

Option 1

The expansion of the railway will most likely have a *minor negative impact* on the air quality due to an increased amount of PM10 and NO_2, caused by the constructions of the new railway and its related traffic congestions. Furthermore, the levels of PM10 inside the railway tunnels will increase due to the increased amount of trains.

Option 2

The expansion of the road will most likely have a *major negative impact* on the air quality due to largely increased amounts of PM10- and NO_2-emissions, both during the construction and operation of the road.

6.5.4 Soil Quality

6.5.4.1 Baseline

Currently no data is available regarding soil quality in the study area. But even though no investigation of soil contamination along the E4 and railways has been done, is it likely an increased concentration of various organic and inorganic contaminants exist through runoff of stormwater and particle deposition next to transport infrastructure. The reason behind the contamination along roads is salting for de-icing purposes (Olofsson & Lundmark 2009), leakage of hazardous substances through accidents (Yanxun, 2011; Eiswirth & Hötzl, 1997), oil/fuel spilling (Halmemies *et al*., 2003) and abrasion of tires and brakes (Adachi & Tainosho 2004). Railway traffic impacts are caused through spilling of lubricants and emissions of heavy metals through abrasion from wheels, brakes, rails and contact lines (Arquiaga *et al*., 2012). The risk of train accidents is quite low but it is still a possible source for leakage of hazardous substances (Yoon, 2009).

Climate change influences the impact of railway traffic on soil and water quality. Extreme precipitation events, which are already increasing in frequency (Eckersten 2016), could lead to a higher runoff of contaminated stormwater into the soil, and subsequently into the surface waters and the groundwater. Furthermore, the increased winter precipitation (SOU, 2007) makes extended use of salt for de-icing the roads necessary.

6.5.4.2 Zero Option

The expected higher traffic frequency due to an increased population could raise the number of accidents. The accidents could contaminate soil through leakage of oil (Yanxun, 2011) and hazardous goods (Eiswirth & Hötzl, 1997). Hence, the more accidents, the higher the risk for groundwater contamination. Another impact is contamination through stormwater, since the concentration of heavy metals, organic substances and nutrients increase proportionally to quantity of cars (Trafikverket, 2011). This impact could be more significant with an increased road traffic. Climate change will affect the significance of road salting because it is likely to be needed more often than today because of higher winter precipitation (SOU, 2007).

6.5.4.3 Option 1

The construction of two extra railway tracks would cause disturbance in soil structure and could lead to soil erosion because of the bare lying soil (Arquiaga *et al*., 2012). Another physical impact of construction will be soil compaction due to the use of heavy machinery (Randrup, 1997). In addition to soil compaction, the use of heavy machinery always holds the risk of spilling or leaking of fuel (Arquiaga *et al*., 2012). Further substances like lubricants, paints and solvents which are also found on construction sites are hazardous and could cause harm to soils (*ibid.*).

During the operation stage, the increased quantity of trains would lead to an increased amount of abrasion materials and also an increased probability of spilling contaminants like lubricants from trains and track switches. More frequent departures of the bus line 583 could have a minimal impact on soil quality due to the increase of road dust emissions.

Mitigation Measures

The impacts during the construction phase are difficult to avoid completely but they can be minimized with well trained staff. The contaminations from abrasion material, especially the brake dust, could be reduced with an adapted braking process of the trains (section 6.5.3.3). The direct deposition itself is hard to prevent but the indirect deposition through eluviation could be decreased with a drainage and a water treatment system.

6.5.4.4 Option 2

The expansion of the E4 with two new lanes would require new construction. This construction would cause similar impacts to those mentioned for Option 1 (section 6.5.4.3). These impacts could be, for example, disturbances to soil structure, soil compaction, erosion and spilling of hazardous substances. During the operation stage, two extra lanes would have two effects. First, with an enlarged road, the traffic and emissions of tire and brake dust would increase and the levels of soil pollutants (especially heavy metals) would be higher (Trafikverket, 2011). Second, during wintertime, significantly more salt would be needed to keep the larger surface free from ice and snow (Ihs, 2002).

Mitigation Measures

Mitigation of construction impacts: see section 6.5.4.3. The discharge of tire and brake residues and salt can be removed with street sweeping and street washing (AIRUSE, 2013). Street cleaning can reduce, but not avert, discharge of road dust into nearby soil and water. A roadside drainage system with an attached water treatment would be more efficient (Trenouth, 2018).

Summary of Possible Impacts Connected to the Soil Quality

Zero Option

The zero option is assessed to have a *minor negative impact* on soil quality due to an increased amount of road dust and road salting. There will also be a higher risk for leakage of hazardous substances due to an increased amount of accidents.

Option 1

The expansion of the railway is assessed to have a *minor negative impact* on soil quality due to an increased amount of abrasion material and a higher probability of spilling hazardous substances.

Option 2

The expansion of the road is assessed to have a *major negative impact* on soil quality due to a large increase in the amount of road dust and due to the significant increase of road salting required due to a larger road surface.

6.5.5 Water Quality

6.5.5.1 Baseline

The study area includes two lakes, five streams and six groundwater bodies which will be assessed (figure 6.9). Appendix table 6.7 and appendix table 6.8 give an overview of the current condition of water bodies and what significant impacts have contributed to their status. The lakes Norrviken and Brunnsviken, which are located east of the E4 (figure 6.9), have an unsatisfying ecological status and a chemical status which isn't qualified as good (VISS, 2017a; VISS, 2017b). Heavy metal contaminants like copper or environmental toxins like ammoniac are found in these water bodies. However, reports from VISS (*ibid.*) mention agricultural, industrial and urban land use as well as atmospheric deposition as causes for the pollution while transport and transport infrastructure is not seen as having a significant impact on water quality (*ibid.*).

There are streams present in the area that either cross the railway tracks and the E4 or are located alongside this infrastructure (VISS, 2017c; VISS, 2017d; VISS, 2017e; VISS, 2017f). Märstaån, Oxundaån-Verkaån and Oxundaån-Väsbyån (Väsbyån, Edsån), visualized in figure 6.9, exhibit a moderate ecological status as determined by VISS, while Igelbäcken has a good ecological status. None of the waterways achieve a good chemical status. Pollution is again the result of agriculture, industry, urban activities and atmospheric deposition (*ibid.*).

There are six groundwater bodies in the area, shown in figure 6.9, that are part of a 40 km wide groundwater system running from Solna to Källström (around 10 km north of Arlanda airport) (VISS, 2017g). The three northern groundwater bodies are partly covered by groundwater

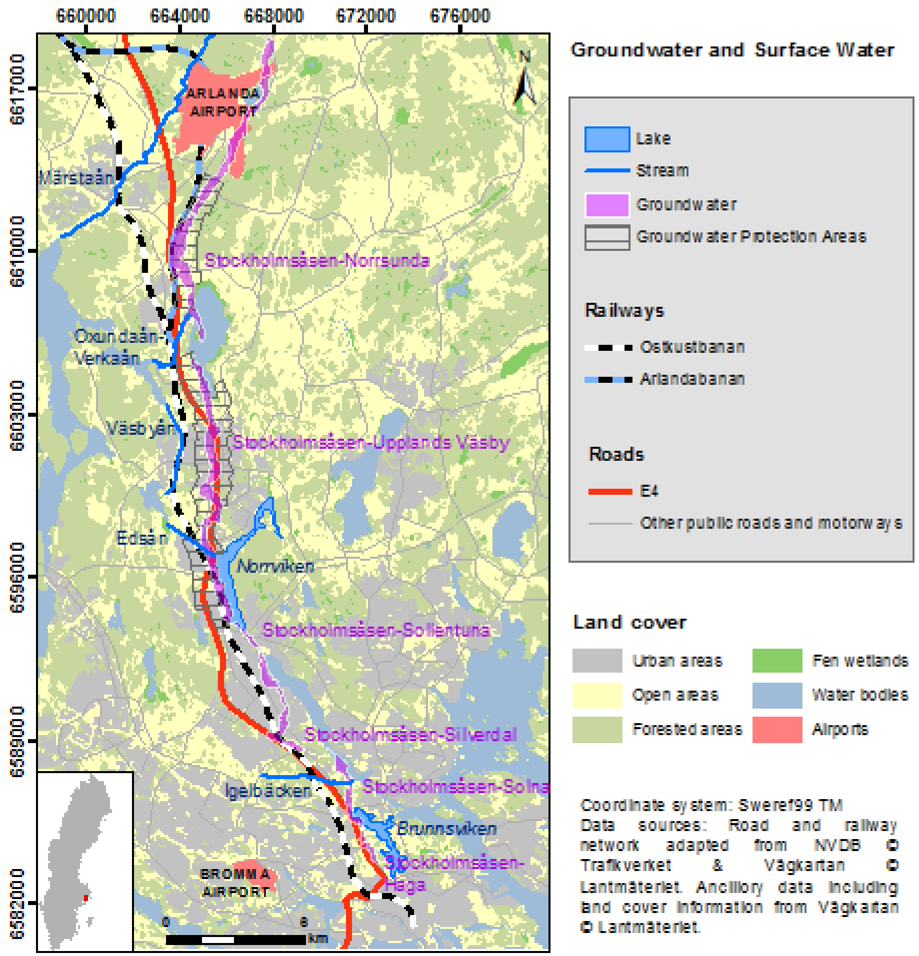


Figure 6.9. The map gives an overview of groundwater and surface water bodies in the study area, as well as ground water protection zones

protection zones (Lantmäteriet, 2017). All aquifers consist of quaternary sand and gravel and have a good status in regard to the amount of water they hold (VISS, 2017h; VISS, 2017i; VISS, 2017j; VISS, 2017k; VISS, 2017l, VISS, 2017m). The chemical status is assessed as good for most groundwater bodies aside from Stockholmsåsen-Upplands Väsby which is deemed unsatisfying (*ibid.*). This water body has the largest overlap with the E4, and contains increased concentrations of Tri-, Tetrachloroethene, PFAS (per- and polyfluoroalkyl substances) and most importantly from a road-perspective it contains high concentrations of chloride which is a salt component (VISS 2017h). Even if the chloride has decreased significantly from 2008 to 2012 (EK & Rondahl, 2017), the latest VISS-report (2017h) does not expect a good chemical status for Stockholmsåsen-Upplands Väsby in 2021.

Aside from contaminated discharge from polluted areas, transport and traffic is seen as the most significant impact determining water quality for all groundwater bodies (VISS, 2017h; VISS, 2017i; VISS, 2017j; VISS, 2017k; VISS, 2017l, VISS, 2017m). The transport network impacts water quality in much the same way it impacts soil quality, through road salting, leakage of hazardous substances from accidents, spilling of oil/lubricants and use of abrasive materials for transport vehicles. The influence of climate change, as already mentioned in section 6.5.4.1, will lead to an increased significance of surface runoff and salting in impacting water quality.

6.5.5.2 Zero Option

The estimated impacts on soil (section 6.5.4.2) apply to water quality as well. Hence, a higher risk of leakage through accidents, more contaminated storm waters and a greater need for road salting could have a negative effect on water quality. In addition to these impacts, heavy road traffic could have an indirect impact through increased emissions and atmospheric deposition (Lim *et al.*, 1999), which is a significant impact to surface water quality in the present according to VISS reports. Increased emissions (section 6.5.4.2) could lead to a higher atmospheric deposition of nitrogen and PM10, although the effects from just one road will be minimal.

6.5.5.3 Option 1

The construction of two extra railway tracks could impact surface water bodies through discharge of sediments, lubricants, fuel, paints and solvents from the construction site (Arquiaga *et al.*, 2012). Groundwater bodies could be affected by percolation of these fuels, paints and solvents. A larger quantity of trains would produce a higher amount of abrasive material and the risk of spilling hazardous substances would be higher. This could increase direct deposition of contaminants into surface waters, but also the concentration of contaminants in railway ballast and soil (ibid.). Furthermore, more frequent bus departures of line 583 could increase the amount of road dust, which might have a minimal impact on water quality of Märstån.

Mitigation Measures

Mitigation of construction impacts: see section 6.5.4.3. During the operation, the impact on water quality could be reduced through minimizing brake dust emissions with adapted breaking processes (section 6.5.3.3) and through creation of a drainage system that prevents leaching of pollutants into water bodies (section 6.5.4.3).

6.5.5.4 Option 2

The construction of two additional lanes on the E4 could impact the water quality in ways similar to the railway construction (section 6.5.5.3). In the operational phase, the higher concentration of residues from tires and brakes in soil (section 6.5.4.4) could lead to an increased leaching of heavy metals into nearby water bodies (Trenouth, 2018). Due to the higher use of road salt (section 6.5.4.4), the concentrations of sodium and chloride in water bodies is likely to rise.

Mitigation Measures

The mitigation measures for water quality for option 2 are the same as in section 6.5.4.4 regarding soil quality.

Summary of Possible Impacts Connected to the Water Quality

Zero Option

The zero option will most likely have a *minor negative impact* on water quality due to higher levels of contaminants in the stormwater as well as a higher risk of leakage from accidents.

Option 1

The expansion of the railway will most likely have a *minor negative impact* on water quality due to an increased number of contaminants (abrasion material, lubricants), which could pollute the water through direct deposition or leaching.

Option 2

The expansion of the road will most likely have a *major negative impact* on water quality due to an increase in the amount of higher contaminated stormwater from road dust and due to a higher contamination of chloride from road salting because of the larger road surface.

6.5.6 GHG Emissions

Combustion of fossil fuels, such as gasoline and diesel, leads to high emissions of carbon dioxide, contributing to global warming. Road transports account for about 30 percent of Sweden's emissions of carbon dioxide, and the proportion continues to increase as the road traffic increases (Naturvårdsverket, 2017e).

6.5.6.1 Baseline

In order to reduce carbon emissions, several solutions such as biofuels, electrification and energy optimization are combined and widely used today in Stockholm’s transport sector. The majority of the SL buses in the region of Arlanda airport operate on ethanol and locally produced biodiesel. Ninty-five percent of airport coaches (Flygbussarna) run on biofuel (Flygbussarna, 2017). Since 2011, only environmentally-friendly taxis are allowed to pick up passengers at the airport.

In the railway system, both SJ and Arlanda Express trains affirm the use of 100 percent renewable energy (Arlandabanan Infrastructure, 2015). The rail sector remains the most carbon-efficient when taking all elements of the life cycle analysis into account. Despite all effort, the total amount of CO_2 emissions caused by travellers to and from Arlanda airport was estimated to be 176 500 tons in 2016. (Swedavia, 2015). Excluding taxis, airport coaches, SL buses and trains, the majority of these emissions come from personal cars, trucks and heavy-duty trucks which operate on fossil fuels, such as gasoline and diesel.

6.5.6.2 Zero Option

Even without the expansion of Arlanda airport, CO_2 emissions caused by transport traffic will directly reflect the expected population increase in Stockholm. However, since Stockholm has declared its ambition to be a fossil fuel-free city by the year 2050, various measures, plans and policies have been applied to eliminate the use of diesel and gasoline fuels in the transport sector. According to “Roadmap for a fossil-fuel Stockholm”, with projected population growth, CO_2 emissions in the transport sector are expected to decrease by 70 percent by the year 2050 (Stockholms stad, 2014). The reason emissions of CO_2 are not projected to reach zero is the fact that there are still many heavy machinery industries for which transition to biofuels is not possible. Nevertheless, the goal of reaching zero emissions in personal transportation is feasible with public transport operating on biofuels and the transition of privately owned vehicles to environmentally friendly cars, for example, electric cars or hybrids.

6.5.6.3 Option 1

Since regional and commuter trains as well as Arlanda Express use electricity generated from renewable energy sources, the CO_2 emissions during the operational phase are expected to be zero. The main factors that might have an impact on CO_2 emissions are related to the equipment and materials used for the construction of new rail tracks. The transportation of railway infrastructure elements and all related materials requires a big effort and usually makes use of machines operating on diesel fuels, which produce high amounts of carbon emissions. It is therefore suggested that actions to reduce emissions during the construction work are prioritized.

Mitigation Measures

In the planning phase of railway construction, carbon-accounting is highly recommended. Optimizing construction equipment and vehicle usage, as well as the management of excavated materials may significantly reduce emissions from construction sites. For instance, reducing idling time, avoiding inefficiently oversized machines, applying logistics for associated transportations, and maximizing reuse and recycling of materials serves to reduce emissions in carbon extensive activities.

6.5.6.4 Option 2

During the construction phase, CO_2 emissions will definitely increase since almost all heavy machinery used for construction and maintenance activities operate on oil and diesel fuels. The hot mix for asphalt that is used for road pavements also emits large quantities of CO_2, CH_4, and N_2O. When the construction of new lanes is completed, the amount of vehicles on the road is expected to increase, leading to higher emissions of greenhouse gases. However, the ‘green lane’ will hopefully encourage people to use a more sustainable type of transportation (car sharing, public buses, airport shuttles, etc) rather than their own vehicles. In addition, electricity powered vehicles that are becoming more and more popular will play an important role in reducing emissions from burning fossil fuels. But even if the green lane and increased numbers of electric cars could decrease GHG emissions, the higher traffic in total could outweigh this positive influences and the amount of GHG emissions could stay at a similar level to today.

Mitigation Measures

Mitigation measures include careful planning and logistics for the construction phase, including lower-carbon materials and efficient vehicle fleets with a lower unit emission ratio. After construction is completed, further promotion of environmentally-friendly cars is highly desirable, as well as carpooling and public transport preferences when travelling to Arlanda airport.

Summary of Possible Impacts Connected to the GHG Emissions

Zero Option
A *minor positive impact* due to a fossil-free transport policy which is expected to contribute to a decrease in GHG emissions.

Option 1
A *major positive impact* due to zero GHG emissions during the operation phase. The CO_2 emissions during the construction phase can be substantially reduced by advance planning, specified operational strategies and use of proper materials for construction.

Option 2
Option 2 will most likely have *minor negative impact* during the construction phase due to the additional GHG emissions from the construction machinery. During operation phase, option 2 will most likely have *minor negative impact*, the higher GHG emissions from increased traffic could outweigh the saved GHG emissions from the green line and from electric cars.

6.5.7 Biodiversity and connectivity

6.5.7.1 Baseline

Different types of nature and landscapes surround the railway and E4 road that runs from Stockholm to Arlanda airport. The road and railway mainly cross industrial areas and smaller cities, but some parts of the route run through valuable nature. At Rosersberg in Sigtuna municipality, both the railway and the E4 pass close to the border of the nature reserve Fysingen (figures 6.6 & 6.8). The reserve has an area of 110 hectares and consists of a farming landscape adjacent to the northern part of lake Fysingen.

Fysingen is classified as an important nature area due to its cultural landscape, recreational values, high biodiversity and rich bird life. The lake is one of the county's best birdlife areas with hundreds of breeding species, and it is also an important resting place for migratory birds. A part of the reserve is a bird sanctuary that is protected with a ban on access between April 15th and June 30th. The fish fauna in the lake is rich with about 10 different species, and traces of beaver have been observed at the inlet of the lake (Sigtuna kommun, 2017).

The study area also includes a nature reserve called Igelbäcken (figure 6.6). It is located in Solna and contains old pines as well as a small stream with rare fish species. (Solna stad, 2014). Igelbäcken is a green wedge, which means that the reserve is important for preserving the biodiversity of the city's parks and green areas. However, Igelbäcken is already affected by exploitation and developments since both the E4 and the railway cross the reserve.

The Development Plan for the Stockholm region (SLL, 2010) includes lake Fysingen among the lakes prioritized for water protection. The lake is considered eutrophic due to excessive nutrients. It receives nitrogen and phosphorus both from surrounding agricultures, but also from stormwater runoff from industrial areas (Sigtuna kommun, 2017). The nature reserve also has a rich flora due to its grazing lands and meadows. The meadows are mowed which support different types of wildflowers, which in turn are important for pollinating insects and contributes to a high biodiversity (Länsstyrelsen, 2010).

6.5.7.2 Zero Option

If the development plan for Arlanda airport is not implemented, the nature in the area will not be affected by any of the proposed options.

However, due to the future population increase, pressure on existing infrastructure will rise. Traffic congestion with wear and tear damaging roads might lead to higher levels of contaminants, noise and air pollutants, which could have a negative effect on biodiversity and species connectivity in the area. Hence, biodiversity and connectivity could be negatively affected even with the development plan for Arlanda airport not being implemented.

6.5.7.3 Option 1

In option 1, the biodiversity and connectivity in the proposed area will most likely be affected by the railway expansion. During the construction of new tracks, high levels of noise and vibrations could be disturbing for the birds and other animals in the area, especially in Fysingen nature reserve (figure 6.6). Furthermore, the increased railway traffic and more frequent bus departures between Stockholm and Arlanda airport might also contribute to higher noise levels, which could have a negative effect on the wildlife. Additional tracks could also create a greater barrier and contribute to a more fragmented landscape, which is especially important in regards to the nature reserves Fysingen and Igelbäcken (figure 6.6) which have high levels of biodiversity. Several studies show that different types of animals, including insects, amphibians and large mammals, experience large difficulties in crossing wide railway tracks (Helldin *et al.*, 2010). However, the increased efficiency of the railway system will most likely reduce traffic on the E4 which is positive for biodiversity since it reduces the amount of air pollutants and contaminants.

The vegetation in the area would not be negatively affected by the additional tracks, aside from a few trees that might have to be removed. In fact, railways provide an important habitat for several species of flowers and other plants. The rail network is dominated by dry and well-drained soils with high disturbance from anthropogenic activities, which is an important habitat for many species. Overgrowth due to decreased grazing and mowing is one of the largest threats to species depending on cultural landscapes, and these species find new habitats along railways and roads (Trafikverket, 2014).

The nature around the stretch between Märsta and Arlanda airport, where bus 583 travels, will probably not be affected by more frequent bus departures. Sköndalsskogen near the railway to Märsta (figure 6.6) and other nearby recreational areas like Måby vattenpark have no rare or sensitive species, but Sköndalsskogen itself is home to some old valuable trees that might have to be removed. But otherwise the impact in the area will be minimal.

Mitigation Measures

Option 1 is expected to lead to higher noise levels in the landscape adjacent to the E4 and the railway, caused by more frequent train and bus departures. Like mentioned in section 6.5.2.3, noise barriers could be used along the railways to protect birds and other sensitive animals, especially in the area around Fysingen. Further mitigation measures include new types of brakes and polishing of the tracks to reduce the noise levels (section 6.5.2.3). To prevent road kills without making it difficult for animals to cross the railway, different types of fauna passages could be an alternative.

6.5.7.4 Option 2

In option 2, the proposed new driving lanes will run very close to the nature reserve Fysingen (figure 6.8). Igelbäcken nature reserve is not affected by Option 2 as expansion of the E4 will only occur north of Häggvik junction, which is north of Igelbäcken. But an expansion of the E4 will have a major negative impact on the biodiversity in Fysingen due to higher levels of contaminants, noise, vibrations and air pollutants from the increased traffic. Some species, especially birds, are negatively affected by noise.

According to Naturvårdsverket, bird species linked to open or coastal environments are more sensitive to disturbances (Naturvårdsverket, 2004), and a driving lane closer to their habitat would most likely create such disturbance. Fish and other aquatic organisms could be negatively affected by higher levels of contaminants reaching the lake by increased stormwater runoff, and the vegetation could be negatively affected by contaminants and air pollutants.

An additional driving lane could also create a greater barrier for wildlife, and would most likely contribute to a more fragmented landscape. Furthermore, the construction of extra lanes on the E4 will cause additional noise and vibrations in the area.

Mitigation Measures

Option 2 will contribute to higher levels of noise and vibrations, both during the construction and the operation of the new driving lanes. Furthermore, option 2 will most likely create greater barriers in the landscape, which complicates migration for the animals in the area. To prevent road kills without making it difficult for animals to cross the road, different types of fauna passages could be an alternative. For possible mitigation measures to limit the amount of air pollutants and contaminants reaching the surrounding nature, see section 6.5.3.4 and 6.5.5.4.

Summary of Possible Impacts Connected to the Biodiversity and Connectivity

Zero Option

The zero option will most likely have a *minor negative impact* on biodiversity due to higher levels of contaminants, air pollutants and noise, caused by a higher pressure on existing transport infrastructure.

Option 1

The expansion of the railway will most likely have a *minor negative impact* on biodiversity and connectivity due to greater barrier effects and higher noise levels caused by more frequent train and bus departures. However, the increased efficiency of the railways will have a *minor positive impact* on the flora and fauna due to a decreased number of cars travelling on the E4.

Option 2

The expansion of the road will most likely have *a major negative impact* on biodiversity and connectivity due to greater barrier effects as well as higher levels of contaminants, noise, vibrations and air pollutants from the increased road traffic.

6.5.8 Safety and Risk Assessment

6.5.8.1 Baseline

The section of the E4 that runs from Häggvik to Arlanda (figure 6.8) is today nearing maximum capacity and periodically faces congestion issues (Trafikverket, 2017b). The route has seen a total of 491 accidents (with 600 injured) between January 1, 2009 and December 1, 2015 - the majority is the result of rear-end collisions (Trafikverket, 2017b). The route has been classified as generally Good or Very Good, which is based on the mitigation measures in place to prevent traffic accidents. These mitigation measures include physical barriers to separate roads as well as the presence of empty space on the side of the road (*ibid.*).

The railway system is a source of a number of yearly accidents. Trains hitting people is one type of railway-related accident. Exact numbers of accidents on Ostkustbanan on the stretch we're interested in (figure 6.6) wasn't available. However, in the years 2010-2015, 13 fatal accidents related to operations on Arlandabanan occurred (Arlandabanan Infrastructure, 2015). Arlandabanan Infrastructure AB, responsible for operation of Arlandabanan, work systematically to increase and maintain security on the railway (*ibid.*). Another risk with the railway system is accidents involving the transport of dangerous goods. This transport poses a potential risk of dangerous leakage if an accident occurs, although accidents involving dangerous goods are rare. The last time an accident resulting in leakage happened in Sweden was 2008 (Trafikanalys, 2016).

6.5.8.2 Zero Option

A larger population will lead to a more strained transport system with more traffic congestion on the roads. There is an ongoing discussion about the relationship between road congestions and the frequency of traffic accidents. Marchesini & Weijermars (2010) reviewed existing literature and noted that while some studies show that an increase in congestion leads to a higher frequency of traffic accidents, other studies show the opposite or that no clear relationship between the variables exist. However, what most studies agree on is that the severity of accidents decreases with higher congestion where rear-end crashes are most common (Marchesini & Weijermars, 2010). Risks concerning railway traffic are expected to remain the same as in the baseline.

6.5.8.3 Option 1

The risk of an accident resulting in leakage of toxic waste will most likely increase with the increased amount of trains. When expanding the railway with new tracks, it is important that they are not too close to existing buildings. It is also important not to build new buildings too close to new railway tracks. The general recommendation from Trafikverket is to not allow new buildings closer than 30 meters from a railway track, although the practise in Stockholm county is 25 meters (Trafikverket, 2016). This limit is set as a precautionary measure to reduce damage from a potential train derailment or if an accident would result in toxic leakage (*ibid.*). As seen in figure 6.6 an expansion of the railway in residential areas will not only lead to many direct collisions with existing buildings, but also a very close proximity to many others, especially when a 25m buffer is taken into account. Risks involving road traffic however is expected to be the same as in the zero option.

Mitigation Measures

Continued work on accident prevention is essential to reduce the risk of accidents involving railway traffic. It is also important to plan the railway traffic in the safest possible way for avoiding derailment and collisions, and to put up fences around the track areas to avoid unauthorized access. Technical systems operating the signal system and track switch systems and the continuous maintenance of such systems also help to prevent accidents. Education about the dangers of railway track areas is another solution of preventing accidents involving people.

6.5.8.4 Option 2

The construction of two new lanes could increase the traffic congestion during the construction phase. Hence, the risk of traffic accidents during construction is the same as in the zero option. When the expansion of the new road is completed, there will be less traffic congestion. This would increase the risk for severe car accidents that occur at high speeds. However, the number of vehicles on the road will increase as a result of the expansion (Litman & Colman, 2001). Hence, it is reasonable to assume that high-speed car accidents will decrease again after a few years when traffic congestion once again starts to become an issue. When comparing Option 1 (figure 6.6) and Option 2 (figure 6.8) it becomes clear however that the expansion of the E4 will pose less of a risk for car accidents in residential areas where most people live, partly because the E4 is less likely than railways to move through residential areas to begin with. Risks concerning railway traffic in option 2 are expected to remain the same as in the baseline.

Mitigation Measures

Potential mitigation measures to limit traffic accidents or their severity includes putting up physical barriers between roads to separate traffic, rumble strips on roads, creating side-areas of empty space beside roads, and creating transition zones in vulnerable areas like entrances, exits and crossings (Trafikverket 2017b).

Summary of Possible Impacts Connected to the Safety and Risk Assessment

Zero Option

The zero option will most likely have *no notable impact* on the safety and risk assessment since the accidents are expected to increase in number due to more congestion. However, the severity of the accidents is expected to decrease.

Option 1

The expansion of the railway will most likely have a *minor negative impact* on the safety and risk assessment since the risk of accidents involving trains would increase as a result of the increase in railway traffic.

Option 2

The expansion of the road will most likely have a *minor negative impact* on the safety and risk assessment due to the increased number of vehicles on the roads.

6.5.9 Cultural Heritage

Cultural heritage is usually defined as the present manifestation of the human past. It refers to sites, structures and remains of archaeological, historical, religious, cultural, or aesthetic value.

6.5.9.1 Baseline

On the route Stockholm - Arlanda airport, Rosersberg is one of the important cultural areas (figure 6.3). According to the County Administrative Board, the area has a cultural-historical value with artifacts that testified that the land has been inhabited for a long time (Länsstyrelsen, 2010). The medieval church Norrsunda which was completed in the late 1100s is clearly visible from the E4. The area around Norrsunda Church including an old graveyard has a designated landscape protection through section 19 of the Nature Conservation Act (19 § i Naturvårdslagen landskapsbildskydd). Järvafältet is a culture reserve located in Sollentuna (figure 6.8). It’s an ancient cultural landscape with relics from the Bronze Age. Working farms are surrounded with forests and lakes. Järvafältet is important to preserve. Sollentuna municipality is actively working with nature conservationists, to preserve the historical cultural landscape.

Another important area of national interest is located around Lake Fysingen, close to the E4 on the northern part of the transport route (figure 6.8). The entire lake, as well as the surrounding area with castles (Skånelaholm slott and Torsåker slott) and Vallstanäs garden are classified as being of national interest for scientific conservation and cultural heritage (Länsstyrelsen, 2010).

All historical buildings and architectural monuments which are located close to the road are sensitive to air pollution. The combined effects of liquid and gaseous contaminants, resuspension of dust and air moisture might have a negative effect on the external appearance of the buildings due to wet and dry depositioning. As of today, the open areas along the E4 are large enough to disperse dust and particles (*ibid*.).

6.5.9.2 Zero Option

The emissions from road traffic are expected to be well dispersed with winds in the open fields so the cultural areas will stay unaffected.

6.5.9.3 Option 1

The construction of additional railways will enhance the road’s dominance in the historical areas. With construction of new rail tracks the cultural areas might be disturbed due to noise, vibration, air pollution, use of historical sites for construction storage and waste, removal of ancient relics as well as unregulated access to cultural heritage sites. As shown in figure 6.6 some ancient relics (and bigger relic fields) will need to be removed as they are directly in the path of railway expansion. After construction the cultural landscape will be partly obstructed due to enhancement of the visual and physical barrier the trains are.

Mitigation Measures

The alignment of railway constructions that cuts through known cultural sites should be avoided. Borders, buffer zones and logistics for rerouting transport during construction phase should be taken into consideration. Storage and waste facilities should be chosen with the least destructive effect on the heritage site. Further measures may include additional barriers to prevent noise pollution and vibrations during operations.

6.5.9.4 Option 2

Widening the road will affect visual connections and sightlines in the cultural areas (such as Järvafältet, figure 6.8) and open agricultural fields. In the same way as for option 1, there will be an increase in disturbances during the construction phase due to noise, vibrations, air pollution, use of historical sites for construction storage and waste, removal of ancient relics, and an unregulated access to historical sites. All these things will have a negative impact on cultural heritage sites. When construction is completed, cultural buildings located along the E4 road might experience risk of blackening and soiling formation on facades due to enhanced emissions of particulate matter, soot and dust.

Mitigation Measures

To avoid negative impacts during construction it is recommended to reroute traffic from the vicinity of cultural areas and regulate access for cultural heritage sites. Storage and waste facilities should be chosen with the least destructive effect on heritage sites. To prevent damaging of buildings, the widening of the road should be in the areas where ground level pollution is readily dispersed. The mitigation measures may also include creating green barriers with bushes and high trees.

Summary of Possible Impacts Connected to the Cultural Heritage

Zero Option

The zero option will most likely will have *no notable impact* on areas of cultural heritage.

Option 1

The expansion of the railway will most likely have a *minor negative impact* on areas of cultural heritage due to increased disturbances during the construction phase. The cultural landscape might also be partly obstructed due to greater barriers.

Option 2

Option 2 will most likely have a *minor negative impact* on areas of cultural heritage due to increase disturbances during the construction phase and increased air pollution during the operation phase.

6.5.10 Socio-economic Factors

6.5.10.1 Baseline

The area of study is within Stockholm County, where only 6 percent of the population assessed their own health to be poor or very poor (SLL, 2016). However, it varies greatly within the county's municipalities. The area of study focuses on the area around the E4 freeway between Arlanda airport and Stockholm city (figure 6.3). Traffic on large busy roads, such as the E4, are a large source of both noise and pollutants. More than 25 percent of the county's inhabitants consider the air quality near their area of residence as bad or very bad (*ibid.*). Air pollution in the Stockholm area is calculated to shorten the average life expectancy of the inhabitants by 7 months (*ibid.*). Many people live and work in the near vicinity of the E4 and are thereby disturbed and affected by the effects from the traffic. The residents close to Arlanda airport are among the inhabitants most disturbed by noise (*ibid*).

The municipalities surrounding the area of study contain many workplaces. In Upplands Väsby municipality, approximately 15 500 people work (SCB, 2017a), and out of these approximately 9000 commute daily to and from work (SCB, 2017b). It is reasonable to assume that a large fraction of the commuters uses the transport system in the area. The corresponding numbers for Sigtuna municipality are approximately 30 000 workers (SCB, 2017a) out of which 18 500 commute daily (SCB, 2017b). Arlanda airport provides a large amount of workplaces in Sigtuna municipality with 17 500 employees in the airport area (Swedavia, 2017). Furthermore, industries connected to the airport generate 10 000 workplaces in the region (*ibid.*). However, the ratio between the people using the transport system as work commuters and ground based travellers from Arlanda airport, is approximately 30 percent, which means that commuters are a relatively small fraction of the people using the transport system.

6.5.10.2 Zero Option

If the plans to develop Arlanda airport are not carried through, the increase in new job opportunities would be smaller. However, the population increase will require that the transport system is expanded. This would lead to some new job opportunities in order to meet the need for a more efficient transport system with an increased amount of bus and train departures. However, the jobs generated in the zero option are considerably fewer than what the amount of jobs would be if the development plans for Arlanda airport were implemented.

The strain in the transport system due to the population increase would lead to a decrease in human health. Emissions from traffic and levels of noise will increase and thereby have a larger negative impact on the inhabitants. It is likely that more people would live near the E4, which means that a larger fraction of the population would be affected by the negative impacts. A more strained transport system would have a negative impact on the mental health of the people using it. Traffic congestion is also expected to increase. Söderström (2004) finds a clear connection between increasing congestion and increase in less severe injuries in car accidents such as whiplash. Such injuries can lead to long-term health issues, over 50 percent of all people who report traffic-related injuries to insurance companies in Sweden do so because of whiplash-related injuries and this figure keeps on increasing (Söderström, 2004). The health impacts as a result of the zero option would be milder than those as a result of option 2.

6.5.10.3 Option 1

An expansion of the railway system would generate construction jobs in the area. These jobs are not permanent, and when the construction phase is finished the jobs will vanish. However, the new capacity gained from the railway expansion and the more frequent bus and train departures will generate some new, lasting jobs in the area.

The increased frequency of train departures will lead to higher levels of PM10 in the tunnels along the stretch between Stockholm and Arlanda airport. This would lead to a higher risk of exposure to dangerous particles when getting on and off the train at stations inside a tunnel. Inhaling such particles can have negative health effects. There would also be an increase in human health issues related to noise as the railway system is expanded.

The negative health effects from road traffic are expected to be the same as in the zero option. When the railway system is expanded, the trains and buses would get less crowded which would make the train ride more comfortable and decrease stress of travellers which is good for their mental health. This option would also give more people the possibility of a cheap way to travel between Stockholm and Arlanda airport.

Mitigation Measures

A way to mitigate the negative health effects at train stations is to make sure that the technical solutions to reduce the release of PM10 (section 6.5.3.3) are implemented. Sound insulation of buildings is a way to reduce negative health effects from noise. Another important mitigation measure is to make the trains as quiet as possible by using new brake technology.

6.5.10.4 Option 2

Construction of two new lanes would generate new jobs in the area. Again, as in section 6.5.10.3, these jobs are not permanent and when the road expansion is finished they will vanish. The new road will require maintenance, but since the new lanes are an expansion of an existing road, this will not create a significant amount of new jobs. However, an increase in the number of train and bus departures might lead to a few more jobs in the public transport sector.

The expanded road will increase the traffic on the road (Litman & Colman, 2001). Health problems related to air pollution and noise will increase and become more severe as a result of the traffic increase. Option 2 has overall a minor negative impact on the socio-economic factors, since the negative impacts on human health outweigh the positive impacts from the possible job opportunities.

Mitigation Measures

The negative health effects caused by high noise levels can be mitigated using vegetation covered noise walls and special road material as discussed in section 6.5.2.4. Another mitigation measure is to sound isolate new houses built close to the road. These mitigation measures will also have a positive impact on human health problems from poor air quality. Further measures to mitigate negative health effects from poor air quality are to use face masks in heavily polluted areas. Promoting the use of cars equipped with exhaust cleansing as discussed in section 6.5.3.4 is also a necessary mitigation measure.

Summary of Possible Impacts Connected to the Socio-economic Factors

Zero Option

The zero option will most likely have a *minor negative impact* on the socio-economic factors; the amount of jobs in the area would increase somewhat as a result of the expected population increase, but human health would decline caused by the increased strain on the transport system.

Option 1

The expansion of the railway will most likely have *no notable impact* on the socio-economic factors since positive and negative impacts are assessed to balance each other; the amount of jobs would increase both during the railway construction and as a result of the increase in amount of train and bus departures. High levels of PM10 would increase the risk of health issues at train stations inside tunnels but less crowded trains and the possibility for more people travelling cheaply has a positive impact on mental health.

Option 2

The expansion of the road will most likely have a *minor negative impact* on socio-economic factors; the amount of jobs would increase during the road construction. However, the amount of permanent new jobs are few and the expanded road would cause an increase in human health issues.

6.6. Matrices

6.6.1 Impact Matrix

The alternatives assessed in this SEA have been shown to have different impacts on the environmental parameters. The overall assessment is summarized and displayed in the impact matrix below.

Table 6.4. Impact matrix showing the different options and a classification of the environmental impacts. Classification modified from Kloth et al. (2011).

Environmental Parameters	Zero Option	Option 1	Option 2
Physical Landscape	**0** Due to the future population increase, the landscape will become more urban because of the future extensions of residential areas and its connected infrastructure. The opinion of whether or not this is a positive development for the landscape is subjective.	**- -** The expansion of the railway will have a major negative impact on the physical landscape in surrounding areas due to interference between the proposed railway and existing residential buildings.	**-** The additional lanes on the E4 will most likely interfere with a few buildings, and might also require reconstruction of surrounding shopping areas and parking spaces. In rural areas, it will imply some intrusions in the landscape and might lead to tree felling and loss of green spaces.
Noise and Vibrations	**-** Due to the future population increase, the pressure on existing infrastructure will rise, resulting in more traffic congestion and higher noise levels.	**-** Due to the expansion of new railway tracks and increased train departures, noise emissions and vibrations will increase in magnitude. Additional noise and vibrations will occur during the construction phase.	**-** Due to the road expansion, the number of vehicles on the road will increase, leading to increased levels of noise and vibrations. Additional noise and vibrations will occur during the construction phase.
Air Quality	**-** Due to the future population increase, the pressure on existing infrastructure will rise, resulting in more traffic congestion and higher levels of air pollutants.	**-** The expansion of the new railway tracks will lead to increased amounts of PM10 and NO2, caused by the construction of the new railway and its related road congestions. A large increase of PM10 is also expected inside the railway tunnels due to the increased amount of rail traffic. However, emissions of PM10 from trains is lower than the emissions from cars.	**- -** The expansion of the road will lead to increased amounts of PM10 and NO2, caused by construction of the new lanes and its related road congestion. In the operational phase, the number of vehicles on the road will increase, leading to more emissions from the traffic and higher levels of air pollutants.

Soil Quality	- Due to the future population increase, the number of cars and the amount of road dust will increase. This might lead to a negative impact on surrounding soil due to an increased runoff with possible contaminated stormwater	- Due to the expansion of the railway, the quantity of trains will rise. This might lead to an increased input of abrasion materials and a higher risk of spilling hazardous substances into the soil.	- - Due to the road expansion, the amount of road dust and need for road salting will increase. This might lead to a negative impact on surrounding soil due to an increased runoff with possible contaminated stormwater.
Water Quality	- Due to the future population increase, the number of cars and the amount of road dust will increase. This might lead to a negative impact on surrounding soil due to an increased runoff with possible contaminated stormwater	- Due to the expansion of the railway, the quantity of trains will rise. The higher input of abrasion material and higher risk of spilling hazardous substances could lead to a higher input of contaminants through leaching and direct deposition.	- - Due to the road expansion, the amount of road dust and need for road salting will increase. This will lead to a negative impact on nearby surface waters and the groundwater due to an increased runoff with possible contaminated stormwater.
GHG-emissions	+ Due to the future population increase, the number of cars are likely to increase, leading to higher emissions of CO_2. However, environmental goals initiated by the government could lead to fossil free transportation. If the development plan for Arlanda airport is not implemented, the amount of flights and people travelling to and from Arlanda airport will increase at a much slower rate, leading to less emissions of CO_2.	+ + Trains do not emit any greenhouse gases, and option 1 is therefore estimated to have a major positive impact during the operational phase, assuming that the travellers choose the train instead of the car. The CO_2 emissions during the construction phase can be reduced by advance planning, specified operational strategies and evaluations of the choice of material used.	- With the expansion of the E4, the car traffic will most likely increase, resulting in higher emissions of greenhouse gases. If the fossil-free policy is adapted, a shift towards more environmentally friendly vehicles may occur. However, it is hard to anticipate if and when this will happen and how it will affect the already existing vehicles.
Biodiversity and Connectivity	- Due to the future population increase, the pressure on existing infrastructure will rise. This might lead to higher levels of contaminants, noise and air pollutants, which could have a negative effect on biodiversity in the area.	**0** The expansion of the railway will most likely lead to increased noise levels caused by more frequent train and bus departures. However, the increased efficiency of the railway system will probably reduce the car traffic on the E4, leading to decreased emissions of pollutants. Furthermore, the additional railway tracks provide an important habitat for several species of flowers and plants.	- - The expansion of the road will most likely result in an increased number of vehicles, leading to higher levels of contaminants, noise and air pollutants, both during the construction and the operational phase. This will have a major negative impact on biodiversity, and the wider road will also create a greater barrier for wildlife in the area potentially having a big negative impact on species connectivity.

Safety and Risk Assessment	**0** Due to the future population increase, the pressure on existing infrastructure will rise, resulting in more traffic congestions, which in turn might lead to more whiplash-related injuries. At the same time, more traffic congestions lead to a slower traffic pace, reducing the amount of severe accidents.	**-** Due to the increased amount of railway traffic, there will be an increased risk for accidents related to it, involving people being hit by trains as well as derailments and other accidents.	**-** During construction of the new lanes, there will be numerous mild traffic accidents due to an increase in congestions. During the first years when the expanded road is operational, there will be fewer but more severe accidents. After a few years, due to the increased amount of vehicles expected as a result of the expanded road, the accidents will once again shift towards less severe.
Cultural Heritage	**0** The important areas and buildings of cultural heritage will most likely not be affected if the development of Arlanda airport is not implemented.	**-** The expansion of the railway might lead to disturbances of cultural heritage sites in the area during the construction phase. After the construction, the cultural landscape will be partly obstructed due to greater visual and physical barriers.	**-** During the construction period, cultural areas might be disturbed due to noise, air pollution, and use of historical sites for construction storage and waste. During the operation phase, the buildings located close to the road may experience darkening due to increased levels of air pollutants.
Socio-economic factors	**-** Job opportunities at Arlanda airport and within the transport system will increase, but in a slower pace than if the development plan for Arlanda airport would be implemented. Also, the increased traffic due to the increased population will lead to negative health effects, although the severity of the health impacts would be higher if the Arlanda airport development would be carried through.	**0** Due to the railway expansion, new jobs will be generated. However, most of the jobs are within the construction sector, which is not a permanent source of jobs. There will be higher levels of pollutants at the railway stations located in tunnels, which could have negative effects on physical health. However, less crowded trains and the opportunity for cheap travel to and from Arlanda airport has a positive effect on mental health.	**-** Due to the road expansion, new jobs will be generated. However, most of the jobs are within the construction sector, which is not a permanent source of jobs. The road expansion will lead to negative impacts on human health due to an increase in pollution and noise from the increased road traffic. We assess the negative impacts on health as being more significant than the temporary jobs

6.6.2 Impacts on National Environmental Objectives

As mentioned in section 6.1.5, the chosen environmental parameters are connected to the National Environmental Objectives. Consequently, the impact on the chosen environmental parameters means an influence on the National Environmental Objectives can also be reviewed. These influences are significant in a regional perspective.

Table 6.5 shows the contribution of each option to the relevant environmental objective. The different directions of the arrow indicate the magnitude of the contribution:

↑ indicates large positive contribution
↗ indicates small positive contribution
→ indicated no notable contribution
↘ indicates small negative contribution
↓ indicates large negative contribution

Table 6.5. Comparison of the contribution of the options to the environmental objectives (Illustrations from Naturvårdsverket, 2012)

National Environmental Objectives	Zero Option	Option 1	Option 2
Reduced Climate Impact 	→	↗	↘ *
Clean Air 	↘	↘	↓
A Non-Toxic Environment 	↘	↘	↓

Good-Quality Groundwater 	↘	↘	↘
A Good Built Environment 	→	→	↘
A Rich Diversity of Plant and Animal Life 	↘	→	↘

**Note:* *The arrow indicates a negative contribution to the reduction of climate impact.*

6.7. Discussion

6.7.1 Comparison of the Options

As seen in the impact matrix, table 6.4, the zero option has a minor negative impact on most of the environmental parameters and the socio-economic factors. The increased pressure on the transport system due to the population increase is so large that the zero option is not a feasible option for the future development of the study area.

Option 1, the railway option, relieves the pressure from the railway system. This option has a minor negative impact on most of the environmental parameters. However, option 1 is a necessary step towards meeting the future need of transports because of the increase in population and travellers to and from Arlanda airport. We assess that the benefits this option have on the transport system balance or outweigh the negative impacts it has on the environment provided that the plans to expand Arlanda airport are realized. We estimate that the railway expansion will support 16 million out of the approximately 23 million travellers using public transport to and from Arlanda airport when the airport has 70 million passengers. This is based on a prediction by Arlandabanan Infrastructure (2015), which estimates that Arlandabanan could support 8 million passengers with half as many railway tracks on Arlandabanan as in option 1. Furthermore, this means that approximately 7 million will use other means of public transportation such as Flygbussarna buses, SL- buses and the airport shuttle provided by Swedavia. Currently, Flygbussarna buses have approximately 3 million passengers travelling between Stockholm and Arlanda airport yearly. SL-buses between Märsta and Arlanda airport currently have the capacity to carry approximately just under 2 million travellers per year based on the current bus size and frequency of departures. However, it is important to note that even though bus line 583 can carry many passengers, the amount of people using the bus varies greatly with time of day. During the rush hours in the morning and afternoon the bus line is much closer to its maximum capacity than the rest of the day. If we assume that Flygbussarna could double their capacity and have 6 million travellers per year by the time Arlanda airport has 70 million passengers and that the bus line 583 increase its capacity during rush hours, the capacity needed to meet the travellers between Stockholm and Arlanda airport using public transport would be met by option 1. This could be done by, for example, increase the number of departures and the size of the buses. Arlanda Express trains would have the possibility to relieve both commuter trains and the E4 of some pressure if the ticket prices were lowered and if a subsidized seasonal ticket could be bought. This would allow the Arlanda Express trains to function as a form of additional commuter trains. However, in addition to travellers who use public transport, approximately 15 million ground based travellers use car as mean of transportation. Thus, option 1 would not meet this need of transport capacity overall, since the road capacity would be far exceeded as the current road system in the study area is almost as its maximum capacity (Trafikverket, 2017d).

Option 2, the road option, relieves the pressure of the road system. This option has a major negative impact on many of the environmental parameters. Nevertheless, cars would still be needed as a mean of transport since it provides flexibility and high accessibility. However, the habit of travelling one person in each car is not sustainable, and more efficient solutions are needed to solve the problems with traffic congestion. The green lane included in option 2, is a suggestion which promotes more sustainable ways of road transport. Recently, Flygbussarna launched a service called “Door to Gate”. It offers a new, affordable and flexible way to travel to and from Arlanda airport. The traveller is picked up at any location in the Stockholm area, and shares the car with up to two other parties, which makes the price advantageous. Up to nine passengers can share the same car (Flygbussarna, 2016). This type of transport solution can lead to a major improvement regarding traffic congestion, without reducing the flexibility of travelling by car and the green lane encourages further investment in such transport services. However, there would still be a problem with road congestion and a large need for parking places due to the large number of ground based travellers between Stockholm and Arlanda airport. According to Trafikverket (2016), the traffic problems will most likely remain even if the E4 is broadened. This mean option 2 is not enough to fully meet the future need for transport between Arlanda airport and Stockholm.

To solve the capacity problem and decrease the safety risks in traffic, long term combinations of different measures are needed. When looking at the scenarios made by Trafikverket, neither of our two options would be enough to support the growing number of travellers between Stockholm and Arlanda airport. A combination of option 1 and 2 would therefore probably be the most feasible option in order to meet the future need of an efficient transport system between Stockholm and Arlanda airport as a result of the population increase in the area and the plans to develop Arlanda airport. Important to highlight though is that this SEA only addresses the transport of people, not the transportation of air freight to and from Arlanda airport. Since the amount of cargo most likely will increase in the future, the amount of transport of cargo on the road system is also estimated to increase. This would lead to further pressure on the road system, which is not accounted for in this report. The inclusion of it could potentially have led to the conclusion that the road system needs to be even further developed than proposed in this reports options. However, it’s not included in this report since the future demand of cargo transports in Sweden and the Stockholm region is a huge subject that will need a separate investigation. To keep in mind is that cargo transported by air is very marginal compared to other ways of transportation (Transportstyrelsen, 2014). Back in 2010, 86 percent of all the cargo that was transported in Sweden was carried by trucks (Sveriges Åkeriföretag, 2016). Another method used to transport cargo is by ferries.

6.7.2 Assessing Cumulative Impacts

If we in fact do need to combine both of the proposed options in order to cover the future capacity within the transport system between Stockholm and Arlanda airport, cumulative effects may arise. With both an expansion of the E4 with two additional lanes and the railway with two more tracks, effects from the individual projects may together accumulate and worsen the conditions for most of the environmental parameters. The possible cumulative effects have been assessed through creating a Causal Loop Diagram (CLD) and a flowchart for the construction and operation phase. A full explanation of the CLDs causalities for the operational phase can be found as an appendix in chapter section 9.6. A comprehensive flowchart was also assembled in order to provide an overview of the transport systems causalities (figure 6.10). Green arrows indicate a change in the same direction, and purple arrows indicate a change in different directions.

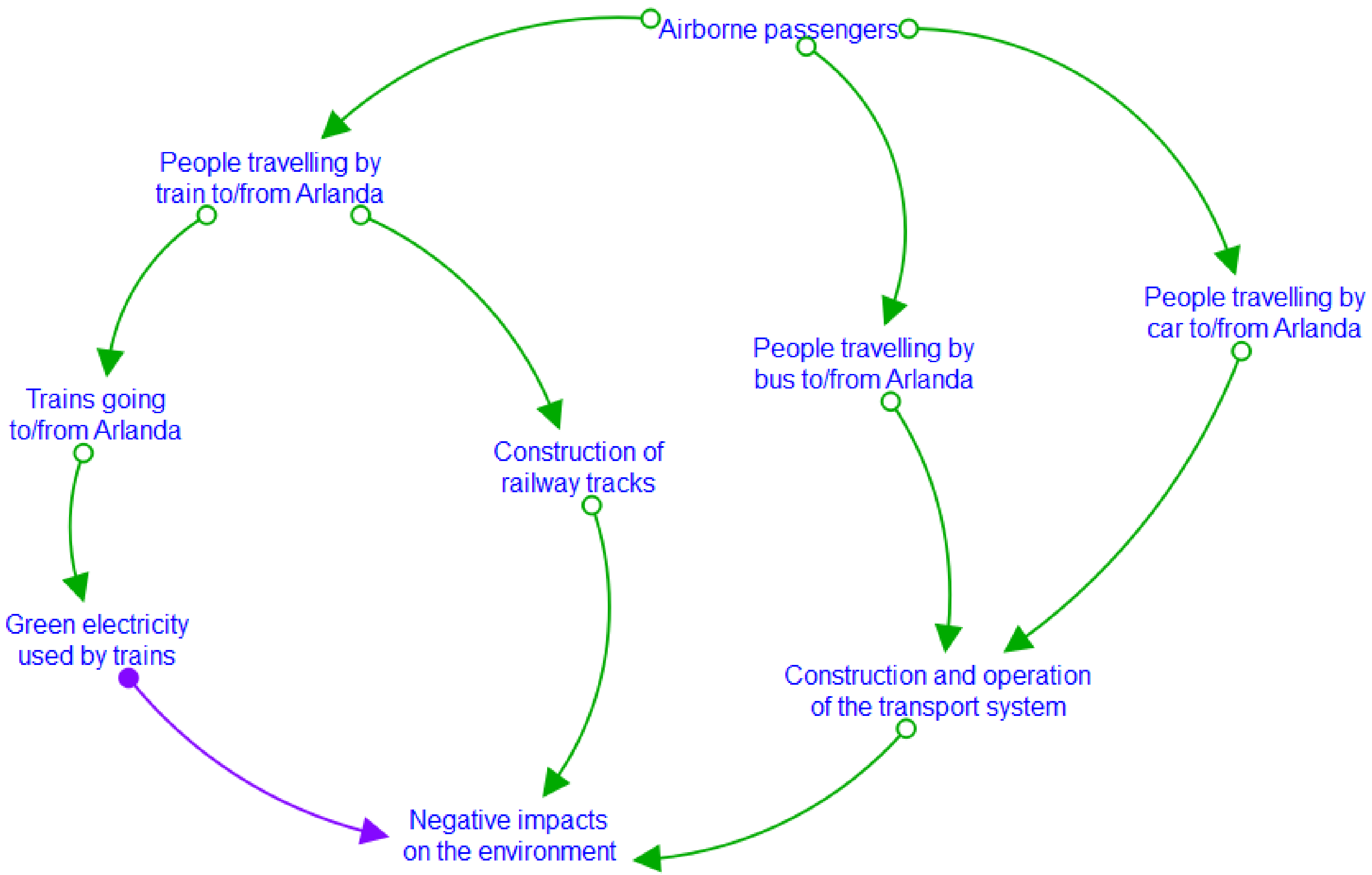
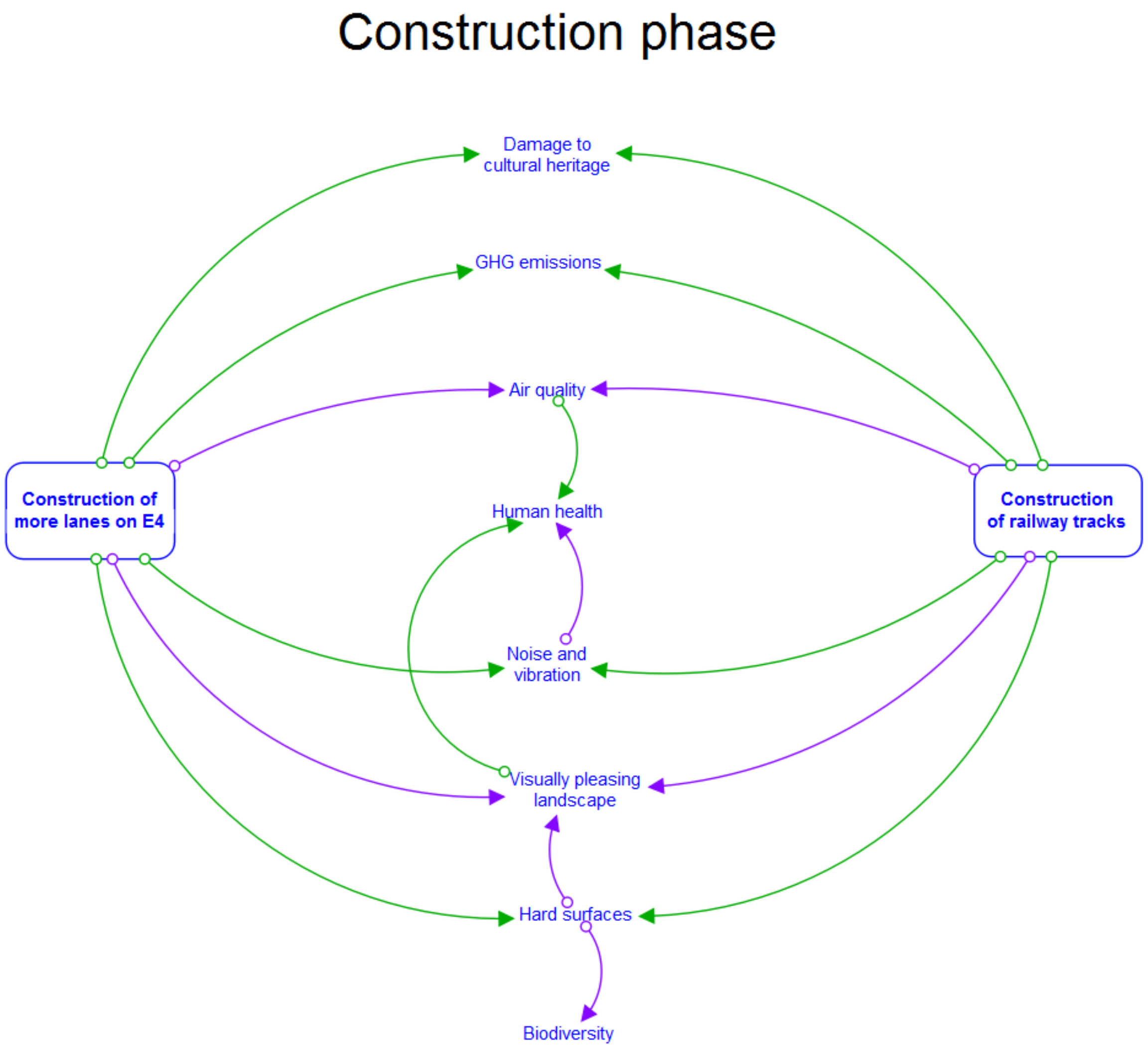


Figure 6.10. A comprehensive flowchart showing the most important causalities in the system due to increase of number of passengers.



In figure 6.11, that shows the construction phase, it is obvious that the construction of two additional lanes at the E4 and two additional railway tracks will lead to the same impacts on the environment and human health. Although they lead to the same impacts, it does not mean that they will occur in the same magnitude, significance or if they are reversible or irreversible. For example, the construction of two additional lanes will create a higher amount of hard surfaces than the construction of two additional railway tracks

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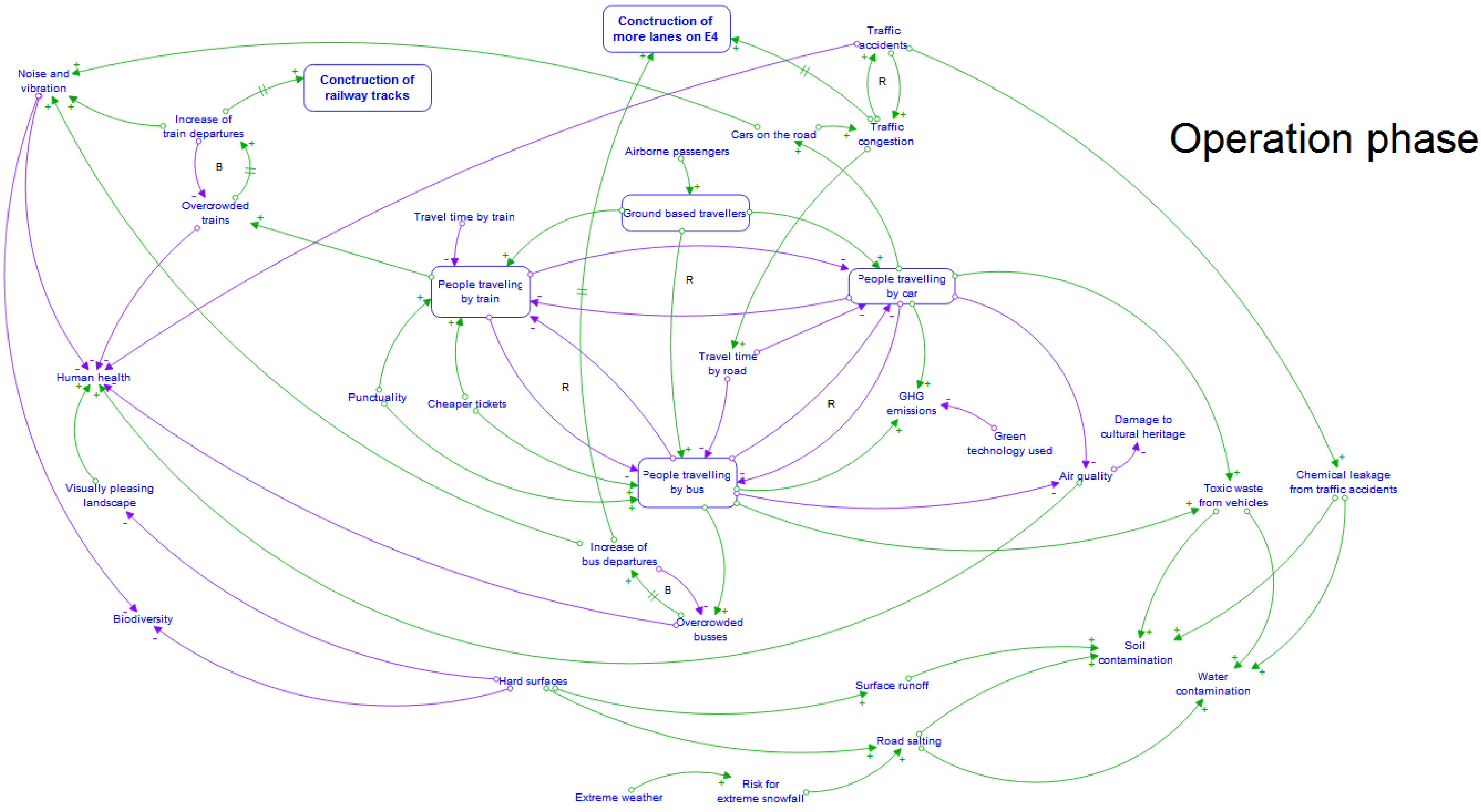

Figure 6.12. CLD over how the operation phase and external factors could lead to impacts on environmental and socio-economic factors.

The operation phase (see figure 6.12) of the proposed options is a bit more intricate. The core of the CLD is ground based travellers choosing different modes of transportation, which in turn leads to various implications in the system, resulting in different impacts on the environment and socio-economic factors such as human health. The amount of airborne passenger flying to and from Arlanda airport is the key driver in the system. The more they increase, the more capacity is required of the ground based transportation system. In the system there are also external factors affecting the magnitude of some environmental impacts. For example, a future increase of extreme weather could lead to more extreme snowfall, which would lead to more road salting, leading to less soil quality and more groundwater contamination. Another external factor is the amount of green technology used within the transport system. The greater the extent that green technology is used, the less greenhouse gases are released. For example, could cars running on electricity or more environmentally friendly fuels instead of fossil based ones.

Through following the casualties in the CLD and flowchart, it is easy to see which cumulative effects may arise when implementing both options. Therefore, the implementation of both options might lead to these cumulative effects regarding the reports established parameters:

- **Physical landscape:** The physical landscape is affected in cumulative ways through loss of green areas due to the construction of new railway tracks and additional lanes on the E4.
- **Noise and vibrations:** In the areas of the expansions the noise and vibrations could create cumulative effects due to their proximity to each other. The noise and vibrations would be present both during construction and operating phase.
- **Air quality:** In areas of expansion air quality could create cumulative effects due to PM10 emissions from trains/cars.
- **Soil quality:** In the areas, where the railway and the E4 are located close to each other, cumulative effects for soil quality could be deposition of abrasion material.
- **Water quality:** The cumulative effects for water could occur where the railway and the E4 overlap and impact the same water body. The cumulative impacts are caused by the abrasion material from cars and trains or more specifically the deposition or leaching of these pollutants into water.
- **GHG emissions:** Since all trains are running with green electricity, no cumulative effects for GHG emissions are expected. Furthermore, the scale of the project is too small to have a significant impact on large-scale GHG emissions.
- **Biodiversity and connectivity:** The expansion of the E4 and the railway could lead to cumulative effects resulting in a more fragmented landscape or a loss of nearby habitats. It could also lead to increased levels of contaminants, noise and pollutants.
- **Safety and risk**: No cumulative effects are seen to have a significant impact on safety and risks.
- **Cultural heritage:** No cumulative effects are seen to have a significant impact on cultural heritage.
- **Socio-economic factors:** The cumulative emissions in areas, where the railway and the E4 are located close to each other, could have negative impact on human health. Furthermore, if the expansion of the E4 and the railways would be done simultaneously, it could lead to in traffic congestion and train delays at same time. The longer and unpredictable travel times could cause public discontent.

Although, construction and operation of both options could also lead to positive cumulative effects, possibly regarding socio-economic factors as in an increasing amount of jobs due to a better connectivity within the project area, and with surrounding areas. Thus, an improved transport system in the project area could increase the attractiveness of the area, attracting businesses and people wanting to live there.

However, cumulative effects could not only occur within one project, but between several different ones. Therefore, cumulative effects may occur due to the implementation of this project in combination with other infrastructural projects in or near the project area. Together, projects can create both minor and major cumulative impacts, which should be properly assessed in an early stage of the planning process, favorably in a SEA similar to this one. When assessed, there may be insights of whether project plans need to be altered in order to eliminate or at least diminish the cumulative impacts. This is a possible scenario for the project of expanding the transport systems capacity between Stockholm and Arlanda airport. Although, due to time constraints, the authors will solely focus on assessing the possible cumulative impacts between the projects described in this combined report of five projects related to the future development plans for Arlanda airport. To read the assessment of cumulative impacts between these five projects, see cumulative impact assessment in the general chapter 7.

6.7.3 Potential Extension of Roslagsbanan

Considering the large number of generalizations, assumptions and uncertainties made to estimate the future of the transport system capacity, there is a possibility that even the combination of two options might not be enough to sustain the enormously large amount of travellers. In this case, the additional way to deal with future challenges might be an extension of Roslagsbanan railway line to the Arlanda airport. Today, Roslagsbanan is the isolated suburban light rail system, which in some segments has already reached its capacity limits due to the lack of double tracks. According to Trafikförvaltningen, the measures to increase the capacity are already in motion, including construction of additional 22 kilometers of double tracks on various segments, purchase of 22 new vehicles to substitute old trains and building a new vehicle depot in Molnby, Vallentuna (SLL, 2015). To connect Roslagsbanan to Arlanda airport the construction of new railway road from Vallentuna to Arlanda airport is being actively discussed among municipalities and SL, although there is still no clear decision about its future. If the extension of Roslagsbanan would be approved, it is very likely that the future transport system would be able to serve the increased number of passengers. With the train capacity of 300 passengers and six departures per hour, Roslagsbanan can provide transportation for approximately 12.5 million travellers per year and thereby relieve the pressure from the road and the existing railway. In addition, Roslagsbanan is expected to get its own station at Arlanda airport where travellers do not suffer from any additional entry and exit fee (SL, 2013). The environmental impact assessment for Roslagsbanan is outside our scope, however, it is certain that the extension of Roslagsbanan line to Arlanda will minimize negative impacts on air quality and climate change caused by road transport, but will also lead to losses and changes in physical and cultural landscape around the area of Arlanda airport.

6.7.4 The Implementation of the Stockholm Bypass

An ongoing project regarding Stockholms transport system is The Stockholm Bypass. It is a road project that will connect the north and the south parts of the Stockholm region. The Bypass will create a potential value increase for big investments such as logistics in the Arlanda area, since it provides the area with good road communications (Stockholms Handelskammare, 2010). However, investing in road expansions such as Stockholm Bypass, will probably result in even more severe negative environmental impacts. Trafikverkets projections state that the opening of the Stockholm Bypass, which will be in 2025, will increase the traffic on the route between Häggvik and Arlanda airport (Trafikverket, 2017d). Stockholm Bypass will most likely affect and increase traffic congestion north of Häggvik. To make the traffic situation possible to manage, option 2, with a broader E4 and additional lanes, should possibly to be adapted in order to meet the need for road capacity.

6.7.5 Bromma Airport

Stockholm Bromma Airport is located about 7.5 km west-northwest of Stockholm city center. In 2016, 2.5 million passengers were travelling to and from Bromma. In case Bromma airport closes in 2038, there are three options to displace services of the domestic airport (Andersson *et al.*, 2015). The first proposed option is to move the domestic flights to Skavsta airport, which is located south of Stockholm (*ibid.*). The second option is to replace the domestic flights with three High Speed Rails, and the third option is to displace the Bromma flights to Arlanda airport (*ibid.*). Another option would be to combine all three options (*ibid.*). However, Trafikverket estimates that three quarters of Bromma's forecasted passengers would choose to travel from Arlanda airport in case of a shutdown (Trafikverket, 2017d). As a consequence of the additional passengers from Bromma airport, there is a possibility that additional development of Arlanda airport would be needed, which would also increase the pressure on the transport system.

6.7.6 Monitoring

Environmental monitoring is needed to understand ongoing and future environmental changes, their impact on society and the ecosystems, and for the appropriate adaptation strategies and mitigation measures. Monitoring should cover all significant environmental effects that are considered with implementation of the plan or program (Regeringskansliet, 2016). However, the design and content of the future plans have not been fully determined in this SEA, and it is therefore difficult to establish how the monitoring should be carried out.

Ideally, the structure of the monitoring procedure should include the segments of the road which are going to be modified, all types of activities during construction (excavation work, resurfacing, demolition of old structures, transportation of materials etc.) and operation, parameters which will be monitored, how often the monitoring will be executed and what measures would be adopted based on the monitoring results.

At such an early stage in the strategic planning regarding this project, it is important to address an extra need of monitoring of some specific parameters. These parameters are water quality, air quality, biodiversity and connectivity, noise and vibrations. Monitoring should be carried out during both the construction and operation phases to ensure that all the proposed activities do not exceed the established environmental limits and standards.

Monitoring of other parameters included in this SEA may be a challenging task due to the availability of data, indicators and resources. Additionally, to decide whether an impact identified during monitoring is caused by the implementation of the particular plan or not might not be an easy task (for example, biodiversity). In addition, the need of monitoring of some parameters might change over time. How extensive and detailed monitoring should be regarding these parameters depends on how damaging the proposed activities will be.

6.8. Final Reflections

6.8.1 Conclusions

The main objective of this SEA is to find ways of expansion of the transport system between Stockholm city and Arlanda airport and evaluate possible environmental impacts from the proposed options in this chapter. Thus, to meet the future needs of transportation demand between Stockholm and Arlanda airport, the increase in efficiency and capacity in both railway system and the E4 most likely will be necessary. The road option on its own will not be able to sustain the enormous amount of travellers. When road capacity increases, the amount of cars on the road will eventually also increase leading to the overloaded traffic capacity and frequent congestions (Litman & Colman, 2001). Thus, the combination of two options is highly desirable.

It should be noted though, that due to absence of the approved plans for future transportation needs, specifically for the segment between Stockholm and Arlanda airport, this SEA's proposed options may not be final and may change over time. To assess environmental impacts, it is necessary to see the system as a whole. For this SEA the access to the relevant information was somewhat limited. Due to the short project time, it was difficult to get a hold of relevant stakeholders and receive sufficient answers. Many stakeholders are specialists within their own field and it is therefore complicated to have a joined expertise on the common development of the plans for the future transport system. Therefore, depending on when and how these long-term plans will be implemented, the options of how to meet the increased demand in transport might be different from the options presented in this SEA. Nevertheless, with Swedavia's vision about Arlanda airports future, environmental impacts of the implemented development must be considered, including both the construction and operation phase.

6.8.2 Recommendations

Final recommendations are given by this SEA regarding how the implementation of the options could be handled, which parameters that could receive the most damaging impacts, and lastly a proposition concerning monitoring.

- Whether option 1 or both of the proposed options would be implemented, measures should be set in motion in order to make people choose public transport instead of travelling by car, which in turn would decrease road congestion. These measures could for example be cheaper ticket prices within public transport, higher taxes on private cars and tolls and more frequent departures.

- Based on this SEAs impact assessment, the authors have concluded that the greatest impacts of implementation of one or both proposed options would mainly concern the parameters air quality and noise and vibrations, but also water quality, biodiversity and connectivity. Therefore, these parameters should be assessed in greater detail and receive a more extensive monitoring.

- The absence of fully determined plans is limiting this SEA in detailed suggestions on how the monitoring should be done. Thus, if one or both of the options would be implemented and detail plans established, detailed EIAs will be required. Therefore, the monitoring will be revisited regarding this project, which is needed.

- Lastly, the authors recommend that another SEA regarding the transportation of gods on the E4 and railway system between Stockholm and Arlanda airport should be conducted. The future capacity needed for transportation of goods ought to be evaluated regarding if the amount of goods will increase and how it is going to be transported in the future. It might give an idea if the capacity of the road system would need even further expansion of capacity or not.

6.9. References

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